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Using Anaerobic Digesters as a Sustainable Approach in Creating Sustainable Cities in Egypt

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Abstract The first digestion plant was built in Bombay, India, in 1859. But since 1895, anaerobic digestion has been used to recover gas as a waste management system in England. Anaerobic digesters are one of the most well-known systems that are used worldwide to get rid of waste and generate energy, yet they have never been employed in Egypt. This research aims to determine the economic, social, and environmental impacts of anaerobic digesters in Egyptian cities and districts. From an economic perspective, the study estimates the energy produced from storing organic wastes in anaerobic digesters, using a quantitative approach to measure the efficiency of anaerobic digesters in Egyptian districts. In this study, the data were collected using surveys among residents and cleaners in the study area. The information gathered in this study was used to estimate the amount of organic waste (OW) produced by area 4 El-korba in Heliopolis, which will be stored in an anaerobic digester (AD) and used to generate heat, electricity, and fertilizer. In terms of social impact, the study relied on a site questionnaire to measure the impact of waste accumulation on the Egyptians. The aim of this paper is to study the storage of the OW collected from El Korba district in AD and how it can save electricity consumed by the district residential sector. Finally, the study applied a quantitative method to measure the amount of waste disposed of and burned in one Egyptian district from an environmental standpoint.

Keywords Anaerobic Digesters (AD), Egyptian District, Electricity and Gas Production, Organic Wastes (OW), Sustainability, Waste Management (WM)

1. Introduction

Ozone depletion and climate changes in the atmosphere are some of the global environmental issues that humanity is facing. The most important and harmful greenhouse gases in the atmosphere are primarily those of anthropogenic origin, particularly CO_2, which is produced by burning wastes and fossil fuels [1, 2, 3]. Whether wastes or special resources are used as feedstocks, biogas energy can make a significant contribution to climate protection and resource conservation. Biomass and bioenergy technologies are numerous. Anaerobic digestion (AD)-based biogas production is one of the most efficient methods in bioenergy investments. Nearly all organic materials and wastes from agriculture and the food industry can be used to make AD biogas.

The burning of wheat and rice straw, which causes the "black cloud," is currently one of the most serious problems confronting Egyptians and polluting Egypt's districts' atmosphere, as well as endangering Egyptians' respiratory systems. Due to a lack of waste management (WM) strategy, nearly 64% of Egyptians are suffering from respiratory illnesses. Every year, Egyptians are affected by the "black cloud" that appears after the rice harvest season. Asthma, respiratory system failure necessitating artificial respiration, and an increase in the number of cases of chest allergies are all effects of the "black cloud" on Egyptian public health [4, 5, 6].

The aim of this study is to examine the impact of using anaerobic digesters tanks in Egypt's cities using AD tanks. As a long-term tool for reusing organic waste in the production of clean energy in the form of electricity and gas, it can be used to meet the needs of Egyptian communities.

The hypothesis of this study is that storing organic waste in anaerobic digesters will produce gas and electricity, affecting the economic state of Egypt's cities and resulting in self-sustainability, as shown in Figure 1. In addition, there will be less pollution as a result of the removal of organic waste, which will have an impact on the residential quality of life.

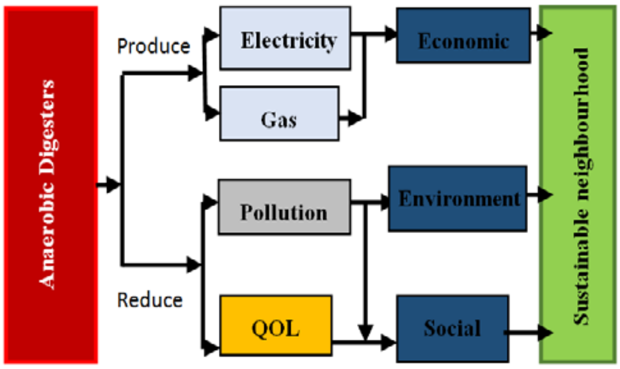

Figure 1. Research Hypothesis

The research will study the impact of storing the OW of Egyptian cities in AD tanks and measure the outputs toward electricity generation, reduction of environmental and social pollutants.

