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Determination of Biogas Potential of Livestock Manure: A Case Study from Mersin Province

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Abstract

Rapidly growing population, ever-evolving industrialization, increasing energy and fertilizer prices with the decreasing natural resources caused the interest in biogas technology. At this point, waste produced from livestock farming is a good source for biogas production either on farm scale or as cooperatives involving several farms of a whole region. In this study, it was aimed to determine the potential of biogas from accessible animal manure such as bovine, ovine and poultry in Mersin province and its equivalence to other types of fuels by the information obtained from the literature. When the animal existence is examined based on districts of Mersin province, it is seen that there are 20,200,937 farm animals in total. In the direction of this numerical data, the total amount of calculated annual manure is 1,752,474 ton/year, while the amount of usable/collectible animal manure is 1,009,452 ton/year. It has been determined that biogas of about 60 million m^3 per year can be theoretically obtained from the sum of the animal manures and this value can produce electric energy of 280 GWh per year. It has been determined that a total of 128,609,656 TL (21,217,378 $) in electricity consumption can be achieved in the district by using animal manure in biogas production. It is also estimated that the biogas produced could meet the need for 1 year cooking energy for approximately 106,606 households. It has been determined that the utilization of animal manures will make an important contribution to Mersin in terms of socio-economic development.

Keywords: Animal manure, Biogas, Electricity, Livestock farming, Mersin

1. INTRODUCTION

Due to the limited availability of fossil fuel reserves, the importance of energy procurement in sustainable development is increasing steadily. On a global scale, it is predicted that energy consumption will increase by 28 percent until 2040 and a large part of this increase will be due to the developing countries. Green energy and new technologies are emerging as priority issues while energy politics is being dealt with nowadays. For this reason, renewable energy is expected to stand out as the world's fastest growing energy source [1].

In the search for all this energy source, biomass energy is the new alternative which has been prominent and demanded among the energy sources in recent years. Encouragement of biomass-related investments, which experts describe as an inexhaustible source of energy, is one of the priorities of the energy sector worldwide. In addition, the conversion of biomass resources to energy is very important because of its positive environmental impacts. When the optimum balance between raw materials and production technologies is established, biomass energy can be produced in an environmentally sensitive manner [2]. Biomass energy will be sustainable if the reduction in carbon emissions and increased economic efficiency are correctly assessed [3].

Nowadays, Turkey's waste biomass potential is about 8.6 million tons of oil equivalent (Mtoe) and the amount of biogas that can be produced is estimated to be 1.5-2 Mtoe by the end of 2017, 634.2 MW of installed power of 122 pieces “waste renewable energy plant” (biogas, biomass, waste heat and pyrolytic oil) is operated in Turkey. This corresponds to approximately 0.7% of Turkey's total installed power base. Biomass-derived electricity production was 1.610 GWh at the end of June, 2018 [4].

Biogas production processes are at the forefront of the most up-to-date technology in which biomass energy is actively produced. It is a flammable gas obtained as a result of the processing of biomass and is derived from organic raw materials, unlike other gases. In addition, energy plants such as corn, barley or sugar beet [5], municipal or industrial wastes [6], animal manure [7], timber wastes [8], forest [9] and agricultural residues [10] etc. can be used as raw material in biogas production. Biogas; to be stored as a flexible energy carrier, the availability of a wide variety of biological resources

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that can be used for production and the advantages of having a wide range of applications, it has an important position in heating, transportation and electricity generation etc. [6].

The use of animal and agricultural wastes, which play an important role in terms of raw material quality for alternative energy production, is gaining importance in terms of environmental and energy optimization within sustainable development models. In particular, animal solid wastes are regarded as the ideal source for the production of biogas (65% CH_4, 35% CO_2) after being subjected to biological treatment [11]. Some of the animal manures are used in agriculture as organic fertilizer, but these wastes, especially stored in open fields on the farms, cause mosquitoes and other pests to replicate. In this way, such nonpoint source (NPS) pollution is transported to other environments and creates non-hygienic conditions. In addition, the odor problem that emerges is an undeniable issue. Uncontrolled disposal and storage of such wastes also lead to contamination of groundwater and surface waters. The evaluation of these wastes is very important in terms of the country's economy and environmental health. In particular, the use of animal manure for energy production presents significant opportunities in areas where intensive stockbreeding is being implemented [12].

