Enabling Solar Mini-grid Development for Off-grid Electrification in Nepal

Narayan Prasad Adhikari[1*], Khem Raj Bhandari[2]
[1]*Director, Alternative Energy Promotion Center*
[2]*Deputy Team Leader, Alternative Energy Promotion Center, KfW-DKTI Solar Project*
Corresponding Email: [1]narayan.aepc@gmail.com, [2]khem45@gmail.com

Abstract

Because of technological advancement and declining costs of the technologies, solar photovoltaic (PV) based mini-grids in the recent days are gaining popularity as a means to provide electricity to off-grid communities especially in the developing countries. Nepal has been implementing solar mini-grid projects to non-electrified rural areas to achieve the target of electricity for all by 2023. The scope of implementation and sustainable operation of such mini-grid projects in rural area is interdisciplinary in nature. This paper presents technical, social, financial aspects along with key issues of 100kWp solar mini-grid project in one of the rural villages of Nepal. The insights from the paper can support to design solar mini-grid program for sustainable electricity supply in remote areas.

Keywords
Solar Mini-grid, Energy Storage System, Real Time Monitoring, Sustainability

1. BACKGROUND INFORMATION AND RESEARCH ACTIVITIES

1.1 Background and Objective of the Study

Nepal has huge potential to develop low carbon economy through its ample abundance of renewable energy resources such as solar energy, biomass, mini or micro hydro, wind energy etc. These renewable energy resources offer great opportunities to enhance energy security and for the environmental sustainability. Although hydropower development is the national priority and will be taken as the lead energy resources of Nepal, the other renewable energy resources are essential to complement and meet the objectives set by Government of Nepal (GoN) for enabling energy mix in the total national energy supply.

Decentralized renewable energy services have been emerged as cost competitive solutions for electrification to non-electrified areas because of both declining cost of the technologies and development of efficient end use devices [1]. On comparing individual energy system, the mini-grid project can offer greater opportunity to increase productive energy uses (PEU) and thus enhances possibility of larger income generation in rural community [2–4][5]. This has increased inclination of development agencies towards support to mini-grid program especially to off-grid areas of the developing countries for achieving Goal-7 of the United Nation's Sustainable Development [6][7][8][9]. Despite some provisions of enhancing end uses thereby generating income at local level, the businesses in mini-grid electrification domain are still not attractive and requires financial support in developing countries [10][11]. Hence, various schemes of financial support are being deployed to implement mini-grid electrification programs. Similarly, intervention of different business approaches; technical innovations for implementation as well as for operation and maintenance have also been emerged in different parts of the world.

In this paper, we present and analyze experiences of implementation of solar mini-grid projects in rural community of Nepal by considering a case study. First, we will briefly provide information on the recent updates on the electrification status in the country and the government's key policies and plans to achieve Nepal's commitment towards sustainable development goal-7 (SDG-7) for universal access to electricity to all by 2030. Second, we will present general idea of solar mini-grid projects that have been promoted by Alternative Energy Promotion Centre (AEPC) with the support of Asian Development Bank (ADB) under South Asia Sub Regional Economic Cooperation (SASEC), Power System Expansion Project. As a case study, we will review one solar mini-grid project to share experiences on four main dimensions: technical, social, economic, and operation and maintenance. We will also provide key issues and challenges that were experienced in various stages during and after implementation of the solar mini-grid project.

1.2 Energy Consumption and Electrification

Nepal's energy resources are broadly divided into three categories of traditional, commercial and renewable energy. The traditional energy includes solid biomass fuels derived from plants and animals. The commercial energy includes electricity and petroleum products. Nepal completely depends on import for its required petroleum products. The demand of petroleum products has been proliferating and the trend remains same in future under business-as-usual scenario. Figure-1 shows the distribution of energy consumption by three major categories of energy resources in the year 2020/21.

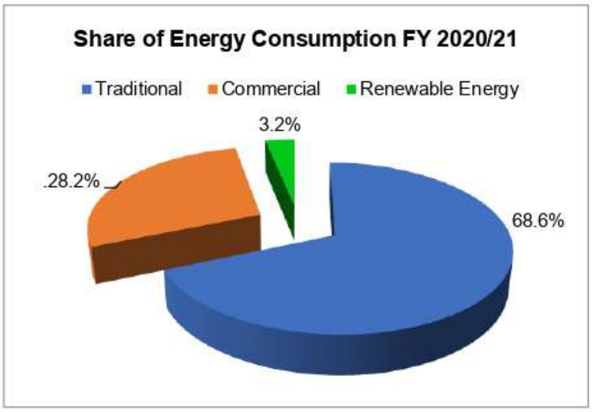

Figure 1: National energy consumption of FY 2020/21

In the total energy consumption for the fiscal year 2020/21, the share of traditional biomass, commercial and renewable energy were 68.6%, 28.2% and 3.2% respectively [12].

