Investigation of Renewable Electricity Generation from Solar-Hydrogen Hybrid System in Tripoli

Ehsan Altayef[1*], Adel Jaber[2], Fatih Anayi[3], Bdereddin Samad[4], Shaima Dhabaa[5]

[1] Tripoli201919@gmail.com, [2] Jaber_ade@yahoo.com,

[3]Anayi@cardiff.ac.uk, [4] Fobadr@gmail.com, [5] Shaima.lutfi@gmail.com

[1] Department of Electrical and Electronics, College of Engineering, University of South Wales, UK

[2, 4] Department of Electrical and Electronics, Azahra Higher Institute of Sciences and Technology, Libya

[3] Department of Electrical and Electronics, College of Engineering, Cardiff University, UK

[5] Department of English Language, Tripoli University , Libya

*Corresponding author email: Tripoli201919@gmail.com

ABSTRACT

This paper presents a stand-alone solar hydrogen plant to cover the daily electricity demand of a residential unit in Tripoli- Libya. Solar power was obtained through International Global Radiation and photovoltaic (PV) panels, while hydrogen was acquired via water electrolysis. This renewable solar-hydrogen community has demonstrated and clarified that it is possible to be fully reliant on renewable electricity daily. This paper also compares the financial feasibility of supplying the residential unit with electricity using hydrogen, diesel generators, gasoline generators and the grid. Actual economic data from Az-zawiya oil refining company and General Electricity Company of Libya is used. The establishment of an integrated solar-hydrogen power plant to provide daily electrical residential requirements in Tripoli is demonstrated. The data calculation of this development is undertaken using Photovoltaic Geographical Information System (PVGIS) software tool that provides a free and open web access to solar radiation and temperature data and to PV performance assessment tools for any location in Europe and Africa, as well as large part of Asia and America to model the radiance and the amount of sunlight (PVGIS) and excel for modeling the hydrogen demand and production. Capacity and the efficiency of the solar-hydrogen plant to provide a community of electricity for a year without any shortages or deficiency is investigated.

Keywords: photovoltaics, electrolyzer, hydrogen, Global warming potential, fuel cell.

1 Introduction

Mostly papers starts with introduction. It contains the brief idea of work, requirement for this research work, problem statement, and Authors contribution towards their research. Recent references [1] should be included for showing previous work done and importance of current work. This section should be succinct, with no subheadings unless unavoidable [2, 3]. State the objectives of the development and provide an adequate background related to your work, avoiding a detailed literature survey or a summary of the results.

The sun is ultimately the source of all energy sources; even fossil fuels are derived from organic life dependent on the sun. Sun energy arrives in the earth's atmosphere mainly as heat and light, which create wind and biomass. On a macro level of analysis, fossil fuels represent extremely concentrated, pressurized stores of solar energy whose rapid combustion disrupts the earth's more gradualist ecosystem. Conversely, harnessing the daily solar energies of light, heat and wind exerts more gentle impacts on the world [1].

Global warming is accelerating and the most important priority of governments nowadays (if not always reflected in practice) is to reduce carbon emissions. CO2 mitigation strategies include sun-oriented cookers, water radiators, dryers, biofuel, enhanced cooking stoves and hydrogen technology.

Hydrogen is the most inexhaustible element in the universe, and its potential has long been noted, for a future 'hydrogen economy' replacing the exiting carbon economy [2, 3]. Hydrogen-related technologies are generally unsuitable for widespread applications, largely due to safety concerns about storage, as discussed later in this paper, but hydrogen clearly shows promise for base capacity power generation, transportation and household use in cooking and heating. Transportation alone consumes 50% of global petroleum, so hydrogen fuel cell vehicles could make a massive contribution to the reduction of greenhouse gases (GHG) [4, 5].

Hydrogen fuel cell technology essentially replaces energy production from fossil fuel combustion with production from the combustion of hydrogen with oxygen, producing only water as a waste product; it is thus intrinsically an ideal solution to halt the negative impact of transport on the environment. However, the isolation of hydrogen in elemental form requires energy-intensive production.

