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Biomethane in Poland—Current Status, Potential, Perspective and Development

Grzegorz Piechota [1,*] and Bartłomiej Igliński [2]

[1] GP CHEM, Laboratory of Biogas Research and Analysis, Legionów 40a/3, 87-100 Toruń, Poland
[2] Faculty of Chemistry, Nicolaus Copernicus University in Toruń, Gagarina 7, 87-100 Toruń, Poland; iglinski@umk.pl
* Correspondence: gp@gpchem.pl; Tel.: +48-665-05-05-44

Abstract: Every year the interest in biofuels, including biomethane, grows in Poland. Biomethane, obtained from biogas, is widely used in the Polish economy; the most important two applications are as gas injected into the gas grid and as automotive fuel. The aim of this work is to determine the potential for the development of the biomethane sector in Poland. The following article presents the technological stages of biomethane extraction and purification. The investment process for biogas/biomethane installation is presented in the form of a Gannt chart; this process is extremely long in Poland, with a duration of three years. In the coming months, the Polish Oil Mining and Gas Extraction will begin to invest in biomethane, which will be connected to the gas grid, while the Polish oil refiner and petrol retailer, Orlen, will invest in biomethane to be used as automotive fuel. This article includes a SWOT (Strengths, Weaknesses, Opportunities, Threats) and PEST (Political, Economic, Social, Technological) analysis of the biogas/biomethane sector in Poland. The main barriers to the development of the biogas/biomethane sector in Poland are high investment costs, long lead times and a strong conventional energy lobby. The most important advantages of biogas/biomethane technology in Poland include environmental aspects, high biomethane potential and well-developed agriculture. The development of biogas/biomethane technology in Poland will slowly reduce environmental pollution, reduce carbon dioxide emissions and allow for partial independence from the importing of natural gas.

Keywords: biomethane; biomethane in Poland; biogas; SWOT analysis; PEST analysis

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1. Introduction

An economy based on inexpensive and renewable energy (RE) sources, a clean environment and energy independence is a feature of responsible societies. One element of this vision is to replace traditional fossil fuels with biofuels. The most promising and already implemented second-generation biofuel is biomethane (BM), produced from biogas (BG) (BG contains up to 75% methane), after being purified from the admixture [1]. For this reason, BM as car fuel or injected into the gas grid is being closely observed by investors [2]. In addition, investment is encouraged by the EU authorities, which grant subsidies to projects promoting BG/BM as gas and car fuel; these subsidies are also carefully monitored by investors. These projects have another objective: to provoke public discussion and interest both among drivers and potential investors in the industry [3].

BG is a gas mixture resulting from anaerobic digestion. In the natural environment, anaerobic digestion takes place in soil, bottom sediments of water bodies, wetlands, marshes, peat swamps, sea beds and oceans, slurry and the digestive tract of ruminants [4].

BG consists mainly of methane and carbon dioxide (CD) and small amounts of nitrogen, hydrogen sulfide and hydrogen [5].

The composition of BG depends mainly on the substrates used and the applied technological process. Typical contents of individual gases in BG are presented in Table 1 [6].

Table 1. Biogas (BG) composition [6].

BG Component	Content (%)
Methane	50–75
Carbon Dioxide	25–45
Hydrogen sulfide	20–20,000 ppm
Hydrogen	<1
Carbon monoxide	0–2
Nitrogen	<2
Oxygen	<2
Other components	Trace amounts

The calorific value of pure methane is 35.7 MJ/m^3, while the calorific value of BG usually ranges from 16 to 23 MJ/m^3 and is strictly dependent on the proportions of the gases it contains. Energy obtained from 1 m^3 of purified BG corresponds to 9.4 kWh of electricity and is equivalent to 0.93 m^3 of natural gas (NG), 1 dm^3 of diesel or 1.25 kg of coal [6].

The possibilities for use of BG/BM include the following:

- for electricity production,
- for heat production,
- for electricity and heat production (co-generation),
- to be injected into the gas grid,
- as fuel for traction engines or vehicles, and
- for technological processes, such as methanol production [7].

BM is applied as transport fuel mainly in Europe and the USA, which are the largest producers and users of BM for transport [8]. Production in the US has increased since 2015, when BM was first included in the Renewable Fuel Standard (RFS) category of advanced cellulose biofuels and in state initiatives such as the California Standard as a low carbon fuel. The consumption of BM in the US under the RFS increased by 20% in 2019 to around 30 petajoules [8].

The BM market is also developing in Western Europe. The number of BM installations has increased in recent years from 187 in 2011 to 540 installations in 2017. The greatest number of such systems are located in Germany (194) and the UK (85) (Figure 1). However, in terms of the number of installations per million inhabitants, Sweden, Luxembourg and Iceland are at the top the list [9]. According to IRENA (International Renewable Energy Agency) estimates [10], the total capacity of BM installations is more than 50 petajoules per year, which is equivalent to the energy obtained from about 1.3 billion liters of diesel oil.

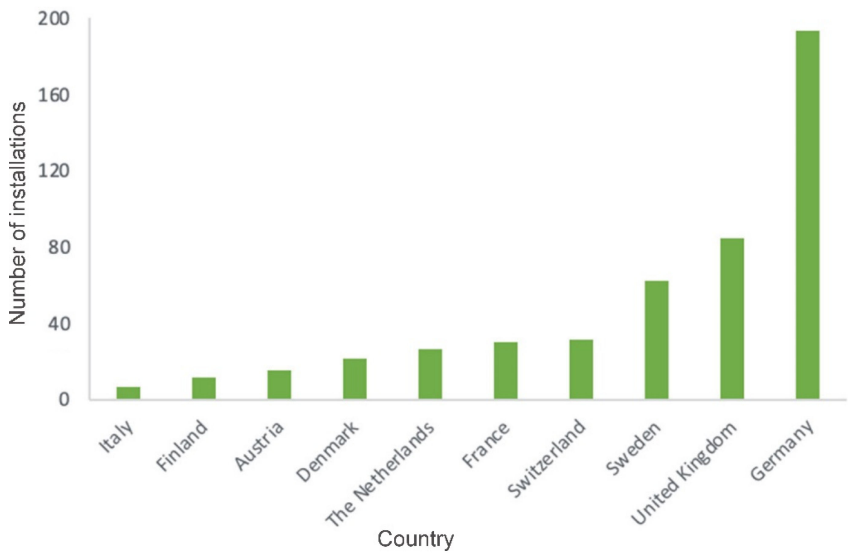

Figure 1. Production of biomethane (BM) in Europe; own elaboration based on [9].

Since March 2020, Toronto, Canada's largest producer of municipal waste, has been serviced by 170 BM-powered refuse collectors. Vancouver uses BM not only in local transport but also in the city's landfill gas grid. California is looking for solutions for cattle producing BM. The UK Government is looking closely at the potential for the use of BM in connection with the halting of crack-bearing shale gas production. A total of £100 million was allocated to the construction of a commercial BG plant for transport. In Genoa, the reconstruction of a waste disposal plant will soon allow for the production of BM for low-carbon transport; as a result, BM will power 1000 vehicles per year. A number of sister BM projects are also being carried out in Italy [10].

The aim of the article is to determine the potential for the development of the BM sector in Poland. For this purpose, BM technology is briefly described, the technical potential of BM from waste and targeted crops in Poland is calculated, the possibilities for the use of BM in Poland are presented, the step-by-step design requirements are described, the environmental aspects of BM use are presented, and a SWOT and PEST analysis of the BM sector in Poland is presented. This is the first publication that broadly describes the possibilities of BM implementation in the Polish economy. BM technology is also an opportunity for Polish agriculture, which will provide substrates for BM installation.

2. Development and Purification of BM

The process of BG formation can be divided into four closely related stages; stage 5 is the acquisition of BM from BG (Figure 2) [6,11].

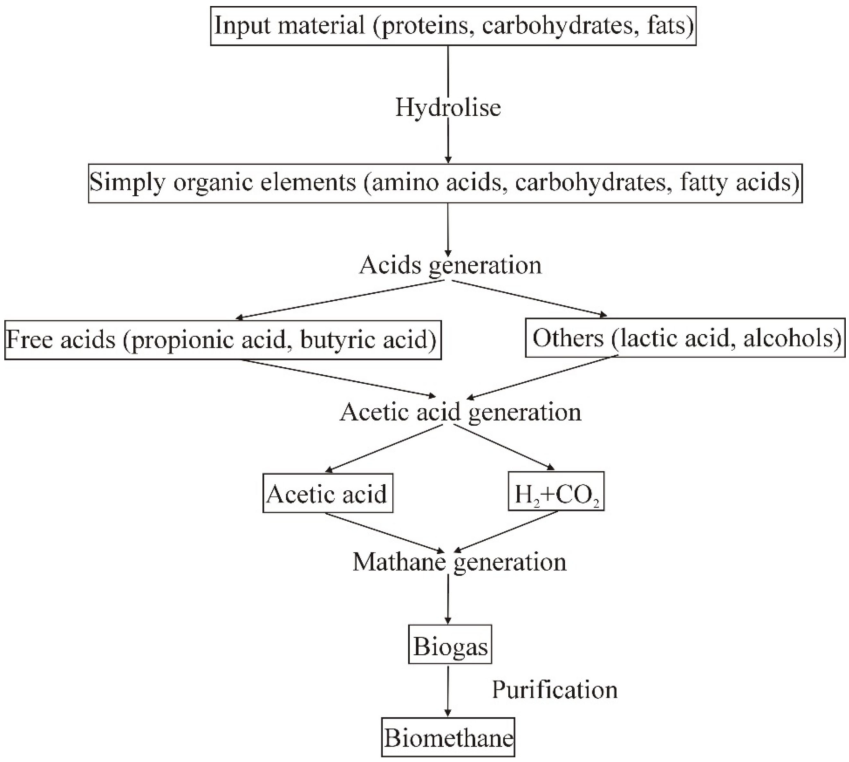

Figure 2. Scheme of the fermentation process for BM production; own elaboration based on [6,11].

The first stage of fermentation, called hydrolysis, breaks down the complex compounds of the starting materials (proteins, carbohydrates, fats) into simple organic compounds: amino acids, sugars, and fatty acids [12]. In the next stage, called acidogenesis, the intermediate products formed are broken down by the acidifying bacteria into fatty acids (acetic acid, propionic acid, and butyric acid) [13]. The next phase, called acetogenesis, produces acetic acid, hydrogen and CD. In the final stage of the process, methane is produced [14].

