Marmara Fen Bilimleri Dergisi 2018, 2 111-118
DOI: 10.7240/marufbd.373820

RESEARCH ARTICLE / ARAŞTIRMA MAKALESİ

Production and Utilization Stage Analysis of Biogas: Case of IZAYDAS Plant

Biyogazın Üretim ve Kullanım Aşama Analizi: İZAYDAŞ Fabrika Örneği

Berrin KURŞUN

Marmara University Faculty of Engineering, Chemical Engineering Department

Abstract

This study investigates size and operating condition effects on energy production efficiency, greenhouse gas (GHG) mitigation and economic potentials in production and utilization stages of a biogas system. In IZAYDAS plant, efficiencies of biogas production and electricity generation are found to be 28 % and 20 % independently from operating scheme, respectively. When these results are compared to a small capacity plant without an automatic control keeping the biogas system at or close to favorable conditions for fermentation and a lower quality electricity generator, both biogas and electricity production efficiencies are found to be lower showing the importance of operating conditions and size on energy production efficiency. Organic waste processing is the major contributor to the GHG mitigation potential followed by fossil electricity and then chemical fertilizer replacement. Economically, liquid fraction of digestate is the major source of income due to its high amount followed by solid fraction of digestate and electricity sold to the grid. When different utilization paths are investigated for biogas, it is found that direct utilization of biogas has a higher GHG mitigation potential and favorable energetically.

Keywords: Biogas production, GHG mitigation, Efficiency, Renewable Energy

Öz

Bu çalışma bir biyogaz sisteminin üretim ve kullanım aşamalarındaki boyut ve işletme koşullarının enerji üretim verimi, sera gazı salınımının azaltılması ve ekonomik potansiyele etkisini incelemektedir. İZAYDAŞ tesisinde, biyogaz ve elektrik üretim verimleri işletim planından bağımsız olarak sırasıyla %28 ve % 20 olarak bulunmuştur. Bu sonuçlar, biyogaz sistemini fermentasyon prosesi için optimum ya da optimuma yakın koşullarda tutan bir kontrol sistemine sahip olmayan düşük kapasiteli bir biyogaz tesisi ile karşılaştırıldığında, hem elektrik hem de biyogaz verimleri işletme koşullarının ve boyutun enerji üretim verimi üzerindeki etkisini gösterir şekilde düşük çıkmıştır. İncelenen tesiste, organik atıkların işlenmesi ve ardından fosil yakıt ve kimyasal gübre kullanımının ikame edilmesi sera gazı salınımlarının düşürülmesinde ki önemli faktörlerdir. Ekonomik olarak, elde edilen sıvı gübre ardından katı gübre ve şebekeye satılan elektrik gelir kaynaklarını oluşturmaktadır. Biyogaz için farklı kullanım yolları incelendiğinde, biyogazın doğrudan kullanımı enerjetik açıdan daha tercih edilir ve sera gazı azaltma potansiyelinin daha yüksek olduğu bulunmuştur.

Anahtar Kelimeler: Biyogaz üretimi, sara gazı salınımı azaltma, verimlilik, yenilenebilir enerji

I. INTRODUCTION

Biogas is a multi-beneficial "green" fuel that is acquired via anaerobic digestion of organic wastes. Broadly, anaerobic digestion (AD) of organic wastes creates value added products, namely organic fertilizer (digestate) and biogas fuel (main component CH_4). Handling organic wastes via anaerobic digestion provides a way to avoid local sanitation problems and methane emissions caused by landfilling of organic materials. Additionally, obtained organic fertilizer in the process can substitute or lessen chemical fertilizer usage that helps avoid another source of greenhouse gas emission [1]. In a developing country context, biogas provides an affordable and reliable clean energy source for the rural households

Sorumlu Yazar/Corresponding Author: Berrin Kurşun, **Tel:** +90 216 348 02 92 , **e-posta:** berrin.kursun@marmara.edu.tr
Gönderilme/Submitted: 02.01.2018, **Düzenleme/Revised:** 03.04.2018, **Kabul/Accepted:** 25.05.2018

where conventional energy from fossil fuels is not available [2, 3]. Having affordable energy eases energy scarcity problems and reduces dependence on wood for cooking or heating [2]. Less dependence on wood alleviates deforestation issues and rural women spend less time on collecting wood. Having clean energy decreases health problems due to wood burning in the house, especially for women and children that have more exposure [2, 4]. Utilization of AD digestate as fertilizer both increase crop yields because of its better quality than animal manure and provide economic benefit because of reducing dependence on chemical fertilizers. Moreover, renewable energy creates job opportunities for local people [2, 4]. In urban areas, biogas can be fed to the central natural gas grid after upgrading or can be used to generate electricity. This reduces the dependence on fossil fuels and contributes to climate change mitigation [5,6]. Hence, biogas is a fuel that has environmental, social and economic benefits locally and in greater scales.