Ironically, fossil fuels are currently the main resource to deliver hydrogen through steam reforming. In this procedure hydrocarbon feedstock is separated to discharge the hydrogen gas. The significant issue with this procedure, aside from the way that fossil fuel is utilized to power it, is that for every kilogram of hydrogen created, more than eight kilograms of carbon dioxide is likewise delivered, making it counterproductive as an alternative energy source [6, 7]. Conversely, the creation of hydrogen gas by electrolysis, whereby water atoms are split by electrical power derived from solar PV to deliver hydrogen and oxygen, creates no direct carbon emissions, making it essentially a clean renewable technology as well as a source of hydrogen production. Conventional sources of energy production are depleting, and their adverse effects on the environment, such as climate change and global warming, are well known. Therefore, the utilization of renewable energy for energy production is increasing in interest worldwide because of sustainable development and environmental concerns [8, 9].

2 Purpose of This Work

Libya is facing a serious issue with the electricity shortages and blackouts due to increasing demand (related to the increasing population and more energy requirements related to climate and lifestyle factors) and damage to the existing power infrastructure due, as well as interrupted oil and gas supply due to on-going conflict in some areas. To solve this persistent daily problem, this study designs a hydrogen from solar plant to supply a residential unit with renewable electricity. This paper is an attempt of reliance on renewable energy in covering domestic electricity demand.

The application of this development will create a competitive environment and motivate other organizations to invest in renewable energy and hydrogen production. The paper aims to investigate the possibility of hydrogen production from PV solar panels and the economic and technical feasibility of hydrogen production from renewable solar energy. It also provides a comparison between the grid and renewable energy regarding the technical, environmental and economic basis.

The objectives of the paper are to: (1) Estimate the residential demand of hydrogen, (2) Define the methods of energy conversion applied, (3) Calculate the technical and economic feasibility of renewable hydrogen generation.

Different methods utilized for transforming hydrogen into energy are evaluated, including combustion in internal combustion engines, hydrogen/oxygen combustion for steam generation, catalytic combustion, electrochemical conversion in fuel cells. The paper examines electro-chemical conversion in fuel cells in detail and looks at the advantages of electro-chemical processes of producing hydrogen and its reliability, and whether it can wholly rely on renewable energy.

This paper proposes a hydrogen production plant relying on a solar energy system, which would be the first established hydrogen plant in Libyan. This research intends to provide a residential unit consisting of six apartments with electricity and make it fully reliant on renewable energy.

3 Data Analysis Techniques

This paper calculated the amount of hydrogen required to supply a residential unit consisting of six apartments with a measured quantity of electricity ranging between 4.5 kW and 5 kW in peak power demand. The highest power demand periods are recorded when utilizing a higher number of devices and machines around the house depending on the daily

requirements of a Libyan household, with particularly high cooling loads in summer and high heating loads in winter related to air conditioning systems.
To work out the amount of hydrogen needed to supply the whole building with electricity some calculations must be undertaken to know the size of the work and the required number of PVs, electrolyzers and ancillary equipment. Some other equally important calculations include those pertaining to the consumed power, power demand and the amount of power to be stored in order to assure that there are no power blackouts during the whole year. These calculations had to be done accurately and correctly. Excel programmer was used to guarantee error-free equations. All the required equations and necessary data were entered in Microsoft Excel to be worked out to get the needed results. Data of global radiation for Tripoli- Libya, the site for the studied building, was obtained from the Photovoltaic Geographical Information System (PVGIS) and the radiation data was entered from sunrise to sunset [10]. The solar radiation was provided to the system every five minutes during daylight hours. PVGIS provides guideline data for latent solar energy from photovoltaic frameworks in Europe, Africa, and South-West Asia. It is a part of the photovoltaic and solar electricity (SOLAREC) work exploring renewable energy for the European Union and private interests. In addition to latent solar radiation, it was essential to determine solar panel efficiency using excel, based on data obtained from the manufacturer. In this paper the chosen PV had an efficiency of 15,75% (Ps-p672305) category from PROPSOLAR manufactory. Each panel can be produce a maximum power of 309.9Wp. The power demand was also considered a key element in the work calculation; in addition to the load demand registered every five minutes for each apartment. And for the comparison with diesel generators, gasoline generators and the grid, actual economic data are used, without factoring in government subsidies of diesel and gasoline.

4 Energy Requirement

The load was assumed to be lighting bedroom, dining room, bathroom, kitchen, living room, the outside area (streetlight); air conditioning; and household appliances such as refrigerator, microwave, toaster, television and computer.

