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Perspectives of Electricity Production from Biogas in the European Union

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Abstract: Biogas is a renewable energy source (RES). The aim of this research was to analyze the perspectives of electricity production from biogas in the European Union. The main source of information was data from Eurostat. We analyzed electricity production from biogas in the European Union (EU). The scope of this research was data from 2012 to 2021. First, we presented biogas production by feedstock type across the world. Then, we presented changes in electricity production from biogas in the EU. We used different methods to evaluate the changes in biogas production. First, we used the ARiMA (Autoregressive Moving Average) model to evaluate the stationarity of the time series. Our electricity production from biogas data proved to be stationary. Second, we elaborated on the prognosis of future changes in electricity production from biogas. The largest producer of biogas is the EU, and it is produced from crops, animal manure, and municipal solid waste. Our research found that the largest production from biogas in 2021 took place in Germany, Italy, and France. These countries have the greatest potential for electricity production from biogas, and they have spent significant funds on facilities and technology. Such countries as Ireland, Greece, Spain, France, Croatia, Poland, Portugal, Romania, Finland, and Sweden increased their electricity production from biogas in 2021 compared to 2020. According to our prognosis, the global production of biogas will increase from 62.300 TWh to 64.000 TWh in 2019–2026 (2.7% increase). In 2022–2026, such countries as Estonia (60.4%), Latvia (29.6%), Croatia (27.6%), Slovenia (10.9%), and Poland (8.2%) will increase their electricity production from biogas the most. In 2022–2026, such countries as Italy (0.68%), Portugal (1.1%), Greece (1.5%), Slovakia (2.3%), and Germany (2.6%) will increase their electricity production from biogas the least. Only Romania (−17.6%), Finland (−11.5%), Lithuania (−9.1%), and Malta (−1.06%) will decrease their production of electricity from biogas in 2022–2026. Such countries as Bulgaria (2344%), Denmark (590.9%), Croatia (449%), and France (183%) increased biogas consumption in 2013–2022. A decrease in the inland consumption of biogas in 2013–2022 was observed in Spain, Cyprus, Latvia, Luxembourg, Austria, and Slovenia.

Keywords: electricity production and consumption; ARiMA model; prognosis

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1. Introduction

Global population growth and technological advancement have caused an increased consumption of energy, which is the driving force for economic growth. Energy was traditionally delivered from fossil fuels, but recently, the need to acquire renewable energy sources (RESs) has increased [1]. The negative impact of climate change as a result of fossil fuel utilization caused people to look for alternative sources of energy. The most important RESs include biomass, photovoltaics, wind energy, hydropower, and biogas.

Biogas can be made in both enterprises and specialized dairy and pork farms. The installation of digesters to use biogas requires an investment in facilities on farms. This source of RESs consists of methane (50–75%), carbon dioxide (25–50%), and other gasses. In total, 1 kg of carbohydrates produces an average of 0.42 m^3 CH_4 From 1 kg of proteins, –0.47 m^3 of CH_4, and from fats 0.75 m^3 CH_4. The calorific value of methane is 35 MJ/m^3. The average calorific value of biogas obtained from municipal bio-waste is estimated at approx. 21.54 MJ/m^3. The energy contained in 1 m3 from such biogas corresponds to the energy contained in 0.93 m^3 of natural gas [2].

The materials that are used in biogas production are transformed in the anaerobic digestion (AD) process [3]. The materials that are used in biogas production include the following: organic waste, biowaste, sludge, manure, and others. Animal manure used as fertilizers creates problems for the environment, and the legislative process in the EU created permitting rules for the use of manure [4]. Livestock farming has developed in recent years, causing many problems for the environment, such as greenhouse gas emissions and the contamination of water resources [5]. The ingredients of manure gas depend on feeding patterns and diet ingredients, diet digestibility, microorganisms, and other factors. Methane, which is the main biogas ingredient, can be used in electricity, heat, and as biofuel for cars, decreasing environmental emissions [6]. The utilization of agricultural biomass in the process of biogas production is widespread. The production generates heat, which can be used for heating the digesters, farm buildings, greenhouses, and other buildings on the farm. Its usage can even be expanded for heating local community facilities such as swimming pools in nearby places. Biogas can be used to produce electricity and heat, but it requires constant investment in facilities and technologies. The production of biomass from organic waste converts it to energy, and the residues can be used as natural fertilizers [7].

Biogas is playing a role in bridging the gap because the EU's economy is focused on decarbonization. The low carbon economy utilizes non-carbon energy sources, and thus, biogas plays an important role. However, the development of this sector requires large investments to increase production. More strategies focused on a national level for biogas production should be developed. Such strategies require the application of different biogas technologies [8]. Biogas is a sustainable energy technology and can be an alternative to fossil fuels [9].

Agriculture has the potential for the production of livestock manure, which is used as a fertilizer and, if not used properly, can create problems such as environmental pollution, contamination, and odors. Therefore, the utilization of agricultural manure for biogas brings many benefits, such as a reduction in greenhouse gas (GHG) emissions the elimination of methane emissions, and odors with manure storage [10]. The EU has great potential to produce biogas, but it is diversified regionally [11].

The current situation with the European energy market is favorable for biogas production using agricultural slurry. Countries with large animal production are pioneers in biogas production [12]. Biogas is a substitute for conventional sources of energy, and it is promising for economic growth. This kind of energy is environmentally friendly, renewable, and resource-efficient [13].

Biogas production can increase efficiency through different innovations, including access to raw materials, the pretreatment of feedstock, utilization of milling, communication, hydrolysis, and other processes [14]. Moreover, the feedstock for biogas is also important because it should be prepared for digestion by eliminating debris, including metals and plastic, which can contaminate the fodder and harm animals [15]. Methane is the ingredient that determines the calorific value of biogas [16]. Based on the European Union's environmental policy, more biogases should be produced to fulfill increasing energy needs.

Data about the production of electricity from biogas are available. However, little attention is paid to prognosis and data analysis in the literature. We wanted to fill in the gaps and evaluate the stationarity of electricity production from biogas in the EU and the world. We focused on changes and statistics for electricity production and evaluated the coefficient of variation, skewness, and kurtosis. Data concerning future renewable energy policies are available. Our research contribution is the prognosis of electricity production from biogas, elaborated for each country of the European Union (EU). Moreover, we discussed the problem of biogas production in the literature, pointing out our problems, barriers, and environmental aspects of biogas production.

The aim of this research was to analyze the perspectives of electricity production from biogas in the EU. To achieve this goal, the following questions should be addressed:

1. What is the production of biogas in the world?
2. How has the production of electricity from biogas changed in 2012–2021 in the EU?
3. What is the future of electricity production from biogas in the EU?
4. What is the prognosis of electricity production from biogas in European Union countries?

The following hypothesis has been evaluated:

Hypothesis 1 (H1). *The production of electricity from biogas increased due to stricter climate and environmental policies in the EU.*

To achieve the goals of this research, the authors used different methods. First, we used descriptive statistics to analyze the changes in electricity from biogas production in the world and in the European Union. Another method was the ARiMA model, which helped us to evaluate the stationarity of the ranks. Finally, we elaborated on the prognosis both for the world and the European Union's (EU's) production of electricity from biogas.

This paper is organized as follows: First, we present an introduction and gaps in the research. Then, we present a literature review describing biogas in the energy strategy of the EU. Next, we describe the research method. Then, we present the stationarity analysis and conduct a prognosis. The final parts are the conclusions and policy implications.

1.1. The Role of Biogas in the Energy Strategy of the European Union (EU)

Biogas is one of the RESs that can increase the productivity and sustainability of farms. One of the problems with farms is the high production of manure. An increase in farm size has caused the greater production of manure and forced farmers to invest in manure tanks and containers. These farms spread manure on fields only at particular times of the year. Moreover, the manure contributes to greenhouse gasses because it emits carbon dioxide (CO_2), methane (CH_4), and other gases. The most important sources of material for biogas production include livestock fertilizers (cattle manure, mink manure, pig manure, and poultry manure), agricultural wastes (barley, corn fruit, meadow grass, palm oil, rice straw, wheat, and others), household, municipal and industrial wastes (kitchen wastes, organic fraction, sewage sludge and other) and microalgae [4]. The production of biogas gained attention after problems with the hazardous impact of fossil fuels on the environment occurred. Its production is environmentally friendly because anaerobic digestion provides the opportunity for electricity, heat, and fuel production [17].

The EU developed a strategy of decarbonization by 2050, which includes goals to reach a 40% reduction in GHG emissions compared to 1990 and a 27% share of RESs [17,18]. These concepts include such topics as climate change, food security, sustainability, and renewable energy sources and are called bioeconomic strategies [19–21]. The EU is the biggest producer of biogas. The reasons for biogas production in the EU are numerous. The infrastructure of biogas utilization in these countries is well-developed. Germany biomethane plants are connected to distribution gas networks and transport grass networks. The main source of biogas production in Germany, Croatia, Serbia, and Slovakia is corn silage. The waste production of agricultural waste and secondary products is widely used in countries such as Denmark, Greece, Luxembourg, and Cyprus [22].

Europe is undoubtedly the leader in the field of biogas production, which is shared mainly between Europe (54%), Asia (31%), and America (14%). Biogas production has increased over the last 20 years. Between 2000 and 2017, global biogas production was more than quadrupled, from 78 to 364 TWh, which corresponds to a global yearly volume of 61 billion m^3 of biogas [23,24].

Biogas is undoubtedly an important element in the bioeconomy. Unlike fossil fuels, biogas is a RES. It is produced from different sources of biomass through the process of anaerobic digestion. Its role is environmental protection, and its conservation of the environment is unparalleled [25]. The production of biogas is a future challenge that will substitute natural gas. Environmental contamination, oil crises, and other problems fostered the creation of biogas plants worldwide. Biogas plants can be placed on livestock farms or as centralized biogas plants where other farms have access to and are connected to the facility [26].

Biogas contributes to economic growth and development. It is competitive with fossil fuels and has increased global interest. It is a competitive energy and is an alternative to fossil fuels. It has potential value in animal farms and households. It provides benefits because it improves sustainable development and the economy [27]. The EU elaborated an important target to develop the RESs by 2020. The European Union (EU) should use 20% of RESs in its final energy consumption [28].

The United States (US) is also an important biogas producer worldwide. The USA biogas market value was USD 60.06 billion in 2021 and is still developing. Large farms produce manure, which can be used for biogas production. The US also introduced a policy for natural resource preservation. The US is the second largest emitter of GHG, and the US Congress has decided to introduce climate legislation. The US Environmental Protection Agency plays an important role because it regulates GHG emissions [28]. Biogas is used in different applications such as electricity, heat, vehicle fuel, and cooking. The demand for biogas is increasing in the US. The market would not have been developing without support. This support includes favorable regulatory and political support, environmental support, customer support, geopolitical support, and agricultural and economic support.

In 2018, the US biogas industry's power generation capacity was (2.4 GW), whereas Germany had (6.2 GW), Italy had (1.4 GW) and the United Kingdom had (1.7 GW). These results demonstrate the scale of investment in this source of renewable energy. Germany, which is the largest economy in the European Union, has the largest investment, exceeding the US [29]. The world's installed biogas capacity in the US was 19.7% in 2016, and this country is the second largest after Germany [30]. In dairy farms, manure is converted into biogas and fertilizers for use in agricultural areas [31].

