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Economic analysis of biogas production from small scale anaerobic digestion systems for cattle manure

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ABSTRACT

One of the major concerns of biogas plants can't be operated economical and environmental sustainable manner. In order to produce biogas in rural areas, using anaerobic systems with high organic content of farm wastes can be able to remove these concerns. The production of biogas can then be used for cooking, lighting and heating. Biogas is a good alternative to kitchen gas cylinder. However, there is a lack of knowledge and experience available on design methods for these systems. Anaerobic digestion is generally economically applicable waste treatment systems for large farms (>100 cattle). However, majority of Turkey farms have less than 100 cattle, making this technology economically inaccessible to the vast majority farms. The objective of this study is to determine the economic viability of small scale anaerobic digester systems taking into account on domestic production conditions.

Keywords: Anaerobic systems, small-scale, biogas, economic analysis

1. INTRODUCTION

Especially in Turkey the establishment of biogas production facilities has generally implemented by foreign-based companies. This creates major problems both for the installation and operation of the biogas production system. There are a lot of studies about anaerobic biogas processes in Turkey and abroad. Local facilities need to be used in the construction of the biogas plant but cost-benefit analysis guide studies are not enough about on this issue.

Sustainable production is one of the most important factors for people's peace and well-being. A healthy environment is essential for continued sustainability and mobility of production. There are many natural resources in Turkey that can be used for human benefit. One of these natural sources is organic waste. In fact, it needs to be disposed of because it is waste. Therefore, biogas production systems are attractive due to useful outputs of anaerobic digestion such as waste disposal, biogas and organic fertilizer production.

Nowadays, it has become a necessity to increase the production volume together with population growth. Along with the increase in production, waste generation has also increased. Generally food products such as meat, meat products, milk and dairy products are considered for this system. An important part of this production area is large, medium and small scale cattle breeding farms. As a result of the increased need for these products in Turkey, the cattle breeding sector has shown a serious growth in recent years with the incentives of the state. According to data of Turkey Statistical Institute (TSI), the bovine animal number increased by 13.2% in 2017 when compared to the previous year and became 16,105,000 heads at the end of the year [1].

The livestock sector, in fact, is an important source of livelihood, but also a labor that requires considerable costs. Lowering costs in this sector is very important for manufacturers. Biogas production is a technology that can help reduce biogas production costs in the livestock sector. It is clear that the use of biogas plants, which have reached significant numbers in many countries such as Germany, Denmark, Italy,

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India, Pakistan and China, should also be widespread in Turkey. Particularly in rural areas and in villages where gas demand is supplied by kitchen gas cylinder is seen that there are many benefits in using animal wastes for biogas production. It is more feasible to use biogas instead of kitchen gas cylinder where natural gas is not used.

There is not much animal manure accumulation in sheep or goat livestock, especially since livestock farming is done in rural areas. But, there is a waste accumulation in cattle livestock because the animals are in the stall at night. For this reason, the selection of cattle manure (CM) as the majority of waste to be used in biogas plants will provide great convenience in terms of operation of the plant. However, the addition of wastes with higher organic load to CM has been found to have beneficial effects which is around 20% [2, 3]. Hereby, the organic wastes with higher organic load will be included in anaerobic process.

In this study, a biogas production system in order to carry out the joint treatment of CM with wastes containing high levels of organic matter and to obtain biogas and organic fertilizer as a result is taken as basis. The use of local industrial facilities in the biogas system has been prioritized. For this reason, the system that can contribute to the economy and the environment that the local people who are engaged in livestock production can implement has formed the framework of the cost analysis work.

2. METHODS

2.1. Small-Scale Digestion System Cost Analysis Study

In this study, it was considered to design a biogas plant to best provide anaerobic conditions. For this reason, fixed dome biogas plant was chosen as the model for the current conditions. It is aimed to use completely local facilities for installation of the biogas plant. It is thought that the plant will be built underground. It is planned to provide the necessary temperature values for anaerobic conditions by solar collectors. It is planned to construct the reactor body from metal materials and to make necessary insulations.

