Hybrid Unit: Photovoltaic Solar Panels and Biogas Digester for Domestic Energy Generation *

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***Abstract*— The main focus of this research is to put forward a new idea of implementing solar photovoltaic panels and anaerobic biogas digester to produce electricity for small residential houses. In the proposed hybrid energy unit, the photovoltaic arrays generate electricity for day time use, while electric generator driven by internal combustion engine powered by biogas digester provides electricity during night time. Calculations show that photovoltaic system of containing 10 panels of 400 Wp can provide day time electricity to a medium residential house. On the contrary, the methane gas produced by the 2m^3 biogas digester supplied with house solid waste can generate electricity for only 2 hours at night. The substrate quantity can be increased by adding more organic material from animal manure or green grass. This system is suggested to solve the problem of energy shortage in remote houses in West Bank and Gaza Strip due to the cruel war and destruction of all energy sources and electricity infrastructure.**

Keywords - Photovoltaic Solar energy; Biogas; Anaerobic Digester; Methane; Biomass; Hybrid Energy Unit.

I. INTRODUCTION

A. Background

Main sources of electricity supply in Palestine comes from Israeli Electric Company IEC 87%, with small contribution form Jordan 2% and from Egypt and Gaza Power Station 8%. Local electricity production is very small mainly from renewable energy resources 3%, and electric power station in Gaza Strip. In addition to the low energy independence ratio, energy sector suffers from high prices. Electricity cost exceeds 17cents per kWh, gasoline and diesel fuels exceed 2.0 $/litre, while LPG around 1.6 $/kg. Annual average per capita electricity consumption in Palestine is 1280 kWh/year. capita. Renewable energy production contributes to 11.4% of the total energy consumption, meanwhile Renewable Energy electricity consists only 4% of the consumed electricity [1].

B. Household energy

Energy consumption in the residential sector contributes to 38% of total energy consumption in Palestine as depicted in Fig. 1. In year 2022 the annual households' consumption of oil products is 179 kTOE, and 4885 GWh of electricity [2]. Table 1 shows annual per household energy consumption from different energy sources. Table 1 includes
average values for whole Palestine, West Bank, and three regions in West Bank; south, middle, and north of West Bank.

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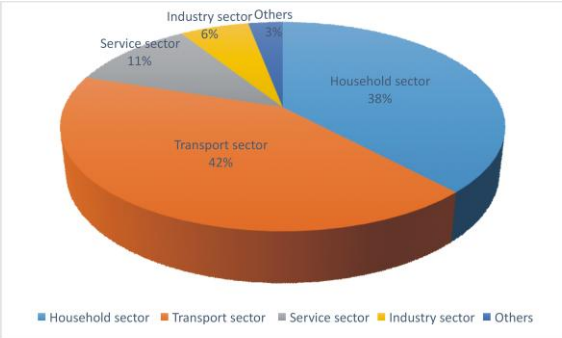

Figure 1. Percentage of energy consumption in various sectors in Palestine.

TABLE I. AVERAGE ANNUAL HOUSEHOLD ENERGY CONSUMPTION [3].

region	Electricity kWh	Diesel Litre	Gasoline litre	Kerosene litre	LPG kg
Palestine	306	149	95	21	22
West Bank	328	160	115	28	26
North of West Bank	272	180	114	23	25
Middle of West Bank	442	183	135	36	25
South of West Bank	294	122	91	27	28

Concerning domestic water heating, electric heaters are used by 60% of houses, 28% use LPG boilers, 9% use biomass heaters, while 3% only use solar water heaters [4].
For space heating 39% of households use electric heaters, 29% use wood stoves, 25% of households use LPG heaters, while only 1% still using kerosene heaters. [5].

C. Solar energy

Palestine located around 32 ºN experiences a good amount of solar irradiation with over 3000 hours of sun shine and 2000 *kWh* per m^2 annually [6]. Daily average solar irradiation varies

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between 6.15 and 8.27 kWh/m^2.day on various areas of West Bank [16].

Solar drying was the main practice of food preservation in the past, then in the 1970s solar water heating was introduce to the area to become as the main source of water heating. Thermosiphon solar water heating units do not require electricity to operate, hence they are used even in areas with no electricity. Solar water heaters in addition to wood and other biomass resources were the main sources of energy especially in rural areas. Recently after year 2000 PV arrays as source of electricity start to be introduced to the market; first as autonomous units with battery storage and mainly for remote applications. Later grid connected units in households was introduced through Palestine solar initiative for 1000 units based on feed in –tariff, however later changed to net metering. As market develops, many small companies entered the market and later also large companies with financial and technical capabilities to install MW units, around 240MWp installed by 2022 which included 2300 household units [7].

