

Techno-Economic Impact of Electrification Rural Areas in Palestine using Micro-Grid Solar Energy “Al-Mkahel& Saeed Villages – Case Study”

Imad Ibrik^{1*}, Fida Salameh²

1- An-Najah National University, Nablus, Palestine.

Email: iibrik@najah.edu (Corresponding author)

2- An-Najah National University, Nablus, Palestine.

Email: fida.salameh@najah.edu

Received: September 2020

Revised: November 2020

Accepted: January 2021

ABSTRACT:

Palestine has a large number of remote small communities with no electricity services and the probability of connecting them with local grid in the near future is very poor, because of political and financial issues. This paper will illustrate the techno- economic impact of electrification small communities using micro-grid photovoltaic systems, and also the CO₂ emission that will be reduced in comparative of using diesel generator which pollutes the environment. The implementation of two micro-grid PV-systems for electrification of two communities in Palestine will cover the electricity needs of households and street lighting, and can replace candles, kerosene and traditional unsustainable biomass and diesel generators. Beside economic and social benefits, micro-grid PV systems also have positive impacts on people’s health and on the environment due to the reduction of smoke and toxic waste.

KEYWORDS: Energy Poverty, Rural Electrification, Micro-grid, Off-grid PV System, Sustainable Development.

1. INTRODUCTION

Palestinian Territories suffer from severe shortage of energy supply as well as the fluctuations of energy prices. The Palestinian authority has no control on borders so all energy products are bought from Israeli companies [1].

Large number of villages and small communities still are utilizing small diesel generators to cover their electrical energy demand in Palestinian territories, as most of them are isolated and far away from the electric grid. Normally the working hours of the diesel generators in those localities are limited to small periods of time. Moreover, the price of diesel fuel is high and keeps increasing in addition to frequent faults which require continuous maintenance. High percentage of air pollution is released from the exhausts of the diesel generators. Therefore, the use of diesel generators is ineffective option for rural electrification.

Palestinian Energy Authority (PEA) is paying great attention to exploit the photovoltaic energy to mitigate the energy crisis of the isolated villages and localities. Palestine is granted high solar radiation potential and high sunshine hours throughout the year in which the

horizontal yearly average daily solar radiation is about 5.4 kWh/m²/day with about 3000 sunshine hours. [2]

The PV electrification could be using the decentralized stand alone and centralized systems depending to the nature of the load and the distribution of houses.

Photovoltaic electrification is limitedly used in different rural areas in Palestine mainly for schools, clinics, Bedouins communities, agricultural and animal farms, and private homes.

2. CASE STUDY: RREMOTE VILLAGES AL-MKAHEL & SAEED-IN YABAD-JENIN.

Khirbat Al-Mkahal is in the south west of Jenin district, the nearest city is Yabad which is 5 km away, the location coordinates for Al-Mkahal village are as follows: 32° 25' 15, 85''N and 35° 07' 33, 94''E.

Depending on a comprehensive assessment on non-electrified villages in the West Bank, Al-Mkahal was found to be one of the most appropriate villages to be subject to a socio-techno-economic impact study of electrification by mini off grid Centralized PV system [4].

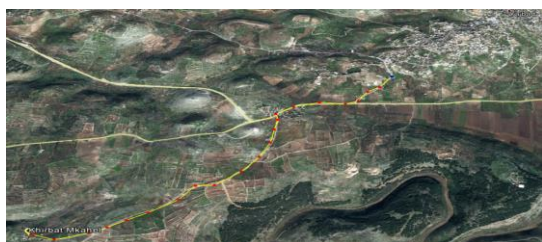


Fig. 1. Al-Mkahal village Location.

Al-Mkahal village inhabitants work mainly in farming and cattle breeding and some of young people are working as construction workers. Their number amount to about 70 individuals, 10 families. Drinking water is obtained from artesian wells in the village area. Some people were using Candles and gas cylinders for lighting, cooking and pumping water and sometimes they operated old generator for 2 hours at maximum due to costly and high fuel consumption, so the cost of energy consumption will be over 50 US\$ /month for some families, including the cost of transportation.