The sizing of the biogas plant has been based on the number of people who will benefit from the biogas to be produced. One person needs 0.34-0.42 m^3 of biogas to meet the need to cook daily meals [6]. The amount of biogas that each person would use for cooking daily was assumed to be 0.5 m^3 day^{-1}. According to this, benefit cost analysis was performed for 6 different reactors' volumes with biogas production capacity of 1, 2, 4, 8, 16 and 32 m^3 day^{-1}, which can be used by 2, 4, 8, 16, 32 and 64 people, respectively. It was also assumed that bovine animals would produce 10 kg of manure per day and reactors were sized according to 20-days hydraulic retention time (HRT). It is planned to make a water jacket around the reactor until half of the required volume for the purpose of temperature control in the biogas plant. Adiyaman city located at the south-east part of the Turkey was chosen as the plant installation place for the account of the necessary solar collectors. The biogas production value of wet CM was assumed to be 0.034 m^3 kg^{-1}. Total solid (TS) of the feed waste ratio was chosen as 5%. It is planned to add 2 - 2.5 L of tap water to 1 kg of CM that has an average TS of 16.67% to capture 5% TS ratio.

In the construction of biogas plants, for construction cost items as fixed cost items; stainless steel sheet, stainless pipe (Ø 10 cm), solar collector, thermostat, plastic pipe, water trap, other consumables were taken into consideration, in the labor items; the costs of pit digging and reactor construction were also considered. As operating cost components; maintenance and repair costs, electricity cost, water cost, labor cost and additional waste cost were foreseen. Water and labor costs in small-scale plants, including the 12 m^3 capacity reactor, are not included in the operating cost calculation. As of the end of 2017, the value of the biogas produced was calculated on the basis of the equivalent price of 12 kg of kitchen gas cylinder. The calculations are not included, such as the cost of animal manure, the gain obtained from the organic fertilizer, social and environmental benefits. The facilities have been tried to be designed as far as possible considering the conditions that can be supplied and operated in the local market. While some cost elements are easily and cheaply available, they have always been tried to stay within safe boundaries.

2.2. Model Selection for Planned Biogas Plant

Several different types of systems have been developed because biogas production and the use of biogas are based on very old ones. Designed facilities are classified according to structure and operating conditions. In fact, anaerobic conditions occur in the presence of an airless environment, an appropriate temperature and fattening medium.

The availability of technological possibilities is up to the point where the cost-benefit relation is optimal. Biogas plants that founded by importing are not preferred because their cost returns are very long. For this reason, the systems to be used for small, medium and large scale biogas plants in Turkey conditions should be able to be produced in the domestic industry. In this case, sustainable systems should be designed with benefit cost analyzes that can be carried out and operated by people engaged in animal husbandry.

The designed biogas generator should be particularly leak-proof and have a stable temperature. Also, as the amount of waste load increases, the mixing need also arises. For this reason, it is considered that the model which can best meet the above mentioned conditions is a fixed domed biogas plant model.

Fixed domed biogas plants are totally enclosed systems with no connection to the outside, except waste input-output and biogas output. When biogas exits from the system, biogas bubbles play an active role in mixing the system. The built-up biogas reactor increases the internal pressure as it accumulates in the upper part, and the reactor raises the mud in the inlet and outlet lines. This likewise helps to stir the reactor.

Due to the fact that it is not a mobile part of fixed domed biogas systems, it has a simple structure and installation cost is very low. When produced with a stainless steel material such as steel, it has a life span longer than 20 years. When the system is digged in the soil, it can be protected from physical external environment conditions and a more stable system can be formed by preventing temperature differences at night and day. If waste input and output are not connected to a mechanic device, waste feed is done by human power, so operating cost is considerably reduced.

There are different models of fixed domed biogas generators. The Chinese model is the first archetype of this model. The reactor consists of a cylindrical body. The Janata-type model is not currently used due to cracks and leakage problems in India. Deenbandhu model is more developed than Janata model and more resistant to cracking. CAMARTEC is a model developed in Tanzania in the 1980s [4].