2. Types of Waste in Egypt

Every year, nearly 38 billion metric tonnes of OW are produced worldwide [7, 8]. Human consumption, population explosion, and human behavior are all contributing to the dramatic increase in OW. Egypt produces nearly 60 million tonnes of solid waste (SW) each year. According to Elfeki & Tkadlec [8], Egypt's recycled OW does not exceed 20%, and the remaining OW will have a negative impact on residents' public health and the environment, so there is a pressing need to manage the remaining OW [9].

The wastage of SW in drains, waterways, and open dumpsites has contaminated water supplies and the atmosphere, endangering Egypt's heritage, natural resources, and populations' wellbeing.

Other wastes, as shown in figure 2 such as glass 4%, paper 10%, and plastics 13%, account for nearly 56% of the total. Although the Egyptian government began numerous strategies in the year 2000 to develop a strategy for the WM sector, their efforts have shown little advancement. The percentage of waste that is recycled or reused does not exceed 2.5 percent, while nearly 83.5 percent of waste is dumped [9, 10].

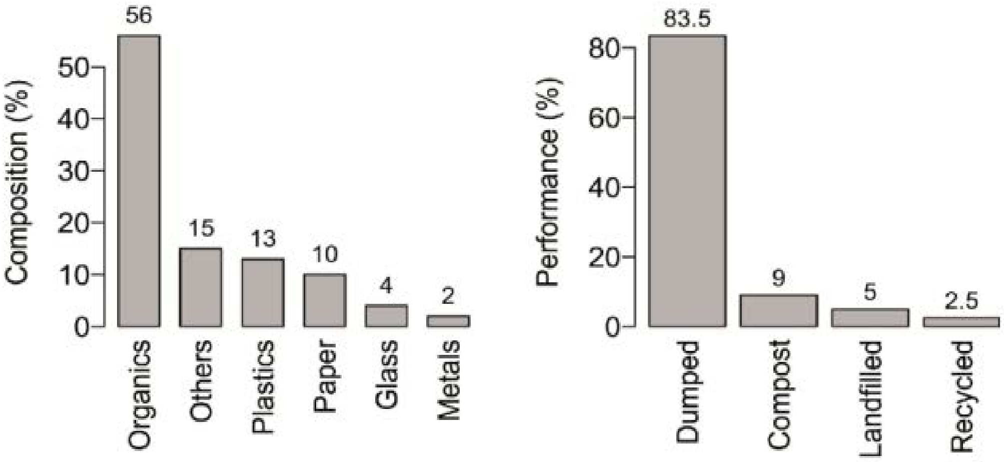

Figure 2. Types of waste in Egypt

3. Anaerobic Digesters

Anaerobic digestion refers to a set of processes in which microorganisms break down biodegradable materials without the use of oxygen. Identified three basic AD processes that occur at different temperature ranges: psychrophilic, mesophilic, and thermophilic. The psychrophilic fermentation process is a process that takes place at a low temperature (around 20°C) [11]. Mesophilic metabolism takes place between 20 and 45°C and can take a month or two to complete, while organisms absorption takes place between 45 and 65°C and is faster but has more delicate microorganisms.

AD is a practical system for OW management because it reduces waste volume and produces a variety of energy sources due to high solid destruction efficiency (up to 90%) and high methane yields [12, 13, 14, 15].

3.1. Economic Barriers

Using renewable energy in creating sustainable cities has many economic aspects as proved by different researches [16,17,18] Despite numerous opportunities for farm biogas regional development and a few successful pilot [19, 20, 23], decentralized biogas technology has yet to gain rapid adoption. Along with its low energy data, durability, service life, operating costs, and lack of efficiency, decentralized biogas production from compost and agricultural wastes are currently not cost-effective or reliable [21, 22].