1.2. Problems and Barriers to Biogas Production

Biogas can be used in different sources of energy for electricity production, transport, and heating [32]. Biogas has multiple applications, including various sources that use energy, for example, electricity, cooking, gas-powered vehicles, cooking, and others. It can also be used in the production of fertilizers. Biogas has a positive meaning on the reduction in GHGs in transport, where (60–80% reductions are possible compared to gasoline operations) [33].

Another important issue is the cost of production of biogas. The cost depends on sources of feedstock materials and plant capacity. Biogas can be produced from plants, and that is why the cost increases. Biogas production from industrial organic waste and residues has lower capital costs (the difference lies between 25 and 30%) compared to energy crops. Small-scale plants also have significantly high costs [34]. The technology of production and handling is also an important problem. If handling systems are not properly designed and maintained, biogas production can result in the release of methane [35].

Biogas production has many problems and barriers, including technical, economic, market, institutional, socio-cultural, and environmental [36]. The production of biogas can lead to water pollution. Using manure for biogas production impacts soil fertility and nitrogen release into the atmosphere and groundwater, highlighting the importance of NH_3

emissions. Moreover, improper disposal increases water pollution and contamination in soil and groundwater [37].

The production of biogas does not solve GHG emissions. It can be released into the atmosphere during the production of crops and manure. Biogas contains carbon dioxide and methane, which impacts global warming and climate change. Manure has environmental impacts on cows and other animals. That is why the diet and its diversification impact manure's characteristics and influence the components of biogas [38]. Biogas can also impact human health. Biogas contains carbon dioxide, hydrogen sulfide, siloxanes, nitrogen oxides (NOx), ammonia, and halogens. These substances can affect the environment and health and have detrimental effects. According to Werkneh [39], biogas impurities can cause different public health concerns (like pulmonary paralysis, asthma, respiratory diseases, and deaths) and environmental impacts (such as global warming, climate change, and their indirect impacts like drought and flooding). These impurities have an impact on biogas conversion devices and create harmful consequences to human health and the environment in the form of emissions when their presence is above their threshold limits [40,41].

1.3. Environmental Aspects on Biogas Production

For agriculture, investments in the field of RESs are an opportunity to build technological advantages, innovate the industry, reduce dependence on imported energy resources, and improve environmental conditions. Biogas plants are starting to play such a role in rural areas. A biogas plant is an installation that produces gas from biomass in the process of methane fermentation. This biogas finds unlimited possibilities for use in the energy sector—both locally to generate electricity and heat, as well as in transport. Agricultural biogas can be independently used in the industry or the energy sector after it is injected into the gas distribution network and for a farm's own needs. An agricultural biogas plant is a plant that produces biogas from plant biomass, animal manure, organic waste (for example, from the food industry), slaughterhouse waste, or biological sludge from sewage.

The main component of biogas is methane (CH_4), which is the simplest aliphatic saturated hydrocarbon and the main component of natural, mine, and mud gas. It is used as fuel, the main source of hydrogen, water, and gas, and as a raw material in the petrochemical and other industries. The amount and composition of biogas generated during fermentation depends on the type of feedstock and the number of organic compounds contained in it.

Biogas production undoubtedly has environmental aspects. Biogas production solves many environmental problems. The main substrate for biogas production is biomass, which is carbon-neutral and a source of C (carbon), H (hydrogen), and O_2 (oxygen) elements. To produce biogas, we can use maize and other agricultural products. Such production increases competition in the market for agricultural prices and, of course, is responsible for price increases [42]. Other substrates can be animal manure, which, in the AD process, produces biogas. Summing up, in the process of biogas production, we can use many products that are utilized in the nutrition, agriculture, and chemical industries [43].

There are at least two options for biogas production. First, it can be produced in plants, which need to buy products for biogas production. It can also be used in agricultural products. Such plants need to be actively managed to reduce costs of production and increase incomes [44]. The second option is the production of biogas from animal waste on farms. It is a good way to use animal waste at low costs. Using animal waste, the use of agricultural products can be decreased. Pollution can be reduced, and the remaining part can be used as a good fertilizer [45]. Animal slurry may be harmful to the environment, and the production of biogas in the process of anaerobic digestion has an important role in climate protection because greenhouse gases are reduced [46,47].

Agricultural biogas is a gaseous fuel obtained in the process of the methane fermentation of agricultural raw materials, agricultural by-products, liquid or solid animal manure, by-products, or residues from the processing of agricultural products or forest biomass, excluding gas obtained from raw materials, sewage treatment plants, and landfills [48].

Slurry from both pig and cattle farms is suitable for biogas production. A comparison of the unit efficiency of these substrates is in favor of pig slurry. In addition, biogas from cattle slurry has a lower biomethane content. These differences result from the fact that in the stomachs of ruminant cattle, the initial fermentation of organic compounds is already taking place, which makes the slurry slightly poorer.

The anaerobic fermentation of excrements of farmed animals and birds in the context of fertilization has the following effects:

- Improvement in fertilization conditions in agricultural fields compared to raw slurry;
- Reducing the amount of nitrate nitrogen in favor of ammonium nitrogen;
- Ability to maintain humus balance in the soil;
- Destruction of weed seeds—reduction in herbicide consumption;
- Elimination of pathogens thanks to, e.g., hygienist processes;
- Reducing the use of artificial fertilizers;
- Reducing the risk of contamination in ground and surface waters, limiting the spread of pathogens contained in animal feces, such as Salmonella, Escherichia coli, tuberculosis bacteria, foot and mouth disease, viruses, etc.;
- Reduction in greenhouse gas emissions, including nitrous oxide and methane emitted during the storage of natural fertilizers [49–51].

2. Materials and Methods

2.1. Data Sources

Data sources included Eurostat, which is the most important source in our paper. The browser of Eurostat enabled us to gather data, including electricity production from biogas. We collected data from 2012 to 2021. Figure 1 depicts the electricity production from biogas in 2021, expressed in thousand tons of oil equivalents. The largest production is in Germany, Italy, France, and Czechia. The production of biogas requires the development of the biogas industry, which is the best developed in Germany, Denmark, Austria, Sweden, the Netherlands, France, Spain, and Italy. Biogas plants in the European Union (EU) are diversified. We can observe large-scale, joint co-digestion plants and farm-scale plants. Co-digestion plants use a mixture of two or more substrates. They are mostly used for generating heat and electricity in the European Union (EU). The second kind of farm is the farm-scale biogas plant that uses animal manure and energy crops. These farms are large pig farms because of problems with slurry production [52].

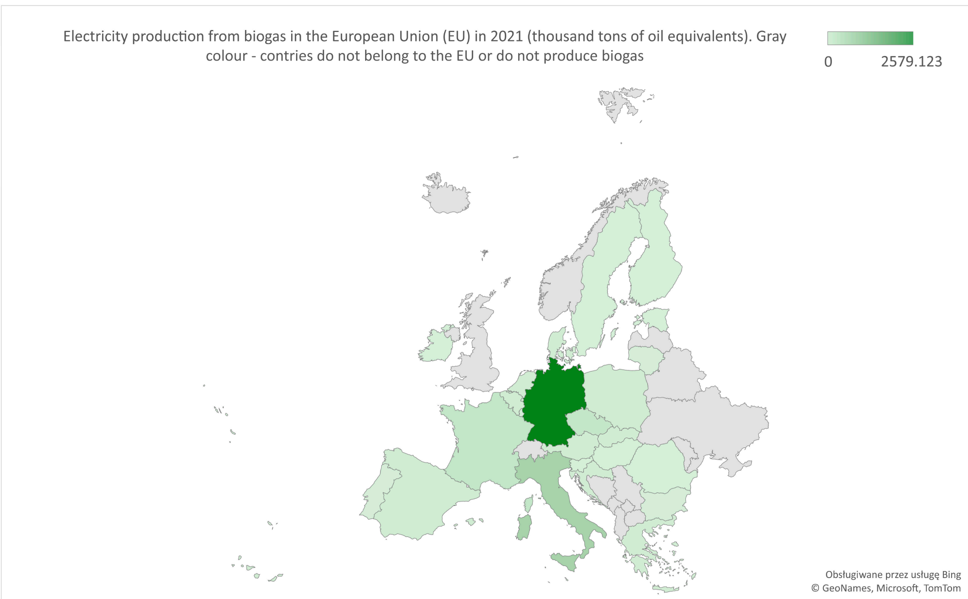

Figure 1. Electricity production from biogas in the European Union (EU) in 2021 (thousand tons of oil equivalents). Source: our own elaborations based on [53].

The main source of information was Eurostat data. Eurostat is considered to be the most important data source. It includes data that are verified before publication. It is gathered from all member states of the European Union. These data include the 2012–2021 period because only the newest data were available. Moreover, we presented data without Great Britain because this country left the European Union (EU) in 2020. We also present the data for all member states and the whole European Union (EU) and Euro area (Table 1).

Table 1. Electricity production from biogas in EU countries in 2012–2021 (Mg megagram).

EU Countries	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
European Union—27 countries (from 2020)	3494.388	4056.994	4375.53	4626.114	4733.206	4784.927	4737.394	4728.44	4794.98	4523.057
Euro area—19 countries (2015–2022)	3260.716	3730.544	3998.977	4227.326	4307.372	4333.192	4279.138	4271.587	4319.059	4045.928
Belgium	57.051	66.518	74.936	82.494	85.408	80.671	81.23	81.41	87.24	83.947
Bulgaria	0.05	1.44	5.334	10.242	16.408	18.553	18.254	19.838	19.401	18.593
Czechia	126.198	197.213	222.129	224.502	222.616	226.936	224.179	217.376	223.254	222.939
Denmark	32.464	32.846	38.765	39.603	42.855	48.739	52.565	53.859	57.833	52.67
Germany	2348.581	2515.477	2672.915	2845.916	2898.624	2913.07	2853.052	2833.362	2880.31	2579.123
Estonia	1.355	1.72	2.322	4.299	3.869	3.59	3.267	3.34	2.664	1.414
Ireland	16.948	15.869	17.509	17.609	1.,882	17.463	15.829	16.165	14.424	14.852
Greece	17.566	18.608	18.887	19.808	23.185	25.816	25.979	32.462	34.729	39.281
Spain	74.463	83.663	77.988	84.437	77.902	80.911	79.364	77.73	75.752	84.179
France	111.467	132.822	137.013	157.683	171.206	181.744	203.762	222.659	237.879	271.168
Croatia	4.857	6.682	9.833	15.14	20.407	26.629	30.516	34.497	36.062	37.85
Italy	397.238	640.385	704.94	706.095	710.123	713.596	713.634	711.66	702.188	698.557
Cyprus	4.284	4.202	4.341	4.406	4.473	4.45	4.892	4.98	5.213	5.154
Latvia	19.207	24.642	30.097	33.681	34.127	34.855	32.163	30.301	29.635	25.098
Lithuania	3.611	5.073	6.707	7.395	10.576	10.941	12.029	13.276	12.846	13.474
Luxembourg	4.97	4.855	5.203	5.297	6.251	6.235	6.489	6.123	5.432	5.243
Hungary	18.103	22.972	24.738	25.193	28.657	29.923	28.891	27.601	27.859	25.365
Malta	0.765	0.507	0.555	0.571	0.714	0.837	0.77	0.55	0.506	0.622
Netherlands	86.73	84.252	86.456	89.288	85.454	79.521	76.667	76.963	74.794	70.101
Austria	55.174	53.55	52.734	54.473	57.241	57.639	54.025	52.611	54.059	51.728
Poland	48.612	59.305	70.187	77.936	88.359	94.276	96.958	97.593	106.092	112.41
Portugal	18.011	21.461	23.826	25.274	24.467	24.637	23.334	22.739	22.31	23.012
Romania	1.668	4.272	4.363	5.226	5.579	5.733	6.033	4.627	4.56	6.27
Slovenia	13.165	12.119	11.156	11.376	12.221	11.187	10.219	8.113	9.717	8.826
Slovakia	16.337	18.315	41.187	46.518	49.527	51.075	46.346	45.916	43.852	41.874
Finland	13.793	26.506	30.205	30.706	34.122	34.954	36.087	31.227	25.509	28.292
Sweden	1.72	1.72	1.204	0.946	0.953	0.946	0.86	1.462	0.86	1.032

Source: our own elaborations based on [53].

