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Ranking of Bioresources for Biogas Production

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***Abstract* – Production of biogas using bioresources of agricultural origin plays an important role in Europe's energy transition to sustainability and to a climate-neutral economy. The usage of some substrates like maize has been increasingly denounced in the last years and there is currently an active discussion about future subsidies to biogas producers depending on the substrate used. The aim of this study is to compare and rank different substrates for biogas production considering their economic feasibility, substrate efficiency and environmental aspects. During the research, eight substrates were evaluated: cattle manure, pig manure, poultry manure, straw, wood, maize silage, waste, and sewage sludge. In order to reach the research goal, multi-criteria analysis using TOPSIS methodology was applied to objectively determine which of the substrates considered would be the most suitable for biogas production in Latvia. The results obtained showed that pig manure is the most suitable raw material for biogas production in Latvia, while poultry manure was ranked second, with little difference in value from pig manure.**

***Keywords* – Biogas; economic feasibility; maize; manure; substrate efficiency; TOPSIS.**

1. INTRODUCTION

Production of biogas using bioresources of agricultural origin plays an important role in Europe's energy transition to sustainability and a climate-neutral economy [1]–[3]. The transition to clean energy has already proven its worth by modernizing the EU's economy, promoting sustainable economic growth and prosperity, as well as improving the environment, creating new jobs and delivering benefits for citizens [4]. Given that around 6 million tons of agricultural waste is produced in the world yearly and the emphasis on pathways and strategic priorities for transition to a net-zero GHG emission economy, there is a promising future for the development of biogas production, especially for upgraded biogas to biomethane, which is flexible both in use and storage and because its production from agricultural, industrial waste and sewage sludge protects soil, air and water from pollution [5], [6]. Not only does biogas produced by anaerobic digestion prevent greenhouse gas emissions and produce renewable energy from waste, but also provides for the production of processed fertilizers, improving nutrient self-sufficiency in the agricultural sector [7].

The biogas production process is an environmental technology that integrates production [8], processing and recycling of degradable by-products [9]. In 2014 there were 54 first- and second-generation biogas plants [10] operating in Latvia with a total capacity of 54.92 MW (3.1 PJ) and

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out of those 54 biogas plants, 44 used agricultural waste, 7 used municipal waste in landfills, but only 3 used domestic or industrial sewage and residues from food production (industrial waste) [11]. Consumption of biogas produced in 2017 increased to 80.73 MW (3.9 PJ) since 2014, reaching a 25.81 % increase of biogas production [12].

The productivity of a biogas plant depends on different aspects, like type of biomass [13], digestion [14], availability of biomass, impurities that may harm microorganisms [15] and lignin content [16].

Different types of manure present variation in organic composition and dry matter content (1.5–30.0 %), which affects the biogas produced. Co-digestion is often used for the very reason that the optimal carbon-nitrogen ratio on biogas production is in the rage of 20:1 to 30:1, but in general, manure has very low carbon ratio and it is important to mix it with other substrates that are carbon-rich to increase the biogas yield [14], [17].

TABLE 1. YIELD OF VARIOUS RAW MATERIALS [18]

	Yield of methane, %	**Yield of biogas, m^3/t**
Cattle manure (liquid)	60	25
Cattle manure	60	45
Pig manure (liquid)	65	28
Pig manure	60	60
Poultry manure	60	80
Maize silage	52	202
Grass silage	52	172
Organic waste	61	100

The most commonly used substrate with manure for co-digestion is maize silage. The yield of different raw materials is shown in Table 1. Comparing the biogas yield of maize silage with the biogas yield of liquid cattle manure, the biogas yield from maize silage is 8,08 times higher [19].

The use of lignocellulosic substrates after pre-treatment [20] for biogas production should be evaluated. Given that the use of maize and rapeseed silage in biogas production will no longer be acceptable, it is necessary to find new raw materials that occurs as a result of other processes as waste. Considering that a half of Latvia's territory is covered by forests in 2016, and 36.5 % of Latvia's territory is covered by agricultural lands, Latvia has a big potential to use harvesting and agricultural crop residues and waste, which have high levels of lignin in their content [21].

Grasslands have a variety of functions in agriculture – not only are they primarily the main source of feed for livestock, but overall, they provide benefits such as carbon storage and soil protection from erosion, groundwater formation and habitat formation in diverse landscapes and natural foundations [22]. Although grasslands can be used in the production of lignocellulosic bioethanol, synthetic natural gas or synthetic biofuels, according to the Green Biorefineries concept, the sustainable use of grass biomass is directly linked to the production of biogas [22]. Knowing the feasibility of successful processing of such raw materials and their practical application, it is understandable that they are potential raw materials also in the agricultural conditions of Latvia.

