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Designing Study on Techno-Economic Assessment of Solar Photovoltaic Mini-Grid Project in Nepal

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Abstract

This paper presents the comprehensive feasibility study of solar mini-grid project located in Bajhang District, Sudur Paschim Province, Nepal. The study has been conducted with the aim of developing a suitable size solar mini-grid system to meet electricity demand of proposed settlements of the village people. The study forecasts that the estimated average daily peak power consumption of load is about 20kW and average daily energy demand of load is about 100-150kWh/day in the base year 2022. The shared ratio of productive end uses is about 25% of the total power consumption and about 27% of the total energy demand, which will be used for small business/income generation activities and required 45kWp size solar power generation mini-grid system. The estimated project cost for the proposed 45kW solar mini-grid system technology, including 3 years of operation & maintenance, as well as power distribution network up to end user's premises is about 0.24 million USD. It is concluded that 45kWp photovoltaic mini-grid is feasible for the location.

Keywords: rural energy project, solar mini-grid, feasibility plan, solar system design

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1. Introduction

Nepal is a country with diverse geographical conditions where large share of population lives in the rural areas. It is very challenging to extend national grid power supply to each and every corner of the nation due to economic viability and geographical consideration. In Nepal, about 88% of the total population is connected to grid including both on-grid and off-grid electricity supply [1]. This data shows that 12% of the total population are still living in dark. The lack of access to electricity is more prominent in the rural areas than in the urban areas, and it remains a significant challenge for the country to improve its national electrification ratio to 100% by the fiscal year 2023~24 [2]. Out of this aggregate number of un-electrified population, majority of them have low income living in remote areas relies on traditional kerosene lamp small solar home lighting.

For many developing countries, growing

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energy demand and its sustainable solution have become a bigger challenge to their economics, which create energy-related issues like a huge demand-supply gap, energy outage, wide fossil fuel (firewood and petroleum) dependency, low accessibility to clean energy, and financial crisis. Through the development of mini-microgrid based on renewable energy we can provide them reliable and affordable energy at affordable cost.

Nepal is a geographically diverse country, which has huge potential for solar energy compared to many other parts of the world [3]. Studies suggest that solar PV energy for self-consumption, as well as residential application, are mostly feasible [4-5]. In the context of Nepal, grid-connected large-scale photovoltaic is techno-economically feasible for addressing the energy crisis of the country [6]. For example, by utilization of only 10% of the total roof area of Nepal, 3,338 MWh of energy can be generated from 492MWp PV plants [7-8]. The Solar Home System (SHS) in Nepal is also increasing annually [9]. However, the commercial large-scale photovoltaic plants in Nepal are just countable, and not many studies have been reported on large-scale solar PV plants in academic institutions in Nepal.

At least four forms of solar energy technology have considerable potential in Nepal: grid-connected PV, solar water heaters, solar lamps, and solar residential systems. With around 300 days of sun each year, Nepal receives solar radiation of 3.6-6.2 kWh/m2/day, making it ideal for solar energy. Solar PV installation should undoubtedly be considered as a viable option to increase generation capacity and meet Nepal's energy demand in a clean manner, given the high solar radiation received at various areas in Nepal.

The main aim of this study is to carry out a detailed feasibility (techno-economic) study of a community electrification project, Chhayala Solar Mini-grid located in Jayprithivi Municipality Ward No-5 of Bajhang District, Sudur Paschim Province, Nepal following the standard method for developing countries like Nepal. This study provides information regarding the rural electrification of rural areas of Nepal to produce clean energy, which adds-in revenue as well as protects the environment.

This paper is arranged as follows: Section 2 focuses on the different microgrid technologies. Section 3 presents the solar mini-grid status in Nepal. Section 4 discusses the methodology of techno-economic assessment. Section 5 presents the analysis collected data and results while Section 6 concludes the paper.

