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THE EFFICIENCY CALCULATION AND SELECTION OF THE OPTIMAL ENERGY CARRIER IN THE ASPECT OF SUSTAINABLE DEVELOPMENT

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ABSTRACT: The article examines energy efficiency as part of macro-scale energy resource management, highlighting its priority in the European Union due to climate change, reliance on fossil fuels, sustainable development, and energy security. The authors aim to evaluate the social and environmental effects of selecting the optimal energy carrier for sustainability. They analysed local energy carrier parameters, focusing on non-forest biomass and municipal waste in five Polish regions. The study compares the economic efficiency and profitability of replacing hard coal with more eco-friendly fuels, like non-forest biomass and biodegradable municipal waste. The hypothesis suggests that non-forest biomass is unprofitable when considering social and ecological criteria, while municipal waste is the most cost-effective fuel. Externalities were assessed using the "impact path" methodology from the European Commission's ExternE project, known for accurately estimating external costs and benefits.

KEYWORDS: energy efficiency, sustainable development, energy carrier, ecological

Introduction

The choice of the optimal energy carrier used by the commercial power industry to produce heat and electricity in terms of social and ownership/investor welfare in the commercial power industry, taking into account external costs, is not apparent. There are legal instruments and other tools to promote energy efficiency, and this document has been prepared with these initiatives in mind. During the current Russian-Ukrainian conflict, European Union countries have been forced to seek solutions that would enable them to gain energy independence. It has become more critical than ever to look for an appropriate energy carrier that is economically viable but also generates low social costs, replacing the traditional fuel (hard coal) with non-forest biomass (this concept includes energy crops and biodegradable waste from the agri-food industry) or municipal waste aims to reduce air pollutants while ethically choosing the fuel and preserving biodiversity for future generations. The studied area from which the potential non-forest biomass and municipal waste originated covered five voivodeships (dolnośląskie, śląskie, wielkopolskie, małopolskie and opolskie). The authors aim to evaluate the social and environmental effects of selecting the optimal energy carrier for sustainability.

These considerations were made in the context of Sustainable Development. Therefore, the definitions of sustainable development relevant to this article are listed below. The most common definition was given in the 1987 Brundtland Report of the World Commission on Environment and Development entitled "Our Common Future". According to it: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987, s.41). Sustainable development has been one of the main goals of EU policy for many years. In 2001, the leaders of the European Union adopted the document "A Sustainable Europe for a Better World: A Sustainable Development Strategy for the European Union". It was updated in 2006 under the name "Renewed EU Sustainable Development Strategy" (SDS). It takes into account new challenges and sets the direction for a long-term vision of sustainable development, in which elements such as economic development, social cohesion, and environmental protection go hand in hand and complement each other. Sustainable development means that the needs of the present generation should be met without compromising the ability of future generations to meet their own needs. This idea, included in the treaty, is the overarching objective of the European Union, guiding all EU policies and actions. It concerns preserving the Earth's capacity to support life in all its diversity and is based on the principles of democracy, gender equality, solidarity, the rule of law, and respect for fundamental rights, including the right to freedom and equal opportunities. It is to ensure that current and future generations will have a constant increase in the quality of life and well-being on Earth. Therefore, it is linked to the promotion of a dynamic economy with full employment of citizens and a high level of education, health protection, social and territorial cohesion, and environmental protection – in a world where peace, security, and respect for cultural diversity prevail (EU SDS 10917/06, s. 2).

Therefore, as Burchard-Dziubińska rightly notes, sustainable development is the development of social, economic, and natural systems that guarantee their remaining in a state of mutual harmony in a way that fully protects biodiversity (Burchard-Dziubińska, 1994). Therefore, it is important to strive to maintain equal treatment or to shape the right proportions between these elements.