2.1. Purification of BG

A three-stage scale of BG purification can be assumed, depending on the type and quantity of unwanted gases and substances removed from BG as well as its applicability. Raw, unpurified BG is used only for cooking and lighting, mainly in developing countries, especially China and India. This gas comes from small domestic installations where the substrate is a mixture of residues from agricultural and animal production and domestic waste [15].

The first stage of BG purification involves the removal mainly of steam and hydrogen sulfide up to less than 1000 ppmv, which is sufficient in BG applications for the production of heat and steam in boilers, combustion in cogeneration engines, micro turbines and power generation in solid oxide fuel cells (SOFCs) and molten carbonated fuel cells (MCFC) [16].

The second stage of BG purification, which is the basic technology of BG purification, includes the removal of CD [17].

The third stage of BG purification involves the removal of various components and pollutants to levels required by standards or arising from the need to use BM as a fuel for vehicles in compressed or liquefied form, for the injection of NG into the grid or for the production of chemicals [18].

2.1.1. Water Content and Trimethylsiloxane Removal of BG

High saturation of BG with water vapor (the relative humidity of BG in the fermenter is 100%) and its adverse effects on transmission systems and plant components make it necessary to dehydrate BG. This process is carried out during the cooling of the gas, where part of the water vapor and trimethylsilanol (coming from water and siloxanes contained in biogas) separates in the form of condensate [19]. The condensate also contains gases and aerosols dissolved in water, which are undesirable components of BG.

2.1.2. Desulphurization of BG

Hydrogen sulfide is present in BG, but its concentration is very diverse and depends on the type of fermented organic matter. The necessity for its removal is mainly due to the corrosive properties manifested during compression, storage and use of BG, especially in internal combustion engines. Hydrogen sulfide is a poison for many catalysts, and when burned into sulfur dioxide, it is dangerous to the environment [6].

Biological desulphurization of BG may take place in a fermenter, provided that oxygen and sulfuric bacteria are present. However, carrying out the desulphurization process in the fermentation tank carries the risk of unintentional oxidation of methane and corrosion of the fermenter's construction [6].

In order to increase the control of the BG desulphurization process and improve its efficiency, the treatment may be carried out outside the fermenter in separate tanks equipped with a biological desulphurization set. The desulphurization column (Figure 3) can be made of steel or polymer [6].

Chemical desulphurization of BG in the fermenter is carried out by adding a sulfur-binding chemical to the substrate. The substances used for biogas treatment include iron salts and meadow ore. Chemical desulphurization in the fermenter is used in systems based on wet fermentation [6].

As in the case of biological desulphurization, the purification of BG from hydrogen sulfide may also take place outside the fermenter, using soda lye. The process is possible in systems based on both wet and dry fermentation. Chemical desulphurization of BG outside the ferment chamber ensures a very high degree of gas purification, even above 95% [6].

Figure 3. BG desulfurizer in the biogas plant in Liszkowo (photo B. Igliński).

2.1.3. Removal of CD

The most demanding process in terms of the applied technology and the most costly process to purify BG is the separation of CD from methane [20].

Physical absorption on active carbon is one of the most popular techniques of BG treatment due to the simplicity of plant construction, ease of use and operation and relatively low investment costs [21].

It is estimated that this technology is used in about 40% of BG treatment plants. This method consists of dissolving CD in water or other solvents; it is then released in a desorption column and is removed from the column after separation from water (or other solvents) with air injected into the column. Separation of methane from CD is due to the difference in solubility of CD and methane; the solubility of CD in water at 25 °C is about 26 times higher than of methane [22].

The chemical absorption process (based on alcanoamines) consists of catching the CD from BG by an amine solution in an absorption column. Before introducing BG into the column, the gas is pre-cleaned of impurities, especially hydrogen sulfide [23].

For example, in aqueous solutions, alkanolamines dissociate to hydroxyl and amino base ions. There are reactions to the CD (1) and (2) [24]:

$$CO_2 + 2RNH_2 + H_2O \rightarrow (RNH_3)_2CO_3 \quad (1)$$

$$(RNH_3)_2CO_3 + CO_2 + H_2O \rightarrow 2RNH_3HCO_3 \quad (2)$$

Another chemical method of CD disposal is the reaction of BG with waste potassium hydroxide [25]:

$$2KOH + CO_2 \rightarrow K_2CO_3 + H_2O \quad (3)$$

The solution also undergoes a further bonding reaction CD:

$$K_2CO_3 + CO_2 + H_2O \rightarrow 2KHCO_3 \quad (4)$$

It is also possible to return potassium hydroxide to the solution, and for this purpose a suspension of calcium hydroxide is introduced into the reaction mixture (whitewash):

$$Ca(OH)_2 + K_2CO_3 \rightarrow CaCO_3 + 2KOH \quad (5)$$

Pressure adsorption is the separation of CD from methane by adsorption of CD on a solid material called a molecular sieve, which can be activated carbon, silica gel, alumina or silicate [26]. BG is fed into a column filled with adsorbent under a pressure of 0.5–1.0 MPa. During this time, CD adsorption takes place, and methane is released from the column during expansion. The gas bound to the sieve is released in a process called molecular sieve regeneration and can be expanded to atmospheric pressure (PSA—pressure swing adsorption) or partial vacuum with an additional vacuum pump (VSA—vacuum swing adsorption). Regeneration of the sieve can also be performed by means of temperature change (TSA—temperature swing adsorption) [27].

Membrane separation consists of retaining large particles of chemical compounds and passing smaller particles through a physical obstacle, which is a module made of specially shaped material that is most often a tubular polyimide fiber system. BG under increased pressure up 5.5 MPa is pumped through the membrane. If the two-component model BG, consisting of methane and CD, is considered, large particles of methane do not permeate through the membrane, and as retentate (gas retained by the membrane), they are separated from small CD particles, which, as a permeate (gas penetrating through the membrane), flow to further technological processes.

The cryogenic separation method consists in separating CD from methane as a result of temperature reduction BG. The boiling point of CD is −78 °C and methane is −161 °C. In the few existing installations for biogas treatment with this method, the process is carried out in a cycle consisting of the following phases:

- cooling BG to a temperature of −25 °C and removal of the resulting liquid and solid fragments,
- compressing BG to a pressure of 1.8–2.5 MPa in order to prevent the conversion of CD to solid phase during cooling while cooling BG,
- cooling BG to a temperature around −55 °C in order to liquidate CD, and
- removing CD in gas or liquid phase [28].

The BG biological treatment method is one of the least-researched methods to improve the physical properties of BG. The results obtained prove the high potential of this method, owing to the simplicity of the technical installation, low cost of the equipment and lack of harmful byproducts. Three basic methods of biological treatment can be distinguished for BG: chemosynthetic conversion, photosynthetic conversion and local desorption during fermentation [29].

3. BM in Poland—Technical Potential

In Poland, agricultural biogas plants are usually operated in the vicinity of large animal farms, using as substrate troublesome waste in the form of slurry and manure [30]. Collection makes a much better alternative to the common disposal method for this waste (in Poland slurry and manure is poured directly onto the cultivated fields) [31]. As a result of the process of gasification, the process of waste removal takes place in order to prevent the risk of groundwater contamination. Fermentation residues are used as fertilizer (Figure 4) [32].

In Poland, as in the whole of Europe, mainly mesophilic fermentation is carried out (32–42 °C); only in the agricultural biogas plant in Mielno is biogas obtained through thermophilic fermentation (50–57 °C) [32,33].

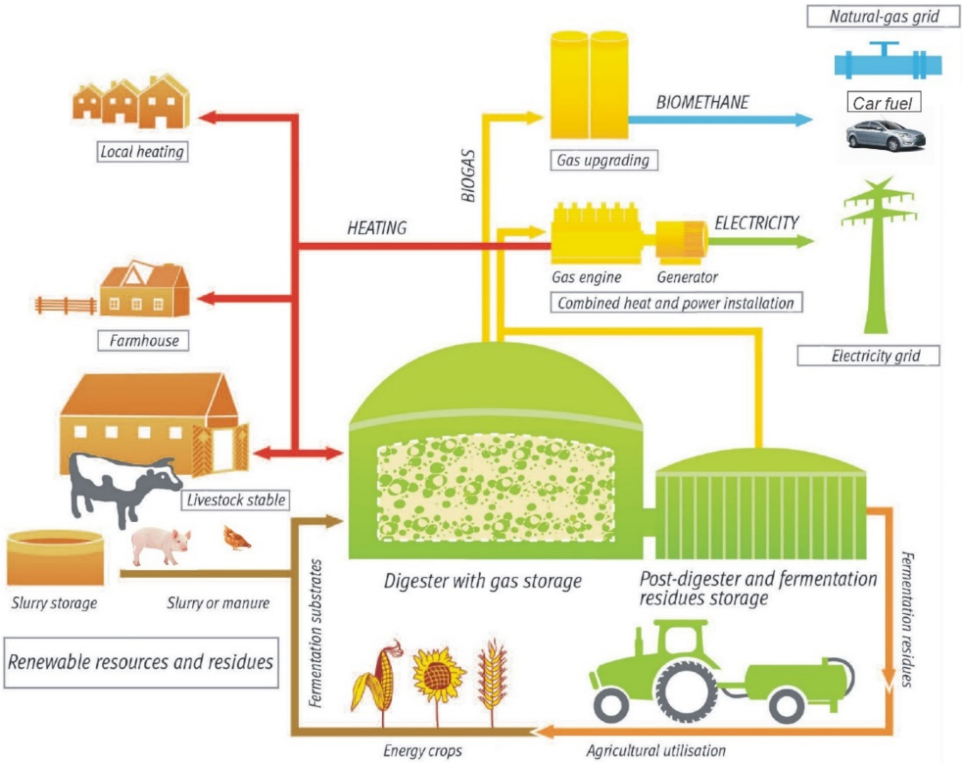

Figure 4. Economic use of BG obtained from biowaste and targeted crops; own elaboration based on [34].

In Poland, in accordance with generally accepted principles, organic waste is used first, and as targeted crops are used second (Figure 5) [35]. In total, in 2019, 36 types of substrate were applied in Polish BG plants [32].

