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Prospect of Stand-Alone Solar PV in Energy Mix in Residential Buildings: A case study of Matipur, Sindhuli

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Abstract

Due to hard land topography and not having sources of energy like oil, gas, coal reserves etc. energy distribution is hard in remote communities of Nepal. So, people use traditional biomass, wood, imported kerosene, etc. in remote areas. The deficiency of energy or electrification of remote areas can be done using stand-alone solar PV system. The requirement of a house, electronic devices as well as comfort condition is required to be considered. With the total energy requirement system sizing of different components of Stand-Alone solar PV is done for its suitability. Also, firewood consumption in remote area needed to be discouraged considering environment and people health.

The energy simulation for existing building is carried out through Ecotect software where the results of total annual heating and cooling was identified and introduced to total energy consumption. For efficient practice, passive design strategies could be used to reduce heating and cooling load. Stand-Alone solar PV could be important element to be used for lighting purpose, includes two number of solar panel and rest energy can be fulfilled by adopting suitable energy mix concept replacing non-renewable source of energy by renewable source of energy.

Keywords

Stand-alone solar PV, energy mix, rural electrification, passive design strategies

1. Introduction

Approximately 1.5 million households are provided with electricity by NEA with the subscriber growth rate of 14 percent per year. About 43.4 percent of national electricity is consumed by private household which accounts for about 2kw energy for lighting only. In the case of rural area of Nepal, electrification is very expensive due to topographical conditions and the purchasing power of consumers is very low. With this fact 56.7 percent including 17 million people of remote area has no access to the electricity [1]. The system that generates the electrical energy by exposing to the solar radiation or by the photoelectric effect is called Solar PV system which can be operated themselves as off-grid systems or grid connected system [2]. Solar PV is the cheapest source of electricity that tap high quality resources as reported by 2020 World Energy Outlook from the International Energy Agency. The solar potential in Nepal is 50,000 terawatt-hours per year. This is 100 times larger than Nepal's hydro resource and 7,000 times larger than Nepal's current electricity consumption [3]. Renewable sources of energy can tackle many challenges like modern electricity, combustion of fossil fuels and carbon dioxide emissions. This also tackles cost, energy security, and reliability and add emergency backup or peak demand power. So Nepal should follow international trend of energy mix, energy efficiency measures and energy audit practices. In terms of efficiency, the solar cells produce energy at the point of consumption and less suffers from wastage [4]. In developing countries, it is hard to defeat energy crisis and hydropower generation and consumption is at the bottom line. Nepal is also struggling in hydropower generation and consumption though has much more possibilities. The production of other alternative source of energy like solar energy, wind energy, and geothermal energy tends to zero [5]. Due to flexibility and low cost of solar energy, hydroelectricity seems to struggle to compete with solar. Also, environmental and social impacts of solar energy is far lower than damming Himalayan Rivers. In addition, the socio-economic, Political and difficulties in infrastructural development in remote area of Nepal have affected energy use either renewable or non-renewable energy.

2. Methodology

The research follows post positivist paradigm to carry out the study of energy mix concept in the rural area of Ghyanghlekh Rural Municipality, Sindhuli. An interpretivist approach to social research is qualitative, therefore using unstructured interviews or participant observation methods. Secondly, while interpretation may vary from one stakeholder to another, this research takes into account the interpretation from the researcher's perspective. In order to study the socio-economic status, demographic position, and analyze the energy consumption pattern in remote residence of Ghyanglekh, Sindhuli, a questionnaire survey was carried out among 5 households. For the data analysis age group, family size, NEA energy consumption per month, total expenditure per month, total income, etc. were carried out. For the energy analysis, a model of existing traditional building is analyzed in Autodesk Eco tect 2011 Analysis software.