Taking the above into account, it becomes important to indicate what the environmental benefits are for the environment. Estimating environmental benefits should be one of the most critical factors determining the economic effects of a pro-ecological investment. At the same time, the attempt to evaluate the external effects caused by the investment and the optimal choice of the energy carrier poses the most difficulties and may be imprecise. Therefore, the author of this article proposes that:

- identify the costs and benefits of choosing the optimal energy carrier between non-forest biomass, waste from the agri-food industry, and municipal waste,
- comparing the benefits with the costs of individual energy carriers,
- identification of energy carriers with positive net benefits,
- choosing from among the examined solutions the one that represents the most significant net benefit (the best benefit-to-cost ratio).

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The quantitative and energetic potential of the analysed energy carriers in the studied area

The use of non-forest biomass from energy crops (energy willow, grasses, oats) is characterised by many controversial aspects. Landowners who could engage in energy cultivation are not particularly interested, as the knowledge of cultivating this type of cultivation is still little known (energy willow and various types of grasses). In the first two years of plantation, there is a significant risk of not accepting relatively expensive seedlings, for example, miscanthus grass or energy willow, or destruction of the crop as a result of weather anomalies such as hail, flood, or severe frost during the growing season of plants. The real possibility of using energy willow as a fuel occurs after three years of cultivation, and there is the issue of freezing investment costs. The owners of power plants are not interested in signing contracts with farmers in which they would bear the frozen expenses and the risk related to the actual amount of biomass that can be obtained in the future. In addition, the energy plant must be able to use alternative fuel in the event of the destruction of the energy plantation. This requires independent negotiations with other economic entities and additional costs to ensure the safety of continuous energy production. Analysing the studied area makes it possible to obtain 60,000 Mg of raw willow wood from this acreage. Assuming the calorific value of the energy willow at 10 GJ / Mg, this acreage can produce 600 thousand. GJ during the year. The important assumption is that all seedlings will catch on.

Another potential energy carrier for power plants may be waste biomass from crops or the agri-food industry. The amount of waste biomass that can be obtained from a given area is 1.6 million Mg[1]. This value should be reduced by the primary use of this organic waste so far, namely as fodder for feeding cattle, then the actual amount of potential fuel that the energy sector can use amounts to approx. 71 thousand. Mg (Misiura, n.d.), although this material is also a reserve for animals. Another essential element is the differentiated moisture content in individual biomass, which requires the investor to spend additional costs related to the unification of matter to conduct a stable process of particle combustion. The varying moisture content is also associated with different aspects affecting the cost of the fuel, i.e., transport, storage, and appropriate on-site treatment. One cannot ignore the issue of the seasonality of most of the characterised non-forest biomass and the related storage to ensure the fluidity of energy production. Additionally, this amount includes biodegradable waste (56 thousand Mg), which, according to the applicable legal regulations, is treated as non-forest biomass and can be used in the commercial power industry as a green fuel (Dyrektywa, 2000). The only difficulty is that there are no technological solutions that guarantee the segregation of biodegradable municipal waste without admixture of other inorganic components. The use of non-forest biomass by the commercial power industry is associated with positive and negative environmental and social effects.

Natural biomass, the so-called bio-waste to be obtained from the analysed area with a moisture content of up to 20%, is approx. 30 thousand. Mg annually. The higher moisture value significantly increased the costs of transport, storage, and drying of the fuel and was ignored. The given value of waste biomass that can be obtained comes from various processing plants, and a different calorific value characterises it from 15 to almost 19 MJ/kg. A power company wanting to use such material as a fuel carrier would first have to unify it by mixing and palletising. Just churning the fuel would give the possibility of obtaining about 510 thousand. GJ during the year, without considering the combustion process's safety. The fuel cost is about PLN 30/GJ. By palletising the material, the energy company could produce about 475 thousand. GJ. The cost of processing the material itself would increase by about PLN 10.8 million because PLN 25 should be added to each GJ (Lenartowska, 2022). The price of transport would be lower, but the raw material subjected to palletisation requires additional costs related to transporting it to the place where it would be processed and then transported to the power plant. Table 1 below summarises the quantitative potential of waste biomass and municipal waste (in the analysed area) that the energy sector can use.

