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An Algorithm for Managerial Actions on the Rational Use of Renewable Sources of Energy: Determination of the Energy Potential of Biomass in Lithuania

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Citation: Kukharets, V.; Juočiūnienė, D.; Hutsol, T.; Sukmaniuk, O.; Čėsna, J.; Kukharets, S.; Piersa, P.; Szufa, S.; Horetska, I.; Shevtsova, A. An Algorithm for Managerial Actions on the Rational Use of Renewable Sources of Energy: Determination of the Energy Potential of Biomass in Lithuania. *Energies* **2023**, *16*, 548. https://doi.org/10.3390/en16010548

Academic Editor: Alok Kumar Patel

Received: 10 November 2022
Revised: 23 December 2022
Accepted: 27 December 2022
Published: 3 January 2023

Abstract: This paper offers an algorithm to account for potential actions on the efficient production of renewable energy. The algorithm consists of a substantiated choice of a certain type of renewable energy, the evaluation of its potential, and the regulation of the processes of obtaining that renewable energy. Also, potential resources for agricultural biofuel production have been analyzed and it has been determined that there is real biomass potential in Lithuania. It will thus be beneficial to make appropriate managerial decisions on the methods of biofuel processing and consumption, as well as on means of receiving the economic, energy and environmental effects. The total potential of by-product biomass of crop production was determined, and the thermal and electric potential of the crop by-products were calculated. Additionally, the potential for production of gas-like types of fuel (biomethane, biohydrogen, and syngas) from crop by-products was determined. The potential for the production of diesel biofuel from oil crop waste (bran) was also found, and the potential for livestock by-products for receiving gas-like types of fuel (biomethane, biohydrogen) was established. The corresponding thermal and electric equivalents of the potential were found and the potential volumes of the biomethane and biohydrogen production were calculated. The total energy equivalent equals, on average, 30.017×10^6 GJ of the thermal energy and 9.224×10^6 GJ of the electric energy in Lithuania. The total potential of biomethane production (taking into account crop production and animal husbandry wastes) on average equals 285.6×10^6 m^3. The total potential of biohydrogen production on average equals 251.9×10^6 m^3. The cost equivalents of the energy potential of agrarian biomass have been calculated. The average cost equivalent of the thermal energy could equal EUR 8.9 billion, electric energy—EUR 15.9 billion, biomethane—EUR 3.3 billion and biohydrogen—EUR 14.1 billion. The evaluation of the agricultural biomass potential as a source of renewable energy confirmed that Lithuania has a large biomass potential and satisfies the needs for the production of renewable energy. Thus, it is possible to move to the second step, that of making a decision concerning biomass conversion.

Keywords: biomass; algorithm; potential; cost; equivalents; crop; production; livestock

1. Introduction

The sustainable development of the European Union countries depends on energy security [1]. Balanced and efficient use of renewable sources of energy is necessary in order to improve the energy security in the world and in the countries of the European Union [2]. It is considered that renewable sources of energy can be highly significant in the quest for energy independence. A common strategy for the bio economy of the European countries was adopted in 2012. This strategy envisages the development of society according to the principles of energy efficiency, food security, and protection of the environment through the rational use of renewable resources and reduction of greenhouse gas emissions [3–5]. Solar, wind and geothermal types of energy, wave and tidal energy, hydro energy, and secondary energy sources (household waste and industrial waste) are topical issues. The countries that are taking a leading position in the deployment of wind energy are Denmark, Portugal, and Ireland, in solar energy Cyprus, Spain, and Greece, and in hydroenergy Sweden, Austria, and Slovenia. But environmental factors, climatic conditions and temperature regime, in particular, have a significant impact on the efficiency of their use. A significant expansion of the use of renewable sources of energy such as solar and wind energy is rather complicated for certain environmental, technical and economic reasons [6–9]. Finland, Denmark, Estonia, Lithuania, and Latvia all enjoy leading positions in using biomass for heating. These countries have sufficient biomass resources, technical resources and technologies, as well as political support [10–14].

Although substitution of traditional energy resources by renewable to a level of 20% was expected to be achieved by 2020, a great number of European countries have figures above the specified level of consumption, such as Sweden, Denmark, Finland, Austria, Latvia, Portugal, Croatia, Estonia, and Lithuania [5]. In most European countries, national energy strategies have been laid out until 2030 [4], but these need to be revised and improved in line with today’s realities.

One of the main sources of biofuel is agrarian (agricultural) production. Agrarian production has significant potential for obtaining biofuels [15] such as biogas, bioethanol, biohydrogen, fuel pellets, and briquettes [16–18], in particular. At agrarian enterprises it is appropriate to utilize two methods of biohydrogen production: the thermochemical method (from biomass of plant origin) and the fermentative method (from biomass of animal origin). It is appropriate to use gasifiers for the thermochemical method and bioreactors for the fermentative method [18]. The lignocellulosic biomass resulting from crop production is the main agricultural raw material for biofuel production [19]. Global agricultural activity generates a great amount of available lignocellulosic biomass, or waste, including solid, liquid, and gas-like waste and is a valuable raw material for biofuel production [20]. The countries of the European Union assume that biofuel production from agrarian biomass reduces greenhouse gases emissions [21]. Taking into consideration the significant potential of agricultural production and the perspective of greenhouse gas reduction a new industry has been formed, that of bioenergy. The raw material for bioenergy is biomass of agrarian (agricultural) origin [22–24].

A great amount of agricultural biomass, which can be turned into biofuel when using various technologies, is being produced in the world. The use of biomass for the production of biofuel gives rise to researchers’ concern, because it can result in a decrease in the amount of food production and have a negative impact on the environment [25]. Moreover, some scientists state that the biofuel obtained in agrarian production has low efficiency [26]. There are also some opinions that biofuel production from biomass will result in reducing the nutritive element supply in the soil [27]. Researchers think that the use of agricultural crops in both short- and long-term agricultural activity must be thoroughly studied [28]. These studies must formalize the impact of fuel production on food security and ecology.

There are many technical barriers for efficient production of biofuel from biomass, such as a significant need for water, an appropriate environment, a significant need for energy, and the high cost of necessary equipment. Such technical and financial aspects are serious problems for the commercial viability of many fuel production technologies [29]. Moreover, modern agricultural production is a complicated ecological and economic system [30]. Such a system must ensure sustainable production of food as well as fodder for livestock and poultry by growing agricultural crops. As a result, it must ensure food security of a country or a region [31]. Increasing the sustainability of agricultural production through increasing the types of agricultural crops is one of the ways of reducing negative effects in biofuel production [32]. Control of the resources that are involved in production is important as well [33]. Scientists state that the criteria which confirm the relevance of such production are necessary for an efficient use of agricultural biomass for biofuel production [34]. In paper [1], the efficiency of biofuel production was evaluated through the energy intensity of a given unit of production. But this assessment does not allow the economic efficiency of biofuel production to be evaluated. Fuel production is a rather complicated process that includes some methods and technologies which are necessary to be used in order to turn lignocellulosic biomass into functional biofuel. Thus, it is necessary to achieve maximal biofuel production in an ecologically clean and economically efficient system [35].