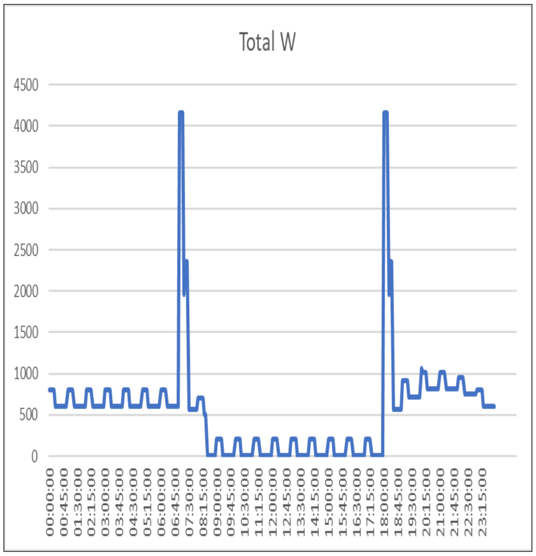
Table 1: *Energy requirement for each dwelling*

No	Application	No of units	Power per unit (W)	Operating hours per day (h)	Energy consumption W/day
1	Refrigerator	1	24	24h	576
2	Microwave	1	600	20m	200
3	Toaster	1	2200	20m	733
4	Kitchen kettle	1	2200	5m	183
5	Washing	1	500	30m	250

	machine				
6	Water heater (boiler)	1	1200	2h	2400
7	Lights	6	60	5h	1800
8	TV	1	150	5h	750
9	Air conditioning	1	495	12h	5940
10	Computer	2	50	2h	200
11	Home internet	1	5	24h	120
12	Street light	2	100	12h	2400
				Total	15552

Table 1 describes the energy requirements for applications in one apartment. Appliance usage time and the loads were estimated for daytime usage.

Each apartment consumes about 4.3 kW; since that building has a three-floors, with two apartments in each floor, the consumption of the whole building will be 26 kW The curve below in Figure 1 shows the daily consumption of each apartment for 24 hours, including the time in which the power consumption peaks. Figure 2 shows the electrical devices utilized in each apartment and the time in which they are used most.



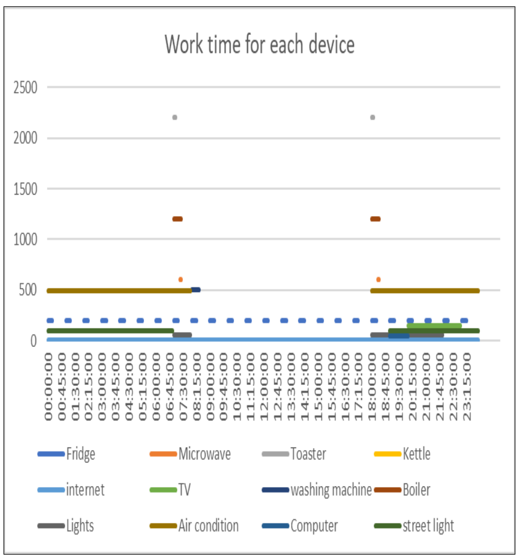


Figure 1:. *Daily electrical consumption.* **Figure 2:** *Daily consumption of each device*

During daylight, the PV array must be capable of providing about 30 kW for the building requirements plus the electrolysis load, which is 75 kW. Fuel cell output power should not be less than 30 kW to ensure that the electricity demand of the building can be met at night. To ensure a modest surplus of power, it is suggested that 30 kW of power will feed the building during the day and an additional 75 kW of power will be used to provide for the generation of hydrogen. Thus, a 105 kW solar array will be necessary.

5 Results and Discuss

The results of the paper in terms of three states: when the number of solar cells was 145, 193 and 552. It also examines the economic feasibility of supplying the residential from solar-hydrogen plant. In addition, it assesses the system's need for hydrogen storage, and provides a comparison between the grid and the renewable energy regarding the technical environmental and economic basis.

Figure 3 shows solar irradiance (W/m²) for a typical day in each month, indicating the latent solar radiance available per m² every 5 minutes throughout the day. It is noteworthy that the months June, July and August are the most energy productive as they represent the summer season, in which the sunlight hours are obviously longer, and solar radiance is stronger. In the winter, particularly December (when the days are shorter), the power production is much less due to the short daylight radiance, which results in smaller hydrogen yield than in other months. Therefore the system was supplied with a considerably higher number of solar cells in order to recuperate the shortage, so that it can generate the sufficient amount of energy to operate the electrolyzer.