2. Mini-Microgrid Techonology

Mini-microgrid concept is not new one. It can indeed be argued that the foundation of the modern micro-grid has its roots in Thomas Edison's first power plant constructed in 1882 – the Manhattan Pearl Street Station [10]. In the past, there was a trend toward larger generator sizes, which was justified by economies of scale considerations. The conventional thought at the time was to encourage the development of large-scale utilities. As huge public or privately held vertically integrated or even unbundled businesses, the era of the typical utility is gradually passing. The need for pragmatic, scalable alternatives, especially for rural and remote locations, has prompted a return to mini/micro-grids as a means of addressing contemporary issues in energy provision and access.

In this context, the key technologies underlying mini-microgrids are related to energy production, distribution, and storage, particularly in the context of renewable energy. These technologies are generally mature and easy to implement. Adapting technologies to make them affordable and adaptable to the harsh environmental conditions found in rural and remote places is a major problem for African countries and Nepal. The issue of energy storage, which allows for the use of energy when microgrid systems are unable to supply it directly, is a big challenge.

Mini-microgrids are a smaller form of the electric power grid that has been defined in a number of ways. Micro-grid can be described as a power generating and distribution system with a maximum capacity of 100 kilowatts and the ability to control local energy supply [11] shown in table 1 below. Mini-microgrids are smaller systems that can provide electricity transmission and, in some situations, it can be integrated to main electrical grid.

Table 1. Mini-microgrid classification

Type	Voltage Level	Maximum Power (kVA)	Application	Complexity
Picogrid	Low Voltage (LV) level	≤ 10 kVA (kilovolt-ampere)	Individual house hold (HH) customers	None
Nanogrid	LV level (microgrid at secondary side)	≤ 100 kVA	Individual HH and/or small group of customers	Low
Microgrid	LV level (microgrid at secondary side)	≤ 1 MVA (megavolt-ampere)	small commercial and/or large group of customers	Middle
Minigrid	Medium voltage (MV) distribution level (microgrid at primary)	About 10s of MVA	Distribution substation	High
Megagrid	≥ 120 kV	about 100s of MVA	Large windfarm with storage	High

Figure 1 shows the various component of microgrid system, where energy can be harvest from solar PV module and wind turbine to meet customer load demands.

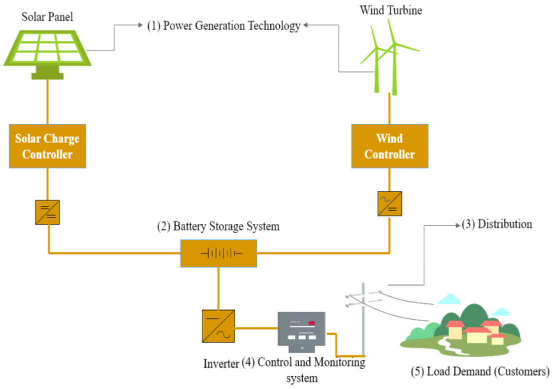


Fig. 1. Microgrid components

Solar Mini-Grid

A solar mini-grid is made up of an electricity generation system that can be paired with a storage system for the energy generated, as well as an electricity distribution system that distributes energy to some isolated loads that aren't generally connected to the national grid.

The solar mini-grid consist solar energy production and management components. In the solar mini-grid project, the major components are: PV modules, DC combiner box, MPPT trackers, charge controllers, battery storage, inverter, loads, circuit breakers and the AC service panel shown in figure 2.