In Turkey, as well as all over the world, animal products are the most important resource in society adequate and balanced nutrition. Animal husbandry is crucial not only in the provision of food but also in the protection of rural areas, the protection of biodiversity and the raising of living standards in rural areas.

Mersin province is located between 36-37 ° north latitude and 33-35 ° east longitude in southern of Turkey and located on the Mediterranean coast and called as "Pearl of the Mediterranean". The total area of Mersin is 16,010 km^2, making it the 9th largest province in the country. In this study, firstly the production potential of livestock manure in Mersin province and districts has been defined. Then, depending on the data obtained, biogas production potential of livestock manure and equivalent quantities of other fuels of this potential are calculated in the province. In addition, bio-fertilizer potential which can be produced after biogas production is calculated.

2. MATERIAL AND METHODS

In this study, for the determination of the biomass potential of Mersin Province, waste manure amounts of bovine, ovine and poultry were evaluated. To obtain the necessary numerical values, Turkey Statistical Institute (TUIK) data of 2017 was used [13]. According to this data, the biogas quantities that can be obtained from accessible animal wastes and the conversion capacities of different types of effective fuels that can be obtained from 1 m^3 biogas have been calculated. The assumptions that can be used in the calculation of the biogas potential that can be obtained from animal wastes and the biogas values that can be produced are given in Table 1 [14-16]. In addition, the effective heat of 1 m^3 biogas and the equivalent of different fuel types are presented in Table 2 [17-20].

Table 1. Theoretical manure and biogas amounts produced per year depending on animal class

Animal Species	Amount of manure produced per animal (ton/year wet manure)	The amount of biogas that can be obtained from one ton of manure (m^3/year biogas)
Bovine	3.6	33
Ovine	0.7	58
Poultry	0.022	78

Table 2. Equivalent to different fuel types of effective heat of biogas (1 m^3)

Energy Type	Equivalent	Energy Type	Equivalent
Electric	4.70 kWh	Butane	0.43 kg
Gas	0.62 L	Propane	0.25 m^3
Diesel	0.66 L	Coal	1.46 kg
Gasoline	0.75 L	Wood	3.47 kg

3. RESULTS AND DISCUSSION

3.1 Theoretical Animal Manure Potential of Mersin Province

There are 20,200,937 livestock including 115,120 bovine, 1,321,761 ovine, and 18,764,056 poultry in Mersin Province. Distribution of total livestock numbers in districts of Mersin Province is given in Figure 1 and initial data including the population of each animal species per districts are given in Table 3 and determined using TUIK data for the year 2017. Generally, potential values are taken into account when estimating animal manure generation data for different animal species, but in practice only a specific fraction of this manure can be collected. The amount of manure can be accessed according to the study conducted for the biogas potential in Turkey has been described as technical biogas potential. In this case, 50% of the current manure of bovine is considered collectible, while for poultry this value is chosen as 99%. In some studies, collectible bovine manure was accepted at 50% for western region while those at the east was accepted at 15%. In this study, acceptances for collectible manure rates were determined as 41% for bovine-ovine and 99% for poultry by taking an average of pasture (3 months) and other months (9 months) [21]. Estimation of the collectible manure amount per year was calculated by multiplying the amount of manure produced per animal species by the collectible manure rate after multiplying with the relevant animal population. Theoretical and collectible manure quantities that can be obtained annually by considering the population of each animal species in Mersin province are given in Table 4. Total theoretical and collectible livestock manure based on districts of Mersin are given in Figure 2.