1 Own study based on interviews with individual producers of the agri-food industry in the studied area.

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Table 1. The summary of the quantitative potential of waste biomass and municipal waste (in the analysed area) that the energy sector can use

biomass	figure	potential in thus. Mg	PLN/GJ*	Caloric value [MJ/kg]	notes
wood	sawdust	500-1000	20-25	19.09	the energy sector cannot use wood of total value for energy production
	wood chips		22-27		
	briquette		25-30	16.54	
	pellets		>30		
rapeseed straw	briquette	150	25-27	15.04	
cereal straw	briquette	4000	>25	15.25	too low ash melting point
energy willow	wood chips	60	22-26	10	40% humidity
Pennsylvania mallow		250	22-25	14	20-25% humidity
giant miscanthus			21-24	19	20-25% humidity
oat	briquette	220	22-38	16	
sugar industry	pulp pellets	12-15	30-35	15.17	11,7% humidity
brewing industry	thresher	500 (in 100% used by farmers)	2	18.5	79% humidity
fruit processing	apple pomace	10 (in 100% used by farmers)	10	18.63	82,2% humidity
potato processing	potato by products	30 (in 100% used by farmers)	6	18.51	85% humidity
oil plants processing		500 (in 100% used by farmers)	21-30	16.44	
municipal waste		4750		8	13% humidity
biodegradable municipal waste		56		11.37	
paper and cardboard	loosely	57		12-18.5	
paper and cardboard	pellets			16.39	14% humidity

* The term PLN/GJ in the table refers to the cost of converting biomass into energy, expressed in Polish złoty per gigajoule of energy produced.
Source: authors' work based on data obtained from entrepreneurs of the agri-food industry in the studied area.

Looking at Table 1 in terms of the quantitative demand for biomass, the fat industry and by-products generated in the production cycles, i.e., extraction meal and rapeseed cake, are attractive sources for the production of green energy. Additionally, there is no seasonality in the production cycles, the calorific value is high, and there are no legal contraindications. The only issue that is not conducive to using these by-products in the energy sector is ethical. The rapeseed meal and the rape cake are entirely used in agriculture as animal feed. Another abundant by-product is spent grain from the brewing industry. Its calorific value is comparable to the calorific value of wood. Only the total moisture content of the spent grain is about 79% and is characterised by seasonality in the production cycle. Therefore, there are additional costs of drying, transporting, and storing fuel and securing production during raw material unavailability. According to the information obtained, 100% of the spent grain is used as animal feed for farmers. By eliminating the materials used as animal feed, energy crops, i.e., energy willow, giant miscanthus, and mallow, are worthy of interest as a potential fuel. These plants do not require special plantation conditions. Although they absorb vast amounts of groundwater, there is a high risk that the seedlings will not take root in the first three years. They can be grown in class IV and V soils and have a high calorific value.

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In the case of municipal waste, in the studied area, more than 5 million Mg of waste is generated annually, 89% of which goes to landfills (GUS, 2021b). The price for landfilling of waste in landfills is between PLN 250-350 / Mg of unsorted municipal waste, code 20 03 01[2]. In the case of mixed municipal waste, the bulk value, moisture content, and calorific value are averaged. When adapting the plant to the thermal treatment of waste, the issue of fuel drying is one of the elements of the production cycle process and does not require additional steps. The calorific value of waste is approximately 11 MJ / kg. By reducing the recoverable waste by the content of the glass, debris, earth, and metals, we can obtain about 4.5 million Mg of potential fuel annually, which makes it possible to produce 49.5 million GJ. The cost of purchasing waste by the energy company is PLN 0. This is because companies dealing with waste management will not incur the charge of depositing rubbish in landfills. Analysing potential energy carriers in terms of the amount of energy expressed in GJ that can be used is presented in Table 2.