For biogas commercialization, a significant barrier is a high cost and low performance of biogas digesters. Due to economies of scale in construction and operation, a rough threshold size of 300 cows or 2000 swine is suggested for digesters with electricity-generating potential [24]. This size of the threshold may be reduced as technology improves. While biogas plant construction costs vary by country, they are frequently high when compared to the income of farmers and other potential users. So many simple, small-scale digesters yield biogas for heating, cooking, and lighting needs in developing countries like China and Nepal, resulting in so-called decentralized biogas technology. A short-lived plant may be expensive, but it may not be redeveloped once its useful life is over. According to the Bundestag (2019), 1 m3 of biogas generates between 5 and 7.5 kWh, as shown in table 1.

Table 1 shows the different types of crops that produce different amounts of electricity, such as feedstuff maize, which produces 18731 kWh on average, and grassland, which produces 9549 kWh on average [22].

Table 1. The amount of energy produced from 1m3 kWh and the Electricity production from different types of crops in one hectare

Energy generated from biogas and biomethane	
1 m^3 biogas	5.0-7.5 kWh energy content
1 m^3 biogas	50-75% methane content
1 m^3 biogas	Approximate 0.6 l heating oil equivalent
1 m^3 methane	9.97 kWh energy content
1 m^3 methane	Heating value 36 MJ/ m^3 Or 50 MJ/kg
1 m^3 methane	1 l heating oil equivalent

Electricity production from different types of crops in one hectare

Energy crop	**Harvest yield (t FM)**	**Methane yield (Nm3)**	**Electricity yield (kWh)**	**Number of households supplies**
Silage maize	50	4,945	18,731	5.2
Sugar beets	65	4,163	15,769	4.4
Whole crop cereal silage (WCCS)	40	3,846	14,568	4.0
Cup plant	55	3,509	13,291	3.7
Grassland	29	2,521	9,549	2.7

Source: (Bundestag 2019; Rauh, 2016)

3.2. Environmental Barriers

In decentralized AD biogas production, problems (such as low biogas) are common, preventing this technique from becoming widely used [24]. Numerous studies have been conducted to determine the mechanism and factors that control biogas production and digester inhibition. Regardless of social or economic factors, there is a significant difference in biogas production achievement between pilot plants and practical plants. These discrepancies arise, in most cases, due to feedstock uncertainty and environmental conditions in the specific area where AD biogas production takes place.

Pilot digesters are designed mainly with anticipated feedstocks and climate conditions in mind. However, due to a lack of feedstocks, keeping the main parameters of scalable digesters consistent with those of the pilot digester is difficult. Because of differences in waste feedstock formation, the pilot plant's efficient operating criteria must be adjusted for some local sophisticated feedstocks and climate.

Table 2. Anaerobic digesters using food wastes in US

AD technology	**HSAD**	**SMARTFERM HSAD**	**SMARTFERM HSAD**	**LSAD**	**HSAD**	**LSAD**	**HSAD**	**3-stage HSAD**	**3-stage HSAD**	**Quasar's LSAD**
Digestate end use	Compost (34,000 TPY)	Compost (2200 TPY)	Compost (5000 TPY)	Fertilizer (5000 MTPY)	Compost (5000 MTPY)	Granular fertilizer (5200 MTPY)	Liquid fertilizer (10 million gal/year)	Liquid fertilizer (4 million gal/year)/ soil amendments	Soil amendment (1000 TPY)	Soil amendment (8600 yds^3/year)
Biogas end use	Electricity (1.6 megawatt MW)	CHP (100 kW)	CNG (+100,000 DGE/year)	7 MW CHP (3.2 MW electrical, 3.8 MW thermal)	2.2 MW CHP (1.1 MW electrical, 1.1 MW thermal)	5.7 MW CHP (2.8 MW electrical, 2.9 MW thermal)	CNG (700,000 DGE/year)	Electricity (5.6 GWh)	Electricity (1300 kWh/day)	CHP (300 kWh)
Capacity	90,000 TPY	5000 TPY	11,200 TPY	>120,000 TPY	40,000 TPY	100,000 TPY	40,000 TPY	20,000 TPY	2900 TPY	15,148 wet TPY
Feedstocks	OW	OW	Food waste/ green waste	Commercial food waste and bio-solids	Food waste/yard waste	Commercial food waste	Organic waste 3-stage	Food waste/manure	Food waste/ cardboard/ other	25 % manure/75 % food waste
Completion date	2013	2013	2014	2013	2012	2012	2013	2014	2012	2011
Facility name/location	Zero Waste Energy, San Jose, CA	Monterey Regional WM District-Marina, CA	SSF Scavenger, South San. Francisco, CA	Harvest Energy Garden, Orlando, FL	Harvest Energy Garden, Richmond, BC	Harvest Energy Garden, London ON	Sacramento BioDigester, Sacramento, CA	UC-Davis READ, Davis, CA	American River Packaging, Sacramento, CA	Jordan Dairy Farm, Rutland, MA

