The Role of Biogas Production in Achieving Sustainable Development Goals Biogas Production in Achieving Sustainable Development

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Abstract: The growing energy consumption in the world, as well as the constantly increasing volume of organic waste of various origins determine the need to use biogas. The biogas industry has the potential to solve these problems by using organic waste to produce energy and materials. The aim of this research was studying the impact and establishing the relationship between the production and use of biogas and the achievement of sustainable development goals. The research involved the methods of economic statistical analysis, cluster analysis, and systems structural analysis. The study found that biogas production has a significant impact on achieving a number of sustainable development goals. It was established that this impact is related to the following main areas: reducing the energy deficit, developing renewable energy, reducing the harmful impact on the environment, improving waste management, creating new jobs, etc. It was determined that the EU countries can be divided into four clusters according to the biogas production volume. Separate clusters include Germany and Italy as undisputed leaders in biogas production. The Czech Republic, Denmark, Spain, France, and the Netherlands are also distinguished by high production volumes. A close relationship between the energy consumption volumes and the biogas production volumes in the EU countries was proved. The assumption on the relationship between the biogas production volume and the food waste volume was not confirmed. The further research should be aimed to study bioenergy in China as the second region in the world in terms of biogas production.

Keywords: Bioenergy, Ecology, Energy, Food waste, Renewable sources, Sustainable development goals.

INTRODUCTION

Achieving the Sustainable Development Goals (SDGs) is top-priority on the agenda for both developed and developing countries. Bioenergy can make a significant contribution to the achievement of the SDGs in two aspects: on the one hand, it is the prevention of the energy crisis, which is an important problem in view of the future urbanization of megacities. On the other hand, bioenergy can largely solve the problem of growing solid household waste volumes caused by a significant increase in the world population (Chowdhury et al., 2022).

Current academic studies consider biogas as one of the most promising sources of energy, which can be successfully implemented both on a domestic and industrial scale to obtain materials and energy (Obaideen et al., 2022). Biogas is one of the effective ways to fight against climate change. Biogas is an important renewable resource consisting of 60% methane (CH4), about 35-40% carbon dioxide (CO2) and small amounts of other gases (Siddiki et al., 2021).

Biogas offers a solution to another no less important problem —increasing amounts of food waste. When decomposing, food waste causes the release of greenhouse gases. Its incineration causes pollution of water and land with sulphur dioxide (SO2) and nitrogen oxide (NOX) (Tang, 2020). The main categories of food waste, which differ in their properties and are generated from different sources, are waste from the dairy, meat and poultry, fish, fruit and vegetable, grain and bakery, brewing and wine industries (Ferdeș et al., 2022).

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Any type of organic waste can be used for biogas production. The advantages of this technology is that it does not produce such harmful elements as sulphur dioxide (SO2), carbon monoxide (CO), nitrogen dioxide (NO2), etc. The use of agricultural waste for biogas and biodiesel production has a positive economic, social and environmental impact (Shaibur, Husain, & Arpon, 2021).

Other advantages of using agricultural waste for biogas production include environmental cleanliness, safety of use, low cost compared to products produced from oil, reduction of greenhouse gas emissions, in particular, carbon dioxide (CO2), fossil gas emissions (Chitara, Chauhan, & Singh, 2021) which contributes to the moderation of global warming, as well as reducing dependence on fossil fuels (Pandey et al., 2021).

In addition to a number of unconditional advantages for the environment, biogas production has a number of financial and economic advantages both when at the household (Meyer et al., 2021) and the national level, as it reduces the cost of electricity produced (Kabeyi & Olanrewaju, 2022).

However, the potential of using biomass to produce materials and energy yields the desired effect in case of proper cultivation and regulation of the biomass. So, the field of bioenergy should be appropriately controlled by the government, which will ensure sustainable development while maximizing the benefits of biomass use and minimizing possible adverse consequences (Thrän, Schaubach, Majer, & Horschig, 2020).

Biogas production is being actively implemented in a number of developed countries, as well as in some developing countries. Germany (about 8,000 agricultural plants) and China (about 7,000 large systems and 24,000 small plants) are the world leaders in agricultural biogas production. The United States have more than 2,200 biogas plants, most of which are designed for wastewater treatment, others are operated on farms, for gas utilization, and also use food waste. In Canada, bioenergy accounts for almost 27% of the renewable energy market. In Australia, the biogas industry provides about half a percent of total energy production, but has the potential to reach 9%. South Africa is the leader on the continent with about 700 biogas plants (Abanades et al., 2022).