The electricity access in Nepal has been reached to 93% of the total population through on-grid and off-grid services [13], where the latter has been reached to 7% of the total population. The desk study by AEPC shows that grid extension has been reached to around 9% of those populations who earlier were provided with off-grid sources like micro or mini hydro and solar PV. The remaining 7% of population have still no access to electricity, mainly in two provinces namely Karnali and Sudurpaschim where building national grid infrastructure has been real challenge due to difficult geographical terrain and its remoteness (Fig-2). The multi-tier framework analysis shows that, about 30% of total population have electricity services of below Tier-3 and only 47.3% grid connected population has access to 24 hours electricity [14].

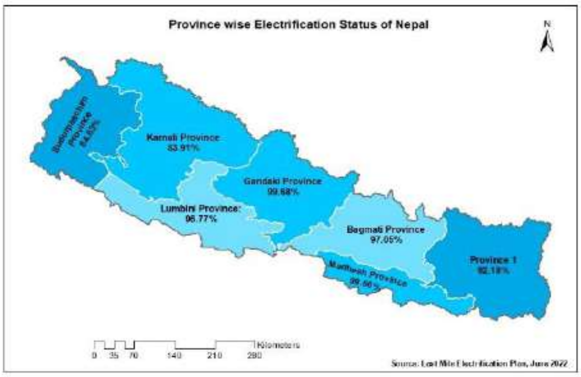

Figure 2: Province-wise electrification status

Nepal Electricity Authority (NEA) is the government owned utility company which has been providing national grid electricity services through generation, transmission and distribution of electricity to its consumers. Likewise, AEPC has been promoting renewable energy technologies to provide access to clean lighting and clean cooking solutions in rural areas since last 25 years. At present, both the institutions have been working under the purview of the Ministry of Energy, Water Resources and Irrigation (MoEWRI).

1.3 Rationale of solar power development in the national energy mix

Solar energy is one of the most promising resources that use abundant and free energy from the sun having clean, inexhaustible and environment friendly nature. Nepal, being located in favorable latitude, receives ample solar radiation. The average solar radiation varies from 3.6 - 6.2 kWh/m2/day with 300 sunny days in a year [15]. The commercial potential of solar power for grid connection of Nepal is estimated to be 2,100 MW [16].

Solar PV has been considered effective technology for rural electrification of large part of the rural population seeking considerably low amount of electrical energy. The operation and maintenance cost of diesel generators for those remote locations is too high. Small hydro power plants need specific topographical conditions that are only found near a small percentage of end users' settlement. Solar power generating systems do not need fuel or extensive infrastructure, it is easy and quick to install for all kind of applications. This option is found to be viable solution to meet basic energy needs in many locations of the country that are scattered with no access to national grid. Hence, the government has aimed to promote solar PV for electrification to non-electrified households in remote areas. Further, in view of energy security, it has been envisioned to develop 5 to 10 % electricity generation to national grid from renewable energy sources including solar PV [17].

2. METHODOLOGY

The primary information for the study is acquired from one of the mini-grid projects that was implemented by AEPC. Here, the primary data were gathered from real time technical monitoring, personal interview with the government line agencies and the stakeholders' consultations by conducting site visit to mini-grid project site. Data analysis was carried out basically for the real time energy generation and consumption balance of solar mini-grid project.

The secondary data were collected from policy, guidelines and relevant studies carried out in past. The relevant documents developed by NEA, AEPC, MoEWRI, MoF along with reports published by International Energy Agency, were mainly referred for this study.

2.1 GoN subsidy policy for solar mini-grids

As per the renewable energy subsidy policy of Nepal, the solar mini-grid projects will be eligible to receive subsidy if the site is not accessible by national grid power supply and no other means of electrification exists.

The 90% upfront capital subsidy to solar mini-grid system is provisioned for the solar mini-grid power plant up 250kWp installed capacity when it is owned by the respective local government. The local government unit is the third level of government division in Nepal.

