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The Energy Potential of Waste from Banana Production: A Case Study of the Mediterranean Region

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Abstract: Recently, with the development of technology, the number of studies on the need for energy and the possibilities of covering this need in a sustainable way has been increasing. The management of agricultural biomass and waste is cited as one of the challenges as well as a solution. Mersin and Antalya sites, where banana production is intensively practiced in Turkey, were selected as the study region. The potential amounts of energy values obtained from the waste generated during banana cultivation in the field area of study were calculated. The energy potential was calculated on the basis of the conversion of biogas that can be obtained from the waste. The values obtained were analyzed and compared with the levels of electricity used to determine the economic gains that can be achieved for Mersin and Antalya regions. The data on bananas used in study were obtained from the Turkish Statistical Institute (for the years 2016–2020). It is calculated that 2884.43 MWh of electricity can be generated in Mersin and 2218.26 MWh in Antalya per 5 years from the waste generated during banana production. The values of the number of houses whose needs can be met with the calculated five-year potential electricity amount are 1237 in Mersin and 952 in Antalya. It can be considered that reusing the potential energy that can be obtained from banana waste, examined as material for energy, used in agricultural production will result in a positive impetus to agricultural activities. Energy obtained from banana waste can cover a very small amount of the electrical energy needs of agricultural production, ranging from 0.19% to 0.34%. However, it is concluded that the potential amount of energy to be obtained by recycling not only banana waste but also other agricultural and food waste will be even higher.

Keywords: banana waste; electricity; waste to value; waste to energy; economic profits; Mersin; Antalya

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1. Introduction

The increase in the world population raises the demand for energy. Energy prices are constantly rising as the current demand cannot meet the need due to the limited reserves of fossil fuels, which are intensively used to meet the world's energy demand; it is therefore clear that there will be difficulties in meeting the world's energy needs in the coming years. The need for renewable energy resources to meet the rapidly increasing energy demand is rapidly increasing [1]. Climate change is causing significantly challenging and intractable problems around the world. Especially after the Paris Agreement in 2015, great efforts are being made to reduce CO_2 emissions. Among the strategies to reduce the effects of climate change is the use of renewable resources as energy sources [2,3]. Energy consumption is an indicator of the development level of countries and is indispensable for individuals to lead a comfortable life. The increase in energy consumption with developing technology and growing populations presents energy as an important worldwide problem. Today's society is characterized by the production of large amounts of agricultural and industrial residual biomass [2] and waste [4]. To address energy need and the worrying change in climate conditions, alternative raw materials for energy production that promote carbon neutrality are needed [5].

The transition to and implementation of the circular economy model as a regenerative economic model is becoming a challenging task. The aim is to close the life cycle of products through increased and optimized use [6]. For this reason, studies on utilizing renewable energy sources have gained an even greater importance in recent years [7]. Biological materials are among the leading renewable sources used for energy production since the earliest times of humanity. Banana biomass, one of the most promising agricultural wastes for bioenergy production, is mainly grown in tropical and subtropical countries [8]. The banana plant is cultivated in more than 130 countries worldwide and is the second most produced fruit after citrus fruits, providing about 16% of the world's fruit production. Almost 60% of banana biomass is in the form of post-harvesting waste and around 114.08 million metric tons of bananas are wasted, leading to environmental problems, including extreme greenhouse gas emissions [9]. In many countries around the world, banana leaves traditionally play an important role in cooking: they can be used as food wrappers or to wrap grilled meats to enhance food aesthetics. The high moisture content of banana leaves protects the meat and provides it a fragrant aroma [10]. Banana waste is also used as animal feed and the stems are left to decompose for use as organic fertilizer (compost). A well-known and often used way of treating banana waste is to use it in direct energy production. Combustion is defined as direct burning to convert stored chemical energy into heat and electricity. However, it is not ideal due to the high moisture contained in banana waste and results in low energy efficiency as heat is expended to destroy the moisture content [11].