So, the aim of this research is studying the impact and establishing the relationship between the production and use of biogas and the achievement of the SDGs. The aim involved the fulfilment of the following research objectives:

- determine the background for the use of biogas to achieve the SDGs in the context of modern trends in the energy industry and the increasing amount of food waste;
- conduct a cluster analysis of biogas production by EU countries;
- conduct a correlation analysis between energy consumption indicators, food waste and biogas production volumes by EU countries.

LITERATURE REVIEW

The aspects of biogas production and use are a topical issue for researchers from all over the world, in particular, because of its important role in achieving the SDGs. Obaideen et al. (2022) assessed the biogas use, identified related challenges, and provided appropriate recommendations. They stated that the main contribution of biogas to achieving the SDGs is its impact on increasing the production of renewable energy, moderation of the climate change, improving waste processing, and creating jobs.

Ferdeș et al. (2022) describe the effects of applying different types of pre-treatment in biogas production. The researchers note that all current types of pre-treatment can be divided into mechanical and physical (ultrasound, thermal, microwave irradiation, etc.), chemical (ozonation, alkali, acid hydrolysis) and biological (use of bacterial and fungal strains, enzymes). A wide range of pre-treatment types makes it possible to increase the positive effect of biogas production by applying the most appropriate technology.

Kabeyi and Olanrewaju (2022) dealt with biogas use for electricity and fuel production. The researchers established that biogas fuel can be used in various types of engines, and noted the contribution of biogas to the development of sustainable energy, as it provides the possibility of its use in fuel cells for conversion into electricity.

Shaibur, Husain, and Arpon (2021) studied the impact and efficiency of the use of residual products generated in biogas plants. The results of the study showed that such residues can be successfully turned into high-quality organic fertilizer, which, on the one hand, increases the safety of plant cultivation products, and on the other hand, is more cost-saving compared to chemical fertilizers. They emphasized a positive impact of using bioplants on ecology and resource recovery among the global consequences.

A number of studies deal with the development of the biogas industry in different countries, both developing and developed. Meeks, Sims, and Thompson (2019) assess the environmental, as well as the economic and social consequences of the development of biogas technologies in Nepal. The work establishes a potential beneficial effect of using household biogas systems by reducing pressure on forest reserves, as well as reallocating people’s time to more valuable activities. Yong, Bashir, and Hassan (2021) studied the effectiveness of bioenergy development using the data for Malaysia. Researchers determined that 45% of the total mass of solid household waste in the state is organic. The work is focused on determining the feasibility of producing energy and biofertilizers from organic solid household waste through anaerobic digestion from the economic and environmental perspective.

Chrispim, Scholz, and Nolasco (2021) explore the potential for energy recovery from wastewater treatment plants. The researchers found that the majority of treatment plants that generate biogas do not use this technology, which could significantly improve energy efficiency and reduce greenhouse gas emissions.

Thrän et al. (2020) study the implementation of sustainable development aspects in the biogas market of Germany, the leader in biogas production. The researchers explore the development of the market according to the Heuss 4-Phase Model, outlining the most important legislative aspects at each of the phases. Brosowski (2021) proves that Germany not only consolidates its success as a leader in biogas production, but also develops it through further improvement of legislation. Moreover, thorough studies are being conducted in the country to establish the relationship and mutual influence between the development of the biogas industry and the achievement of the SDGs.

Recent biogas-related studies focus on ways of modernizing existing technologies. Gkotsis et al. (2023) consider the key latest biogas modernization technologies, paying particular attention to current advances in the field of membrane technologies, which significantly improve the quality of biogas. Leca et al. (2023) focus on the application of anaerobic fermentation in biogas production in order to increase production volumes. The researchers analyse the effects of various additives to co-fermentation reactors. Karne et al. (2023) study systems that can remove contaminants, unwanted impurities and carbon dioxide from raw biogas to improve its quality. Paranjpe et al. (2023) made an attempt to find an effective technology for using sewage sludge and food waste for biogas production.

The conducted literary review determines the need to continue and expand research into the impact of biogas on achieving the SDGs. Such studies are often based on constantly updated statistics, so their analysis requires constant updating and monitoring. Besides, the researchers have contradictions and disagreements in the views on which SDGs are concerned with biogas production. The relationship between the energy production and consumption volumes, the food volumes and biogas production waste is also poorly studied.