D. Biomass

Biomass resources mainly wood, agriculture waste, and animal manure were the sources of fuel for water and space heating, baking, cooking and other energy usages in the past in Palestine. The traditional bread baking method using Taboon is fueled through a mixture of animal manure and agriculture straw residues. This along with kerosene and to some extend diesel fuel are the only sources of energy in the rural areas. Gradually those were replaced with petroleum products, then later with electricity power.

Waste to energy is a sustainable solution to environmental waste management and disposal. Many routes and technologies are available for such conversion among which is biogas production through anaerobic digestion of organic waste materials, landfill gas is another large scale and long term option to produce biogas from municipal solid waste. Incineration of waste to obtain heat directly is a widely employed option, with provision to deal with environmental pollution from exhaust combustion gases. Municipal solid waste in Palestine contain a fairly good amount of organic materials as shown in Table 2 [8]. In Palestine only one landfill biogas project is under way in the Zahrat Al-Finjan landfill with a capacity reaching 1600 $m^3/hour$ by year 2030 and will be developed to generate 20MW of electricity [9]. Smaller scale biogas digester units are being tested and introduced in the local market [10, 11]. Biogas from biomass waste usually contains around 55% of methane and the rest is carbon dioxide, with a heating value around 20 $MJ/\ m^3$ [12]. Biogas can replace LPG for many applications where heat is needed, such as for cooking, and heating. In addition, biogas can be employed to drive internal combustion engines with some engine modifications.

TABLE II. SOLID WASTE COMPOSITION IN SELECTED LANDFILLS IN PALESTINE [8]

Composition	**Landfill**		
	Al Minya	**Zahrat AL Finjan**	**Jericho**
Organic	46%	55%	45.9%
Plastic	18.3%	12%	26.4%
Paper/ cardboard	10.9%	14%	11.1%
Glass	2.35	1.5%	1.3%
Metal	1.8%	2%	4.9%
Others	20.7%	15.5%	10.6%

TABLE III. TYPE OF HOUSING UNITS IN PALESTINE [13]

Region	**Type of housing unit**			
	Villa	House	Apartment	Others
Palestine 2019	0.5	45.3	53.0	1.2
Palestine 2022	0.5	43	54	3

E. Housing type

Palestine population by mid-2023 is estimated at 5.48 million, 78% of population lives in urban areas, 14% live in rural areas while 8% in refugee camps [14]. Concerning housing types as shown in table 3 apartment housing forms 53%, separate housing dwelling consists 45.3% with less than o.5% living in villas. Also as shown in Table 3 trend is moving more toward apartment dwellings in multi- story buildings.

In this paper energy supply to a typical detached house in Palestine based on a hybrid renewable energy resources will be designed. Solar electricity generated from PV array in addition to biogas production from household waste to generate electricity through a biogas engine.

II. RESEARCH METHODOLOGY

The main methodology used in this research is based on designing a hybrid system to produce electricity for household appliances. The system consists of a solar PV panels system integrated with biomass – biogas digester. The sustainability of the system will be tested using society 5.0 system by relating the corresponding Sustainability Development Goals to the outputs of the system. This should take into account the implementation of modern artificial intelligence and mechatronics systems that help to conserve energy consumption. Finally, a case-study calculation is used to verify the results.

III. HYBRID PV-BIOGAS ENERGY UNIT

A. Hybrid energy unit design

Using solar PV panels is a very well-known way to produce electricity for domestic houses. The main problem facing this method is that it is useless at night between sunset and sunrise, unless the excess produced electricity is stored in batteries.

Storage is another story that adds more expenses and less lifetime to the system. Biogas digesters are also widely used to produce methane gas (CH_4) that is usually used for cooking and heating. The main focus of this research is to put forward a concept of hybrid energy unit consists of a solar PV panels integrated with an anaerobic biogas digester.

The PV solar panels as shown in Fig. 2 are used during the daylight to generate electricity and feed it directly to the household network. Because there is no battery or any storage device, solar panels are useful only in day time, while at night the biogas generator is turned on to generate electricity. Batteries can solve the night problem but they add more expenses to the system and reduce the payback period. On the other hand, the batteries' lifetime is very short which means that there will be a need to replace them at least three time during the PV panels lifetime period.

The biogas digester has three openings, one for feeding the household waste, animal and livestock manure, the second hole is for extracting and draining the fertilizer liquid and remaining slurry after the fermentation process, and the third hole on the top of the tank is for withdrawing the produced biogas. The produced biogas is stored in the gas tank to be used for two purposes; the first purpose is for cooking and heating by directing it to fire burners, and the second purpose is to run the biogas electricity generator to produce electricity. The biogas generator is an internal combustion engine that works on gas combustion, this engine is coupled to an electric generator that produces electricity to be fed directly to the house's network. The produced electricity can be used at night, when the PV solar panels are not active, to provide the house with electricity without the need for storage batteries.