It is necessary to note that the development of the world economy is determined by limited natural reserves of traditional sources of energy resources as well as by the necessity of taking measures for food-security stabilization and natural environment protection. A systematic approach to studying the possibility of energy independence of a country or a region, while taking into account the economic and social mechanisms of the relationship between the society and the environment, is very important.

Considering tendencies in global economic and social development, a proper system of managerial decisions and actions will play an important role in the introduction of a policy of rational use of renewable sources of energy. Such a system needs to be focused not only on making a maximal profit but also on balancing of the economic, energy, ecological, and social interests of society. Studies show that rational use of biofuel improves the economic state of a society. However, it is necessary to combine certain strategies related to both production and fuel consumption. In addition to this, it is necessary to include political decisions on the increase in consumption of environmentally friendly energy [36–39]. These political decisions are impossible without an evaluation of the rational use of bioenergy resources.

Having analyzed the available scientific publications, the authors suggest evaluating a rational use of bioenergy resources on the basis of three criteria: economic, energy, and ecological. The goal of including managerial decisions on the implementation of biofuel management policy is to save financial resources, increase energy security, transform energy resources (conversion), ensure food security, and improve the ecological state of the environment. There is a necessity to create an algorithm of managerial actions on the rational use of renewable energy. Such an algorithm could be used with some corrections on macro, meso, and micro levels.

2. Materials and Methods

The algorithm of managerial actions envisages the development of a decision-making program. The decision-making program is based on a sequence of certain actions for achieving a desired (necessary) result.

The algorithm of managerial actions for choosing a source of renewable energy consists of the substantiation of the types of renewable energy, an assessment of their potential, and the regulation of the processes of obtaining them. This algorithm can be presented in the form of these three blocks:

- Decision formation for choosing the most rational source of renewable energy;
- Formation of managerial decisions on the potential of the types of renewable energy (the amount of raw material needed to obtain renewable types of energy);
- Formation of managerial decisions on ways of obtaining and consuming renewable types of energy (ways of conversion).

This algorithm is presented graphically in Figure 1.

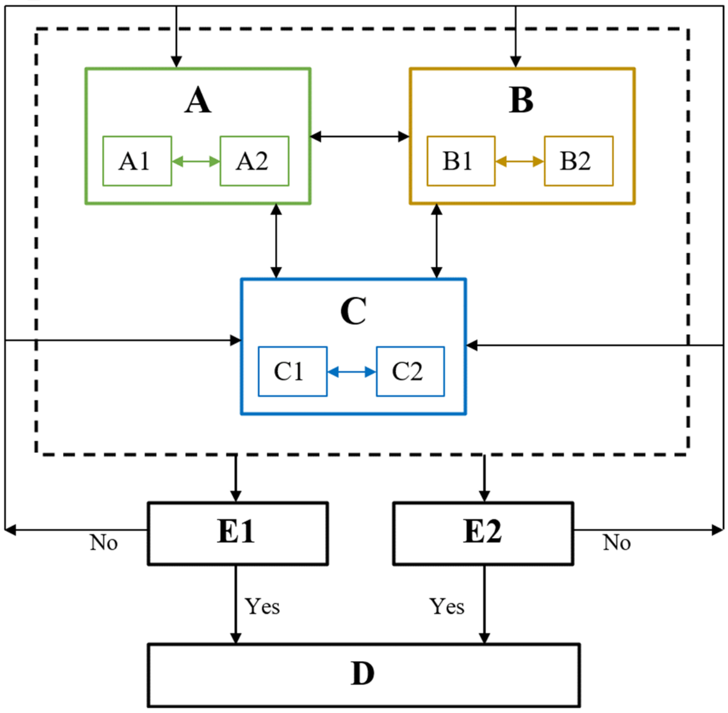

Figure 1. The algorithm for managerial actions on the rational use of renewable sources of energy: A—the block where the source of the renewable energy is chosen; A1—the analysis of the types of renewable sources of energy; A2—making decisions on using certain types of renewable sources of energy; B—the block of the potential of the source of the renewable energy; B1—the analysis of the factors that affect the potential of the renewable sources of energy; B2—the evaluation and making decisions on the available potential of the source of the renewable energy; C—the block of choosing the methods of obtaining or consuming the renewable energy; C1—the analysis of the factors that affect the efficiency of the renewable energy production and use; C2—making decisions on the method of renewable energy production and use; E1—energy independence, the economic effect; E2—environmental friendliness, food security, social effect; D—total effect (making a decision on the renewable energy production or use).

Each block envisages an execution of two stages in sequence. In the first stage an analysis of the external and internal factors that have influence on the use of renewable sources of energy is executed. These are for Block A the amount of the potentially available source of the renewable energy, for Block B the factors that have influence on the efficiency of the process of conversion of the renewable energy, and for Block C the block of choosing the methods of obtaining or consuming the renewable energy. In the next stage decisions regarding the use of the renewable sources of energy for each of the blocks are either made or rejected.

The availability of the resources and of the technological potential, the availability of the raw material potential, and the need for raw materials in other branches of industry are evaluated for Block B on the stage of the analysis of the renewable energy potential for conversion. The introduction of technologies of receiving raw materials, the possibility of allocating areas for the renewable sources of energy, the decision regarding a part of the raw materials for own needs and a part for its conversion into an energy resource subject to evaluation on the stage of decision making on the possibility of the raw material conversion occur in Block B.

If the potential of the source of the renewable energy does not satisfy the needs, realization of the project regarding conversion is rejected. To realize the process of conversion in the future, this paper considers decisions on improving the potential of the raw materials and the technical potential. If the potential of the renewable source of energy for conversion satisfies the needs, the possibility of making another step is considered—making a decision on the possibility of conversion. The decision is made on the part of the energy resource for own needs, a part—for the conversion into the energy resource, taking into consideration possible economic and ecological effects. The move is made to the next block of a subsystem of the algorithm of the managerial decisions on the method of the renewable energy conversion.

The methods of conversion, their economic and technological indicators, the biofuel market, and the efficiency of using bio resources for own needs are assessed for Block C on the stage of analysis. On the second stage managerial decisions regarding the choice of the method of the conversion process and of the renewable energy realization are made.

There is an inverse relationship among the blocks. Making a decision depends on the change of the factors of analysis. On the contrary, the decisions affect the change of the indicators that are used when analyzing. Thus, it would be possible to make an official regulation of the conversion process of the renewable sources of energy. The purpose of the regulation is energy independence as well as maximization of the economic effect and improvement of the ecological indicators.

The relationship among the blocks makes it possible to correlate a necessary amount of the renewable energy that can be used depending on the energy and economic situation. The relationship will also allow to make a correct decision on the ways of obtaining (conversion) renewable energy depending on the potential. An efficient strategy for the development of the bioenergy branch of the economy can be developed by means of this algorithm.