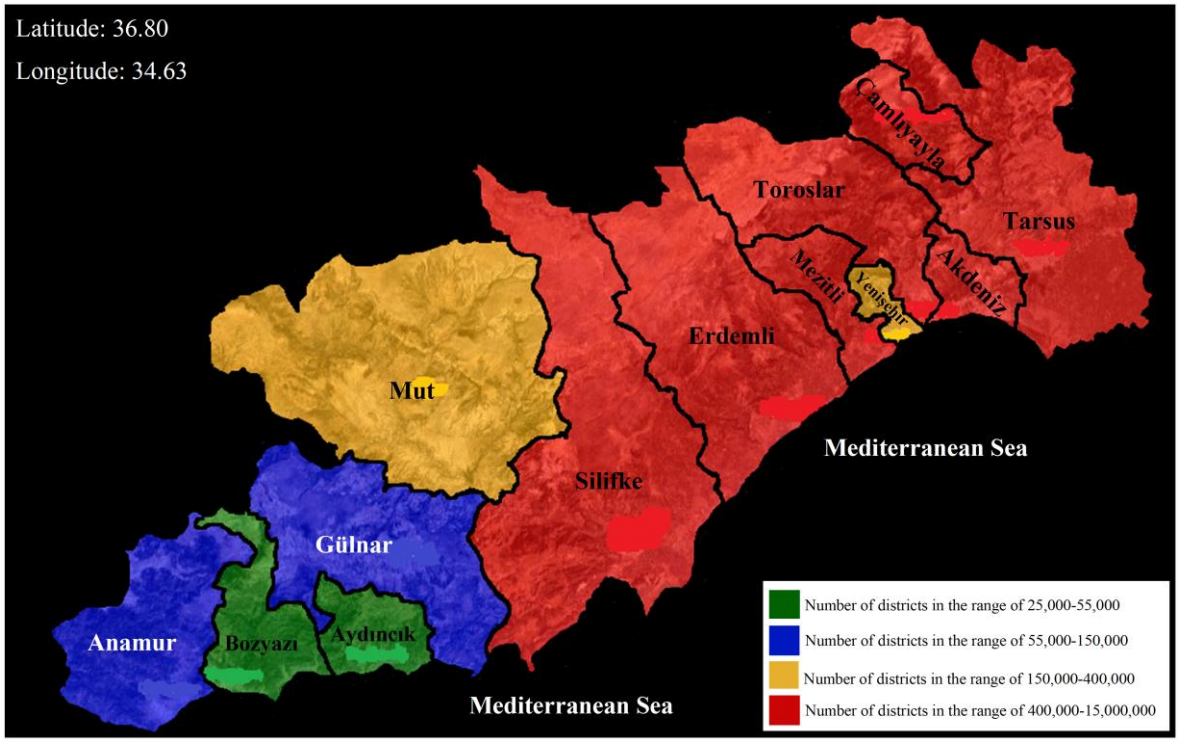

Figure 1. Distribution of total livestock numbers in districts of Mersin Province

Table 3. Distribution of livestock numbers according to districts of Mersin

Districts	Bovine	Ovine	Poultry	Total
Akdeniz	13,279	79,856	1,671,400	1,764,535
Anamur	3032	39,086	55,213	97,331
Aydıncık	424	37,741	3250	41,415
Bozyazı	1133	31,369	4905	37,407
Çamlıyayla	1631	43,564	903,290	948,485
Erdemli	8550	218,768	281,350	508,668
Gülnar	6283	91,635	51,925	149,843
Mezitli	2167	36,097	985,497	1,023,701
Mut	20,403	178,848	172,792	372,043
Silifke	12,737	200,376	187,910	401,023
Tarsus	37,956	275,710	12,450,630	12,764,296
Toroslar	5849	60,701	1,757,250	1,823,800
Yenişehir	1676	28,070	238,644	268,390
Total	**115,120**	**1,321,761**	**18,764,056**	**20,200,937**

Table 4. Theoretical and collectible manure quantities that can be produced per year in Mersin

Districts	Theoretical manure (ton/year)				Collectible manure(ton/year)			
	Bovine	Ovine	Poultry	Total	Bovine	Ovine	Poultry	Total
Akdeniz	47,804	55,899	36,771	140,474	19,600	22,919	36,403	78,922
Anamur	10,915	27,360	1215	39,490	4475	11,218	1203	16,895