We also analyzed documents describing biogas development perspectives. Directives on waste, including the policy of recycling recovery, restricting landfill disposal, and final residues, had a positive impact on biogas production's increase. These regulations have been described in many documents [53]. Biogas production in the European Union (EU) would not be developed without supporting policy. As we know from official documents, the most important directives impacting biogas production in the European Union (EU) include the Renewable Energy Directive (2009/28/EC) [54], the Directive on Waste Recycling and Recovery (2008/98/EC) [55] and the Directive on Landfills (1999/31/EC) [Directive on Landfills (1999/31/EC)] [56–59].

In 2012–2021, six countries decreased the production of electricity from biogas as follows: Sweden (−40%), Slovenia (−32.9%), the Netherlands (−19.2%), Malta (−18.7%), Ireland (−12.4%) and Austria (−6.2%). The biggest increase was observed in Bulgaria (3708.8%), Croatia (679.3%), Lithuania (273.1%) and Slovakia (203.6%). In fact, the production of electricity from biogas increased the most among small producers. The production of electricity from biogas increased by 29.4% in the 27 countries of the European Union in 2012–2021.

When analyzing the data in 2020–2021, we observed a decrease in electricity production from biogas in member states of the European Union (EU). Only Ireland, Greece, Spain, France, Croatia, Poland, Portugal, Romania, Finland, and Sweden increased their electricity production in 2021 compared to 2020. COVID-19 did not have a negative impact on electricity production from biogas in these countries. Other countries of the European Union (EU) recorded a decrease in electricity production from biogas in 2021–2022.

2.2. Methods

Different methods were used to check the changes in biogas production in the EU (Figure 2). We analyzed the changes in biogas production in EU countries. The method that we used first was statistical analysis. We used such descriptive statistics as the average, median, minimal, maximal, standard deviation, coefficient of variation, skewness, and'kurtosis.

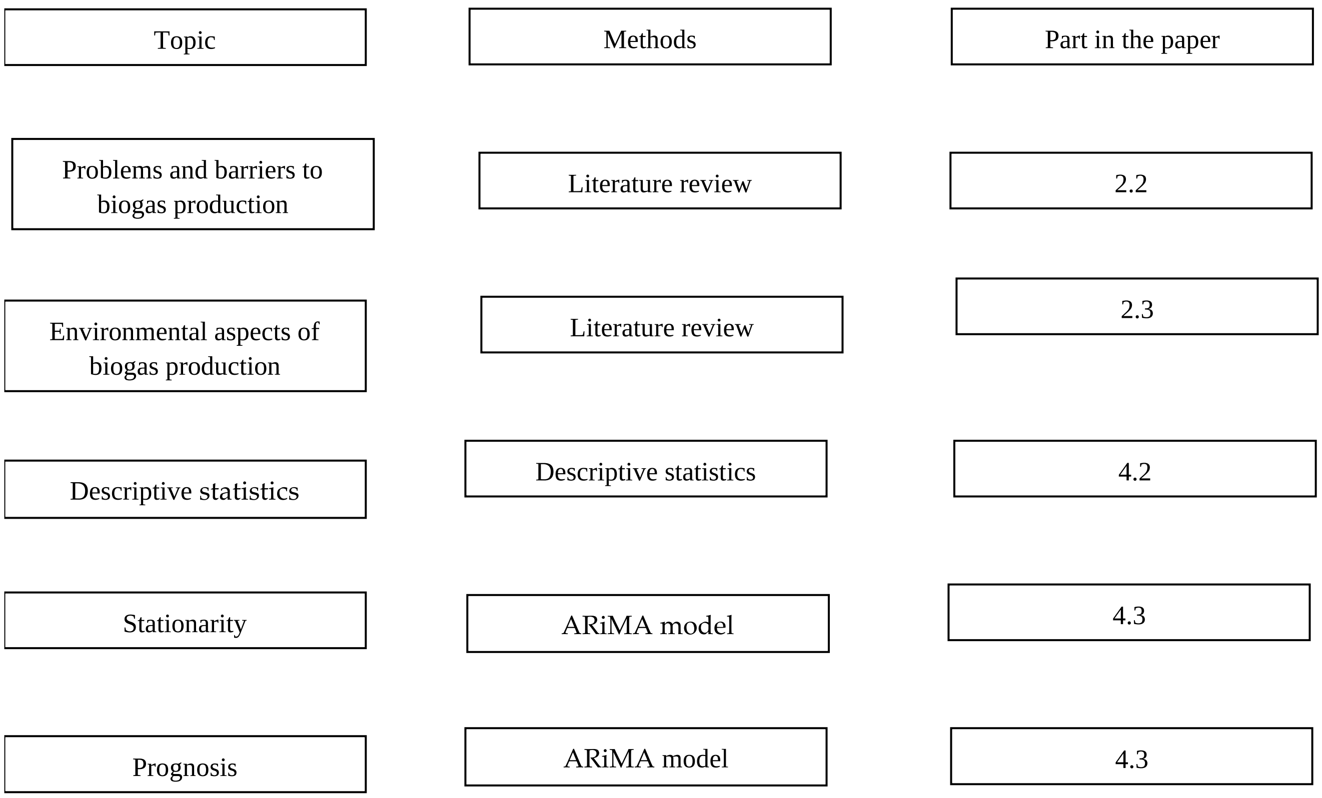

Figure 2. Diagram of conducted research. Source: our own elaborations based on [53].

The average is the average arithmetic electricity production from biogas in European Union (EU) countries. The minimal is the minimal amount of electricity production in EU countries. The maximal is the maximal value of electricity production in EU countries from 2012 to 2021. Standard deviation describes a random variable and the square root of its variance [60]. The coefficient of variation is a very important statistical measure of the dispersion of data points in a data series around the mean. Skewness is a measure of the asymmetry of a random variable about the mean. It can be positive, negative, zero, or undefined [61]. In negative skewness, the left tail is longer. It can be described as a right-leaning curve. Positive skewness has a longer right tail. The right-skewed distribution is the left-leaning curve. The final measure is kurtosis shows the "tailedness" of the probability distribution of a variable. Finally, the authors of the paper prepared a prognosis to evaluate future changes. Before that, we conducted the ARiMA model, which is a method used for stationarity evaluation. Both our prognosis and the evaluation of the ARiMA model were optimistic for the development of biogas production in European Union countries and biogas production in the world.

The classic forecasting model is ARiMA. It is comprised the following components [60]:

Autoregression (AR): the model displays the variable's regression with respect to its prior values.

Data are replaced by the integration (I) of the difference between their values and previous meanings.

Moving Average (MA) is a model that analyzes the correlation between an observation and the residual errors of a Moving Average model that is used for lagged data.

The sesonal model ARIMA is a very useful tool used for forecasting. It is also used for stationarity analysis and is useful in prognosis elaboration [61].

There were two theories investigated. It was established that the time series was stationary in the first hypothesis, and r = 1 was checked. The second premise determined whether the time series was stationary. The alternative hypothesis H1, which states that the series does not have a unit root, is accepted if we reject H0. The series remains in place [62].

The Autoregressive Moving Average Model was then run (ARIMA model). This model is dependent on the series' autocorrelation patterns [59]. The following is a description of the ARIMA model: the order of the Moving Average process is represented by the MA, the difference order is represented by I, and the order of the autoregressive process is represented by AR [63].

This model uses historical values to explain a specific time series [64]. The ARIMA model was used to examine electricity production from biogas trends. Their form is as follows:

$$Y_t = B_1Y_{t-1} + B_2Y_{t-2} + \ldots + B_pY_{t-p} + E_t + \theta_1E_{t-1} + \theta_2E_{t-2} + \ldots + \theta_qE_{t-q} \quad (1)$$

where:

B—the delay operator;
Y—the analyzed variable;
E—the random component;
θ—autoregression parameters;
q—the amount of delay [57].

We used the process of the Auto-Correlation Function (ACF) and Partial Auto-Correlation Function (PACF). The use of the Auto-Correlation Function (ACF) and Partial Auto-Correlation Function (PACF) for the same data [65] was suggested by Box and Jenkins [66]. The analyzed features, which are a linear mixture of the future and current values of the process, are predicted using time series models. A random process with uncorrelated components and finite variance is known as an autoregressive model [67–69]. The ARIMA model was used to generate the prediction of the examined variable to identify the order of the ARIMA model in the current study, which employed data from biogas from 2012 to 21. For the analysis of upcoming changes in the markets and the execution of business plans, the use of prediction methods is crucial [70,71]. It is well-liked. This model is well recognized and is appropriate for the analysis of research results. This model enabled us to elaborate on the prognosis of electricity production from biogas in the EU.

3. Results

3.1. Biogas Production in the World

The production of biogas is increasing in the world due to the development of THE bioeconomy and sustainability concepts. Biogas production is diversified and has different sources, and the EU is the leading producer [39]. This is the result of the relevant action plans of the European Commission (EC) of a public–private partnership (PPP) titled "Biobased Industries" (BBI) that spent EUR 3.7 billion for research projects and demonstration facilities in 2013–2020. This project helped to develop clusters that involved around 140 partners from Europe [24]. The European Commission was responsible for managing and implementing the EU Framework Programs in Biotechnology and Life Sciences. The aim of this program, organized and realized within the European Union, was to promote scientific excellence and solve the global problems with the environment [72].

The sector of biogas is developing well. The annual growth rate was 9% during 2000–2018 (Figure 3). Such a large increase was the effect of its supply to a variety of users and markets, including electricity, heat, and transportation. The EU is the leader in biogas production. It produced 30.3 billion m^3 of biogas in 2018. The second place is taken by Asia with the production of 19.3 billion m^3 and the third by America with 8.34 billion m^3.