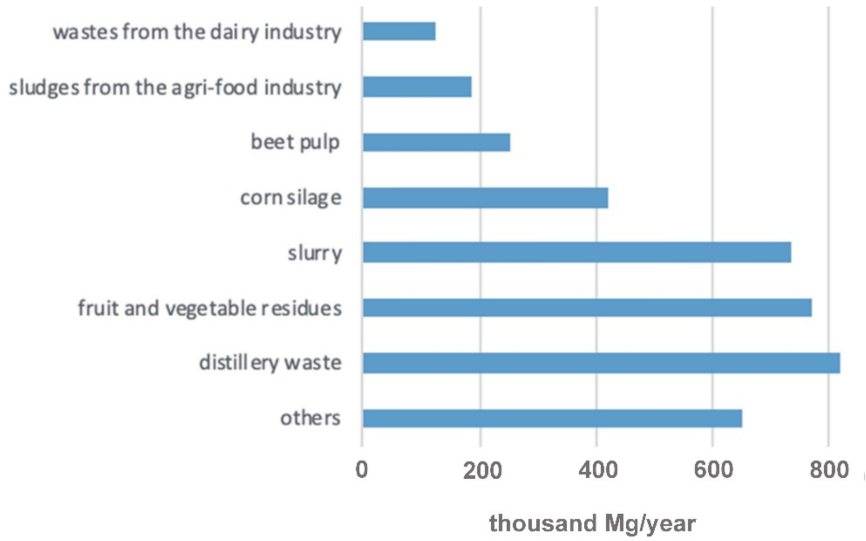

Figure 5. Raw materials applied in agricultural BG plants in Poland (Mg); own elaboration based on [32].

The BM potential was calculated on the basis of data on the availability of agricultural waste, municipal waste, sewage sludge as well as targeted maize silage crops [32,36].

3.1. BM from Animal Slurry and Poultry Manure

In order to estimate the achievable annual amount of BM from animal manure or poultry manure [37], the following assumptions were made:

- livestock unit conversion factors to large livestock units DJP (500 kg) are: for cattle 0.8, for swine 0.2, for poultry 0.004 [38],
- the average weight of livestock manure or poultry manure produced by the livestock unit is 16.4 Mg/year for cattle, 15.9 Mg/year for swine and 9.8 Mg/year for poultry [38],
- BG yield obtained from cattle slurry is 50 m^3/Mg, from swine slurry 55 m^3/Mg and from poultry manure 140 m^3/Mg [38],
- BG obtained from animal slurry or poultry manure contains 60% BM [38], and
- the technical potential of BM is 25% of the theoretical potential.

Equation (6) shows the annual volume of BM that can be extracted from animal manure or poultry manure:

$$V_a = 0.25 \times 0.6 \times (0.8 \times N_c \times M_c \times Y_c + 0.2 \times N_s \times M_s \times Y_s + 0.004 \times N_p \times M_p \times Y_p) \quad (6)$$

where

V_a—volume of BM obtained from animal slurry or poultry manure (mln m^3/year),

N_c, N_s, N_p—number of cattle, swine and poultry, respectively (mln of pieces),

M_c, M_s, M_p—annual mass of animal manure or avian manure from the large conversion unit of cattle (16.4 Mg/year), swine (15.9 Mg/year) and poultry (9.8 Mg/year), respectively, and

Y_c, Y_s, Y_p—yield of BG obtained from cattle manure (50 m^3/Mg), swine manure (55 m^3/Mg) and poultry manure (140 m^3/Mg), respectively [38].

Figure 6 shows the amount of BM that can be obtained annually from animal slurry or poultry manure in Poland.

Figure 6. Volume of BM obtained from animal slurry or poultry manure in Poland (mln m^3/year).

The total volume of BM that can be obtained from animal slurry or poultry manure in Poland is 1071 mln m^3. Most of the BM can be obtained in the Wielkopolskie Voivodship (238 mln m^3), in the Mazowieckie Voivodeship (178 mln m^3), in Podlaskie Voivodship (120 mln m^3), in the Kujawsko-Pomorskie Voivodeship (93 mln m^3) and in the Łódzkie Voivodeship (89 mln m^3). There are the largest number of large livestock farms in these voivodships; therefore, the construction of BM plants in these areas is most justified.

It is worth noting that the theoretical potential is four times greater and amounts to as much as 4.284 mln m^3. It is therefore important to locate BM plants close to animal farms in order to make the most of the theoretical potential.

3.2. BM Obtained from Agri-Food Industry Waste

Significant amounts of waste generated in Poland are Group 02 waste, i.e., waste from the agri-food industry [37].

In order to estimate the achievable volume of BM from waste from the agri-food industry, the following assumptions were made:

- 50% of waste from the agri-food industry will undergo methane fermentation,
- BG yield obtained from agri-food industry waste is 150 m^3/Mg, and
- BG obtained from agri-food industry waste contains 55% of BM [38].

Equation (7) shows the annual volume of BM that can be obtained from waste from the agri-food industry in Poland:

$$V_b = 0.25 \times 0.55 \times M_b \times Y_b \tag{7}$$

where

V_b—volume of BM from biodegradable waste obtained from the agri-food industry (mln m^3/year),

M_b—annual weight of biodegradable waste from the agri-food industry (mln Mg/year), and

Y_b—BG yield obtained from waste from the agri-food industry (150 m^3/Mg).

Figure 7 shows the volume of BM that can be obtained annually from biodegradable waste from the agri-food industry in Poland.

Figure 7. The volume of BM that can be obtained from biodegradable waste from the agri-food industry in Poland (mln m^3/year).

Figure 7 shows the total volume of BM that can be obtained in a year from agri-food waste in Poland is 176 mln m^3. The largest amount of BM can be obtained in voivodships with highly developed agriculture, i.e., Wielkopolskie (41 mln m^3) and Mazowieckie Voivodships (27 mln m^3).

3.3. BM Obtained from Maize Grown in Idle Land and Waste Land

Poland has a significant area of idle land and waste land, some of which can be used for the development and cultivation of maize silage for BM [39].

In order to estimate the achievable annual volume of BM from maize silage cultivated in idle land and waste land, the following assumptions were made:

- 50% of idle land and 25% of waste land will be used to plant maize,
- BG yield obtained from maize silage is 180 m^3/Mg [38], and
- BG from maize silage contains 60% of methane [38].

Equation (8) shows the volume of BM that can be obtained from maize silage cultivated in idle land and waste land in Poland:

$$V_m = 0.6 \times (0.5 \cdot A_m + 0.25 \times A_m) \times Y_m \quad (8)$$

where

V_m—volume of BM obtained from maize silage cultivated in idle land and waste land (mln m^3/year),

A_m, A_m—area of idle land and waste land (ha), and

Y_m—BM yield obtained from maize silage (180 m^3/Mg),

Figure 8 shows the volume of BM that can be obtained annually from maize silage cultivated in idle land and waste land in Poland.

Figure 8. Volume of BM that can be obtained annually from maize silage cultivated in idle land and waste land in Poland (mln m^3/year).

Total volume of BM that can be obtained annually from maize silage cultivated in idle land and waste land in Poland is 10.7 mln m^3. Most of the BM from maize silage can be obtained in the Mazowieckie Voivodeship (1.7 mln m^3), in the Lubelskie Voivedeship (1.0 mln m^3), and in the Podkarpackie Voivodeship (0.9 mln m^3).

3.4. BM Obtained from Maize Cultivated on Agricultural Land

It was assumed that 5% of the agricultural land in Poland would be planted with maize for BM. The following assumptions were made:

- 5% of the agricultural land will be used to plant maize,
- BG yield obtained from maize silage is 180 m^3/Mg, and
- BG obtained from maize silage contains 60% of BM [38].

Equation (9) shows the annual volume of BM that can be obtained from maize cultivated on 5% of agricultural land:

$$V_{ma} = 0.05 \times 0.6 \times A_{ma} \times Y_m \quad (9)$$

where

V_{ma}—volume of BM from maize silage cultivated in idle land and waste land (mln m^3/year),

A_{ma}—area of agricultural land (ha), and

Y_m—BM yield obtained from maize silage (180 m^3/Mg).

Figure 9 shows the volume of BM that can be obtained annually from maize grown on agricultural land in Poland.

Figure 9. Volume of BM that can be obtained from maize grown on agricultural land in Poland (mln m^3/year).

The total volume of BM that can be obtained from maize silage is 74 mln m^3. Most of the biomethane from maize silage can be obtained in the Mazowieckie Voivodeship (9 mln m^3) and in the Wielkopolskie Voivodeship (8 mln m^3).

3.5. BM Obtained from Municipal Waste

Municipal waste has historically been (and still is) destined for landfill sites in Poland. The rubbish collected there slowly decomposes, emitting, among others, explosive methane. To prevent frequent fires in landfills in Poland, since 2003 [40] there has been an obligation to dispose of the created BG. The simplest solution is to burn BG in a biogas flare. A considerably better solution is to obtain BM from municipal waste.

Figure 10 presents the technological scheme of using BG from municipal waste. BG is extracted from wells using mostly little negative pressure. Water vapor is removed in the gravity dehydrator. Some of the BG plants in Poland also are in possession of a gas tank with a regulatory function, which allows for storage of some BG stock. BG can be combusted on site to produce electricity and heat in co-generation or cleaned to become BM.

According to the Central Statistical Office [37], the annual mass of municipal waste generated in households and public facilities in Poland is about 12 million Mg/year, of which more than half is biodegradable. Due to the large dispersion of bio-waste sources as well as the (still) low degree of waste segregation in Poland, the technical potential of BM from municipal waste can be estimated at 25% of the theoretical potential.

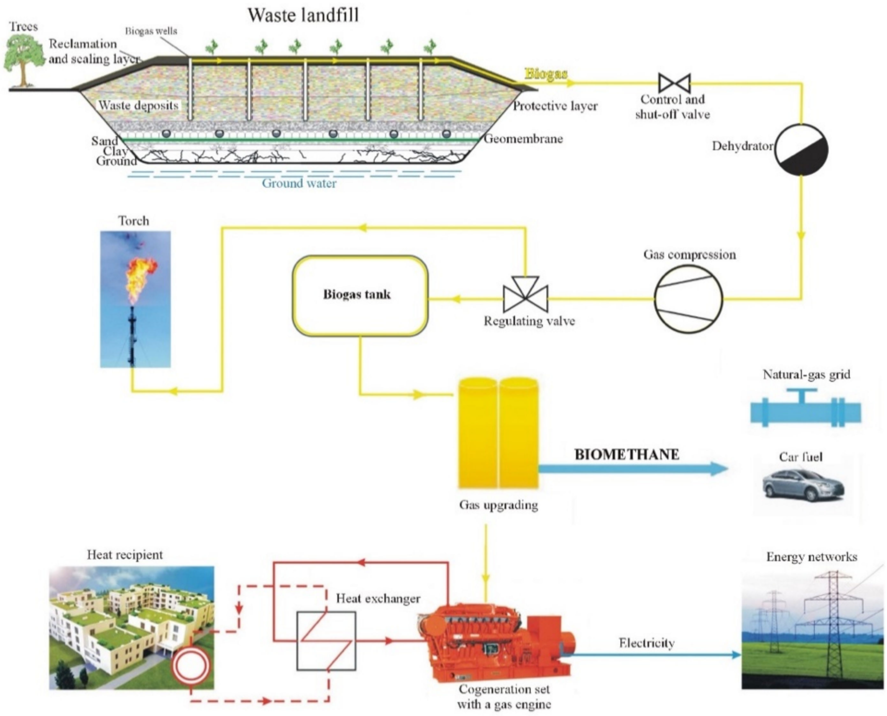

Figure 10. Economic use of BG obtained from municipal waste.