Al-Saeed Village is in the southwest of the province of Jenin. The closest urban center is the city of Y'aabad which is 3 km away. The village is located at bottom of mountain where the settlement was built on top. The location coordinates are 32° 25' 23''N and 35° 10' 56''E.



Fig. 2. Al-Saeed village Location.

People were also using candles, batteries and gas cylinders for lighting, cooking and pumping water, this sources is costly due to transportation and they have high dependency on them because there are no other power resources, so the cost of energy consumption was higher than 50 US\$/month for some families.

3. DESIGN OF PV SYSTEMS

3.1. Measuring Solar Radiation (Solar Energy)

The availability of solar radiation will affect the power output of PV modules, as the generated energy will decrease in rainy and cloudy day.

The readings indicate that the annual average solar radiation rate is 5.4 kWh/m²/day for both sites, and the maximum value was 8.19 & 7.56 kWh/m²/day in June for Saeed and Mkahel, respectively, while the minimum solar irradiation was in December of 2.7 & 3.13 kWh/m²/day.

So according to the result collected using weather station sensors in area, we can easily analyze the performance of PV system.

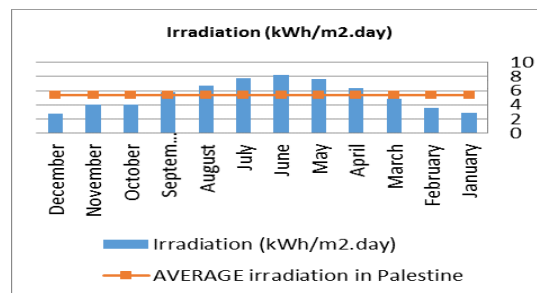


Fig. 3. Irradiation - Khirbat Saeed.

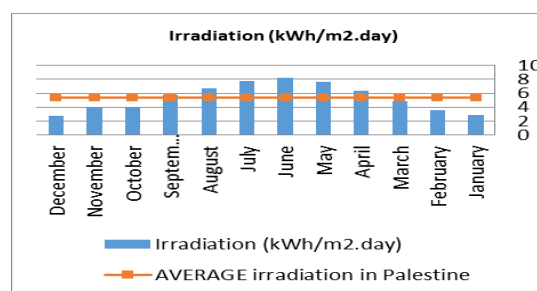


Fig. 4. Irradiation - Khirbat Saeed.

3.2. Selection Elements of System Design

3.2.1. Electrical load

An estimation of family user daily consumption has been realized based on the information in questionnaire and the beneficiaries needs regarding the electricity.

The estimated daily demand and all the appliances which will/may be used in communities are shown in Table 1.

Table 1. Estimated Total daily consumption/Family.

Applications	# quantity	Power (Watt)	H/day	W.h/day
PL lamp	2	11	4	88
TV	1	120	5	600
Radio	1	20	5	100
Mobile charger	1	10	1	10
Small refrigerator	1	200	5	1000
High efficient washing machine	1	180	2	360
			Total=	2158

Using high efficient appliances in this kind of project, the total loads in the village will be around 21, 58 kWh/day.

3.2.2. Electrical load

In selecting a suitable PV module when designing PV solar system to cover average load energy demand of (21580 Wh/day), PV array size can be determined, using the following equation [4].

$$PPV\text{-array} = EL \times Sf \eta_v \times \eta_R \times PSH \quad (1)$$

EL : Estimated average daily load energy consumption in Wh/day (21580 Wh/day)

PSH : Peak Sun Hours (5.4 h) [5]

η_v : Efficiency of inverter (95%)

η_R : Efficiency of wire losses (97%)

Sf : Safety factor (1.15)

$$PPV\text{-array} = 4987 \text{ watt}$$

The PV module of type 135 Wp Canadian solar is installed in this project, so number of modules in system (Nm) is determined in following equation:

$$Nm = \frac{PPV\text{-array}}{P_{\text{selected module}}} \quad (2)$$

$$Nm = 36.9 \approx 36 \text{ module}$$

3.2.3. System Voltage Selection

Selecting the operating DC voltage of standalone PV system is based on system requirements, so the selected system voltage is 48 Vdc .