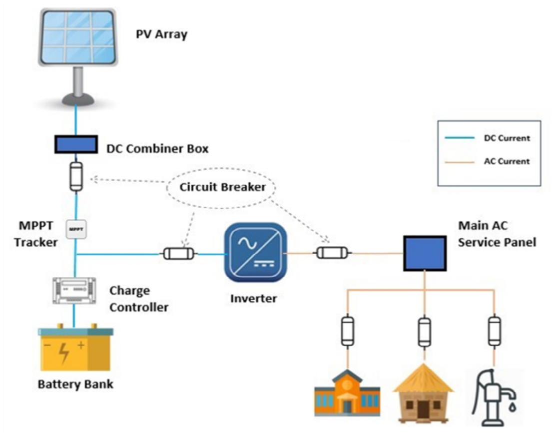


Fig. 2. Off grid solar mini-grid structure

The electricity generated from the array of solar modules is transmitted to a central controller called the Power Conditioning Unit (PCU), which is a large power inverter. The PCU is connected to the Distribution Box (DB) on one hand and the storage system (battery bank) on the other. The PCU controls regulates and directs the electrical energy transmitted from the solar array, and supplies electricity directly to load like homes, shops, offices, street lights. During the production from solar energy is stored in the battery storage system. During the day if the power generated is not used or surplus power is generated, the PCU directs this to the energy storage system which stores power. This power can then be used at night (after the sun sets or cloudy days when there is no production from the Solar).

The microgrid and battery bank can also be connected to a remote monitoring system for regular power generation and electricity consumption monitoring. In case of solar-wind microgrid, figure 1 system energy is produced by both the resources and feed to load as well store when there is surplus. In solar-wind hybrid microgrid, wind turbine can produce energy during the night and solar can generate during the day.

3. Solar Mini-Grid Status in Nepal

Solar PV installation should undoubtedly be considered as a viable option to increase generation capacity and meet Nepal's energy demand in a clean manner, given the high solar radiation received at various areas in Nepal shown in figure 3 below.

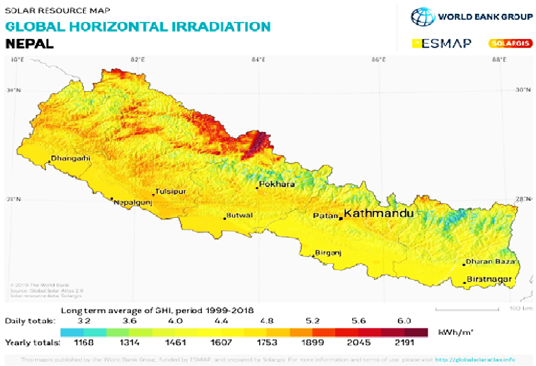
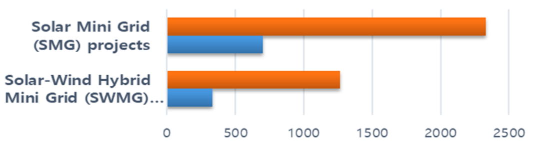


Fig. 3. Global horizontal irradiation map
(Source: Global Solar Atlas)

Solar PV technology is one of the widely implemented renewable energy technology in Nepal where about 800,000 households are electrified through solar home lighting systems to meet basic electricity needs in off-grid areas. For off-grid populations, about 200 kW solar/wind hybrid isolated mini-grid systems have already been built. Alternative Energy Promotion Centre (AEPC) is implementing further 1032 kW solar and solar/wind hybrid mini-grid projects with financing from the Asian Development Bank (ADB) and the South Asia Subregional Economic Cooperation (SASEC) to serve rural homes and boost rural entrepreneurs, consequently helping local economic activity.

By erecting 10 kW wind turbines and 2 kWp solar PV electricity hybrid pilot project at Dhaubadi village in Nawalparasi District in 2010, the Asian Development Bank (ADB)-funded RETA Project set a major milestone for solar/wind mini grid (SWMG) hybrid technology in Nepal. Following the pilot, AEPC began developing solar and hybrid solar/wind mini-grid systems in off-grid communities.

Figure 4 shows overall installed data of solar-wind hybrid and solar mini-grid projects by AEPC. In recent years, there has been clear evidence of tremendous success in community rural electrification using solar and solar/wind hybrid mini-grid technology. The goal of off-grid energy initiatives was to boost local economic activity, provide families with modern forms of electricity, and provide community services to run electrical appliances and enterprises.