Fixed domed biogas generators resistant to cold climates have known designs in the range of 5-200 m^3. These facilities, which can be easily done with local amenities and have a low installation cost, have been preferred systems with ease of temperature control. Gas leaks and low underground temperatures are important disadvantages of the system. The plant is designed with a metal body and it is considered that these problems can be avoided together with the necessary insulation when heating with solar energy. Nowadays fiberglass material can be produced at very low cost. However, in terms of longer reactor life, a metal body design would be more advantageous.

3. DESIGN OF BIOGAS PRODUCTION PLANT

Especially the amount of waste generated in the design of biogas plants is the most important design criterion. In recent years in Turkey, cattle livestock has become widespread with state incentives. Due to the lack of adequate pastures, especially cattle breeding is done more often in stables. At least the bovine animals in the stalls at night can produce enough fertilizer to operate the biogas plant. When cattle farming is carried out in the stable, there is no waste stagnation and CM to be treated are formed in considerable volumes.

If only the bovine animal feed is used in the planned reactor, the daily amount of manure, the feeding patterns of the animals and the solids content of the manure must be known. Daily amount of manure can vary depending on the type and age of the animals. Manure production can be accepted for cattle 10-20 kg day^{-1} (wet) or 5-6% of live weight can be used for daily manure production [5].

3.1. Required Waste Account

The biogas plant to be designed can be sized according to the amount of biogas produced per day. The biogas plant can be designed according to biogas needs or the amount of available CM. 0.04 m^3 biogas can be produced from 1 kg wet CM. According to this, 1 m^3 biogas can be produced 25 kg wet CM [6, 7]. The daily biogas consumption varies according to different uses and the daily biogas consumption required for cooking is 0.227 m^3 [8]. According to this, the number of people that could be benefited, the amount of CM needed and the number of bovine animals were shown in Table 1 according to the amount of biogas to be produced.

3.2. Reactors Volume Calculations

In order to anaerobically treatment wastes with high organic content, it is necessary to adjust the organic loading ratio with the addition of water. In this case, as the volume of waste increases, the cost of the processes such as heating, mixing, pH balancing, dewatering will increase as the reactor volume increases. Accordingly, the initial investment cost and operating cost will increase. For this reason, it is necessary to select a solid matter rate that CM and other additive wastes can easily be fed into the system and evacuated from the system. The rate of solid matter of the substrate fed to the biogas reactors was selected as 2.8% [9], 5% [10], 6.07% [11] and 6.7% [12] by some researchers. In the experimental study, the anaerobic sludge TS ratio in the reactors varied between 3% and 6% [13]. The approximate reactor volume according to the amount of biogas desired to be produced is given in Table 2.

Table 1. The amount of CM needed, the number of animals and the number of people to benefit from different designs

Biogas plant design no	Biogas capacity of plant (m^3 day^{-1})	The number of people who can benefit	The amount of CM needed (wet) (kg day^{-1})	The number of animals
1	1	2	29	3
2	2	4	59	6
3	4	8	118	12
4	8	16	235	24
5	16	32	471	47
6	32	64	941	94

Table 2. Required reactor volume calculated on the basis of biogas production for HRT of 20 days

Biogas capacity of plant (m^3 day^{-1})	The amount of CM needed (wet) (kg day^{-1})	Amount of water to be added (L day^{-1})	Feeding volume (L day^{-1})	Required reactor volume for feeding liquid (m^3)	Total volume with biogas collection section (m^3)
1	29	68	98	2	3
2	59	138	197	4	6
4	118	275	393	8	12
8	235	548	783	16	24
16	471	1099	1570	31	47
32	941	2196	3137	62	94

3.3. Initial investment cost (fixed cost)

In order to temperature control in the biogas plant, a water jacket with half of the volume of the biogas plant should be constructed around the reactor. Accordingly, the installation of the solar collector and the thermostat has been considered. The assumed biogas plant is shown in Figure 1.