According to system voltage, the number of modules in series (Nms) is calculated according to the following equation:

$$Nms = \frac{V_{\text{system}}}{V_{\text{module}}} \quad (3)$$

$$= 48 / 17.6 = 2.72 \approx 3 \text{ module in series}$$

The PV array is composed of 36 PV modules on galvanized steel metallic support and distributed by three sub-array of 4 string and each string has 3 modules (3 modules * 4 string * 3 sub-array=36 modules), the array capacity is 4.86 KWp of 135Wp PV module, and also with approximated area of 38.88 m2.

So, the modules of system were installed in series, and as a result;

$$Vo.c.array = 22 \times 3 = 66 \text{ V}$$

$$IS.C. array = 8.19 \times 4 = 32.76 \text{ A}$$

3.2.4. Sizing of Battery Bank

Battery is the most important part in stand-alone PV system, so we consider that the battery will cover the needs of beneficiaries at night and cloudy day which required high efficient battery. The capacity of

battery(CA-H) is measured in Amper-hours, As in the following formula;

$$CA\text{-H} = \frac{Nc \times EL}{VB \times DOD \times \eta_v \times \eta_R} \quad (4)$$

Nc : Numbers of days of autonomy (1.5 - 3 days)

VB : Operating voltage for system (48 V)

DOD : Maximum depth of discharge (0.6-0.75)

$$CA\text{-H} = 1045 \text{ A.H}$$

Table 2. Characteristics of installed batteries.

Battery Module Type	AGM LEAD ACID RITAR 2 V
No. of Battery Bank	24
Capacity (100)	1000 Ah
days of autonomy	1.5

$$CWH = CA\text{-H} \times VB \quad (5)$$

$$CWH = 1000 \text{ Ah} \times 48 \text{ V} = 48 \text{ Kwh}$$

3.2.5. Sizing of Charge controller

The basic function of charge controller is to extract as energy as possible from PV array in order to maintain a high state of charge of the battery and avoid its complete discharge, so it controls the cycle of charge and discharge avoiding over charge and deep discharge.

After selecting the charge controller, it was considered that the unit has the following characteristics:

- High efficient charge controller with low self-consumption
- Maximum Power Point Tracker (MPPT) to get the maximum power of PV array
- Possibility to maintain the batteries at floating voltage to compensate the losses in case of full charge
- Advanced algorithm of charge and discharge control

The size of the charge controller will be selected according to following equation:

$$P = VB \times I \quad (6)$$

$$4860 = 48 \times I \times 1.15$$

$$I = 88 \text{ A} \times Sf2$$

$$I = 110 \text{ A}$$

Sf2 Safety factor (1.25); in special conditions, the panel produces more power from its normal rated (about 25% - 30%). For example, sun light reflects from snow, water.

So, the MPPT- 150 A and peak efficiency of 97.5% were used,

3.2.6. Sizing of Inverter

For selecting the inverter which will be used in project; the system voltage, output voltage 230V/50Hz, low self-consumption with efficiency, max charge current > 15A and as well as, the input of inverter have to be matched with the battery bank voltage as in electric grid as follow [6]:

$$\text{Rating inverter} = \text{PV rating} = 135 \text{ Wp} \times 36 = 4860 \text{ W}$$

$$\text{The input energy of inverter} = \text{PV rating} \times \text{PSH} \times \eta_R = 4860 \times 5.4 \times 0.97 = 25,456 \text{ Wh}$$

$$\text{The output energy of inverter} = \text{input energy of inverter} \times \eta_V = 25456 \times 0.95 = 22974 \text{ Wh} .$$

The inverter with high efficient sinusoidal bidirectional generator with self-consumption less than 10 W was used, the working voltage is 48Vdc and the output voltage is 220V/50Hz, with capacity of 5 kW.