The following assumptions were made to calculate the volume of BM from municipal waste:

- BG yield obtained from municipal waste is 100 m^3/Mg [38],
- BG contains 55% of BM [38], and
- the technical potential of BG is 25% of the theoretical potential.

Equation (10) shows the annual volume of BM that can be extracted from the biodegradable fraction of municipal waste:

$$V_w = 0.25 \times 0.55 \times N_b \times U_b \quad (10)$$

where

V_w—volume of BM from the biodegradable fraction of municipal waste (mln m^3/year),
N_w—annual weight of the biodegradable fraction of municipal waste (mln Mg/year), and
U_w—BG yield obtained from the biodegradable fraction of municipal waste (100 m^3/Mg) [38].

Figure 11 shows the volume of BM that can be obtained annually for municipal waste in Poland.

In Poland it is possible to obtain a total of 171.7 mln m^3 BM annually. The highest number appears in the highly populated voivodships, i.e., the Mazowieckie Voivodship (24.9 mln m^3) and Ślaskie Voivodship (22.9 mln m^3).

3.6. BM Obtained from Sewage Sludge

Medium- and large-sized municipal sewage treatment plants generate significant amounts of sludge in primary and secondary settling tanks. The amount of sludge released after sewage treatment ranges from 0.5% to 2% of the volume of sewage. Sewage sludge can be used for agricultural purposes, burned after drying or anaerobically digested. Electricity and heat from the BG created can be used on site, increasing the profitability of the plant, or can be sold. BG can also be cleaned to BM quality, fed into the gas grid or used as vehicle fuel (Figure 12) [6].

Figure 11. Volume of BM that can be obtained for municipal waste in Poland (mln m^3/year).

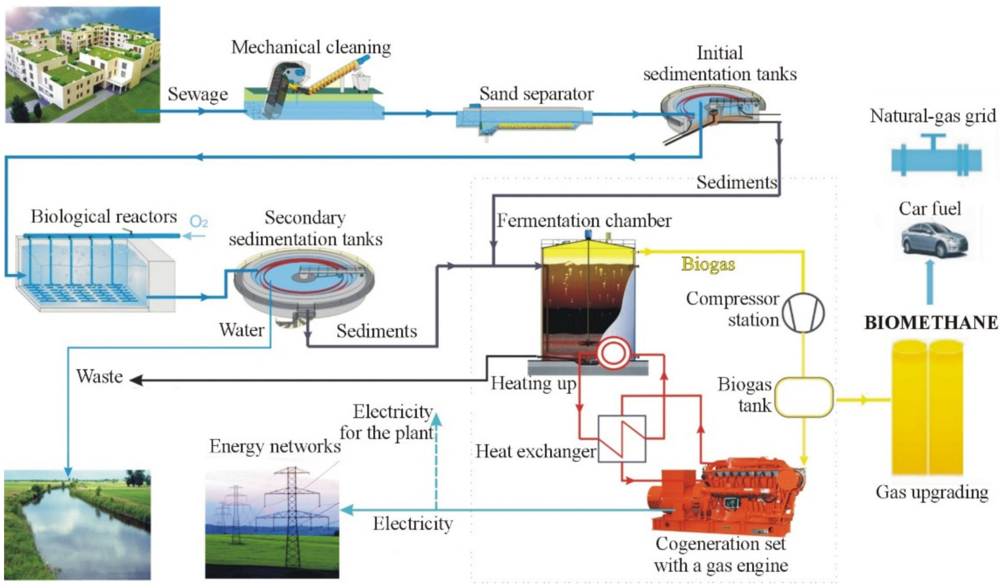

Figure 12. Economic use of BG obtained from sewage sludge.

In order to calculate the volume of BM that can be obtained from (municipal) sewage sludge, the following assumptions were made:

- 50% of the municipal waste water will be used to obtain BM,
- the volume of sewage sludge is 1% of the incoming municipal waste water, and
- the BG yield obtained from municipal waste is 15 m^3/m^3 = 15 (BG obtained from sewage sludge contains 60% of BM [38].

Equation (11) shows the annual volume of BM that can be obtained from sewage sludge:

$$V_s = 0.5\ \times \cdot 0.01\ \times \cdot 0.6 \times \cdot V_s \cdot \times\ Y_s \tag{11}$$

where:

V_s—volume of BM obtained from sewage sludge (mln m^3),

V_s—the annual volume of municipal waste water entering the treatment plant (mln m^3/year), and

Y_s—BG yield obtained from sewage sludge (15 m^3/m^3 = 15) [38].

Figure 13 presents the volume of BM that can be obtained annually from sewage sludge in Poland.

Figure 13. Volume of BM that can be obtained from sewage sludge in Poland (mln m^3/year).

In the case of Poland, it is possible to obtain 92.8 mln m^3 BM. The highest number is in highly populated voivodships, i.e., the Śląskie Voivodship (14.2 mln m^3), the Małopolskie Voivodship (11.1 mln m^3), the Mazowieckie Voivodship (11.0 mln m^3) and the Wielkopolskie Voivodship (11.0 mln m^3).

4. BM in Poland—Development Opportunities

BM technology is in the spotlight of investors and politicians in Poland. Both private investors and representatives of large corporations speak about its production projects. They think of BM being pumped into the gas grid, used as transport fuel and used "to green" the gas used in industry. A significant breakthrough is to occur in 2021, when the first installation applying BM in Poland is to be constructed. Importantly, this renewable fuel would support meeting the obligation to use RE in transport, which appears to be a huge problem in Poland [41].

The main direction for BM is the transport sector, because apart from BM in Europe and in Poland, refineries have no other ideas for large quantities of biofuels and biocomponents of the so-called second generation (advanced biofuels). Thus, in this context, BM is agreed to be the only option, even in Poland, to achieve the RE objectives for 2023–2030, when it should be at the level of 4% in the fuel market [41].

The Polish potential of BG may soon be realized. A BM-treated system could replace some NG in the grids. The needed breakthrough may be the recent declarations by the Polish Oil Refiner and Petrol Retailer, PKN Orlen (Płock), and Polish Oil Mining and Gas Extraction (PGNiG) (Warszawa) of future investments in BG plants. The first BM production installations should be connected to the network in coming months [41].

PGNiG wants to convince entrepreneurs to invest in BM. The company has estimated that it could take about 4 billion m^3 BM. Such a plan would require the construction of approximately 2000 BM plants within 10 years and an expenditure of approximately Polish złoty (PLN) 70 bn. PGNiG has declared that it is prepared to cooperate with BM plants and to connect such installations to the gas distribution network. Quality standards have been developed for BMs that can be fed into the distribution network, for connection conditions and for a model gas distribution agreement. PGNiG is currently focusing on developing a model of business cooperation between PGNiG and entrepreneurs interested in BM production. It is also known that the government administration is working intensively on the adaptation of regulatory provisions. PGNiG assumes that the first BM production facilities will be connected to the network in the coming months [41].

PKN Orlen recently announced plans to invest in BM. The company from the Orlen South Group signed a letter of intent concerning the construction of 20 installations, which will enable the development of substrates from farms and their conversion into electricity and BM. Investments would be carried out in the largest agricultural holdings of the National Agricultural Support. The main investor in the project would be Orlen South. In Trzebinia, a hydrogen fuel production plant is being constructed, for which the raw material may be BM itself. Electricity production and BM from BG is primarily a business-friendly solution. It will also facilitate achievement of the National Index Target and respond to the needs of Europe today [41].

Currently, the provisions of the RE Act provide for high support for co-generation of BG plants. BG may also be introduced into the gas distribution grid, but this provision is deadlocked because there is no public assistance for this project. There is a lack of dedicated auction baskets and a lack of implementing rules to convert BG into electricity equivalents. It is important to enable the installations producing BM and feeding it into the gas grid to participate in the FiT and FiP systems. The authors of the "White Paper on Biomethane" also propose an extension of the Polish system of guarantees of origin of energy from renewable sources to include guarantees issued to BM producers [41].

4.1. BM in the Polish Gas Grid

The commissioning of BM to the NG grid could create further opportunities for its use in Poland in the future. BM would not be used on site in combined heat and power plants to combine power and heat and would be fed directly into the existing NG grid [42].

However, the existing legal problems and technical and economic barriers still need to be tackled [43]. If BM was to be fed into the grid, nothing would fundamentally change in the configuration of the BG installation, except the elimination of the block heat and power plant. When removing the co-generation plants, alternatives to the production of electricity and heat necessary for the individual processes should be taken into account. The electricity needed could come from the power grid, and the digester could be heated with a heating boiler. In order to be able to inject BM into the NG grid, it is necessary to ensure the quality of natural gas. To obtain the required parameters, BG needs to be purified of hydrogen sulfide and then dried. In addition, methane and CD must be separated. In addition to proper treatment, the pressure of the gas to be fed into the NG network must be increased to the pressure in the grid. Moreover, the pipes must ensure that the BG is transported to the correct point of entry into the network [44].

The distribution of BG may be carried out by pumping it into the national gas grid after it has been purified and upgraded to BM [45]. The regulations in force allow for pumping into the industrial network BM that does not contain substances harmful to the gas infrastructure, with a composition corresponding to that of the transmitted NG.

According to the Polish norm no. PN-C-04750 [46], NG is divided into two groups in Poland: NG high-methane E and NC nitrided L. There are four subgroups among nitrogenous NCs: Lm, Ln, Ls and Lw.