The support to energy service company (ESCO), Cooperatives and Users Committee is up to 60% upfront subsidy for the solar mini-grid power plant up to installed capacity of 100kWp [18].

2.2 Solar Mini-grid Promotion by AEPC

AEPC initiated first solar-wind hybrid mini-grid project in 2011 by the support of ADB, and further replicated large numbers of micro-grid systems in various part of the country. AEPC has been implementing solar mini-grid special program to provide electricity service of at least of Tier-3 level to off-grid households where no alternative potential of micro or mini hydro exists. The electricity service of Tier-3 level refers to have at least 8-hours electricity per day which includes at least 3-hours per evening, capacity sufficient to power medium loads above 200Watt and can afford a basic consumption of 365kWh per year [19]. Till date more than 30 solar mini-grids of cumulative capacity above 1.2MWp have been implemented serving to more than 6,000 households and powering more than 150 small scale rural enterprises.

AEPC implemented ADB supported SASEC Project (2015-2021), under which nine solar mini-grids with the cumulative capacity 565kWp were successfully completed. By following guidelines of project selection criteria, the site selection and feasibility assessment of mini-grid project was carried out by AEPC in coordination with Local Governments (LGs) and users' communities.

The technical standards for solar photovoltaic system components used in Nepal are guided by Nepal Photovoltaic Quality Assurance (NEPQA) and Renewable Energy Test Station (RETS) Nepal conducts testing of PV components as per NEPQA guidelines. In addition, during procurement of major system components such as solar PV modules, energy storage system or batteries, PV controllers and solar inverters international quality test certifications have been provisioned as mandatory requirement. Following are the key innovative approaches adopted for implementation of solar mini-grid projects.

- All single phase and three phase consumers are connected through pre-paid energy meters ensuring timely collection of energy tariff.
- Power conditioning devices (i.e. controllers and PV inverters/Battery Inverter) are integrated in the mini-grid systems that allow system to efficiently operate in off-grid mode as well as provision to connect into the

national grid power line when grid power supply will arrive in the village in future.

- The technical standards of the power distribution network are required to be of at least national grid quality and standards so that the present off-grid power transmission and distribution network is grid compatible for future grid integration.
- As long as the telecom data network or internet services are available to the remote sites, the real time data can be monitored and analyzed through the web-portal space given by the respective manufacturers of power conditioning devices integrated in these solar mini-grid projects.

In terms of financing mix, the upfront subsidy of 90% of the total project cost has been provisioned whereas the remaining 10% has been raised from local community as an equity investment. The land required for installations of hardware and powerhouse construction have been managed by the community. Prior to implementation, the formation of cooperatives with inclusive representation of women and disadvantaged group at community is made mandatory. Such cooperatives are made responsible for raising equity, monitoring during construction, exploring business opportunities, tariff management and conflict management. Various capacity building activities have been conducted by AEPC through the social mobilizer in community to enable them to execute their obligations. The supplier and installer companies have been selected by following standard procurement and bidding procedures. The provisions of operation and maintenance to provide on-site services for 3-years by the installer company have been integrated in the bidding documents. On having such provisions, it has envisioned to have effective transfer of skills and knowledge from Installer Company to hosting cooperatives.

2.3 Case study of 100kWp Gutu solar mini-grid project

2.3.1 Site information

The site is located at 390 m above sea level having its geographical coordinates 28^{0}54'30"N and 81^{0}19'15.3"E. The Gutu village is located at the western part of the Surkhet district in Karnali province (Figure 3).

Figure 3: Site Location

The project was completed in one-year time from the beginning of its project cycle including procurement process and is in its operation phase till now. The field visit, real time remote system monitoring and performance analysis of the case were intended to acquire project related information through possible means within the intended research study time frame.

During the feasibility study, the proposed site was selected considering various village clusters in the proposal to efficiently distribute power through isolated grid line as demonstrated in the below map showing service area (Figure 4).

Figure 4: Gutu Solar Mini-grid service clusters map

During the field visit for data and information collection, informal meetings with the local stakeholders were conducted to understand operational issues and challenges.

2.3.2 Solar resource assessment of the site

The local environmental resource assessment of the site is the preliminary input for the technical design and feasibility analysis of the PV mini-grid projects. The solar resources for PV energy production are 1,727kWh/m^2/year global horizontal irradiation and 1,907kWh/m^2/year global tilted irradiation at 28^o optimum tilt angle of the solar PV array towards south direction [20]. The annual average solar PV energy output at the site was estimated to be 1,430kWh for each kWp PV installed capacity forecasted through simulation tool (Solargis).

