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Environmental and Economic Analysis of Bioenergy Production and Utilization in Adana Turkey

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Abstract

This work investigates the most feasible ways of processing biological wastes in Adana from energetic, environmental and economic points of view. Energetically, syngas constitutes 59% of bioenergy produced in Adana whereas biogas constitutes 41%. In total, $9.5x10^5$ MWh electricity can be generated from bioenergy of which $5.6x10^5$ MWh comes from syngas. Based on 2020 electricity consumption values, 13.3 % of electricity demand can be met by electricity generated from organic wastes. Substitution of Turkish grid electricity by the renewable electricity and prevention of organic waste decay provide 464 thousand and 391thousand tons of GHG mitigation, respectively. Economically, utilization of certain agricultural wastes as animal feed instead of bioenergy resource appears as a more feasible option. 13.2 billion TL can be gained through sales of animal feed, renewable electricity and organic fertilizer in Adana and 9.25 billion TL of this gain is solely acquired from animal feed. This result confirms the feasibility of evaluating nutritious resources as feed instead of energy resource for syngas production through gasification. Hence, appropriate utilization of biological waste materials can make significant energetic, environmental and economic contributions to a region without creating competition with food or feed resources.

Keywords: Bioenergy production, economic feasibility, greenhouse gas (GHG) mitigation, renewable electricity generation,

1. Introduction

57.7 % of the electricity generation in Turkey for the year 2020 was realized from fossil fuels. Hard coal and natural gas that are imported constitute the majority of the utilized fossil fuels in electricity production. Share of the electricity generated from waste materials was only 1.87 % in the 2020 electricity mix [1]. Excluding hydropower, potentials of other renewable energy resources are underutilized in the country [2]. Electricity generation is responsible form 33% of the greenhouse gas (GHG) emitted in the country for the same year. Also, considering energy resource dependency of the country, it is crucial for Turkey to utilize her renewable energy potential to the fullest [1,3]. Furthermore, Turkey committed to reduce her CO_2 emissions in the ratio of 30% by 2030 under United Nations Framework on Climate Change (UNFCC). Hence, utilizing her renewable energy resources can help meet this target [4].

Our work aims to evaluate potential and utilization pathways of bioenergy, one of the most promising renewable energy sources, in Adana Turkey. To be able to place this work into context, available studies should be reviewed. The studies about bioenergy for Turkey cover several aspects. Policy issues hindering wider adoption of bioenergy [2,5,6], potential assessment for electricity and transportation fuel production from bioenergy [7-10], evaluation of energy crops' potential contribution on bioenergy production [11], impact of bioenergy production on ecosystem services [12] and general assessments of bioenergy production and potential from different resources are the aspects studied [13-18].

While evaluating potential of different renewable energy resources (RER) in Turkey, Barıs et al conclude that bioenergy is the most feasible RER due to its social benefits including local job creation and clean energy access opportunity for rural communities. Policy wise, they emphasize the necessity of establishment of policies specific to each renewable energy because of different characteristics belonging to each energy type [2]. Kaygusuz [5] and Bahadır [6] point out that inclusion of stakeholder view and wishes, social impacts, local job creation potential, potential environmental impacts in construction of policies is vital for wider adoption and success of bioenergy projects [5,6]. Potential assessment of bioenergy from animal and agricultural wastes to generate electricity is estimated by Rincon et al for Turkey. However, they did not consider municipal or forestry wastes in their analysis. Adana is found to be a resourceful location in generating electricity from the accounted biomass types and 0.3 million tons of waste potential is estimated for Adana per year [7]. Bilgili analyze electricity generation from biogas in Mediterranean region of Turkey. He concludes that 6.9% of the electricity demand can be met and 2.6 million tons of CO_2 emission reduction can be achieved in the region [8]. Akyürek reveals that $4.0x10^{10}$ MJ energy can be generated from biogas in Mediterranean [9]. Transportation fuel production potential of Turkey from biological materials is investigated by Emeksiz and Yuksel. They find that Turkey's biodiesel and bioethanol potentials are 1.67 and 13.5 million tons, respectively. However, the resources they evaluate are competing ones with feed and food at the same time such as soybean, sunflower, wheat and corn. Adana Province is also found to be a suitable location for biofuel production in this work [10]. Possible contribution of energy crops on bioenergy production based on shrub willows is assessed by Acar and Gokok. Alleviating the problem of competition with food or feed resources, energy crops are found to be "promising" resources for bioenergy production if grown suitably [11]. Deniz and Paletto analyze how the forest management styles and bioenergy production affect ecosystem services and environmental sustainability. The most negatively affected ecosystem services are found as soil protection and biodiversity. They analyze how these services can be protected by changes in forest management [12]. Lastly, bioenergy potential estimation from different feedstocks is made in numerous works [13-18]. Of those, biomethane (biogas) from animal wastes is estimated to provide 2.9%–3.3% of Turkey's natural gas usage [17]. And, Balat states that bioenergy can create 160 thousand jobs with 17 Mtoe technical potential in Turkey [18].