An important part of studies in literature deals with life cycle energy performance of biogas production systems [7,8,9]. One common finding is that utilizing mixed feedstock (a mixture of different types of feedstocks) increases biogas production [7,8,9]. Burning biogas in a combined heat and power (CHP) system and recovering cogenerated heat improves the energetic performance of whole system significantly [7,8]. If extra biogas formed in AD digestate store areas is harvested, system efficiency can improve an additional 5-6 % [7]. Transportation of feedstock is another factor that affects energetic performance of biogas production [9]. Transportation from distant places can make the net energy gain negative, which also emphasizes the local character of renewable energy technologies.

In literature environmental impacts of biogas production are also broadly investigated. Climate change mitigation due to deterred GHG emissions is the common result [10-13]. In most life cycle impact categories, biogas production performs better than target fossil fuels to be replaced if digestate is handled and utilized properly [10,11]. If digestate is utilized as fertilizer in required amounts (different for each soil and crop type), ammonia emissions can be avoided, making biogas production system better in acidification and eutrophication impacts than alternative fossil fuels [6, 13]. However, one should be careful in broad utilization of AD digestate as fertilizer since digestates may contain heavy metals that can accumulate in soil. Necessary precautions should be taken for widely utilization of AD digestate as fertilizer [14].

This study focuses on biogas production and biogas utilization phases in a biogas system rather than life cycle impacts (which are evaluated in many contexts and scales) to be able to study more energy efficient and more GHG mitigating ways to use produced biogas. For this, analysis of production efficiency, GHG mitigation and economic potentials of biogas production in IZAYDAS biogas plant (located in Kocaeli, Turkey) are performed. Secondly, a scenario where biogas is directly utilized instead of being converted into electricity and where biogas replaces natural gas and fossil electricity in cooking has been analyzed in terms of energetic performance and GHG emissions.

The organization of the rest of this article is as follows: Following introduction come the background section that presents plant specifications, input-output characteristics and process details. Methodology section includes assumptions and techniques utilized in these calculations. Production efficiency, GHG mitigation, economic potential and energy utilization scenario findings are presented in results and discussion section. Lastly, conclusions drawn from the findings of this study and related recommendations are presented.

II.BACKGROUND

2.1 IZAYDAŞ Biogas Plant

IZAYDAS biogas plant is a result of a collaboration project realized for Kocaeli Municipality and is located in Kocaeli, Turkey. It has been operating since April 2011. Figure 1 shows the geographical location of the plant and the digesters where the fermentation process takes place.

Figure 1: IZAYDAS biogas plant [15,16]

Table 1: Input and output characteristics of IZAYDAS biogas plant under current and ideal operating schemes [16].

Inputs	**Current**	**Ideal**
Grass (tonnes/year)	535	5900
Cow Dung(tonnes/year)	2729	350
Chicken Manure(tonnes/year)	178	1950
Vegetable Wastes(tonnes/year)	484	2050
Rumen Wastes	233	430
Total	4159	10680
Outputs	**Current**	**Ideal**
Biogas(m^3/year)	145000	340000
CH_4 (%)	67,0	67,0
H_2 (%)	1,5	1,5
CO_2 (%)	30,0	30,0
Other (%)	1,5	1,5
Electricity(kWh/year)	200000	482000
Solid Fraction of Digestate (tonnes/year)	29	85
Liquid Fraction of Digestate (tonnes/year)	3446	10100

The plant consists of a storage for vegetable waste of 100 m^3 volume, two fermenters of 2400 m^3 volume each with mixers and H_2S removal system, a 330 kW electricity generator and a storage for liquid fraction of digestate of 1000 m^3 volume. IZAYDAS biogas plant processes various organic wastes including cow dung, chicken manure, grass and vegetable wastes coming from different parts of the province. Plant operates under two schemes, **current** and **ideal** cases. Under current case plant generates 145000 m^3 of biogas and 200000 kWh of electricity annually. For the ideal case, these numbers are 340000 m^3 and 482000 kWh, respectively. Generated electricity is sold to grid and organic fertilizer is given to farmers who provide cow dung and chicken manure. Table 1 summarizes the input and output characteristics of the plant under two operating schemes analyzed [16].