	Solar-Wind Hybrid Mini Grid (SWMG) projects	Solar Mini Grid (SMG) projects
Beneficiary Households	1265	2332
Installed Capacity (kW)	334	698

Beneficiary Households   Installed Capacity (kW)

Fig. 4. Summary of solar-wind hybrid and solar mini-grid projects installed by AEPC (Source AEPC, 2022)

4. Methodology

To conduct detail assessment of site with the necessary data collection required for the design and analysis purpose in order to implement solar mini-grid electrification projects in rural areas. To carry out the feasibility assessment and optimal design of solar mini-grid project we follow following approach and methodology shown in figure 5 and 6 respectively.

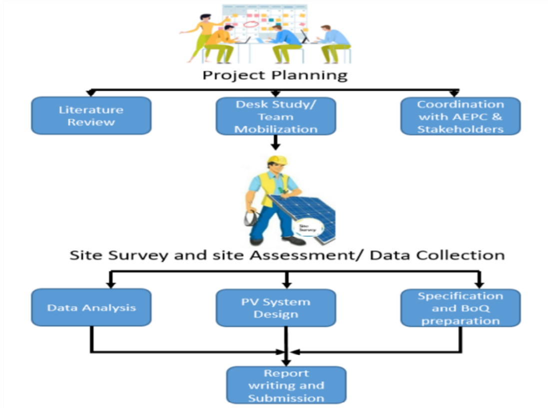


Fig. 5. Approach and methodology for mini-grid

The data collected from site survey will be the major primary source for estimating electrical energy demand of the sites. Based on the energy demand and their need, the sizing of the solar PV generation system will be estimated.

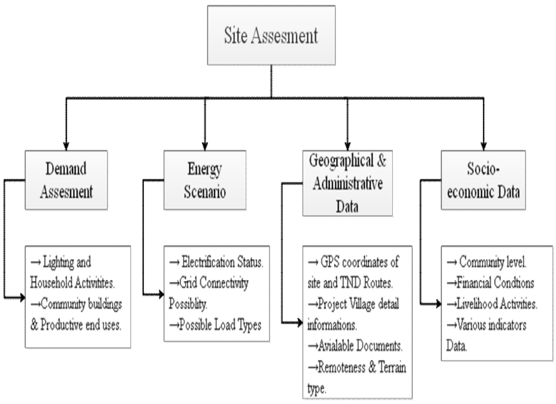


Fig. 6. Flowchart of solar mini-grid site assessment

5. Energy Resource Assessment and Demand Analysis

5.1. Household energy demand

For sizing a photovoltaic system or any other system that uses solar energy to convert it into electricity or thermal energy, it is very important to have data relating to solar radiation. To calculate the amount of energy that can be obtained by means of solar PVs, the radiation data for these coordinates is considered.

The solar resource information used for selected village at a location at 29' N latitude and 81' E longitude was derived by Meteonorm for project site by interpolating data available in nearest place in India. This area has two distinct temperature seasons summer and winter relatively varying during the year.

Temperatures drop sharply at night, and the month 'July' is characterized by high quantity of solar radiation as the driest season of the year is mostly observed in this month. Calculations shows that the annual average solar irradiance at Global tilted irradiation at optimum angle is 5.968 kWh/m2/day.

The selected or projected household of higher income family is composed of few modern electrical and electronic appliances. These include: 6 lamps for lighting purposes, 1 cell-phones as communication facilities, 1 Television (TV) set and 1 radio set. The daily power consumption in watt and daily energy use profile for this category household is analyzed.

It is estimated that a high energy consuming single household may consume 1.29 kWh per day. With the random variability of load for each day and time step to time step we consider certain penetration factor for each load, having cumulative energy consumption projection of around 85 kWh per day for residential loads with the peak load of 18.9 kW from 8 to 9 PM in the evening. Based on these estimated values, a typical daily load curve for a household load with hourly resolution has been observed and shown in below figure 7.