In this context, our work evaluates biogas and synthesis gas production from biological waste materials in Adana Province. Accounted wastes are agricultural, husbandry, forestry and municipal solid wastes produced in the city. Conversion of biogas and synthesis gas into electricity, utilization of certain agricultural wastes as animal feed instead of bioenergy resource, the resulting economic and environmental benefits are assessed. So, this article investigates most feasible ways of utilizing bio-waste by evaluating Adana Province as a case study. Hence, our work neither focuses on specific waste types nor only bioenergy production as the utilization option. And, the holistic assessment structure of the work is what makes it contribute and add to the existing literature. If this assessment performed specific to Adana is generalized to the whole country it can significantly contribute to the national bioenergy planning.

Organization of the article is that Section 2 presents background information about bioenergy production methods, the energy utilization and available waste materials in Adana. Methodology section presents assumptions and techniques utilized in the study calculations. Section 4 includes the assessment results and discussion followed by the main conclusions derived in the last section.

2. Background

2.1. Bioenergy Production Processes

2.1.1. Biogas Production

Biogas is produced through anaerobic digestion and process slurry can be utilized as organic fertilizer. Polysaccharides, proteins and fats in the organic waste are broken into simpler compounds through a sequence of reactions in O_2 free environment. As a result, CO_2 and CH_4 constitutes the main components of the product [19]. In biogas production, wastes that have high moisture content such as animal manures (bovine, ovine, poultry) and vegetable residues are mainly utilized. These feedstocks are more easily processed by the facultative bacteria performing the anerobic digestion. This clean energy resource can be utilized in electricity generation, heating or transportation after upgrading [19,20]. Table 1 presents available compounds and their volumetric percentage ranges in biogas.

Table 1: Biogas constituents and their volumetric percentage ranges in the composition [19].

Biogas Constituents	Compound Formula	Volumetric Percentage
Methane	CH_4	50-80
Hydrogen	H_2	0-5
Carbon dioxide	CO_2	20-50
Water	H_2O	0-1
Nitrogen	N_2	0-3
Ammonia	NH_3	Trace amount
Hydrogen sulfide	H_2S	Trace amount

2.1.2. Synthesis Gas (Syngas) Production

In essence biomass gasification is an incomplete combustion process where O_2 is utilized less than the stochiometric ratio. Gasification process has 4 phases. Firstly, feedstock is dried to have moisture less than 15%. In following step pyrolysis, volatile organic compounds are evaporated with heat and carbonized compound are left. Carbon and hydrogen in the carbonized feed stock are oxidized in combustion also providing all heat for other process steps. Lastly, reduction takes place to produce mainly CO and H_2 [21]. Small amounts of CH_4 and H_2O are also available in syngas content. Syngas can be utilized in electricity generation as well as H_2 production for hydrogen fuel cells [21, 22].

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The reactants and formed products in combustion and reduction zones are given below.

Combustion Zone

$$C + O_2 \longrightarrow CO_2$$
$$H + 1/2\, O_2 \longrightarrow H_2O$$

Reduction Zone

$$C + CO_2 \longrightarrow 2CO$$
$$C + H_2O \longrightarrow CO + H_2$$
$$C + 2H_2 \longrightarrow CH_4$$
$$CO_2 + H_2 \longrightarrow CO + H_2O$$

2.2. Adana Province

Adana has a very high bioenergy potential due to its geographical conditions and climate. It has an annual bio-waste amount of around 6.0 million tons and only 0.71milliom tons of this amount is processed in Adana Integrated Solid Waste Disposal Facility [23,24]. At the beginning of 2011, this facility that is owned by the ITC company and managed jointly with Adana Metropolitan Municipality started its operations. In the facility, domestic solid wastes of fifteen districts, commercial and institutional domestic solid wastes are sorted, composted and stored regularly, and medical wastes originating from hospitals, treatment and preventive health services are disposed of. The integrated facility consists of a mechanical separation and biomethanization system, a power generation facility, a medical waste sterilization facility and a sanitary landfill. On average, 1950 tons of solid waste collected from residential, commercial and institutional areas are processed daily [24]. Table 2 presents total amount of products and resulting bio-waste in Adana annually.