Requirements concerning the quality of NG, transmitted under high pressure through pipelines and transferred from the transmission grid to distribution networks or to industrial customers in Poland, as specified in the Polish standard, are presented in Table 2 [46].

Table 2. Parameters of natural gas (NG) in the gas grid [46].

Specification [Unit]	Kind of NG	
	High-Methane E	High-Nitrogen Lw
Combustion heat (MJ/m^3)	38–41.6	30–33.5
Scope of the Wobbe Index (MJ/m^3)	45–56.9	37.5–45
Hydrogen sulfide content (%mol/mol)	≤7.0	
Oxygen content (%mol/mol)	≤0.2	
CD content (%mol/mol)	≤3.0	
Mercury vapor content (μg/m^3)	≤30.0	
Water dew point temperature for 5.5 MPa from 1 April to 30 September	≤+3.7	
Water dew point temperature for 5.5 MPa from 1 October to 31 March	≤−5.0	
Carbohydrate dew point temperature (°C)	0	
Dust content with particle size greater than 5 μm (mg/m^3)	≤1.0	
Total sulfur content (mg/m^3)	≤40.0	
Range of temperature variation of gaseous fuel fed the industrial network (°C)	0–50	

The Regulation of the Minister of Economy on technical conditions to be met by gas networks distinguishes the following types of gas pipelines:

- low pressure: up to and including 10 kPa,
- medium pressure: above 10 kPa, up to and including 0.5 MPa,
- increased medium pressure: above 0.5 MPa, up to and including 1.6 MPa, and
- high pressure: above 1.6 MPa, up to and including 10 MPa.

The selection of the gas grid for BM pumping is determined by the amount of methane it contains. The pumping of BM into low-pressure grids is the most practical solution, but gas consumption during the summer months must be higher than BM production [47].

Figure 14 presents the gas grid in Poland [48]. NG is used mainly in the west and center of the country; there are still many places in Poland without a gas grid. The construction of BM plants could provide gas to communities far from the gas grid [49].

Figure 14. Gas grid in Poland; own elaboration based on [48].

4.2. BM to Power Polish Vehicles

BM as a motor fuel can power many types of motor vehicles in Poland, including passenger cars, trucks and buses.

There are only 24 stations where compressed BM could be refueled in Poland. Another restriction is that CNG (compressed natural gas)/BM storage is more complicated than that for LPG (liquefied petroleum gas). It is stored in the volatile phase, under very high pressure (200 bar), and has to be refueled into heavy and expensive tanks [49]. This also means that vehicles using BM can travel no more than 400 km on a single tank. The solution to this problem is to use BM in liquefied form [50,51].

Every month, LPG can be refueled at petrol stations, and it will be possible to fill up with liquid BM. As of 30 November 2020, there were 4099 such stations in Poland, with most in the center [51]. This is already a very large number; thus LPG can be easily refueled in Poland.

Figure 15 presents the possibilities of using BM as biofuel in vehicles in Poland.

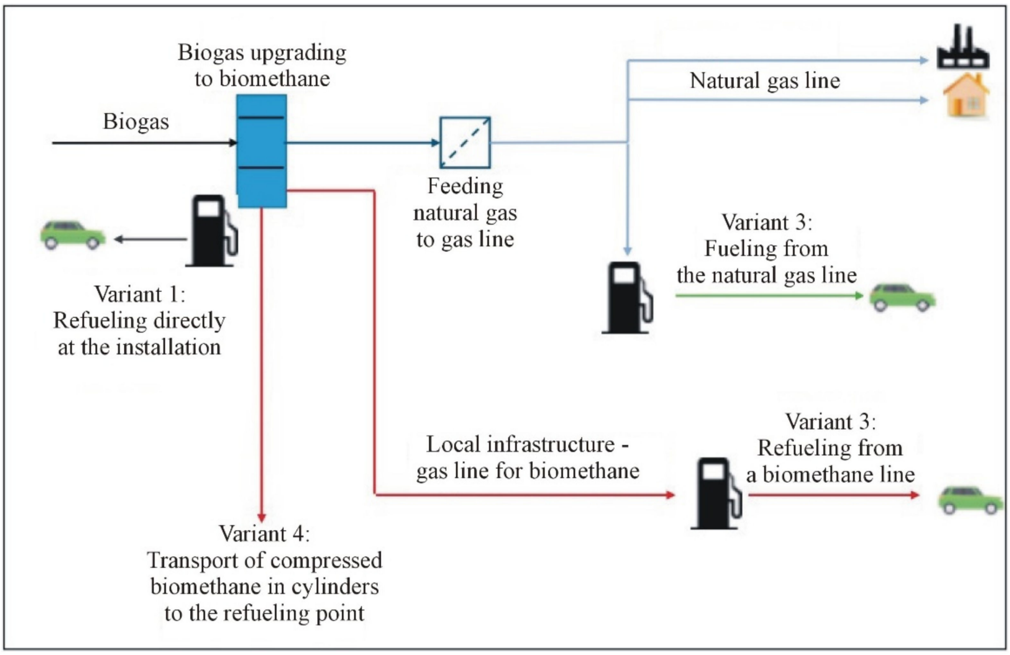

Figure 15. Possibilities of using BM as a fuel in vehicles in Poland.

If BM is to be used as vehicle fuel, it must be processed to achieve a quality acceptable to ordinary car engines [52]. In addition to corrosive substances acting on engines, such as hydrogen sulfide, CD and steam must also be removed from BG. Due to the necessary technological investments and in order to cover investment costs, biogas installations producing at least 2500 m^3 of BG per day are desirable for BM production for automotive purposes in Poland [53].

Another characteristic of BM is its relatively high cleanliness and lack of particles, which slows down engine wear. Many users report extended lifetime of these units and less frequent oil changes, which reduces operating costs.

NG/BM powered cars can be divided into three types:

1. Mono-fuel vehicles—engines where the main (often the only) energy source is NG/BM. The advantage of these engines is that they are optimized for this type of fuel. This ensures the maximum efficiency of such units with minimum emissions. Some vehicles provide for a small petrol tank as a reserve in the event of gas exhaustion.
2. Bi-fuel vehicles—engines that can run on NG/BM and petrol or other fuel for spark ignition engines. The petrol in these units is used at startup. Such units can be after-sales modifications of traditional units or new constructions.

3. Hybrid cars combining a NG/BM and an electric motor—the drive system developed this way, which includes energy storage capacitors and brake energy regeneration, can result in up to a 30% reduction in fuel consumption compared to a typical NG/BM-only unit [54].

5. BM in Poland—Project Implementation

In Poland, the duration of the investment process of agricultural BG/BM plants is very long. The Gantt chart presented in Figure 16 is based on the legal requirements (deadlines imposed by the authorities issuing decisions) and investors' practice to date [6].

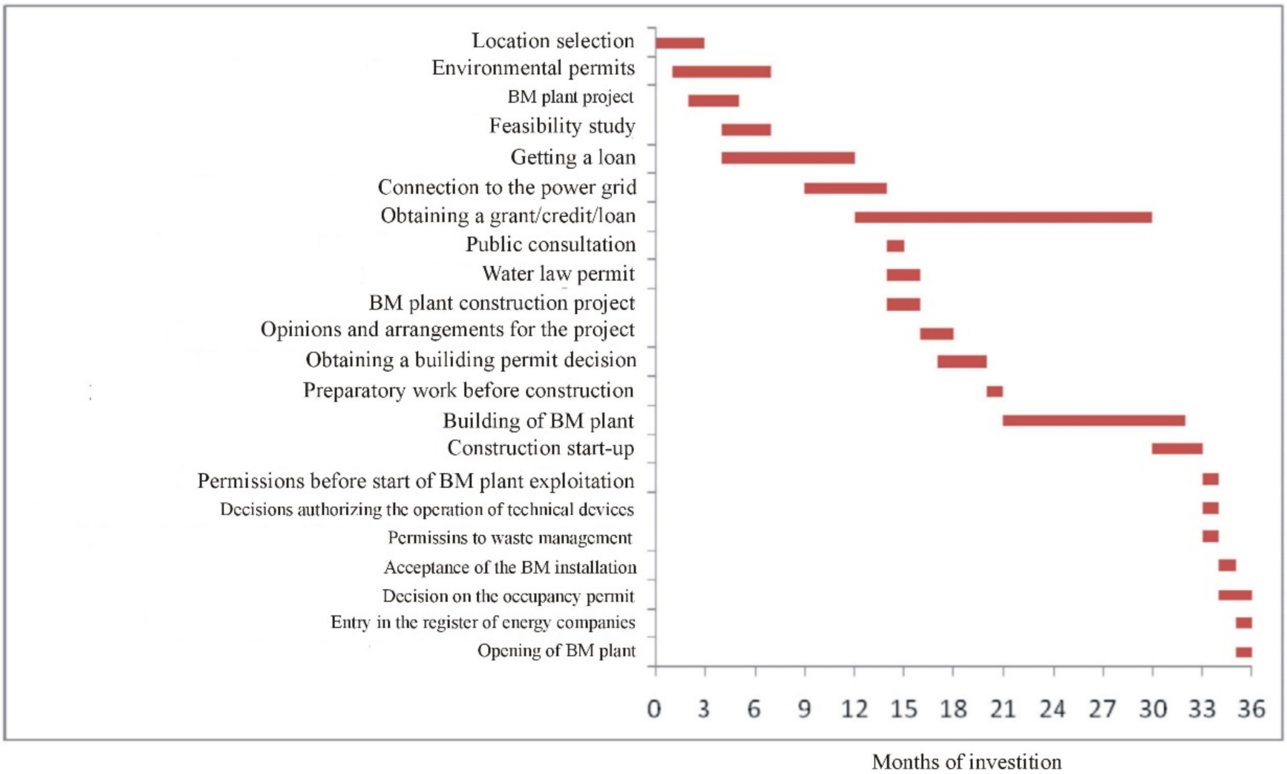

Figure 16. Schedule for the implementation of BM investments in Poland in the form of a Gantt chart.

The time necessary to prepare project documentation, obtain decisions and permits and conclude contracts for the implementation phase is about two years. The following year is occupied by the implementation of the investment along with the startup and acceptance of the biogas plant. This year, in connection with the coronavirus epidemic, the investment time for biogas plants in Poland has been extended even further.

Support System for BG/BM Plant Construction

Sources of financing for BG plants in Poland are subsidies, credits and subsidies to credits from public and EU funds, bank commercial credits and funds of the entities implementing the project. Without financial support, many of the existing and built biogas plants in Poland would probably not have been constructed. Depending on the status of the beneficiary, appropriate financial assistance may be received [38].