Several research works indicate various methods of banana processing and the application of waste generated during cultivation in new production processes. They support ideas and challenges for the use of treatment waste in new productive chains. Studies are focused on various types of banana waste generated after banana crop cultivation. Fruit waste can be used for different purposes within the scope of biorefinery due to its lignocellulosic nature. In general, they are a renewable raw material to obtain valuable products such as gases, chemicals, and other thermochemical compounds [12]. Furthermore, process residues can be used for biogas and heat production. A biorefinery chain can extract a high-value component present in the biomass, and the process residue is used to convert it into energy. Banana peel can be used for carbohydrate degradation, where 9.9 g of xylose, 0.5 g of XOS, and 8.2 g of glucose were obtained from 100 g of waste [13]. Slow pyrolysis with a heating value of 16.15 MJ·kg^{-1} can be converted into bark vinegar, tar, and biochar for agricultural practice [14].

Banana stalks have high holocellulose and low lignin content and therefore have applications in pulp and paper making. It can be used as a low-cost substrate for the production of ethanol (17.1 g·L^{-1}) after chemical and biological pretreatments for further sugar release [15]. It is reported that its leaves can be used for energy production through incineration (19.8 MJ·kg^{-1}) [13].

Serna-Jimenez et al. [2] evaluate the usefulness of banana peel waste for different renewable energy systems. The valorization of four scenarios to obtain bioethanol from banana peel waste with the lowest environmental burdens indicate the oxalic acid-based scenario as the best solution [16]. Alzate Acevedo et al. [9] provide a comprehensive view of agro-industrial waste generated during banana processing and evaluate their potential uses and practices in different processes such as biofuel production, bioplastics production, wastewater treatment, nanotechnology, etc. Much attention is paid to environmentally friendly solutions. A suitable and promising use of banana waste for eco-friendly bioenergy generation and for developing a circular economy in the banana agroindustry are introduced [17].

The use of products from agricultural waste obtained from the banana plant as different raw materials by undergoing different technological processes and increasing their energy values will play an important role in the recycling and recovery of these waste [18]. It is commonly stated that the use of banana waste represents an extensive opportunity for bioenergy production [8]. There is still an insufficient amount of studies on the contribution of biomass use and applications on energy consumption, especially taking into account the regional and local specificities and related limitations.

Türkiye has a high biomass energy potential, and this potential is currently not being evaluated. Only 10% of the total energy consumption in this country is provided by renewable energy sources, which are hydroelectric and geothermal energy. The International Energy Agency report highlights that in Türkiye, close attention should be paid to the sustainability of its energy sector and its long-term carbon footprint to establish a modern and competitive economy [19]. To meet these challenges, Türkiye has established several renewable energy targets by 2023, including a goal to produce 30 percent of domestic electricity from renewable sources, such as wind, solar, and biomass. The biomass component is set to reach 1000 MWe by 2023 [20]. Achieving these goals is also crucial to reduce the dependence of the Turkish economy on expensive imported fossil fuels. However, considering the total cost of renewable energy production, these sources can be used to supply the energy required in the country [21].

Biomass, a mass of non-fossil organic matter of biological origin, is the most favorable renewable source at the moment [22,23]. Biomass, whose source is agricultural and forest products, food waste, marine plants, industrial, and household waste, is an environmentally friendly, renewable, and locally acceptable energy source that can meet economic needs. Importantly, if biomass is not used as an alternative energy source, this may lead to severe hazards to the environment in the form of discarded materials [22]. Therefore, biomass is considered as a strategic energy source because it can be grown everywhere, contributes to environmental protection, generates electricity, provides heat to homes, fuels vehicles, and provides process heat for industrial facilities [23]. However, the biomass residues are distributed as resources with a diversified spatiotemporal availability, and their energy potential depends on their properties [24].