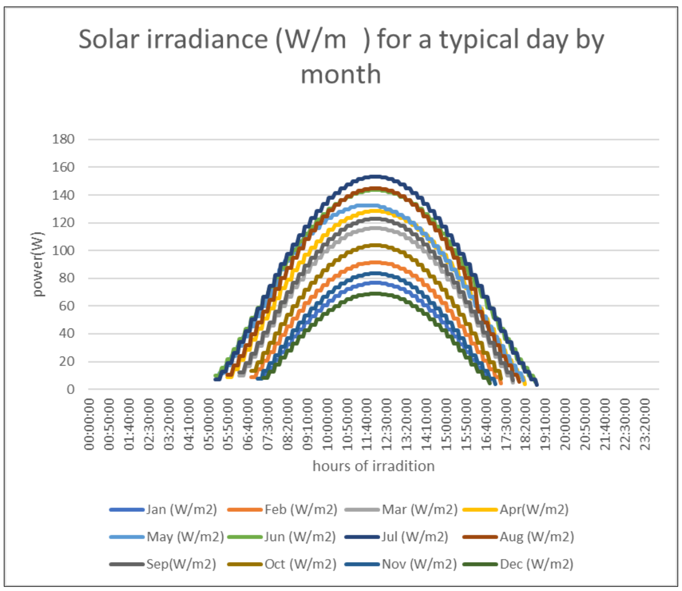
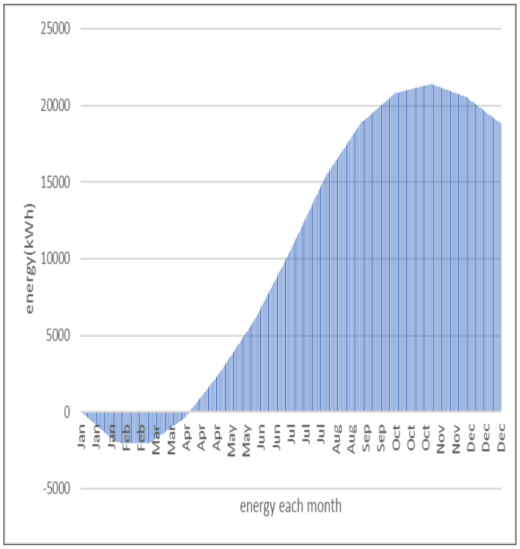


Figure 3: *Solar irradiance (W/m²) for a typical day of the month.*

The solar panels' efficiency (15.75%) indicates that a great amount of power can be produced from the solar radiation in summer, ranging from 150-160W/m² for almost 14 hours from 5:00 am to 18:00 pm. In the winter the produced energy is less, ranging between 65-85Wp for every m². This amount of energy is generated in shorter period, over about 10 hours between 7:00 am and 16:00 pm. This amount of produced energy gives this job a great potential of success with many solar cells (particularly to increase the efficiency of winter collection).



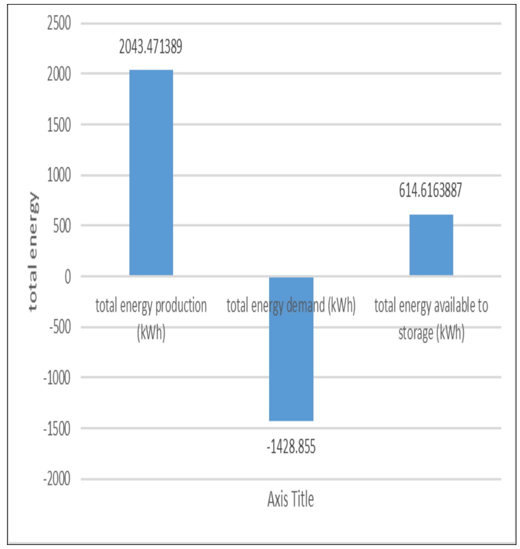
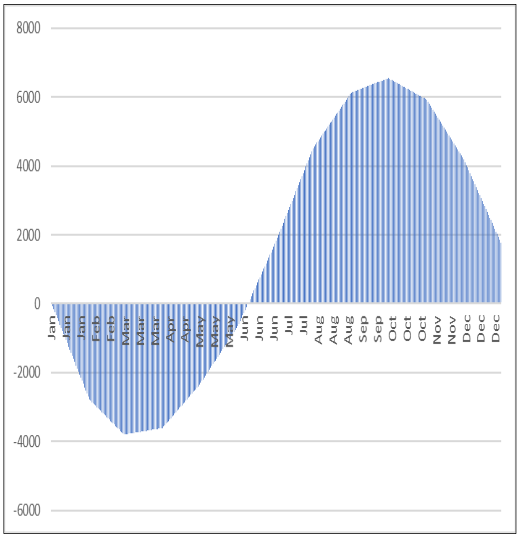


