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Impact Study on Decentralized PV Generation for Peak Load Reduction in Urban Residential Sector of Kathmandu Valley

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Abstract
Residential sectors are energy intensive sectors. Demand side management in residential sectors is not under practice in our country. The purpose of the thesis is to find the contributions of the solar PV generation in the electricity peak load reduction due to residential consumers of the Kathmandu Valley. This thesis aims to first determine the peak load condition of the Kathmandu valley arising from the residential consumers. Bottom up approach in load profile estimation was used to find the load pattern. Method of maximum diversified demand was used in calculation of load on the distribution transformer due to residential consumers. Using this method, the load curve and hence the peak load was calculated and found to be around 257 MW at peak hour. Household survey was done to find the penetration of the electrical appliances, income level, use of backup source during load shedding etc. We designed the system that meets 30% and 50% of the daily energy use from solar PV system. Among them we choose the system that will meet around 50% of daily energy consumption from the solar system. The designed system was then operated at peak hour and found to minimize the total peak power demand at utility level by around 84.8% that is production of 216 MW by implementation of the whole system to technically feasible areas of the urban Kathmandu valley. To fulfill the 50% of energy requirement, total of 256 MWp solar PV installation at households is essential.

Keywords
Peak load – Solar PV – Residential sector – Decentralized generation – Smart grid

1. Introduction

Energy is becoming an important aspect of urban growth with increasing use of technology. Countries are being graded on the basis of the energy they consume i.e per capita consumption of energy. Every advanced economy requires secure access to modern sources of energy to fortify its development and growing prosperity. While many developed countries may be focused on domestic energy security or decarbonising energy fuel mix, many other developing countries like Nepal are still seeking to secure enough energy to meet basic human needs [1].

Electrical energy is considered as superior to all other forms of energy because it is cheap, convenient, easily convertible, easy to control, and versatile. It has innumerable uses in home, industry, agriculture, transport, defense, aviation, telecommunication, and what not [2]. It has today become the basis for enhancement to quality of life. Electricity plays a vital role in socio economic development of a country. Economic growth and improvement of peoples' living standards are all directly or indirectly related to the increasing utilization of energy, of which electricity is the most important. There is increasing demand of electricity and it will go up dramatically in the years to come.

Nepal has been undergoing load shedding period of average 14 hours. This has affected our economy in one way or another. Currently, electricity demand during peak time is around 1000 MW, but supply is barely 700 MW during summer and 400 MW during winter, which includes total NEA production from hydro and thermal, purchase from the private sector, and import from India. Of the total availability, NEA supplies 55 per cent (including both hydro and thermal), private sector contributes 27 per cent, and 18 per cent is imported from India. Demand increases by around 100 MW every year but electricity production is moving at very slow pace. There is huge potential to generate electricity from solar photovoltaic in our country that could be used in residential sectors.

2. Overview of the Country

The Population of Nepal as of the census 2011 stands at 2.65 million showing population growth rate of 1.35 per annum and number of households to be 5.423 million. About 17% population live in urban areas and 20% of the households are in urban areas. The income of urban household is almost double than the rural household. Altogether, 85.26% of the households reside in their own house whereas 12.81% in rented, 0.63% in institutional and 1.30% in other arrangements. Urban areas have high percentage of 40.22 living in rented house for various reasons like for education, business, job and other purposes. Kathmandu district stands at the highest position of households living in rented house. 58.65% of the households in Kathmandu valley are rented. Kathmandu valley comprises 24% of Nepal's total urban population [3].

The energy resources of Nepal are broadly classifies into three categories - traditional, commercial and alternative. Traditional sources include biomass (e.g. Fuel wood, animal dung, agriculture residue etc), commercial sources include fossil fuels and electricity, and alternative sources include new and renewable like solar, wind, bio gas etc. Nepal reserves no significant fuel resources, most of them are imported from other countries. However hydropower in Nepal has enormous potential and if utilized maximally, could be the most important sector for country's development.