An efficient strategy would allow improvement in the energy potential of the region and would strengthen its financial position. In order to realize a strategy of bioenergy development, it is necessary to substantiate beforehand the directions and the methods of the energy resource conversion. The possibilities for the fast realization and for the improvement of the ecological state of the environment must be taken into consideration.

In order to choose a rational type of biomass and method for its conversion into an energy resource, it is necessary to make a comparative assessment of the available raw material potential for its conversion into an energy resource as well as of the efficiency of the technological processes or technologies. From an economic point of view the conversion of biomass into an energy resource is not only the movement of some resources from one sector to another for receiving future benefits but also a very complicated and dynamic process of economic restructuring.

The economic effect of conversion envisages a change in the proportion of the distribution of the financial, material and human resources among different spheres of the economy. The economic assessment of the conversion of organic raw material expects some steps: determining the amount of the raw material that is available for the conversion into a bio resource; establishing the amount of a certain energy resource based on the quantity of the raw material available for conversion as well as the thermal power of a given type (energy security); determining the cost equivalent (which is equivalent to the amount of the traditional energy resource) of the energy obtained by the raw material conversion (financial savings).

Thus, when the algorithm of managerial actions is created, it would be possible to determine the level of energy efficiency of the biofuel conversion (energy independence). The efficiency of the use of renewable sources of energy depends on the parameters of the working machines that are used in the technological processes of the corresponding structural elements (blocks) of the algorithm. Most of them are the energy production costs: maintenance fees; salary deductions; fuel and energy cost deductions; deductions for wasted products; deductions for logistics costs and other constituents; and a payback period. Some parameters of the machines and the equipment are established on the basis of cost minimization on performing the technological operations [40–42].

In the process of conversion of energy resources it is necessary to clearly understand the directions of the use of the agricultural resources. The algorithm of managerial actions must take into consideration the interactions among the branches of the agricultural production: animal husbandry; crop production; agricultural products processing; and bioenergy [19,40,41,43].

The technological processes of the biofuel production or use must be correlated with the needs of the related branches of agricultural production; they must support the humus balance in the soil environment [44–46], because fertile soils are a necessary condition of an efficient agricultural activity [47,48]. Humus is considered the main soil-state parameter [47,49]. Thus, the impact on humus balance is the main criteria of the ecological effect of biofuel production in agriculture. Any biofuel production must not reduce the level of humus in soil. The main ecological criteria of using biomass as fuel in comparison with the fossil-fuel types are soil conservation and reduction of greenhouse gas emission.

Making adequate managerial decisions on ways of biomass processing and on the directions of getting economic and ecological effects is not possible without establishing real biomass potential. Suppose the biomass potential that is available for conversion into biomass, electric and heat energy looks like this:

$$P_1 = \sum_{i=1}^{n} a_i u_i [k_1 - (k_2 + k_3 + k_4)], \quad (1)$$

where:

P_1—the biomass potential (by-products), t;
a_i—the area allocated for growing i-crop, ha;
u_i—the yield capacity of i-crop, t/ha;
k_1—the coefficient of the biomass output of i-crop;
k_2—the coefficient of the biomass loss in the process of biomass collecting;
k_3—the coefficient that takes into account the biomass input in the support of humus balance;
k_4—the coefficient that takes into account some additional needs of the branches of the agricultural production for biomass.

The conversion factor, the biomass-yield factor and the factor of the availability of plant biomass were used in this paper. The need for by-products in the branches of agricultural production, as well as for the support of humus balance was taken into account [19,43–46].

The production of diesel biofuel from food raw materials is not economically expedient because the market price of the edible oil is higher than the price of diesel fuel. To increase economic efficiency, it is expedient to get cheap raw materials for the production of diesel biofuel, and to process the oil crop waste that cannot be used for the production of food produce [47]. Thus, the potential of diesel biofuel can be calculated using the formula:

$$P_2 = \sum_{i=1}^{n} a_i u_i k_5 k_6 k_7, \quad (2)$$

where:

P_2—the potential of diesel biofuel, t;
a_j—the area allocated for growing j-crop, ha;
u_j—the yield capacity of j-crop, t/ha;
k_5—the coefficient of waste (bran output);
k_6—the coefficient of oil production;
k_7—the coefficient of the production of diesel biofuel.

It is also necessary to consider the potential of animal husbandry biomass for the production of gas–like types of fuel:

$$P_3 = k_8 k_9 \sum_{j=1}^{m} n_j \tau_j m_j, \quad (3)$$

where:

P_2—the potential of biomass for the production of biogas (biomethane, biohydrogen) m^3;
k_8—the coefficient of using biomass for supporting humus level;
k_9—the coefficient of using biomass in biogas plants;

n_j—the number of j- species of animals or birds, items (heads);
τ_j—the period of animal housing, days;
m_j—the weight of the waste of j-species of animals or birds, t/item (head) per day.

3. Results and Discussion

Lithuania as a European country has adopted a strategy of energy and climate (The National Plan of Action) relating to the provision and implementation of the political goals of the energy and climate framework of the European Union. The implementation of The National Plan of Action envisages the introduction of advanced energy, the use of technologies with a low greenhouse gas emission, the use of "clean" sources of energy and a stable energy supply with competitive prices [48].

The natural and climatic factors are favorable for the choice of biomass as one of the sources of renewable energy. Lithuania has sufficient resources of biomass as well as technical resources and technologies for making decisions on the use of biomass as an energy resource [11]. Solid biofuel forms the largest part of the renewable energy of Lithuania. About 80.6% of the renewable energy is made of wood and of agricultural production waste [5]. In 2022 biofuels represented 70.5% of the structure of the fuel that was used for heat production [49]. Thus, it would be expedient for Lithuania to make a decision to use agricultural production biomass as a source of renewable energy.

Having used statistical data on the gross yield of crops, areas under crops and livestock [50], the potential of plant production biomass in Lithuania and in its counties in particular, has been established (Figures 2 and 3).

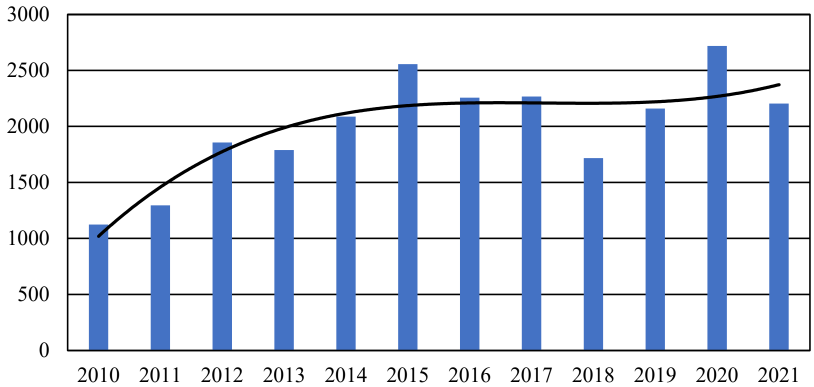

Figure 2. The potential of by-products of crop production used for conversion in Lithuania (thous. t.).