Aydıncık	1526	26,419	72	28,017	626	10,832	71	11,528
Bozyazı	4079	21,958	108	26,145	1672	9003	107	10,782
Çamlıyayla	5872	30,495	19,872	56,239	2407	12,503	19,674	34,584
Erdemli	30,780	153,138	6190	190,107	12,620	62,786	6128	81,534
Gülnar	22,619	64,145	1142	87,906	9274	26,299	1131	88,212
Mezitli	7801	25,226	21,681	54,708	3198	10,343	21,464	35,005
Mut	73,451	125,194	3801	202,446	30,115	51,329	3763	85,208
Silifke	45,853	140,263	4134	190,250	18,800	57,508	4093	80,400
Tarsus	136,642	192,997	273,914	603,552	56,023	79,129	271,175	406,327
Toroslar	21,056	42,491	38,660	102,207	8633	17,421	38,273	64,327
Yenişehir	6034	19,649	5250	30,933	2474	8056	5198	15,728
Total	**414,432**	**925,234**	**412,810**	**1,752,474**	**169,917**	**379,346**	**408,683**	**1,009,452**

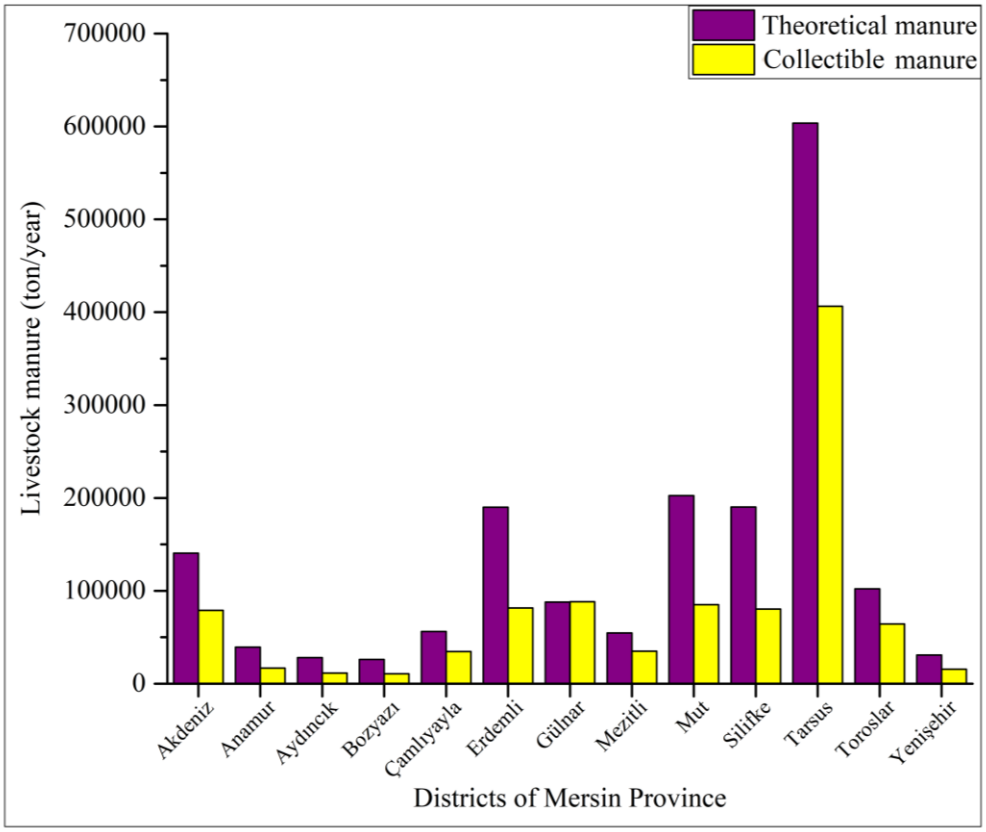

Figure 2. Total theoretical and collectible livestock manure based on districts of Mersin

3.2 Theoretical Biogas Production Potential from Animal Manure in Mersin Province

When biogas potential that can be obtained according to animal species is examined, it is estimated that more biogas can be produced from poultry in proportion to the amount of animal fertilizer that can be collected in Mersin Province. Due to the fact that the bovine and ovine livestock are carried out in the grassland and the control of waste manure in the pasture areas cannot be provided, the biogas production potential from the livestock activity is technically low despite the fact that it is high in theory. Theoretical biogas production potential calculated by taking into consideration collectible animal manure in Mersin province is given in Table 5. In accordance with the calculations performed, the biogas potential from animal manure across Mersin has been

determined as 59,486,428 m^3/year. Theoretical biogas production potential according to manure type in Mersin province is given in Figure 3.