Table 1: Electricity Consumption by sectors [4]

SN	Sector	Percentage of share
1	Residential	42.44
2	Industrial	35.60
3	Commercial	11.30
4	Agricultural	4.14
5	Others	6.53
	Total	11.365 Million GJ

Table 1 clearly shows that residential sector consumes most of the electrical energy followed by industrial, commercial and agriculture. In Nepal due to inadequate numbers of energy intensive industries, industrial sector come in the second position in electricity consumption.

Energy consumption in Urban Residential Sector

Almost 54 percent of energy consumed in residential sector is for cooking purpose. The figure below shows the residential sector end use electricity consumption in year 2013.

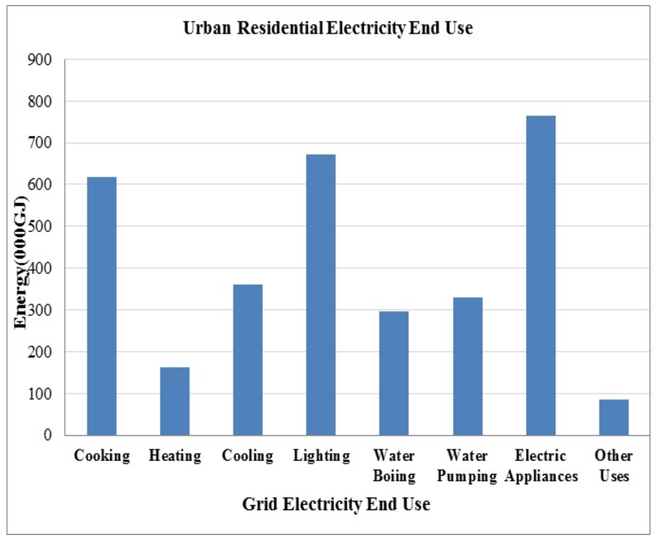

Figure 1: Urban Residential Electricity End Use [4]

Electrical energy use in residential sector is used vastly for electrical appliances and followed by lighting. Lighting holds the second position in electrical consumption. Using energy efficient lamps could decrease those figures.

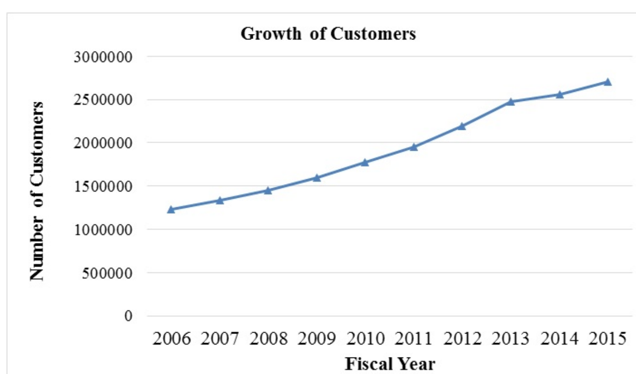

Figure 2: Growth of Electricity Customer [5]

Smart Grid

The "smart grid" is the application of technologies to all aspects of the energy transmission and delivery system that provide better monitoring, control and efficient use of the system. The goal is to enable and integrate all applicable smart technologies while operating the grid reliably, securely and efficiently, and facilitate effective, open markets that engage and empower consumers while meeting state environmental and energy policies. Energy storage and smart grid technologies are widely proposed as the tools to integrate these future diverse portfolio mixes within the more conventional power systems. The choice in these technologies is determined not only by their location on the grid system, but by the diversification in the power portfolio mix, the electricity market and the operational demands.Application at Homes/Industries are:

- Plug-and-play of smart home appliances, electric vehicles, micro generation
- Enabling customers to trade in energy markets
- Allowing customers to have greater choice and control over electricity use
- Providing consumers with accurate bills, along with faster and easier supplier switching
- Industries, homes Giving consumers accurate real-time information on their electricity use and other related information
- Enabling integrated management of appliances, electric vehicles (charging and energy storage) and micro-generation
- Enabling demand management and demand side participation

Demand Side Management (DSM)

DSM is a mechanism through which the load of some customers is managed (i.e., reduced or shifted to a different time period) in response to certain conditions (e.g., price, peak load, network constraints, emergencies, etc.). As a concept, DSM is not new and has been applied by transmission and distribution network operators mainly to reduce costs or relieve dangerous system operating conditions. These activities usually involved mostly industrial and commercial customers and took place within an agreed contractual framework.