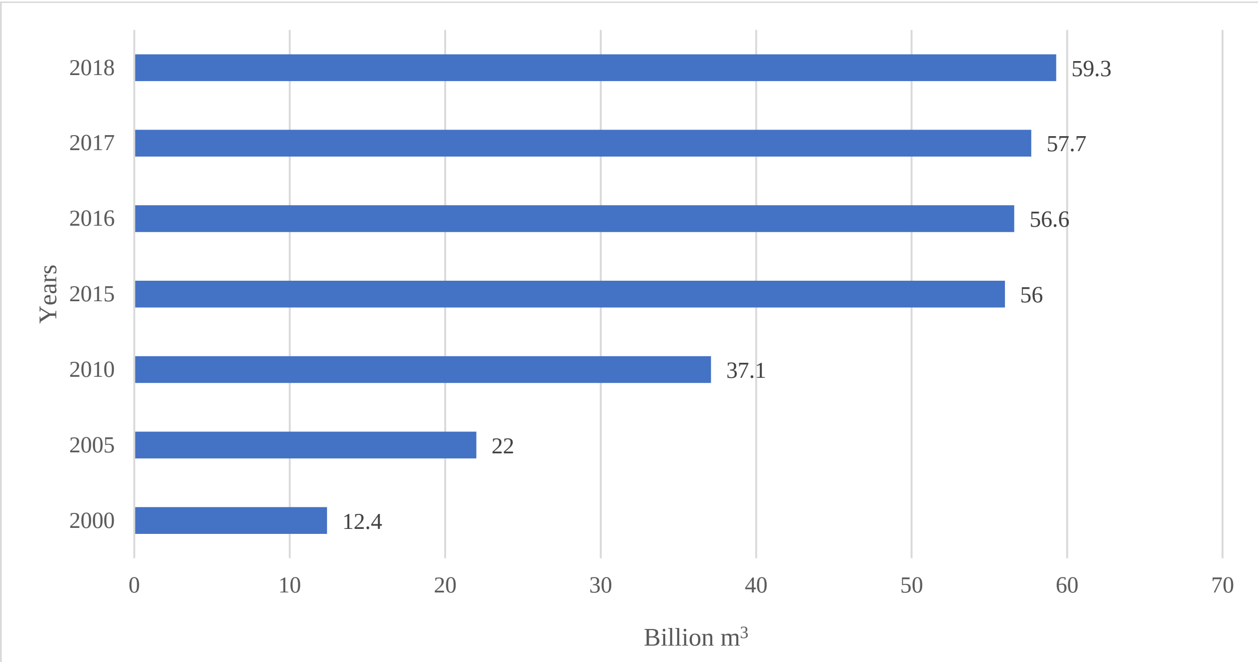

Figure 3. Biogas production globally (billion m^3). Source: our own elaborations based on [73].

In 2022, the global biogas market size was evaluated at USD 55.84 billion. The prediction is that the market will increase to USD 78.8 billion (Figure 4). This is a tremendous increase, showing the potential for development. In 2021, most of the biogas was used for electricity (31%). Biogas production increased from 0.29 exajoules to 1.46 exajoules in 2020 (Figure 4).

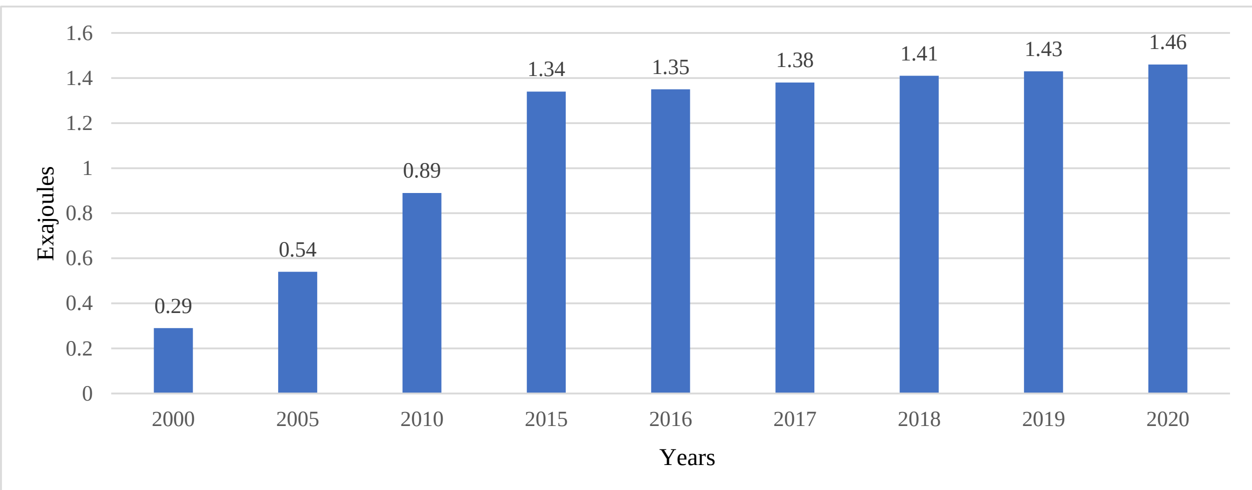

Figure 4. Biogas production worldwide from 2000 to 2020 (in exajoules). Source: our own elaborations based on research [73].

The biogas market is estimated to reach USD 78.8 billion by 2023 (Figure 5). This is a tremendous growth that will impact the world's economy [73].

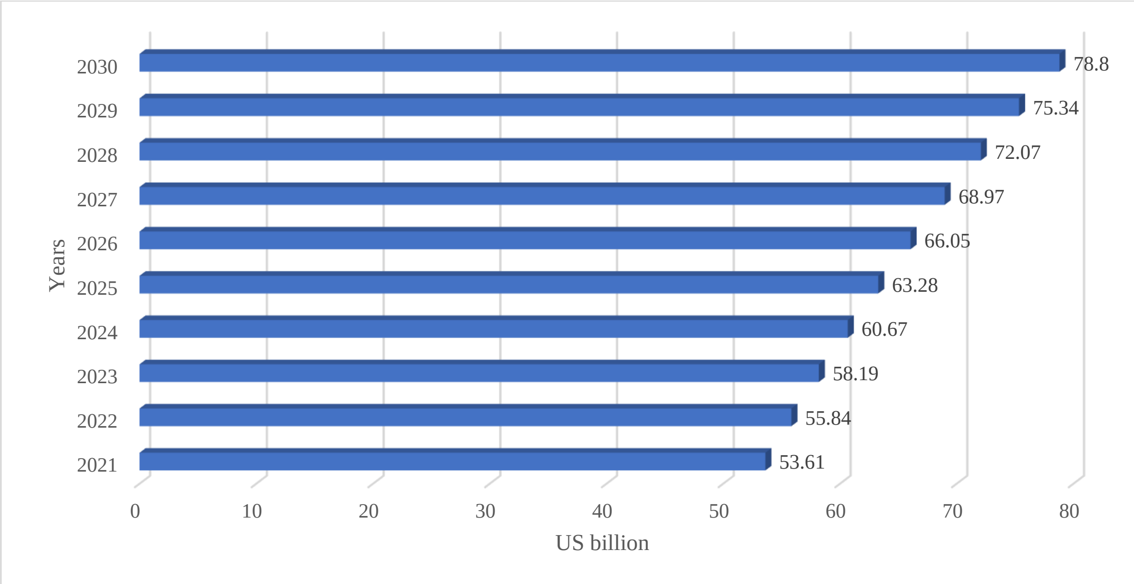

Figure 5. Biogas global market size (US billion). Source: our own elaborations based on [73,74].

China is a very big country and has the world's largest energy demand. But its economy is based on coal. So, this country is the largest emitter of CO_2 and CH_4 but has also achieved success with photovoltaic development and other RESs based on biomass [66–68]. China is also an important producer of biogas. However, biogas is produced not only from animal manure but also from straw. Using modern technologies, a reduction in carbon emissions alongside environmental protection can be achieved [9]. The diversification of biogas production in world regions depends on many factors, such as their development level, dietary habits, animal production efficiency, population density, straw resources, and others (Figure 6). In Europe, for example, factors differentiating biogas production and distribution are population sizes, dietary habits, and historical background [5].

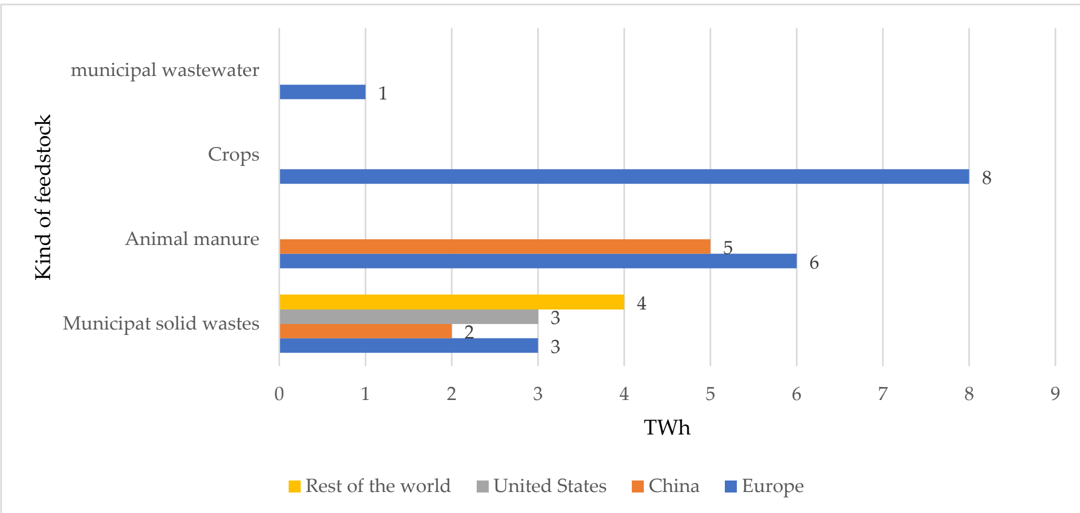

Figure 6. Biogas production by feedstock type, 2018. Crops include energy crops, crop residues, and sequential crops. 1 Mtoe = 11.63 terawatt-hours (TWh) = 41.9 petajoules (PJ). Source: our own elaborations based on [75]. https://www.iea.org/data-and-statistics/charts/biogas-production-by-region-and-by-feedstock-type-2018 accessed on 1 March 2023.

3.2. Stationarity and Prognosis for Global Biogas Production

The authors of this paper conducted the prognosis of global biogas production. It is clear from our analysis that the global production of biogas will increase in the coming years. First, we conducted the ARiMA model to evaluate the changes in global biogas production (Table 2). This model belongs to a wide variety of models, and its application is the evaluation of a time series. The ARMA model was used to develop a forecast of vegetable fat consumption. Models were analyzed for all combinations (p,q) in which p <= P and q <= Q. The version of the model for which the information criterion had the minimum value was selected. The Kalman filter test was used to evaluate the model. The research shows that the hypothesis about the normality of the residual distribution cannot be rejected. From the analysis of the data in Table 2, it can be concluded that the model parameters are statistically significant at the 0.05 level. Based on these data, we can conclude that the time series are stationary.

Table 2. ARIMA model characteristics for global world biogas production (TWh).

Specification	Arithmetic Mean of the Dependent Variable	Mean of Random Perturbations	R-Squared Determination Coefficient	Likelihood Logarithm	Critical Bayesian Schwarz Criterion	Standard Deviation of Dependent Variable	Standard Deviation of Random Disturbances	Corrected R-Square	Critical Information Akaike Criterion	Critical Hannan–Quinn Criterion
Global world biogas production	53.340	0.658	0.905	−12.039	30.514	9.164	2.687	0.873	32.077	27.884

Specification	AR Coefficient	AR Std. error	AR Z	AR *p* value	MA coefficient	MA Std. error	MA Z	MA *p* value
Global world biogas production	0.577	0.138	4.175	0.002	−1.000	0.899	−1.113	0.266

Source: our own elaborations based on [75].