Table 2: Annual bio-waste quantities from different sources in Adana [23]. (TOE: Tons of oil equivalent)

Animal Type	**Number**	**Waste Quantity (tons/year)**	**Economic Energy Equivalent (TOE/year)**
Bovine	$2.68x10^5$	$2.07\ x10^6$	$4.23\ x10^3$
Ovine	$8.08\ x10^5$	$7.29\ x10^5$	$1.20\ x10^2$
Poultry	$7.25\ x10^6$	$2.22\ x10^5$	$4.10\ x10^4$
Total	$8.32\ x10^5$	$3.02\ x10^6$	$4.54\ x10^4$
Plant Type	**Amount (tons)**	**Waste Quantity (tons/year)**	**Economic Energy Equivalent (TOE/year)**
Field	$5.53\ x10^6$	$2.71\ x10^6$	$6.76\ x10^5$
Garden	$2.20\ x10^6$	4.07E+04	$1.75\ x10^4$
Vegetable	$1.72\ x10^6$	$5.93\ x10^5$	$1.78\ x10^5$
Total	$9.45\ x10^6$	$3.34\ x10^6$	$8.71\ x10^5$
Forestry	NA	$7.88\ x10^5$	$1.76\ x10^5$
Municipal	NA	$7.62\ x10^5$	$1.18\ x10^4$

Around 68.5 % of the husbandry waste comes from bovines that also have the highest energy content. Field wastes constitutes the major part of the waste originating from plant material. Forestry and municipal wastes are almost equal in quantity while forestry wastes have higher energy content than municipal solid wastes [23]. Breakdown of municipal solid waste in Adana for the year 2019 is shown in Figure 1. Of the 762 thousand tons of municipal waste, 495 thousand tons (65%) are organic. 8% of wastes are of plastic while wastes that cannot be sorted (classified as other) constitute 23% of the whole [24].

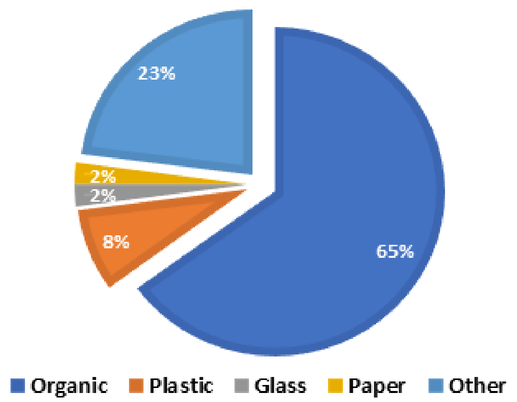

Figure 1: Breakdown of municipal waste in Adana [20].

Adana Province is the most populated city of Mediterranean region and the 6th largest city of Turkey. Beyond agricultural activities, it is also highly industrialized [24]. Hence, produced bioenergy can be utilized in several sectors increasing self-sufficiency of the city. Electricity and natural gas consumption quantities in Adana by different sectors in 2018, 2019 and 2020 are presented in Table 3 [25-30]. On average, 3% of Turkish electricity consumption realizes in Adana. When electricity and natural gas consumption data are analyzed, industrial and household sectors stand out as the main users of both energy resource.

3. Methodology

The scope of this work covers three main parts. The electricity that can be generated from biogas or syngas that are obtained from the waste material in Adana; GHG mitigation potential due to prevention of waste material decay, renewable electricity generation and chemical fertilizer replacement; lastly economic benefits of these activities are examined. This section presents the assumptions and calculation details utilized in our work.

3.1. Renewable Electricity Generation

Biomass energy potential atlas (BEPA) prepared by the General Directorate of Energy Affairs (GDEA) presents biomass energy potential at the country, city and district level sourcing from several biological waste material [23]. Waste data belonging to different biomass types in Adana were classified as suitable for biogas (anaerobic

Table 3: Annual electricity and natural gas consumption in Adana [25-30].