There are number of techniques by which we can implement DSM techniques. Some of them are:

i) Load priority techniques: Domestic appliances of an individual consumer (or a group of consumers) are classified by their importance. When a given peak condition is reached, single loads (i.e., appliances) can be disconnected for some time by a central management system according to the some specified criteria.

ii) Control of appliances: Rather than disconnecting appliances, their power requirements are reduced or their operation is delayed.

iii) Differential tariffs: By introducing different electricity tariffs i.e for during peak and off-peak hours, residential consumers can be encouraged to change their behavior .Example: Time Of Use (TOU),Critical Peak Price (CPP), Real Time Price (RTP) etc.

iv) Conservation voltage reduction: Given that the voltage influences the power required by some domestic loads, it is possible to lower the demand by adjusting the set point of Low Voltage(LV) transformers.

v) By use of local intermittent resources: At peak load condition or for use during peak hours one can use distributed energy resources with storage facility especially for intermittent energy resources such as wind and solar PV.

Demand Response

Demand Response is the concept that end use loads can be active participants without impacting the end use customer. With load as an active participate there are multiple benefits that can be obtained. Demand Response can be used for:

- Peak load reduction
- Regulating services
- Emergency Conditions

Distributed Generation (DG)

Generally refers to small-scale (typically 1 kW – 50 MW) electric power generators that produce electricity at a site close to customers or that are tied to an electric distribution system. Distributed generators include, but are not limited to synchronous generators, induction generators, reciprocating engines, microturbines (combustion turbines that run on high-energy fossil fuels such as oil, propane, natural gas, gasoline or diesel), combustion gas turbines, fuel cells, solar photovoltaics, and wind turbines. There are number of benefits of DG such as peak load shaving thus reducing the network upgrades, low transmission loss as generation is near consumption, energy security, optimum use of available grid resources, reduce pressure on distribution and transmission lines, increases renewable energy use etc.

3. Methodology

Primary data survey

Data on peak load and timing of peak load was gatherer by visiting the Sub-Station for the some feeder of the electrical network.

A household appliance stock survey was done by visiting households of the three districts Kathmandu, Lalitpur and Bhaktapur. Only urban residential households were surveyed. Sample survey was conducted with 120 samples households in the three districts of Kathmandu valley to analyze the necessary data. The stratified sampling was done to select number of samples from each districts. Then within each district, random sampling of households was done. With 120 samples,and 95 percent confidence level, we get confidence interval of 8.94.

Sample Size for survey:

Table 2: Sample size district wise

S.N	District	Total	Percentage
1	Kathmandu	70	58
2	Lalitpur	30	25
3	Bhaktapur	20	17
	Total	120	100

Model Development in MATLAB

The name MATLAB stands for MATrix LABoratory is a high-performance language for technical computing. It integrates computation, visualization, and programming environment.

The step begins with writing matlab codes that contains information on household electricity consuming patterns and information .After writing codes for different set of households they are summed as according to the model to generate the load profile. The code is then run for 24 hour data and thus generating the load profile.Then we use solar PV system to offset the peak load under different use algorithm.

Designing of system in PVSYST

PVsyst V6.0 is a PC software package for the study, sizing and data analysis of complete PV systems. It deals with grid-connected, stand-alone, pumping and DC-grid (public transportation) PV systems, and includes extensive metero and PV systems components databases, as well as general solar energy tools.

The energy requirements per day of different households under different cases were input to the software and optimum size of the system was choosed.Then the system is simulated to find the energy generated per year,performance and other outputs.