Our prognosis of global biogas production proves the development of this market in the future. The reasons for this development are numerous. First, the world has undertaken the policy of renewable energy to meet the increase in global energy consumption. Second, the war impacted the breakdown of the supply chain of fossil fuels. Moreover, the demand for energy is increasing worldwide (Table 3). Global biogas production will increase from 62.300 TWH to 64.000 TWh in 2019–2026.

Table 3. Prognosis of global biogas production (TWh).

Specification	Prognosis															
	2019		2020		2021		2022		2023		2024		2025		2026	
	Prediction	Std. Error	Prediction	Std. Error	Prediction	Std. Error	Prediction	Std. Error	Prediction	Std. Error	Prediction	Std. Error	Prediction	Std. Error	Prediction	Std. Error
Global biogas production	62.300	2.690	63.000	2.920	63.500	2.990	63.700	3.010	63.800	3.000	63.900	3.030	64.000	3.030	64.000	3.030

Source: our own elaborations based on [75].

3.3. Descriptive Statistics of Electricity Production from Biogas in EU Countries in 2012–2021

The authors used descriptive statistics to analyze the changes in biogas production in EU countries. The arithmetic value of the average shows that the biggest value of electricity production from biogas was achieved in such countries as Germany, Italy, and France [76]. These data show that these countries have the biggest potential and the largest outlays for facilities of biogas production.

The smallest minimal value of electricity production from biogas was achieved in 2012–2021 in Bulgaria, Malta, and Sweden. The undoubted leader in biogas production in the European Union (EU) is Germany. There are more than 9000 biogas plants in Germany. Moreover, it has 28.1% of the world's installed biogas capacity [77]. These results are the effect of favorable subsidization schemes in European Union (EU) countries. France, Spain, Italy, and Sweden are also growing markets for biogas. These countries are adopting German solutions in the market [78]. Spain also has good prospects for biogas development because of its high position in animal production in the European Union (EU). The production of manure is high in Spain, and this country takes the fourth position. Spain is the second-largest producer of swine and the sixth-largest producer of cattle, making Spain the largest producer of animal manure [79].

The largest coefficient of variation was achieved by Bulgaria, Croatia, Estonia, Greece, and Slovakia. This means that these countries noted the largest changes in electricity production from biogas in 2012–2021.

Skewedness and kurtosis are the measures of asymmetry of random variables. The value of skewness was negative in the majority of countries. Only Greece, Spain, France, Cyprus, Luxemburg, Malta, and Austria achieved positive skewness. Kurtosis was also negative in most countries. However, only Belgium, Czechia, Finland, Hungary, Italy, Portugal, and Romania achieved positive kurtosis (Table 4).

Table 4. Descriptive statistics of electricity production from biogas in EU countries in 2012–2021 (MG Megagram).

Countries	Average	Median	Minimal	Maximal	Std. Dev.	Coefficient of Variation	Skewedness	Kurtosis
Austria	54.323	54.042	51.728	57.639	1.9207	0.035358	0.57645	−0.69096
Belgium	78.091	81.320	57.051	87.240	9.4576	0.12111	−1.2967	0.48233
Bulgaria	12.811	17.331	0.050000	19.838	7.8629	0.61374	−0.66501	−1.2564
Croatia	22.247	23.518	4.8570	37.850	12.581	0.56553	−0.14034	−1.5232
Cyprus	4.6395	4.4615	4.2020	5.2130	0.37982	0.081866	0.42960	−1.4497
Czechia	210.73	222.78	126.20	226.94	30.881	0.14654	−2.3467	3.9676
Denmark	45.220	45.797	32.464	57.833	9.1299	0.20190	−0.14232	−1.4061
Estonia	2.7840	2.9655	1.3550	4.2990	1.0511	0.37755	−0.12421	−1.3568
Finland	29.140	30.456	13.793	36.087	6.4222	0.22039	−1.3318	1.3409
France	182.74	176.47	111.47	271.17	50.903	0.27855	0.29540	−0.97870
Germany	2734.0	2839.6	2348.6	2913.1	194.70	0.071212	−0.86121	−0.62686
Greece	25.632	24.500	17.566	39.281	7.5693	0.29531	0.60054	−0.98220
Hungary	25.930	26.483	18.103	29.923	3.5112	0.13541	−1.0443	0.44426
Ireland	16.455	16.556	14.424	17.882	1.2134	0.073743	−0.40709	−1.1697
Italy	669.84	705.52	397.24	713.63	98.207	0.14661	−2.4519	4.3545
Latvia	29.381	30.199	19.207	34.855	4.9939	0.16997	−0.81316	−0.34778
Lithuania	9.5928	10.759	3.6110	13.474	3.6102	0.37634	−0.44879	−1.2901
Luxembourg	5.6098	5.3645	4.8550	6.4890	0.60064	0.10707	0.25833	−1.5422
Malta	0.63970	0.59650	0.50600	0.83700	0.12150	0.18994	0.38421	−1.3862
Netherlands	81.023	81.886	70.101	89.288	6.2916	0.077653	−0.31302	−1.1513
Poland	85.173	91.317	48.612	112.41	20.679	0.24278	−0.47981	−0.92065
Portugal	22.907	23.173	18.011	25.274	2.0686	0.090306	−1.2903	1.2214
Romania	4.8331	4.9265	1.6680	6.2700	1.3206	0.27324	−1.3282	1.3773
Slovakia	40.095	44.884	16.337	51.075	12.387	0.30895	−1.2823	−0.0080354
Slovenia	10.810	11.171	8.1130	13.165	1.5842	0.14655	−0.31059	−0.88804
Spain	79.639	78.676	74.463	84.437	3.5403	0.044455	0.15088	−1.2747
Sweden	1.1703	0.99250	0.86000	1.7200	0.34158	0.29188	0.76945	−1.0407

Source: own elaborations based on [53].

The descriptive statistics presented in Table 4 show the changes in electricity production from biogas. The EU is a very diversified region in the production of electricity from biogas. Bearing in mind that this region should use more RESs for energy production, the future of this energy is very diversified. Poland, for example, has about 300 biogas plants on farms, whereas its neighbor, Germany, has about ten thousand. The possibilities of creating biogas plants are numerous in all countries of the EU.

3.4. Prognosis of Electricity Production from Biogas in EU Countries in 2022–2026

A clean source of energy can be produced from organic waste. Many organisms' feedstock has the potential to be utilized for biogas production. Many farmers undertake the construction of small installations because they provide many benefits to farms. First, they make you independent of energy supplies, and this is especially important in peripheral areas where voltage drops are very high and power outages are frequent. Surplus energy can be sold to the grid and generate additional income for the farm. Such biogas plants stabilize the power grid in rural areas.

In biogas plants, by-products from agriculture and the agri-food industry can be used, which is important for environmental protection because the disposal of these products generates high costs. The zero-carbon balance of energy production (not counting transport issues), as well as a reduction in greenhouse gases, mainly methane, are also important for the environment. The production of biogas embodies the idea of a circular economy. This additional source of energy can be used for producing heat and electricity. It also offers contributions to decrease environmental pollution and increase ecological balance [80]. Biogas is produced in the process of anaerobic digestion and is a substitute for conventional sources of energy. Conventional sources deplete fossil fuels and create environmental problems [81]. Biogas production is undoubtedly part of the bioeconomy, which could adapt to the changes that take place in the environment [82].

To elaborate on this prognosis, we used the Autoregressive Moving Average model (ARiMA model). This model is a simple way to evaluate the stationarity of the variables. We used biogas production as the dependent variable. Our research proved that these data can be classified as stationary. Based on the p-value, we can conclude that the ARiMA model used for prediction can be a good tool for prognosis (Tables 5 and 6). The r-squared determination coefficient was quite high, confirming the good choice of the model.

Table 5. ARIMA model of electricity production from biogas in EU countries in 2012–2021 (MG Megagram).

	AR				MA			
Country	**Coefficient**	**Std. Error**	**Z**	***p* Value**	**Coefficient**	**Std. Error**	**z**	***p* Value**
Austria	0.004	0.604	0.007	0.994	0.999	0.374	2.669	0.008
Belgium	0.803	0.223	3.601	0.000	0.447	0.301	1.487	0.137
Bulgaria	0.849	0.108	7.838	0.000	0.489	0.483	1.013	0.312
Croatia	0.971	0.056	17.420	0.000	0.413	0.656	0.630	0.529
Cyprus	0.863	0.462	5.328	0.000	0.121	0.260	0.466	0.642
Czechia	0.765	0.276	2.774	0.006	1.000	0.732	1.367	0.172
Denmark	0.827	0.199	4.149	0.000	0.382	0.408	0.937	0.349
Estonia	0.406	0.584	0.695	0.487	0.466	0.406	1.147	0.251
Finland	0.588	0.362	1.625	0.104	1.000	0.316	3.168	0.002
France	0.953	0.067	14.120	0.000	0.675	0.345	1.955	0.051
Germany	0.501	0.354	1.415	0.157	−0.162	1.538	−0.105	0.916
Greece	0.931	0.094	9.915	0.000	0.265	0.259	1.024	0.306
Hungary	0.458	0.874	0.525	0.560	0.356	1.058	0.336	0.737
Ireland	0.747	0.656	1.139	0.254	−0.010	0.759	−0.132	0.895
Italy	0.228	0.039	5.769	0.000	0.360	0.349	1.031	0.302
Latvia	0.536	0.197	2.724	0.006	0.999	0.652	1.534	0.125
Lithuania	0.925	0.102	9.029	0.000	0.269	0.292	0.923	0.356
Luxembourg	0.631	0.327	1.932	0.053	0.157	1.009	0.156	0.876
Malta	0.000	0.488	0.000	0.999	0.600	0.423	1.418	0.156
Netherlands	0.843	0.171	4.929	0.000	0.999	0.295	3.395	0.000
Poland	0.875	0.094	9.258	0.000	0.112	0.408	0.275	0.784
Portugal	0.393	0.524	0.751	0.453	0.366	0.459	0.796	0.426
Romania	0.525	0.741	0.710	0.478	0.146	0.996	0.146	0.884
Slovakia	0.558	0.119	4.695	0.000	−0.387	0.436	−0.889	0.374
Slovenia	0.747	0.310	2.413	0.016	−0.033	0.406	−0.084	0.933
Spain	−0.979	0.209	−4.686	0.000	0.769	1.339	0.575	0.566
Sweden	0.626	0.177	3.543	0.000	−0.999	0.535	−1.867	0.062

Source: our own elaboration on the basis of [53].

Table 6. ARIMA model characteristic of electricity production from biogas in EU countries in 2012–2021 (MG Megagram).