3.3. Total Energy Generated by PV Power Plant

The system was monitored using data logger and the data was collected and stored each hour, so the total produced energy on monthly and annually basis can be obtained, using the following equation:

$$E_t = \text{sum} (E_{m1} + E_{m2} \dots \dots \dots E_{m12}) , \text{ where } m1 = \text{January} , \dots , m12 = \text{December} \dots \dots (7)$$

Em: Actual energy production by plant in month (KWh)

Et: Annual energy production by plant (KWh)

The estimated energy generated by PV plant:

In order to inspect the performance of PV power plant in reference to global and technical factor, the estimated energy that may be produced using this PV plant have to be calculated, using the following equation:

$$E_e = H * A * \eta \dots \dots \dots (8)$$

Ee: Estimated energy generated by PV plant (KWh)

H: Irradiation (KWh/m²)

A: Net plant area (m²)

η: Efficiency of photovoltaic module in operating condition

The following figure shows the actual vs. estimated Energy output and the load consumption in both villages.

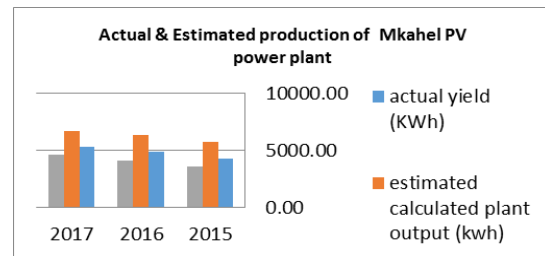


Fig. 5. Khirbat Al-Mkahal-PV Power Plant Production.

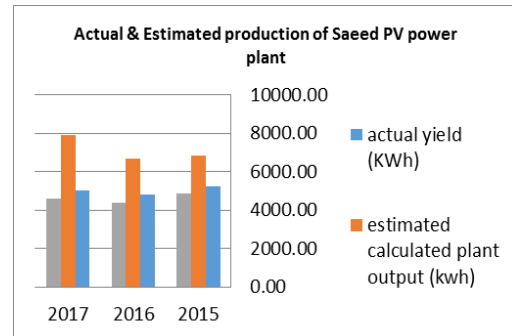


Fig. 6. Khirbat Saeed-PV Power Plant Production.

According to result, the total energy generated for period (2015-2017) is 15.12 MWH & 14.5 MWH in Saeed and Mkahel, respectively.

The maximum generated energy was 626.2 KWh in June, 2017 and the minimum was 201.8 KWh in December, 2017 for Saeed Area, whereas in Mkahel, the maximum generated energy was 605.07 KWh in July, 2016 and the minimum was 271.5 KWh in February, 2015.

4. TECHNICAL IMPACT OF RURAL ELECTRIFICATION IN AL-MKAHAL AND SAEED VILLAGES

4.1. Performance Ratio (PR) of PV systems

This impact factor is called also quality factor because it measures the actual energy ratio to estimated energy and shows the losses effect on yield due geographical and season factors which affect the PR value to fall to 40% to 90%, and for well-designed system PR ratio range is 70-90%. [3, 5]

$$PR = E_t / E_e \text{ (for annual PR) } \dots \dots \dots (9)$$

$$PR = E_m / E_e \text{ (for monthly PR)}$$

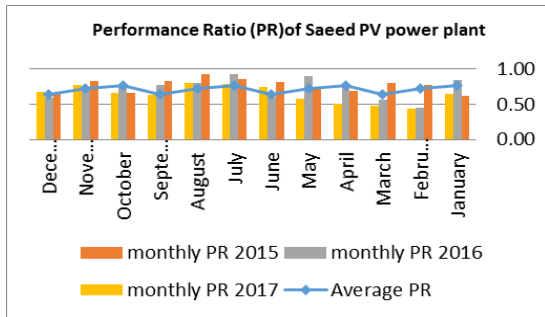


Fig. 7. PR of Saeed PV Power Plant.

The annual average of PR is 71%, and the maximum value of PR is 93% in August, 2015 and the minimum value of PR is 43% in February, 2017.

