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Calculation of the Potential Biogas and Electricity Values of Animal Wastes: Turkey and Poland Case

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Abstract: This research aimed to analyze the potential amount of electrical energy from biogas energy obtained from animal wastes in Turkey and Poland. Animal waste values were calculated by taking into account the recommended literature values. In determining the biomass energy potential of livestock enterprises in Turkey and Poland, FAO's 2012–2021 data were taken into account. The animal breeds selected as material in this study were cattle, goat, sheep, chicken, duck, goose, turkey, horse, pig, mule and donkey. Considering 10-year calculations, the potential amount of biogas energy that can be obtained from animal wastes for Turkey is 28,845,975 GJ, which is equivalent to 8,105,058 MWh of electrical energy. In Poland, the potential amount of biogas energy that can be generated from animal waste is 13,999,612 GJ, which is equivalent to 3,902,020 MWh of electricity. Moreover, it is estimated that the percentage of the potential amount of electricity to be obtained in 2021 to cover the amount of electricity consumed is 0.303% for Turkey and 0.392% for Poland. For 2021, the amount of economic gains that can be from electricity obtained was also calculated, and it was determined that this value can be 78,650,302 Euro for Turkey and 62,182,435 Euro for Poland. At the same time, it was calculated that the electricity needs of 406,170 houses in Turkey and 171,958 houses in Poland can be met in 2021. As a result, it is thought that the potential electricity to be obtained will contribute to determining energy gains and investment plans for biogas plants.

Keywords: Turkey; Poland; animal waste; electricity; biogas

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1. Introduction

The need for energy has emerged with industrialization and population growth. Fossil fuels have a large share in the world's energy needs and cause current environmental problems, especially air pollution and global warming. With the widespread use of fossil fuels in energy production and the limited lifetime of these fuel reserves, the trend towards new and renewable energy sources is increasing worldwide [1]. Environmental problems arising from using fossil resources as energy raw materials lead to the search for alternative energy sources [2]. Studies show that oil reserves will be depleted by 2047, natural gas reserves by 2068 and coal reserves by 2140 [3]. Problems, such as decreased fossil resources, such as coal, oil and natural gas, and environmental problems due to operating processes, are also encountered [4]. The fact that biogas energy, one of the renewable energy sources, is environmentally friendly and economical in terms of cost has increased in importance day by day [5,6].

Worldwide, there is an increasing trend towards using renewable energy sources instead of fossil fuels for fundamental reasons, such as climate change. As a result of the decrease in energy resources and the search for new sources, biogas production from organic wastes is seen as an alternative source [7–9]. Using organic wastes in biogas production constitutes an effective waste management step in waste disposal and waste-to-energy production [10,11].

Environmental impacts can be reduced by storing manure from animal barns. Biogas material emerges from the stored manure. This material can be used as biogas energy due to various processes and contributes to the environment and the economy [12]. Today, alternative energy sources, which constitute a way to reduce external dependence on the energy sector, have become extremely important [13].

In countries where biogas technology is widespread, all kinds of organic wastes are processed in biogas production facilities to obtain energy. These wastes, which can harm the environment, are transformed into stable final products at the end of the biogas processes, preventing soil and water pollution, and organic fertilizer from the facilities can be used in agricultural areas [14,15].

Animal manure is one of the organic wastes that can be used in biogas production. Due to their reproductive capacity, especially cattle and chicken manure reaches huge amounts [16]. Anaerobic treatment is one of the effective methods to prevent odor problems caused by animal manure. Animal wastes bring air pollution with odor problems. They also cause water pollution and health problems [17].

Animal waste is one of the main organic wastes that can be hazardous to the environment if not properly managed. Animal manure contains high concentrations of nutrients, such as nitrogen (N) and phosphorus (P), which cause nutrient imbalances and environmental pollution. Furthermore, manure contains residues of some harmful substances, such as antibiotics, growth hormones and heavy metals. Thus, microorganisms in animal manure can contaminate the environment, leading to human diseases. In this context, the disposal of animal manure has been found to have a polluting effect on the environment, contaminating air, soil and water resources. Therefore, treating animal manure and slurries with anaerobic digestion processes has beneficial results, such as producing sustainable energy sources in biogas and the quality fertilizer reduction of odors and microbial pathogens [18,19].

Biogas, one of the renewable energy sources, is formed due to the decomposition of organic substances in the absence of free oxygen during the anaerobic fermentation process, and this process is also used to purify different wastes/residues [20]. The anaerobic fermentation process transforms waste/residues of different origins into useful products, such as biogas as a renewable energy source and fermented manure as a potential fertilizer source [21]. Anaerobic fermentation can occur in small or large-scale controlled environments and natural environments. Fermented fertilizer formed as a result of biogas production has properties suitable for agricultural activities and ensures that the basic nutrients required for plant growth are easily absorbed by plants [22]. Thanks to the application of fermented fertilizer, soil fertility is maintained, and the soil structure and humus balance are also improved [23]. Fermented manure is a mixture of partially decomposed organic matter, microbial biomass and inorganic substances [24]. Fermented fertilizer, which emerges as the primary product at the end of the biogas production process, has a high value in plant cultivation and is predicted to replace commonly used mineral fertilizers [25]. Essential plant nutrients, including trace elements necessary for plants, are preserved in fermented manure [26].

Biogas represents a renewable energy source resulting from the anaerobic digestion of almost any organic matter. Animal manure is one of the most widely used organic materials for biogas production, as it has large methane-production potential in anaerobic digestion [27].

Biogas can be produced from organic materials via the anaerobic digestion method. The methane gas contained in biogas gives it flammable properties. Anaerobic digestion is a highly preferred process in recent years due to its advantages, such as high performance and low-cost energy production. The anaerobic digestion method requires less energy and nutrient resources than other commonly used purification techniques. In addition, the anaerobic digestion method allows methane gas to be obtained in a suitable form that can be used in heat and electrical energy with low operating costs [28]. Cattle manure is mainly used in biogas production in the world. The most important reason is that the daily amount of fertilizer is higher than with other animals [29].

It has been proposed how biogas from organic wastes can contribute to meeting the energy requirements for power generation and transportation sectors [30–33]. The application of waste to energy technology, such as biogas production from animal waste, is recognized as one of the best tools to achieve sustainable energy development goals in many developing countries [34].