METHODS

The research was divided into several coherent and consistent stages because of its complex nature. The first stage of the study involved determining the prerequisites for the use of biogas to achieve the SDGs in the context of current trends in the energy industry and food waste growth trends through economic and statistical analysis. The following indicators were analysed with regard to trends in the energy sector: global energy consumption, the structure of fuel consumption by countries, energy balances for the 27 EU countries, China's energy consumption, China's renewable energy consumption, CO2 emissions worldwide, in China and the EU, the structure of consumption by fuel types in the EU, final energy consumption by European countries. The food waste growth trends were studied through an economic and statistical analysis of the following data: average values of food waste per capita in high-income, upper-middle-income, lower-middle-income and low-income countries, as well as the amount of food waste in EU countries. The conducted analysis determined the countries consuming the largest amounts of energy, as well as those producing the maximum amount of waste among the studied sample. This was the ground for the assumption about what the identified trends are related to.

The second stage provided for a cluster analysis of biogas production by EU countries, which resulted in the division of the studied countries into four clusters. The optimal number of clusters was found through the analysis of their mean on graphs. The cluster analysis was carried out through the use of data by country that are publicly available on Eurostat (Eurostat, 2023b). These data are shown in Tables **1** and **2**.

The conducted cluster analysis enabled grouping countries according to the biogas production volumes, and compare the composition of each cluster with previously obtained data on the energy consumption volumes. This made it possible to identify the dependence between the energy consumption volumes by countries and their biogas production volumes.

Table 1. Biogas Production Volumes by EU Countries in 2012-2016 (in terajoules).

	2012	2013	2014	2015	2016
Belgium	6 730,000	8 358,600	9 129,900	9 860,400	9 814,400
Bulgaria	5,000	93,000	435,000	820,000	2 511,000
Czechia	15 698,000	23 910,000	25 457,000	25 681,000	25 161,000
Denmark	4 399,147	4 587,832	5 561,231	6 285,248	9 047,985
Germany	266 005,000	280 646,000	298 275,000	314 418,000	320 998,000
Estonia	122,000	302,000	403,000	550,000	722,000
Ireland	2 340,994	2 061,661	2 186,842	2 317,499	2 327,724
Greece	3 710,000	3 704,000	3 640,000	3 826,000	4 258,000
Spain	12 179,000	20 072,000	14 791,000	10 954,000	11 557,000
France	21 024,115	24 013,607	25 423,321	28 801,248	31 412,412
Croatia	478,636	693,370	1 096,494	1 506,133	1 952,042
Italy	49 352,000	76 013,000	82 105,000	78 355,000	78 505,000
Cyprus	476,000	466,000	475,000	471,000	492,000

Latvia	2 175,000	2 695,000	3 136,000	3 674,000	3 762,000
Lithuania	484,000	649,000	876,000	981,000	1 341,000
Luxembourg	657,791	653,087	701,203	739,381	832,910
Hungary	2 218,000	3 336,000	3 323,000	3 335,000	3 708,000
Malta	93,000	59,000	73,000	77,000	80,000
Netherlands	12 165,000	12 777,000	13 094,000	13 733,059	13 377,410
Austria	8 434,550	8 006,158	11 899,034	12 340,901	12 515,183
Poland	7 033,000	7 593,000	8 685,000	9 581,000	10 924,000
Portugal	2 383,000	2 763,000	3 432,000	3 457,000	3 364,000
Romania	1 143,000	822,000	810,000	767,000	739,000
Slovenia	1 597,000	1 454,000	1 290,000	1 242,000	1 264,000
Slovakia	2 594,000	2 300,000	4 025,000	6 223,000	6 357,000
Finland	2 425,000	3 725,000	4 173,000	4 321,000	4 694,000
Sweden	5 303,000	6 070,000	6 422,000	7 009,000	7 265,000
Iceland	73,000	71,000	71,000	69,000	71,000
Norway	800,000	700,000	600,000	1 100,000	1 200,000
United Kingdom	82 643,000	85 396,000	89 412,579	95 839,000	112 933,000

Source: (Eurostat, 2023b).

Table 2. Biogas production volumes by EU countries in 2017-2021 (in terajoules).

	2017	**2018**	**2019**	**2020**	**2021**
Belgium	9 423,100	9 546,600	9 698,000	10 261,400	10 291,500
Bulgaria	1 958,390	2 244,673	2 133,311	2 231,674	2 499,393
Czechia	25 443,789	25 279,127	24 331,895	24 888,839	24 736,519
Denmark	10 906,278	13 333,410	16 481,514	21 151,581	26 194,576
Germany	323 250,000	318 527,000	317 935,000	325 115,000	314 773,000
Estonia	540,000	571,000	581,000	832,000	762,400
Ireland	2 321,780	2 108,248	2 120,085	2 105,006	2 178,973
Greece	4 484,000	4 723,900	5 232,830	5 665,000	5 325,642
Spain	12 237,000	12 374,000	12 184,000	13 539,000	13 644,000
France	33 817,190	36 609,292	40 716,538	45 640,314	58 793,004
Croatia	2 671,634	3 081,243	3 441,762	3 480,516	4 154,180
Italy	79 452,908	79 220,551	84 288,213	84 484,094	87 007,196
Cyprus	504,345	553,550	578,767	556,275	559,040
Latvia	3 902,011	3 643,253	3 376,039	3 358,877	2 763,421
Lithuania	1 350,000	1 554,000	1 632,000	1 617,000	1 682,000
Luxembourg	866,983	915,433	753,191	755,440	690,900
Hungary	4 141,000	3 916,000	3 785,000	3 748,000	3 518,000
Malta	77,000	69,834	73,381	60,398	54,547