Investors in the RE sector in Poland can apply for funding/loans from both the EU and national resources. Large loans/credits are granted by the Environment Protection Bank [55]. The Environment Protection Bank is a Polish eco-bank, which for over 30 years has specialized in financing projects supporting environmental protection, being one of the main sources of financing for environmental investments in the country. The installations for RE sources financed by the Bank in the form of wind farms have a significant 20% share in the domestic production of clean energy.

Investors in BG plants in Poland can apply for funding for the construction of installations under the National Fund for Environmental Protection and Water Management as well as in the Voivodeship Fund for Environmental Protection and Water Management [56].

6. Environmental and Ecological Aspects of BM Plants

The most important environmental benefits achieved through the disposal of BG in Poland include:

- reduction of methane emissions from the natural decomposition of organic substances,
- economy using dispersed energy, thanks to which losses on energy transmission (reaching several percent in Poland) are avoided,
- sanitary aspects,
- the reduction of CD emissions from diesel and petrol combustion.

The BM plant allows for the controlled management of waste organic matter. The natural processes of biomass decomposition produce methane, which, if released into the atmosphere, increases the greenhouse effect [57].

According to the data of the National Centre for Emission Management and Balancing (2020) [58], in Poland, methane accounts for 11.8% of the emitted greenhouse gases, at 1951 kt. Methane emissions in Poland are the highest in agriculture, comprising one third of emissions; it is also a significant producer of emissions from municipal waste, with methane comprising more than 20% of the total emissions in Poland. The growth rate since the end of the 1990s has been stimulated by the growing share of the litter-free system as well as a focus on high-energy nutrition.

BM is a powerful weapon against climate change. Anaerobic digestion of manure and similar materials captures methane emissions, which are up to 23 times more harmful than CD [59]. In the absence of BG technology, methane is emitted to the atmosphere due to decomposing manure and waste, such as sewage sludge, municipal waste, agro industrial effluents and agricultural residues. Therefore, the CD emissions from burning BM are a small fraction of the avoided methane emissions from decomposing manure and waste. As a result, the total carbon footprint is very low when compared with its fossil fuel equivalents, as shown in Figure 17 [60].

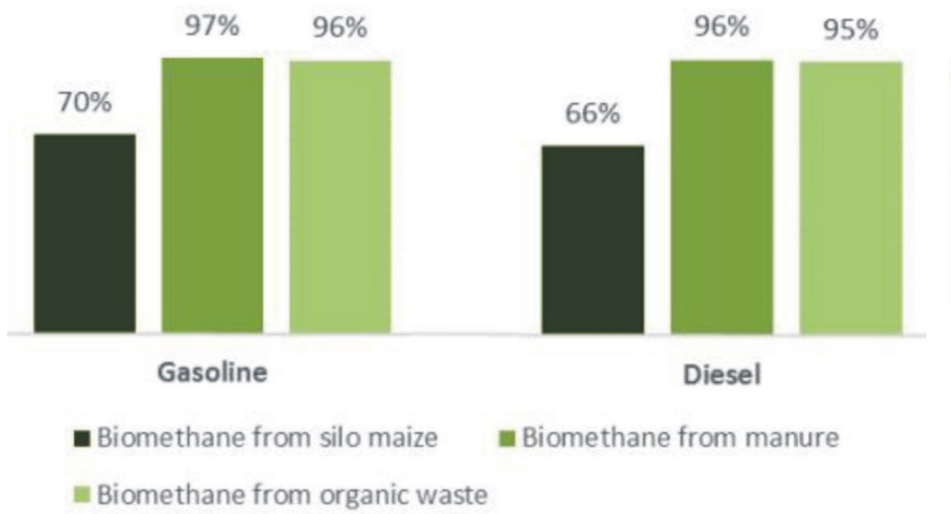

Figure 17. Well-to-wheel GHG emission reduction potential of BM compared to diesel/gasoline; own elaboration based on [60].

In the case of manure, it often has a negative emission balance (i.e., by turning it into BM, more GHG emissions are prevented from reaching the atmosphere than what production releases) [60].

Using substrates in a biogas plant that are often treated as hazardous waste, such as slaughterhouse waste, makes it possible to dispose of them safely, thus improving sanitary standards. BM production also allows for a significant reduction in odor emissions, which are emitted in large quantities during the natural decomposition of animal excrement [33].

The advantage of BM is not only waste disposal and green energy production but also high negative CD emissions. The use of BM instead of diesel enables a reduction in CD emissions of 75% to 200%. Engines powered by BM also generate less noise compared to engines powered by other fuels.

City buses, rubbish trucks and lorries can all be powered by BM. A BM-powered city fleet emits virtually no pollutants, i.e., it does not contribute to smog. According to the WHO [61], there is very poor air quality in Poland, which is the result of low emissions, including emissions from the combustion of petrol and diesel fuel.

7. SWOT Analysis of BM Plants in Poland

SWOT analysis is a comprehensive method of strategic analysis, which includes both an examination of the interior of an undertaking or organization and an examination of its external environment [62]. It consists of identifying key strengths and weaknesses and confronting them with current and future opportunities and threats. SWOT analysis is one of the most commonly used tools for strategic analysis [63]. SWOT analysis includes the following:

- **S** (Strengths)—strengths to be reinforced,
- **W** (Weaknesses)—weaknesses to be overcome/reduced,
- **O** (Opportunities)—opportunities to be utilized, and
- **T** (Threats)—threats to be avoided (Figure 18) [64].

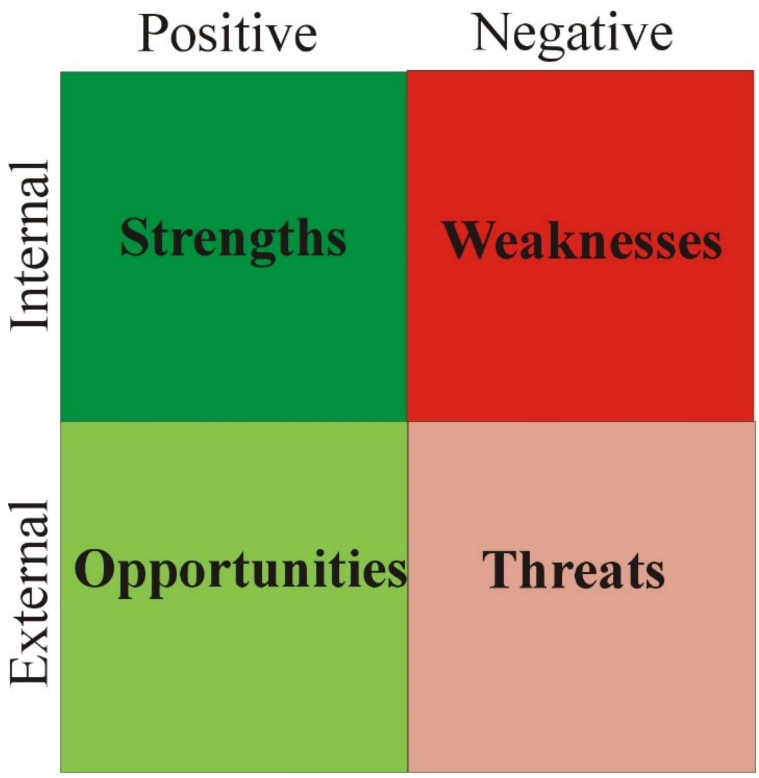

Figure 18. SWOT analysis diagram (own elaboration).

SWOT analysis allows people to systematize knowledge, see new opportunities or threats, and maintain sensitivity to certain issues. SWOT is a good method to identify the market or environment, verify design assumptions, study trends, etc. [65].

The SWOT analysis of BG/BM plants in Poland is presented in Table 3.

Table 3. SWOT analysis of BG/BM plants in Poland.

Strengths	Weaknesses
• well-developed agriculture and significant BM potential • deodorizing and waste disposal technology • increase the yield by using the digestate pulp as a fertiliser • possibility to feed BM into the gas grid • the possibility of using BM as automotive fuel • increase in employment in agriculture	• coronavirus pandemic • not sufficient financial aid for investment • high investment costs • long investment process • resistance of the local community to the construction of BG/BM installations • problems with connection to the gas grid • BM can only be used in specially adapted vehicles
Opportunities	**Threats**
• rapid development of BM technology • depletion of oil and gas resources • developmet of petrol station where BM can be refuelled • high popularity of cars on CNG in Poland • use of algae for BM production • other methods of BM production • possibility of producing BM and other RE	• price fluctuations of substrates from agriculture • no guarantee of stable feed supply in BM plants • increase in popularity of electric vehicles

7.1. Strengths

One of the strengths of the BM sector is the fact that Poland, as an agricultural country, has a large biomass potential. BM production can use targeted crops (e.g., maize) as well as a wide range of waste, including troublesome slurry [66]. Importantly, the previously calculated potential of BM from waste in Poland amounts to a total of 1596 mln m^3 per year. It is worth emphasizing here that the theoretical potential is four times greater.

The strength of the BM sector is also the fact that it is a deodorizing and waste disposal technology. A BG/BM plant allows for the controlled management of waste organic matter. The natural processes of biomass decomposition produce methane, which, if released into the atmosphere, increases the greenhouse effect. The economic use of BM allows for the reduction of CD emissions that would be generated by burning conventional fuels.

The possibility of using substrates in a BG plant that are often treated as hazardous waste, such as slaughterhouse waste, makes it possible to dispose of them safely, thus improving sanitary standards. The production of BG/BM also allows for a significant reduction in odor emissions, which are produced in large quantities during the natural decomposition of animal manure [9].

Another strength of BM technology is that the digestate is a good, natural agricultural fertilizer that can increase yields. The digestate can be poured directly onto the fields or dried and processed into pellets. Pellets can be successfully used as fuel or as dry, almost odorless agricultural fertilizer. Figure 19 shows a bio-pellet from the biogas plant in Sobawiny (center of Poland).

Among the strengths of BM technology is the fact that BM has a wide range of applications. First and foremost, it can be fed into the gas network and can also be used as automotive fuel. In the coming months, the feeding of BM into the gas network will be managed by PGNiG, and the production of BM as automotive fuel will be managed by PKN Orlen [41]. It is worth noting that BM plants work in rural areas with high unemployment. Most of the materials and services for the construction of BG/BM plants are provided by local suppliers, therefore creating jobs.