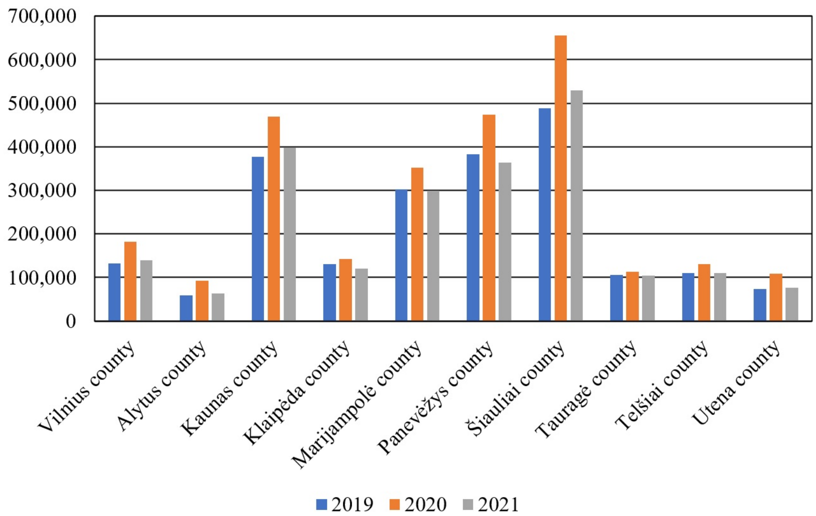

Figure 3. The potential of crop production by-products used for conversion in the counties (t.).

The potential of by-products of crop production depends on crop yield, needs of industries for the produce and other factors; thus, this potential is changeable. In 2010 the potential of biomass of crop production for the conversion equaled 1.124 $\times$ 10^6 thous.t., in 2020—2.718 $\times$ 10^6 t., in 2021—2.203 $\times$ 10^6 t. On average during the period 2010–2021 the biomass potential of crop production equaled 2.002 $\times$ 10^6 t. The dynamics of crop production potential (P_1) can be described using Equation (4) (probability of the approximation R^2 = 0.71):

$$P_1 = 3.3026x^3 - 81.12x^2 + 659.09x + 438.04. \quad (4)$$

The most probable forecast of the potential assessment of crop production by-product used for conversion in Lithuania is given when using the polynomial third-order function.

As for the counties, the potential is not evenly distributed there as well. During the last three years Šiauliai county had the biggest potential—656,157 t. (in 2020), and Alytus county had the smallest potential—59,043 t. (in 2019). It is necessary to admit that during the period of the research there was a tendency regarding the biggest potentials in such counties as Šiauliai, Kaunas, Panevėžys, Marijampolė. In these regions the potential equaled 300 $\times$ 10^3 t. or more. Thus, it is necessary to make managerial decisions as to the conversion of plant biomass into energy resources and developing the technologies for its realization in these regions.

Knowing the potential of biomass, it is possible to evaluate the amount (the potential) of electric energy, thermal energy, biogas, generator gas or biohydrogen, which can be obtained through thermo-physical transformations [23,24,34,50]. After that, knowing the energy cost, it is possible to determine the economics effect of using this or that type of energy or biofuel. The environmental effect can be determined by knowing the physical properties of fuel.

Taking into account the average calorific value of biomass, 16–17 MJ/kg, and the performance efficiency (PE) for thermo-technical and electrical equipment, it is possible to determine the thermal and electric energy equivalents of a by-products' potential for crop production.

For example, if the performance efficiency for thermo-technical equipment is 0.8, and for electrical equipment—0.3, the corresponding energy potentials can be found (Figure 4).

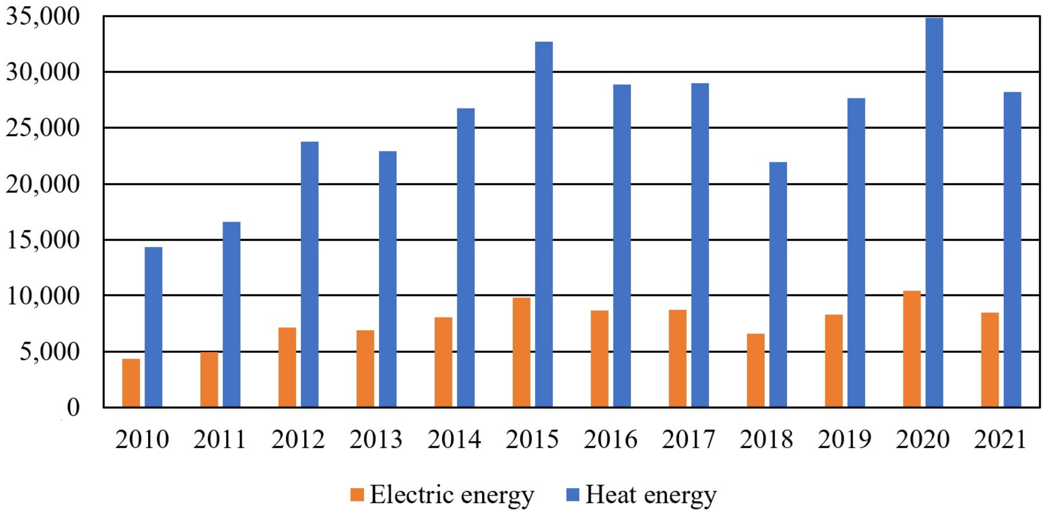

Figure 4. Thermo- and electric energy equivalents of the potentials of crop production by-producys in Lithuania (thousand GJ).

On average during the period 2010–2021, the thermal potential of crop production by-products equaled 25.632 $\times$ 10^6 GJ, and the electric potential was 7.690 $\times$ 10^6 GJ.

Knowing the output of biomethane or generator gas (syngas) from one ton of biomass, the production potential of the corresponding gas can be determined (Figure 5).