Electricity Consumption (MWh)						
Year	**Lighting**	**Household**	**Industry**	**Irrigation**	**Commercial**	**Total**
2020	1.22 x10^5	1.98x10^6	3.37 x10^6	1.79 x10^5	1.50 x10^6	7.15 x10^6
2019	1.23 x10^5	1.80 x10^6	3.09 x10^6	1.61 x10^5	1.58 x10^6	6.75 x10^6
2018	1.08 x10^5	1.71 x10^6	3.15 x10^6	1.41 x10^5	1.60 x10^6	6.71 x10^6
Natural Gas Consumption (Sm^3)						
Year	**Conversion /Cycle**	**Industry**	**Service**	**Household**	**Other**	**Total**
2020	7.38 x10^7	3.32E+08	2.73 x10^7	1.08 x10^8	2.33 x10^7	5.64 x10^8
2019	7.67 x10^7	2.48E+08	2.84 x10^7	9.67 x10^7	2.29 x10^6	4.52 x10^8
2018	3.17 x10^7	2.83E+08	2.67 x10^7	7.63 x10^7	8.41 x10^6	4.27 x10^8

digestion) or syngas (gasification) production. Animal (bovine, ovine, poultry), vegetable and organic municipal wastes are evaluated as the wet waste types suitable for biogas production. On the other hand, dry wastes that cannot be efficiently used in anaerobic digestion are chosen to be used in syngas production.

3.1.1. Biogas Electricity

In biogas production from animal waste, biogas energy equivalences were readily available as data. Hence, direct conversion of biogas into electricity is calculated according to Equation 1, where j_i is the biogas energy content of waste in question and e_i is the efficiency factor. Energy efficiency for electricity generation from biogas ranges from 8% to 54%. Conversion of biogas into electricity with 31% average efficiency is accepted here [31]. Lastly, the electrical energy calculated in MJ has been converted into MWh electricity by dividing 3600 (1 MWh equals 3600 MJ).

$$E_j = \sum_1^i (j_i e_i)/3600 \qquad \textbf{(1)}$$

The annual average temperature in Adana is 19.2 ^{0}C and the annual minimum is 13.9 ^{0}C [32]. Because of its temperate climate and that mesophilic bacteria like this warm environment, 40% efficiency for biogas production is accepted in Adana [33]. For vegetable and organic municipal wastes, the economic calorific energy values given in TOE (tons of oil equivalent) units are converted to MJ (1 TOE equals 41840 MJ), multiplied by biogas (e_i) and electricity (c_i) efficiency factors and then converted to MWh as presented in Equation 2 [23].

$$E_w = \sum_1^i (41840 t_i e_i c_i/3600) \qquad \textbf{(2)}$$

3.1.2. Electricity from Syngas

The economic energy equivalents for plant, forest and dry organic municipal wastes suitable for gasification were converted from TOE to MJ [19]. For synthesis gas, the thermal efficiency is determined as 0.755. The syngas equivalence was calculated by multiplying 0.755 by the economic energy equivalents in MJ unit. The electrical equivalence is calculated by multiplying the calculated syngas equivalences by using conversion factor of 0.30 [34]. The gasification electrical equivalence was calculated using Equation 3, where t_i is the thermal efficiency, c_i is the conversion factor and j_i is the calorific value of the feedstock in MJ.

$$E_c = \sum_1^i (j_i t_i W_i c_i) \qquad \textbf{(3)}$$

3. Greenhouse Gas (GHG) Mitigation

3.1.3. Substitution of Grid Electricity by Renewable Electricity

When global warming potential (GWP) of the 2020 Turkish electricity mix is examined, GHG emissions of each resource in the mix and their corresponding shares are required. Table 4 presents the share and GWP of each energy resource in the 2020 Turkish electricity mix [1, 35,36]. GWP of 2020 mix is found as 494 g CO_2 eq/kWh when GWP of each resource is multiplied by its share in the mix and results are added up. However, the GWP of the electricity obtained from wastes alone is 4.10 g CO_2 eq/kWh [35,36].

In Equation 4, g_i is the coefficient found by subtracting GWP of waste electricity from the grid GWP value (494-4,1). Using equation 4, the magnitude of GHG emissions mitigated due to substitution of grid electricity by electricity generated from bio-waste is calculated.

$$\text{GHGM}_1 = \sum_1^i (E_{w_i} g_i) \qquad \textbf{(4)}$$

3.1.4. Prevention of Chemical Fertilizer Production

Utilization of the organic fertilizer produced in anaerobic digestion process replaces chemical fertilizer use needs and the GHG emissions due to chemical fertilizer production can be avoided. 0.03% of the weight of wet vegetable waste and 0.051% of wet animal waste is N [37]. Therefore, wet waste amounts are multiplied by 0.3 and 0.51 and the amount of nitrogen in kg per ton of waste is found.