The main clean energy sources are biomass, solar, wind, geothermal and water. Among these energy sources, biomass energy has an important place [35]. The biogas energy obtained is converted into electrical energy in production plants, which is transferred locally or to the grid. The heat energy released during the combustion phase is used to heat buildings, houses or greenhouses inside and outside the facility and to air the barns [36]. However, although the CO_2 rate is 50–55%, reducing the methane gas rate is of great importance because methane gas is 20–25 times more efficient than carbon dioxide [37]. Biogas, included in biomass energy, is considered renewable because it comes from organic waste that cannot be utilized elsewhere and, therefore, is part of the circular economy. It can be used locally to produce electricity, heat or both simultaneously. Using biogas as an energy source in industries instead of fossil fuels creates a much more environmentally friendly, carbon-free and sustainable environment [38]. Industries and households benefit from biogas energy for heating and hot water production. Food industries, which need very clean fuel, have also started to benefit from biogas energy, which does not produce odor and particles when burned. In many low-and middle-income countries in Africa and Asia, biogas produced through various means is used for heating, cooking or lighting in rural areas [39]. Using the heat obtained from biogas combustion provides essential economic and environmental benefits because it is renewable [40] and suitable for various purposes [34]. Biogas also creates employment. It can easily be applied as an alternative energy source in rural areas. If biogas is used for heating instead of fossil fuels, it is possible to reduce greenhouse gas emissions by 75–90%. Since organic waste is utilized with biogas, it contributes to sustainability for the natural balance by preventing pollution in soil, air and water [41].

Some of the environmental factors that are effective in the optimum operation of the anaerobic digestion process are volatile organic solids (VOSs), the organic loading rate (OLR), volatile fatty acids (VFAs), the Chemical Oxygen Demand (COD), Total Organic Carbon (TOC), alkalinity, VFA/alkalinity, pH, the solid retention time (SRT), temperature, biogas amount and methane (CH_4) ratio. In order for the process to operate at maximum efficiency, the parameters affecting the system must be constantly monitored and kept under control [42]. A study conducted by [43] stated that, in general, 28% of the methane formed in anaerobic treatment was produced from CO_2 and H_2, and 72% was produced from acetic acid. Methanogenic respiration, carried out by methanogens using hydrogen, produces CH_4 from CO_2 [44]. Buffering compounds involved in the anaerobic process are bicarbonate, hydrogen sulfide, phosphate and ammonia [45,46], and in their study, they found that with the addition of trace elements to the digester, the degradation efficiency of volatile fatty acids increased, and more biogas was produced by improving the performance of the process.

In Turkey, the total economic energy equivalent of our wastes from which biogas energy can be obtained is approximately 3.9 MTOE (million tons of oil equivalent) year^{-1}. The installed power based on biomass and waste heat energy in Turkey is 2172 MW as of the end of June 2022, and its ratio to the total installed power is 2.14%. In Turkey, four different methods are used to convert biomass into energy: thermochemical, biochemical, physicochemical and physical. Many different sources are used for Türkiye. These resources are agricultural biomass resources, biomass resources obtained from forests and forest products, animal biomass and industrial wastes [47]. All agricultural biogas plants registered in Poland use the biogas produced to generate heat and electricity in cogeneration. In 2019, 3.96 million tons of substrates were used to produce agricultural biogas, among which the predominant substrates were post-agricultural stock, fruit and vegetable residues and slurry. These substrates collectively accounted for 59% (m m^{-1}) of the substrates used in this period for agricultural biogas production in Poland [48].

Biogas energy has advantages and disadvantages. Biogas is a renewable and clean energy source. It is a truly environmentally friendly system that does not harm the environment, soil, water resources and living creatures. It is very useful in producing quality fertilizer for agricultural activities. It prevents the bad smell of fertilizers and animal manures from contaminating the soil and water resources. The waste remaining after production can be reused for agricultural fertilization purposes. It reduces the amount of harmful substances, such as methane and ammonia, in the air. Biogas organic fuel, which is entirely organic, also allows for more environmentally friendly and reliable energy to be obtained. One of the most important benefits is that it enables waste recycling. Therefore, it reduces waste storage costs and creates a cleaner environment. It is an economical energy source due to its affordable production costs. These are the advantages of biogas energy, but there are also disadvantages. Biogas contains some impurities even after the refining processes. Using biogas on a large scale is not cost-effective. It is not easy to increase the efficiency of biogas systems. At the same time, since biogas is an unstable gas, it can cause explosions if methane comes into contact with oxygen and becomes a flammable substance. Although biogas has disadvantages, countries have started to make it possible to use biogas in daily life. With population growth and developing technology, the use of biogas, which provides the opportunity to produce energy from waste obtained from renewable energy sources, to meet energy needs will increase [49].

This study aimed to determine the amount of electrical energy that can be obtained by utilizing the wastes generated in livestock enterprises in Turkey and Poland in biogas technology and to draw attention to how it can provide recovery for these countries.

2. Materials and Methods

2.1. Materials

In determining the biomass energy potential of some livestock enterprises in Turkey and Poland, the Food and Agriculture Organization of the United Nations data for 2012–2021 were considered. This research used cattle, goats, sheep, chickens, ducks, ducks, geese, turkeys, horses, pigs, mules and donkeys as animal material. In order to calculate the potential biogas energy that can be obtained from animal wastes in the research area, annual data were first calculated. The total potential biogas energy amounts that can be obtained from animal wastes for the years 2012–2021 have been calculated.

Since Turkey and Poland have great potential in animal husbandry, the resulting animal waste can be used as biogas energy. In addition, the idea that the ever-increasing energy need can be met increases the importance of the study for both countries. However, it is thought that the cooperation of the researchers in the study will be important for both countries in terms of the development and continuity of this and similar studies in the future.

2.2. Methods

In this part of the study, calculations regarding the amount of biogas and electricity that can be obtained from animal waste, the amount of CO_2 emissions that can be prevented and the economic gain that can be obtained from biogas energy are explained.

2.2.1. Calculation of the Amount of Wet Fertilizer That Can Be Obtained

In determining the wet manure that can be obtained from animal wastes and the biogas potential, the manure production per unit animal, dry matter and volatile dry matter ratios of manure and methane production rate of manure and the availability of manure from animals were calculated [50,51].

$$\Sigma FM = AN \cdot ADM \cdot 365 \quad (1)$$

Here:

FM: Amount of fresh manure (kg·year^{-1})
AN: Animal number
ADM: Average daily manure production per animal (kg·day^{-1}·animal $^{-1}$)

2.2.2. Calculation of the Amount of Biogas Energy That Can Be Obtained

$$\Sigma ME = FM \cdot SM \cdot VDM \cdot RM \cdot utilizationpercentage \quad (2)$$

Here:

ME: Energy value that can be obtained from methane gas (MJ)
FM: Amount of fresh manure (kg·year^{-1})
SM: Solid matter content (%)
VDM: Volatile dry matter content (%)
RM: Raw material-specific methane production rate (m^3·CH_4·kg^{-1}·VDM^{-1})

The manure of the animals cannot be collected as long as they are in the pasture, and not all of the manure is used in the calculation to avoid raw material problems for the continuous operation of the facility. The collectability of animal manure is related to the duration of the animals' stay in the shelter and the possibility of collecting and accumulating the waste generated in the shelter. For this reason, the usability of animal manure is expressed as a percentage (%).