Figure 4: *Deficit and surplus of accumulated hydrogen storage* **Figure 5:***Hydrogen amount.*

As shown in Figure 4, 193 PV cells were used in the work. When the project starts operating in January the generated hydrogen is insufficient during the first three months, due to the short daylight period and the high demand, while the rate of the generated power rises significantly at the beginning of April. It is clearly noticed that the captured solar power is very low in winter, yet it starts to increase gradually in spring and summer as the hours of sunlight increase, and the amount of generated energy is sufficient.

It is noteworthy to mention that the increasing rate of hydrogen production will guarantee a total power sustenance for the residential building, and an additional amount of hydrogen that can be stored or even utilized to supply other apartments. Consequently, the optimal month to start operation is April for securing power provision. Figure 5 shows the amount of the generated energy, approximately 2043.471389 kWh, and energy demand, which is -1428.855 kWh, leaving 614.6163887 kWh to be stored or sold.

Figure 6 illustrates the possibility of having 145 solar cells less than the number of cells in the previous cases. In this scenario, when the project starts in July the number of PV cells is decreased to minimize costs. The figure clearly shows that produced energy in the first five months was insufficient to cover the power demand, while it was significantly higher from June onwards because of longer daily sunlight. Figure 7 indicates the amount of the produced energy (1481.723079 kWh), total energy demand (-1428.855 kWh), and the surplus (52.86807899 kWh); stored hydrogen is only enough to supply the building for less than two days in the absence of more production. In this case, the power production will be enough for the whole residential unit, yet there is a small chance of power shortages in case of cloudy weather or sandstorms or high-power load.



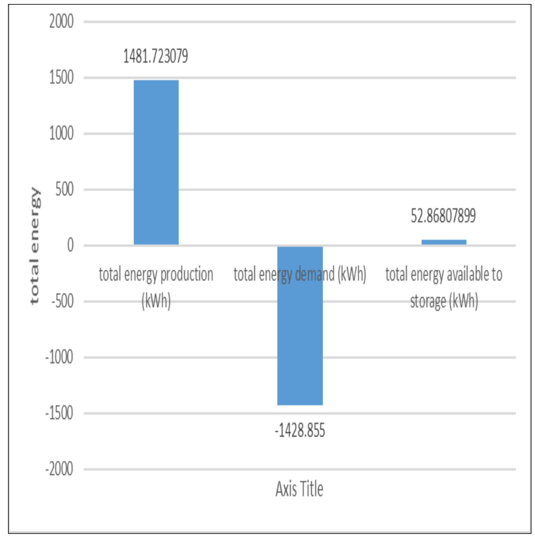
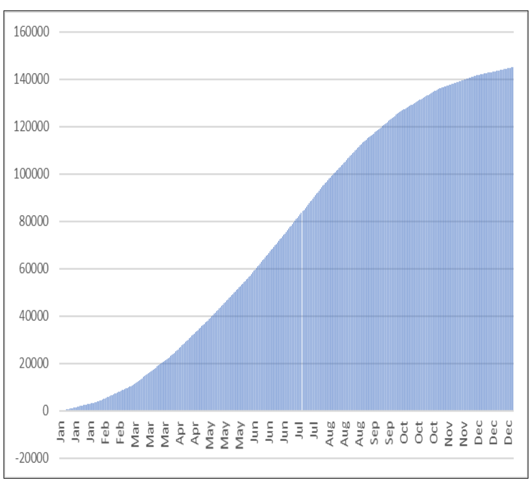


Figure 6:*Energy storage content.* **Figure 7:***Hydrogen amount.*

Figure 8 shows the scenario of the number of solar cells being increased to 552. Clearly the amount of produced energy is enough to supply the building, guaranteeing no shortages throughout the year. Nevertheless, the cost increases because of the increased number of PV cells. However, this offers great potential for selling stored hydrogen (or even direct electrical energy) to other buildings or the grid in the case of a hybrid system.