2.2 Process

In the process, the vegetable wastes are copped into proper size in the waste storage, all wastes are mixed and water is added to this mix in the dosing unit to obtain a 9.0 % dry matter content required for the fermentation. This mixture is fed to two fermenters via conveyor unit. The residence time in fermenter changes from 47 to 95 days [16]. Biogas procured at the end of the fermentation is sent to cogeneration unit to produce electricity and heat, simultaneously. Most of the heat is utilized for the parasitic needs of the plant to achieve the fermentation temperature, 37^0C. And, the digested slurry is sent to the separator where liquid and solid fractions of digestate (solid and liquid fertilizer) are separated. Here, solid fraction of digestate sinks to the bottom due to gravity and is filtrated, then these different fractions are sent to different storage areas. Figure 2 presents the process steps in IZAYDAS biogas plant [16].

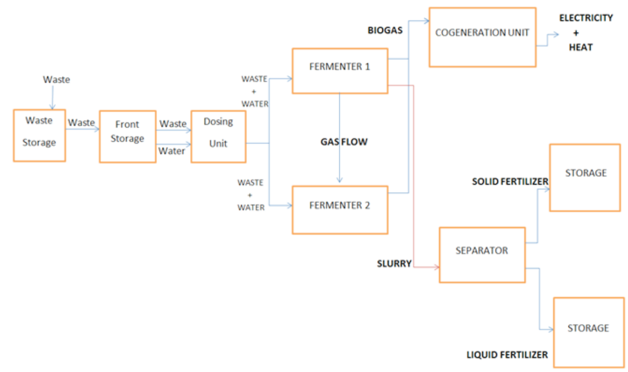

Figure 2: Process steps in IZAYDAS biogas plant.

III.MATERIALS AND METHODS

3.1 Biogas Production and Electricity Generation Efficiency

Biogas production efficiency refers to the ratio where the energy content of biogas is divided by the energy content of waste material processed in biogas digesters. And, electricity generation efficiency refers to the ratio where energy content of generated electricity is divided by the energy content of biogas used in electricity generation. Equations 1 and 2 represent the mathematical calculation of biogas production and electricity generation efficiencies, respectively.

$$\eta biogas = \frac{Energy\ content\ of\ biogas}{Energy\ content\ of\ organic\ material\ processed} \quad (1)$$

$$\eta electricity = \frac{Energy\ content\ of\ electricity\ generated}{Energy\ content\ of\ biogas\ used\ in\ electricity\ generation} \quad (2)$$

To calculate energy content of organic material mix processed in IZAYDAS plant, the moisture content and the dry weights of each feedstock type are determined. Then, dry weights are multiplied the by corresponding unit calorific values and all energy values are added to calculate the calorific value of 1 kg of organic material mix after being multiplied by each type of feedstock's ratio in the mix. Table 2 summarizes the moisture content, dry weights and calorific values of organic wastes processed. Last column of the table presents the references utilized.

$\sum_1^i (m_i c_i r_i)$ (3)

Equation 3 represents the calculation of energy content of 1 kg of organic material mix where m_i is the dry weight of ith organic material, c_i is the energy content and r_i is the ratio of this material in the mix. Energy content of biogas is calculated according to the gas percentage data given in table 1 as 25.04 MJ/m^3.

Produced biogas and generated electricity quantities are presented in table 1 for both current and ideal cases. After conversion of kWh to MJ with appropriate conversion factor (which is 3.6), equation 2 is applied for electricity generation efficiency calculation.

Table 2: Moisture, dry solid and calorific content values utilized in biogas and electricity production efficiency calculations.

Inputs	Moisture	Dry Solid	Calorific Content (MJ/kg)	References
Grass	89,0%	11,0%	16,50	[17]
Cow Dung	80,0%	20,0%	17,61	[16]
Chicken Manure	28,7%	71,3%	11,25	[18]
Vegetable Waste	89,0%	11,0%	14,90	[17]
Rumen Wastes	86,0%	14,0%	4,18	[16]

3.2 GHG Emission Mitigation

GHG emission mitigation potential of biogas production in IZAYDAS plant is based on three aspects. First is due to the prevention of decomposition of organic waste in landfills. Secondly, liquid and solid fractions of digestate can substitute the chemical fertilizer use in agriculture. Thus, GHG emitted for chemical fertilizer production can be prevented. Lastly, electricity generated from biogas can replace fossil electricity use and related GHG emissions [1].