Figure 5: Estimation of monthly PV Output of 100kWp

By using Solargis application tool, the average monthly solar PV output has been estimated (Figure 5). It is observed that the month of March and October do have highest PV production, whereas July has the lowest energy yield condition.

3. RESULTS AND FINDINGS

3.1 Salient features of solar mini-grid

The power generation system includes 100kWp solar PV array, 768kWh energy storage system (battery bank), 100kW PV grid-tie inverters, 72kW off-grid/battery inverters and a multi-cluster control system.

The DC power produced by 100kWp solar PV array converts to 3-phase 400Vac through two units of each 50kW PV grid-tie inverters that are synchronized with the AC bus bar. PV string inverters serve day-time electrical loads as well as deliver energy for battery bank charging through battery inverters. The core of the system components inside powerhouse are solar PV inverters, battery inverters, multi-cluster control system and the OpzV series valve regulated lead acid (VRLA) battery bank. There are 12 battery inverters (four clusters of each three inverters stacked) connected to the multi-cluster box. Each battery inverter provides 6kW rated capacity with cumulative capacity of 72kW. In this configuration, the battery inverters are not connected into grid or diesel generator at the moment, and they perform function of battery charging and energy supply to village loads. In order to optimize battery charging and PV direct power supply to the day-time loads, the PV inverters and battery inverters do communicate to each other. There are four battery banks of each 4,000AH@C10 at 48V nominal voltage. The total capacity of energy storage system is 768kWh battery bank. The battery banks and inverters are wired to the DC switch board with MCCBs and battery fuses. The charging system is comprised of 100kW of three phase PV grid-tie inverter technology with inbuilt solar maximum power point tracker (MPPT) charge controllers which are synchronized together with the battery inverters as demonstrated in the block diagram (Figure 6).

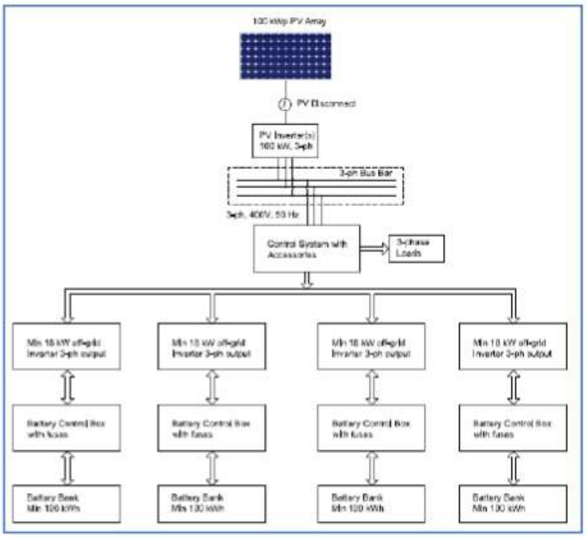

Figure 6: Power generation system block diagram

On the 3-phase bus-bar, the output feeder cables are connected to supply power to village power transmission and distribution network. The electricity produced by solar PV system has been transmitted through low voltage three phase 400V AC and single phase 230V AC as required by the demand of household and other loads. The data manager device is used for the system monitoring and control purpose which is connected with the cluster battery inverters and PV string inverters via multi-cluster communication interface. Figure-7 and Figure-8 depict ground mounted 100kWp PV array together with a powerhouse, energy storage battery system and power conditioning devices.

Figure 7: Powerhouse and 100kWp PV array

Figure 8: Battery bank and inverters inside powerhouse

3.2 Analysis of energy production and consumption

During its first year of operational phase, the real time remote monitoring has been conducted in order to analyze monthly energy production and consumption balances. It is observed that the day-time consumption or PV direct consumption is 37% of total production which basically provides energy service to business enterprises and public institutions in the day-time. Out of total annual energy consumption, 63% of the energy has been supplied through battery energy storage system (ESS) in the evening and morning hours. The actual PV energy production of this off-grid solar mini-grid varies from day to day because of the following two key factors:

CASE-1 (energy surplus): When there is no day-time electricity demand and battery bank is also fully charged, the solar PV plant will not produce energy.