Table 2. The potential of energy production during the year by individual energy carriers

energy carrier	PLN/GJ	GJ/Mg	Mg/year [thou.]	potential GJ/year [hou.]
energy willow	22-26	10	60	600
waste biomass from the agri-food industry	30	15-19 (used 17)	30	510
waste biomass pellets	55	19	25	475
municipal waste	0	11	4500	49500

The cheapest fuel (Table 2) to be obtained is municipal waste, while the amount possible to get potential energy is the largest. In such aspects, municipal waste is the most attractive fuel for investors. However, the process requirements are different for these fuels. The use of waste fuel requires significant investment outlays for the power plant to meet environmental standards, and only about 42% of used municipal waste can be classified as green energy. However, the use of the first three energy carriers listed in Table 2 does not require significant investment outlays, and 100% of the fuel is classified as a green fuel. At this point, it should be noted that to adapt a given plant to use other than traditional fuel, its efficiency must be at least 100 thousand. Mg/year. The amount of non-forest biomass that can be obtained from the studied area is not sufficient. To guarantee the minimum efficiency of the installation, it would have to be mixed with the primary fuel, e.g., with hard coal. In the case of municipal waste, there is no need for additional conventional fuel dosing, as there is a significant surplus of the energy carrier.

The establishment of a biomass plant capable of utilising municipal waste requires significant initial investment. These costs typically include:

- **Infrastructure and Equipment cost:** Procurement of specialised technology for waste sorting, pre-treatment, and energy conversion.
- **Permitting and Compliance:** Expenses for environmental impact assessments, obtaining permits, and ensuring adherence to Polish and EU regulations.
- **Operational Setup:** Investment in training, staffing, and commissioning the plant.

The total initial investment can vary significantly based on the plant's capacity and technology used, ranging from millions to tens of millions of PLN.

Currently in Poland are several municipalities in Poland have taken steps toward integrating biomass plants for municipal waste utilisation, for example, in Krakow (Ekospalarnia Kraków, n.d.) or Warsaw (Sweco, n.d.). These facilities often function as part of a broader waste management strategy, addressing both energy production and waste reduction goals. However, such facilities remain limited in number, and widespread adoption faces barriers such as funding challenges, public acceptance, and technological readiness.

Worldwide, the utilisation of biodegradable waste is also not developed on a large scale. Existing facilities are usually small installations, such as:

[2] Average value of the price obtained from the websites of individual marshal offices.

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- **Denmark** has been a pioneer in utilising straw for district heating and electricity. Biomass combined heat and power (CHP) plants, such as the one in Studstrup, use large quantities of agricultural residues, contributing significantly to renewable energy targets.
- **India** uses rice husks and other agricultural residues for small-scale power generation, particularly in rural areas. Companies like Husk Power Systems convert biomass into electricity using gasification technology.
- **Sweden** uses wood chips and pellets as a significant part of its energy mix, especially in district heating systems. Policies promoting bioenergy and carbon taxes have made biomass energy economically viable.
- **Canada** in British Columbia, forest residues from logging and sawmills are converted into wood pellets and exported globally. Domestically, these pellets are also used in residential and industrial heating.
- **Japan** has an extensive waste-to-energy (WtE) program. Facilities like the Maishima Incineration Plant in Osaka use municipal waste to produce electricity while adhering to strict emissions standards.
- **Germany** integrates WtE plants into its circular economy model. MSW is used for power and heat generation, contributing to waste reduction and renewable energy production.
- **Netherlands** farms use anaerobic digestion to convert manure into biogas, which is then upgraded to biomethane and injected into the natural gas grid or used for electricity generation.
- **United States** like California and Wisconsin, dairy farms deploy methane digesters to manage manure, reduce greenhouse gas emissions, and generate renewable electricity. Additionally, research initiatives funded by the U.S. Department of Energy are advancing the use of algae for biofuel production. Pilot projects explore converting algae into biodiesel and jet fuel.
- **Brazil** is a global leader in utilising sugarcane bagasse (a by-product of sugar and ethanol production) to generate electricity and steam. The surplus electricity is fed into the national grid (IEA Bioenergy, n.d.).