The biomass or biogas digester is usually made of elastic synthetic material for safety of operation and operators. The overall electricity load of domestic household appliances can be calculated and should be equal or less than the total sum of electrical energy produced by both PV panels and biogas digester.

Figure 2. Hybrid energy unit, PV solar panels and anaerobic biogas digester

IV. Sustainability of the Hybrid Energy Unit

According to the requirements of the Society 5.0 sustainability conditions put by Japan in 2016, human being is the center of the development process. The implementation of AI and modern technologies in functioning the system supported by implementing the Sustainability Development Goals (SDGs) leads to have a sustainable and developed society. The hybrid energy unit has an influence on 7 SDGs. As it saves money and has a short payback period it helps in reducing poverty and eliminating hunger (SDG1 and SDG2) as shown in Fig. 3.

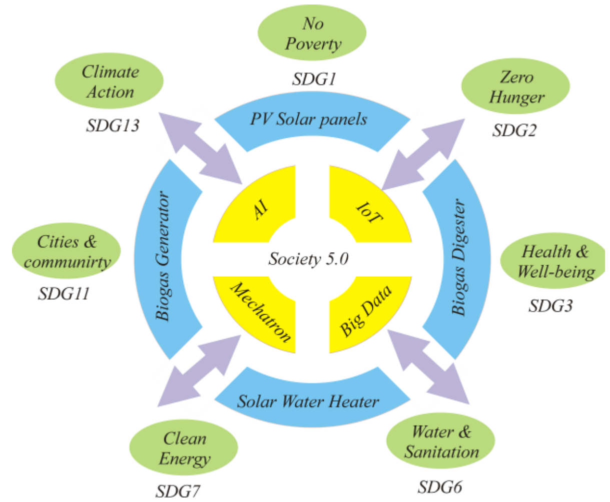

Figure 3. Sustainability of the hybrid energy unit

Producing electricity from PV panels and from biogas digester improves the level of life for people by giving them the ability to use all electrical household devices without restriction and in a healthy manner because these methods reduce the green-house emissions as indicated by SDG3. SDG6 is related to water and sanitation, this system saves the ground water from contamination because it uses animal manure in the digester instead of disposing it on soil.

SDG7 of clean energy is directly implemented by two renewable energy sources; biogas and solar energy. Applying the hybrid energy unit in all houses improves community and creates a green city obtaining SDG11. Finally, climate change in SDG13 is improved by implementing this hybrid unit. It is clear that this unit satisfies the three main pillars of sustainability; environmental, social and economic.

V. Hybrid System Sizing

A. Sizing the PV system

Solar PV panels are designed to cover the total load of the household appliances where during the day time the whole load will be met by them. To estimate the size and power of the required PV panels, it is necessary first to estimate the daily use of energy [15]:

$$E_d = \frac{E_m}{d} \quad (1)$$

Where E_d stands for the daily energy use (*kWh/day*), E_m is the monthly energy use (*kWh/month*) and *d* is the number of days in month. The output power required is calculated by:

$$P = \frac{E_d}{h} \quad (2)$$

Where *P* is the output power (*kW*) required for the house and *h* is the daily number of hours of full sun. The final size of the PV system is calculated by the following:

$$PV = \frac{P}{f} \quad (3)$$

Where PV is the total power (*kW*) required from the PV system and *f* is the de-rating factor of the PV solar panels.

B. *Sizing the Biogas digester*

The size of the anaerobic biogas digester can be estimated by the following equation:

$$V_d = S_d \times R_T \quad (4)$$

Where V_d is the volume of the digester tank (m^3), R_T is the retention time or the number of days required for digestion and depends on the temperature. S_d is the volume of substrate input to the digester per day (m^3/day) which includes the solid waste and the added water. The quantity of the produced biogas depends on the type of substrate inserted in the digester and the temperature. The produced gas contains several types of gases. The typical composition of the produced biogas is shown in Table 4.

TABLE IV. COMPOSITION AND PERCENTAGES OF BIOGAS [17]

Compound	Formula	Volume percentage (%)
Methane	CH_4	50-80
Carbon dioxide	CO_2	15-50
Nitrogen	N_2	0-10
Hydrogen	H_2	0-1
Hydrogen sulfide	H_2S	0-0.5
Oxygen	O_2	0-2.5

Table 5 depicts the yield biogas and the methane percentage produced from the fermentation of different kinds of substrate materials in the biogas digester. Fig. 4 shows the quantities of produced methane from the fermentation of different materials.