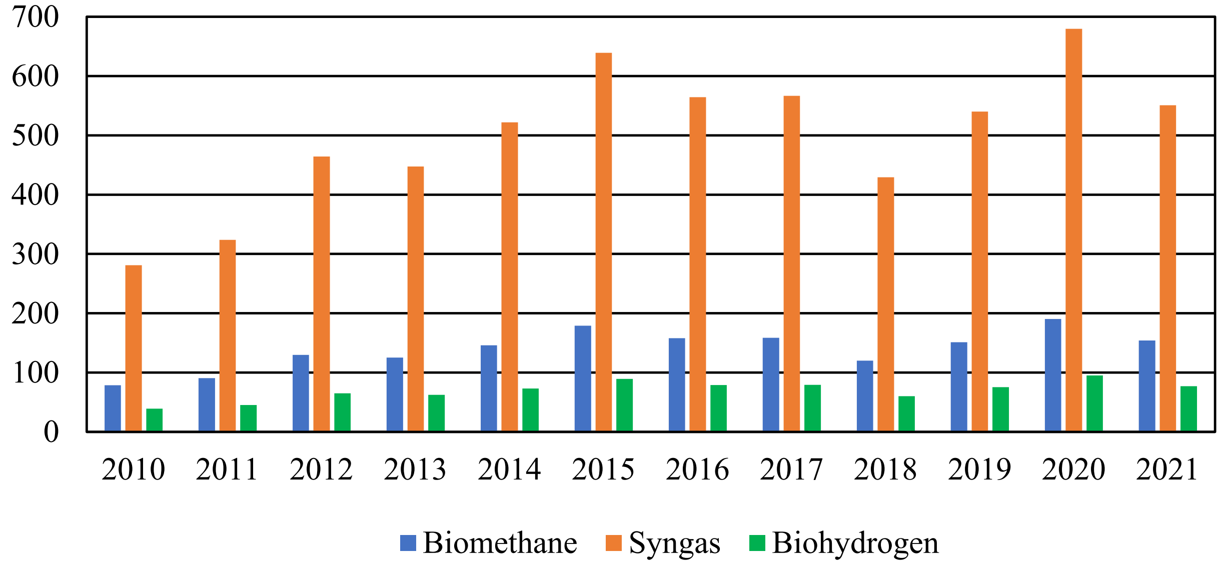

Figure 5. The potential of gas-like types of biofuels obtained from crop production by-products in Lithuania (mln. m^3/year).

As follows from these calculations, it is possible to obtain the greatest amount of generator gas (syngas), but its calorific value is significantly lower than that of biomethane—5–7 MJ/m^3 and 33–35 MJ/m^3, respectively. Moreover, the availability and cost of the corresponding equipment must be taken into consideration. It is also necessary to evaluate the economic and environmental effectiveness of using gas-like types of biofuel.

The potential of diesel biofuel production from oil, which is received from non-food waste (bran), was calculated for oil crops such as sunflower, soy beans, and rapeseed (Figures 6 and 7). For the calculations coefficients were used to: calculate the output of bran (waste) from manufactured products for sunflower—0.08— and rapeseed—0.04; calculate the oil output from bran—0.25 for all crops; calculate the oil output from oil mass—0.65 for all crops; calculate the production of diesel biofuel from oil—0.8 [47,51].

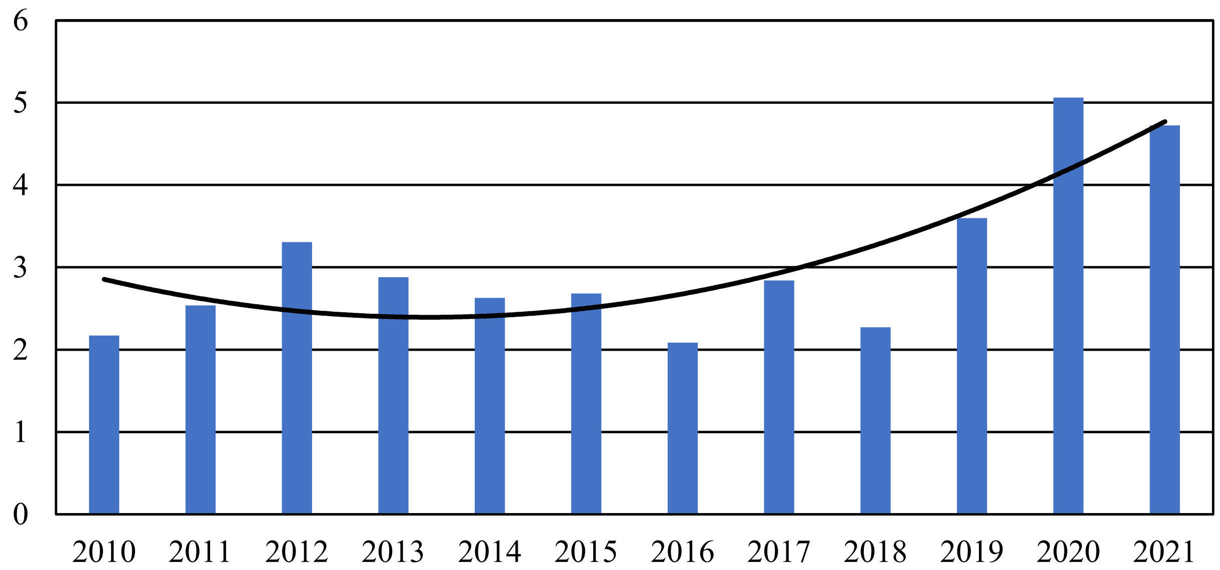

Figure 6. The potential of biodiesel production from oil-crop waste (bran) in Lithuania (thous. t.).

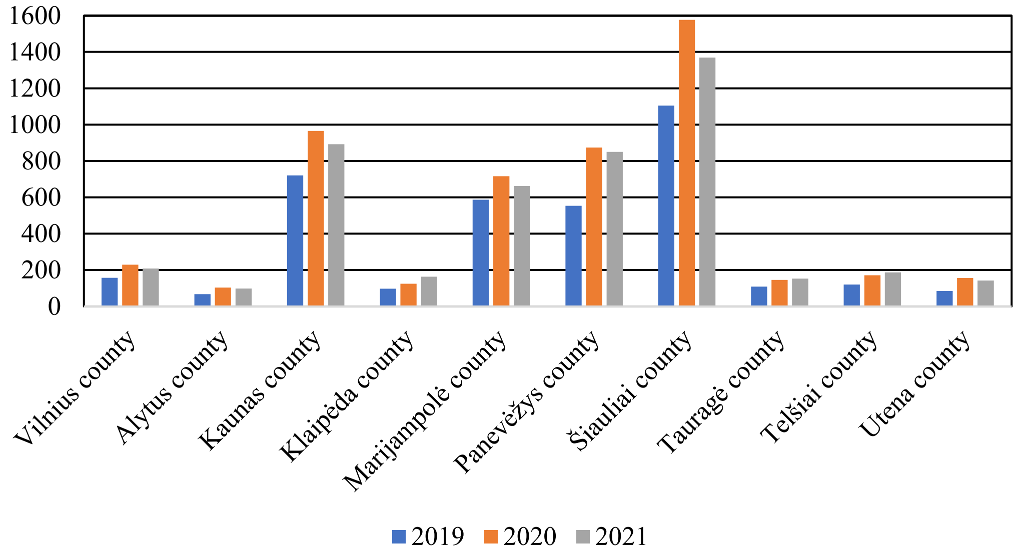

Figure 7. The potential of biodiesel production from oil crop waste (bran) in the counties (t).

About 5601 t. of diesel biofuel (maximal amount in 2020), which has a low cost due to own production as compared with a traditional fuel, can be obtained from oil crop waste (bran).