When the seasonal effect is considered, the amount of collectible manure is increased by making livestock in enclosed areas in winter months. This is an indication that biogas production potential may change depending on the waste variability that can be achieved during summer and winter months.

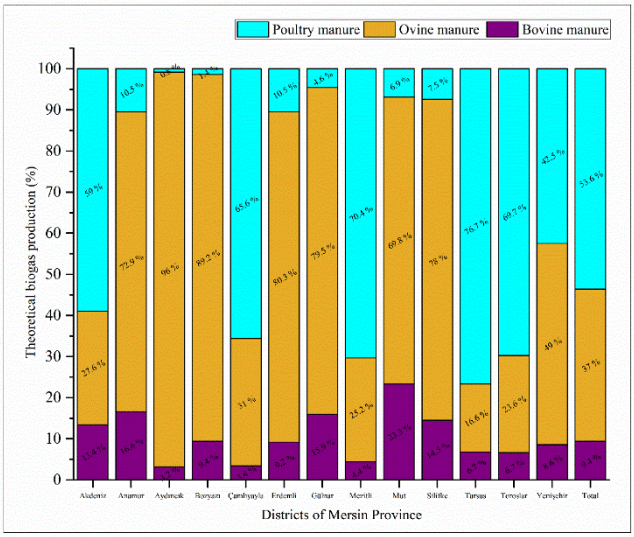

Figure 3. Theoretical biogas production potential according to manure type in Mersin province

3.3 Conversion of Biogas Heat Power to Other Fuels in Mersin

The equivalent heat power of the producible biogas in Mersin Province to other fuels is given in Table 6. It has been determined that the thermal energy corresponding to the theoretical amount of biogas that can be produced annually in Mersin in the direction of the calculations made can be provided with 279,586,210 kWh electrical, 206,417,900 kg wood, 44,614,820 L gasoline or 39,261,041 L diesel fuel.

Consumption of 1 kWh of electricity [22], 1 kg wood [23], 1 L gasoline and 1 L diesel [24] are billed as 0.46 TL, 0.5 TL, 6.95 TL and 6.35 TL, respectively for the year 2018 in Turkey.

Considering the other fuels that are equal to producible biogas potential from animal manure annually in Mersin, it is estimated that a profit of 128,609,656 TL; 103,208,950 TL; 310,072,999 TL and 249,307,610 TL could be achieved from electric energy, wood, gasoline and diesel, respectively. The value of the financial savings that can be obtained from the use of other fuels through the production of biogas in Mersin is given in Table 7.

When the table is examined, it is seen that the province-wide income that can be obtained from electricity is 20,689,380 $, 16,513,432 $ from wood, 49,611,680 $ from gasoline and 39,889,218 $ from diesel oil. The amount of income that can be obtained based on districts of Mersin Province is given in Figure 4.

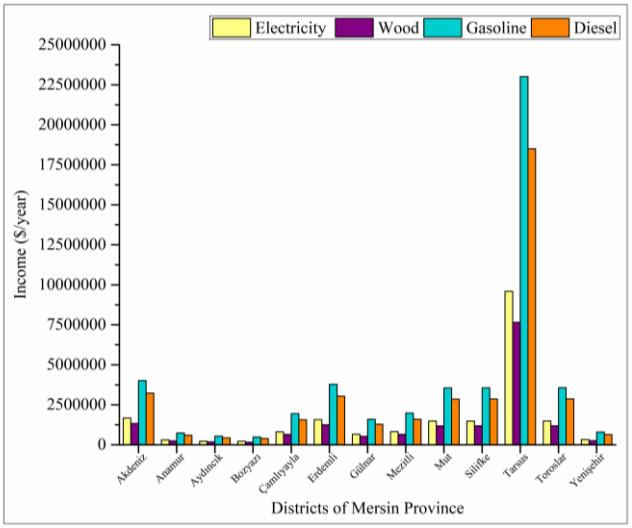

Figure 4. The amount of income that can be obtained based on districts of Mersin Province