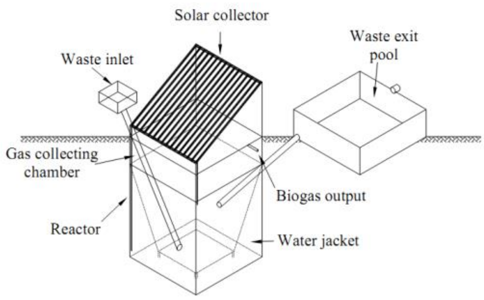

Figure 1. Considered Fixed Dome Biogas Plant with Solar Collector

The ratio between the volumes of the reactors considered is approximately 2 times. The increase coefficient of material to be used according to the volume increase was determined as about 1.6. For this reason, cost calculations were approximate calculations. Initial investment costs for biogas plants for different volumes are given in Table 3.

The parameters affecting the determination of the collector surface area depends on the time of utilization of the system, the amount of water to be heated, the inlet temperature of the water system and the temperature level. Biogas plant was planned to be installed in Adiyaman. It was desired to utilize the solar collector system year-round. For this reason, the most efficient collector angle (latitude x 0.9) for Adiyaman at 37.4 latitude was calculated as 33.66 for the whole year. In the calculation of the required collector surface area; the water temperature to be heated as to 38 °C, and the return water temperature was 34 °C. The amount of total solar irradiation (TSI) coming to the collector surface was calculated as 4328 (kcal m^{-2} day^{-1}). Collector yield was determined as 60% for the required collector area [14]. The collector costs required for different volumes are given in Table 3. The required collector surface area was considered by using the equations in the footnote of Table 3.

3.4. Annual Operating Cost

Maintenance costs for the plant, electricity costs for the control, labor costs for feeding the CM and additional waste costs may be added to the annual operating costs of the biogas plant. Water and labor costs have been neglected up to a volume of 24 m^3 reactor, since some of the water required for waste preparation in the biogas plant is considered to be supplied from the reactor effluent. It is seen that the Total Chemical Oxygen Demand (TCOD) values of the gram dry matter of the additional waste to be used are close to each other [13]. In terms of cost security, maize silage, which is a valuable animal feed that could be costly in Turkey, is considered as an additive material. Maize silage contains at least 30% dry matter [15] and according to the price statistics for 2018, 1 ton maize silage is 300 Turkish Liras (TL) [16]. The TS ratio of CM was determined to be 16.67% [13], which is about half of the maize silage TS ratio. It is considered that an operating cost to represent the additional cost of the waste at safe intervals is chosen. In the reactor with a volume of 24 m^3 and larger volumes, the feeding of the waste should be considered by using a pump. For this reason, electricity cost will increase in these reactors. Annual operating costs for the reactors considered are given in Table 4.

4. RESULTS & DISCUSSION

The need for cooking in the rural area is covered with liquefied petroleum gas (LPG) cooking gas cylinders. As of the end of 2017, the average price of 12 kg LPG cooking gas cylinder is approximately 92.5 TL [17]. 1 m^3 biogas equivalent to 0.43 kg LPG [6]. According to the calculations made, about 1 m^3 day^{-1} of biogas could be produced from about 3 cattle (10 kg CM day^{-1} cattle). When considered annually, about 157 kg of LPG (13 LPG cooking gas cylinder (12 kg)), will be produced as 365 m^3 of biogas equivalent. According to the calculations which were made the cost analysis, it was determined that in the planned biogas installations for 3, 6, 12, 24, 47 and 94 bovine animals, there will be a clear return of 5, 14, 31, 27, 90 and 218 LPG cooking gas cylinder per year, respectively. Table 5 provides cost-benefit calculations of biogas plants according to their capacities. In addition, when a biogas plant capable of being operated with high CM and organic wastes is installed, fermented fertilizer will be produced along with biogas with high calorific value. However, the financial value of the organic fertilizer formed at this stage has not been added to the cost calculations, since the CM is regarded as agricultural fertilizer in the unprocessed state in the sense of the farmers. In addition, it is an invisible gain that the environmental defects such as odor, fly, pathogenic microorganisms, water pollution and greenhouse effect which can be caused by these wastes have been eliminated.