The main lessons from International Experience are:

- **Policy and Incentives:** Countries like Sweden and Germany demonstrate the importance of government incentives, such as subsidies and carbon pricing, in fostering biomass adoption.
- **Technological Innovation:** Advanced technologies, such as anaerobic digestion and gasification, are critical for efficient biomass utilisation.
- **Integration into Existing Systems:** Many countries successfully integrate biomass into existing energy systems, such as district heating (Sweden) or grid electricity (Brazil).
- **Local Resource Optimization:** The most effective biomass projects utilise locally available resources, such as agricultural waste in India or forest residues in Canada (European Environment Agency, 2024).

Identification of external costs and benefits for individual energy carriers

The European Union emphasises that while its electricity and heat production costs are included in its market prices, energy policymakers should take external costs into account. The goal should be to optimise the use of natural resources and ensure the most significant benefit to society. Currently, the methodology of the "impact path" developed under the ExternE project is considered the most authoritative methodology for estimating the external costs of electricity and heat generation.

Identification of the external costs caused by the fuels taken under consideration will facilitate the decision on the method of preventive action and the assessment of possible benefits resulting from it.

The estimated external costs resulting from energy willow as an energy carrier are primarily the cost of groundwater absorbed by plantations worth 60 million Mg. By quantifying this value, we get the value of PLN 72 million (Cire.pl, 2014). On the other hand, if the land in question were to be used for another purpose, e.g., grazing animals or forest, the external cost would be avoided by the calculated value.

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Exploiting the potential of waste from the agri-food industry would involve searching for other forms of cattle nutrition, which could be associated with an increase in human morbidity and even an increased risk of mortality. Such an example is known in Europe when farmers wanted to reduce the cost of raising cattle by feeding them a cube of flour. As a result, the animals contracted mad cow disease, and poultry became infected with salmonella (Wprost, 2002). According to the European Union proposal, the loss of human life is estimated at EUR 1 million, and the reduction of a person's life by a year at 50,000 euros. In the case of permanent health impairment, the ExternE method costs 12.5 thousand euros. Assuming that only 10% of the population living in the analysed area could get sick, the external costs of energy use of waste from the agri-food industry would amount to approximately PLN 84 billion. Table 3 summarises the estimated external costs related to the acquisition of waste from the agri-food industry and agricultural waste. As shown in the table below, the main external cost is generated by valuing human health. Other values, even those related to the avoidance of carbon dioxide emissions to the atmosphere and income from green energy production, are small in assessing the risk of morbidity in society.

Table 3. Summary of external costs and benefits related to obtaining fuel from agricultural waste and the agri-food industry

costs	units	waste biomass from the agri-food industry	waste biomass pellets
no cost of CO2 in the combustion of the carrier (green energy)	million PLN	0.14	0,13
risk of mad cow disease or salmonella as a result of substitutes in animal feeding	million PLN	-84 000	-84 000
avoided the cost of CO2 as a result of coal combustion	million PLN	2.3	1.9
Sum	million PLN	-83 997.56	-83 997.97

Source: authors' work based on Bickel and Friedrich (2005).

The use of municipal waste for energy production would contribute to the gradual closure of landfills and, consequently, the elimination of about 70 thousand. Mg of carbon dioxide is emitted into the atmosphere. Using the valuation of CO_2 value using the EnternE methodology, the tonne of emitted pollution amounts to EUR 21. Therefore, by ceasing to store waste in the studied area, we will avoid an external cost of over PLN 6.6 million per year. In addition, the elimination of landfills is associated with a lower risk of diseases spread by animals feeding in landfills. So again, there is the avoidance of costs related to, for example, respiratory diseases, valued at 38 Euro/day. Assuming that about 10% of society would have health problems associated with the respiratory system 14 days a year, it would cost about PLN 3.6 billion.