3.4. Biogas for Cooking in Mersin Province

Biogas is a type of alternative energy that can be used for cooking and heating needs in areas such as homes and offices. A family of five or six people needs an average of 1m^3 of methane (CH_4) per day to cook three meals [25]. According to this information, if 1 m^3 of biogas contains about 65% methane on average, it is possible that one family can provide daily cooking needs with 1.53 m^3 biogas. The annual theoretical biogas potential of Mersin Province is 59,486,428.5 m^3 as shown in Table 5. When this value is divided by the biogas value (558 m^3), which is the annual cooking requirement of a family, it is predicted that the cooking needs of 106,606 families living in Mersin province can be met. Thanks to the biogas energy, it is also possible to meet the heating or electricity needs of the residents in the region.

Table 5. Theoretical biogas production potential from animal manure in Mersin province

Districts	Theoretical biogas production (m^3/year)			
	Bovine	**Ovine**	**Poultry**	**Total**
Akdeniz	646,793.5	1,329,283	2,839,441.2	4,815,518
Anamur	147,682.7	650,625.6	93,798.053	892,106.3
Aydıncık	20,652.19	628,236.7	5521.23	654,410.1
Bozyazı	55,186.16	522,168.4	8332.8102	585,687.3
Çamlıyayla	79,442.75	725,166.3	1,534,545.2	2,339,154
Erdemli	416,453.4	3,641,612	477,968.63	4,536,034
Gülnar	306,032.4	1,525,356	88,212.267	1,919,601
Mezitli	105,550.2	599,871.9	1,674,201.7	2,379,624
Mut	993,789.3	2,977,104	293,545.96	4,264,439
Silifke	620,393.8	3,335,459	319,229.02	4,275,082
Tarsus	1,848,761	4,589,469	21,151,628	27,589,858
Toroslar	284,893.1	1,010,429	2,985,286.6	4,280,609
Yenişehir	81,634.61	467,253.2	405,417.97	954,305.8
Total	**5,607,265.1**	**22,002,034.1**	**31,877,128.6**	**59,486,428.5**

3.5. Bio-fertilizer Production and Sales in Mersin Province

The proportion of dry matter content contained in animal wastes is important in the production of bio-fertilizer. The dry matter ratios vary according to the animal species. It is stated that the dry matter ratios are 15-20% in bovine manure, 40% in ovine manure and 30% in poultry manure [14,26].

In calculations for bio-fertilizer production after producing biogas; the dry matter content of bovine manure, ovine manure and poultry manure were accepted as 20%, 40% and 30%, respectively. In Mersin province, annual collectible bovine, ovine and poultry manure were given as 169,917 ton/year; 379,346 ton/year and 408,683 ton/year, respectively in Table 4. If the dry matter content of the manures attached to animal species were calculated in Mersin Province according to Eq (1);

$$CDM = M \times \%DM \quad (1)$$

CDM: Dry matter content of manure (tonDM/year),
M: Amount of annual manure (ton/year),
%DM: Dry matter content)

Bovine manure: 169,917 x 0.20 = 33,983 tonDM/year
Ovine manure: 379,346 x 0.40 = 151,738 tonDM/year
Poultry manure: 408,683 x 0.30 = 122,604 tonDM/year

It is stated that packable-pelleted bio-fertilizer should contain an average of 12% moisture [27]. The annual amount of bio-fertilizer that can be obtained after achieving this moisture content in manures was calculated according to Eq (2);

$$BF = CDM + (CDM \times 0.12) \quad (2)$$

BF: Amount of bio-fertilizer (ton BF/year),
CDM: Dry matter content of manure (tonDM/year)

Bovine bio-fertilizer: 33,983+ (33,983 x 0.12) = 38,060 ton BF/year or 3172 tonBF/month

Ovine bio-fertilizer: 151,738 + (151,738 x 0.12) = 169,946 ton BF/year or 14,162 tonBF/month

Poultry bio-fertilizer: 122,604+ (122,604 x 0.12) = 137,317 ton BF/year or 11,443 tonBF/month

In calculations for the income from the sale of bio-fertilizer; the price of 1 kg bovine, ovine and poultry bio-fertilizer were accepted as 1.57 TL, 1.49 TL and 1.80 TL, respectively. In this case, with the sale of bio-fertilizer that are formed after biogas production in Mersin province 59,754,200 TL; 253,219,540 TL and 247,170,600 TL can be earned by bovine, ovine and poultry bio-fertilizers, respectively.