To calculate emissions due to organic waste decomposition, dry weights of each type of waste is multiplied by corresponding unit emission values. And, total emissions mitigated are calculated by addition of the individual emissions of each type of waste processed. GHG emission prevented per kg of N included in the wet feedstock is calculated for chemical fertilizer replacement. Emissions per kg of N are listed in table 3. Lastly, emissions mitigated due to substituted fossil electricity are calculated by multiplying Turkey energy mix emission value (462gCO_2/kWh) with the generated electricity quantity in IZAYDAS [19]. Table 3 summarizes unit conversion values utilized for GHG emission mitigation calculations.

Equations 4, 5, 6 present calculation of avoided GHG emissions from organic waste decomposition, fertilizer and electricity substitution, respectively. Here, m_i is the dry weight of ith organic material, e_i is the corresponding emission coefficient. E_i is different GHG types (CO_2, CH_4, NO_2) emitted per kg of N available in wet feedstock. N_i is the nitrogen content of feedstock in kilograms. Lastly, P_{kWh} represents electricity generated in kWh in current and ideal cases. NO_2 and CH_4 emissions in these calculations are converted into CO_2 equivalent by multiplication with appropriate factors. Details regarding these conversions can be found in reference 12.

$Ed = \sum_1^i (m_i e_i)$ (4)

$Ef = \sum_1^i (E_i N_i)$ (5)

$Ee = 462 P_{kWh}$ (6)

Table 3: GHG coefficients utilized in calculations.

GHG Mitigation Sources	Turkey Energy Mix (gCO2/kWh)	References
1.Fosil fuel sourced electricity replacement	462	[19]
2. Chemical fertilizer replacement	**g/kg of N**	[13]
CO_2	3200	
CH_4	3,1	
NO_2	18	
3.Organic Waste Processed	**g CO_2/kg of dry feedstock**	
Grass	420	[20]
Cow Dung	447	[21]
Chicken Manure	447	[21]
Vegetable Waste	420	[20]

3.3 Economic Analysis

In Turkey, government subsidies renewable energy and purchases electricity generated from renewable sources for 13.3 cents per kWh. Hence, electricity generated in the plant is sold to the grid for 13.3 cents per kWh [16]. Liquid and solid organic fertilizers are sold for 0.5 $ per kg and 0.6$ per kg, respectively [22]. Quantities presented in table 1 for electricity, liquid and solid fractions of digestate are multiplied by corresponding prices and added up to calculate the revenue acquired from process outputs. Although there is no legal regulation related to usage of digestates as fertilizer in Turkey and some economic investment is necessary to benefit from them as fertilizer, using them chemical fertilizer replacement has its economic benefits in addition to environmental and social benefits [4,6, 23]. Since these policy issues are beyond the scope of the article, they are not analyzed.

1.4 Different Energy Utilization Scenarios and Related Emissions

We spend different amount of energy to perform the same task with different fuels. For example, we use less joules of natural gas than coal in generation of the same joules of electricity. To convert one energy type to equivalent of another energy type, this difference should be considered [24, 25]. Hence, on the basis of energy conversion efficiencies 1 J of electricity is accounted as equivalent to 2.5 J of natural gas and 5.0 J of biogas energy and all energy types accounted are converted into electricity equivalents as kWhelect. Equation 7 presents the coefficients utilized in energy equivalence calculations.

1.0 J of elect = 5.0 J of biogas =2.5 J of natural gas; 1 kWh=3600kJ (7)

Then, to achieve the same magnitude of cooking task; required electricity, natural gas and biogas energy quantities are calculated based on cooking efficiencies of these fuels. Lastly, GHG emissions related to utilization of the fuels are calculated. Table 4 summarizes the coefficients used. With these calculations, the aim is to compare the validity of different energy utilization scenarios based on energy efficiency and GHG emission magnitudes.

Table 4: Cooking related GHG emission and efficiencies of fuel utilization in cooking.