Biogas technology can be produced anywhere to meet energy needs, as well as reduce pathogens, reduce odor and visual pollution caused by wastes, obtain cheap and environmentally friendly energy, and in addition, the wastes are not destroyed after use but instead turn into a much more valuable organic fertilizer. Biogas is an important renewable energy source in that it can be produced with modern technologies as well as primitive methods in regions where organic waste are found and made ready for use [25].

Banana cultivation in Türkiye is carried out intensively in the Mediterranean region, and waste generated after production cannot be evaluated efficiently. Producers can compost these wastes with different organic and inorganic materials and use them as solid organic fertilizer [26]. However, this process is not preferred by manufacturers in Türkiye due to the need for more time and its higher cost [27,28]. On the other hand, since the disposal of waste materials is considerably costly, these waste materials are spread by the producers inside their greenhouses to improve the soil quality through decomposition. However, an increase in diseases and pests in the greenhouse during the decomposition of these wastes creates a negative effect for the plants [27]. Banana production in Antalya and Mersin provinces takes place for 12 months. Therefore, biomass waste is available throughout the year and after harvest.

The energy potential of these agricultural wastes, which are released after banana cultivation, can be made usable. For this, the focus on the use of these generated wastes should always be turned to high-value processed raw materials or products that meet market demands and create significant economic impacts [29]. Unfortunately, the energy potential of these wastes is still not sufficiently recognized. The literature lacks in descriptions and calculations for the practical use of waste from banana cultivation in the energy sector (especially for the production of electricity for residents). Biogas production is mainly based on the decomposition of organic matter and can be based on crop waste or animal manure.

We therefore hypothesized that the most efficient way to generate electricity would be to produce biogas from banana farming waste and convert it into energy for residents.

Therefore, the aim of this study is to determine the potential electrical energy and usage areas that can be obtained from the waste of bananas, which are widely grown in the selected Turkish regions: Antalya and Mersin. For this purpose, the electrical energy potential of banana waste is calculated, and the percentages of meeting the electrical energy used in agricultural production are shown. In addition, the number of buildings that can meet the electricity need with the potential electrical energy has also been determined. The main novelty of the research is to reveal the potential of banana waste as an alternative raw material to generate electricity with biogas energy without harming the environment in relation to a specific area and its conditions.

2. Materials and Methods

2.1. Material Characteristics

Wastes generated during banana production, such as banana leaves and peels, banana stems (leaf sheath), and wastes generated during the care and cultivation of the banana plant were evaluated. The amount of banana cultivation used in this study and the potential amount of waste to be generated were evaluated as potential energy according to the literature. Waste for the study was obtained from orchards from both regions: Mersin and Antalya. The waste was mixed due to the similarity of the material composition. The weight of each primary sample was 100 kg. Table 1 presents the basic properties of the analyzed banana waste mix, which had a significant impact on the obtained calorific value (based on own study). The physicochemical properties of the banana waste mix were analyzed in accordance with the methodology described by Martin [30], Dziedzic et al. [31], Wolny-Koładka et al. [24], and Malinowski et al. [25,26] in three repetitions. Potential methane yield and caloric value are given as minimum and maximum values (from laboratory test results). The methodology for determining biogas yield (used in these studies) was described, among others, by Niemiec et al. [32] and Sikora et al. [33].

Table 1. Physicochemical characteristics of the banana waste from the Mediterranean region (Türkiye).

Properties	Unit	Value
Moisture content	% of fresh weight	63.7 ± 4.9
Ash content	% of dry mass (DM)	13.1 ± 0.6
Volatile solid (VS)	% DM	86.9 ± 2.2
Total carbon	% DM	36.2 ± 1.2
Total nitrogen	% DM	1.1 ± 0.4
H	% DM	5.1 ± 0.7
S	% DM	0.2 ± 0.1
C:N ratio	-	32.9
Fat	%	1.1 ± 0.2
Protein	mg protein·g^{-1} VS	69.3 ± 0.2
Sugar	mg glucose·g^{-1} VS	262.7 ± 0.2
Hemicellulose	%	23.1 ± 2.5
Cellulose	%	28.1 ± 2.6
Lignin	%	7.3 ± 1.3
Methane yields range	L·kg^{-1} VS	298–328
Calorific value range	kcal·kg^{-1} MJ·kg^{-1}	3800–4300 15.9–18.0

Mean ± standard deviation are the average of three replicated samples.

