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Demand Side Management for Electricity in Nepal: Need analysis using LEAP Modeling Framework

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Abstract

Fuel consumption share varies according to different sectors like residential, industrial, commercial etc. Traditional fuel is predominant fuel source in case of developing countries like Nepal. Energy efficiency in these fuels are very low compared to other fuels. Use of fossil fuels is also increasing in Nepal which are imported. These fuels cause economic burden in country in addition to environmental problems like CO_2 emissions. Hence, switching over the fuels with least environmental problems, efficient energy is a requisite in today's world. Energy efficiency plays a critical role in energy policy debates because meeting our future energy needs comes down to only two options: increasing supply or decreasing the demand for energy. In due time, the demand is bound to increase due to increase in population, income growth and other factors. The switch-over from traditional fuels and fossil fuels to electricity is imminent in very near future in Nepal. In Nepal, the generation being well below the maximum demand and that the generation increment requiring time and capital investment, Nepal Electricity Authority requires to adopt demand side management to control the load growth pattern as well as dwell in the supply side investment. This paper intends to analyze the electrical energy and Peak Power requirements in Nepal in the study year 2015-2050 and thus the need for implementation of effective Demand Side Management in Electricity promptly.

Keywords

Peak Power requirement – Energy – DSM – LEAP – NEA – Energy Balance – Demand Side Management – Efficiency – Nepal Electricity Authority – Fuel Switch – Fuelwood – Fossil fuel – Electricity – BAU – CFL – LED

1. Introduction

Nepal has a very immense potential in hydropower generation but so far it has failed to harness to its full extent. Even so, Nepal's primary electricity generation source has been hydropower with solar and diesel providing small contribution. So far only 782.45 MW [1] of electricity has been generated as of year 2014/15 from the available water resources from Nepal, a country with having economically feasible hydropower potential of around 42,000 MW [2].

NEA has major role to play to increase access of electricity. Continued industrialization, increase in living standards, modernization, rapid growth in the population are contributing into the increase in the demand of electricity in the country. The demand is increasing in each year whereas the generation is not increasing in the same pattern. And thus, Nepal is facing acute load shedding which will continue until the gap between Supply and demand is narrowed down.

Peak demand of electricity in the fiscal year 2014/15 was 1291.80 MW to which the contribution from NEA hydro generation was 357.68 MW; IPP[1] hydro generation was 124.71 MW, import from India was 224.21 MW and the contribution of load shedding was 585 MW [1]. Peak Demand has doubled from 2006 to 2015 whereas the available energy has increased only by 80%. The electricity import from India has increased by more than five times in 2015 as compared to 2006. Over the past decade, the average annual growth of peak demand is 8.87% whereas that of available energy is only 6.73%.

[1] Independent Power Producer

2. Demand Side Management

Demand side management (DSM) commonly refers to programs implemented by a utility to control the energy consumption at the customer side. These programs are employed to use the available energy more efficiently without installing new generation and transmission infrastructure. Thus, DSM is the least cost planning and integrated resource planning tool. The benefit for the consumer is reduced energy costs for a given output. And for the energy provider, the benefit is a better use of its existing supply capacity. Hence, basically DSM is a concept for win-win situation for both utility and the end-users.

In case of Nepal, the peak demand is during 6 to 9 pm (depending upon summer and winter), the load being mostly residential loads. At the off-peak, the demand is much lesser than that at the peak hour. So, only in order to meet the peak demand for 2-3 hours a day, the utility has to install the higher generating stations. DSM targets to somehow make the difference in the demand of a day to possible minimal by peak clipping, load shifting or valley filling. The main target of DSM is to make the load factor very close to unity. DSM program's main objective is to improve the load factor of a system with the efficient use of available energy. This is achieved by the clipping of demands in peak hours, shifting of demands to off-peak hours and valley filling of the off peak hours as well.

According to [3], the need of DSM on electric generation planning by reducing the peak demand which minimizes the costs associated with operating the peaking units and/or delays the need for new and costly generation and transmission additions necessary to meet system reliability requirements.