	Cooking Efficiency	CO_2 Emissions Due to Cooking	References
Natural Gas	55%	91,4 g CO_2/ MJ	[26,27]
Electricity	70%	462 gCO_2/ kWh	[26,27]
Biogas	55%	2,8 g CO_2/MJ	[26,27]

IV.RESULTS AND DISCUSSION

4.1 Biogas Production and Electricity Generation Efficiencies

Figure 3 shows the efficiency results for biogas production and electricity generation in IZAYDAS plant. Here, operating scheme (current or ideal) does not create a difference in production efficiencies (28 % for biogas and 20 % for electricity). However, if these values are compared to the results of small capacity biogas plant located in Jhansi district of India [28], efficiencies are found to be 17 % and 11% for biogas and electricity, respectively. Indian biogas plant is a 1.75 kW capacity floating dome biogas digester with no automatic system control or system heating for environmental conditions lower than 15^{0}C. The feedstock for Indian biogas plant is cattle manure only [28]. On the contrary, IZAYDAS plant has an automatic control system including mixing for homogenous dispersion, and external heating with hot water to keep temperature fixed at 36-37^{0}C. Being kept at or close to favorable conditions for fermentation through control in IZAYDAS plant explains the higher biogas production. Additionally, the generator used in IZAYDAS plant has a higher capacity (330 kW) than the Indian plant generator (6 kW) with better specifications explaining the higher electricity generation efficiency IZAYDAS. Accordingly, efficiency results for biogas and electricity production in industrial scale biogas has comparable results with IZAYDAS plant. And, as the extent of process control increases, energy production efficiency increases [7,10,11,29,30]. Lastly, the usage of mixed feedstock can contribute the higher efficiencies in IZAYDAS which is in accordance with the literature [7,8,9].

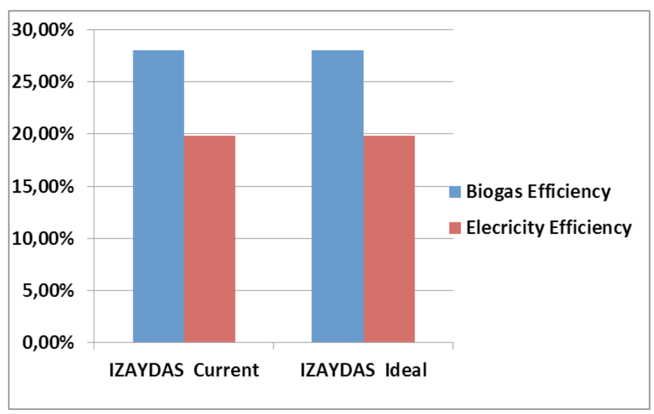

Figure 3: Biogas production and electricity generation efficiencies of IZAYDAS biogas plant.

4.2 GHG Mitigation Potential

The amount of GHG emissions mitigated due to biogas production is determined by the quantities of organic waste processed, chemical fertilizer production substituted and fossil based electricity use replaced. Among these, quantity of organic waste processed contributes the most to the GHG mitigation followed by fossil based electricity and chemical fertilizer production replacement both for the current and ideal cases. As seen in figure 4, total amount of GHG emissions prevented almost triples in ideal case because of higher quantity of waste processed, electricity generated and fertilizer replaced.

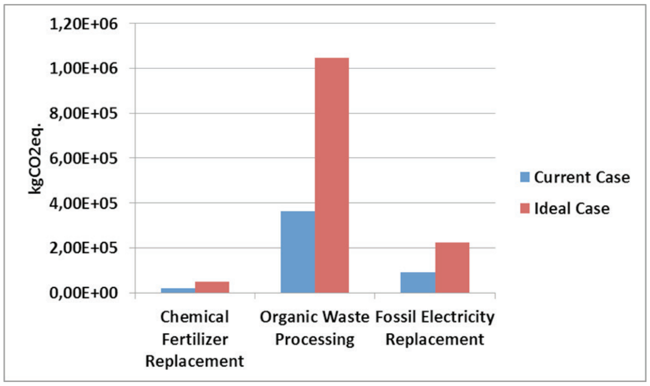

Figure 4: Comparison of GHG mitigation sources in IZAYDAS plant for current and ideal cases

4.3 Economic Potential

Figure 5 shows the revenue gained from sold products in IZAYDAS plant. The highest source of revenue is from liquid fraction of digestate selling due to its high quantity. If a proper market can be created, liquid digestate selling can be an important source of income for the facility.