Source: adapted from (Linville, et al., 2015)

4. The Current State of AD Worldwide

In Europe, AD technology is more common and well-established than in the United States [25, 26]. Germany, Denmark, and the United Kingdom are leaders in generating energy from AD, having established a successful public policy for the technology's development. Landfill taxes, landfill bans, and a variety of separate OW collection systems are part of their public policy [25, 28]. Germany and many other European governments provide direct financial support for renewable energy generation, which has aided in the spread of AD [28]. According to 2013 statistics, Europe has over 244 AD plants with a combined treatment capacity of nearly 8 MMT/year [15].

Table 2 shows that anaerobic digestion has been successfully practised in the United States, with 175–240 AD systems currently using OW [29, 30]. In the United States, biogas production produced nearly 545 million kWh of energy while reducing fossil fuel emissions by approximately 1.2-2 MMT CO2e. However, many of these facilities are small "farm-scale" processes. There are 1484 WWTPs that use AD technology; however, as shown in Table 2, less than 10% of those plants use biogas for energy production [15]. Table 2 shows the most recent AD installations for FW, manure, or other OW in North America.

5. The Study Method

The impact of AD on Egyptian neighborhoods is investigated using an empirical method in this study. For the data collection phase of this study, surveys were conducted among residents and cleaners in the study area. The information gathered in this study was used to estimate the amount of OW produced by area 4 El-korba in Heliopolis as shown in figure 3, which will be stored in AD and used to generate heat, electricity, and fertilizer.

Figure 3. korba Building.

5.1. Study Area

Heliopolis city has been chosen to be the study area of this research as it is one of the neighbourhoods that have gas and electricity issues in Egypt. Heliopolis city is a heritage-oriented city with approximately 9,1641.20 km^2 of land. El Korba was then home to for the most part privileged Egyptians and a few Europeans, albeit in contrast to other Egyptian urban communities at that point. The city has two primary regions, a modern region, presently known as Medan El Gamee (The Mosque Square) and El Korba; coming from the Italian word La Curva, or the bend as shown in figure 4 [36].