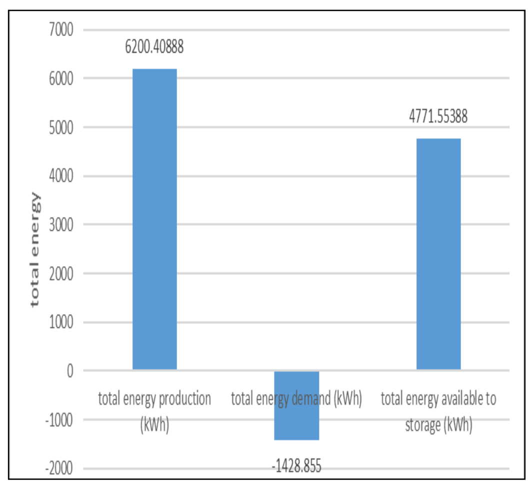


Figure 8:*Energy storage content.* **Figure 9:***Hydrogen amount.*

It can be noticed from figure 9 that the produced energy is 6200.40888 kWh, whereas the power demand was -1428.855 kWh, thus the power demand of the residential unit will be fully covered with a surplus of 4771.55388 kWh for storage. From the given three cases, it can be ascertained that the amount of generated hydrogen increases with the increase of the

PV cells. Both methods are renewable and reliable, so producing electricity from hydrogen will be very successful in replacing petrol and gas.

From the three cases, it is evident that hydrogen can be efficiently produced from solar energy. In addition, it is possible to produce hydrogen from a stand-alone PV system in this work. Thus, hydrogen production from solar PV renewable energy source in Tripoli, Libya, is feasible both technically and economically.

6 Comparison

This section compares the financial feasibility of supplying the residential unit with electricity using hydrogen, diesel generators, gasoline generators and the grid. Actual economic data are used, without factoring in government subsidies of diesel and gasoline.

Four diesel generators are necessary to supply building demand, with each generator supplying 15 kw. The total installation cost is 80,000 LYD [12] approximately £43,000. Each needs 3.5L/h to run and the price for one liter of diesel is 0.15 LYD with government subsidy. The real prices of gasoline and diesel in the Libyan market are 0.45LYD and 0.65 LYD per liter, respectively [13]. Every two generators work for 12h/d, requiring 7L of diesel per hour. The volume of diesel required for two generators to work 12h:

(L) = (3.5+3.5L/h) * 12h = 84L

The volume of diesel required for four generators to work 24h:

(L) = (84 + 84) = 168L/Day

The cost of diesel for four generators to work 24h:

168L * 0.65 LYD=109.2LYD /day

Therefore, the monthly diesel cost = 109.2 * 30 = 3276 LYD/month (approximately £1770).

In addition, the gasoline generator has the same price and number if generators, however it needs 4.5L/h; however, there is a difference in the amount of gasoline per hour and the price of gasoline.

Volume of gasoline required for two generators to work 12h:

(L) = (4.5+4.5L/h) * 12h = 108L

Volume of gasoline required for four generators to work 24h:

(L) = (108 +108) = 216 L/day

The cost of gasoline for four generators to work 24h:

216 * 0.45LYD = 97.2 LYD/day

Therefore, the monthly gasoline cost = 309.0924 * 30 = 2916LYD/month (approximately £1576).

Both diesel and gasoline generators need two people to work on their maintenance, one in the morning and the other at night, with a salary of £1500 per month.

On the other hand, electricity from the grid will be the cheapest. In Libya, the price for 1 kWh is 0.02 dirhams [14] with a 150LYD fee to connect to the power supply for lighting and housing apartment buildings consisting of two floors or more according to Libyan General

Electric Company. However, the price for kWh without support of government is 0.1677LYD according to the Zawia CCPP Maintenance Manager [15].

The cost of electricity per (kWh) = the energy demand for six flats (30 kWh) * kWh unit price (0.1677LYD) = 5.031LYD

Therefore, the monthly cost of electricity is 5.031LYD * 30 = 150.93LYD (£81.583). The cost and efficiency of using a dedicated hydrogen plant is shown in (Table 2), using data from [16], considering the building cost and four staff members (two maintenance workers and two supervisors working two shifts, each with a salary of £1500 per month).