Table 4: Share and GWP potential of different resources in the Turkish electricity mix in 2020 [1,35,36].

Energy Resource	GWP (g CO_2 eq/kWh)	Share in the Mix (%)
Hard Coal	1.06 x10^3	22.14
Lignite	1.13$10^3$	12.38
Natural Gas	4.99$10^2$	23.14
Hydro (Reservoir)	8.30x10^0	18.75
Hydro (Stream)	4.10 x10^0	6.74
Wind	7.30 x10^0	8.11
Waste	4.10 x10^0	1.88
Geothermal	6.30 x10^1	3.28
Sun	2.95x10^1	3.58

In Table 6 section 2, the quantities of CO_2, CH_4, NO_2 emissions corresponding to 1 kg of nitrogen content in the waste are given in grams. In equation 5, m_i is the organic waste amount, N_i is the coefficient used to calculate the amount of nitrogen contained in the chemical fertilizer. Through Equation 5, the quantities of CO_2, CH_4, NO_2 emissions that are reduced by using organic fertilizer instead of chemical fertilizer are calculated.

$$GHGM_2 = \sum_1^i (m_i e_i N_i) \qquad \textbf{(5)}$$

3.1.5. Prevention of Decay of Organic Wastes with Biogas Production.

Prevention of the GHG emissions due organic material decay creates a big opportunity for GHG mitigation as well as having a renewable energy source. Here, the dry weights of organic wastes are needed to calculate the amount of mitigated GHG emissions.

Table 5: Moisture and dry solid values utilized in biogas and electricity production efficiency calculations.

Inputs	Moisture	Dry Solid (d_i)	Ref.
Municipal Organic Wastes	89.0%	11.0%	[39]
Cow Dung	80.0%	20.0%	[40]
Chicken Manure	28.7%	71.3%	[41]
Vegetable Waste	89.0%	11.0%	[39]

Therefore, using the ratios in Table 5, dry weights of bovine, ovine, poultry, plant and organic municipal waste are calculated [39-41].

In Table 6 section 3, the GHG emissions due to decay of each organic material type are presented. Hence, these emissions are avoided by biogas production. Equation 6 stands for the calculation of the mitigated GHG emissions by organic fertilizer production where m_i is the amount of organic waste, d_i is dry solid content ratio, C_i is the grams of CO_2 emitted when 1 kg of dry feedstock decays.

$$GHGM_3 = \sum_1^i (m_i d_i C_i) \qquad \textbf{(6)}$$

Table 6: GHG coefficients utilized in calculations.

GHG Mitigation Sources	Turkey Energy Mix (gCO_2/kWh)	Ref.
1. Fossil fuel sourced electricity replacement	494	[35,36]
2. Chemical fertilizer replacement	g/kg of N	
CO_2	3200	[38]
CH_4	3.1	[38]
NO_2	18	[38]
3. Organic Waste Processed	g CO_2/kg of dry feedstock (C_i)	
Organic Municipal Wastes	420	[42]
Cow Dung	447	[40]
Chicken Manure	447	[41]
Vegetable Waste	420	[42]

3.2. Economic Assessment

3.2.1. Animal Feed

Majority of the agricultural wastes are burned in Adana. The economic return of using these nutritious wastes as animal feed instead of burning is particularly important. By using the current feed prices in 2022 [43-45], the financial value of the feed is calculated by multiplying the quantity by the unit price for each feed type as presented in Table 7. Although these dry feedstocks could have been used to produce syngas and from syngas electricity, utilizing them as animal feed is determined to be more feasible for Adana's economy.

3.2.2. Sales of Generated Renewable Electricity

The active energy unit price for electricity that is being sold to the grid before transmission is determined to be 0.78919 TL/kWh [46]. In the light of this information, the income that can be obtained from electricity is calculated by multiplying the unit price with the amount of electricity as shown in Equation 7. Here, u_i is the unit price of electricity in 2022 and E_i electricity generated in kWh.

$$EG_1 = \sum_1^i (E_i u_i) \quad \textbf{(7)}$$

Table 7: Amounts of nutritious wastes in Adana and their market value in 2022 [43-45].