The dynamics of the potential of diesel fuel production from oil-crop waste (P_2) can be described using Equation (5). The most reliable forecast of the assessment of the production potential of diesel biofuel from oil-crop waste in Lithuania is given when using a polynomial second-order function (probability of the approximation R^2 = 0.64):

$$P_2 = 0.0408x^2 - 0.3558x + 3.1695. \quad (5)$$

The average indicator of diesel biofuel production from waste during the period 2010–2022 equals 3065 t. Such biofuel can be efficiently used in agricultural production. It allows reductions in both gas emissions into the atmosphere and cost of production.

During the study period there was a tendency regarding the biggest potential of diesel biofuel, similar to the potential of crop biomass. The biggest volume potential was available in such counties as Šiauliai, Kaunas, Panevėžys, and Marijampolė. The biggest potential for diesel biofuel production from waste was in Šiauliai county—1576 t. in 2020, the smallest was in Alytus county—67 t. in 2019 (during the period 2019–2021).

Using statistical data on livestock, the number of birds and crop area [50], the potential of livestock biomass in Lithuania and its counties was determined (Figures 8 and 9).

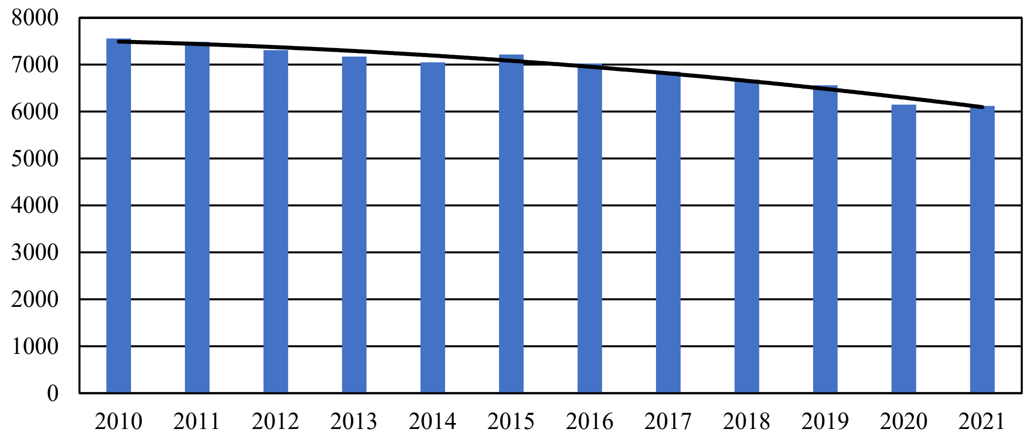

Figure 8. The potential of livestock by-products for production of gas-like types of fuel in Lithuania (thous. m^3).

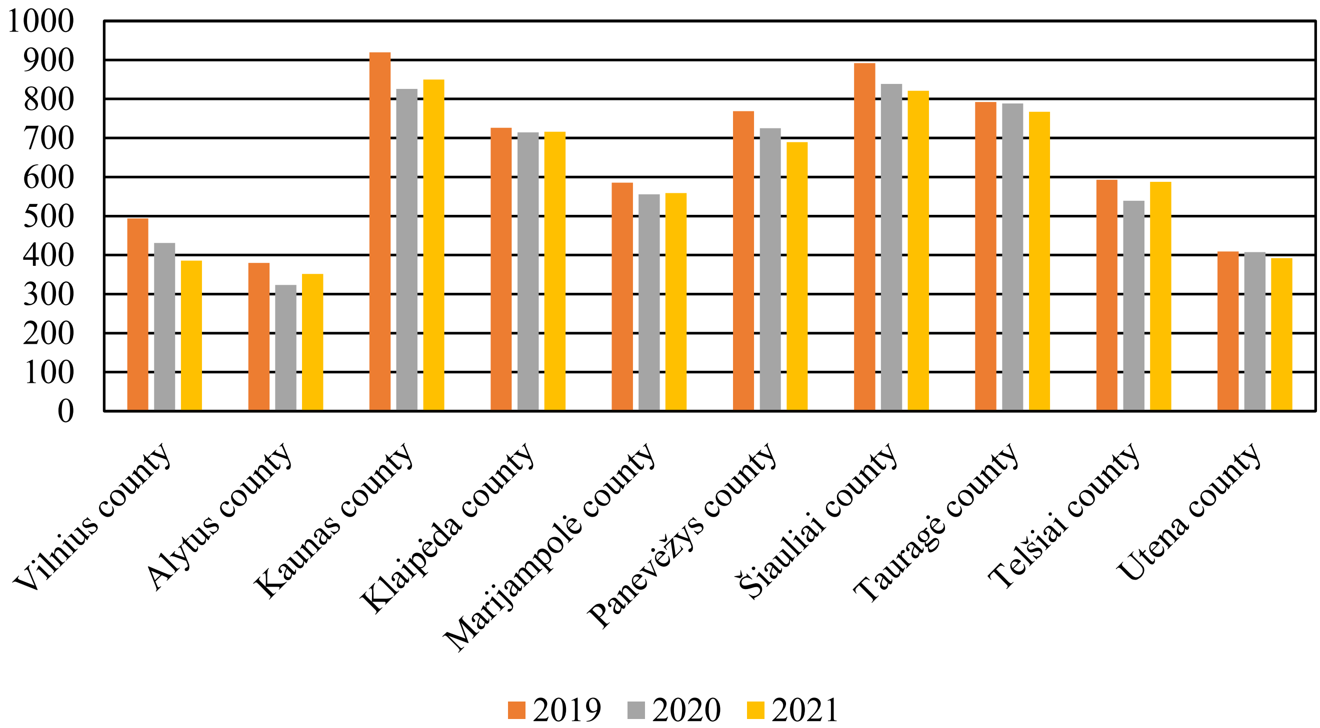

Figure 9. The potential of livestock by-products for production of gas-like types of fuel in the counties (thous. m^3).

The maximal potential of livestock by-products for production of gas-like types of fuel was realized in 2010—7.556 × 10^6 m^3. During the last five years there has been a tendency toward its reduction. In 2021, 6.119 × 10^6 m^3 of biomass was produced. On average during the period 2010–2021, 6.931 × 10^6 m^3 of biomass was produced.

The dynamics of the potential of livestock by-products for production of gas-like types of fuel (P_3) can be described using Equation (6) (probability of the approximation R^2 = 0.96):

$$P_3 = -7.5293x^2 - 29.142x + 7528.35. \quad (6)$$

The most reliable forecast of the assessment of livestock by-product potential for production of gas-like types of fuel in Lithuania is given when using a polynomial second-order function. There was a reduction in the potential of livestock by-products for production of gas-like types of fuel during the period 2010–2021.