DSM decreases the cost of meeting customers' energy demand growth through investing in end-use energy efficiency and load management [4]. Demand-side resources can avoid, reduce or postpone investment in generation, transmission, and distribution capacity, and decrease fuel consumption, improve environmental quality, and reduce emissions of damaging greenhouse gases that cause the global warming. DSM policy can be upgraded by incorporating it into the current electricity system reform.

According to [5], due to poor historical studies and programs, up to early 2004, NEA had not considered DSM as a cheaper and faster way to meet its rapidly increasing peak demand. Rather, it focused on supply side investment. Yet he stressed that there is an urgent need to identify the most cost-effective areas for DSM programs which will be able to mitigate Nepal's power shortages.

3. Potential of DSM in Nepal

As per [5], the majority of the potential DSM technologies in Nepal are financially viable. The study concluded that the most promising and cost-effective areas for DSM technologies in Nepal include power factor correction, energy-efficient lighting in the residential and commercial sectors; and the installation of intelligent motor controllers for industrial induction motors.

The technical potential of avoided electricity generation during the period of 2007-2020 and peak load avoided in the year 2020 in Nepal is about 6.9% (4861.4 GWh) and 14.1% (254.1 MW) respectively with the use of efficient lighting and energy efficient motors in residential, commercial and industrial sectors [6].

About 60% of the daily energy usage in lighting in Kathmandu Valley can be saved daily if switching of all the lighting devices to LED bulbs is achieved [7].

In Nepal, the energy consumption by residential buildings accounts for 89% of the total energy consumption of national consumption [7]. Energy efficient improvements can reduce the demand for of cooling and heating systems. The study concluded that the usage of different technologies can reduce considerable amount of heat losses.

4. DSM in Electricity in Nepal

In the fiscal year 2009/10, NEA introduced Compact Fluorescent Lamp (CFL) program to dissuade the use of incandescent lamps and then introduced the installation of Capacitor banks in secondary side of transformers as well as in distribution substations to improve the poor power factor (which was contributing to high reactive power demand) due to CFL as DSM. Energy efficiency in lighting project was launched by NEA which was jointly financed by ADB and NEA. The program has distributed over 1,500,000 CFLs in selected areas [1]. Just recently on April 2015, under the program "Bright

Nepal, Prosperous Nepal", in order to save the energy and reduce the demand for the promoting use of high efficiency Light Emitting Diodes (LED) Lamps in place of Incandescent Lamps, NEA has called for Expression of Interest from Lighting Manufacturers, Wholesaler and Retailers who sell AC LED lighting products in Nepal. Time of Day (TOD) meters are being used by NEA for commercial and industrial consumers employing TOD tariff with high energy rate during peak hours to dissuade the energy usages in peak hours.

Though not extensively, NEA has used media for public awareness for not to use high energy consuming appliances during peak hours. And then there has been load shedding which is being used by NEA, which is making the consumers discomfort. These DSM options have been used but have not been as effective as it should be. The availability of cheap CFL in market, which has very low power factor has led to requirement of Capacitor bank installation. The load shedding has enforced the consumers to use appliances, inverters (for charging battery backups) whenever the electricity is available. Hence the implemented DSM tools have not resulted in the solution of electricity crisis in the country.

5. DSM Options

The options usually used in DSM include:

- awareness of consumers to use energy efficient appliances or energy star appliances
- usage of CFL, LED instead of incandescent lamp, usage of electronic ballast
- shifting of high energy consuming loads like water pumping to off peak hours
- restructuring tariff in order to dissuade consumer for usage of electricity during peak hours
- power factor correction of load/installation of capacitor bank
- power factor penalty approach
- enforce Energy Efficient Building Codes (EEBC) for Residential and Commercial buildings
- Periodic maintenance of electric equipment of industrial, commercial consumers etc.
- load shedding

So, not only energy provider but consumers, local authority, municipality and government should collectively introduce these policies in order to develop control mechanism for load growth.

6. Energy Consumption in Nepal

The energy consumption of different sectors and of different fuels were studied from the data published in Economic Survey 2013/14 and 2014/15 (Ministry of Finance), National Survey of Energy Consumption and Supply Situation in Nepal (WECS)[2], NEA Annual Reports and Nepal Oil Corporation publications. These data were analyzed and energy consumption for the different sectors like Residential, Commercial, Industrial, Transport and others were estimated for the year 2014/15. Table 1 depicts the energy consumption in these sectors for the year 2014/15. Table shows the details of the fuels and their contributions in the different sectors.