Plant	Waste Amount (tons)	Feed Price (TL/ton)
Barley	11837	4100
Safflower	151.50	65000
Sunflower	406270	3750
Wheat	681905	3500
Rye	200.80	1750
Rapeseed	36.800	5000
Corn	1011240	4150
Cotton	220408	4000
Potato	43815	3000
Sugar Beet	1021.2	1000
Sesame	2581.5	26875
Triticale	249.60	1750
Oat	33.6	1900

3.2.3. Sales Revenue of the Organic Fertilizer Produced

Solid and liquid organic fertilizers are produced as byproducts of anaerobic digestion process. The liquid portion is determined to be given free as an incentive in return for the cooperation of the farmers in collecting the waste and delivering it to the facility. 50-75% of the dry weight of organic waste is converted into solid organic fertilizer in biogas production [47]. In this study, 62.5% conversion is accepted. The calculation of the total amount of organic fertilizer obtained is given in Equation 8. Here, f_i is the coefficient used to calculate how much of the organic waste is converted into solid organic fertilizer.

$$O_f = \sum_1^i (m_i f_i) \quad \textbf{(8)}$$

The price of a ton of organic fertilizer varies between 500 and 800 dollars in 2022 [48]. It has a value above the average market price for chemical fertilizers since the organic fertilizer produced will be completely composed of biological content without mixed chemicals. Since the municipality will be selling this fertilizer, it has been decided to sell 1 ton of organic fertilizer for $400 at a subsidized price. The exchange rate was taken as 14.5 TL/$ to convert US Dollar to Turkish Lira as presented in Equation 9. Here, l_i is the coefficient representing the unit price of one ton of organic solid fertilizer, b_i is exchange rate between TL to $.

$$EG_2 = \sum_1^i O_f \, l_i \, b_i) \quad \textbf{(9)}$$

4. Results and Discussion

4.1. Electricity Generation

Although dry weights of the wastes suitable for biogas production are more than that of the wastes suitable for syngas production (0.82 versus 0.54 million ton) in Adana, higher conversion efficiency of waste to syngas transformation produces more energy than waste to biogas transformation. Hence, syngas constitutes 59% of the energy in electricity generation whereas biogas constitutes 41% (6.7×10^9 MJ syngas versus 4.5×10^9 MJ biogas). Rincon et al. [7] estimate 0.3-2.65 million tons of bio-waste availability per year for Adana Province. Our 1.36 (0.84 and 0.54) million tons of bio-waste calculation is well in accordance with this range. Furthermore, Akyurek [9] calculates biogas energy potential of Adana Province as 1.1×10^{10} MJ per year. 4.5×10^9 MJ biogas potential we calculate is lower than this value since some wastes are dedicated to animal feed and syngas production as more feasible utilization paths in our work.

The electricity generated from different waste resources in Adana can be seen in Figure 2. Animal, plant and municipal wastes are utilized to produce biogas. Dry wastes such as shells of nuts, forest residues are utilized in syngas production through gasification. High energy content of the waste material gasified produces substantial amount of syngas resulting in being the dominant source of energy in renewable electricity generation. A total of 9.5×10^5 MWh electricity is generated from the waste material of which 5.6×10^5 MWh is generated from syngas followed by plant waste sourced biogas. Results show that the electricity generated from waste material can meet 13.3 % of the electricity demand in Adana based on 2020 consumption and production values. Bilgili [8] finds that biogas sourced electricity can meet 6.9% of the electricity demand in Mediterranean Region also stating that Adana is the city with highest bioenergy potential of the region. Hence, 13.3 % meeting ratio for Adana can be explained by Adana's high bioenergy potential and additional syngas production.

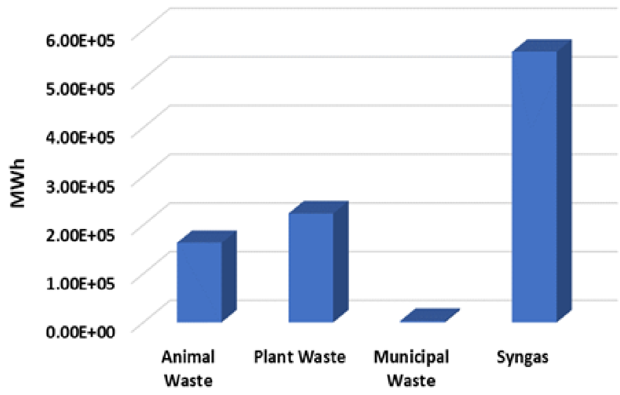

Figure 2: Electricity generation from different organic wastes in Adana Province.