4. Methods in Load Profile Estimation:

Methods in load profile estimation

A substantial number of literary sources have investigated domestic electricity demand in the residential sector, using either top-down, bottom-up, neural network methods, or fuzzy logic.The appliance end use model is the “bottom-up” approach of estimating the aggregate load profile of the residential customers. Here the pattern use of each individual is represented .This model has already been successful in load forecasting and demand analysis. The accuracy of these models is highly dependent on detailed bottom level consumption of the appliances. Capasso et al. have successfully used this model where probability functions representing the relationship between the demand of a residential customer and the psychological and behavioral factors typical of households were established through the use of a Monte Carlo method. On the other hand, Paatero and Lund also developed a simplified bottom-up model similar to that of Capasso et al. but that uses a representative data sample and statistical averages. The random nature of consumption was generated by using stochastic processes and probability distribution functions.

Appliance ownership and use

The most fundamental determinants of electricity usage in households are appliance ownership, their power load characteristics and their frequency of use. Logically this is extended to time of use when developing a daily load profile.

A consequence of the huge growth in gadgets and electronic goods has been an even more randomized and unpredictable domestic load profile. Furthermore the DSM potential in the home is increasingly becoming difficult to harness due to the nature of these new loads. Whilst this may support a stronger case for DSM through Time of Use (TOU) tariffs, which would penalize or incentivize the time when electrical loads are being used, the social acceptability or successful management of this is still to be implemented and verified in context of Nepal.

Model Overview

In our study, diversified demand method was used for estimating the load curves of the major household appliances and aggregating the consumers, the load curve was generated. This method was developed by Arvidson in 1940. Arvidison developed a method of estimating distribution transformer load in residential areas by diversified method, which takes into account the diversity between similar loads and the non-coincident of the peaks of different types of the loads. Initially used to estimate the load on distribution transformers when measurements of the actual load are limited this method of diversified demand has seen increased interest recently due to interest in residential demand response and the need for a component-by-component analysis of residential load.

According to the method of diversified demand, if a location can be considered, in aggregate, statistically representative of the residential customers as a whole, a load curve for the entire residential class of customers can be prepared. If the same technique is used for other classes of customers, similar load curves can be prepared [6]. The construction of the load curve requires certain load information to be available. Load saturation and load diversity data are needed for the class of customers whose load curve is to be generated. The method takes into account the fact that households may not be using all the electrical appliances that constitute the connected load of the house at the same time and/or to their full rated capacity. The curve is generated from the most probable load at a given time.

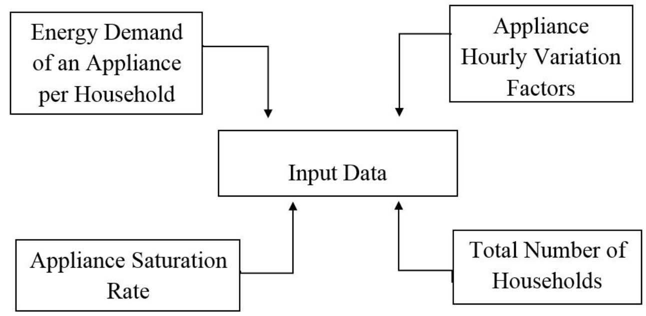

Figure 3: Inputs to the model

5. Model Inputs Calculation

After the survey and use of secondary data sources the inputs to the model were calculated.

Appliance Saturation Data

This is the percentage of total population that owns particular electrical appliances.

Table 3: Appliance saturation

Appliance	Saturation
LCD/LED Television	0.67
Flatorn TV	0.57
Rice cooker	0.84
Desktop Computer	0.5
Laptop	0.9
Internet Router	0.83
Refrigerator	0.81
Microwave	0.44
Washing machine	0.36
Water Pump	0.80
Iron	0.83
Vacuum Cleaner	0.6
Lighting & misc	1.00

Appliance hourly variation factor

This term models the fraction of the total load particular appliance that is on demand at the particular time. This depends on various factors like socio-economic condition, habit, lifestyles, income, season etc. The appliance hourly variation factor needs a detailed investigation of used of specific devices throughout the day and is out of the scope of our research and hence a generalized variation factor is used.