Figure 4. Location of the el korba masr gdeda, Egypt

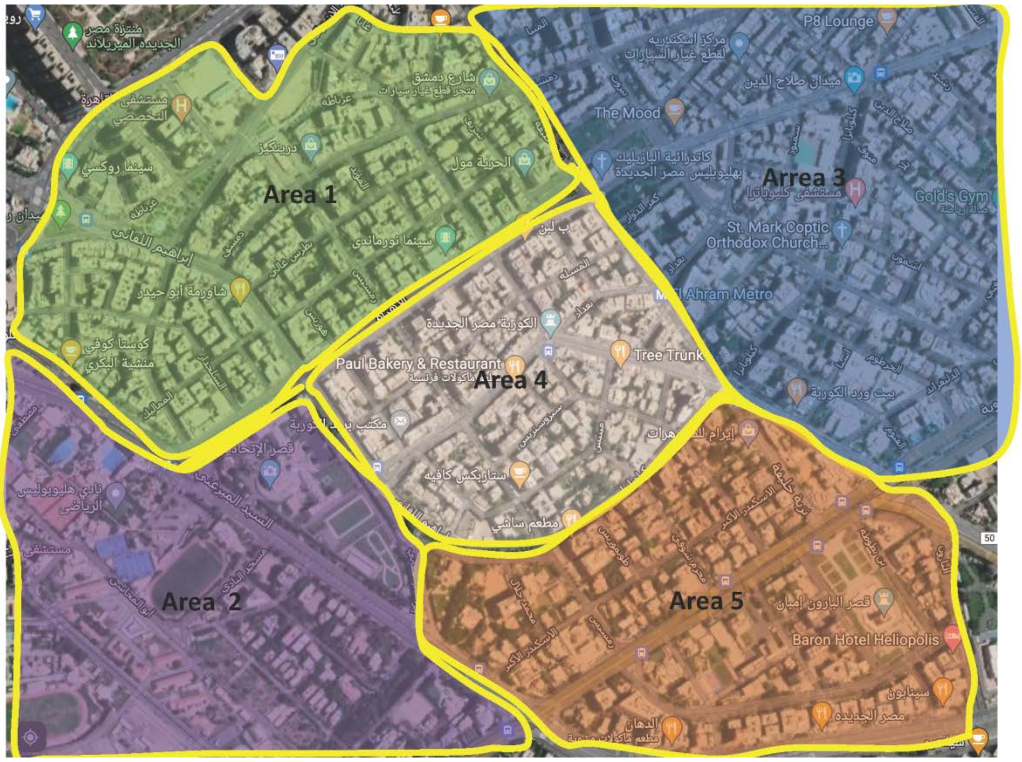

Figure 5. The urban zooning of el korba masr gdeda, heliopolis

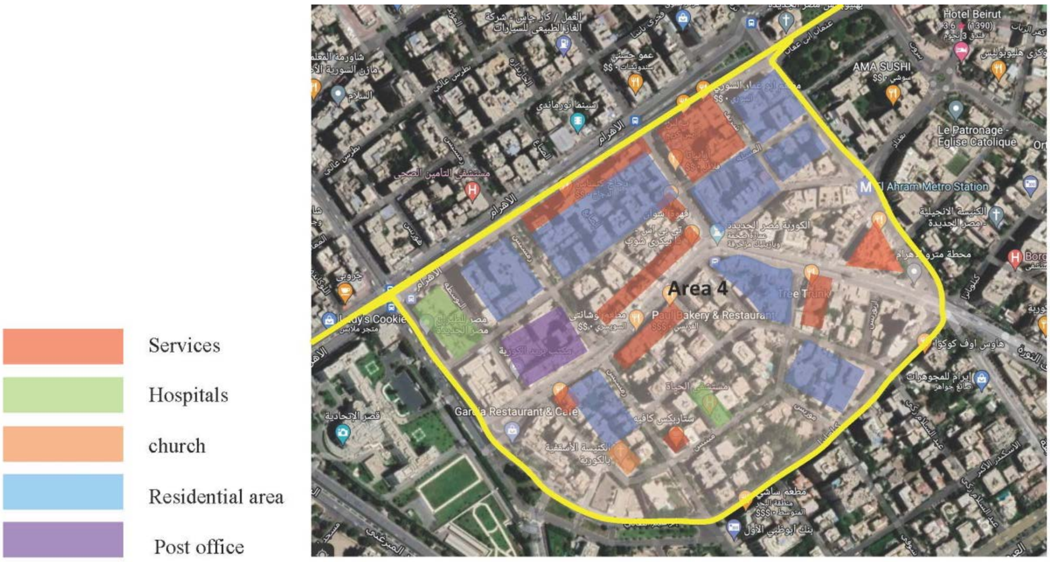

Figure 6. The monumental buildings in area 4

Moreover, a lot of employments have vanished like age-old shops, bistros, banks, and names of roads have been changed cutting the string of ceaseless taking care of history. In addition, affluent excited financial backers purchase resources and crush them obliterating their character. The study area of this research is Heliopolis located inside Masr Gdeda neighbourhood, one of the biggest neighbourhoods in Cairo City. Area 4 El-korba, is a middle-class residential area, surrounded by area 2 and areas 3 as shown in figure 5.