Netherlands	13 508,671	13 696,226	14 913,297	17 428,542	17 926,824
Austria	13 021,335	9 504,878	8 983,395	8 787,162	6 684,902
Poland	11 738,620	12 068,301	12 498,053	13 498,148	13 371,974
Portugal	3 561,284	3 453,040	3 355,158	3 464,321	3 651,991
Romania	755,471	864,936	794,294	772,084	970,035
Slovenia	1 076,471	1 018,173	929,681	1 128,738	1 044,268
Slovakia	6 384,000	6 228,000	5 984,000	5 479,000	5 472,000
Finland	7 147,000	7 804,000	7 851,000	7 080,000	8 138,000
Sweden	7 445,000	7 359,000	7 600,000	7 780,000	8 154,000
Iceland	75,500	77,969	51,274	77,503	
Norway	1 535,000	2 226,200	3 630,970	2 696,724	2 710,955
United Kingdom	113 933,000	114 177,000	114 931,000		

Source: (Eurostat, 2023b).

The third stage involved a correlation analysis for energy consumption, food waste, and biogas production by EU countries. The aim of the analysis is to check for close correlations between indicators to determine their mutual influence. The conducted correlation analysis identified the density of the correlation between the amount of food waste produced by the country, the biogas production volume and the energy consumption volume. This method additionally confirmed the dependencies identified at the previous stage.

The research sample includes the EU countries that have publicly available data. The region was chosen for the study because the EU is the world leader in biogas production. Germany's policy on the biogas production and consumption is analysed separately, because Germany is the leader among the EU countries in the relevant field, producing about half of the biogas from the entire production volume of the EU countries. Besides, the study examined the statistics of China as the world's second largest biogas producing region.

The information background of the research is the academic periodicals of the countries of the world, as well as data that are publicly available on the following resources: Enerdata, World Energy and Climate Statistics, Eurostat, The World Bank, United Nations Environment Programme. The following software was used for calculations and preparation of graphic materials: MS Excel, STATISTICA.

RESULTS

Background for the use of biogas to achieve the SDGs in the context of current trends in the energy industry and in relation to increasing food waste amounts.

Global energy consumption has almost doubled over the past two decades. For the most part, this growth was determined by the active rise of developing countries (for example, China), while the energy consumption of developed countries did not change significantly (Enerdata, 2022). The growth of energy consumption was relatively insignificant in Europe, while it decreased in the CIS countries. Notable growth can be observed in North America and the Pacific region. Energy consumption has doubled, and in some cases tripled in Latin America, Africa and the Middle East, but the share of these regions in the overall consumption is relatively small. The largest growth was determined by a more than three-fold increase in energy consumption by Asian countries. It can be assumed based on current rates that their share in the consumption structure is going to reach half of the world's energy consumption soon.

The intensified energy consumption can not only lead to its shortage, but also has a significant negative impact on the environment. Most energy today is produced from fuels such as oil, coal and gas (Enerdata, 2022). These resources are non-renewable, moreover, significant emissions of harmful substances into the environment are produced when processing these types of fuel. This determines the search for alternative energy sources, in particular, energy production from biomass. Only 10% of energy is produced from biomass, while about 80% is produced from oil, coal and gas. This determines the need to find opportunities to expand the potential of using biomass for energy production, to intensify the actions of the governments related to the introduction of relevant technologies.

The EU is currently the most successful example of the introduction of measures for the development of bioenergy, and China ranks second. Over the past 10 years, the EU energy balances have not actually changed due to the energy policy, but they have decreased according to the volume of gross available energy, total energy supply, primary energy consumption, and final energy consumption. At the same time, the volumes of energy available for final consumption slightly increased (Eurostat, 2023a). Comparison of energy consumption in the EU with China reveals significant differences. These differences are determined by the fact that China is a developing country, which made the most significant leap in its development in the last 20 years. This leap was accompanied by a rapid increase in energy consumption. As China's energy consumption has increased, the total renewable energy use decreased (The World Bank, 2023). Over 30 years, the share of renewable energy sources in China has more than halved.