The biggest potential of livestock by-products for production of gas-like types of fuel during the last three years was in Kaunas county (919.3 × 10^3 m^3 in 2019), and the smallest was in Alytus county (323.3 × 10^3 m^3 in 2020). Thus, it is necessary to make managerial decisions on both plant biomass conversion into energy resources and development of technologies for its realization in these particular regions.

Gas-like types of biofuels can be obtained through biological and chemical transformations (fermentation) with their further purification to biomethane or biohydrogen [18] (Figure 10). During the period2010–2021 the average potential of biomethane production from livestock by-products equaled 145.4 × 10^6 m^3 and of biohydrogen—181.8 × 10^6 m^3.

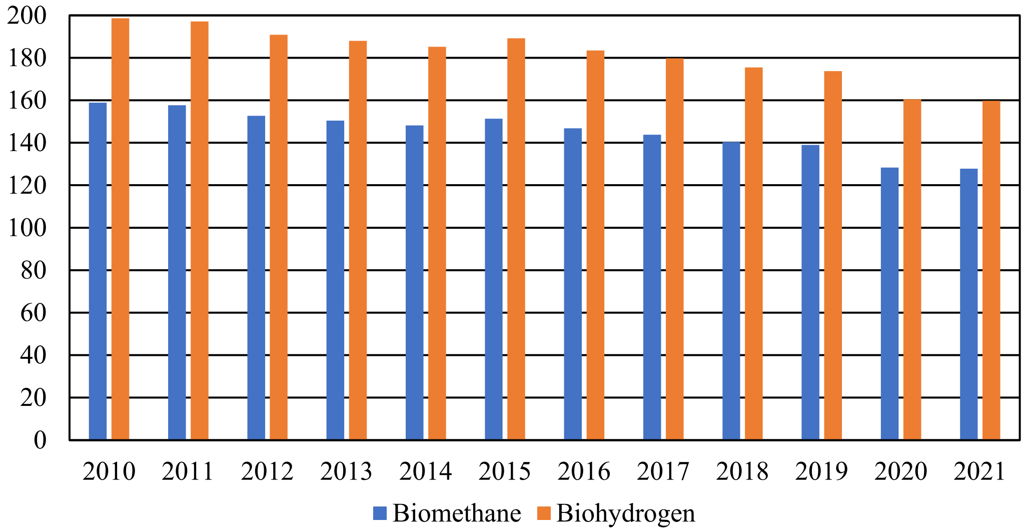

Figure 10. The potential of biomethane and biohydrogen production from livestock by-products (mln. m^3).

Taking into consideration the average calorific value of biomethane—33 . . . 34 MJ/kg—and taking into account the performance efficiency (PE) of thermo-technical and electrotechnical equipment (cogeneration plant), the thermal and electric energy equivalents of the potential of livestock by-products can be determined (Figure 11).

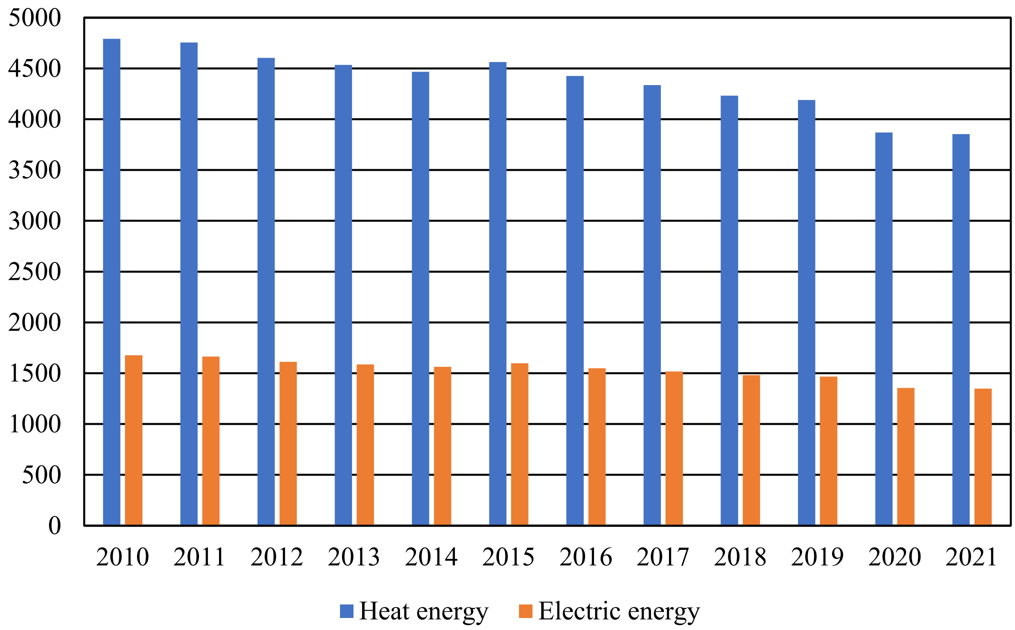

Figure 11. **The** thermal and electric energy equivalents of livestock by-product potential in Lithuania (thous. GJ).

On average during the period 2010–2021, the thermal equivalent of the potential of livestock by-products equaled 4.385×10^6 GJ, and the electric equivalent was 1.535×10^6 GJ.

Taking into account crop by-products, the average thermal equivalent during the period 2010–2021 equaled 30.017×10^6 GJ of thermal energy and 9.224×10^6 GJ of electric energy, which equaled approximately 6.2% of the thermal energy consumption and 22.5% of electric energy consumption in Lithuania. The total potential of biomethane production (taking into account crop- and livestock-product waste) equaled, on average, 285.6×10^6 m^3, which equaled nearly 10% of all natural gas consumption in Lithuania. The total potential of biohydrogen production equaled 251.9×10^6 m^3.

Having taken into consideration the calorific value of biomethane, 33.5 MJ/m^3, and of biohydrogen, 120 MJ/m^3, the corresponding energy equivalents were determined in GJ. Having taken into account the price of thermal and electric energy as well as of biomethane and biohydrogen in 2022, their cost equivalents were calculated (Table 1). The average price of electric energy in Lithuania during the period of August, 2019–2021, equaled approximately 59.87 EUR/MW-hour, and in August, 2022, the average price of electric energy equaled 480.39 EUR/MW-hour [52]. According to VERT the average central heating price in Lithuania equaled 8.25 EUR/kV–hour [49]. The weight average cost of imported gas in the first half of 2022 equaled 95.21 EUR/MV-hour, which was five times higher than in 2021 [52]. The average price of gas in August 2022 equaled 222.20 EUR/MW-hour (GET-Baltic) [52].

Table 1. Energy and cost equivalents of the biomass potential of agricultural origin.