Country	Arithmetic Mean of the Dependent Variable	Mean of Random Perturba-tions	R-Squared Determina-tion Coefficient	Likelihood Logarithm	Critical Bayesian/ Schwarz Criterion	Standard Deviation of Dependent Variable	Standard Deviation of Random Distur-bances	Corrected R-Square	Critical Information Akaike Criterion	Critical Hannan–Quinn Criterion
Austria	54.229	−0.110	0.524	−15.410	39.609	2.012	1.341	0.456	38.820	37.117
Belgium	78.090	1.631	0.736	−31.169	71.549	9.457	4.975	0.703	70.339	69.011
Bulgaria	14.229	0.166	0.933	−17.617	44.024	6.851	1.714	0.924	43.235	41.533
Croatia	24.180	0.087	0.984	−15.852	40.493	11.665	1.408	0.982	39.704	38.001
Cyprus	4.640	0.049	0.786	2.394	4.422	0.380	0.176	0.759	3.211	1.884
Czechia	210.734	5.656	0.693	−45.169	99.549	30.881	17.841	0.654	98.339	97.011
Denmark	45.220	1.034	0.836	−28.086	65.383	9.129	3.657	0.815	64.173	62.845
Estonia	2.943	0.009	0.377	−9.931	28.651	0.979	0.729	0.288	27.862	26.159
Finland	29.140	0.912	0.659	−29.111	67.432	6.422	3.700	0.616	66.221	64.894
France	182.740	8.829	0.944	−43.520	96.250	50.903	15.390	0.937	95.039	93.712
Germany	2776.872	−1.150	0.449	−54.564	117.916	148.355	103.926	0.371	117.127	115.425
Greece	25.632	1.339	0.895	−26.169	61.549	7.569	2.919	0.882	60.338	59.011
Hungary	26.800	0.004	0.651	15.058	38.904	2.315	1.289	0.601	38.115	36.413
Ireland	16.400	−0.007	0.354	−12.455	33.699	1.274	0.966	0.261	32.910	31.208
Italy	700.131	0.106	0.938	−28.250	65.289	22.998	5.584	0.929	65.500	62.798
Latvia	30.511	−0.443	0.728	−18.417	45.624	3.699	1.873	0.689	44.835	43.132
Lithuania	9.593	0.667	0.881	−18.474	46.157	3.610	1.358	0.866	44.948	43.621
Luxembourg	5.681	0.007	0.511	−4.295	17.378	0.591	0.390	0.441	16.590	14.887
Malta	0.639	−0.007	0.236	8.507	−7.804	0.122	0.101	0.140	−9.014	−10.342
Netherlands	81.023	−0.584	0.887	−24.298	57.806	6.292	2.165	0.872	56.596	55.268
Poland	89.235	0.006	0.976	−20.945	50.679	17.187	2.480	0.973	49.891	48.188
Portugal	23.451	0.010	0.589	−10.040	28.869	1.219	0.738	0.531	28.080	26.377
Romania	4.833	0.221	0.226	−15.686	40.583	1.321	1.133	0.129	39.373	38.045
Slovakia	42.734	−0.363	0.682	−28.005	64.799	9.707	5.434	0.636	64.011	62.308
Slovenia	10.810	−0.249	0.466	−15.763	40.736	1.584	1.126	0.399	39.525	38.198
Spain	79.639	−0.126	0.472	−23.800	56.811	3.540	2.453	0.406	55.601	54.273
Sweden	1.109	0.040	0.669	2.352	4.085	0.299	0.186	0.622	3.296	1.594

Source: our own elaborations based on [53].

Because they control how the moving operator q and the autoregressive operator p are applied, the ACF and PACF functions are crucial [83]. This approach controls errors due to seasonal variation and other flaws, making it very versatile [84].

A relatively common statistical method for assessing variables and projecting their future values is the ARIMA model. It is possible to examine the energy management system using biogas forecasts. This approach can reduce expenditure overall while also enhancing the network and quality of biogas [85]. Like Phinikarides et al. [86], our investigation demonstrates how the length of the time series has an impact on the decomposition procedure. These methods do not include the seasonal component in time series [87]. Although our time series was stationary, the model was rigorously run. The ARIMA model's prediction is crucial for the integration of biogas systems. It is significant because it informs the utility of the biogas scenario that could possibly occur. This research's findings led us to the conclusion that time series patterns improve predicting outcomes [88].

Finally, the authors of this paper elaborate on the prognosis of electricity production in EU countries. The production of electricity from biogas will likely increase in the EU as a whole region. However, not all countries will record an increase in electricity from biogas. Four countries from the EU, according to our prognosis, will record a decrease in biogas production Finland, Lithuania, Malta, and Romania. This prognosis shows the big mistakes of statistical analysis (Table 7).

Table 7. Prognosis of electricity production from biogas in EU countries in 2012–2021 (MG Megagram).

Countries	2022	Error	2023	Error	2024	Error	2025	Error	2026	Error
Austria	51.928	1.3408	54.186	1.900	54.196	1.900	54.196	1.900	54.196	1.900
Belgium	87.766	4.874	88.521	7.965	89.324	9.402	90.142	10.153	91.154	11.865
Bulgaria	19.052	1.713	19.790	2.863	20.417	3.463	20.949	3.838	21.401	4.087
Croatia	40.664	1.408	43.595	2.405	46.441	3.059	49.203	3.568	51.885	3.989
Cyprus	5.173	0.176	5.288	0.246	5.332	0.289	5.398	0.316	5.398	0.335
Czechia	223.945	17.840	224.404	36.185	233.637	43.459	239.229	47.195	239.858	49.248

Table 7. *Cont.*

Countries	2022	Error	2023	Error	2024	Error	2025	Error	2026	Error
Denmark	57.302	3.657	58.101	57.403	59.285	6.807	59.446	7.451	59.751	7.861
Estonia	1.745	0.729	2.389	0.968	2.650	1.001	2.756	1.007	2.799	1.008
Finland	30.355	3.699	28.720	6.643	27.758	7.754	27.192	8.0165	26.860	8.104
France	273.769	15.3902	277.906	29.404	282.248	37.857	286.804	44.181	287.563	49.211
Germany	2738.199	103.926	2775.953	109.7291	2794.856	111.136	2804.320	111.487	2809.000	111.574
Greece	39.776	2.19	39.966	4.552	40.003	6.595	40.261	6.362	40.356	6.959
Hungary	25.558	1.289	26.500	1.663	26.932	1.731	27.129	1.745	27.220	1.748
Ireland	15.083	0.965	15.249	1.150	15.373	1.241	15.465	1.289	15.535	1.316
Italy	704.691	5.584	708.398	6.478	709.242	6.522	709.435	6.524	709.479	6.524
Latvia	24.349	1.873	27.996	3.343	29.950	3.762	30.996	3.852	31.557	3.877
Lithuania	13.405	1.357	13.061	2.114	12.744	2.592	12.450	2.940	12.178	3.201
Luxembourg	5.379	0.389	5.497	0.496	5.572	0.533	5.619	0.547	5.649	0.552
Malta	0.658	0.101	0.651	0.117	0.651	0.118	0.651	0.118	0.651	0.118
Netherlands	69.026	2.165	70.678	4.538	72.070	5.647	73.243	6.318	74.232	6.754
Poland	115.923	2.480	118.796	3.484	121.309	4.089	123.508	4.498	125.431	4.787
Portugal	23.534	0.738	23.693	0.926	23.756	0.953	23.781	0.957	23.790	0.957
Romania	5.743	1.133	5.224	1.365	4.951	1.422	4.807	1.438	4.732	1.442
Slovakia	46.098	5.434	46.621	5.513	46.913	5.537	47.076	5.545	47.168	5.547
Slovenia	9.383	1.126	9.760	1.383	10.042	1.508	10.253	1.574	10.411	1.609
Spain	84.304	2.453	87.473	2.506	88.565	2.556	89.653	2.606	90.431	2.913
Sweden	0.883	0.186	0.907	0.199	0.922	0.203	0.931	0.205	0.937	0.206

Source: our own elaborations based on [53].

According to our prognosis, such countries as Estonia (60.4%), Latvia (29.6%), Croatia (27.6%), Slovenia (10.9%), and Poland (8.2%) will increase their electricity production from biogas the most in 2022–2026. Such countries as Italy (0.68%), Portugal (1.1%), Greece (1.5%), Slovakia (2.3%), and Germany (2.6%) will increase their electricity production from biogas the least in the same period. Such countries as Romania (−17.6%), Finland (−11.5%), Lithuania (−9.1%), and Malta (−1.06%) will decrease their production from biogas in 2022–2026.

Our prognosis coincides with the European Biogas Association data, according to which the sector of biogas production and its utilization will increase. Nowadays, the production of biogas in Europe is about 21 bcm (billion cubic meters), whereas in 2030, production will increase to 35–45 bcm (billion cubic meters) and 167 bcm (billion cubic meters) by 2050. The potential for biogas production in Europe is big, and this sector will provide 1.7 million jobs by 2050 [88].

3.5. Hydrogen, Biomethane and Green Methanol Production in the EU

The European Union is transforming the biogas market into producing new low-carbon gases. The most important and new biogases are hydrogen, biomethane, and green methanol.

Hydrogen (H_2) is considered to be the cornerstone of the renewable energy portfolio. Hydrogen is a very promising factor that can help replace fossil fuels and reduce CO_2 emissions. Hydrogen production can be made from biogas [89]. Moreover, hydrogen can be used not only as a fuel in heat production but also as an energy carrier [90]. Hydrogen can be produced via natural gas from thermochemical methods [91]. Global hydrogen production reached almost 95 Mt in 2022: an increase of 3% compared to 2021 (Figure 7). The sector of hydrogen is constantly increasing due to increasing demand in industries [92]. In 2040, global hydrogen production will reach the level of 240 MT H2. Asia and Oceania will share 55%, North and South America 28%, Europe 15% and MENA 12%. The sectors that will consume the most are the manufacturing industry (48%), mobility (30%) and energy sectors (15), and the heating of buildings (7%).

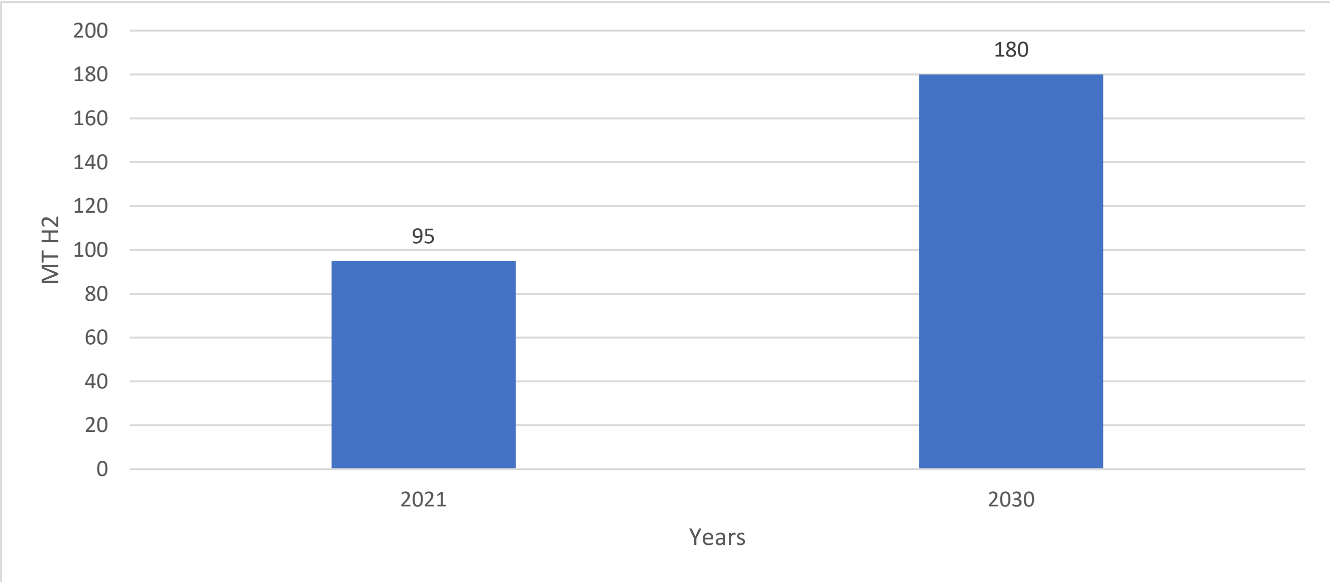

Figure 7. Global hydrogen production (MT H2). Source: our own elaborations based on [92] Global Hydrogen Review 2022 (windows.net, accessed on 1 March 2023).