The values in Table 1 are the reference researchers' average values, which were used in this study.

Table 1. The amount and characteristics of manure accepted for the biogas process according to animal breed [50–52].

Animal Breed	Manure Production Per Animal Unit (kg·Animal^{-1}·Day^{-1})	DM (Dry Matter) (%)	VDM (Volatile Dry Matter) (%)	Raw Material-Specific Methane Production Rate (m^3 ·CH_4·kg·VDM^{-1})	Availability of Animal Manure (%)
Cattle	43.00	13.95	83.33	0.18	50 *
Sheep	2.40	27.50	23.00	0.30	13
Goat	2.05	31.71	23.17	0.30	13
Horse, Donkey, Mule	20.40	29.41	19.61	0.30	29
Poultry	0.18	25.88	77.27	0.35	19
Turkey	0.38	25.53	19.36	0.35	26
Duck and Geese	0.33	28.18	17.27	0.35	22
Pig	3	17	83	0.29	50 *

* Usage percentages vary in studies conducted by different researchers. In our study, this value was taken as 50%.

2.2.3. Calculation of Electricity Generation from Biogas Energy

As Ertop et al. [53] stated in their study, the reference value of 1 MJ energy equal to 0.000278 MWh energy was used. In this context, energy conversions were carried out by determining that 1 MJ of energy equals 0.278 kWh of energy and 1 kWh of energy equals 3.6 MJ of energy.

2.2.4. Number of Houses Whose Electricity Needs Are Met

The number of houses that can meet the electricity need if the electricity that can be generated is used in the houses is calculated. The number of dwellings was calculated by dividing the electricity that the average electricity consumption of a house could generate.

2.2.5. Calculating the Amount of CO_2 Emissions That Can Be Avoided with the Biogas Energy That Can Be Obtained

The average greenhouse gas emission for 1 kWh of electricity generation by burning pulverized coal is 710 g CO_2, which is 26 g CO_2 for burning biogas [54]. In this way, to calculate how much CO_2 emissions can be prevented annually by obtaining biogas from animal waste, the difference between the two values was calculated using a coefficient of 684 $g{\cdot}kWh^{-1}$ [55]. Coal provides 34.6% of Turkey's electricity generation [56]. About 68.5 percent of the electricity produced in Poland is generated from coal. This makes the energy sector a major polluter [57]. In both countries, the highest electricity generation is obtained from coal. Therefore, the emission values of coal have been calculated.

2.2.6. Economic Gain from Electricity

The unit price of electricity for medium-sized households varies annually. The economic gain can be achieved if the available electricity energy used for medium-sized households has been calculated. The economic gain that can be obtained from electricity is calculated by multiplying the unit price by the unit of electrical energy in kWh.

2.2.7. Economic Gain from Fermented Fertilizer

The dry matter content values of the wastes belonging to animal breeds in Table 1 and the animal presence values in Tables 2 and 3 were used to calculate the amount of fermented manure that can be obtained during biogas production. However, Gümüşcü and Uyanık [58] stated that the biofertilizer turned into packable pellets should have an average moisture content of 12%. In order to achieve this, the fertilizer obtained was calculated with the addition of 12% moisture. The production of biofertilizer that can be obtained by considering these criteria was calculated. The moisture content of the material to be pelletized is an important factor in determining the pellet density and durability. In order to produce strong and durable pellets, the material moisture must be at an optimum value. However, the optimum moisture content varies depending on the material type. In pelletizing, moisture acts as an adhesive that strengthens particle bonds. In organic and cellulosic products, water strengthens the binding effect of Van der Walls forces by increasing the actual contact surfaces of the particles. However, this effect of water is quite critical and depends entirely on the type of material. High moisture content causes the material to slide through the compression holes more easily. This situation reduces the pellet quality considerably. On the other hand, if the moisture content is low, very high pressure is required for the palletization process. This causes the material to become stuck in the mold holes. Such a situation negatively affects the pelletizing process and causes a loss of time [59].

The price per ton of fermented manure and the amount of fermented manure that could be obtained were determined for Turkey and Poland. The economic gain from fermented manure was calculated by multiplying the unit price of fermented manure in tons.

Table 2. Changes in Turkey's livestock population by years ($\times 10^3$).

Year	Animal Breed								
	Cattle	Sheep	Goat	Horse, Donkey, Mule	Poultry	Turkey	Duck and Geese	Pig	Total
2012	12,386	25,032	7277	398	253,712	2761	1033	0	302,599
2013	13,914	27,425	8357	377	266,153	2925	1123	0	320,274
2014	14,415	29,284	9225	363	293,728	2990	1312	0	351,317
2015	14,223	31,140	10,344	342	312,256	2820	1249	0	372,374
2016	13,994	31,508	10,416	320	329,011	3183	1347	0	389,779
2017	14,080	30,984	10,345	310	342,801	3872	1470	0	403,862
2018	17,043	35,195	10,922	273	353,561	4043	1613	0	406,650
2019	17,688	37,276	11,205	259	342,567	4541	1677	0	415,213
2020	17,965	42,127	11,986	223	379,349	4798	1934	0	458,382
2021	17,851	45,178	12,342	202	39,394	4704	2018	0	473,689
Total	137,559	335,149	102,419	3067	3,264,532	36,637	14,776	0	3,894,139

Table 3. Changes in Poland's livestock population over the years ($\times 10^3$).