Table 3. Initial investment costs for biogas plants for different volumes

Expenditure items		Cost of materials used according to biogas plant volume (TL)					
		3 m³	6 m³	12 m³	24 m³	47 m³	94 m³
A. Construction							
1.	Stainless sheet	1040	1840	2880	4150	6910	11520
2.	Stainless pipe (Ø 10 cm)	186	186	372	372	372	558
3.	Solar collector*	1200	1200	2400	4800	9600	19200
4.	Thermostat	272	272	272	272	272	272
5.	Plastic pipe	60	60	60	60	60	60
6.	Water trap	45	45	45	45	45	45
7.	Other consumables	120	132	145	160	176	193
8.	Painting	70	112	180	287	459	734
9.	Insulation	120	180	240	420	660	1020
Subtotal		3113	4027	6594	10566	18554	33602
B. Labor							
1.	Digging the pit	120	240	480	960	1920	3840
2.	Reactor construction	1200	1920	3072	4915	7864	12582
Subtotal		1320	2160	3552	5875	9784	16422
Total cost (A+B)		4433	6187	10146	16441	28338	50024

*$F_k = Q_{hot}$ (TSI η)$^{-1}$ F_k: Collector surface (m^2), Q_{hot}=m c Δ_t : Hot water energy requirement (kcal day^{-1}), m: Amount of water to be heated (L day^{-1}), c: Water heating tem**p**erature (kcal kg^{-1} °C^{-1}), 1 can be taken., Δt: Difference between the desired water temperature and the water inlet temperature (°C), TSI: Amount of solar energy coming to the collector surface (kcal m^2.gün^{-1}), η: Collector yield (%). The average yield in collectors can be taken between 55-65%.

Table 4. Annual operating costs for reactors considered

	Cost component	Cost of operations to be performed according to biogas plant volume (TL)					
		3 m³	6 m³	12 m³	24 m³	47 m³	94 m³
1.	Maintenance and repair expenses (4%)	177	247	405	657	1133	2000
2.	Electricity costs	240	240	240	600	960	1680
3.	Water costs	-	-	-	416	815	1630
4.	Labor costs	-	-	-	2920	2920	2920
5.	Additional waste costs	318	646	1292	2573	5157	10304
	Total cost	735	1133	1937	7166	10985	18534

Moreover, the world has been particularly interested in the release of greenhouse gases in recent years. For this reason, anaerobic systems have a separate precaution for controlling greenhouse gas formation. It is known that when greenhouse gases are evaluated according to global warming potentials, CH_4 and N_2O are 23 and 296 times more greenhouse effect than CO_2, respectively [18]. As a result of the anaerobic treatment of the wastes, a 10% reduction in N_2O emissions can be achieved. Moreover, 1 m_3 of biogas is equivalent to 0.5 kg of petroleum, and CO_2 emissions are reduced by 2.6 kg when biogas is preferred instead of petroleum [19]. Barton et al. [20] assessed emissions of greenhouse gases on the assumption that waste with high organic load was treated with different treatment methods. According to this, 0.74 tons (CO_2 eq ton^{-1} waste) of greenhouse gas is formed when organic wastes are applied in the field. Whereas, in the case of anaerobic decay, they reported that the effect on greenhouse gas emissions was reduced by 0.21 tons (CO_2 eq ton^{-1} waste). In Turkey CM is generally applied to the land. If these wastes are treated in anaerobic systems without applying to the surface, greenhouse gas emissions will be reduced by (0.74 + 0.21) 0.85 tons CO_2 equivalents per ton of waste. According to this report, when the manure of 100 cattle is subjected to anaerobic decay, the greenhouse gas emissions will be reduced by the equivalent of (100 cattle x 3,65 tons wet manure year^{-1} cattle x 0.167 TS / wet manure x 0.85 tons CO_2 eq) 51.8 tons CO_2 equivalent per year.