Table 1: Energy Consumption in year 2014/15

Economic Sector	Traditional Fuel, PJ	Commercial Fuel, PJ	Renew. Fuel, PJ
Residential	353	14	12
Industrial	9	30	0
Commercial	9	8	0
Transport	0	32	0
Agriculture	0	5	0
Others	0	1	0
Total	371	90	12

Source: Author's Calculation with [1, 8, 9, 10]

Figure 1 illustrates that current scenario of sectoral energy consumption which is dominated by Residential sector as Nepal being developing country. The Residential energy consumption is found to be around 80% followed by Industrial and Transport sector which contributed around 8% of total energy consumption. The commercial sector energy consumption is found to be 3.6% whereas agriculture and other energy combine consumption contributed to just over 1% of total energy consumption.

[2] Water and Energy Commission Secretariat

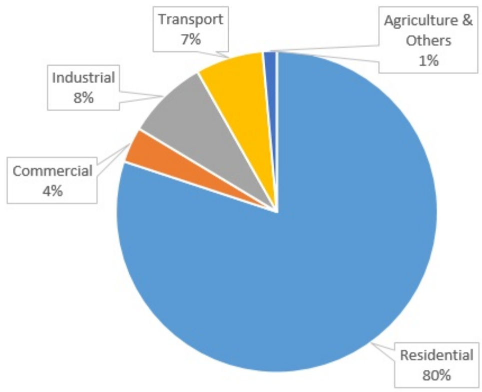

Figure 1: Sectoral Energy Consumption

Figure 2 shows the shares of fuels for the total energy consumption. Fuel shares for the total energy consumption was dominated by Traditional fuels which contributed to 79% of the total energy consumption. The traditional fuels include fuelwood, animal wastes and agricultural wastes. Around 16% of energy was contributed by fossil fuels whereas electricity's contribution was merely 3% of total energy. The renewable energy's contribution was only around 2%. This shows that huge energy contribution is due to traditional fuels which have very low efficiency.

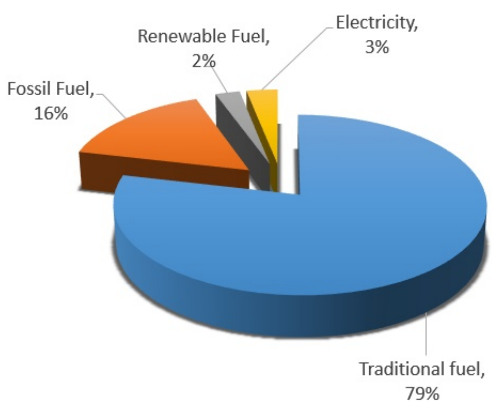

Figure 2: Fuel Share in Total Energy Consumption

6.1 Residential Consumption

Figure 3 depicts the fuel share in Residential sector. The traditional fuel, namely Fuelwood contributes to more than 85% of the total fuel share whereas the contribution by agricultural wastes and animal wastes is almost 8%. The petroleum combined contributes little over 2% whereas Electricity's contribution is 1.6%. The Biogas fuel contributes almost 3% of fuel shares in residential sector. There is very low contribution of solar and micro hydro in residential sector.