CASE-2 (energy deficit): When day-time load is high, battery bank is poorly charged or discharged, the PV plant will produce its maximum capacity to meet direct-loads or day-time electricity demand as well as to charge the battery bank system.

Figure 9 illustrates total monthly energy production, amount of energy used for battery charging and the amount of energy served from PV direct loads in the day-time without going through battery bank.

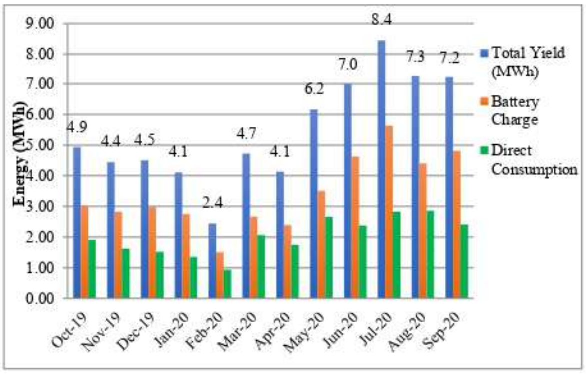

Figure 9: Energy production-consumption of Gutu SMG

Figure 10 shows typical daily load curve of power supply and consumption pattern traced through real time system monitoring. In this daily load curve, power consumption pattern in a particular day (11, Jul, 2020) corresponding to the day-time PV power production is presented.

The night-time electrical load varied in between 12kW to 17.5kW which had been served through the battery bank, where the battery state of charge came down to 63% from 88% during evening peak hours. The system started power production from 5:45AM and peaking at 10:15AM when it was producing 66.83kW real power from a 100kWp solar PV array. The day time loads were directly served through PV inverter without seeking any additional power from ESS and battery inverter during 5:45AM to 5:50PM.

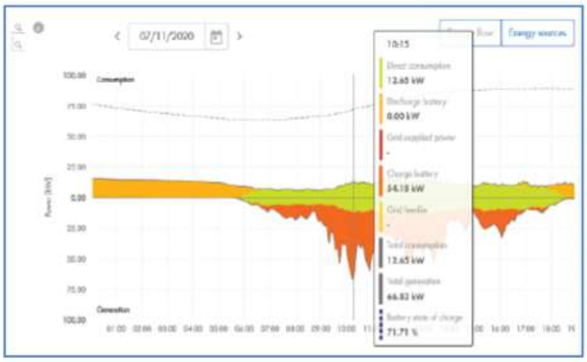

Figure10: Daily energy balance scenario of Gutu SMG site

3.3 Social mobilization

AEPC has supported to enhance institutional capacity of the users committee (UC). The locally formed UC had been capacitated to convert into a legal entity of energy service provider Cooperative in order to conduct energy business. The capacity development included technical trainings to the system operator, tariff management and account keeping of the mini-grid energy business to maintain financial transparency as well as operational sustainability.

3.4 Social and financial aspects

The households connected to national grid system in the semi-urban and urban area have access to grid electricity without contributing to the upfront investment who pay only monthly electricity tariff. The investment cost of solar mini-grid is also high compared to other comparable energy service technologies. Therefore, as social justice, the government has made special provision of providing up to 90% investment subsidy to remote and rural households for implementation of off-grid solar micro/mini-grid project. The off-grid projects are more of social projects than the commercial projects serving rural communities with the lighting and basic electricity services. The 90% of the project investment cost of Gutu SMG had been subsidized by AEPC whereas the remaining 10% of the upfront cost has been contributed by both communities and Chaukune rural municipality (Local Government).

The solar mini-grid has been serving to 344 households, 30 productive energy use (PEU) demands, 10 public service institutions, grocery shops within the Gutu village market center. The operation cost covers expenses of system operator, office expenses and funds for repair and maintenance. The operation cost (general administration and repair) is inflated over a period with the inflation rate of the project life cycle. The total upfront investment of the project is NRs 56.55 million. The cost includes all the power generation and distribution components, powerhouse, pre-paid energy meters, miniature circuit breakers (MCBs), LED lights for end users as well as operation and maintenance (O&M) costs for 3-years. The financial analysis has been carried out for the 10% equity investment excluding value added tax (NRs 5.005 million). The estimate shows that the payback period for 10% equity is 4 years with the project internal rate of return (IRR) of 25% at the levelized cost of energy NRs 9.0 per kWh (Tables-1 and Table-2 indicated input parameters of financial analysis).