El Korba area is located in the middle of masr gdeda which gives this area a special concentration. With beautiful Andalusian-style architecture and a plethora of old churches and cultural centres dating back to the days when Cairo was a cosmopolitan, multicultural metropolis, the Korba district is Heliopolis' historic heart. The average area of elkorba zone is 5952 feddan around 24,998,422 m^2. Area 4 is considered a residential area, but it includes services. Elkorba area, contains different building types such as; residential, educational, religious, hospitals, fire stations, and post offices as shown in figure 6.

The Korba district is Heliopolis' historic heart, with beautiful Andalusian-style architecture and a plethora of old churches and cultural centres dating back to the days when Cairo was a cosmopolitan, multicultural metropolis. The section of this line that is currently in service is between Ataba Station and El-Shams Club Station. Most of the buildings in the study area are residential buildings but it includes parks and clubs as well. The Merryland is additionally a renowned sporting park; it contains a lake and was at the stature of its class during the 1960s and 70s.

5.2. Characteristics of Participations

The questionnaire was distributed among two kinds of participants: The research first targeted the street cleaners and garbage collectors working in the Heliopolis district, in addition to the residents of the district. A total of 410 participants participated in this research; they were surveyed between March 12th and March 22nd, 2021. The research interviewed 401 residents living in Heliopolis district. Moreover, nine garbage collectors and cleaners work daily to collect the garbage from Heliopolis district.

5.3. Data Collection Questionnaires

In this research, part of the data collected was from site questionnaires. The site questionnaires were made to estimate the percentages of OW produced from Egyptian districts. In addition to that, the research will measure the environmental and social effects of using AD in Egyptian districts.

Two types of questionnaires were designed; the first questionnaire was targeting the district garbage collectors and street cleaners, it is aiming to identify the nature of the waste gathered from the district and calculate the percentages of organic materials in the district garbage.

The second questionnaire was targeting the district residents and hotel workers, the survey aimed to validate the data collected from the 1st questionnaire as well as it will measure the negative impact of garbage accumulation in Egyptian districts. The study area is considered a middle-class residential area, knowing that most middle-class families consist of 4 to 5 persons. During the second interview, the residents were asked about their monthly electricity and gas consumption, knowing that in 2021, the energy cost of 1kWh in Egypt is 0.712 L.E while the cost of natural gas in residential houses is 2.50 L.E. The research will estimate the percentage of electricity and gas satisfaction that the AD will provide to the area. The average electricity and gas consumption of a single residential house is presented in table 3.

6. Data Analysis

This section introduces the results of the data collected from the field survey and analyse using AD in Egyptian districts. This section intends to calculate the amount of OW produced from El Korba district and calculate the amount of gas & electricity generated from storing the OW produced in AD. Moreover, the research will compare the amount of gas & electricity generated from AD with the gas & electricity consumed in the residential apartment to identify the percentage of self-satisfaction that the AD system will provide.

The residential questionnaire proved that a single residential apartment gets rid of an average of 4-6 trash bags every week. While the school gets rid of approximately15-20 trash bags/week as shown in table 4.

The survey revealed that residential trash bags contain more than 60% OW [28]. The average weight of residential trash bag is 2.5kg and the average weight of the hotel trash bags is 4kg.

Table 3. The electricity and gas bills of single residential house in El Korba district

Bills Date	Electricity Consumption			Gas Consumption			
	Consumption in kWh	**Number of days**	**Price**	**Date**	**Number of days**	**Amount of BTU consumed**	**Price**
7/2020	500	30	356 L.E	5/2020	30	20	50 L.E
8/2020	630	31	449 L.E	9/2020	31	32	80 L.E
10/2020	420	30	299 L.E	10/2020	30	22	55 L.E
Average Consumption	**516.6 kWh**	**30**			**30**	**24.6 Btu**	

Table 4. Number of trash bag waste produced from different buildings of the neighborhood/week

Type of building	No. of trash bags				
	1-6	6-15	15-25	25-35	More than< 35
Residential apartment	✔ from 1 -6 bags/week are collected				
Hotel					✔