Anaerobic digestion has been mainly implemented for the management of animal manure, organic and agricultural waste, sewage sludge, plant green mass etc. [23]. Theoretically it is possible to use forest and wood processing waste and peat [24].

Manure is the most suitable material for biogas production. The easiest way to get biogas is from cattle manure. The dry matter content of the manure depends on the used amount of litter, moreover if a lot of washing water is used, the manure is watery [25].

Pig manure is also very suitable for biogas production, because it contains not only manure, but also feed residue and litter. Bird manure is very suitable for biogas production also, but there tends to be sand and feathers mixed in the manure, which can cause problems, when specially adopted pumps are not used. Because of the high concentration of nitrogen, it is advisable to mix poultry manure with cattle manure [24].

2. METHODOLOGY

Multi-criteria analysis was carried out to determine Latvia's biogas sector potential – to predict the best feedstock depending on resources available in the country, which of the substrates for biogas production has the highest potential and sustainability. The following raw materials were analysed in this multi-criteria analysis: cattle manure, pig manure, poultry manure, sewage sludge, organic waste, wood, straw, maize silage.

The year 2017 was used for data collection, and multi-criteria analysis does not take into account the size of the farms, which is related to the actual number of livestock, manure collection technology and the transportation distance from the raw material extraction site to the biogas plant.

For the purpose of multicriteria analysis, the efficiency of different feedstocks in terms of yield, were how many cubic meters of biogas can be obtained from a ton of a given feedstock was analysed. The efficiency of raw materials was determined as an average value [26]–[28].

In order to determine the importance of using a particular substrate in the production of biogas, data was collected on how many emissions could be eliminated altogether, thus approximating the proportion of their availability and importance, and environmental impact depending on how much this material is produced in one year and its emission factor. To calculate objectively the amount of emissions that could potentially be avoided (both nitrous oxide and methane), emissions were compared to carbon dioxide equivalents and added up. 1 kg of nitrous oxide was calculated as 298 kg carbon dioxide, while 1 kg of methane was calculated as 25 kg carbon dioxide [28].

In total three main criteria were considered: substrate efficiency, environmental friendliness, and economic feasibility.

TABLE 2. CHARACTERISTICS OF LIVESTOCK NUMBERS AND EMISSIONS FROM MANURE MANAGEMENT IN 2017 [29]

	Mature dairy cattle	**Other mature cattle**	**Growing cattle**	**Pig**	**Poultry**
Population size, thousands	150.4	77.5	177.9	320.6	4943.8
CH_4 emissions, kt	2.60	0.15	0.20	0.79	0.07
CH_4 emissions, kt CO_2 equivalent	65.00	3.75	5.00	19.75	1.75
N_2O emissions, kt	0.11	0.01	0.02	0.02	0.01
N_2O emissions, kt CO_2 equivalent	32.78	2.98	5.96	5.96	2.98
Emissions in total, kt CO_2 equivalent	97.78	6.73	10.96	25.71	4.73

In order to determine, which is the most important criteria, a survey and a vote was carried out among different experts in the field of biogas production. As a result, of the 100 % experts voted that the most important criteria was climate friendliness with 35 % as the deciding factor. Only 5 % less important was the technological aspect responsible for substrate efficiency. The economic justification for this sector's priorities and comparison with the other two criteria was determined as the last one with 35 %.

In order to objectively determine the potential of manure for biogas production, a summary was made, which is shown in Table 2, to summarize the amount of specific livestock manure and emissions in Latvia in one year.

Since the information about livestock population and emissions for 2017 is available, it is used for the analysis. Table 2 shows that although poultry has the highest numbers, methane emissions from cattle are the highest and to use them for biogas production would be more significant, if only by looking at annual emissions, because altogether cattle emissions reach 115.47 kt/year, but pig manure is also a very important resource, although the number of pigs is 21 % lower, the emissions emitted are still significant.

Domestic and industrial wastewater emissions are calculated and showed in Table 3.