The chemical and physical characteristics of the analyzed waste are similar to the results developed by Martin [30], Jewiarz et al. [34], and Islam et al. [35], who showed a greater C:N ratio (73.2). According to Khan et al. [36], methane yields ranged between 223 and 336 L·kg^{-1} volatile solids (VS) for banana peel, and between 188 and 334 L·kg^{-1} VS for banana stalk, respectively, while banana flesh may have reached almost 400 L·kg^{-1} VS. They also proved that biogas yield can be higher if banana waste is mixed with vegetables and fruits. The calorific value of banana waste confirms their beneficial use for energy purposes. The obtained results are higher than those reported by Qian et al. [37,38] for selected biomass, lignocellulosic waste, and others.

Thermochemical biomass conversion processes include combustion, gasification, pyrolysis, and liquefaction. The most practiced conversion of biomass industrially is the combustion process, which is used for heat and electricity generation. However, in order to be in line with the principles of the circular economy, this paper assumes that the best solution is to convert biomass to biogas and then to electricity. Biogas is used as fuel for combustion engines, which convert it to mechanical energy, powering an electric generator to produce electricity [39,40]. Biogas production is more circular because the energy obtained is 100% "green", and the waste from the process is a fertilizer, whereas during the production of energy from waste combustion, (apart from the emission of gases and dust into the atmosphere), there are also wastes (ashes) that should be managed in a way other than in agriculture.

2.2. Data for Calculations and Formulas

Considering the production areas between 2016–2020, Antalya and Mersin provinces cover 97.74% of banana production areas in Turkey. For this reason, Antalya and Mersin provinces were chosen as the study area in determining the biomass (banana waste) potential that can be obtained from banana cultivation (Figure 1).

Figure 1. Location of the research area.

Production areas (Table 2) were taken as hectares (ha) and average dry biomass amounts and energy potentials (biogas yield and calorific value) were based on data given in Table 1. An average of 25–30 tons of dry biomass is obtained from 1 ha of field per year and the calorific value of dry biomass varies between 3800 and 4300 kcal (Table 1), which is similar to the results described by Demirel and Pınar [18] and Yorgun et al. [41]. Average values were calculated using the following:

$$B_1 = 25 \times A; \; B_2 = 30 \times A \tag{1}$$

where A is area (ha) and B_1 and B_2 are the minimum and maximum amounts of dry biomass of banana waste (tons), respectively. Average dry biomass amount (tons) is B_{ave} and is calculated using Equation (2):

$$B_{ave} = \frac{(B_1 + B_2)}{2} \tag{2}$$

Table 2. Banana production area (ha) and amount (ton) in the research area.

Year	Banana Production Area (ha)		Banana Production Amount (ton)	
	Antalya	Mersin	Antalya	Mersin
2016	2550.5	3634.7	82,566	221,064
2017	2746.5	3969.9	109,668	253,728
2018	3200.5	4283.4	163,422	327,486
2019	3560.5	4743.4	201,954	333,999
2020	5067.6	5637.1	296,456	405,214

Calculations of dry biomass caloric value are based on Equations (3) and (4):

$$C_1 = B_{ave} \times 3800;\ C_2 = B_{ave} \times 4300 \quad (3)$$

where C_1 and C_2 are minimum and maximum dry biomass calorific values (kcal), respectively.

$$C_{ave} = \frac{(C_1 + C_2)}{2}, \quad (4)$$

where C_{ave} is the average dry biomass calorific value (kcal).