Year	Animal Breed								
	Cattle	Sheep	Goat	Horse, Donkey, Mule	Poultry	Turkey	Duck and Geese	Pig	Total
2012	5776	267	90	222	112,477	9156	3791	11,581	143,360
2013	5859	249	82	207	117,054	8161	4139	11,162	146,913
2014	5920	223	82	207	129,861	9449	7253	11,724	164,719
2015	5960	228	82	207	146,123	10,320	6824	11,640	181,384
2016	5939	239	44	185	169,033	11,706	6864	10,865	204,875
2017	6143	261	44	185	177,640	12,228	7354	11,353	215,208
2018	6183	277	44	185	182,200	14,173	9705	11,028	223,795
2019	6262	269	50	185	183,121	15,592	10,619	11,215	227,313
2020	6279	278	44	185	182,473	15,892	7408	11,727	224,286
2021	6379	265	54	157	168,629	15,256	6163	10,242	207,145
Total	60,700	2556	616	1925	1,568,611	121,933	70,120	112,537	1,938,998

2.2.8. Total Economic Gain

The total economic gain that can be obtained by adding the total economic gain from electricity and the total economic gain from fermented fertilizer is calculated.

3. Results and Discussion

Turkey's livestock population is given in Table 2, and Poland's livestock population is shown in Table 3.

When the tables of the livestock stock of Turkey and Poland are analyzed, it is seen that Turkey has a greater livestock presence than Poland. The lowest livestock presence in Turkey was in 2017, and the lowest in Poland was in 2021. Moreover, the highest livestock presence in Turkey was in 2021, and the highest livestock presence in Poland was in 2018. It was determined that the lowest share of the animal presence in Turkey was horses, donkeys and mules, while in Poland, it was goats. Furthermore, the highest share of the animal presence in both countries was chicken. The reason for the highest share of chickens in the animal presence is that chickens can meet both the need for cheaply accessible white meat and the need for eggs, which is one of the basic nutrients, and that chicken breeding can be realized in a short time and can be raised at a more affordable cost compared to other animal breeding. The amount of wet manure that can be produced as a result of animal husbandry activities in Turkey is given in Table 4, and the amount of wet manure in Poland is given in Table 5.

Table 4. Available quantities of fresh manure that can be obtained in Turkey (megatons).

Year	Animal Breed								
	Cattle	**Sheep**	**Goat**	**Horse, Donkey, Mule**	**Poultry**	**Turkey**	**Duck and Geese**	**Pig**	**Total**
2012	194,398	21,928	5445	2964	16,669	382	124	0	241,910
2013	218,380	24,024	6253	2807	17,486	405	135	0	269,490
2014	226,243	25,652	6903	2703	19,298	414	158	0	281,371
2015	223,230	27,278	7740	2547	20,515	391	150	0	281,851
2016	219,636	27,601	7794	2383	21,616	441	162	0	279,633
2017	220,986	27,142	7741	2308	22,522	537	177	0	281,413
2018	267,490	30,831	8172	2033	23,229	561	194	0	332,510
2019	277,613	32,654	8384	1929	22,507	630	202	0	343,919
2020	281,961	36,903	8969	1660	24,923	665	233	0	355,314
2021	280,171	39,576	9235	1504	25,715	652	243	0	357,096
Total	2,410,108	293,589	76,636	22,838	214,480	5 078	1 778	0	3,024,507

Table 5. Available quantities of fresh manure that can be obtained in Poland (megatons).

Year	Animal Breed								
	Cattle	**Sheep**	**Goat**	**Horse, Donkey, Mule**	**Poultry**	**Turkey**	**Duck and Geese**	**Pig**	**Total**
2012	90,654	234	67	1653	7389	1270	457	12,681	114,405
2013	91,957	218	61	1541	7690	1132	499	12,222	115,320
2014	92,914	195	61	1541	8531	1311	874	12,837	118,264
2015	93,542	200	61	1541	9600	1431	822	12,745	119,942
2016	93,212	209	33	1378	11,105	1623	827	11,897	120,284
2017	96,414	229	33	1378	11,671	1696	886	12,431	113,067
2018	97,042	243	33	1378	11,971	1966	1169	12,075	125,877
2019	98,282	236	37	1378	12,031	2163	1279	12,280	127,686
2020	98,549	244	33	1378	11,988	2204	892	12,841	128,129
2021	100,118	232	40	1169	11,079	2116	742	11,214	126,710
Total	952,684	2240	459	14,335	91,384	16,912	8447	123,223	1,209,684

When the tables of the wet manure that may occur in the study area are examined, it is determined that the amount of wet manure is 3,024,507 megatons in Turkey and 1,209,684 megatons in Poland as a result of the ten years. In the research area, the most wet manure is found in cattle holdings, although chicken holdings have the highest number of livestock. This may be because cattle's average wet manure production is 43 kg day^{-1}.

One of the biggest problems encountered in livestock farms is waste management. Atılgan et al. [60] stated that the uncontrolled disposal of animal wastes with biogas can be prevented, and environmental health can be protected. Therefore, it can be mentioned that these wastes should be utilized in biogas technology in terms of waste management and environmental protection.

The potential biogas energy obtained from animal waste in the research area is shown in Table 6 for Turkey and Table 7 for Poland.

Table 6. The potential biogas energy that can be obtained in Turkey (GJ).

Year	Animal Breed								
	Cattle	Sheep	Goat	Horse, Donkey, Mule	Poultry	Turkey	Duck and Geese	Pig	Total
2012	2,033,811	54,091	15,602	14,870	221,668	1722	466	0	2,342,230
2013	2,284,712	59,262	17,917	14,085	232,537	1825	507	0	2,610,845
2014	2,366,977	63,279	19,778	13,562	256,630	1865	592	0	2,722,683
2015	2,335,450	67,290	22,177	12,777	272,817	1759	563	0	2,712,833
2016	2,297,848	68,085	22,332	11,955	287,456	1985	608	0	2,690,269
2017	2,311,970	66,952	22,180	11,582	299,505	2416	664	0	2,715,269
2018	2,798,501	76,052	23,417	10,199	308,906	2522	728	0	2,911,419
2019	2,904,412	80,549	24,024	9676	299,301	2833	757	0	3,321,552
2020	2,949,896	91,031	25,699	8331	331,437	2993	873	0	3,410,260
2021	2,931,176	97,624	26,462	7547	341,961	2934	911	0	3,408,615
Total	25,214,753	724,215	219,588	114,584	2,543,312	22,854	6669	0	28,845,975

Table 7. The potential amount of biogas energy that can be obtained in Poland (GJ).