Table 5. Amount of wastes produced/week from El Korba district

Building type		No. of trash bags/ week	Avg. Weight of one trash bag	Total amount in Kg	Total amount of wastes in study area/week
Apartments	55 apartments in each building	6 bags	2.5 kg/bag	55 x 4 x 2.5= 825 Kg	825 + 200 = 1025 kg
Hotel	400 Room	50 bags	4 kg/ bag	40 x 4 = 200 kg	

Table 6. Amount of OW produced/ week

Types of OW	Percentage of wastes in trash bags	Total amount of wastes produced from the neighbourhood	Total percent of OW
(food and vegetables leftovers	74.5%	1025 kg	(1025 x 60) ÷ 100 = 615 kg
Paper	10%		
Animal wastes	2%		
Plants waste	1.5%		
Other organic waste	12 %		

Table 7. The total Energy generated from storing OW produced from El Korba district in AD tanks

Amount of OW produced from the study area in week	Electricity		Biogas	
	Electricity generated from 1kg of OW	Total electricity produced in 15 days	Amount of Btu produced from 1kg of OW	Total gas in Btu in 15 days
615 kg	0.2 kWh	615 kg x 0.2 kWh = 123 kWh	200	615 kg x 200 Btu = 123,000 Btu
Total electricity production		123 kWh		
Total Gas production				123,000 Btu

Table 8. The total Costs of electricity production

	energy produced from AD	Cost of energy from power plants (L.E)	Total saving (L.E)
Electricity	123 kWh	0.715	87.945 L.E
Biogas treatments	123,000 Btu	2.50	307,500 L.E
Total weekly saving			87.945 + 307,500 = 307,588 L.E

According to the field survey, the study building has 55 apartments and one hotel. A single apartment may produce 6 trash bags/week, each bag may weigh 2.5kg/bag as shown in table 5.

According to table 6, 1025 kg of SW is produced from the study area weekly. According to Guirguis and Moussa 2019 [37] and the field survey, 60% of the trash bags are OW, the percentage of OW from leftovers food and vegetables represents 74.5% of the total OW, while 10% represent waste papers & 15.5% from other OW like fertilizers & liquids as shown in table 7. The average amount of wastes produced from the study area is 1025 kg weekly, which is equivalent to 615 kg of OW as shown in table 6.

7. Results

The literature stated that AD needs 15 days to complete the digestion process, moreover, the literature stated that the amount of energy produced from AD system could be calculated as follows:

1kg of any OW produces approximately $0.04m^3$ of biogas which means that 1m3 of biogas can be produced from 25 kg. In addition, $1m^3$ of biogas produce approximately 5kWh electricity & approximately 5000 Btu of gas, which means 1kg, can produce 200 Btu. The amount of electricity & Gas produced from storing district 4 OW in AD is calculated in table 7.

As shown in table 7, the total energy generated weekly from storing the OW in AD tanks of 1 building located in El Korba district is 123 kWh, which is equivalent to 123 x 4 = 492 kWh/month.

In 2021, the cost of 1kWh in Egypt is 0.712 L.E while the cost of natural gas in residential houses is 2.50 L.E. Therefore, using AD in one building in El Korba district, will save an average of 307,587 EGP weekly as shown in table 8.

8. Conclusions

This article discussed the potential of using OW to become a major energy supplier, a sustainable solution for getting rid of OW produced from residential neighbourhoods in developing countries such as Egypt and using it to generate energy and gas. The research proposed that AD system could play the principal role in minimizing the activities of garbage collection and wastes exposition in low income countries by incorporating large AD tanks in the residential neighbourhoods and districts. These large AD tanks are cheap and will satisfy the resident's needs for energy. Incorporating AD system will generate renewable energy that salsify the needs of the residential sector.

The result section showed that,

- Using AD in developing countries such as Egyptian neighbourhoods will generate 396 more gas than that the neighborhood consumed and this energy can be used as an extra income for the neighbourhood by selling this non-stop energy to the government.
- Using AD in return will help in solving one of the major problems facing the developing counties and standing in front of its development which is the availability of gas and power supply.
- Storing OW in AD can contribute considerably to the national energy balances. The proposed action can encourage the community to deal with the local garbage as a natural resource and not as a source of pollutants, resulting in a better quality of life and a cleaner environment.

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