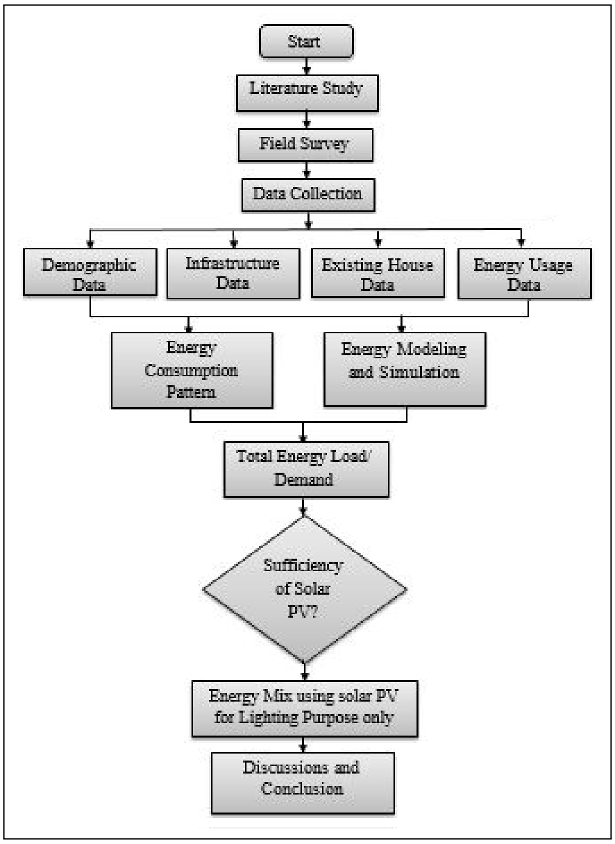

Figure 1: Methodoloogical Framework of the research

3. Literature Review

3.1 Solar Potential of Nepal:

Although Nepal gets most of its electricity from hydropower, solar power is expanding in its energy mix. The average solar radiation in Nepal varies from 3.6-6.2kWh/m2/day. The sun shines for about 300 days a year and average insolation intensity about 4.7kWhm2/day.

Power cuts had been common in Nepal and NEA used to publish a time table for power cuts. So solar energy can be more reliable source than the traditional electricity in Nepal. Also private solar panels are frequently installed which still can be improved more [6].

3.2 Components of Stand-alone solar PV:

Solar photovoltaic (PV) energy systems are made up of different components which has a specific role. The type of system and purpose determines the type of components in the system. For example, a simple PV-direct system is composed of a solar module or array (two or more modules wired together) and the load (energy-using device) it powers. A stand-alone system with energy storage (a battery) will have more components than a PV direct system [7].

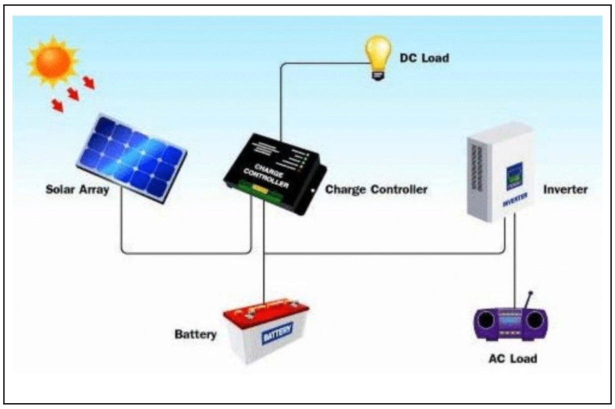

Figure 2: Different components of standalone solar PV

3.3 System Sizing

3.3.1 Battery sizing

The parameters (capacity, voltage and the type) of the battery used in solar PV system should match the daily energy requirement of the load and the energy generating capacity of the solar module. The required load voltage normally detects the voltage of the battery/battery bank. The capacity of the battery of given voltage is calculated using the following formula:

$$C = (E \times Na)/(\eta b \times DOD \times Bv), \quad Ah$$

Where, E - Average daily energy consumption by the load (in Wh)
Na - Number of autonomy days (in numbers)
ηb - Battery charging efficiency
DOD - Allowable depth of discharge of the battery
Bv - Battery voltage (in Volts)

3.3.2 Sizing of charge controller

The selection of the CC will be based on the three basic parameters: the system voltage, the maximum charging current and the maximum load current. The load current (IL) is calculated by the simple formula:

$$IL = Pt/Bv, \quad A$$

Where,
Pt - the total power of the devices to be powered from the system
Bv - the battery voltage

The rated charging current (IC) is the current delivered to the battery by solar module/array and is calculated using the following formula:

$$IC = E/(HpxBv), \quad A$$

Where,
E - Total energy consumed per day (Wh)
Hp - Peak sun (Hours)
Bv - Battery voltage

The current handling capacity of the selected CC should exceed both IL and IC.

3.3.3 Sizing of Inverter

If the total AC load is known (Pl), then the minimum VA rating of inverter (Pi) can be calculated as: $Pimin = Pl/PF$ Where, PF is the power factor of the inverter

The rated capacity of the selected inverter Pi is chosen to be double of Pi min so as to ensure that surging capacity is considered.