On the other hand, the energy use of waste is associated with CO_2 emissions to the atmosphere at the level of 55%; the rest, as in the case of other carriers, is classified as green energy. Closing landfills is associated with the possibility of another land use, for example, afforestation, which will improve the quality of the environment and enrich the aesthetic value of the landscape. Additionally, increasing the value of real estate located in the vicinity of the recruited area. Assuming the site would be entirely forested. The cost of establishing the forest would be approximately PLN 7.2 million, and during the year of its existence, about 4.5 million pure oxygen and 6.4 million Mg of absorbed CO_2 would be produced (Agropolska, 2020). Converted into monetary value, the absorbed gas amounts to approximately PLN 605 million. The table below provides a financial valuation related to municipal waste for energy production.

Table 4 shows the net social benefit of using municipal waste from the existing landfills for the entire analysed area and the possible net social benefit for an installation that would use only 47% of the waste fuel potential. The collected data show that in the case of the operation of a landfill, what constitutes a social cost, for example, gas emissions into the atmosphere, becomes a social benefit in the event of its liquidation.

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Table 4. Summary of external costs and benefits related to the use of municipal waste for energy production in the analysed area and installations with a capacity of 100,000 Mg/year

costs	for the entire study area [mln PLNł/year]	for facilities with a capacity of 100 thousand Mg /year [mln PLN/year]
landfill costs avoided	1 425	670
landfill gas costs avoided	6.6	3,1
avoiding respiratory diseases	3 591	1 688
afforestation of the area	-7.22	- 3.4
absorption of CO2 from the atmosphere	605	284.35
improving the aesthetic qualities of the landscape	-1 425 *	-670
use of the energy potential	- 1 259 **	-591.73
formation of CO2 ¬ (55%) as a result of combustion	-27.22	16.6
no cost of CO2 in the combustion of the carrier (green energy)	7.57	13.5
avoided the cost of CO2 as a result of coal combustion	3734	0.3
sum	6 651	1 410.72

* It was assumed that the cost of depositing waste in landfills is equivalent to the price that society is willing to pay for improving the aesthetic value of the area. Probably, the community would be able to pay much more to get rid of the landfill in the immediate place of their residence than the one that lives a significant distance from it.
** Valuation based on the Kogeneracja (2022), the price of GJ is PLN 62.47.
Source: authors' work based on Bickel and Friedrich (2005).

The next stage of selecting the appropriate fuel is the issue of capital expenditure related to the adaptation of the existing power and heat generating plant into a municipal waste processing plant.

Table 5. Summary of social and environmental costs depending on the type of energy used for installations with a capacity of 100,000 Mg/year

energy carrier	external cost [million PLN]	external benefit* [million PLN]	external benefit net [million PLN]	unit environmental cost million PLN /GJ	potential thousand GJ/year
energy willow	72000	225.16	-71774.8	0.105	684
waste biomass from the agrifood industry	84000	2.44	-83997.6	0.128	657
waste biomass pellets	84000	2.03	-83998	0.115	727
municipal waste	1400	2676	1276	0.00127	1 100

The avoided amount of CO_2 produced from *coal is included in the cost of the substitution fee according to Urząd Regulacji Energetyki (2022) – 101 PLN/GJ.
Source: authors' work based on Bickel and Friedrich (2005).

Because there are not enough quantities of the first three carriers in the studied area for the adaptation of the existing power plants to be economically justified (orders for machines and devices), the lack of fuel was supplemented with the primary fuel. The addition of hard coal increased the value of external costs due to the additional carbon dioxide emission into the atmosphere by PLN 6.04 million for energy willow, PLN 10.5 million for agro-industrial waste, and PLN 11.3 million for pellets from agricultural and food waste. These values have not been included in Table 5 as they are imperceptible given the current level of external costs. When comparing the value of unit costs of the environment, municipal waste has the lowest value because there are many positive aspects of using residual waste, the energy that is wasted. The more significant the scale of the thermal utilisation of municipal waste is, the greater the environmental effect. On the other hand, in the case of the traditional economic approach to the choice of the carrier, in a situation where the power industry aims to

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maximise profit, the investor will not be interested in using municipal waste. When choosing municipal waste, one should also consider the benefit to society due to the lack of penalties related to the storage of municipal organic waste.