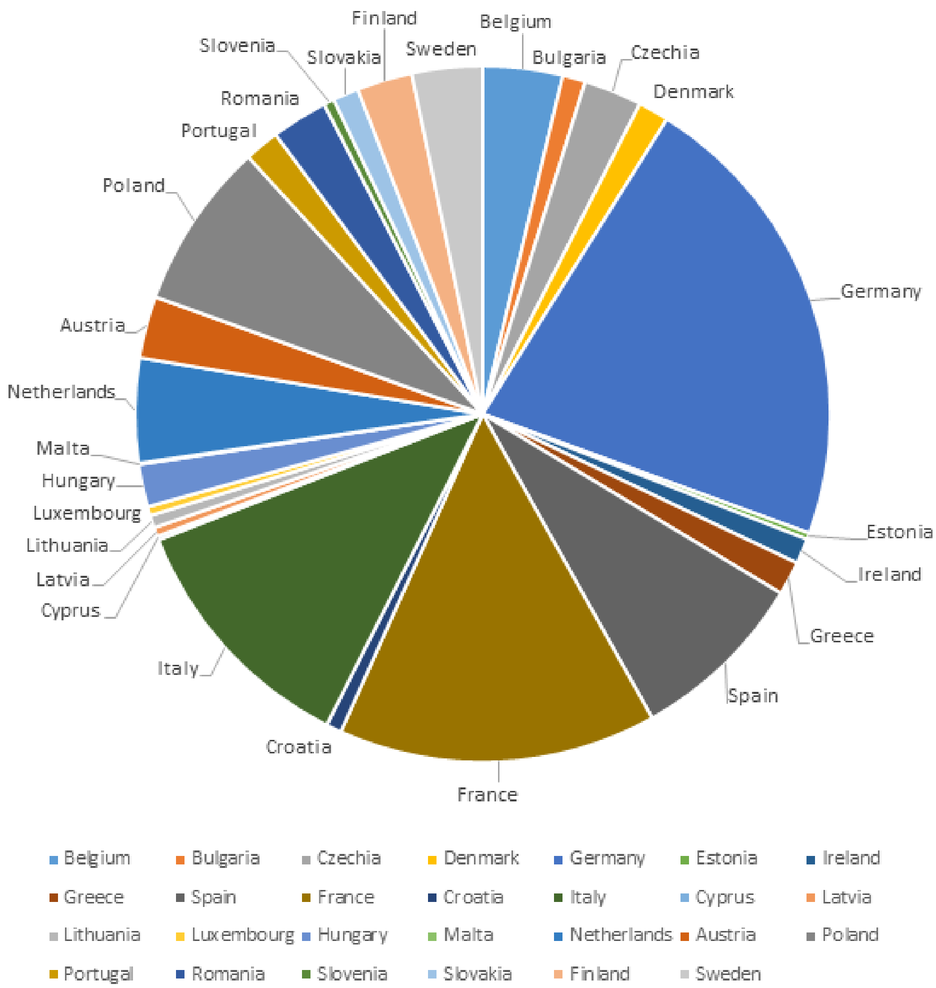

Fig. (1). Final energy consumption by European countries for 2021 (built by the author according to (Eurostat, 2023a)).

A sharp leap in non-renewable energy consumption in China is followed by a slowing growth trend. The share of renewable sources is gradually increasing: it increased by about 3% in 2019 compared to 2013. China is currently one of the world leaders in terms of the production of energy from renewable sources. This is confirmed by a study of the trend of CO2 emissions for China, which has been increasing sharply since around 2002, and has slowed significantly after 2010 (The World Bank, 2023). At the same time, for the period from 1990 to 2019, while the trend of CO2 emissions in the EU was stable. Moreover, the value of the CO2 emissions indicator for the EU is significantly lower — by more than 800 thousand kt — at the end of the specified period than at the beginning of the period.

The analysis gives grounds to conclude that the EU pursues a balanced policy on energy production and consumption, including biofuels. The share of solid fossil fuels in the structure of EU energy consumption is 10%, being almost three times lower than the world average. On the other hand, 7% more energy in EU countries is produced from renewable sources, including biofuels. The share of consumption of refined products is 5% higher than in the world (34%), and nuclear fuel is also more widely used (13%). The shares of natural gas consumption in the EU and the world are the same (24%) (Eurostat, 2023a). The largest consumers can be identified when considering final energy consumption by European countries (Fig. **1**).

Therefore, the largest European energy consumers are Germany, France, Italy, Spain, Poland, and the Netherlands. At the same time, these countries are among the largest producers of energy from biofuels in the EU (Eurostat, 2023b).