The value of 1 kcal is taken as 10^{-7} TOE (tons of oil equivalent) and dry biomass energy amount is calculated using Equations (5) and (6):

$$D_{ave} = C_{ave} \times 10^{-7} \quad (5)$$

where D_{ave} is the average dry biomass energy amount (TOE).

$$E_{ave} = D_{ave} \times 11.63 \quad (6)$$

where E_{ave} is the average dry biomass energy amount (MWh).

The yield of biogas from food waste and the methodology for calculating the related costs are described in studies by Niemiec et al. [32] and Sikora et al. [33]. The energy that can be obtained from banana waste is compared with electrical energy and its costs are compared. The economic income that can be provided from the electricity produced from banana waste is also determined. The Turkish electricity distribution company (TEDAS)'s prices were used in the calculations.

3. Results and Discussion

When the area and production amounts of banana production are examined, it can be seen that banana production in Antalya and Mersin provinces took place on a total area of 10,704.7 hectares in the year 2020, and the total production in a 5-year period was 2,395,557 tons. It is seen that banana cultivation, which was 2550.5 hectares in 2016 in Antalya, increased by 98.69% in 2020 and reached 5067.6 hectares. In parallel with this, it is seen that banana production increases every year, and in Antalya, it has increased by 259.03% between 2016 and 2020, reaching 296,456 tons in 2020. Similarly, in Mersin province, it was calculated that the banana production areas increased by 55.09% and the amount of banana production increased by 83.30% compared to 2016. It should be mentioned that the high amount of water and organic matter present in banana waste prevents their disposal according to the current legislation (Directive (EU) 2018/850) [42]. A high content of cellulose, pectin, and hemicelluloses in this biomass allows it to be used as feedstock for the generation of bioenergy [9,43]. The banana production area and amount in the research area are given in Table 2.

The average yield of bananas is also growing, albeit less dynamically (Figure 2). The average yield of banana ranges from 32.4 tons per ha in Antalya province in 2016 to 76.5 tons per ha in Mersin in 2018.

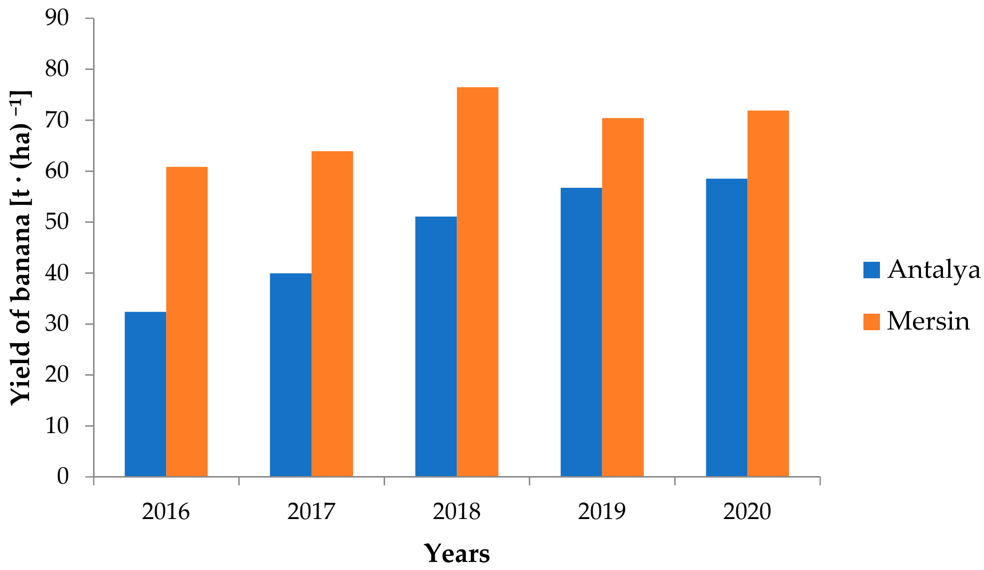

Figure 2. The average yield of banana per hectare in research areas in a 5-year period.