Table 5. Benefit-cost calculations of biogas plants according to their capacities

Biogas plant capacity (m^3)	Annual biogas production (m^3)	LPG equivalent value of biogas (kg)	Biogas annual turnover (TL)	Initial installation cost of biogas plant (TL)	Annual operating cost of biogas plant (TL)	Annual net turnover of biogas plant (TL)	Biogas plant payback period (years)	Net profit over 20 years' (TL)
3	365	157	1210	4433	735	475	9.3	5067
6	730	314	2420	6187	1133	1287	4.8	19553
12	1460	628	4841	10146	1937	2904	3.5	47934
24	2920	1256	9682	16441	7166	2516	6.5	33879
47	5840	2511	19356	28338	10985	8371	3.4	136082
94	11680	5022	38711	50024	18534	20177	2.5	353516

The biogas that can be produced in the biogas plants planned to be established is calculated based on the equivalent LPG value. According to the annual turnover, 20 years of facilities' return and repayment period have been determined, assuming that the life of the plants is 20 years. As can be seen from Table 5, as the plant capacity increases, the payback period and net profit increase. In this study, all the possible costs were tried to be considered. As a result, fluctuations in net earnings are seen. The initial investment cost will be reduced when different materials except metal are used, especially in the construction of small plants. The income from the organic fertilizer produced in the same way is not included in the calculations. In addition, the environmental protection of the biogas plant to be installed should not be overlooked. This is an important indicator of the need for state support in such projects. When the necessary support is given to these investments, it is thought that the number of biogas plants will increase rapidly in Turkey.

5. CONCLUSIONS

When a general evaluation is made, about 1 m^3 of reactor volume is needed for each cow, and approximately 120 m^3 year^{-1} biogas production can be achieved. On the other hand, biogas equivalent to 4.4 LPG cooking gas cylinder (12 kg) per year can be produced from the manure of a cow. This means an additional income of 400 TL year^{-1}. It is also envisaged that again manure of 1 cow will be reduced by 518 kg year^{-1} of greenhouse gas emissions as CO_2 equivalents by this method. When the reactor volume was increased from 1 m^3 to 100 m^3, the initial investment cost decreased from 1500 TL m^{-3} to 500 TL m^{-3}. The annual operating cost has changed between 150-300 TL m^{-3} (Approx. mean 217 TL m^{-3}). According to cost-benefit analysis, it is feasible to establish biogas plants for farms larger than 50 cattle. It has been concluded that the increase in the number of biogas plants in Turkey depends on the fact that biogas plants are produced in own domestic industry and are offered to the public at accessible costs. For this reason, it is proposed to increase incentives and supports for university-industry cooperation projects on anaerobic treatment and biogas production. It is also suggested that 75% of the installation and operation costs in these facilities should be supported by the government in order to increase environmental benefits.

REFERENCES

[1] Turkish Statistical Institute. “Animal Production Statistics", Available: http://www.tuik.gov.tr/PreHaberBultenleri.do?id=27704, (accessed 26 February 2018.

[2] Tufaner, F., Avşar, Y. and Gönüllü, M. T. "Modeling of biogas production from cattle manure with co-digestion of different organic wastes using an artificial neural network," *Clean Technologies and Environmental Policy*, Vol. 19(9), pp. 2255-2264, 2017.

[3] Tufaner F. and Avşar Y. "Effects of co-substrate on biogas production from cattle manure: a review," *International Journal of Environmental Science and Technology*, Vol. 13, pp.2303–2312, 2016.

[4] Types of Biogas Plants, Fixed-dome Plants, Available: http://www.sgpindia.org/documents/Biogas_Plants.pdf, (accessed 20 February 2018).

[5] Berkes, F. and Kışlalıoğlu, M., (1994). Ekoloji ve Çevre Bilimleri, Remzi Bookstore, İstanbul.

[6] Singh, K.J. and Sooch, S.S. "Comparative Study of Economics of Different Models of Family Size Biogas Plants for State of Punjab, India," *Energy Conversion and Management*, Vol. 45 (9), pp. 1329-1341, 2004.