Another promising gas is biomethane, which is derived from biomass. Biomethane production worldwide is achieved by anaerobic digestion followed by upgrading and biomass gasification followed by methanation [93]. As we can see from Figure 8, the production of biogas increased in Europe from 6.8 bcm in 2011 to 16.8 bcm in 2022 (an increase of 147%). In the same period, the production of biomethane increased from 0.5 bcm to 4.2 bcm (an increase of 740%). These data prove the big potential of biomethane production, which only increased to 20% in 2022 compared to 2021.

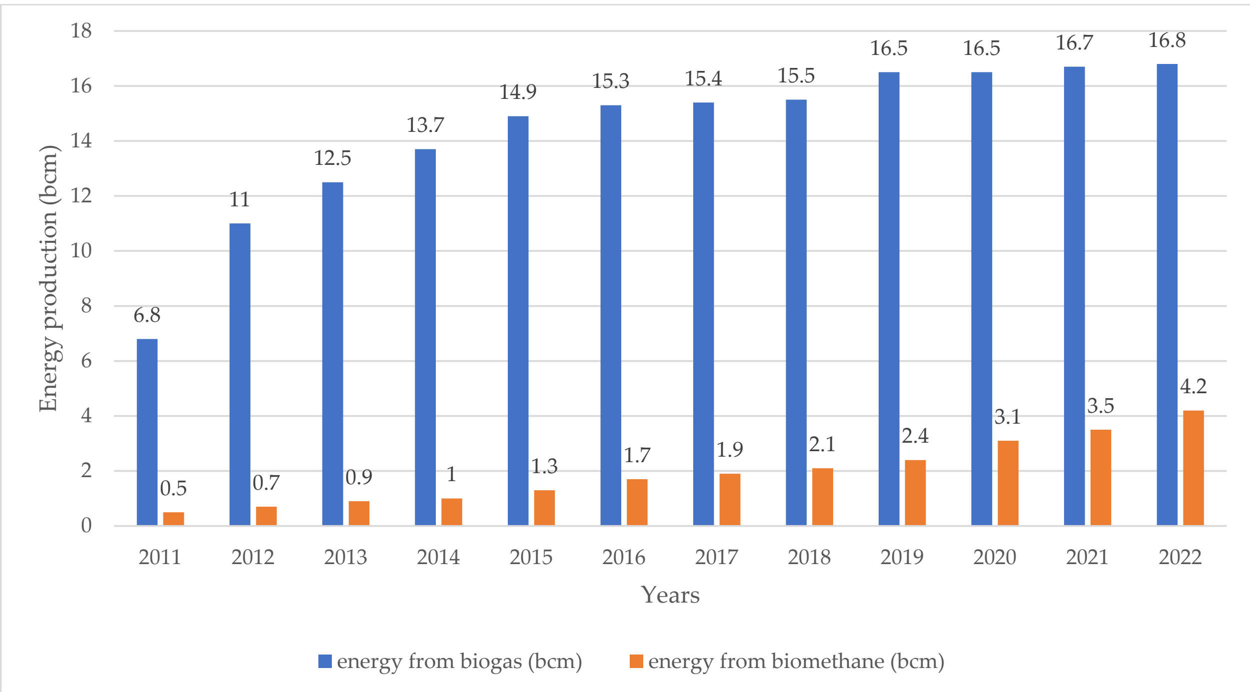

Figure 8. Biomethane and biogas production in Europe. Source: EBA 2023 [94]. https://www.euractiv.com/section/energy-environment/opinion/biomethane-production-up-20-in-2022-boosting-renewable-gas-ramp-up/ accessed on 1 March 2023.

The production of biomethane is diversified in Europe. Germany is the most important producer of biomethane and produces about 30% (12.8 TWh), followed by the UK (6.2 TWh), Denmark (5.7 TWh), and France (4.5 TWh). The average plant sizes across Europe are about 460 m^3/h, in Germany 582 m^3/h, and in Denmark 1.431 m^3/h [95].

Green methanol is another promising low-carbon gas. It is also called renewable methanol, which is "a liquid, flammable chemical compound with very low carbon dioxide emissions produced from biomass, then called biomethanol, or obtained from carbon dioxide and hydrogen using renewable electricity". Catalytic CO_2 hydrogenation to methanol is a green process that produces valuable methanol. This gas is neutral compared to conventional methanol, which is produced from coal or natural gas [96]. The value of the market size of green methanol reached in 2022 was –88 thousand tons, whereas it is projected in 2032 to be –460 thousand tons. Green methanol is projected to be mainly used by the automotive sector (58%), chemicals (28%), power generation (8%), and others (6%) by 2032 (Figure 9). The green methanol market is evaluated at USD 156.06 million and is set to rise to USD 3149.05 million in 2031. The growth of the green methanol market is closely tied to the growing demand for green methanol from the maritime industry as a clean and sustainable fuel source [97].

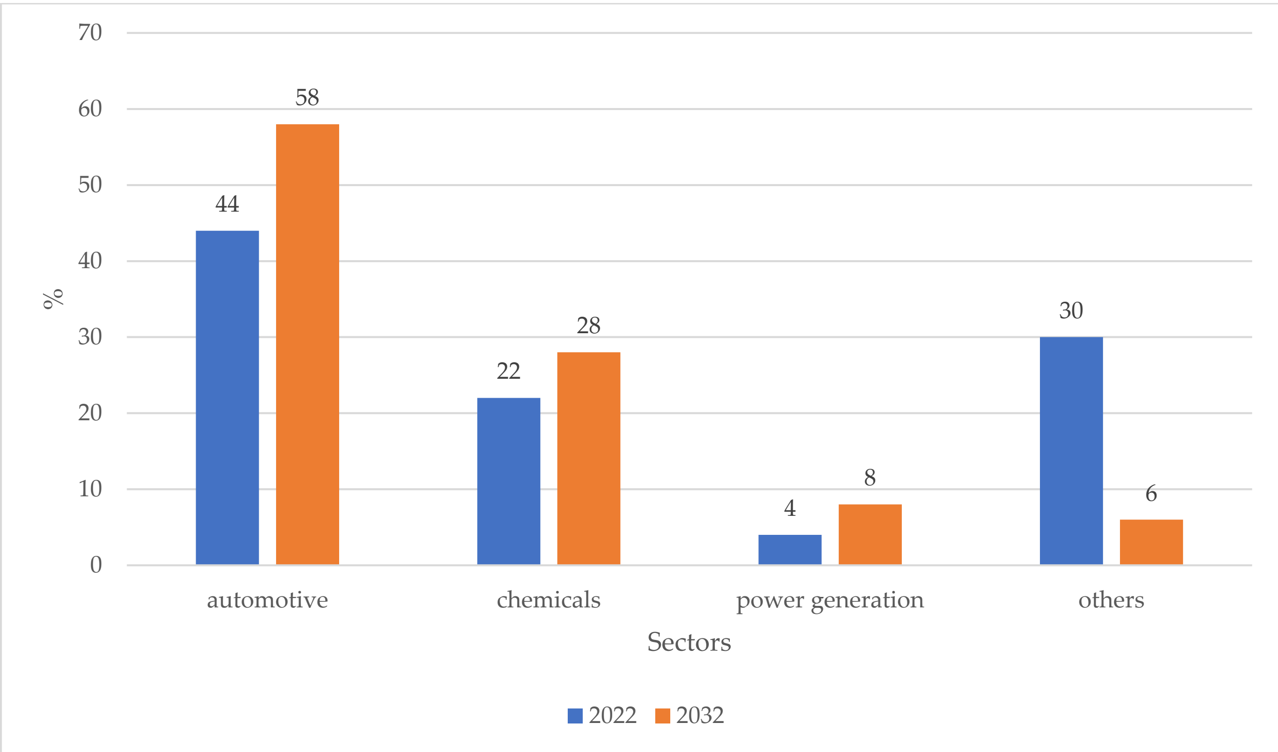

Figure 9. Green methanol share by end-use and volume in 2022 and 2032. Source: our own elaboration based on [98] https://www.chemanalyst.com/industry-report/green-methanol-market-310 accessed on 1 March 2023.

3.6. Biogas Consumption in the EU

The consumption of biogases is depicted in Table 8. The biggest consumers of biogas are Germany, Italy, and France. These countries also have the largest production of biogas and the highest number of biogas and biomethane plants with prepared infrastructure. In 2022, there were about 20,000 biogas and biomethane plants, and in 2018, there were 18,202. Germany has 11,084 biogas plants, Italy has 1655, France has 837, and Poland has 300. In 2021, The energy production from biogas reached the level of 14.9 billion cubic meters (bcm). By 2030, the EU's biomethane production needs to reach 35 billion cubic meters (bcm) per year. Until 2050, sustainable biogas can cover up to 30–40% of the EU's gas consumption

(60–70 bcm). Biogas is used in various sectors, including transportation, service, industrial, agricultural, and municipal. Biogas plants in Europe are powered by agricultural substrates (silage of energy crops, slurry, agricultural waste); 16% operate at sewage treatment plants and 8% at landfills. In total, 4% are "municipal" biogas plants fed with bio-waste, with the remaining industrial plants using distillery or brewery waste [99]. Most of the biogas is used to generate electricity and heat. Around 30% was consumed in buildings, mainly in the residential sector, for cooking and heating, with the remainder upgraded to biomethane and blended into the gas networks or used as a transport fuel [100].

Table 8. Inland consumption of biogases in EU countries in 2013–2022 (TJ).