Year	Animal Breed								
	Cattle	Sheep	Goat	Horse, Donkey, Mule	Poultry	Turkey	Duck and Geese	Pig	Total
2012	948,433	577	193	8294	98,271	5712	1711	259,450	1,322,641
2013	962,061	538	176	7734	102,270	5091	1868	250,063	1,329,801
2014	972,078	482	176	7734	113,460	5895	3274	262,654	1,365,753
2015	978,646	493	176	7734	127,668	6438	3080	260,772	1,385,007
2016	975,197	516	94	6912	147,684	7303	3098	243,410	1,384,214
2017	1,008,695	564	94	6912	155,204	7628	3319	254,343	1,429,131
2018	1,015,263	599	94	6912	159,188	8842	4381	247,062	1,433,499
2019	1,028,235	581	107	6912	159,993	9727	4793	251,251	1,451,872
2020	1,031,027	601	94	6912	159,427	9914	3344	262,721	1,464,126
2021	1,047,447	573	116	5866	147,331	9517	2782	229,453	1,433,568
Total	9,967,082	5524	1320	71,922	1,370,496	30,439	31,650	2,521,179	13,999,612

In Table 6, it is shown that the potential biogas energy that can be obtained as a result of the 10-year process is 28,845,975 GJ. Similarly, when Table 7 is analyzed, it is determined that the potential biogas energy that can be obtained from the 10-year process is 13,999,612 GJ. Furthermore, when the tables of Turkey and Poland are analyzed, it is seen that the highest biogas energy can be obtained from cattle wastes. However, the table for Turkey shows that the least biogas energy can be obtained from duck and goose wastes. Moreover, when the table for Poland is analyzed, it is determined that the least biogas energy can be obtained from goat wastes. The number of horses, donkeys and mules in Turkey is lower than that of ducks and geese. However, the potential biogas energy obtained from ducks and geese is lower. The main reason for this is that the unit amount of manure that horses and donkeys can produce is 20.40 kg, which is quite high compared to ducks and geese. Chicken with 0.18 kg of manure per unit has a very low production amount compared to goats with 2.05 kg of manure per unit. However, the potential amount of biogas energy that can be obtained from goats in Poland is the lowest, which is related to the number of animals. The total potential amount of electricity generated from biogas energy is given in Table 8 for Turkey and Table 9 for Poland.

Table 8. The potential amount of electricity that can be generated in Turkey (MWh).

Year	Animal Breed								
	Cattle	**Sheep**	**Goat**	**Horse, Donkey, Mule**	**Poultry**	**Turkey**	**Duck and Geese**	**Pig**	**Total**
2012	565,399	15,037	4337	4134	61,624	478	130	0	651,139
2013	635,150	16,475	4981	3916	64,646	507	141	0	725,816
2014	658,020	17,592	5498	3770	71,343	518	165	0	756,906
2015	649,255	18,707	6165	3552	75,843	489	157	0	754,168
2016	638,802	18,928	6208	3324	79,913	552	169	0	747,896
2017	642,727	18,613	6166	3220	83,262	672	184	0	754,844
2018	777,983	21,142	6510	2835	85,876	701	202	0	895,249
2019	807,426	22,393	6679	2690	83,206	788	210	0	923,392
2020	820,071	25,307	7145	2316	92,140	832	243	0	948,054
2021	814,867	27,139	7356	2098	95,065	816	253	0	947,594
Total	7,009,700	201,333	61,045	31,855	792,918	6353	1 854	0	8,105,058

Table 9. Potential amount of electricity that can be generated in Poland (MWh).

Year	Animal Breed								
	Cattle	**Sheep**	**Goat**	**Horse, Donkey, Mule**	**Poultry**	**Turkey**	**Duck and Geese**	**Pig**	**Total**
2012	263,664	160	54	2306	27,319	1588	476	72,127	367,694
2013	267,453	150	49	2150	28,431	1415	519	69,517	369,684
2014	270,237	134	49	2150	31,542	1639	910	73,017	379,678
2015	272,063	137	49	2150	35,492	1790	856	72,494	385,031
2016	271,105	144	26	1921	41,056	2030	861	67,668	384,811
2017	280,417	157	26	1921	43,147	2121	923	70,707	399,419
2018	282,243	166	26	1921	44,254	2458	1218	68,683	399,751
2019	285,849	162	30	1921	44,478	2704	1332	69,848	404,992
2020	286,625	167	26	1921	44,321	2756	930	73,037	409,783
2021	291,190	159	32	1631	40,958	2646	773	63,788	401,177
Total	2,770,846	1536	367	19,992	380,998	21,147	6248	700,886	3,902,020

It was determined that the biogas energy that can be obtained in Turkey as a result of 10 years by utilizing animal wastes using biogas technology is 8,105,058 MWh and 3,902,020 MWh in Poland. Kozłowski et al. [61] found that animal wastes in Poland have great biogas potential, and the highest electricity generation potential can be obtained from cattle and chicken wastes. Similarly, Ertop et al. [53] reported that cattle wastes have high electricity-generation potential in Turkey. As stated by previous researchers, it can be concluded that animal wastes have great electricity-generation potential in both countries. On the other hand, Wicki et al. [62] reported that the share of energy from agricultural biogas is 0.12% in Poland. In Poland, where a high level of electricity generation can be achieved if animal waste is used in biogas, it can be considered that the waste is not utilized at sufficient levels.

The development of the agricultural biogas market in Poland will accelerate in the coming years thanks to new regulations on market organization. A green certification system has existed in Poland since 2005 [63]. The electricity produced in green certificates is calculated based on a predetermined amount [64]. YEKDEM is a mechanism that supports legal entities that produce electricity through renewable energy sources and have a production license and those that produce without a license [65]. Within the scope of the regulation on the "Use of Renewable Energy Resources for Electrical Energy Production", YEKDEM base and ceiling prices in production facilities based on biogas energy are 81.0 dollars MWh^{-1} and 99.0 dollars MWh^{-1}, respectively [66]. In both countries, biogas energy is supported as a state policy, and the energy obtained has a purchase guarantee. The fact that biogas energy is guaranteed to be purchased shows that the future of biogas facilities is also adopted as a state policy.

The demand for electricity from renewable energy facilities increased yearly in almost all EU countries and Turkey between 2008 and 2018. Turkey has many legal regulations, plans and programs regarding renewable energy. In producing energy efficiency and savings policies, European Union country practices are followed, and the necessary regulations are included in plans and programs. Turkey's renewable energy resource reserves are high. Renewable energy facilities are increasing day by day. However, high installation costs require external resources for power plant investment. The number of incentives implemented in Turkey is high, but the government incentives are still insufficient. Supporting environmentally friendly renewable energies through EU harmonization laws positively impacts these resources. Although the state has created many legal regulations to encourage renewable energy facilities, some bureaucratic obstacles may still occur. When we compare it with the European Union, the state should also support changing consumption behavior rather than just providing production incentives. For example, all public buildings must take precautions, such as replacing their bulbs with energy-saving bulbs and equipping their roofs with solar energy systems. It is necessary to raise public awareness about climate change due to global warming [64]. Moreover, the electricity consumption values in Turkey and Poland are given in Figure 1.