Therefore, the largest European energy consumers are Germany, France, Italy, Spain, Poland, and the Netherlands. Moreover, these countries are among the largest producers of energy from biofuels in the EU (Eurostat, 2023b).

SDG 12.3 is one of the SDGs directly related to biogas production, which focuses on food products and their inedible parts. Target indicators include, among others, the Food Waste Index, which measures food waste at retail and consumer level (United Nations Environment Programme, 2021). Therefore, it is also appropriate to outline trends of the growing amount of food waste that can be used for biogas production along with the study of energy consumption trends. Fig. (**2**) presents the amount of food waste by EU countries.

Fig. (**2**) gives grounds to note that households generate the largest food waste volumes. Slovenia, Austria, Belgium and the Netherlands produce the least household food waste (up

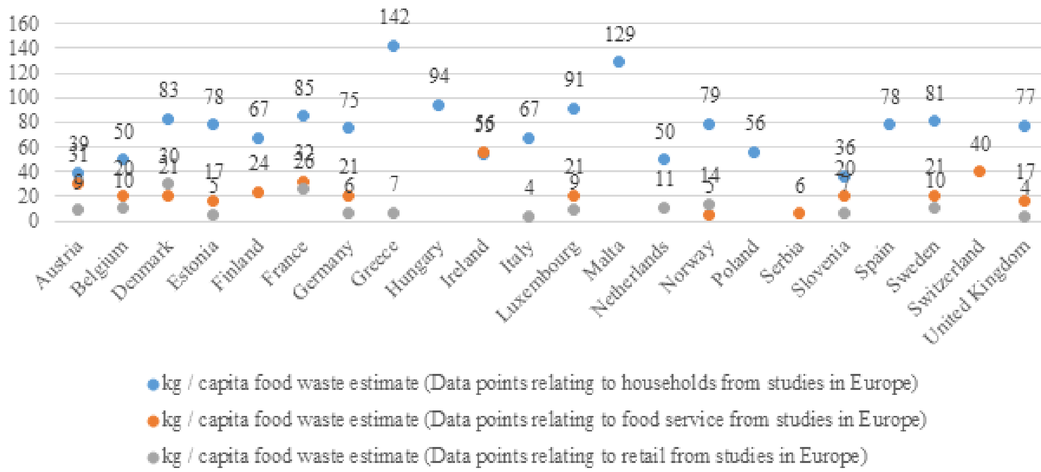

Fig. (2). Food waste volumes in EU countries (built by the author according to (United Nations Environment Programme, 2021)).

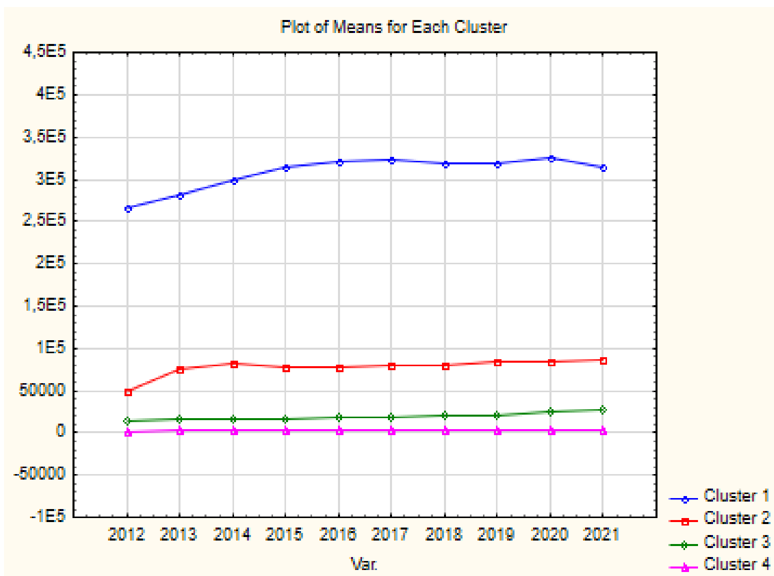

Fig. (3). Graphs of averages for the clusters.

to 50 kg), Norway and Serbia — the least food waste in the catering industry (up to 6 kg), Estonia, Italy, and Great Britain — the least food waste in the retail trade industry (up to 5 kg). Such indicators are related to the environmental policy of countries, their specialization, and cultural traditions. If you multiply the values in Figure 2 by the population in each country and add them together, the final figure is impressive – just for EU countries. The results of the assessment determine the need for the development of the biogas industry in the countries around the world as a way to reduce the burden on the planet in terms of food waste pollution, as well as to achieve SDG 12.3.