[7] Vu, Q.D., Tran, T.M., Nguyen, P.D., Vu, C.C., Vu, V.T.K. and Jensen, L.S. "Effect of Biogas Technology on Nutrient Flows for Small- and Medium-Scale Pig Farms in Vietnam," *Nutrient Cycling in Agroecosystems*, Vol. 94 (1), pp. 1-13, 2012.

[8] Karttek, D., Venkata Seshaiah, C., Suresh, J., Punyakumari, B., V., D.R.M. and Srivani, M. "Potential for Value Addition of Buffalo Dung through Eco-friendly Disposal in India," *International Research Journal of Natural Sciences*, Vol. 3 (12), pp. 52-57, 2014.

[9] Neves, L., Oliveira, R. and Alves, M.M. "Fate of LCFA in the Co-Digestion of Cow Manure, Food Waste and Discontinuous Addition of Oil," *Water Research*, Vol. 43 (20), pp. 5142-5150, 2009.

[10] El-Mashad, H.M., Zeeman, G., van Loon, W.K.P., Bot, G.P.A. and Lettinga, G. "Effect of Temperature and Temperature Fluctuation on Thermophilic Anaerobic Digestion of Cattle Manure," *Bioresource Technology*, Vol. 95 (2), pp. 191-201, 2004.

[11] Ahring, B.K., Ibrahim, A.A. and Mladenovska, Z. "Effect of Temperature Increase from 55 to 65 Degrees C on Performance and Microbial Population Dynamics of an Anaerobic Reactor Treating Cattle Manure," *Water Research*, Vol. 35 (10), pp. 2446-2452, 2001.

[12] Boe, K. and Angelidaki, I. "Serial CSTR Digester Configuration for Improving Biogas Production from Manure," *Water Research*, Vol. 43 (1), pp. 166-172, 2009.

[13] Tufaner, F. "Investigation of improving biomethanization processes of cattle manure," Ph.D. thesis, Yıldız Technical University, Institute of Science and Technology, Istanbul, 2015.

[14] Abuşka, M., Güneş Enerjisi ve Uygulamaları Ders Notları III, Güneş Enerjili Su Isıtma Sistem Projelendirilmesi, Available: http://akhisarmyo.cbu.edu.tr/db_images/file/gunes-enerjisi-3-1285TR.pdf, (accessed 17 February 2015).

[15] Vet, E., (2018). Hayvancılık San. ve Ticaret Limited Şirketi, Kaba Yem Kalitesi – Türkiye'de İnek Performansını Arttıran En Önemli Faktör, Available: http://www.egevet.com.tr/kaba_yem_kalitesi_turkiyede_inek_performansini_artiran_en_onemli_faktor.htm, (accessed 22 February 2018).

[16] TDSYMB, (2018). Türkiye Damızlık Sığır Yetiştiricileri Merkez Birliği (TDSYMB) Fiyat İstatistikleri, Available: http://www.dsymb.org.tr/, (accessed 22 February 2018).

[17] EPDK, (2018). Enerji Piyasası Düzenleme Kurulu (EPDK), LPG Piyasası Ürün Fiyatları, Bayi satış fiyatı bülteni, Available: https://bildirim.epdk.org.tr/bildirim-portal/faces/pages/tarife/lpg/yonetim/bultenSorgula.xhtml, (accessed 22 February 2018).

[18] Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M. and Haan, C.d. "Livestock's Long Shadow: Environmental Issues and Options," Food and Agriculture Organization of the United Nations (FAO), Rome, Italy, 2006.

[19] Güç, M. and Yılmaz, V. "Organik Atıklardan Kaynaklı Sera Gazları Salınımlarının Azaltılmasında Anerobik Bozundurmanın Önemi," VII. Ulusal Temiz Enerji Sempozyumu, UTES'2008, 17-19 December 2008, İstanbul, 2008.

[20] Barton, J., Issaias, I. and Stentiford, E.I. "Carbon–Making the Right Choice for Waste Management in Developing Countries," *Waste Management*, Vol. 28 (4), pp. 690-698, 2008.