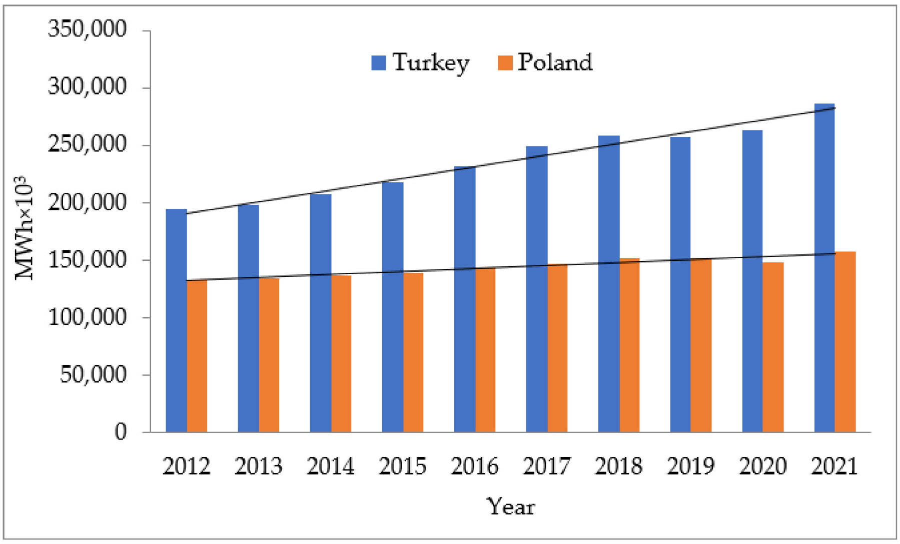

Figure 1. Electricity consumption in Turkey and Poland (MWh × 10^3) [67].

Figure 1 shows that the highest electricity consumption was realized in both countries in 2021. However, when their electricity consumption is compared annually, it is determined that Turkey's electricity consumption is approximately twice as much as Poland's. The main reason for this is that the population of Turkey [68] is greater than the population of Poland [69]. In addition, it can be said that differences in the amount of electricity consumption may be caused by factors, such as different industrial electricity use and urbanization rates. Figure 2 shows the percentage of the total potential electrical energy available in Turkey and Poland that covers the electrical energy used, prepared using Tables 8 and 9 and Figure 1.

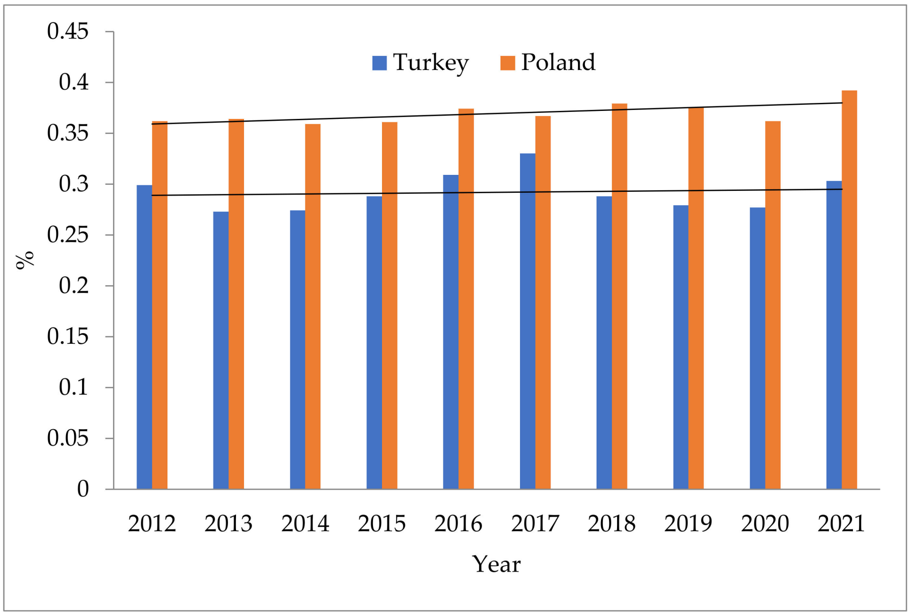

Figure 2. Percentage of electricity available in both countries that cover the electricity consumed (%).

When Figure 2 is analyzed, it is seen that the rates vary annually and are below 1%. The reasons for the low coverage levels are the high amount of electricity used, the limited variety of animal waste included in biogas production and the number of animals. Ertop et al. [53] stated that the total installed capacity of 106 biogas plants in Turkey is 675.42 MW, while Kusz et al. [70] reported that the total installed capacity of 128 biogas plants in Poland is 125.323 MW. Considering the electricity consumption in Table 10, it can be found that the capacity of biogas production facilities in both countries should be increased. In this context, it can be mentioned that more types of animal wastes can be evaluated, the number of animals can be increased and plant production wastes should also be evaluated when designing biogas plants.

Table 10. Economic gains from electricity for medium-sized households.

Year	Turkey			Poland		
	Obtainable Electricity (MWh)	Unit Price * (€·MWh^{-1})	Total Economic Gain (€)	Obtainable Electricity (MWh)	Unit Price * (€·MWh^{-1})	Total Economic Gain (€)
2012	651,139	131	85,299,209	367,694	142	52,212,548
2013	725,816	150	108,872,400	369,684	148	54,713,232
2014	756,906	119	90,071,814	379,678	142	53,914,276
2015	754,168	136	102,566,848	385,031	144	55,444,464
2016	747,896	127	94,982,792	384,811	133	51,179,863
2017	754,844	105	79,258,620	399,419	144	57,516,336
2018	895,249	90	80,572,410	399,751	141	56,364,891
2019	923,392	85	78,488,320	404,992	134	54,268,928
2020	948,054	99	93,857,346	409,783	148	60,647,884
2021	947,594	83	78,650,302	401,177	155	62,182,435
Total	8,105,058	-	892,620,061	3,902,020	-	558,444,857

* The unit price of electricity for medium-sized households.

The unit price of electricity for medium-sized households varies annually [67]. The economic gains that can be achieved if the available electrical energy is used for medium-sized households are given in Table 10.

When Table 10 is analyzed, it is determined that an economic gain of 892,620,061 € in Turkey and 558,444,857 € in Poland can be achieved in 10 years. The amount of biofertilizer that can be obtained is given in Figure 3.