EU Countries	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Changes (%)
European Union—27 countries (from 2020)	497,823.315	530,918.025	551,325.869	568,982.066	581,985.260	580,267.668	592,251.404	614,908.409	625,835.295	641,002.324	128.0
Euro area—20 countries (from 2023)	451,411.483	480,224.794	497,847.621	509,626.081	519,596.712	515,202.221	524,627.337	540,838.083	545,597.788	555,207.273	122.9
Belgium	8358.600	9129.900	9860.400	9814.400	9423.100	9546.600	9698.000	10,261.400	10,291.500	10,575.000	126.5
Bulgaria	93.000	435.000	820.000	2511.000	1958.390	2244.673	2133.311	2231.674	2499.393	2180.253	2344.3
Czechia	23,910.000	25,457.000	25,681.000	25,161.000	25,443.789	25,279.127	24,331.895	24,888.839	25,529.529	26,000.000	108.7
Denmark	4587.832	5561.231	6285.248	9047.985	10,906.278	13,333.410	16,481.514	21,151.581	26,194.576	31,695.437	690.8
Germany	280,646.000	298,275.000	314,418.000	320,998.000	323,250.000	318,527.000	317,935.000	325,115.000	314,773.000	317,236.000	113.0
Estonia	302.000	403.000	550.000	722.000	540.000	571.000	581.000	832.000	762.400	700.000	231.8
Ireland	2061.661	2186.842	2317.499	2327.724	2321.780	2108.248	2120.085	2105.006	2178.973	2229.546	108.1
Greece	3704.000	3640.000	3826.000	4258.000	4484.000	4723.900	5232.830	5665.000	5325.642	6215.269	167.8
Spain	20,072.000	14,791.000	10,954.000	11,557.000	12,237.000	12,374.000	12,184.000	13,539.000	13,644.000	13,902.579	69.3
France	24,013.607	25,423.321	28,801.248	31,412.412	33,817.190	36,609.292	40,716.538	45,640.314	58,793.004	68,115.438	283.6
Croatia	693.370	1096.494	1506.133	1952.042	2671.634	3081.243	3441.762	3480.516	4154.180	3811.788	549.7
Italy	76,013.000	82,105.000	78,355.000	78,505.000	79,452.908	79,220.551	84,288.213	84,484.094	87,007.196	85,115.660	111.9
Cyprus	466.000	475.000	471.000	492.000	504.345	553.550	578.767	556.275	559.040	231.619	49.7
Latvia	2695.000	3136.000	3674.000	3762.000	3902.011	3643.253	3376.039	3358.877	2763.421	2322.853	86.2
Lithuania	649.000	876.000	981.000	1341.000	1350.000	1554.000	1632.000	1617.000	1682.000	1750.000	269.6
Luxembourg	653.087	701.203	739.381	832.910	866.983	915.433	753.191	755.440	690.900	548.266	83.9
Hungary	3336.000	3323.000	3335.000	3708.000	4141.000	3916.000	3785.000	3748.000	3518.000	4085.000	122.4
Malta	59.000	73.000	77.000	80.000	77.000	69.834	73.381	60.398	54.547	70.677	119.8
Netherlands	12,777.000	13,094.000	13,733.059	13,377.410	13,508.671	13,696.226	14,913.297	17,428.542	17,926.824	17,617.699	137.9
Austria	8006.158	11,899.034	12,340.901	12,515.183	13,021.335	9504.878	8983.395	8787.162	6684.902	7420.478	92.7
Poland	7593.000	8685.000	9581.000	10,924.000	11,738.620	12,068.301	12,498.053	13,498.148	13,371.974	13,355.326	175.9
Portugal	2763.000	3432.000	3457.000	3364.000	3561.284	3453.040	3355.158	3464.321	3651.991	3418.598	123.7
Romania	822.000	810.000	767.000	739.000	755.471	864.936	794.294	772.084	970.035	970.035	118.0
Slovenia	1454.000	1290.000	1242.000	1264.000	1076.471	1018.173	929.681	1128.738	1044.268	1014.803	69.8
Slovakia	2300.000	4025.000	6223.000	6357.000	6384.000	6228.000	5984.000	5479.000	5472.000	5500.000	239.1
Finland	3725.000	4173.000	4321.000	4694.000	7147.000	7804.000	7851.000	7080.000	8138.000	7411.000	198.9
Sweden	6070.000	6422.000	7009.000	7265.000	7445.000	7359.000	7600.000	7780.000	8154.000	7509.000	123.7

Source: [101] Eurostat https://ec.europa.eu/eurostat/databrowser/view/nrg_cb_rw/default/table?lang=en accessed on 1 March 2023.

The biggest changes in biogas consumption have been observed in Bulgaria (2344%), Denmark (590.9%), Croatia (449%), and France (183%) in 2013–2022. Countries such as Spain, Cyprus, and Latvia. Luxembourg, Austria, and Slovenia decreased their inland consumption of biogas in 2013–2022. In the analyzed period, the EU increased the consumption of biogas by 29% and in the Euro area by 23%.

4. Discussion

Biogas production is developing sufficiently worldwide. Farms that have large resources of biomass and fertilizers have great potential for the utilization of waste, both manure and food waste, in the process of biogas production. Biogas (biomethane) causes slow GHG emissions compared to fossil fuels and biodiesel or advanced biofuels [27]. Biogas production helps to achieve environmental, economic, and social benefits. The production of biogas from agricultural manure and other sources of waste is a very good solution in a decarbonization era. This kind of energy is a substitute for conventional fuels [102].

Our research proved big changes in the development of biogas production worldwide and its use in electricity production. The EU increased production, and so did the US. The reason for this increase was the world policy aiming at the decarbonization of the economy and national policies. The EU is striving to be a carbon-neutral economy without carbon emissions by 2050.

The size of the global biogas market was USD 55.84 billion. The market is set to increase. Biogas is used for heating. Biogas is also used for electricity production worldwide. From the possible ways biogas utilization is increasing, its use in vehicles is an example.

The production of electricity from biogas changed from 2012 to 2021. This was the effect of policies introduced in the EU and at the national level. Countries that have large resources of biomass and animal manure are dominant in the production of biogas, including Germany, Italy, France, and Czechia.

The changes in the EU are particularly visible in Bulgaria, Croatia, Estonia, Greece, and Slovakia. These countries showed the largest changes in the coefficient of variation. All countries in the EU showed increases in biogas production.

However, our prognosis proved that not all countries are likely to have an increase in biogas production. Reasons for this are numerous, including the effects of plant production usage in biogas production, increasing competition for agricultural products, and huge and expensive outlays for technology and machinery for biogas production. Biogas production does not eliminate the problem of GHG production, but it can be useful in decreasing the production of these gases.

The production of biogas also has implications for agriculture and animal production. Production could decrease in the future for various reasons, such as problems with the environment, lower employment in agriculture, and strong worldwide competition for agricultural products. According to our prognosis, a decrease in biogas production will most likely occur in Finland, Lithuania, Malta, and Romania.

The COVID-19 pandemic did not have a tremendous impact on the energy market in the EU. Some countries were strong enough to overcome the problems and increased their production of electricity from biogas (Ireland, Greece, Spain, France, Croatia, Poland, Portugal, Romania, Finland, and Sweden) in 2021 compared to 2020.

The consumption of biogas is correlated with production. Most of the biogas is consumed domestically for electricity, heat, and transportation. The biggest producers of biogas, such as Germany, Italy, and France, are also the biggest consumers. They have the largest investments in biogas and have better infrastructure for biogas production, storage, and utilization.

The utilization of biogas requires investments in appliances for the storage and distribution of biogas, especially in the smaller countries of the EU. The storage of biogas is a bigger problem than production. Many small farms in countries such as Poland, Latvia, Lithuania, and Estonia do not have access to gas pipelines. That is why the development of the biogas market also depends on infrastructure development.

In the research, we demonstrate that the first **Hypothesis 1 (H1)**—*the production of electricity from biogas increased due to the stricter climate and environmental policies of the European Union (EU)*—was positively verified.

The EU introduced strict policies aimed at reducing carbon dioxide (CO_2) and other harmful greenhouse GHGs. In the meantime, the production of RESs increased, hitting the target of 20% of its share in total energy. The EU is a leader in the production of biogas for electricity. The biggest producers are Germany, Italy, France, and Czechia. The development of biogas depends not only on access to biomass and animal manure but also on technology.

Big companies have business in biogas production. Small farms, which are the majority in countries such as Romania, Estonia, Croatia, Cyprus, Poland, Latvia, Lithuania, and Estonia, are not strong enough to produce biogas. They require special funding and training. Countries that have the least production of biogas also have the lowest number of biogas plants. Such countries do not have a great opportunity to produce biogas because they have low animal production. Countries with many small farms and low biogas production could use special funds to install biogas production and be competitive.

5. Conclusions

Biogas is considered to be a promising source of renewable energy used in electricity and heating. This source of energy requires investment outlays, as establishing the technology is expensive. However, many farms worldwide have decided to develop biogas production from animal manure. Biogas production is based on the concepts of bioeconomy and sustainability. Animal production has global impacts on the environment and can produce 20 million tons of dry matter and 10 million tons of organic matter through manure. If not used in an environmentally friendly manner, this manure can create environmental issues [5].

The number of agricultural biogas plants in the EU is constantly growing, but the main barrier is formal and legal problems during the investment phase. The public administration is largely unaware of the potential of these new investments. High investment outlays and a high degree of complexity make such projects difficult to build and operate. This is very important in the case of small investments because unit costs increase dramatically, and such projects must be supported more extensively, which is proposed in the draft act on RESs. The lack of qualified design and construction staff results in difficulties in the implementation of such investments. In addition, there is often resistance from the local community, which is largely due to a lack of awareness. Despite so many obstacles, one can observe interest in the implementation of such projects. A particularly important issue is the feedstock for biogas production. Innovative methods should be used to eliminate indigestible parts such as metals, plastic, and other items before waste is pumped into the digester.

The development of biogas is a challenge for policymakers because the elaboration and realization of global bigas production requires strategies. New biogas technologies should increase the supply of biomethane and fulfill the demand for biogas [8].

The expansion of biogas in the EU requires policies that are congruent with agriculture and the energy sector, as well as focused on energy and climate goals. The composition of manure, feedstock, and other sources of biomass is critical for success [37]. The EU is a leader in biogas production [102]. Friendly policies that stimulate the biogas market are needed. Countries with the largest production and consumption of biogas have such policies. Countries with low production of biogas should rethink their policies and increase support to increase production [103].

The most important sources of biogas include crops, animal manure, municipal solid waste, and municipal wastewater. There is controversy about using crops as they can also be used for feeding people and animals. The production of biogas increases competition for agricultural crops and, subsequently, their prices. As the prices of crops increase, the production of biogas is less profitable. The other source of biogas is animal manure. Using manure does eliminate GHGs. These gases are exposed to the atmosphere in barns during intensive animal production. Municipal solid waste and municipal wastewater have a lower impact because their share in biogas production is low.

The production of biogas also has implications for agriculture and animal production. Production could decrease in the future for various reasons, such as problems with the environment, lower employment in agriculture, and strong worldwide competition for agricultural products. According to our prognosis, the decrease in biogas production will be most pronounced in Finland, Lithuania, Malta, and Romania.

The EU is the largest producer of biogas in the world. The global production of biogas is estimated at 59.3 billion m^3. Each year, this sector is increasing by about 9%. The reasons for this are numerous; for example, it is used as an energy source in markets, including electricity, heat, and transport. The second biggest producer of biogas is Asia, and the third is America.

The COVID-19 pandemic had a negative impact on electricity production from biogas. Only ten countries from the EU increased their production of electricity from biogas. This group consisted of Ireland, Greece, Spain, France, Croatia, Poland, Portugal, Romania, Finland, and Sweden. Seventeen countries decreased their production of electricity from biogas in the EU [104].

The future of the biogas market in the EU and all energy markets should be connected to production in Ukraine, which is one of the biggest producers of agricultural products in the world. Policymakers should consider Ukraine as an important producer of biomass, which can be used for biogas production for electricity, heat, and transportation. The potential for biogas production in Ukraine is large [105].

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Nomenclature

AD	Anaerobic digestion
ARiMA	Autoregressive Moving Average
BBI	Biobased Industries
BCM	Billion cubic meters
C	Carbon
CH_4	Methane
CO_2	Carbon dioxide
EC	European Commission
EU	European Union
GDP	Gross Domestic Product
GHG	Greenhouse gas
GW	Giga Watt
H_2	Hydrogen
MG	Megagram
M^3	Cubic meter
NOx	Nitrogen oxides
NH_4	Ammonium
O_2	Oxygen
PPP	Public–private partnership
RED	Renewable Energy Directive
RES	Renewable energy sources
T	Ton
USA	United States of America
USD	United States Dollar

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