Figure 19. Bio-pellet from Sobawiny biogas plant (photo B. Igliński).

7.2. Weaknesses

The coronavirus pandemic slowed down the Polish economy and also affected the development of the BG/BM sector in Poland. As a result, many projects have had significant delays.

Investors and owners in Poland stress that the capital-intensive construction of BG/BM plants encounters economic barriers, including a shortage of financial assistance programs during project implementation. It is difficult for investors to pin down the financial specifics, because the banks have previously withheld financial aid for this type of undertaking, and the money from the banks affects the amount that needs to be contributed by investors. The development of the BM sector depends to a large extent on regulations concerning support for RE sources in the form of green certificates and auctions [38].

Potential investors are also deterred by the cost of constructing BM plants, which is at least several million PLN/MW and represents much more than in the case of wind turbines, for example [38].

The construction of a BS/BM plant is a multi-stage and very complex process, as illustrated earlier by the Gantt chart (Figure 16). The chances of obtaining approval for a positive location should be analyzed. A decision on environmental conditions is necessary to obtain approval for the investment process to be carried out. It is an accepted standard that when issuing a location decision on the construction of a BG/BM plant, local government units are obliged to organize public consultations [38].

Construction of BS/BM plants requires signing contracts with many entities and at different stages of investment implementation. Typical contracts relating to the construction and operation of agricultural BG plants include contracts for the following: supply of technology, investment execution, comprehensive execution of design works, supply of substrates, connection to the power grid (which can be very problematic), supply and reception of utilities (including sale of heat), insurance during construction, and financing of the investment project [38].

Almost half of the investments in BG plants have encountered or are encountering social resistance in Poland. The main reasons for opposition may be as follows:

- lack of reliable sources of information on BG plants, or
- the NIMBY effect—accepting the need to develop the RE sector, but “not in my backyard” [38].

The gas network is relatively well developed in western and central Poland. Only in these locations will it be possible to feed BM directly to the gas grid. In other areas, it will be necessary to build a gas network or use BM in other ways, for example, to power vehicles.

One weak point is that, unlike vehicles using biodiesel, BM-powered cars have to be converted accordingly and are therefore more expensive to be purchased.

7.3. Opportunities

Extensive research, both on a laboratory and technical scale, is being carried out all over the world to optimize the BG/BM acquisition process. The number of publications and patents relating to BG/BM technology is several tens of thousands per year and is increasing every year [67].

Oil and NG are non-renewable resources. In particular, crude oil has many applications in the chemical and petrochemical industries. As a result, the role of alternative fuels in the automotive sector is increasing, including BM.

At petrol stations, it is possible to fill up with NG/BM. As of 30 November 2020, there were 4099 such stations in Poland, with most in the center of Poland (2020) [51]. This is already a very large number, and LPG can be easily refueled in Poland. The situation is worse with LPG: there are 24 such stations in Poland, but there are plans to adapt more stations to the possibility of LPG/LPB refueling.

Gaseous fuel is very popular in Poland; every year more and more cars are powered by CNG (in the future, they can be powered with BM). In 2018, 1,835,000 tonnes of CNG were sold, and 3,135,000 LPG-fuelled cars were driven on Polish roads. This means that nearly 14% of all passenger cars in Poland have a gas installation [68].

Poland has a significant capacity to produce BG using algae. This can take place in sewage treatment plants or in agricultural BG/utilization plants. Algae are characterized by a rapid growth of biomass, while at the same time treating pretreated wastewater or pretreated digestate [38].

Work is also in progress [69] on CD methanization according to the reaction equation:

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \quad (12)$$

7.4. Threats

The main threats to the development of the BM sector in Poland include the volatility of substrate prices for BG plants. The sudden increase in the price of raw materials for methane fermentation puts BG plants almost on the verge of bankruptcy. A good solution to the problem is to sign long-term contracts for the supply of substrates for BG plants.

Investors are struggling to ensure an uninterrupted supply of basic substrates for the fermentation process. Continuity of supply requires the development of a logistics network, which generates additional costs and adversely affects the economy of the project. Already at the stage of selecting a location for a bioelectric power plant, this problem must be considered as a priority; the plant must be located close to the raw materials [38].

The growing popularity of electric vehicles in Poland is a certain threat. Every month there are more places to charge electric cars, often free of charge.

7.5. Recommendations

- increased financial support for BM plants,
- simplification of the necessary documentation,
- long-term batch supply contracts,
- the use of BM to supply the gas grid, and
- the use of BM as automotive fuel.

8. PEST Analysis of the BM Sector in Poland

PEST (Political, Economic, Social, Technological) analysis belongs to the group of methods used to study the environment, in this case RE (Figure 20) [70]. The following environment is most often distinguished:

- political: political stability, BM policy, legislative environment,
- economic: among others, global and Polish economic situation, labor market, interest rates,
- social: including demography, knowledge of the BM sector, human resource structure and availability of human resources, and
- technological: innovation in the BM sector and transfer of techniques and technologies, among other things [71].

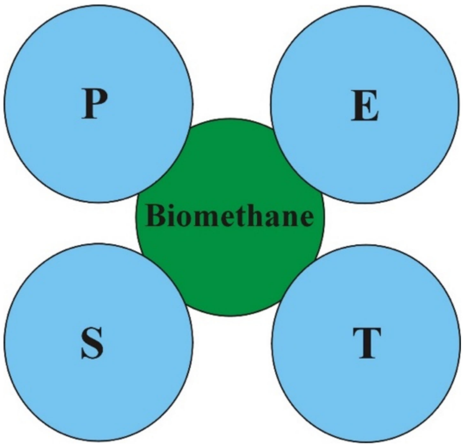

Figure 20. Macro-environment of the BM sector; P—political, E—economic, S—social, T—technological (the PEST analysis).

In the adopted study, it was considered advisable to subject the diagnosed factors to a score-based assessment, depending on their degree of favoring the development of the biomethane sector in Poland. On a favorability scale of 1 to 5, the individual numbers are as follows:

- 1—very unfavorable factor,
- 2—unfavorable factor,
- 3—neutral factor,
- 4—favorable factor, and
- 5—very favorable factor.

At the same time, a formula was adopted for averaging the assessments of selected factors, assuming that this impact on its development means the following:

- below 2.00 points—very unfavorable macro-environment,
- 2.00–2.99 points—unfavorable macro-environment,
- 3.00–3.49 points—neutral macro-environment,
- 3.50–4.49 points—favorable macro-environment, and
- 4.50–5.00 points—very favorable macro-environment [70].

The PEST analysis was carried out for the BM sector on the basis of current legislation, information obtained directly from BG employees and questionnaires conducted among BG plant owners, farmers and teachers.

8.1. PEST Analysis—Political Environment

Table 4 presents the political environment of BG/BM plants in Poland in the context of their development potential.

Table 4. Political environment of BG/BM plants in Poland in the context of their development potential.

	Factor	Favor of BG/BM Plants
1.	The political system and its stability	3.50
2.	Public administration system and efficiency of its functioning	2.00
3.	BG/BM policy at state level	2.00
4.	Wide possibilities of BM use	5.00
5.	Legislation on BG and BM	4.00
6.	Strong conventional energy lobby	1.00
7.	EU Membership	5.00
	General assessment	**3.21**

The political environment of Poland's RE sector generally results from the political system in which it operates. According to the Constitution of the Republic of Poland [72], Poland is a parliamentary republic and implements the principles of national sovereignty; independence and sovereignty of the state; the democratic state of law; civil society; the tri-partition of power, pluralism, and the rule of law; the social market economy; and inherent human dignity. The political system in Poland can be regarded as relatively stable. However, we should mention the recent protests of women in Poland in connection with the "abortion law".

Public administration is an integral part of the state; it is a carrier of memory of the state tradition and is endowed with the privilege of legislative initiative. Preamble to the Constitution of the Republic of Poland [72] defines a very important objective related to the need to improve the functioning of the public sector in Poland. Despite efforts, the public administration does not work efficiently in Poland; this can act to discourage the development of BG/BM technology.

A huge number of regulations and documents deter potential investors in BG/BM plants. This significantly increases the investment time, as previously shown in the Gantt chart (Figure 16).

A friendly factor should include the possibility of the extensive use of BM. It can be fed into the gas grid, used as automotive fuel or used as a chemical reagent in chemical technology.

In Poland, legal regulations related to the use of the environment, including those regarding GHG emissions, are specified by the Environmental Protection Law [73]. According to the Act, the principles of sustainable development constitute the basis for drawing up and updating the national spatial development concept, voivodeship development strategy and voivodeship spatial development plans.

The development of BG/BM plants in Poland is hampered by a strong conventional energy lobby, mainly the coal lobby. Associated with mines, coal-fired power plants and trade unions, this lobby openly opposes the development of RE in Poland.

The guarantee of institutional "maturity" in Poland comes from membership in the European Union and other international organizations, such as international tribunals and judicial institutions. The development of BG/BM technology is supported by the elimination of political and economic borders as a result of globalization processes, including participation in the EU. Upon accession, Poland undertook to take over the EU acquis in the field of science and research. This would create unprecedented opportunities for the European Research Area in the field of science and research in Poland. This would also allow the free movement of research staff, joint projects, and the creation of joint research centers.

8.2. PEST Analysis—Economical Environment

Table 5 presents the economic environment of BG/BM plants in Poland in the context of their development potential.

Table 5. Economic environment of BG/BM plants in Poland in the context of their development potential.

	Factor	Favor of BG/BM Plants
1.	Economic growth and socio-economic development	3.00
2.	The global economic situation, global energy and fuel prices, global fuel resources	3.00
3.	Labor market (including BG/BM sector), unemployment rate	3.00
4.	Ability to finance investments from own resources	2.00
5.	Interest rates, availability of loans and grants	4.00
6.	Innovation, entrepreneurship and investor activity	4.00
7.	Globalization—free movement of goods, capital, services (EU membership)	5.00
	General assessment	**3.43**

The coronavirus pandemic and the associated lockdown in many countries caused an economic slowdown globally and in Poland. Many investments, including those in BG/BM, are well behind schedule, and some have been abandoned. The economic crisis in Spring 2020 can be seen in a significant drop in GDP from 103.6 at the end of 2019 to 91.6 in the second quarter of 2020. The third quarter is a "reflection" to 98.4. The partial lockdown introduced in 2020 is likely to cause a fall in GDP in Poland again [74].