TABLE 3. WASTEWATER DRY CONTENT AND EMISSIONS IN 2017 [29]

	Total organic product, kt DC/year	CH_4 emissions, kt	CH_4 emissions as CO_2 equivalent, kt	N_2O emissions, kt	N_2Oemissions as CO_2 equivalent, kt	In total, kt CO_2 equivalent
Domestic wastewater	42.71	3.16	79.00	0.11	32.78	111.78
Industrial wastewater	13.51	0.07	1.75	0.00	0.00	1.75

Methane emissions from solid waste are shown in Table 4. In total both managed and unmanaged waste disposal sites emit 403.50 kt CO_2 equivalent per year, because of the organic waste in disposal sites. This problem could be partly overcome by changing the shopping and eating habits of people, thus reducing the amount of food thrown away. However, such a shift in people's behaviour takes a long time and, until it is successful, this "waste" can be used effectively in biogas production because it is creating the biggest emissions of all analysed raw materials in this research.

TABLE 4. ANNUAL SOLID WASTE EMISSIONS IN 2017 AT THE WASTE DISPOSAL SITES [29]

	Annual waste, kt	CH_4 emissions, kt	CH_4 emissions, kt CO_2 equivalent
Managed waste disposal sites	230.62	10.55	263.75
Unmanaged waste disposal sites	–	5.59	139.75

3. RESULTS

In order to determine, which feedstock is the most economically advantageous for biogas production, information on feedstock prices was collected. The largest advertisement portal in Latvia www.ss.com was used to find out the price of manure, as well as straw and corn, which showed that, on average, cattle manure is sold for 3 €/t , poultry manure for 2 €/t, but pig manure is charged a very symbolic price of about 1 €/t [30]. Straw bales were found to weigh an average of 0.45 t, but 1 bale is sold for an average of 7 €/piece, while 1 t of corn silage costs 50 € [30]. By making the calculations, 1 t of straw costs 15.56 €/t. A symbolic price of 1 €/t was adopted for wastewater sludge. The price of organic waste was determined by obtaining information on the website of the largest landfill site in Latvia, where it is offered to deliver the organic waste to landfill for 60.81 €/t +VAT. It means that the cost of transferring the waste in total with VAT costs is 73.58 €/t [31]. As the transfer of this waste costs a certain amount of money, its use at the on-farm biogas plant means a reduction in costs and for that reason the cost of organic waste is shown with a minus sign in Table 5. According to surveys of the biggest woodchip suppliers, its price is currently 12 €/m^3. Given that 1 t of woodchips is equivalent to 3.5 m^3 of woodchips, the price per t is assumed to be 42 €.

Summarizing the information obtained on the biogas efficiency of the particular feedstocks as well as the price per t of the feedstock, it is possible to obtain an economic justification for each substrate. To obtain the cost of producing 1 m^3 of biogas from a given substrate, the substrate price was divided by the substrate efficiency.

TABLE 5. CALCULATION OF ECONOMIC JUSTIFICATION FOR EACH SUBSTRATE

	Effectivity, yield of biogas, m^3/t	**Price of the feedstock, €/t**	**Economically justified, €/m^3 biogas**
Cattle manure	35	3.00	0.09
Pig manure	44	1.00	0.02
Poultry manure	80	2.00	0.03
Sewage sludge	218	1.00	0.01
Organic waste	100	–73.58	–0.74
Wood	35.5	42.00	1.18
Straw	190	15.56	0.08
Maize silage	202	45.00	0.25

As a result, the three main criteria identified as determinants of biogas substrate selection were summarized in Table 6 for objective comparison.

TABLE 6. MULTI-CRITERIA ANALYSIS VALUES

	Effective (yield of biogas, m^3/t)	**Environmentally friendly (emissions to be collected in Latvia, kt CO_2 eq/year)**	**Economically justified (€/m^3 biogas)**
Cattle manure	35.0	115.47	0.09
Pig manure	44.0	25.71	0.02
Poultry manure	80.0	4.73	0.03
Sewage sludge	218.0	113.53	0.01
Organic waste	100.0	403.50	–0.74
Wood	35.5	0.00	1.18
Straw	190.0	0.00	0.08
Maize silage	202.0	–6.56	0.25

After gathering information about the substrates, it can be seen that the highest efficiency of biogas production is in the production of biogas from sewage sludge as well as maize silage. Straw does not lag behind in the productivity of maize silage biogas. The lowest efficiency is observed in cattle manure and wood, with average efficiency values almost equal. Only slightly higher efficiency is observed in pig manure.