6. Data Computation and Findings

Types of Buildings in Kathmandu valley:

The survey results showed that according to the storeys of the residential buildings in Kathmandu valley, it is distributed as follows with greatest of the three storeyed building followed by two storeyed building.

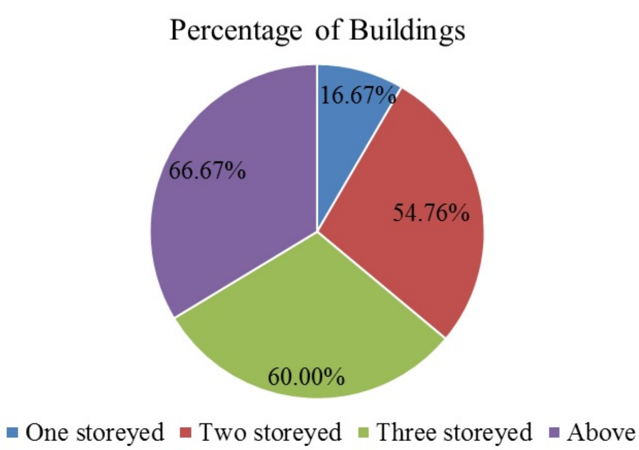

Figure 4: Percentage of Buildings in the valley

Rented Status According to the Building Types:

In Kathmandu valley most of the residential houses are on rent and the income from rent is also the major part of their income. Hence residential houses are usually given on rent.Here in our analysis we used building type to find the rented status. This is distributed as shown in figure below highlighting that above three storeyed building, most of them are rented.

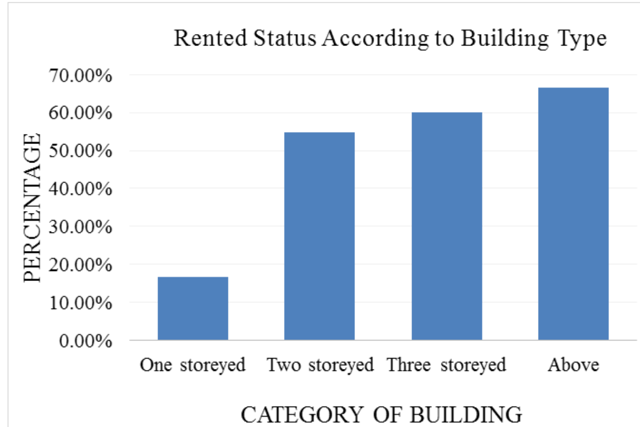

Figure 5: Rented Status according to the building category of the building

Shading condition of the roof:

Viewing the roof shading condition that 67% of the roof have direct sunlight and 33% have shading condition. This hugely affects the power output of the module. Hence only 67% of the total roof is suitable for the solar PV installations. This data will be used in the technically possibility.

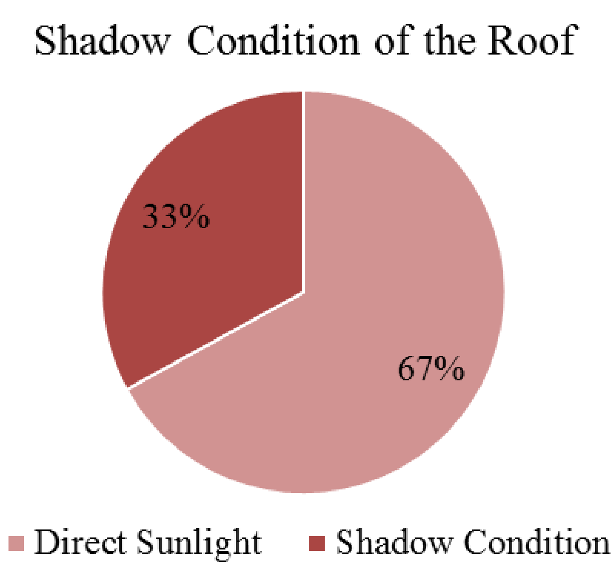

Figure 6: Shadow condition of the roof

Household Income distribution:

Monthly income of each household were categorized and it was found that most of the income of household person was between thirty five thousand to fifty thousand followed by income between fifty thousand to one lakhs.