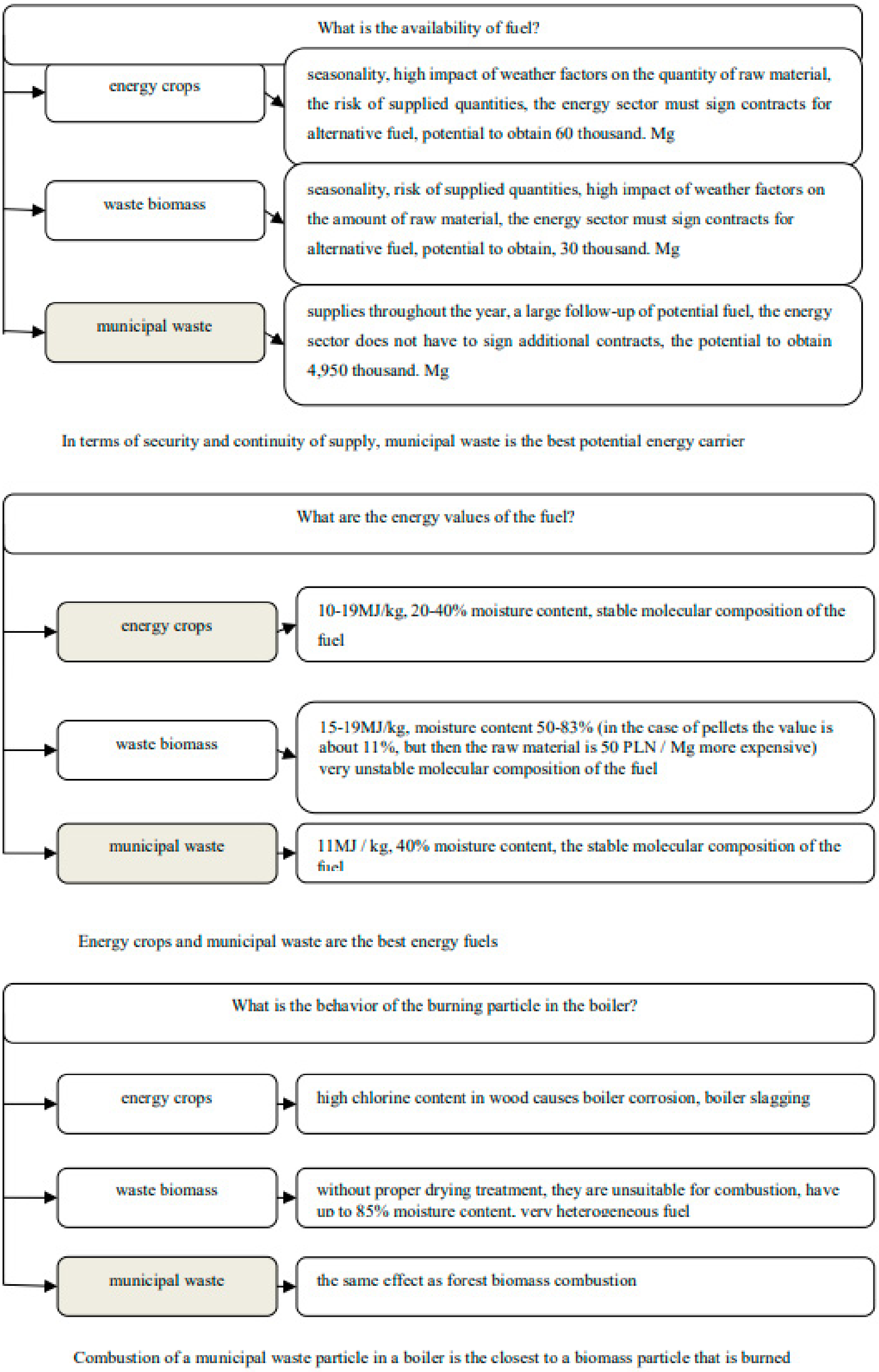

Figure 1. Selection of the success of carriers that influence the behaviour properties of the natural and energetic consequences of social changes

An attempt to choose the optimal energy carrier in terms of the local community and the entity of professional energy

Analysing the selection of the optimal energy carrier in Figure 1 contains a summary of the results obtained during the study along with an attempt to select the optimal carrier in terms of economic, ecological, and social aspects, taking into account the principle of sustainable development.