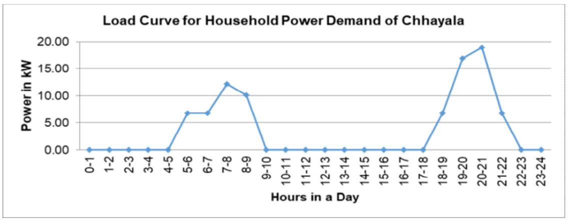


Fig. 7. Daily averages household load profile

5.2. Productive uses and public demand

A village consist of grinding mills, furniture, school, printers and other similar uses. For small industries, business and street lighting demand energy consumption projection of around 32 kWh per day is required with the peal load of 5 kW. Based on these estimated values, a typical daily load curve for a productive uses and public demand loads with hourly resolution has been observed and shown in below figure 8.

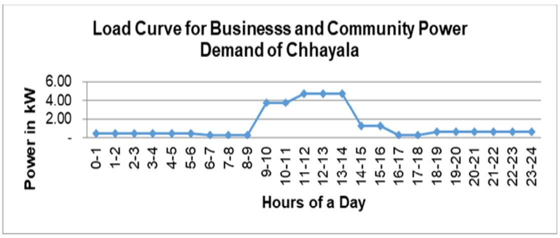


Fig. 8. Daily averages productive uses and public demand load profile

In total cumulative energy consumption of the project village is about 117 kWh per day with the peak load of 20 kW during 8 to 9 PM in the evening. Based on these estimated values, a typical daily load curve for a whole village with hourly resolution has been observed.

5.3. Solar mini-grid system sizing and energy production estimate

To fulfill the above energy demand, we had designed 45kWp solar mini-grid system.

Calculated 45kWp solar PV mini-grid of this project is sufficient to produce the required amount of energy to the village as the site is receiving a rich average solar radiation of 5.968kWh/m2/day and an annual average temperature of about of 16.3˚C (Source: Meteonorm).

The analysis highlights the preliminary design of the project such as feasibility study. The annual energy production and energy yield assessment values of the minigrid are computed using the Global Solar Atlas Tool. The annual energy production of the plant at 74.790MWh/year is recorded. It is for sure that reference recorded data indicates a good agreement over the performance of the proposed solar mini-grid power plant.

The Global Tilted Irradiance was found to be 5.968 kWh/m2/day at Chhayala (Source: Global Solar Atlas Tool). The value of 4.5 hours has been considered as peak sun for system design and estimation of average daily energy output. The total estimated average daily energy output is calculated as 205kWh/day with the installation of 45kWp solar PV. The required average daily energy output is calculated as 117kWh/day. The estimated average daily energy output is calculated as below table 2.

Table 2. Energy estimation of the village per day

Equipment	Rated Capacity	Quantity	Total Capacity	Estimated Average Daily Energy (kWh)
PV Module	0.325kWp	140	45.50 kW2	205
Estimated Average Daily Energy Output				205 kWh/day
Required Average Daily Energy Output				117 kWh/day

5.4. Financial analysis

The financial analysis would center on two parameters applied to every alternative. These parameters are the initial project cost and the present worth. Initial project cost is the estimated upfront investment for the project which can be taken from summing up the cost of equipment, materials, transportation & labor cost. Other costs such as engineering fees and other indirect costs shall not be accounted for in the cost estimates. Since these Solar Mini-grid would be provided once by maximum share of cost from government and minimal from locals there would be revenue from the system coming from the recipient families.

In effect, the present worth analysis would account only purely for cost with revenues). The discounted cash flows projected at the present year are due primarily from the replacement of the batteries. The sum of these cash flows at present with an assumed discount rate of 6.5% for all the recurring costs constitutes the present worth of that alternative.

Bar below the year line indicates a cost or a negative annual or accumulated cash flow, whereas bar above indicate income or positive cash flows. 20% incremental benefit earnings of total CAPEX have been considered for the economic analysis purpose.