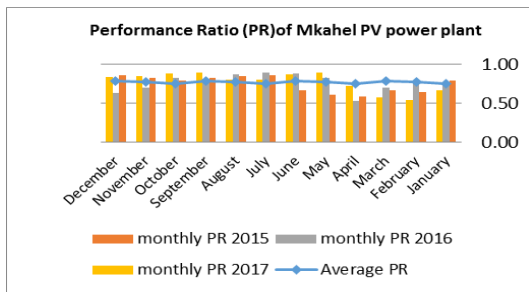


Fig. 8. PR of Al-Mkahal PV Power Plant.

The annual average PR is 77%, and the maximum value of PR is 90% in July, 2016 and the minimum value of PR is 54% in April, 2016.

4.2. Capacity Utilization Factor

This factor measures the actual energy to output if the system operates at nominal power during the specific period, using the following equation [3]:

$$CUF = (Et / (H * P)) * 100\% \dots \dots (10)$$

P: Installed capacity of plant (Wp)

H: Number of hours in one year/month/day

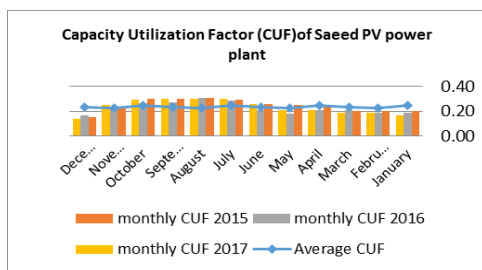


Fig. 9. CUF of Saeed PV Power Plant.

The annual average CUF is 23%, and the maximum value of CUF is 31% in August, 2015 and the minimum value of CUF is 13% in December, 2017.

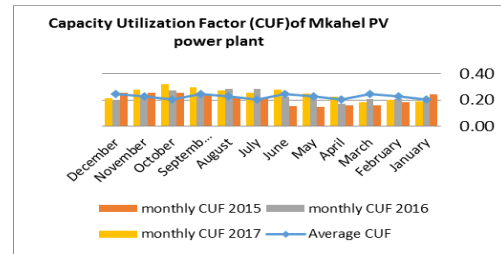


Fig. 10. CUF of Al-Mkahal PV Power Plant.

The annual average CUF is 23% as Kkirbat Saeed, and the maximum value of CUF is 32% in October, 2017 and the minimum value of CUF is 15% in May, 2015.

CUF value refers to the period of time during a year when the PV system is generating energy at its full power energy, so for Saeed and Mkahel area is about 84 days in a year.

4.3. Performance of Battery Charging and Discharging

In both sites, the monitoring system checks each day using the sensor and installed data logger the following parameters:

- Battery temperature
- Ambient temperature
- Charging and discharging state of battery

These values help the analyzer to ensure that the system works without problem, and to solve any issues that may affect the operation of system in future.

The figures below are a sample from both sites:

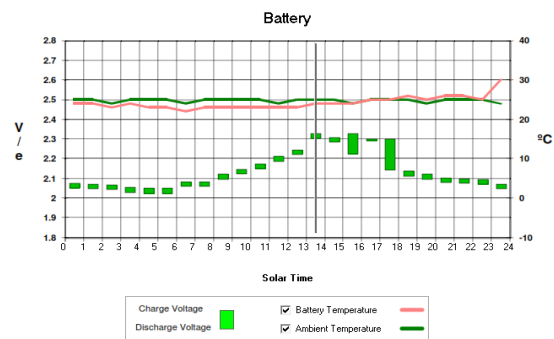


Fig. 11. Battery State - Khirbat Saeed.

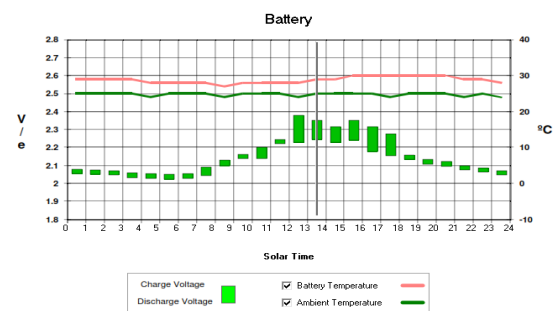


Fig. 12. Battery State - Khirbat Mkahel.