The above Figure 1 attempts to select the choice of municipal waste as the optimal energy carrier for power plants. The costs of adapting the plant (so that it meets the thermal waste processing company) are the highest, and therefore, from the investor's point of view, they are not attractive energy fuel. Meanwhile, the costs of obtaining fuel are zero, the prices of transport are much lower due to the short distance of waste storage, and there is no need to build special warehouses where the fuel has to be stored. There is no need to look for additional fuel because there is overproduction and no seasonality in obtaining the carrier.

Taking into account the environmental aspect, the use of waste as a fuel is associated with closing municipal waste landfills, which are the habitat of bacteria, poisoning the groundwater, and emitting harmful substances into the atmosphere, including methane, which is many times more poisonous gas than carbon dioxide. The elimination of landfills will improve air quality and enhance the aesthetic value of the landscape. Conducting energy crops seems to be environmentally friendly, the existing tree states absorb pollution, and green plantations give the impression of woodland, but no one takes into account the amount of groundwater absorbed by the plantation, which significantly drains the land.

Summary

In this article, the study's author attempted to evaluate the emerging externalities of the analysed potential energy carriers. To this end, the author used the 'impact path' methodology in the framework of the European Commission's ExternE project, which is considered the most advanced and authoritative methodology for estimating external costs and benefits. The quantification of the discussed environmental and social aspects confirms the hypothesis put forward at the beginning of this article that the use of non-forest biomass, taking into account social and ecological criteria, is unprofitable. On the other hand, municipal waste is the cheapest potential fuel carrier, both in obtaining fuel and in environmental aspects. It should be emphasised that elaborating a bold development strategy in the energy area is one of the primary responsibilities of regional and local authorities. The presented considerations should be considered during the energy management process both in the regional and local dimensions.

The contribution of the authors

Conceptualization, M.P. and M.R.; literature review, M.P. and M.R.; methodology, M.P. and M.R.; formal analysis, M.P. and M.R.; writing, M.P. and M.R.; conclusions and discussion, M.P. and M.R.

The authors have read and agreed to the published version of the manuscript.

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RACHUNEK EFEKTYWNOŚCI I WYBÓR OPTYMALNEGO NOŚNIKA ENERGII W ASPEKCIE ZRÓWNOWAŻONEGO ROZWOJU

STRESZCZENIE: W artykule podjęto problematykę efektywności energetycznej jako elementu zarządzania zasobami energii w skali makro, podkreślając jej priorytet w Unii Europejskiej ze względu na zmiany klimatyczne, wykorzystanie paliw kopalnych, zrównoważony rozwój i bezpieczeństwo energetyczne. Celem autorów jest ocena skutków społecznych i środowiskowych wyboru optymalnego nośnika energii dla zrównoważonego rozwoju. Przeanalizowano parametry lokalnych nośników energii, koncentrując się na biomasie nieleśnej i odpadach komunalnych w pięciu województwach Polski. W badaniu porównano efektywność ekonomiczną i opłacalność zastąpienia węgla kamiennego paliwami bardziej ekologicznymi, takimi jak biomasa nieleśna i odpady komunalne ulegające biodegradacji. Hipoteza sugeruje, że biomasa nieleśna jest nieopłacalna ze względu na kryteria społeczne i ekologiczne, natomiast odpady komunalne są paliwem najbardziej opłacalnym. Efekty zewnętrzne oceniono przy użyciu metodologii „ścieżki wpływu" z projektu Komisji Europejskiej ExternE, znanej z dokładnego szacowania kosztów i korzyści zewnętrznych.

SŁOWA KLUCZOWE: efektywność energetyczna, zrównoważony rozwój, nośnik energii, ekologia