Table 2: *Hydrogen system cost*

No	Type of device	The cost (£/kW)	Efficiency (%)
1	Electrolyzer	£1177	70%
2	Compressor	£784	90%
3	Hydrogen tank	£690	95%
4	Converter	235	95%
5	Fuel cells	£1569	50%
6	PV	£0.41/W = £410/kW	15.75%
7	The building	£10,000	
8	Total	£14,865	

Figure 10 demonstrates the operating bills for the grid, diesel generator, gasoline generator and hydrogen plant options. It is clear that the prices of using gasoline and diesel generators converge, while the hydrogen cost is slightly substantially higher, while the grid price is negligible. Furthermore, as shown in Figure 11, the equipment cost of hydrogen is of vastly greater magnitude than the diesel and gasoline generators, costing about £450,000.

Utilizing renewable energy sources particularly solar in hydrogen generation is intrinsically feasible both economically and technically, but obviously the only sensible option for a Libyan citizen is to source electricity from the grid if possible, due to the overwhelming cost advantage. However, this could change in the long term if the government follows the example of many Gulf Cooperation Council (GCC) countries and reduces subsidies of national oil and gas, and instead subsidies hydrogen generation, which has a beneficial net effect on the national economy over the long term, as it is dependent on oil exports [17]. In addition to the more important objectives of being environmentally friendly and reducing Green House Gase (GHG) emissions [18].

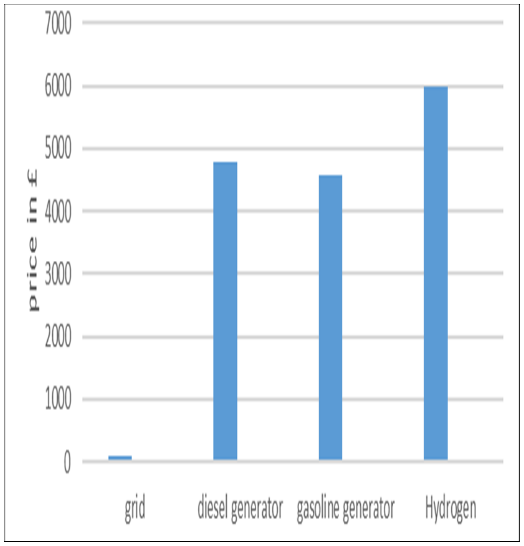


Figure 10:*Monthly operating bill.*

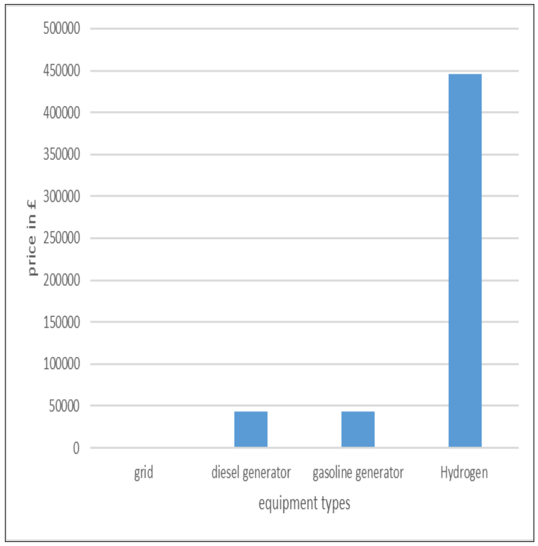


Figure 11:*Equipment cost.*

7 Conclusions

Hydrogen is a clean fuel that produces only water on combustion or when combined with oxygen in fuel cells to produce electrical power. Like electricity, it is an energy carrier, and it has potential for energy storage, transportation and electricity generation for countless outlets, such as lighting, heating, and powering motor vehicles. This paper focused on generating renewable electricity from combined solar-hydrogen system. This paper has also investigated the capacity and the efficiency of the solar-hydrogen plant to provide a community of electricity for a year without any shortages or deficiency. In order to ensure the successfulness of the development, solar radiance was collected from the Global Radiance Agency along with the manufacturers' data on solar panels' efficiency to calculate the daily solar power generated. The produced solar power that is utilized in electrolysis to generate the hydrogen enables the later back-transformation of hydrogen into electricity.