5. ECONOMIC AND SOCIAL IMPACT OF RURAL ELECTRIFICATION IN AL-MKAHAL AND SAEED VILLAGE

5.1. Capacity Utilization Factor

Economics is the basis of most engineering decisions so, this section presents an economic analysis of the proposed stand-alone PV system estimated using the life cycle cost method. The LCC of an item consists of the total costs of operating and owning it over its lifetime. The costs of this system items include buying cost expressed in today's price, operating cost, maintenance and replacement cost.

Table 3. Economic Aspects.

	Saeed	Al-Mkahal
Energy output (Kwh)	19446.93	17945.1
Monthly bill from PV system (US\$/family)	15	15
Monthly energy expenses before PV installation (\$/family)	50 \$	50\$
Monthly saving (\$/family)	35	35
Yearly total saving \$	12x35x9= 3780	12x35x10= 4200
PV installation cost \$	22000	22000
S.P. B.P (year)	5.82	5.3

Economic and social impacts of rural electrification at the household level are multidimensional; both tangible and intangible. The multifaceted impacts and benefits are either direct or indirect. Rural areas in Palestine consume above 65 percent of supplied electricity in household level. The direct impacts are mostly economic, and reflected in enhanced income, and employment, and optimized expenditure pattern, surpluses, savings, and asset building. Most indirect impacts are related to the social and cultural aspects of life, which include, among others, such areas as education, health, women's status, modernization etc. These direct and indirect benefits together produce synergy in economic growth, poverty reduction, and human development.

6. ENVIRONMENTAL IMPACT OF RURAL ELECTRIFICATION IN AL-MKAHAL AND SAEED VILLAGE

Recently, environmental benefits may be one of important reasons for using PV systems in rural areas. The annual reduction of CO₂ for Al-Saeed and Al-Mkahal villages is shown in table .4.

Table 4. Co2 emission Production.

#	System	CO2 emission reduction (Kg.CO2)
1	Khirbat Saeed	13612.851
2	Khirbat Emkahel	2561.57

7. CONCLUSION

The design, and results analysis of the implemented systems, and technological configuration of electrification of Saeed and Al-Mkahal villages with micro grid system generation have been performed in this study very well. The electricity dispenser and training on load management are keys for no blackouts, battery in good health and minimum startups of the generator set. From this pilot project, it is clear that, utilizing PV-hybrid system is more economic feasible for electrification of remote villages of geographic, climate and load conditions similar to these communities in Palestine. In addition, the PV-system do not pollute the environment as the case of using diesel generator.

8. ACKNOWLEDGMENT

The research leading to these results was made possible by funding from the Spanish Cooperation, and supervision by ERC at An-Najah National University. Therefore, we would like to express our gratitude to the all above partners for their support

REFERENCES

- [1] Country report of Palestine- "Paving the way for MSP", *Palestinian Energy and Environment Research Center PEC*, 2012.
- [2] Mahmoud M.M, Ibrik H.I. "Techno – economic feasibility of energy supply of remote villages in Palestine by PV – systems, diesel generators and electric grid", *Renewable and Sustainable Energy Reviews*, Vol. 10, pp. 128 – 138. (Article), 2006.
- [3] Ishaq M., Ibrahim U.H., Abu baker, H., "Design of an Off Grid Photovoltaic System: A Case Study of Government Technical College, Wudil, Kano State": *International Journal of Scientific & Technology Research*, Vol. 2, Issue 12, 2013.
- [4] Energy Research Centre – ERC. "Meteorological measurements in West Bank / Nablus". *An-Najah National University. (Standards and Reports)*, 2014.
- [5] Radhika J. Savalia, Shatrughan Yadav, Akash Davda, Sarika Kanojia, "Performance Evaluation of 190 KwP Rooftop Solar Photovoltaic Plant in CMPDI, Ranchi," *International Journal of Advance Research in Engineering, Science & Technology*, p-ISSN: 2394-2444, Special issue for ITECE 2016.