It is general to accept that the household with more income can afford for the solar system.

Figure 7: Income Distribution

Choice of backup during load shedding hours:

Interviewers were asked to what type of technology they are using for lighting and other electrical purposes during the time of load shedding. Most of the home have installed inverter and battery for use during load shedding. Solar system is also becoming choice for users due to cost reduction in solar system and adoption to new technology.

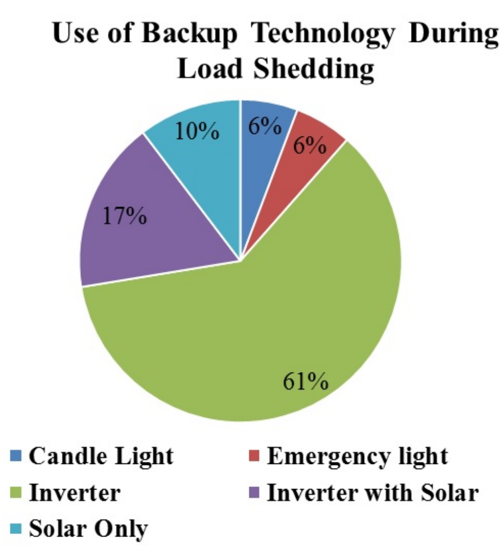

Figure 8: Choice of technology used for backup

Peak Load Data:

Different substations of the Nepal Electricity Authority in the Kathmandu valley record the total hourly load on their distribution feeders. At peak time, half hour data is recorded as there is greater change in the electrcity consumption. The recorded current of the 11 kV feeder was used in our analysis.

The maximum of the month's hourly recorded was used to calculate the peak demand. The peak record from each substation of the Kathmandu valley was summed and calculated to give monthly peak demand for the year 2071.

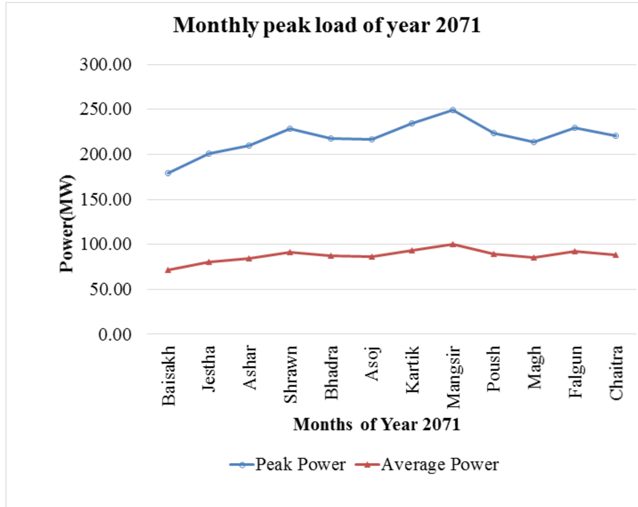

Figure 9: Monthly peak load of the year 2071

Maximum diversified demand calculation:

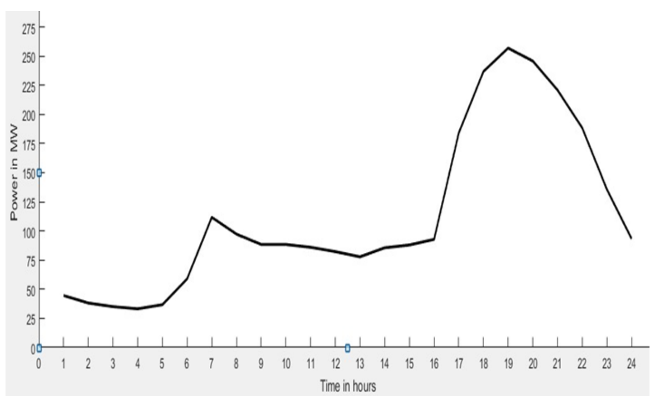

Figure 10: Load Curve generated from maximum diversified demand

The results from the survey was used as the input to find the load curve using maximum diversified demand model. The model is straightforward but there is need of extensive data to calculate the parameters of the model. No such study is done in our country till now for the appliance hourly variation factor and is out of the scope of the study, so we used generalized data. The calculated load curve is:

Residential Solar System Design:

The study done on year 2014 at residential sector by of Kathmandu valley estimated that the average energy consumption per household is 3.3 kWhr[7]. We designed our design and included technical and financial option as according to “Highlights on Urban Solar Subsidy, Jesth 207”.

Two cases were done with the supply of 30 % and 50% of the total average energy consumption by use of solar PV system.

We selected second case that is,supply of around 50% of average energy by use of solar PV system.

Table 4: Case 2 analysis

Stories	Two	Three	Four
Energy per day(kWh)	1.65	3.3	4.95
Solar PV module(Wp)	500	1000	1400
Battery capacity(Whr)	3600	7200	12000
Performance Ratio	0.597	0.597	0.633
Net Investment(Rs)	137000	251800	377800
Annuities(Rs/year)	23422	43048	64589
LCOE(RS/kWhr)	28.70	23.84	23.89

Potential of Peak Load Shaving:

The proposed system will run at full or maximum capacity of the inverter output value at the peak load time. The system is also automated to reserve the battery charge to be used at peak time and the remaining charge is used at other hours of the day. The control on the inverter automatically performs this function.

By considering shading condition on 67% of the total households were only feasible to install solar that receives adequate sunlight throughout the day.

Table 5: Solar and peak power potential

Solar Capacity(MWp)	Power Generation(MW)
Theoretically possible:381	Theoretically possible:325
Theoretically possible:256	Theoretically possible:218

7. Conclusion and Future Works

Due to cost of the system, all of the households could not offer to install the desired system. This is because of the limitation of the earning of the households.

It was found that the system peak load is around 257 MW at the peak time. By using the proposed system the technical feasibility of the standalone solar system is 256 MWp. If all of the designed system is operated at the same time, it could produce up to 218 MW. This is the power available that can be used during peak load condition. There is some excess energy production from our system that can be transmitted to other loads or feed into the grid.

Recommendations

The work indicates need of directing efforts for implementation of peak load reduction pilot programmes in residential sector of urban Kathmandu. The effective implementations of the peak load reduction from the customer’s side take the burden away from the electricity supply side of Nepal which is government owned electricity utility, Nepal Electricity Authority.

For the effective implementation of peak load reduction, following points has been recommended:

- Peak load reduction
- Regulating services
- Emergency Conditions
- Government should consider the adverse effects of increasing electricity consumption and demand and create separate DSM unit to ensure effective implementation of programme.
- Government should establish robust database of energy consumption pattern of the region. This includes management of available secondary information from various relevant authorities and carry out frequent customer survey and changing load and energy patterns.
- Detailed energy audit survey is needed for very high end households with higher electricity consumption which may give us more detailed information.
- Detailed time of use variation data of different electrical appliances according to consumer’s behavior is needed.

- There is need for developing the effective implementing mechanisms (institutional, legal and regulatory) for the increasing use of renewable energy resources and increase energy mix.

Future Works

i. The sample size can be increased to incorporate more households in the study

ii. The study can be extended to larger geography of Nepal

iii. Further study can be done to include other end use sectors like commercial, agriculture, transportation and industrial

iv. Detailed time of use survey can be done to precisely find the load use pattern,

v. Energy management system can be designed to optimally use the generated energy and peak load reduction,

vi. More sophisticated tools like GIS can be used to determine the exact shadow patterns on the roofs of the buildings

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