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4.2. GHG Mitigation

Figure 3 shows the comparison of nitrogen content of the waste material types. The animal originated organic waste contains more nitrogen than the plant and municipal wastes, proportionally. Bovine waste contains the highest quantity of nitrogen due to both high waste amount and nitrogen content. However, since the amount of plant waste is significantly higher than that of poultry waste, plant waste contains more nitrogen than poultry waste in absolute terms. The nitrogen content of wastes is important in GHG emissions during the course of biological material decay.

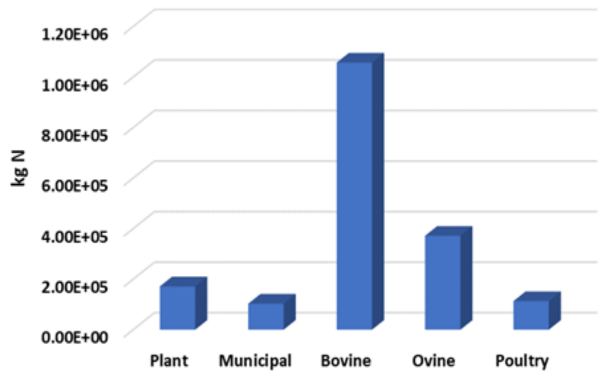

Figure 3: Nitrogen content comparison of different organic waste types in Adana Province.

Turkish electricity grid has a GWP of 494 g CO_2 eq/kWh for the year 2020. Substitution of the grid electricity by the renewable electricity generated from the wastes in Adana results in 464 thousand tons of CO_2 eq. GHG emission mitigation as can be seen in Figure 4. This makes the renewable electricity the major source of GHG emission reduction followed by the avoided emissions due to organic waste decay and chemical fertilizer production. 391 thousand tons of GHG can be avoided due to the prevention of biological waste decay in Adana.

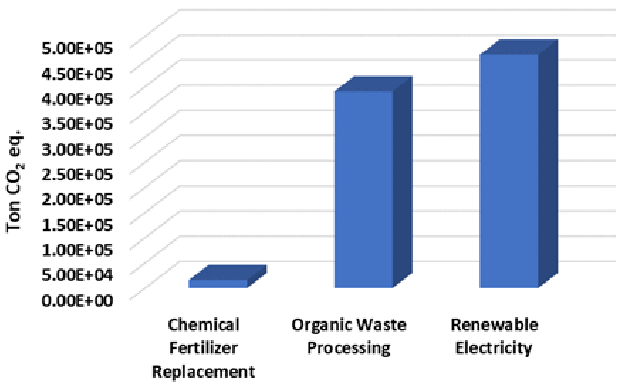

Figure 4: GHG mitigation from different resources in Adana Province.

Bilgili [8] and Akyurek [9] estimate 2.65 and 27.0 million tons of CO_2 emission prevention for Mediterranean region due to substitution of the grid electricity and coal sourced electricity by the electricity from biogas. Akyurek's [9] high result is due to substitution of coal (energy source with the highest GHG emission). 464 thousand tons of GHG mitigation due to grid electricity substitution and 1.01 tons of total GHG mitigation results for Adana are then in harmony with their results.

4.3. Economic Gain

Figure 5 presents the economic benefits acquired from different sales. High level of agricultural activity and the resulting nutritious waste that can be used as animal feed becomes the major source of income gained from the waste material in Adana. Organic fertilizer produced as a by-product of anaerobic digestion together with biogas is sold at a price of 400$/ton and provides 3.3 billion TL income at an exchange rate of 14.5 TL/$. Although the renewable electricity is the major GHG reducing factor, the least economic benefit is gained from the renewable electricity sales with 0.79 TL/kWh unit price. Totally, these sales can provide13.2 billion TL to Adana's economy of which 9.25 billion TL solely comes from the animal feed sales. This result confirms the feasibility of evaluating resources given in Table 6 as feed instead of energy resource for syngas production through gasification.