As it may be observed from the table, the whole installation of Chhayala village would have a pay-back time of approximately 6 years, which is a more than acceptable figure considering the project's lifetime.

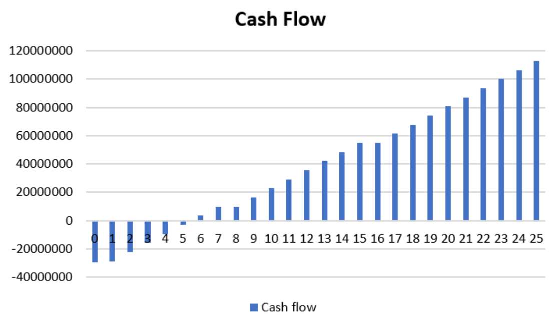


Fig. 9. Cash flow for solar mini-grid project

6. Conclusion

Based on our calculations we recommend the medium system of 45kW for the project village. We chose the medium system because it meets the power requirements needed to power everything in the village inclusive of productive end uses. This is the most cost-effective solution with the sufficient amount of electricity to the users.

For the off-grid users as in Chhayala village such mini-grid technology is best suited. This study suggests the implementation of this project by next year for providing stand-alone photovoltaic system for a 205kWh/day of total daily supply in the village reveals the system is able to produce excess of 32,120 kWh annually (42.92 %).

The system is completely renewable energy technology. The estimated project cost for the proposed 45kW solar mini-grid system technology, including 3 years of operation & maintenance, as well as power distribution network up to end user's premises is about 0.24 million USD. It is concluded that 45kWp solar mini-grid is tech-economically feasible for the studied location.

Acknowledgnts

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References

[1] NEA (2021) A year in review fiscal year 2020/21. Nepal Electricity Authority 9-10 https://www.nea.org.np/annual_report

[2] National Planning Commissioning Report, Nepal (2021) A year in review: fscal year 2020/21.

[3] Adhikari, K. R., S. Gurung, and B. K. Bhattarai. 2014. Solar energy potential in Nepal and global context. Journal of the Institute of Engineering 9 (1):95-106. doi:10.3126/jie.v9i1.10675

[4] Espinoza, R., E. Muñoz-Cerón, J. Aguilera, and J. De La Casa. 2019. Feasibility evaluation of residential photovoltaic self-consumption projects in peru. Renewable Energy 136: 414-27. doi: 10.1016/j.renene.2019.01.003.

[5] Foles, A., L. Fialho, and M. Collares-Pereira. 2020. "Techno-economic evaluation of the Portuguese PV and energy storage residential applications." Sustainable Energy Technologies and Assessments 39 (December 2019). Elsevier: 100686. doi: 10.1016/j.seta.2020.100686.

[6] Fu, R., D. Feldman, and R. Margolis. 2018. U. S. Solar Photovoltaic System Cost Benchmark: Q1 2018. NREL. doi:10.7799/1325002.

[7] Gautam, B. R., L. Fengting, and R. Guo 2015. "Assessment of urban roof top solar photovoltaic potential to solve power shortage problem in Nepal." Energy and Buildings 86. Elsevier B.V.: 735-44. doi: 10.1016/j.enbuild.2014.10.038.

[8] Hasapis, D., N. Savvakis, T. Tsoutsos, K. Kalaitzakis, S. Psychis, and N. P. Nikolaidis. 2017. "Design of large scale prosuming in universities: the solar energy vision of the TUC campus." Energy and Buildings 141. Elsevier B.V.: 39-55. doi: 10.1016/j.enbuild.2017.01.074.

[9] AEPC (2021) Annual report fscal year 2020/21.

[10] Contejean, A., Verin, L., (2017). Making Mini-Grids Work: Producitve Uses of Electricity in Tanzania. Working Paper, IIED, Hivos. http://pubs.iied.org/16632IIED/

[11] IRENA. (2014). International renewable energy agency. The Socio-economic Benefits of Solar and Wind Energy, 108.