3.3.4 Wire sizing

NIPQA has specified the formula for determining the wire size (in sq.mm) based on both Ampacity and voltage drop requirements:

$$S = (0.3LI_m)/\Delta V$$

Where,
S – Required wire size (cross-sectional area of the copper wire in sq.mm),
L – Length of the wire in meters,
Im – The maximum current in Ampere, and
ΔV – Maximum allowable voltage drops in percent [8]

3.4 Renewable energy mix

Energy mix refers to the combination of the various primary sources of energy used to meet energy needs in a geographic region. Many renewable energy such as wood and other bio energies, hydro, wind, solar and geothermal could be mixed with each other or with non-renewable sources such as fossil fuels (oil, natural gas and coal). These primary sources of energy are used for providing fuel for transportation, generating power and heating and cooling residential as well as other buildings. The suitability of energy mix (of solar and micro hydro) in Nepal is shown in the table 1 below [9]:

Table 1: Suitability of different RETs by geological region

RETs	Terai	Hilly	Mountainous
Micro-hydro	-	Yes	Yes
Solar	Yes	Yes	Yes

3.5 Renewable energy subsidy policy of Nepal

It revises the subsidy determinded in the Renewable Energy Subsidy Policy – 2012 and Urban Solar System Subsidy and Credit Mobilization Guidelines. The subsidy amount is expected to cover 40percent of the total costs; with around 30percent coming from credit and around 30percent from private sector investment and/or community or households' contribution (cash or in kind). Detail of the subsidy for each technology type is provided in the policy document. The subsidy amount differs according to technology and the region - with higher subsidy being offered for remote areas [10].

4. Case Study and Research Context

4.1 Housing detail

Traditional houses are abundant till date and are most visible and prominent type of houses found in Matipur village. The houses are built with local materials available in the site such as stone, mud, local wood, slate for flooring, bamboo etc. The walls were built from stone masonry covered with mud plaster on both internal and external surfaces of the building. The plinth had mud stone combination with mud layer at the top and first floor had mud layer floor supported by wooden rod series. Likewise, the roofs were two way sloped corrugated GI sheet roof having wooden plank as ceiling. Almost all houses are oriented to North-West direction having openings towards north and west sides.

Figure 3: Traditional building in study area

4.2 Features of traditional house in the site

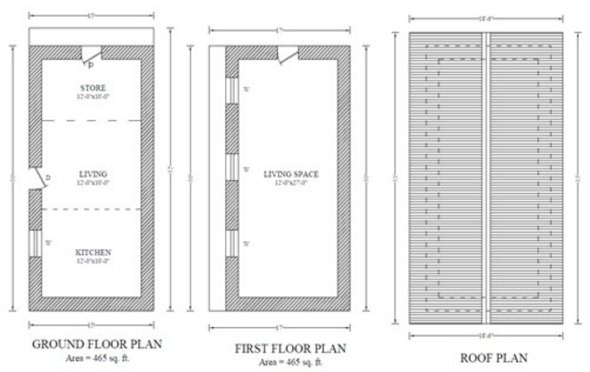

Figure 4: Floor plans of existing traditional building

The architectural plans contain single room on ground floor and first floor. Although it is a single compartment the use of room has been separated according to the need. Towards the entrance on the ground floor, the first use of the space is used as store section, the living space is followed as shown in the floor plan above and finally towards the corner there is a kitchen space. The first floor is wholly used as a living space and has no separation. According to the survey and measurement of the house, the total height of the house is approximately 13 feet with floor height of 6 feet and the remaining height is of the pitch height.

5. Energy Consumption Pattern Analysis

For the analysis of total load consumption, the source of energy was identified using questionnaire survey. Obviously traditional fuel i.e. firewood was mostly used from cooking to even lighting during shortage of solar energy. Approximately 5 kg of firewood was used mostly for cooking not only for human but also for domestic animals. Equivalency conversion showed that about 25 kwh power is consumed per day alone from firewood in Matipur residence. Similarly, solar energy and kerosene are used for lighting purpose only. The total energy consumption pattern is shown in the table 2 below:

Table 2: Energy consumption pattern

S.N.	Items	Unit	Qt	h	W	Energy (Wh)	Remarks
1	Bulb	No.	5	2	6	60	LED
2	Firewood	Kg	5	-	-	25640	Per day
3	Kerosene	L	0.5	-	-	0.053	Per day
	Total		-	-	-	25700.053	Per day

5.1 Lighting load calculation

The solar energy is used for lighting purpose only. The used solar PV and its use in lighting in different zone has been calculated as shown in the table 3 below:

The auditing for lighting load consumption of the building was carried out. The types of luminaries used were identified with their basic characteristics like

Table 3: Lighting load calculation

S N	Sp-ace	Area (m2)	lux reqd.	Lu/w	Pow-er(w)	Provid-ed lux
1	B/R	11.15	200	90	6	48.43
2	K	11.15	300	90	6	48.43
3	L/R	30.12	200	90	6	17.93
4	T	2.23	100	90	6	242.15
5	S	11.15	100	90	6	48.43

power requirement and luminous efficacy. The standard illuminance required for proper visibility with in various spaces were obtained and also the illuminance provided by the luminaries were calculated and compared as shown in the figure 5 below:

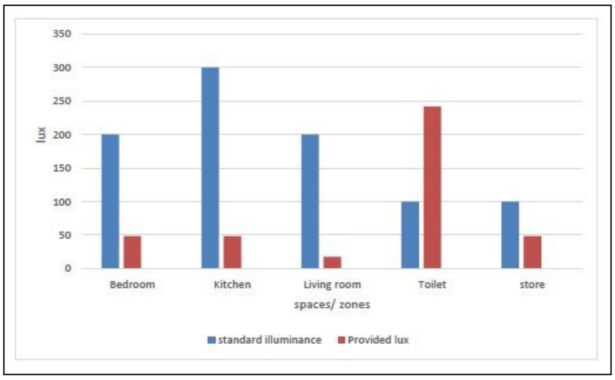

Figure 5: Comparision of standard illuminance with provided lux

5.2 Improved lighting load and solar PV sizing

The obtained observation and analysis showed the insufficiency in the provided lux. So, it is required to use higher power luminaries or better luminaries with higher luminous efficacy and lower power could be adapted. The table 4 below shows the total lighting load when illuminance condition fulfilled with respect to area and area of use:

Table 4: Improved lighting power and load calculation

S N	Parti- culars	No.	Ho- urs	Pow- er (w)	Energy (wh)	Rem- arks
1	Bulbs (B/R& L/R)	3	4	24	288	LED-Bulb
2	Bulbs (Kitchen)	1	4	24	96	LED-bulb
3	Bulbs (Toilet)	1	1	6	6	LED-bulb
4	Bulbs (Store)	1	1	13	13	LED-bulb
	Total				403	

PV system sizing for lighting

Selection of Solar PV module

Here, The system voltage = 12V

Now, expressing load in ampere hour (Ahr)= total load/system voltage

= 33.58 Ahr@24V

Peak sun X De-rating factor X Columbic efficiency

Where,
Columbic efficiency= 0.9
De-rating factor= 0.9
Peak sun= 4.5

Now, Iarray = 9.21

number of strings required, Ns= Nominal system voltage/ Nominal module voltage

= 12/12
= 1.00

Number of required module, Np = Iarray / Imp

(Current of maximum power of module)

(Used GEPV-110 M, Imp= 6.6) = 1.40

Now, total number of modules, Nt = Np X Ns = 1.40

Therefore, the required Solar PV module = 1.40 = 2
Battery Sizing For calculation of battery capacity:
Capacity of battery, C = Dah X DOA/ DOD X EFF
DOA= days of autonomy = 2
DOD = Depth of discharge= 80 percent= 0.8
EFF = efficiency of battery= 60 percent= 0.6

Now, Capacity of battery, C = 139.93 Ah

Therefore, the capacity of battery, C= 139.93 Ah

Selection of Charge Controller
IL max = PT/BV
IL max = PT/BV
= 5.58

5.2.1 Probable Requirement and consumption Pattern

According to the questionnaire survey, there is a strong demand of electricity to fulfil the needs of people. In order to replace firewood, electric cooking system can be used as alternative which consumes less power and also emission is less which causes adverse effect on the residents. According to the demand of the people living there, the probable equipment requirement along with the power consumed by respective equipment is shown in the table 5 below:

Table 5: Probable use of electronic equipment as per survey and energy calculation

SN	Particulars	No.	Hours	Power (w)	Energy (wh)
1	Bulbs (B/R & LR)	3	4	24	288
2	Bulbs (K)	1	4	24	96
3	Bulbs (T)	1	1	6	6
4	Bulbs (S)	1	1	13	13
5	TV	1	4	60	240
6	Heater	1	3	1500	4500
7	Cooking	1	2	1500	3000
8	Misc.	2	4	100	800
Total					8943

PV system sizing
Selection of Solar PV module
Here, The system voltage = 12V
Now, expressing load in ampere hour (Ahr)= total load/system voltage = 745.25 Ahr@12V

Iarray = Total average daily load in Ahr@system voltage
Peak sun X De-rating factor X Columbic efficiency
Where, Columbic efficiency= 0.9
De-rating factor= 0.9
Peak sun= 4.5

Now, Iarray = 204.46

Number of strings required, Ns= Nominal system voltage/Nominal module voltage = 12/12 = 1.00

Number of required module, Np = Iarray / Imp (Current of maximum power of module) = 30.98