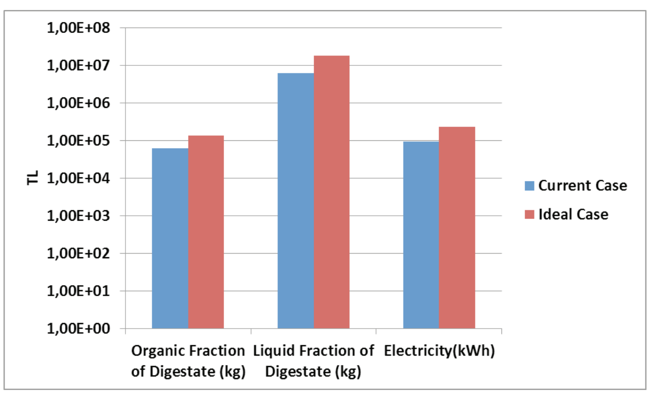

Figure 5: Revenue obtained from biogas production in IZAYDAS plant

4.4 Different Energy Utilization Scenarios and Related Emissions

4.4.1 Energy utilization

We consider that 1.0 J of electrical energy is equivalent to 2.5 J of natural gas energy and 5.0 J of biogas energy to convert all energy types into electricity equivalents. As explained in methodology section, it takes 5.0 J of biogas and 2.5 J of natural gas energy to generate 1.0 J of electrical energy. Based on this and cooking efficiencies of each energy source, figure 6 shows the results to perform equal magnitude of cooking task. There is almost 4 times difference between the necessary electrical and biogas energy types needed to perform the same magnitude of cooking. This difference is sourced mainly from the available energy lost during generation of electricity from biogas or natural gas. Hence, utilizing biogas directly instead of converting into electricity is more favorable energetically.

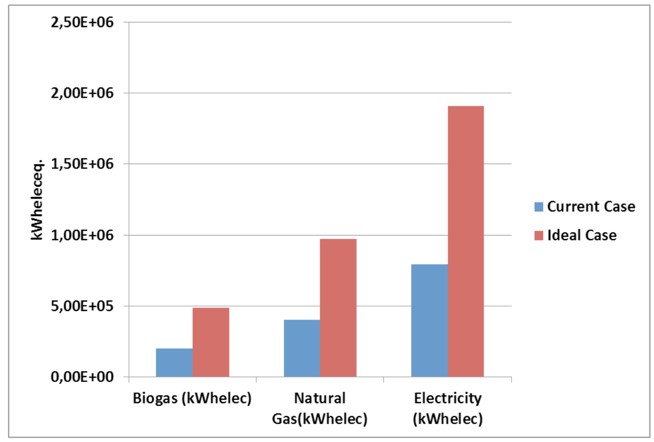

Figure 6: Energy required toperform equal amount of cooking task with different fuels.

4.4.2 Emissions

The results for GHG emitted in CO_2 equivalents for cooking are given in figure 7. The tremendous difference (the graph is logarithmic!) between biogas and electricity use emission results also confirm favorable direct utilization of biogas rather than being converted into electricity from environmental point of view. Additionally, there is significant difference for the emission values of fossil fuel natural gas and a renewable fuel biogas that promotes biogas use.

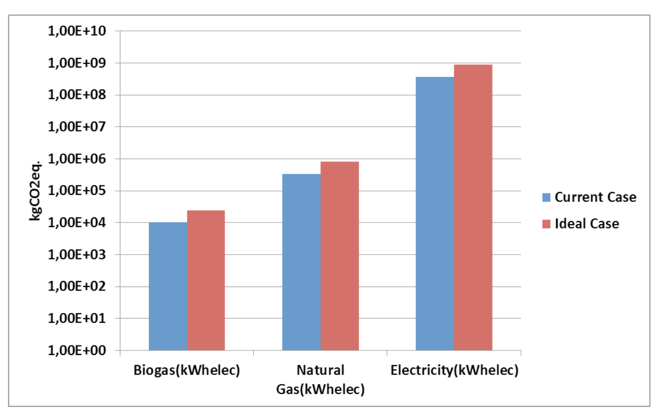

Figure 7: GHG emitted in CO_2 equivalents for cooking.