Cluster Analysis of Biogas Production by EU Countries

The conducted analysis identified the largest energy consumers among the EU countries — Germany, France, Italy, Spain, Poland, the Netherlands, as well as the countries that produce the largest amounts of food waste (Denmark, France, Greece, Hungary, Luxembourg, Malta, Sweden — by household food waste). It is appropriate to determine the contribution that these and other EU countries make to the development of the biogas industry. For this purpose, it is proposed to carry out a cluster analysis to divide countries into clusters depending on the biogas production volume. It was determined during the analysis that it is optimal to divide the countries into four clusters (Fig. **3**).

Four clusters were obtained: Cluster 1: Germany; Cluster 2: Italy; Cluster 3: Czech Republic, Denmark, Spain, France, Netherlands; Cluster 4: Belgium, Bulgaria, Estonia, Ireland, Greece, Croatia, Cyprus, Latvia, Lithuania, Luxembourg, Hungary, Malta, Austria, Poland, Portugal, Romania, Slovenia, Slovakia, Finland, Sweden, Norway.

Such countries as Germany and Italy are included in separate clusters, because the biogas production volumes in these countries cannot be compared with others. Germany produces about half of all biogas produced by EU countries. Italy's rate is also high and is almost a third of Germany's. The countries included in Cluster 3 — Czech Republic, Denmark, Spain, France, and the Netherlands — are distinguished by high biogas production volumes (from about

Var	Average	St.dev.	Food waste	Biogas	Final energy consumption
Food waste	0,000000	1,000000	1,000000	-0,057015	-0,144231
Biogas	0,000000	1,000000	-0,057015	1,000000	0,871477
Final energy consumption	0,000000	1,000000	-0,144231	0,871477	1,000000

Fig. (4). Results of correlation analysis.

13,000 terajoules to over 58,000 in 2021). All other countries produce less than 11 thousand terajoules of biogas. So, it can be concluded that most of the countries that are the main energy consumers in the EU are also the biggest producers of biogas (Germany, Italy, Czech Republic, Denmark, Spain, France, Netherlands).

Correlation Analysis between Indicators of Energy Consumption, Food Waste Amounts and Biogas Production Volumes by EU Countries

It is appropriate to analyse the predetermined relationship between biogas production and energy consumption in more detail, and to determine the degree of this relationship in numerical values. Moreover, the food waste amounts by country should be included in the analysis in order to the relationship between this indicator and the two mentioned above. Correlation analysis is most suitable for the specified purposes, which will establish whether there are close relationships between the studied indicators. Fig. **4** shows the results of the analysis.

The results of the correlation analysis (Fig. **4**) give grounds to state the existence of a close relationship between energy consumption and biogas production indicators. So, the previous assumption that the more an EU country produces biogas, the higher its energy consumption is, was confirmed. This gives grounds to conclude that it is necessary to find a balance between energy production and consumption, as well as effectively diversify energy sources in order to achieve the SDGs.

DISCUSSION

The paper analyses the role of biogas production in achieving the sustainable development goals. It was found that biogas can, on the one hand, solve the problem of lack of energy, as well as partially replace the production of energy from non-renewable sources, and significantly harm the environment. On the other hand, biogas has a positive effect on reducing food waste amounts. Strong correlation between energy consumption and biogas production in the EU countries was established, which indicates the high efficiency of the energy industry and the need for a balanced approach to determining the optimal ratio between energy production and consumption, as well as to the selection and diversification of its sources. The results of the analysis confirm the impact of the development of the biogas industry on the achievement of the SDGs.

Brosowski (2021) emphasized that the development of biogas production has a direct impact and is used by Germany to achieve five SDGs: 6, 11, 12, 13, 15. The most likely connection with 2, 14, 3, 7, 8, 9, will be investigated by the country's specialists in the future. SDGs 1, 4, 5, 10, 16, and 17 do not currently apply to biogas production.

Obaideen et al. (2022) also identified specific biogas-related SDGs. The researchers believe that biogas has a direct impact on the achievement of SDGs 2, 3, 6, 7, 8, 9, 11, 12, 13, 14, and 15. According to them, the biogas contributes to sustainable development by increasing the production of renewable energy, moderation of climate change, reducing air and water pollution, improving the productivity of agriculture and the use of land resources, improving waste management process, creating jobs, and stimulating the development of the economy, water management.

Yong, Bashir, and Hassan (2021) provide a slightly different list of SDGs that can be achieved with the use of biogas. These SDGs include: 1, 3, 6, 7, 8, 11, 12, 13, 14, 15. Therefore, compared to the previous study, Goal 1: No Poverty was added to the list, and Goal 9: Industry, Innovation and Infrastructure was removed. In the author's opinion, this approach is not sufficiently justified: biogas industry development has indirect impact on poverty alleviation, while much more interrelationships can be established between biogas production and industry, innovation and infrastructure.