TABLE V. YIELD OF BIOGAS AND METHANE PERCENTAGES [17]

Substrate input materials	Yield biogas (m^3/kg)	Methane (CH_4) percentage (%)
Animal manure	0.27	55
Green grass	0.63	70
Wheat straw	0.432	59
Leaves	0.25	58
Sludge	0.64	50
Carbohydrate	0.75	49
Protein	0.98	50

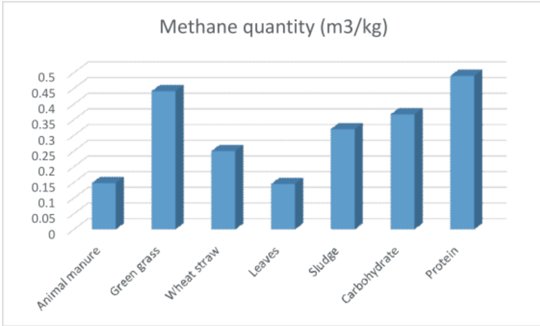

Figure 4. Quantities of methane biogas produced from different materials [17]

VI. CASE STUDY: MEDIUM RESIDENTIAL HOUSE

A. *PV calculations*

This section is to provide a sample calculation for a medium Palestinian house. A normal medium house with 8 persons consumes electric energy of around E_d = *700 kWh/month*. To estimate the daily use of energy in a month of 30 days, equation (1) gives:

$$E_d = \frac{700}{30} = 23.3\ kWh/day$$

Knowing that Palestine has an average daily full sun of 7.2 hours [16], the output power required is calculated from equation (2) by:

$$P = \frac{23.3kWh/d}{7.2\ h/d} = 3.24\ kW$$

Where *P* is the output power (*kW*) required for the house taking the daily number of hours of full sun is 7.2. Knowing that the de-rating factor for most of the PV panels equals to 0.85, the final size of the PV system is calculated from equation (3) by the following:

$$PV = \frac{3.80\ kW}{0.85} = 3.81kW$$

Selecting a PV panels rated at 400 *Wp*, then the number of PV panels required for a medium house is equal to:

$$Panels = \frac{3.81\ kW}{0.4\ kW} = 9.52\ \cong 10\ panels$$

The expected cost for PV systems reaches $1200/*kWp*. This means that the expected cost of this PV system is about 4800$.

B. *Biogas calculations*

To estimate the required biogas digester for a medium house of 8 persons, it is necessary to estimate size of the digester. Knowing that the leftover food quantity for residents equals to one kg/person/day and the retention time for the fermentation of the carbohydrates and proteins is around 40 days. The size of the anaerobic biogas digester can be estimated by equation (4):

$$V_d = 1\ kg/person\ /day \times 8\ person \times 40\ days = 320\ kg$$

If the average density of leftover food is close to water density, then the volume of the substrate material is 0.32 m^3. The normal ratio for the substrate material to water is 1:1, the ratio of the digestion tank to the gas tank is 3:1, then the total volume of the digester with the gas tank is 1.92 m^3 [18]. The produced methane gas from this digester can be calculated taking the methane quantities from Figure 4 as 0.45m^3/kg:

$$Methane\ gas\ production = 1\ kg/person/day \times 8\ person \times 0.45\ m^3/kg = 3.6\ m^3/day$$

Each one cubic meter of biogas can generate 6 kWh_{th} of thermal energy, assuming efficiency of biogas engine and electric generator is 33%, which means that the one cubic meter of biogas can produce only 2 kWh_e of electrical energy, while the rest turns into heat. Knowing the calculated biogas digester produces 7.92 m^3/day, then the generated electricity is:

$$Electricity\ generation = 2\ kWhe \times 3.6\ m^3/day = 7.2\ kWh/day$$

If we need to use electricity at a power of 3.6 kW at night, then biogas generator will work only for about 2 hours. This period can be doubled by using energy efficient lighting and household appliances that can reduce the rated power and increase the running time. The other option is by adding further animal manure or green grass in the digester to increase the quantity of substrate material and hence the biogas quantity.

VII. Conclusion

The idea of the foregoing research comes from the high need for energy sources in Gaza Strip after the catastrophic demolishing of all shelters and sources of life specially energy sources. The suggested hybrid energy targets medium houses with 8 persons in average. The hybrid unit consists of 10 PV panels, 400 Wp each and 2 m^3 biogas digester that uses the leftover food from residential kitchen as a substrate feed material.

The PV system is expected to generate 28.8 kWh of electricity during the day time which is enough to cover about 2.88 kW electric load for 10 hours. Proposed hybrid system avoids using batteries for energy storage because they are expensive and have a short life time.

The suggested biogas two cubic meter digester system produces methane gas through the fermentation process of the organic solid waste to drive a biogas generator, that consists of a modified gasoline engine and an electric generator that generates 7.2 kWh of electricity daily. The main problem facing the use of the biogas digester is the small quantity of leftover food hence limiting generated biogas and electricity. The shortage in biogas digester can be recovered by using energy efficient lighting and household appliances that can reduce the rated power and increase the running time and by adding further animal manure or green grass in the digester to increase the quantity of substrate material and hence the biogas quantity.

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