Now, total number of modules, Nt = Np X Ns (Used GEPV-110 M, Imp= 6.6) = 30.98

Therefore, the required Solar PV module = 30.98

Battery Sizing
Capacity of battery, C = (Dah X DOA)/ (DOD X EFF)

Dah = load in ampere hour
DOA= days of autonomy = 2
DOD = Depth of discharge = 80percent = 0.8
EFF = efficiency of battery = 60percent= 0.6

Now, Capacity of battery, C = 3105.21 Ah

Selection of Charge Controller
IL max = PT/BV = 267.50

Selection of DC/AC Inverter
Pinverter = Pload/PF x Efficiency

Pinverter = 3210 VA
The inverter should be capable of supplying the surge power.

Therefore, the power rating of the inverter selected should be 2 to 3 times of this calculated power.

Therefore, Pinverter = 3210 x 2 VA = 6420 VA

Wire sizing

S = 0.3 xLx Im/DV

According to site, L = 30 m, IM= 4A and DV= 5percent then using equation , we get

Therefore, the size of wiring = 8 mm2

5.3 Load calculation by simulation

One of the research objectives of the research was to perform energy modeling through simulation tool. To attain this objective, typical traditional building of Matipur Village was measured, consumption pattern of these households were surveyed through various structured questionnaire, and such patterns were used for zone setting to simulate these buildings in existing setting. The software adopted for the simulation of this project is Autodesk Ecotect 2011.

5.3.1 Result of simulation

The figure 6 below shows the monthly heating and cooling load to maintain thermal comfort of the house. According to calculation made by Ecotect Analysis the total annual heating load by traditional building is 1845270 Wh. The graph shows maximum heating load is 7876W at 22:00 on 3rd January. The total annual cooling load is 2633884 Wh. The building has maximum cooling load of 6461W at 18:00 on 4th June. According to result the heating and cooling load is maximum and minimum at January and Jun respectively. Therefore, the total annual heating-cooling load of the building is 4479154Wh.

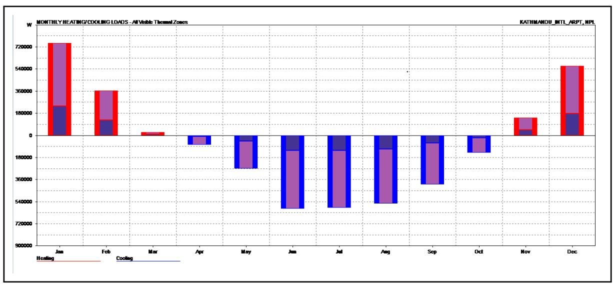

Figure 6: Monthly load/ discomfort chart

6. Discussions and Conclusion

The approaches followed by government and agencies alike are to assist rural electrification effectively so that rural people can get electricity easily and economically. In the present context, almost all the houses are deprived of proper electricity. These populations are deprive of other important infrastructure that could lift up their way of living. According to the local government, they have been trying to figure out the possible solutions but due to limited budget and topography their assessment has not been concluded.

On the basis of literature review and guidance to meet the objectives, this research was conducted with the main purpose of analyzing the total energy demand and its assessment of traditional building considering the impact of residential building across social, economic as well as energy parameters. The energy parameters were analyzed to replace the non-renewable resources (firewood and kerosene) by renewable source of energy especially solar PV. In addition, the lighting load per meter square was calculated in order to meet the lighting standard in different zones (bedroom, living room, store, toilet, etc.). With total load consumption, calculated, stand-alone solar PV system components were designed.

According to the energy consumption pattern, the total energy consumed by lighting with sufficient illuminance was found to be 403 wh which could be fulfilled by 2 solar modules with battery capacity 140 Ah which showed the possibility of affording by the individual inclusive of subsidies provided for rural electrification. Also the people of Matipur village desire to use modern technologies along with efficient use which consumes more energy and the total energy was calculated to be 8943 wh which required almost 31 solar modules with battery capacity 3106 Ah. For single household, it is almost impossible to afford 31 solar modules so energy mix concept can be suggested. Also probable requirement may differ according to living standard of people, availability, climatic condition of the place, etc. which might be the limitation of this research.

Throughout the detailed simulation of traditional building of Matipur village, analyses on monthly load/ discomfort was observed. The outcome of energy simulation and modelling showed the total monthly heating and cooling load was 4479154Wh. For making it optimum or efficient, the buildings could be constructed using passive strategies or active strategies. There could be different factors that controls loading such as building orientation, construction materials, construction technologies, climatic condition etc. For any additional loads, since solar can be used for lighting, the fulfillment of electricity can be compensated adopting energy mix technologies.

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