Kabeyi and Olanrewaju (2022) deal with the main dimensions of sustainable development combined with the consumption of energy produced from biogas – economic, social, environmental, technical, institutional and political sustainability. Energy production from biogas can have the following positive effects in the context of achieving economic sustainability: reducing energy costs, which will ultimately improve people's quality of life, increasing soil productivity, and saving on chemical fertilizers. The impact of biogas on social sustainability is primarily the creation of new jobs for skilled and unskilled workers, as well as improved health. Biogas is closely related to the improvement of ecology through the creation of a sustainable source of energy, waste processing, minimization of greenhouse gas emissions, and reduction of load on soils. The researchers established the impact of biogas production on increasing the technical stability of systems and confirmed the need to elaborate an institutional and political framework for the development of the biogas industry Bliznjuk et al. (2022).

A study by Lu and Gao (2023) studied the potential for biogas production in China. The researchers found that this potential is not being used in full, because the country has great opportunities to generate electricity from biogas in much larger volumes than it does. Therefore, the researchers advise to intensify the construction of large biogas plants. Ferdeș et al. (2022) emphasized the need to improve the food waste management and its sustainable use, in which goals such as creating a circular bioeconomy, achieving zero waste, sustainable production and consumption, reducing greenhouse gas emissions, etc., play an important role. In these works, the researchers came to conclusions that correspond to the main results obtained from the analysis carried out in the article, namely: biogas plays an important role in improving the energy industry and reducing food waste amounts.

There are some studies on positive effects from the use of biogas, which are not discussed in detail in this article. Meeks, Sims, and Thompson (2019) note the sustainability benefit of reducing forest cover loss by using biogas instead of firewood. Shaibur, Husain, and Arpon (2021) indicate the benefits of biogas when it is used when cooking food and producing organic fertilizers from it, which, among other things, saves money on chemical fertilizers and makes plant cultivation products more environmentally friendly. The research of Chrispim, Scholz, and Nolasco (2021) emphasize the strategic importance of treatment plants in the energy sector in terms of energy production from biogas. The researchers compare the policies of developed and developing countries regarding biogas production. They note that developing countries should improve their biogas production policies, and introduce appropriate subsidies to producers to achieve the main goal of moderating climate change.

Thrän et al. (2020) provided detailed recommendations for government officials and other interested parties on the development of the biogas market. In general, these recommendations relate to the introduction of political support measures, stimulation of the cultivation of energy crops with due regard to the problems in managing this process, coordination of the developed measures with the political framework for the general bioeconomy, increasing the transparency of sustainable development management, using adaptive approaches in legislation, monitoring market growth and stability indicators. The researchers note that the existing biogas infrastructure in Germany is capable of contributing to the reduction of greenhouse gas emissions in the agricultural and energy sectors Prokopenko et al. (2021).

So, most researchers agree that the development of biogas has a significant positive impact on achieving sustainable development goals in economic, environmental, social, technological and political terms. There are numerous ways and purposes of using biogas, besides, different countries have individual approaches to biogas development. This creates a wide space for further research. In particular, it is important to study the development of biogas in China as the second world largest biogas producer.

CONCLUSIONS

The study established the impact of biogas production on achieving sustainable development goals. This issue is urgent because of the generally recognized need and reasonability of implementing sustainable development goals into the policies of different countries, as well as the need for renewable and less harmful energy sources and reducing food waste amounts.

The background for the use of biogas to achieve sustainable development goals in the context of modern trends in the energy industry and the growing food waste amounts are determined. It was proved that the growing energy consumption among countries around the world causes its shortage and increases harmful emissions. The use of biogas can partially solve this problem, because its use minimizes damage to the environment, and creates an additional renewable source of energy. It was established that the countries produce huge food waste amounts, thereby causing pollution and growing greenhouse gas emissions. Biogas solves this problem by processing food waste and turning it into energy and materials.

The conducted cluster analysis of biogas production by EU countries enabled dividing the countries into four clusters. Germany is in a separate cluster as a country that produces about half of EU biogas (more than 300,000 terajoules). Italy (over 80,000) also got into a separate cluster. The third cluster included countries producing from about 13,000 terajoules to more than 58,000 (in 2021): the Czech Republic, Denmark, Spain, France, and the Netherlands. Other countries produce less than 11,000 terajoules of biogas and belong to the fourth cluster.

The conducted correlation analysis confirmed a strong correlation between energy consumption and biogas production.

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