Table 6. The equivalent heat power of the producible biogas in Mersin to other fuels

Districts	Animal Species	Biogas production (m^3/year)	Electricity (kWh/year)	Wood (kg/year)	Gasoline (L/year)	Diesel (L/year)
Akdeniz	Bovine	646,794	3,039,930	2,244,374	485,095	426,884
	Ovine	1,329,283	6,247,630	4,612,612	996,962	877,327
	Poultry	2,839,441	13,345,374	9,852,861	2,129,581	1,874,031
Anamur	Bovine	147,683	694,108	512,459	110,762	97,471
	Ovine	650,626	3,057,940	2,257,671	487,969	429,413
	Poultry	93,798	440,851	325,479	70,349	61,907
Aydıncık	Bovine	20,652	97,065	71,663	15,489	13,630
	Ovine	628,237	2,952,712	2,179,981	471,178	414,636
	Poultry	5521	25,950	19,159	4141	3644
Bozyazı	Bovine	55,186	259,375	191,496	41,390	36,423
	Ovine	522,168	2,454,191	1,811,924	391,626	344,631
	Poultry	8333	39,164	28,915	6250	5500
Çamlıyayla	Bovine	79,443	373,381	275,666	59,582	52,432
	Ovine	725,166	3,408,282	2,516,327	543,875	478,610
	Poultry	1,534,545	7,212,362	5,324,872	1,150,909	1012800
Erdemli	Bovine	416,453	1,957,331	1,445,093	312,340	274,859
	Ovine	3,641,612	17,115,577	12,636,394	2,731,209	2,403,464
	Poultry	477,969	2,246,453	1,658,551	358,476	315,459
Gülnar	Bovine	306,032	1,438,352	1,061,932	229,524	201,981
	Ovine	1,525,356	7,169,174	5,292,986	1,144,017	1,006,735
	Poultry	88,212	414,598	306,097	66,159	58,220
Mezitli	Bovine	105,550	496,086	366,259	79,163	69,663
	Ovine	599,872	2,819,398	2,081,555	449,904	395,915
	Poultry	1,674,202	7,868,748	5,809,480	1,255,651	1,104,973
Mut	Bovine	993,789	467,0810	3,448,449	745,342	655,901
	Ovine	2,977,104	13,992,388	10,330,550	2,232,828	1,964,889
	Poultry	293,546	1,379,666	1,018,604	220,159	193,740
Silifke	Bovine	620,394	2,915,851	2,152,766	465,295	409,460
	Ovine	3,335,459	15,676,657	11,574,042	2,501,594	2,201,403
	Poultry	319,229	1,500,376	1,107,725	239,422	210,691
Tarsus	Bovine	1,848,761	8,689,176	6,415,200	1,386,571	1,220,182
	Ovine	4,589,469	21,570,503	15,925,456	3,442,101	3,029,049
	Poultry	21,151,628	99,412,653	73,396,150	15,863,721	13,960,075
Toroslar	Bovine	284,893	1,338,998	988,579	213,670	188,029
	Ovine	1,010,429	4,749,016	3,506,188	757,822	666,883
	Poultry	2,985,287	14,030,847	10,358,944	2,238,965	1,970,289
Yenişehir	Bovine	81,635	383,683	283,272	61,226	53,879
	Ovine	467,253	2,196,090	1,621,369	350,440	308,387
	Poultry	405,418	1,905,464	1,406,800	304,063	267,576
Total		**59,486,428**	**279,586,210**	**206,417,900**	**44,614,820**	**39,261,041**