4.5 Discussion

Presented study covers two main stages of a biogas producing system: Production and utilization. Production stage analysis includes biogas production and electricity generation efficiency calculation, comparison of these results with a smaller capacity biogas plant and comparable size industrial plant; GHG mitigation and economic potential analysis. Utilization stage analysis includes a scenario where biogas is directly utilized instead of being converted into electricity and this biogas replaces natural gas or fossil electricity use in cooking. This scenario analysis has been done in terms of energetic performance and GHG emissions.

The biogas production and electricity generation efficiencies in IZAYDAS plant are found to be 28% and 20%, respectively. Whereas these results are 17% and 11% for the small capacity plant operating in Jhansi district of India. Being a higher capacity and being operated under the control of a process control system, IZAYDAS plant has better energy efficiency values. This stresses the importance of providing optimum environmental and technical conditions to have effective energy production from biological sources also confirmed by results obtained from many industrial scale biogas plants. Under ideal operating conditions, the amount of organic wastes (in terms of dry solid) processed in IZAYDAS plant roughly triples. This directly reflects to the GHG mitigation potential of the plant in current and ideal cases. For both cases, organic waste processing is the major contributor to the GHG mitigation potential followed by fossil electricity replacement and then chemical fertilizer replacement. Economically, liquid fraction of the fertilizer is the major source of income due to its high amount followed by organic fertilizer and electricity sold to the grid. Here, lack of legal regulation for use of digestates as fertilizer in Turkey can create drawbacks for economic potential. Extent of these drawbacks should be studied and recommendations to facilitate biogas digestate use adoption instead of chemical fertilizer utilization should be made. This can have two benefits. Firstly, increased economic potential can stimulate spreading o biogas plants especially in rural areas. Secondly, in addition to its economic benefits, environmental and social benefits of using digestates as fertilizer can be harnessed.

To perform the same magnitude of cooking task, it is found that almost 4 times more the electrical energy (as available energy) is needed compared to biogas. This difference is sourced mainly from the available energy lost during generation of electricity from biogas. Hence, utilizing biogas directly instead of converting into electricity is found to be favorable energetically because more available energy can be harnessed from direct utilization pathway. In terms of GHG emitted due to cooking, there is a tremendously more GHG is emitted when electricity is used compared to biogas again confirming favorable direct utilization of biogas. Additionally, the significantly more GHG emission values of fossil fuel natural gas pushes the preference towards the renewable fuel, biogas. All in all, utilizing biogas directly instead of converting into electricity is found to be more favorable both energetically and environmentally in our study.

Acknowledgements

Writer expresses her special thanks to Şahan Dede and Arzu Ulutaş for providing IZAYDAS data and their support during this work.

References

[1] Deublein, D., Steinhauser, A. (2011). Biogas from waste and renewable resources. Weinheim, Germany. WILEY-VCH.

[2] Katuval, H., Bohara, A.K (2009). Biogas: A promising renewable technology and its impact on rural households in Nepal. Renewable and Sustainable Energy Reviews 13, 2668-2674.

[3] Abbas, A., Ali, G., Adil, S.A., Bashir, M.K., Kamran, M.A. (2017). Economic analysis of biogas adoption technology by rural farmers: The case of Faisalabad district in Pakistan. Renewable Energy 107, 431-439.

[4] Yasar, A., Nazir, S., Tabinda,A.B., Nazar, M., Rasheed, R., Afzaal, M. (2017a) Socio-economic, health and agriculture benefits of rural household biogas plants in energy scarce developing countries: A case study from Pakistan. Renewable Energy 108, 19-25.

[5] Holm-Nielsen, J.B., Saedi, T.A., Oleskowicz-Popiel, P. (2009) The future of anaerobic digestion and biogas utilization. Bioresource Technology 100, 5478–5484.

[6] Yasar, A., Rasheed, R., Tabinda, A.B., Tahir, A., Sarwar, F. (2017b) Life cycle assessment of a medium commercial scale biogas plant and nutritional assessment of effluent slurry. Renewable and Sustainable Energy Reviews 67, 364–371.

[7] Poschl, M., Ward, S., Owende, P. (2010). Evaluation of energy efficiency of various biogas production and utilization pathways. Applied Energy 87, 3305–3321.

[8] Bacenetti, J., Megri, M., Fiala, M,, Gonzalez-Garcia, S (2013). Anaerobic digestion of different feedstocks: Impact on energetic and environmental balances of biogas process. Science of the Total Environment 463–464, 541–551.

[9] Berlund, M., Borjesson, P. (2006). Assessment of energy performance in the life-cycle of biogas production. Biomass and Bioenergy 30, 254–266.