The development can be completely felicitous throughout the whole year in terms of technically meeting the power demand. Despite the high cost of plant, it is still the best method as it is renewable and environmentally friendly, and it produces energy from sunlight and water. The high cost of the system can be overcome by gaining government support for hydrogen to electricity developments as an infinite energy carrier, preserving oil and gas reserves for export. From the previous comparison it can be said that hydrogen is the fuel of the future and it can be produced from the most abundant sources, sunlight and water. However, the cost of producing hydrogen is high compared to petrol and gas, mainly related to installation and equipment costs, which will decrease over time as technologies improve and market competition increases, and which will become increasingly cost competitive with fossil fuels as the latter diminish, dwindle and ultimately expire. Thus, while there is little in the short term to recommend the utilization of solar-hydrogen renewable energy generation and renewable economically, considering long-term prospects and the reliance of the national economy on oil and gas exports, it is clearly sensible to start preparing for a greater role for renewable.

This paper is considered to be the first hydrogen study in Libya it will gain a lot of public acceptance as it is an environmentally friendly and safe facility demonstrating the feasibility of the use of alternatives to fossil fuels in the country.

8 Acknowledgment

Third Conference for Engineering Sciences and Technology (CEST-2020) Alkhoms - Libya
The Authors thanks Azahra Higher Institute of sciences and Technology and Cardiff University for their support.

References

[1] E. COMMISSION, "Hydrogen Energy and Fuel Cells," 2003.

[2] U. S.-E. U Summit, "Hydrogen Economy Fact Sheet," *Cooperation on the Development of a Hydrogen Economy*, 2003. [Online]. Available: https://georgewbush-whitehouse.archives.gov/news/releases/2003/06/20030625-6.html. .

[3] G. W. Crabtree, M. S. Dresselhaus, and M. V Buchanan, "*If the fuel cell is to become the modern steam engine , basic,"* no. December, pp. 39–45, 2004.

[4] J. K. Dahl *et al.*, "*Rapid solar-thermal dissociation of natural gas in an aerosol flow reactor*," vol. 29, pp. 715–725, 2004.

[5] I. Papagiannakis, "*Studying and Improving the Efficiency of Water Electrolysis Using a Proton Exchange Membrane Electrolyser,"* 2005.

[6] P. L. Spath, M. K. Mann, and M. K. Mann, *"Life Cycle Assessment of Hydrogen Production via Natural Gas Steam Reforming Life Cycle Assessment of Hydrogen Production via Natural Gas Steam Reforming*," no. February, 2001.

[7] E. Centurioni, D. Iencinella, R. Rizzoli, and F. Zignani, "*Silicon Heterojunction Solar Cell : A New Buffer Layer Concept With Low-Temperature Epitaxial Silicon,"* vol. 51, no. 11, pp. 1818–1824, 2004.

[8] O. Behar, A. Khellaf, and K. Mohammedi, "*A review of studies on central receiver solar thermal power plants," Renew. Sustain. Energy Rev.*, vol. 23, pp. 12–39, 2013.

[9] T. Solar *et al.*, *"Performance Improvement and Energy Cost Reduction under Di ff erent Scenarios for a Parabolic,"* vol. 2019, pp. 1–23.

[10] "PHOTOVOLTAIC GEOGRAPHICAL INFORMATION SYSTEM," *PV potential estimation utility*, 2016. [Online]. Available: https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html.

[11] P. E. Dodds, I. Staffell, A. D. Hawkes, and F. Li, ScienceDirect *"Hydrogen and fuel cell technologies for heating : A review,"* International Journal of Hydrogen Energy, vol. 0, 2014.

[12] D. Paper, *"Issues in China Power Sector Reform : Generator Dispatch,"* no. July, 2016.

[13] Brega petroleum marketing Co. A.Daw@brega.ly.

[14] RCREEE, *"PA-CEMP program in Libya*," 2016. [Online]. Available:https://www.rcreee.org/content/pa-cemp-program-now-libya.

[15] Gaeer, A. (2016). *The cost of electricity in Libya* [email].

[16] O. V Marchenko and S. V Solomin, ScienceDirect "*The future energy : Hydrogen versus electricity," Int. J. Hydrogen Energy*, vol. 40, no. 10, pp. 3801–3805, 2015.

[17] Live Population, "Population of Libya (2019)," *live population*, 2019. [Online]. Available: https://www.livepopulation.com/country/libya.html.

[18] S. G. Elsharkawy and E. S. Elmallah, *"Spatiotemporal investigation of long-term seasonal temperature variability in Libya,"* vol. 179, pp. 535–549, 2016.

.