Table 1: Inputs to financial analysis

Parameters	Values
Project financial analysis period (years)	10
Plant capacity (*kWp*)	100
Number of households	344
Numbers of commercial entities	30
Inflation (%)	8.3
Depreciation (years)	10
Discount rate (%)	5
Insurance Premium (%)	1
Revenue default rate (%)	10% in year 1st & 2nd, 5% thereafter

Table 2: Average tariff for mini-grid consumers

Customer category	Energy (kWh)	NRs/kWh
(i) Domestic		
Minimum tariff	*10*	*150*
>minimum tariff	*1*	*15*
(ii) PEU		
Minimum tariff	*20*	*400*
>minimum tariff	*1*	*20*

Although the initial estimate was made on the basis of above figures, the UC takes need-based decisions after consultation with AEPC and related stakeholders. Afterwards, the tariff was revised with NRs 13 per kWh for domestic consumers on top of monthly service charge NRs 50. Similarly, NRs 18, NRs 21 and NRs 25 for 16Amp single phase, 32Amp single phase and 25/32Amp three phase consumers respectively.

3.5 Operation and maintenance

AEPC provided various types of technical, financial and managerial trainings before the system were handed over to the local community. As provisioned, the installer company has the responsibility to keep system operation and to provide maintenance services for the first three years. The cost associated with operation and maintenance for the first three years has been covered by the initial project implementation contract between AEPC and the installer company. A potential candidate from the same village had been trained as an operator of the project from the installation phase to undertake responsibility for operation, daily or routine maintenance, pre-paid energy meter recharge, energy logbook maintaining and distribution line maintenance. The operator has been paid on monthly basis (NRs 13,00 per month) by the installer company who works as full time mini-grid system operator on-behalf of the company, at least for the first three years. The installer company does routine maintenance on quarterly basis in order to do preventive and corrective maintenance of the SMG. Beyond the first three years of maintenance period, the users committee may extent technical service of the same company through signing annual maintenance contract.

3.6 Key issues and challenges

The key issues and challenges encountered during project implementation and operation phases are:

- The detailed feasibility study and energy demand survey was conducted in 2015 thereby estimating service to 107 households and other end users. Total recommended solar mini-grid system size was 39kWp solar PV. However, during the community consultation in 2017 for the implementation plan under AEPC-SASEC project, total 344 households (107 old houses and 237 new houses) had to cover as recommended by the local government, because of which a 100kWp system was suggested. Hence, an increased system size of 100kWp capacity was considered for the implementation which was commissioned in May, 2018. The temporal difference between survey study and actual field implementation may result variation of estimated energy users which may lead difficulty for collecting capital cost (community equity part).
- Gutu SMG site was observed as potential site for economic activities because of which 5% energy growth rate was considered in the initial design. Nevertheless, after one year of implementation the energy demand was increased more than the expected rate. Public institutions as well as energy based PEU demands are increased in the Gutu market center, the migration of some energy end users happened from the adjoining village settlements and summer season loads (fans, refrigerators) were owned by the large number of end users those who did not demand that in initial site survey. Hence, the system has required to do power-cut in some days of summer season in order to avoid the issues of the power plant overload and technical faults.
- The historical data monitoring demonstrates that, the majority of plant shut-down occurred during the first six months of SMG operation, whereas first two years average shutdown was recorded up to 8.7% of the total time.
- One of the technical issues identified is load unbalance of three phase power which causes disruption in power due to plant shutdown by phase overload.

- Although the online real time remote system monitoring has been set up, but due to poor telecom network in remote villages and lack of internet service provider or WIFI connection, the remote data monitoring has still been challenging.
- Despite provisioning of local operator for both day-to-day operation and maintenance of the solar mini-grid system and to make communication with Installer Company for handling technical difficulties, it was observed that the training provided to operator was inadequate for handling with computer, data monitoring and diagnosing minor problems. Therefore, it is advisable to develop effective criteria while selecting operator and to provide refresher trainings continuously to keep up the operational capability of the operator.
- One of the challenges to isolated solar mini-grid is switching of energy users to the national grid mains line when grid arrives in the village. If this case encountered in future, the UC of Gutu SMG has plan to bulk purchase electricity from NEA grid and distribute locally through the same Cooperative to run local community electrification program and also do the grid connection of the solar mini-grid.