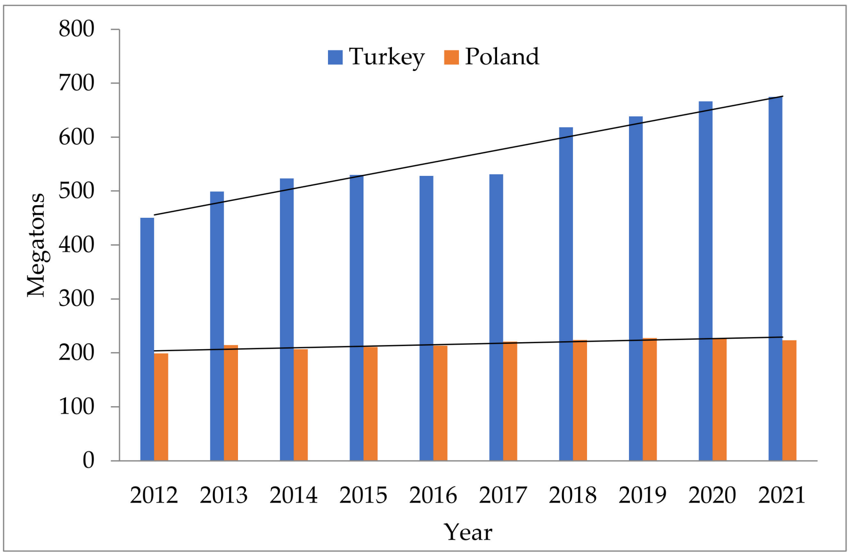

Figure 3. Amount of biofertilizer that can be obtained in Turkey and Poland (megatons).

Figure 3 shows that 565,902 megatons of biofertilizer will be obtained in Turkey and 216,678 megatons in Poland in 10 years. Turkey's price per ton of fermented manure is €16.05 [34]. Poland's price per ton of fermented manure is 20 € [71]. Using the values in Figure 3, the values of the economic gain that can be obtained from fermented manure resulting from biogas production are given in Figure 4.

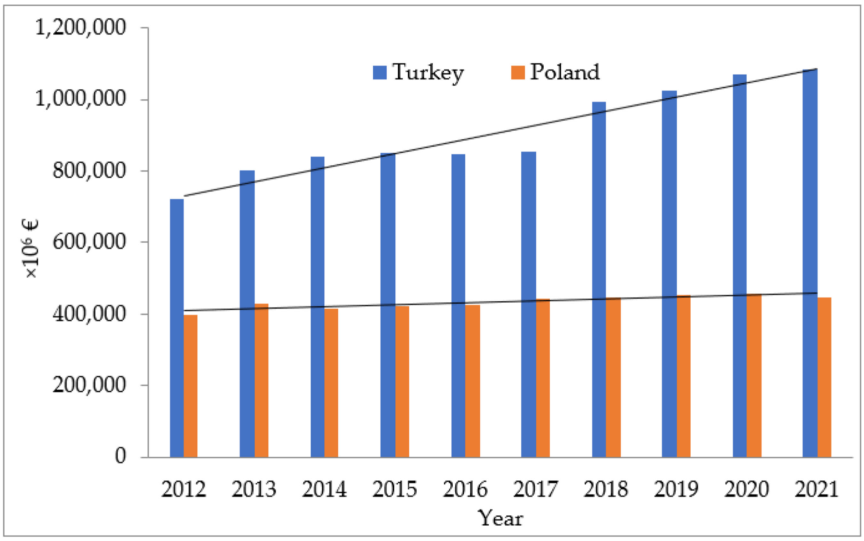

Figure 4. Amount of economic gain from bio-generated fertilizer that can be obtained in Turkey and Poland ($\times 10^6$ € year^{-1}).

Furthermore, when Figure 4 is analyzed, it is determined that an economic gain of 9,082,730 $\times$ 10^6 € in Turkey and 4,333,560 $\times$ 10^6 € in Poland can be achieved in 10 years.

The by-product fermentation waste can be sold to the agricultural operator as high-quality fertilizer. Plants absorb these fermentation wastes more easily than raw liquid or solid farmyard manure. It is also less caustic than raw farmyard manure and is generally odorless. Disease-causing bacteria and parasites are also largely eliminated during production [72]. With proper waste management, they can become a suitable product for both agricultural lands and the environment [73]. In addition, using these fermented fertilizers that can be obtained domestically and exported abroad will provide a great economic benefit to both countries. Using Table 10 and Figure 4, the values of the total economic gains that can be achieved for both countries are given in Table 11.

Table 11. Total economic gains from biogas activities in Turkey and Poland (€·year^{-1}).

Year	Turkey			Poland		
	Income from Obtainable Electricity (×10^6 €)	Income from Biofertilizer Production (×10^6 €)	Total Economic Gain from Biogas Production (×10^6 €)	Income from Obtainable Electricity (×10^6 €)	Income from Biofertilizer Production (×10^6 €)	Total Economic Gain from Biogas Production (×10^6 €)
2012	85.3	722,523	722,608	52.2	397,360	397,412
2013	108.8	800,751	800,860	54.7	428,420	428,475
2014	90	840,266	840,356	53.9	413,480	413,534
2015	102.5	850,201	850,304	55.4	421,680	421,735
2016	95	847,649	847,744	51.2	426,060	426,111
2017	79.2	852,800	852,879	57.5	442,280	442,338
2018	80.5	992,147	992,228	56.4	448,040	448,096
2019	78.5	1,024,183	1,024,262	54.3	454,860	454,914
2020	93.9	1,064,757	1,064,851	60.6	455,400	455,461
2021	78.7	1,082,653	1,082,732	62.2	445,980	446,042
Total	892.4	9,077,930	9,078,824	558.4	4,333,560	4,334,118

In the Table 11 it is determined that a total economic gain of 9,077,930 × 10^6 € in Turkey and 4,334,118 × 10^6 € in Poland can be achieved.

One of the most important factors affecting the profitability of biogas facilities is the level of energy prices and the level of energy production costs [74,75]. Investment in biogas plants is characterized by high sensitivity to price changes from the sale of energy and changes in raw material costs [76,77]. Another factor that determines the profitability of biogas facilities is the energy production scale. The size of the facility should be adjusted to the planned amount of processed raw materials. Suppose the ratio of the size of the facility is not adjusted to the possibility of obtaining raw materials. In that case, capital costs will be too high, which reduces the profitability of the investment and extends the payback period [76,78]. If it becomes difficult to obtain raw materials from outside the enterprise, the profitability of biogas production in biogas facilities decreases rapidly; prices and logistics costs increase [79].