The world economy had managed to recover from the crisis in 2008 when the coronavirus pandemic crisis emerged. Prices of energy carriers remain low: in November 2020 the oil price was about 47–48 USD/barrel (commodity quotations, oil, 2020) [75], hard coal price was 59–60 USD/Mg (coal price, 2020) [76] and NG price was 2.95 USD/million btu (NG price, 2020) [77].

An important element of the macro-economic environment of the BG/BM sector in Poland is the labor market, which includes the unemployment rate, structure and dynamics of employment, and migration. According to the Central Statistical Office [78], the unemployment rate in Poland at the end of October 2020 was 6.1%, compared to 5.5% in January 2020, which is undoubtedly related to the coronavirus pandemic. However, it is worth noting that the areas with the highest unemployment have very good conditions for the development of the BG/BM sector. High unemployment, which reached 20% in 2004/2005, and entry into the EU have led to increased emigration. It is estimated that there are currently over 2.2 million Polish citizens outside the country. Inflation in Poland is decreasing: while in 2016 it was 3.7%, in November 2020 it was 0.1% [79].

Interest rates in Poland are among the lowest in history and are as follows:

- reference rate: 0.10,
- lombard rate: 0.50,
- the rediscount rate: 0.00, and
- lombard rate: 0.11 [80].

RE is one of the few branches of the Polish economy where annual employment growth is recorded [10]. Construction of BM plants will provide work in areas with high unemployment.

Investors in BM plants in Poland can apply for funding/loans from the European Union as well as national funds. Large loans/credits are granted by the Environmental Protection Bank [55]. Investors in BM plants in Poland can apply for funding for the construction of installations under the National Fund for Environmental Protection and Water Management as well as the Voivodeship Fund for Environmental Protection and Water Management [56].

It should be mentioned that the EU budget for 2014–2020 assumes that 20% of all budget expenditures should serve climate protection, including research and projects that will contribute to the reduction of GHGs, including RE technologies.

Polish BG plant investors are characterized by great innovation, entrepreneurship and activity. They often put their own ideas into practice by improving existing technology, so that the processes for methane, for example, run smoothly. For example, a homogenizer (own idea) of feedstock for methane digestion was introduced in the Sobawiny biogas plant; the stored batch was not covered with foil but with chokeberry and blackcurrant pulp, which nearly eliminated the odor nuisance. More and more investors are developing two or more types of RE, such as BG plants and photovoltaic panels.

The opening of borders after Poland's accession to the EU allowed for the free movement of goods, technologies and services. The latest EU technological achievements are increasingly being implemented in Poland as well.

8.3. PEST Analysis—Social Environment

Table 6 presents the social environment of BG/BM plants in Poland in the context of their development potential.

Table 6. Social environment of BG/BM plants in Poland in the context of their development potential.

	Factor	Favor of BG/BM Plants
1.	Demographic situation	2.00
2.	Level of education	3.50
3.	Knowledge about BG/BM	3.00
4.	Social acceptance of BG/BM	4.00
5.	Structure of human resources and availability of staff	3.00
6.	Impact of biogas plants on the labor	4.00
7.	EU membership	4.50
	General assessment	**3.43**

At the end of 2019 [81], the population of Poland was 38.383 million, down 28,000 from 2018 [82]. In 2020, a further decline in the population in Poland is expected in connection with the coronavirus pandemic. As of 30 November 2020, 17,150 people had died of coronavirus in Poland [83]. There has also been an increase in the overall number of deaths from other diseases due to poor access to a specialists during the pandemic (many surgeries were postponed or cancelled).

The Polish population is aging. In addition, the population is about to decrease, due to a 2019 fertility rate of only 1.32 [81]. The unfavorable demographic situation in Poland has a significant impact on the regional labor market. The problems that this entails are limited employment mobility and a reduced ability to respond flexibly to changes in the economy and in labor. A large number of the unemployed are people with higher education. For both the elderly and young people, the development of RE is an opportunity for employment. Local authorities should support entrepreneurship by creating favorable conditions for employment in small and micro-enterprises.

Graduates of secondary schools (general and vocational) occupy a dominant position in the population structure by level of education. Currently, the percentage of such people is around 30%. Since 1995, the share of people with higher education in the 24–64 age group has increased from 9.7% to 21.3% [81].

Access to the Internet, the promotion of RE (seminars, conferences, demonstrations) and trips abroad make have led to a gradual increase in knowledge of and support for bioenergy plants gradually. Secondary school students have indicated that BG/BM knowledge is drawn from the Internet, television and newspapers, and to a lesser extent, from school curriculum content.

Polish society generally accepts the construction of BG plants, although it fears that this will significantly increase the cost of energy and consumer goods. People almost unanimously believe that the development of RE will have a positive impact on reducing emissions of harmful substances to the environment.

Until recently, there were no RE-related courses of study on offer at universities. In recent years, more than 30 universities have expanded their course offerings by introducing RE-related studies. This includes engineers (technologists or designers) responsible for the technical side of projects as well as specialists in economic and legal sciences who will deal with issues related to investment planning and analysis of profitability. There are currently a number of opportunities in the country to gain knowledge of the BG/BM sector. These fields of study or specialization are, to a large extent, provided by technical universities, but similar courses are also offered by natural science and economic universities.

The fairly well-developing BG/BM sector in Poland needs workers, and this is most often in areas with high unemployment. Development of agricultural biogas plants can reduce unemployment in rural areas of north-eastern Poland. In addition, EU membership ensures the free movement of new technologies and, consequently, new jobs in the BG/BM sector.

8.4. PEST Analysis—Technological Environment

Table 7 presents the technological environment of BG/BM plants in Poland in the context of their development potential.

Table 7. Technological environment of BG/BM plants in Poland in the context of their development potential.

	Factor	Favor of BG/BM Plants
1.	Innovativeness of the economy and the BM sector	4.50
2.	Degree of gas infrastructure availability	3.50
3.	Number of LPG/CNG stations	3.00
4.	The ability of science-economy cooperation	2.00
5.	Management technologies for BM	4.00
6.	Domestic manufacturers of devices for bio-power plants	3.00
7.	Technique and technology transfer (EU membership)	4.50
	General assessment	**3.50**

The BG/BM sector is one of the fastest growing branches of the economy in Poland and worldwide. Extensive research in research centers has resulted in an increase in the efficiency of BG/BM energy generation as well as a decrease in installation prices. Investment costs are expected to decrease with development and production growth; these costs are currently a significant barrier to implementation and development.

The gas network is located mainly in western and central Poland, where it is possible to build a BM installation for BM to be injected into the grid. In other areas, it is worthwhile to produce BM for automotive purposes.

Poland has a significant number (4099) of petrol stations where liquid gas can be refueled, but only 24 where LPG can be refueled. The other stations will be adapted for LPG refueling.

In Poland, there is still little cooperation between science and industry. This also applies to the BM sector. This cooperation is necessary in order to develop modern and cheap RE technologies. An opportunity for the development of this sector is the emergence of numerous cluster initiatives based on the endogenous potential of different regions.

In Poland, the market of domestic manufacturers of RE equipment and installations can be described as "crawling". It requires the import of sub-assemblies and full equipment, and as a result, older technology is often imported.

An opportunity for the development of RE is membership in the EU (cooperation and transfer of knowledge within the European Research Area), the development of an information society and the development of information and telecommunications technologies.

8.5. Discussion

The political environment in the field of science and research in the BM sector can be classified as relatively neutral (3.21 points) in Poland. An opportunity for the development of BG power plants lies primarily in Poland's participation in the structures of the European Union, active participation in the European Research Area, and the stability of the democratic political system in Poland and the country's institutional order. The main threats to science and research in the BM sector are extensive and complex legislation and low effectiveness in the practical implementation of innovation policy objectives.

The economic environment can be considered as neutral to the development of the BM sector (3.43 points). A development opportunity is first and foremost membership in the EU, which allows funding for research and investment in RE. In addition, the relative stability of Poland's economic situation as well as the innovativeness and activity of investors is an opportunity. The threats include high investment costs and the negative impact of the coronavirus pandemic both nationally and globally.

The social environment can be considered as neutral for the BM sector (3.43 points). Above all, being a member of the EU allows for integration processes that educate society in terms of creativity, innovation and openness to change. Transnational partnerships and investment in human capital are being developed. The main threats include the persistence of low-level science in society, an aging population and a decreasing population.

The technological environment can be regarded as reasonably friendly (3.50 points). Innovation in the BM economy and sector as well as the transfer of techniques and technologies within the EU are an opportunity for development. The greatest risks are low cooperation between science and economy and too few domestic producers of RE installations.

To summarize, the PEST analysis indicates that the BM sector has a chance to develop in Poland. Friendly legislation, greater financial subsidies, education of the public and development of domestic plant manufacturers can contribute to a significant reduction in GHG emissions and greater energy independence for Poland.

9. Conclusions

In many countries, as in Poland, the interest in biofuels, including BM, is increasing. The advantage of BM is that it can be produced on site, without imports, using a wide range of waste and targeted crops. The combustion of BM also results in negative CD emissions and traces of pollutants.

Poland has over 300 BG plants. Some of them will be able to introduce BG treatment equipment for BM. Both PGNiG and PKN Orlen are planning to construct typical BM plants in the near future. BM will be used as a gaseous fuel injected into the gas network or as a fuel to power vehicles.

Poland has been struggling with smog for years. The introduction of BM power in city buses, refuse trucks and cars would significantly reduce blast emissions and at least partly reduce smog. In rural areas, some Polish people still cook and fry with coal or wood. Replacing coal or wood will also reduce the emissions of harmful compounds into the atmosphere.

Poland has extensive administrative and clerical structures. Everyone who wants to invest in anything in Poland must show great mental resilience as well as knowledge of many regulations. Regulations are often amended, which makes investment in Poland even more difficult.

The development of RE, including BG and BM, will allow for increased employment in Poland, especially in rural areas, i.e., areas with high unemployment. In the coming years, approximately 10,000 BM plants are planned to become operational. Assuming employment of 15 people/plant, it will allow up to 20,000–25,000 people to find employment. Even more people will find work in the construction of BM plants as well as in conservation. Farmers selling agricultural waste and maize silage and taking back the ferment to be used as fertilizer will also benefit.

The development of BG and BM technologies in Poland is a good example for other countries that it is possible to combine economic development with environmental protection. BM derived from waste can replace NG or liquid fuels to some extent, reducing greenhouse gas emissions as well as "low emissions". Further development of BG/BM technology will allow for partial independence from the import of uncertain NG supplies, increasing the country's energy security.

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