In the next step, it was possible to calculate: average dry biomass amounts (tons) that can be obtained from banana waste (B_{ave}), average dry biomass calorific values (kcal) (C_{ave}), and average dry biomass energy amounts (D_{ave}) (E_{ave}). Results are shown in Table 3. While the average amount of dry biomass that can be obtained from banana waste for Antalya province was 70,138.75 tons in 2016, it was calculated to be 139,359 tons in 2020 with an increase of 98.70%. While this value for Mersin province was 99,954.25 tons in 2016, it was determined to be 155,020.25 tons in 2020 with an increase of 55.09%.

Table 3. Dry biomass and energy values calculated from banana waste.

Year	B_{ave} (tons)		C_{ave} (kcal)	
	Antalya	Mersin	Antalya	Mersin
2016	70,138.8	99,954.3	82,566	221,064
2017	75,528.8	109,172.3	109,668	253,728
2018	88,013.8	117,793.5	163,422	327,486
2019	97,913.8	130,443.5	201,954	333,999
2020	139,359.0	155,020.3	296,456	405,214
Year	**D_{ave} (TOE)**		**E_{ave} (Mwh)**	
	Antalya	**Mersin**	**Antalya**	**Mersin**
2016	28.4	40.5	330.4	470.8
2017	30.6	44.2	355.8	514.2
2018	35.7	47.7	414.6	554.8
2019	39.7	52.8	461.2	614.4
2020	56.4	62.8	656.4	730.2

In one average biogas plant with a capacity of 1 MW, approximately 30,000 tons of biomass, such as banana waste, can be processed annually [44]. As shown in Table 3, the amount of banana waste varies in subsequent years and shows an upward trend. In the Antalya region in 2020, the number of necessary biogas plants would be 5, and in the Mersin region, about 6, respectively. Due to the high potential of energy production from biogas in Turkey, there are currently 36 biogas plants operating there, and another 49 are planned.

These significant and growing biomass amount supports and justifies the need to use this mass for useful purposes, avoiding wastage. Within the limits of socioenvironmental policies is the potential to apply the economic model based on minimizing waste, preserving long-term value, reducing primary resources, and the efficient use of resources through closed production cycles [9,45]. While the amount of biomass energy that can be obtained from the average dry biomass was 330.36 MWh for Antalya in 2016, it became 656.40 MWh in 2020 with an increase of 98.69%. For Mersin province, while it was 470.80 MWh in 2016, it was determined to be 730.17 MWh with an increase of 55.09% in 2020. The energy need of a house is approximately 2332 kWh per year [46,47]. A household's energy use needs vary every day. Between 20:00 and 22:00 is the time when the energy consumption of a medium-sized household is at its highest, and between 14:00 and 18:00 is the time when it is at its lowest. Therefore, the average energy consumption of a medium-sized household on an hourly basis for one day is taken into account [46]. The number of households whose electricity demand can be supplied by using the average dry biomass energy values (E_{ave}) obtained is given in Table 4.

Table 4. Number of buildings whose electricity needs can be covered with the calculated energy amount (unit).

Year	Number of Buildings (Unit)	
	Antalya	Mersin
2016	142	202
2017	153	221
2018	178	238
2019	198	263
2020	281	313
Total	952	1237

The number of households whose electricity needs can be covered in a five-year period is calculated to be 1237 in Mersin and 952 in Antalya. It should be considered that choosing the residences where the electricity needs can be met from the regions where agricultural production is common will be an important criterion for the development of these regions. The ratio of the electricity that can be obtained to the electricity used in agricultural production [48] is given in Table 5.

Table 5. The ratio of obtainable electrical energy to meet the electricity used in agricultural production.