Table 7. The value of the financial savings in US dollars (May 2019) that can be obtained from the use of other fuels through the production of biogas in Mersin (1TL=0.16$)

Districts	Animal Species	Electricity ($/year)	Wood ($/year)	Gasoline ($/year)	Diesel ($/year)
Akdeniz	Bovine	224,955	179,550	539,426	433,714
	Ovine	462,325	369,009	1,108,622	891,364
	Poultry	987,558	788,229	2,368,094	1,904,015
Anamur	Bovine	51,364	40,997	123,167	99,031
	Ovine	226,288	180,614	542,622	436,284
	Poultry	32,623	26,038	78,228	62,898
Aydıncık	Bovine	7183	5733	17,224	13,848
	Ovine	218,501	174,398	523,950	421,270
	Poultry	1920	1533	4605	3702
Bozyazı	Bovine	19,194	15,320	46,026	37,006
	Ovine	181,610	144,954	435,488	350,145
	Poultry	2898	2313	6950	5588
Çamlıyayla	Bovine	27,630	22,053	66,255	53,271
	Ovine	252,213	201,306	604,789	486,268
	Poultry	533,715	425,990	1,279,811	1,029,005
Erdemli	Bovine	144,842	115,607	347,322	279,257
	Ovine	1,266,553	1,010,912	3,037,104	2,441,919
	Poultry	166,238	132,684	398,625	320,506
Gülnar	Bovine	106,438	84,955	255,231	205,213
	Ovine	530,519	423,439	1,272,147	1,022,843
	Poultry	30,680	24,488	73,569	59,152
Mezitli	Bovine	36,710	29,301	88,029	70,778
	Ovine	208,635	166,524	500,293	402,250
	Poultry	582,287	464,758	1,396,284	1,122,653
Mut	Bovine	345,640	275,876	828,820	666,395
	Ovine	1,035,437	826,444	2,482,905	1,996,327
	Poultry	102,095	81,488	244,817	196,840
Silifke	Bovine	215,773	172,221	517,408	416,011
	Ovine	1,160,073	925,923	2,781,773	2,236,625
	Poultry	111,028	88,618	266,237	214,062
Tarsus	Bovine	642,999	513,216	1,541,867	1,239,705
	Ovine	1,596,217	1,274,036	3,827,616	3,077,514
	Poultry	7,356,536	5,871,692	17,640,458	14,183,436
Toroslar	Bovine	99,086	79,086	237,601	191,037
	Ovine	351,427	280,495	842,698	677,553
	Poultry	1,038,283	828,716	2,489,729	2,001,814
Yenişehir	Bovine	28,393	22,662	68,083	54,741
	Ovine	162,511	129,710	389,689	313,321
	Poultry	141,004	112,544	338,118	271,857
Total		**20,689,380**	**16,513,432**	**49,611,680**	**39,889,218**

4. CONCLUSIONS

In this study, considering the number of registered bovine, ovine and poultry in the districts of Mersin Province; The amounts of animal manure that can be collected, the related theoretical biogas production values and the energy data obtained from equivalent fuels, the financial gain values, the amount of bio-fertilizer production was calculated. According to the calculations, it was determined that biogas could be produced over 59 million m^3 per year from the total of animal fertilizers produced in a year. Approximately 280 million kWh of electricity will be generated from this biogas annually. With this value, it is calculated that a profit of 128,609,656 TL (20,495,234 $) can be achieved in electricity consumption in the province. Also, it is predicted that the cooking needs of 106,606 families living in Mersin province can be met by biogas production. Bio-fertilizer production after producing biogas is an important advantage. In this

case, with the sale of bio-fertilizer that are formed after biogas production in Mersin province 59,754,200 TL; 253,219,540 TL and 247,170,600 TL can be earned selling of bovine, ovine and poultry bio-fertilizers, respectively.

As a result, considering the livestock potential of Mersin Province, if animal waste is evaluated in biogas and then in bio-fertilizer production, it will reveal many social, economic and environmental positive effects on provincial basis. For this purpose, biogas production should be encouraged and supported by feasibility studies by taking into consideration the animal numbers and operating conditions in the province.

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