Considering which raw material should preferably be selected for the most environmentally friendly production of biogas, it appears that the most airborne emissions can be prevented by anaerobic fermentation of organic waste. The use of sewage sludge for biogas production as well as the use of cattle manure would provide about 3.4 times less, but still significant emission savings. Equally important is the use of pig manure, but their total methane emissions are lower due to pig numbers. It is also very important to use poultry manure, as their biogas efficiency is only 20 % lower than the efficiency of solid waste, but their environmental impact is less significant due to the quantitative value of this manure. The emissions from biogas maize production in Latvia is the only substrate considered here that generates emissions rather than being neutral.

Economically, the most detrimental raw material for biogas production is wood, if purchased as wood chips, but the most advantageous is the use of organic waste, as it not only allows biogas to be produced, but also helps to reduce the cost of waste transfer to landfills.

In order to determine objectively the best raw material for biogas production, the TOPSIS model was developed.

After the TOPSIS methodology calculations were made, a rating was obtained of which, according to the accepted three criteria (environment, technology, economic), indicates where the given substrate is ranked from the most suitable substrate for biogas production in Latvia ranked first to the worst substrate from this list, ranked in the last 8th place.

Pig and poultry manure were ranked in the first two places according to the criteria, while straw with pre-treatment was ranked 3rd; cattle manure was ranked 4th, and sewage sludge ranked 5th. The last three places are organic waste, corn and wood, which took a convincing last place in the ranking.

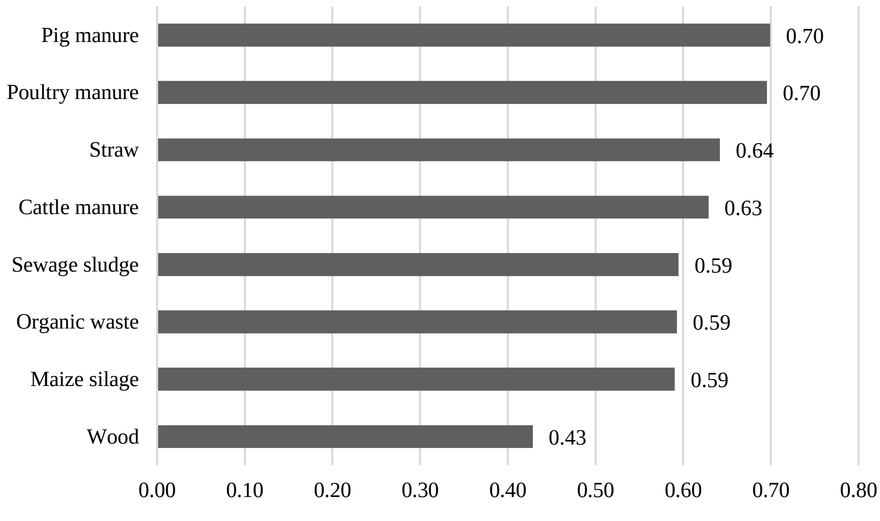

Fig. 1. Relative closeness to the ideal solution with TOPSIS method.

Fig. 1 shows that the raw materials are basically divided into four groups according to the suitability of the substrate for biogas production:

- Group with convincing highest relative closeness to the ideal solution with TOPSIS method, which includes pig and poultry manure and have very similar values;
- Group with the second highest relative closeness to the ideal solution with TOPSIS

method, which includes straw and cattle manure and have very small difference in values between them;

- Group which includes sewage sludge, organic waste and maize silage – feedstocks, the numerical value of which in terms of relative closeness to the ideal solution is nearly the same;
- Group which consists with the worst feedstock among the ones considered for the particular biogas production method is wood.

4. Conclusions

A multi-criteria analysis using TOPSIS methodology and taking into account three main parameters: economic feasibility, substrate efficiency, and environmental aspects, showed that pig manure is the most suitable raw material for biogas production in Latvia, while poultry manure was ranked second, with very little difference in value from pig manure.

Despite the claim that lignocellulose rich plants are not a successful choice for biogas production, straw was the third best substrate for biogas production in Latvia, and cattle manure was in 4^{th} place. Wood was identified as the most unsuccessful choice for biogas feedstock.

The penultimate place in the ranking was for specially grown maize for biogas production, which until now has been a popular substrate for agricultural biogas production.

Based on the criteria used in the model, the organic waste and sewage sludge are roughly the same as biogas maize in the rating. This work proves that pre-treatment straw can serve as a great substitute for biogas maize.

The use of any waste for energy production is important, but the greatest potential shows in agricultural biogas from manure and straw.

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