Year	Electrical Energy Used in Agricultural Production (MWh)		The Amount of Electrical Energy That Can Be Obtained (MWh)		The Percentage of Covered Needs for Electrical Energy in Agricultural Production (%)	
	Antalya	Mersin	Antalya	Mersin	Antalya	Mersin
2016	172,504.6	195,967.2	330.4	470.8	0.19	0.24
2017	162,170.4	177,862.5	355.8	514.2	0.22	0.29
2018	174,467.3	178,180.7	414.6	554.8	0.24	0.31
2019	180,281.3	185,305.6	461.2	614.4	0.26	0.33
2020	206,469.0	217,577.0	656.4	730.2	0.32	0.34

The needs for electrical energy in agricultural production can be partially met with energy obtained from the banana waste. This value was 0.19% in Antalya in 2016 and 0.32% in 2020. In Mersin, this value was calculated to be 0.24% and 0.34% in 2016 and 2020, respectively. Ertop and Atilgan [49] stated that in Antalya and Mersin provinces, the ratio of electrical energy that can be produced from biogas energy from greenhouse waste to the electricity used in agricultural production is 100%. This indicates that greenhouse waste should also be taken into consideration in order to meet the electricity used in agricultural production. In a study by Atilgan et al. [50], it was calculated that the total electrical energy that can be obtained from greenhouse waste is 62,557,345.11 kWh. In this context, it can be stated that as a result of evaluating greenhouse waste together with banana waste, more electrical energy can be produced and gains can be obtained by using this form of electrical energy for heating or other purposes, especially in greenhouses. In agricultural production, the average consumption prices of kWh in a 5-year period are: EUR 0.06 for 2016, EUR 0.05 for 2017, EUR 0.06 for 2018, EUR 0.08 for 2019, and EUR 0.06 for 2020 (according to TEDAS prices—electricity distribution company, calculated from Turkisch Liras to Euros) [51].

For the calculation of the initial investment cost of a biogas production plant that is to be designed, it will be useful to plan the capacity of the biogas plant according to this situation, as the availability of raw materials may increase. In addition, in planning the size of the biogas plant, situations such as continuous access to raw materials, the ability to sell bio-fertilizer, and the ability to connect the generated electricity to power lines should be taken into consideration. In addition, consultancy fees, facility maintenance and renovation, the costs of legal permits, employee wages, etc., should also be considered as capital costs. The electrical energy from banana waste and the economic gain values that can be provided to the provinces from the potential electrical energy are given in Table 6.

Table 6. Economic income that can be provided from the electricity that can be produced (Euros).

Year	The Amount of Electrical Energy That Can Be Obtained (MWh)		Economic Income from the Electricity That Can Be Produced (Euro)	
	Antalya	Mersin	Antalya	Mersin
2016	330,360	470,800	19,696.1	28,069.1
2017	355,750	514,220	16,031.7	23,173.1
2018	414,560	554,830	24,783.6	33,169.4
2019	461,190	614,410	35,321.2	47,055.8
2020	656,400	730,170	36,251.4	40,325.5

It has been determined that the production of electrical energy from banana waste in the research area can bring economic income over EUR 132,000 in 5 years for Antalya and almost EUR 172,000 for Mersin in this period. These are financial resources of great importance for the development of the regional and national economy. It also shows that the idea of converting waste to energy is a needed technology for cost-effective and sustainable waste management options and for the generation of renewable energy [52]. Furthermore, to reduce the environmental footprint of banana production, it is essential to treat the waste stream instead of the traditional practice of incineration. Special attention should be paid to the treatment of bioreactor digestion water to further reduce the environmental footprint [53]. Examples of solutions for this type of digestate are described by Malinowski et al. [25] and Michorczyk et al. [54].

In addition to the economic and environmental benefits of using agricultural waste, building eco-energy awareness among the society and farmers is crucial. They are responsible for applying energy-saving and sustainable measures in their households and, in a broader perspective, for the whole economy [7,55]. Moreover, environmentally responsible people are willing to pay more for the 20% portion of green energy they need [56].