Industry	Thermal Energy		Electric Energy		Biomethane		Biohydrogen	
	Energy Equivalent, $\times 10^6$ GJ	Cost Equivalent, Billion EUR	Energy Equivalent, $\times 10^6$ GJ	Cost Equivalent, Billion EUR	Energy Equivalent, $\times 10^6$ GJ	Cost Equivalent, Billion EUR	Energy Equivalent, $\times 10^6$ GJ	* Cost Equivalent, Billion EUR
Crop production	25.632	7.613	7.689	13.298	4.696	1.610	9.111	3.936
Animal husbandry	4.385	1.302	1.535	2.654	4.872	1.670	23.634	10.210
Total	30.017	8.915	9.224	15.953	9.568	3.279	32.745	14.146

* The price of hydrogen was determined according to forward estimates–120 EUR/MV-hour.

The cost equivalent of the biomass potential of thermal energy in the prices of 2022 equaled EUR 8.9 billion, including electric energy—EUR 15.9 billion, biomethane—EUR 3.3 billion, and biohydrogen—EUR 14.1 billion.

The evaluation of the agricultural biomass potential as a source of renewable energy confirms that Lithuania has a large biomass potential and satisfies the needs for the production of renewable energy. Thus, there is a possibility to make the second step—to make a decision concerning biomass conversion. First a decision is made concerning a part of the resources for own needs, and a part for conversion into an energy resource taking into account possible economic, energy and environmental effects. Then decisions are made concerning conversion of the biomass into energy resources in the regions with the highest potential of plant biomass and livestock by-products. In Lithuania the regions with the largest plant biomass potential are Šiauliai, Kaunas, Panevėžys, and Marijampolė counties; those with the highest livestock by-product potential are Šiauliai, Kaunas, Panevėžys, and Taurage counties. In other regions decisions are made concerning additional research or rejecting the conversion of available biomass into energy resources. Then a step is made to another subsystem block of the managerial action algorithm concerning the conversion method or the use of the type of renewable energy.

For an efficient production of thermal and electric energy from agricultural biomass it is necessary to introduce new technical equipment, which requires significant financial resources. Moreover, biomass transportation costs, taking into account its physical properties, constitute a significant part of the energy or biofuel cost [53]. Optimization of the logistics costs will result in reducing the cost of introducing biomass processing technologies [54]. The efficiency of the technologies for biomass processing into energy improves when the productivity of the technological lines for biomass processing increases [55–58]. Smooth operation of production lines requires large amounts of biomass. Thus, it is necessary to combine efforts and resources (raw materials and finances) of the agricultural enterprises in order to improve the efficiency of biofuel production of thermal and electric energy [59]. Research towards combining the efforts and resources of the agricultural enterprises would allow the creation of added value for the regions of Lithuania [60], as well as solve the logistical and financial problems. A combination of effort and resources would allow the creation of regional business units that could recruit specialists and solve the social problems. New energy communities should be established in upcoming years and use modern types of biomass valorization techniques such as biomass torrefaction in new biorefineries and in CHP plants run on biomass [61–64].

Only the general form of the algorithm was presented in this article. We also improved the methodology for assessing biomass potential (as a component of the algorithm) and, accordingly, performed an analysis of possible biomass resources in Lithuania. These studies can be scaled to other countries [65,66]. Determining biomass resources (renewable fuel) makes it possible to make decisions about methods of their energy conversion and the possibility to detail the algorithm of management actions. We plan to describe that in future publications.

4. Conclusions

The algorithm for managerial decisions on the rational use of renewable sources of energy consists of regulation of the processes of obtaining the renewable energy, the substantiation of the types of renewable energy, and assessment of their potential. The algorithm for managerial decisions can be presented in a form of blocks: a block of decision formation on the choice of the source of renewable energy; a block of managerial decision formation on the potential of the types of renewable energy (the analysis of raw material potential for obtaining the renewable energy); a block of the managerial decision formation on the methods of obtaining and consuming the energy (a block of the ways of conversion). However, it is impossible to make adequate managerial decisions on methods of biomass conversion or biofuel use, as well as on getting economic, energy and environmental effects, without establishing real biomass potential.

The by-product potential of crop production depends on crop yield, the needs of the industries for these by-products, etc.; thus, this potential is changeable. In Lithuania, on average during the period 2010–2021, the thermal potential of crop by-products equaled 25,632.1 $\times$ 10^3 GJ., and the electric potential was 7689.6 GJ. From oil-crop waste (bran) 5601 tons of diesel biofuel can be produced (a maximal amount in 2020), which is low cost due to own production, when compared with a traditional fuel. The average fuel production from waste equaled 3065 t. during the period 2010–2022.

It is necessity to note that during the study period there was a tendency regarding the biggest potential in such counties as Šiauliai, Kaunas, Panevėžys, and Marijampolė. During the study period there was also a tendency regarding the probable largest volume of diesel biofuel, which is analogous to the potential of crop biomass. In the given regions the potential equals 300 $\times$ 10^3 t. or more. The biggest potential of crop biomass was in Šiauliai, Kaunas, Panevėžys, and Marijampolė counties. Thus, decisions on crop biomass conversion into energy resources are made for a given county.

The maximal potential of livestock by-products in Lithuania for production of gas-like types of fuel was achieved in 2010—7.556 $\times$ 10^6 m^3. On average during the period 2010–2021, 6.931 $\times$ 10^6 m^3 of biomass was produced. During the study period there was a tendency towards reducing the potential of livestock production in general. On the average during the period 2010–2021, the thermal equivalent of potential of livestock by-products equaled 4.384 $\times$ 10^6 GJ, and the electric potential equaled 1.535 $\times$ 10^6 GJ.

The total energy equivalent equaled, on average, 30.017 $\times$ 10^6 GJ of thermal energy and 9.224 $\times$ 10^6 GJ of electric energy, which is approximately 6.2% of the thermal energy consumption and 22.5% of the electric energy consumption in Lithuania. The total potential of biomethane production (taking into account crop production and animal husbandry wastes) equals, on average, 285.6 $\times$ 10^6 m^3, which is 10% of the natural gas consumption in Lithuania. The total potential of biohydrogen production equals, on average, 251.9 $\times$ 10^6 m^3. The average cost equivalent of the thermal energy could equal EUR 8.9 billion, electric energy—EUR 15.9 billion, biomethane—EUR 3.3 billion and biohydrogen—EUR 14.1 billion.

Author Contributions: Conceptualization, V.K. and D.J.; methodology, S.K., V.K. and O.S.; validation, J.Č., P.P. and T.H.; formal analysis, D.J. and S.S.; literature review, I.H. and A.S.; project administration, V.K. and S.K.; supervision, V.K. All authors have read and agreed to the published version of the manuscript.

Funding: The studies presented were financed by the National Center of Research and Development (NCBR) Poland under the research program LIDER. The research and development project is entitled by the acronym BIOCARBON, with the title "Modern technology biomass torrefaction process to produce fuel mixtures, biocoal as additives for fertilizers, activated carbon for energy sector, agriculture, civil engineering and chemical industry", "LIDER IX" NCBR 2014-2020 (grant no. LIDER/43/0155/L-9/17/NCBR/2018).

Data Availability Statement: Not applicable.

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

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