The average electricity consumption of a household is 2.333 MWh·year^{-1} [80]. It is assumed that 2.333 MWh of electricity is the electricity consumption of a medium-sized house where a core family lives. Based on this, the values of the number of dwellings whose electricity needs can be met if the total potential electricity energy obtained in Turkey and Poland is used in households, prepared by utilizing Tables 8 and 9, are given in Figure 5.

When the number of households for which electricity needs can be met is analyzed, it is seen that the highest number of households for which electricity needs can be met in Turkey and Poland is in 2021. Over ten years, it is calculated that 3,474,093 households in Turkey and 1,672,534 households in Poland can meet their electricity needs. When Table 10 and Figure 3 are analyzed together, it can be said that using the available electric energy for the electricity needs of the houses can be advantageous both in terms of economic gains and the number of houses. Gökdoğan [81] and Atılgan et al. [82] stated that the electricity obtained from biogas could be used to heat greenhouses. Furthermore, Ertop et al. [52] found that using the electricity equivalent energy obtained in the lighting and heating of animal barns can give a positive impetus to animal husbandry activities. As stated by previous researchers, it can be said that the electricity that can be obtained can be utilized for applications other than residences, and the electricity obtained from biogas can also provide a gain to different branches of agriculture.

Data on CO_2 emissions avoided due to electricity generation from biogas energy in Turkey and Poland are given in Figure 6.

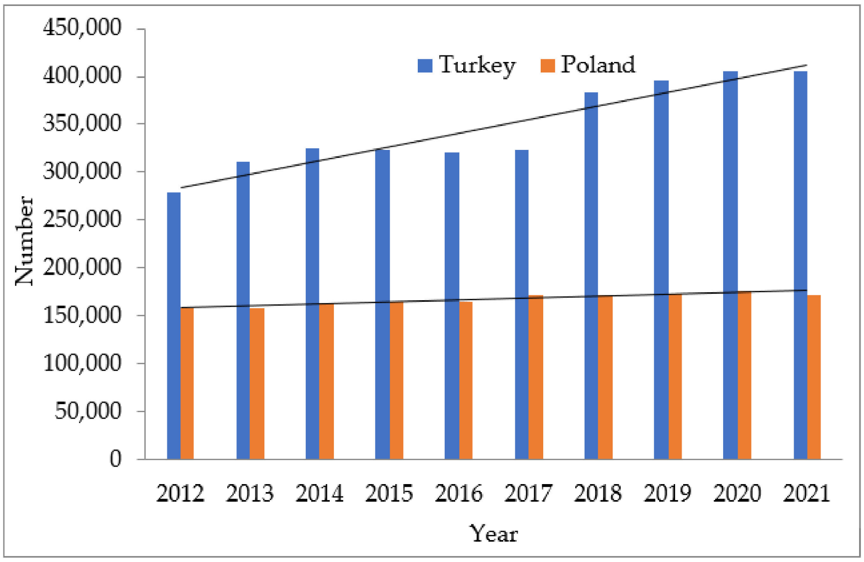

Figure 5. Number of houses that can meet the electricity demand in Turkey and Poland.

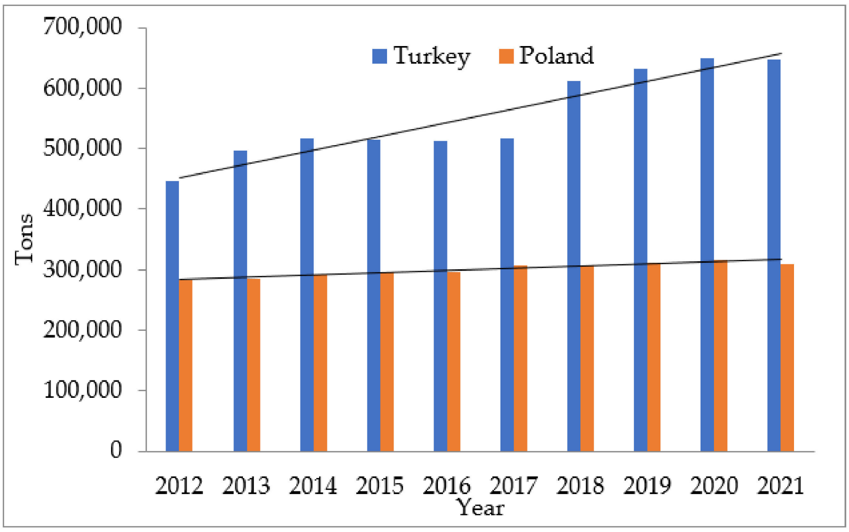

Figure 6. CO_2 emissions avoided as a result of electricity generation from biogas energy (tons).

Moreover, the table of prevented CO_2 emission values determined that 5,543,857 tons·year^{-1} of CO_2 emissions can be prevented in Turkey, with 3,004,552 tons·year^{-1} of CO_2 emissions in Poland, as a result of 10 years. Preventing CO_2 emissions from electricity generation using renewable energy will also reduce the global warming effect. Therefore, it can be said that using animal waste in energy production has economic and environmental advantages.

4. Conclusions

Turkey and Poland have a high potential for biogas feedstock. The utilization of animal waste is crucial in this respect. The biogas utilization of animal waste has many advantages. The most important of these advantages is the potential for electricity generation. At the end of 10 years, it has been determined that the potential energy that can be obtained in Turkey is 8,105,058 MWh and in Poland, this value is equivalent to 3,902,020 MWh of potential electricity. In addition to this equivalent electricity that can be obtained, an economic gain of 892,620,061 € in Turkey and 558,444,857 € in Poland will be achieved. However, it is calculated that the electricity needs of 3,474,093 houses in Turkey and 1,672,534 houses in Poland can be met. These gains can be considered the economic advantages of biogas. In addition to the economic advantages of biogas, it is noteworthy, as an environmental gain, that 5,543,857 tons·year^{-1} of CO_2 emissions can be prevented in Turkey and 3,004,552 tons year^{-1} in Poland.

Due to population growth, energy needs are increasing day by day. Providing energy needs from renewable, environmentally friendly sources instead of fossil fuels is important for economic and environmental protection. In this context, the idea of meeting energy needs with biogas technology is attractive. However, evaluating waste and disseminating biogas technology throughout the country is costly and time-consuming. Considering that large-scale transformation throughout the country will not be possible in the short term, but in the long term, the population will increase. Therefore the energy need will constantly increase, and energy prices may pose a great burden on the country's economy; it is thought that a transformation of this scale can make great contributions to countries in the future.

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