Several potential economic benefits associated with producing electricity from banana biomass waste, include:

1. Reduced waste management costs: By using banana biomass waste to produce electricity, banana growers can reduce their waste management costs, as they no longer have to pay to dispose of the waste in landfills.
2. Lower energy costs: Generating electricity from banana biomass waste can help banana growers to lower their energy costs by providing them with a cheaper source of energy than traditional fossil fuels.

3. Increased revenue: Banana growers can generate additional revenue by selling excess electricity produced from their banana biomass waste to the grid or nearby communities.
4. Carbon credits: The production of electricity from banana biomass waste can qualify for carbon credits, which can be sold to companies that need to offset their carbon emissions.
5. Job creation: Establishing a banana biomass waste-to-energy plant can create job opportunities in the local community, both in the construction phase and in ongoing operations.

Overall, the economic benefits of producing electricity from banana biomass waste can help to improve the financial sustainability of banana farming operations, while also contributing to a more sustainable and environmentally friendly energy system.

4. Conclusions

The fact that fossil fuels are exhaustible and negatively impact the environment increases the importance of renewable energy. The rapidly growing energy prices are also a contemporary problem. The continuous availability of agricultural waste brings biogas energy to the fore among renewable energy sources. The use of these waste as an energy source in the provinces of Antalya and Mersin, where agricultural activities are intense, will also contribute to the economy of the region and the country. The research shows the significance of banana waste and its utilization scenario to decrease environmental effects and add value to them. The regular collection, transportation, and storage of post-harvest biomass waste will ensure the continuity of energy production.

It has been concluded that 2218.26 MWh electrical energy in Antalya and 2884.43 MWh in Mersin can be obtained from banana waste in 5 years. With this obtainable potential electrical energy, it has been determined that the electricity needs of 952 houses in Antalya and 1237 houses in Mersin can be met within a 5-year period. It can be hypothesized that the reutilization of potential energy from agricultural waste for energy used in agricultural practices will result in a positive effect on rural development. Results show that proper waste management allows for the closure of production cycles and a reduction in waste accumulation from the banana industry through its use, contributing to the growth of the circular economy and possibly generating real economic and environmental profits. However, it is concluded that the potential amount of energy to be obtained by recycling other agricultural and food wastes alongside banana waste will be even higher.

However, the final amount of potential energy to be generated from banana and other food wastes depends largely on infrastructure conditions. The correlation between the amount of waste or product to be treated locally and the specific energy needs of a population should be met. Consuming agricultural waste to generate biomass requires a great deal of public awareness because a transition to a more sustainable circular model requires a strong public consensus [57]. The benefits of the bioeconomy for the environmental and human well-being can be sustained for a long time if these benefits are wisely identified and achieved [22].

In addition to the utilization of banana wastes with biogas technology, there is also the possibility of composting and utilizing the wastes as biomass. As a result, energy production diversity will increase, job opportunities will be created, and rural and national economies will be developed.

The presented work is limited to the selected area, hence a comparative analysis with other regions with similar farming conditions could be made in subsequent works. An investigation of potential electrical energy from other types of agricultural and food wastes based on different energy conversion technologies, as well as the economic costs for these technologies are the subject of the next research conducted by the authors.

In the future, the authors plan to investigate the suitability of this waste for the production of refuse-derived fuel (RDF) as a result of the bio-drying process in accordance with the methodology presented by Wolny-Koładka et al. [24] and Gajewska et al. [58].

Refuse-derived fuel is an alternative type of fuel obtained from non-recyclable material with high calorific value and in combustible form after separating the recoverable part of municipal or industrial solid wastes. A wide range of solid, liquid, and gaseous wastes with a certain calorific value from domestic, commercial, forestry, agricultural, and industrial areas can be utilized as RDF in waste-to-energy plants or co-incineration plants as a result of the application of various processing techniques [59,60].

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