[10] Eriksson, O., Bisaillon, M., Haraldsson, M., Sunberg, J. (2016). Enhancement of biogas production from food waste and sewage sludge environmental and economic life cycle performance. Journal of Environmental Management 175, 33-39.

[11] Whiting, A., Azapagic, A. (2014). Life cycle environmental impacts of generating electricity and heat from biogas produced by anaerobic digestion. Energy 70, 181-193.

[12] Börjesson, P., Berglund, M. (2006). Environmental systems analysis of biogas systems—Part I: Fuel-cycle emissions. Biomass and Bioenergy 30, 469–485.

[13] Börjesson, P., Berglund, M. (2007). Environmental systems analysis of biogas systems—Part II: The environmental impact of replacing various reference systems. Biomass and Bioenergy 31, 326–344.,

[14] Nkoa, R. (2014) Agricultural benefits and environmental risks of soil fertilization with anaerobic digestates: a review. Agronomy for Sustainable Development, 34, 473-492.

[15] Location of IZAYDAS (2017). https://www.google.com.tr/maps/search/ IZAYDA%C5%9F+HAR%C4%B0TA/@40.7889202,12.0834592,4z?dcr=0. Accessed June 22.

[16] IZAYDAS (2016). Process data and documents provided by plant operators.

[17] Bouallagui, H., Cheikh, R.B., Marouani, L., Hamdi, M. (2003). Mesophilic biogas production from fruit and vegetable waste in a tubular digester. Bioresource Technology 86, 85–89.

[18] Oliveira, M.O., Somariva, R, Ando Junior, O.H., Neto, J.M., Bretas, A.S., Perrone, O.E., Reversat, J.H.(2012). Biomass electricity generation using industry poultry waste. International Conference on Renewable Energies and Power Quality (ICREPQ'12) Santiago de Compostela (Spain), 28th-30th March.

[19] Energy mix of Turkey (2017). http://www.enerjiatlasi.com/elektrik-uretimi/ Accessed July 20.

[20] Lou, X.F., Nair, J.(2009).The impact of landfilling and composting on greenhouse gas emissions – A review. Bioresource Technology 100, 3792–3798.

[21] Hao, X., Chang, C., Larney, F.J., Travis, G.R. (2001) Greenhouse Gas Emissions during Cattle Feedlot Manure Composting. Journal of Environmental Quality 30, 376–386.

[22]Alibaba fertilizer prices (2017).https://turkish.alibaba.com/g/organic-fertilizer-prices.html. Accessed July 20.

[23] Senol H., Elibol, E.A., Açıkel U., Senol M. (2017). Türkiye'de Biyogaz Üretimi İçin Başlıca Biyokütle Kaynakları. BEU Journal of Science 6, 81-92.

[24] Bakshi, B.R,, Baral, A., Hau, J,L. (2011) Thermodynamic Methods for Resource Accounting. In Thermodynamics and the Destruction of Resources ; Bakshi, B.R,, Gutowski, T.G., Sekulic, D.P.. Eds.; Cambridge University Press: Cambridge, U.K.,87−112

[25] Cleveland, C. J. (1992). Energy quality and energy surplus in the extraction of fossil fuels in the U.S. Ecological Economics 6, 139−162.

[26] Bhattacharya, S.C., Salam, P.A. (2002). Low greenhouse gas biomass options for cooking in the developing countries. Biomass and Bioenergy 22, 305 – 317.

[27] Kaygusuz, K. (2011). Energy services and energy poverty for sustainable rural development. Renewable and Sustainable Energy Reviews 15, 936–947.

[28] Kursun,B., Bhavik, B.R., Mahata, M., Martin, J.F. (2015). Life cycle and emergy based design of energy systems in developing countries: Centralized and localized options. Ecological Modelling 305, 40-53.

[29] Nizami, A.S., Shahzad, K., Rehan, M., Ouda, O.K.M., Khan, M.Z., Ismail, I.M.I., Almeelbi, T., Bahasi, J.M., Demirbas, A.(2017). Developing waste biorefinery in Makkah: A way forward to convert urban waste into renewable energy. Applied Energy 186, 189-196.

[30] Budzianowski W.M., Budzianowska D.A. (2015). Economic analysis of biomethane and bioelectricity generation from biogas using different support schemes and plant configurations. Energy 88, 658-666.