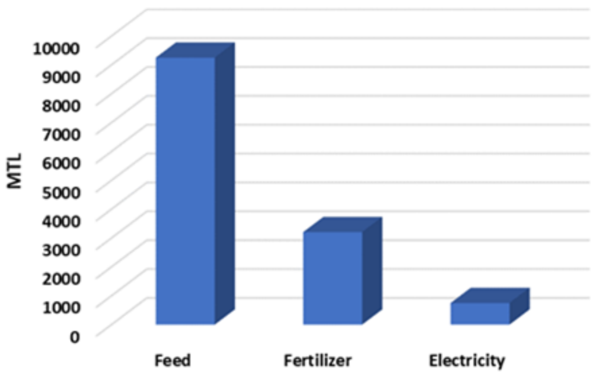

Figure 5: Economic gain from different resources in Adana.

Economic gain acquired from biomass reported in literature depends on utilization pathways and assumptions of the works as well as the value of currency at the time of each study. Hence, stating a robust value is not feasible. However, Balat [18] points that bioenergy can create 160000 jobs in Turkey and can make significant contribution to the economy. That bioenergy has significant economic potential is also the main result of other studies [7, 8, 9] which is also in accordance with our result.

5. Conclusions

This work investigates the bioenergy potential of Adana Province from biological waste materials that are the by-products of agricultural, husbandry, forestry activities and also including municipal organic wastes. Conversion of these materials into biogas and synthesis gas and then into electricity is studied from energetic point of view. Study scope also covers utilization of certain agricultural wastes as animal feed instead of bioenergy resource. Furthermore, the economic and environmental benefits of these interventions are assessed. Hence, our work investigates the most feasible ways of utilizing bio-waste by evaluating Adana Province as a case study. As a result, generalizing this holistic assessment to the whole country can significantly contribute to the national bioenergy planning of Turkey.

Energetically, syngas constitutes 59% of the bioenergy produced whereas the remaining 41% is biogas from 1.36 million tons of biomass in Adana, annually. This situation is due to the higher conversion efficiency of waste to syngas transformation process that produces more energy than waste to biogas transformation. 1.36 million bio-waste amount calculated for Adana is well in accordance with Rincon et al.'s [7] 0.3-2.65 million tons of bio-waste availability estimation range for the city. Although lower biogas potential of $4.5x10^9$ MJ than Akyurek's [9] $1.1x10^{10}$ MJ of biogas estimation is calculated here. This can be explained by dedication of some wastes to animal feed and syngas production as more feasible utilization paths in our work.

Based on 2020 electricity consumption values in Adana, 13.3 % of electricity demand can be met by the electricity generated from organic wastes. This higher ratio than Bilgili's [8] 6.9 % estimation for Mediterranean can be explained by Adana's high bioenergy potential and additional syngas production.

Substitution of Turkish grid electricity mainly generated from fossil resources by the renewable electricity generated from waste in Adana results in 464 thousand tons of CO_2 eq. GHG emission mitigation. This makes the renewable electricity the major source of GHG emission reduction for the city. Nitrogen content is important in GHG emissions during the course of biological material decay. Processing of biological wastes creates a great opportunity for GHG mitigation as well as having a clean and renewable energy resource. In Adana, bovine wastes are found to have the highest quantity of N content and 391 thousand tons of GHG can be avoided due to prevention of biological waste decay in Adana. Also, 1.01 tons of total GHG mitigation calculated for Adana is determined to be in harmony with literature values.

Economically, 13.2 billion TL can be gained through sales of animal feed, renewable electricity and organic fertilizer. 9.25 billion TL of this gain is solely acquired from animal feed. This result confirms the feasibility of evaluating nutritious resources given in Table 6 as feed instead of energy resource for syngas production through gasification. Organic fertilizer that is a by-product of biogas production contributes 3.3 billion TL to Adana's economy and the least economic benefit is gained from the renewable electricity sales. That bioenergy has significant economic potential is the main result of many studies [7, 8, 9, 18] which is also in accordance with what we conclude economically.

All in all, this work reveals that appropriate utilization of biological waste materials can make significant energetic, environmental and economic contributions to a region without creating competition with food or feed resources.

Author's Contributions

Deniz Pesen: Performed study calculations under supervision of Dr. Berrin Kurşun and drafted the manuscript.
Görkem Gençay: Performed study calculations under supervision of Dr. Berrin Kurşun and drafted the manuscript.
Berrin Kurşun: Supervised the study, rewrote and edited the manuscript.

Ethics

There are no ethical issues after the publication of this manuscript.

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