4. CONCLUSIONS

The study provides a window into various aspects of solar mini-grid systems such as technical, socioeconomic and financial in rural areas of Nepal. There have been good evidences of a significant progress in the community rural electrification schemes by the mini/micro hydro and solar or solar/wind hybrid mini-grid technologies in the recent years. The motivation for off-grid energy projects aimed to increase local economic activities, access to modern form of electricity for the households as well as community services to operate electrical appliances, medium of communications that are essential for day-to-day activities. The solar mini-grid systems are proven to be effective and sustainable tool to provide modern energy services to the off-grid communities of Nepal that are far from the national grid electricity system.

The case study demonstrates that, with a certain fixed capacity it is often difficult for solar PV mini-grid system to provide 24/7 electricity service and fully sufficient electricity. Except for increasing system capacity, the amount of electricity generated from solar PV system generally is not fully capable of meeting unlimited electricity demand such as energy services above Tier-3 level. Hence, the overall management of solar PV power stations in terms of technical, financial, human resource, and institutional capacity building is critical to improving the reliability of electricity service and sufficiency of electricity supply.

REFERENCES

[1] IRENA. Renewable Power Generation Costs in 2017, Vol. B. Abu Dhabi: 2018

[2] Pueyo A, DeMartino S. The impact of solar mini-grids on Kenya's rural enterprises. Energy Sustain Dev 2018; 45:28–37.https://doi.org/10.1016/j.esd.2018.04.002.

[3] Azimoh CL, Klintenberg P, Wallin F, Karlsson B, Mbohwa C. Electricity for development: Mini-grid solution for rural

electrification in South Africa. Energy Convers Manag 2016;110:268–77. https://doi.org/10.1016/j.enconman.2015.12.015.

[4] Ulsrud K, Winther T, Palit D, Rohracher H, Sandgren J. The Solar Transitions research on solar mini-grids in India: Learning from local cases of innovative socio-technical systems. Energy Sustain Dev 2011;15:293–303. https://doi.org/10.1016/j.esd.2011.06.004.

[5] Bhandari KR, Adhikari NP. Grid Integration of Solar and Solar/Wind Hybrid Mini-Grid Projects: A Case of Solar/Wind Hybrid Mini-Grid Project Implemented by AEPC. J Inst Eng 2020;15:42–8. https://doi.org/10.3126/jie.v15i3.32004.

[6] Madriz-Vargas R, Bruce A, Watt M. A Review of Factors Influencing the Success of Community Renewable Energy Mini-grids in developing countries. Sol Res Conf 2015:1–11.

[7] Nam K-Y, Zhai Y. Guidebook for Deploying Distributed Renewable Energy Systems. Manila: Asian Development Bank; 2019.

[8] World Bank. Reliable and Affordable Off-Grid Electricity Services for the Poor 2016:1–7.

[9] UNDP and ETH Zurich. Derisking Renewable Energy Investment: Off-Grid Electrification 2018.

[10] Bhattacharyya SC. Mini-grids for the base of the pyramid market: A critical review. Energies 2018;11. https://doi.org/10.3390/en11040813.

[11] Knuckles J. Business models for mini-grid electricity in base of the pyramid markets. Energy Sustain Dev 2016;31:67–82. https://doi.org/10.1016/j.esd.2015.12.002.

[12] Economic Survey 2020/21, Ministry of Finance, Government of Nepal

[13] Nepal Electricity Authority, A year in review -fiscal year 2020/21, Nepal 2021.

[14] ESMAP/WB. Nepal - Multi-Tier Framework for Measuring Energy Access Household Survey (MTF) 2017. 2019. Https: //doi.org/Ref. NPL_2017_MTF_v01_M.

[15] Government of Nepal, Water and Energy Commission Secretariat, Singha Durbar, Kathmandu(2013),*National Energy Strategy of Nepal*.

[16] Alternative Energy Promotion Centre (AEPC) Nepal, *Solar and Wind Energy Resource Assessment (SWERA, 2008).*

[17] White paper 2018, Ministry of Energy, Water Resources & Irrigation, Government of Nepal

[18] Renewable Energy Subsidy Policy 2022, Alternative Energy Promotion Centre, Government of Nepal.

[19] ESMAP/The World Bank, Technical Report, Multi-tier Framework for Energy Access, https://www.worldbank.org/en/topic/energy/publication/energy-access-redefined.

[20] Global Solar Atlas, Online resource assessment tool prepared by SOLARGIS, ESMAP.