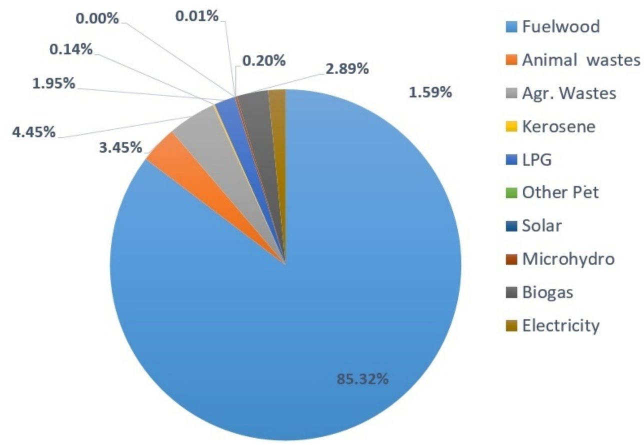

Figure 3: Fuel Share in Residential Energy Consumption

Figure 4 illustrates the shares of energy consumption by the activities in the residential sectors. The cooking activity majorly consumes energy (∼61%) whereas space heating (∼14%) and water boiling (∼13%) are next two activities contributing highly in energy consumption. Lighting only consumes 0.72% of residential energy consumption. Electrical appliances contribute 0.41% residential energy consumption whereas water pumping contributes only 0.12% of residential energy consumption. The other activities share almost 10% of residential energy consumption. These two figures imply that fuelwood is majorly used in cooking activity of residential sector.

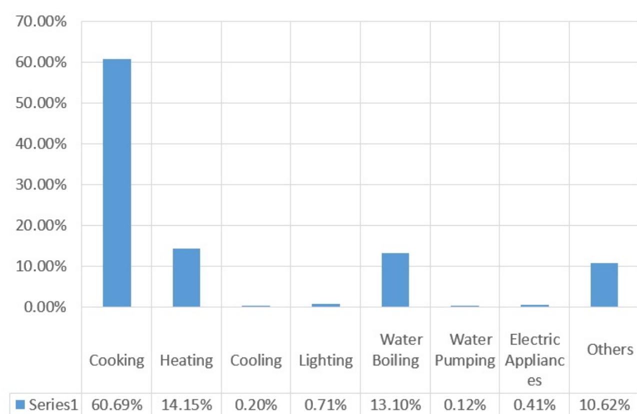

Figure 4: Activities in Residential Energy Consumption

6.2 Industrial Consumption

Figure 5 depicts contribution of coal is major in industrial sector. The coal contributes to almost 49% of total industrial energy consumption. The coal is majorly used for boilers and process heating in industries. After coal, fuelwood contributes to over 23% of total industrial energy consumption. The fuelwood is also used majorly for boilers and process heating in industries.

Diesel is being used by the industries especially for power motives and lighting purposes. The fuel is being used by diesel generator sets. The other significant fuel in the industrial sector is electricity. Electricity contributes to around 13% fuel share. The electricity is also used for power motives and lighting purpose in industrial sector. It is the only fuel being used in the industrial sector for process cooling purpose. The contribution of other petroleum is very low in case of industrial sector.

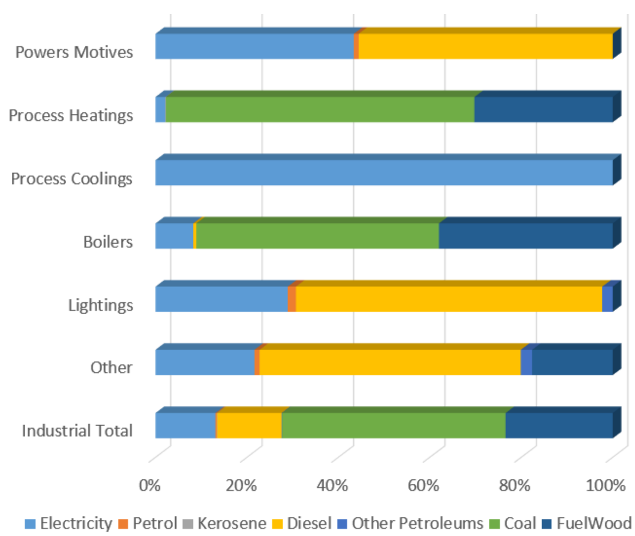

Figure 5: Industrial Energy Consumption

6.3 Commercial Energy Consumption

Figure 6 shows the activity wise fuel consumption in the commercial sector of Nepal. The fuelwood share is above 54% which is used mostly in cooking, space heating and water boiling. LPG contributes above 23% of fuel share in commercial energy consumption, which is used in cooking and water boiling mostly.

The other significant fuel shares in the commercial energy consumption are electricity and coal. Electricity contributes to around 13% of fuel share whereas coal contributes to around 9% of fuel share. Coal is used in commercial sector for cooking whereas the electricity is used mostly for lighting, water pumping, electric appliances, cooling, heating and water boiling.

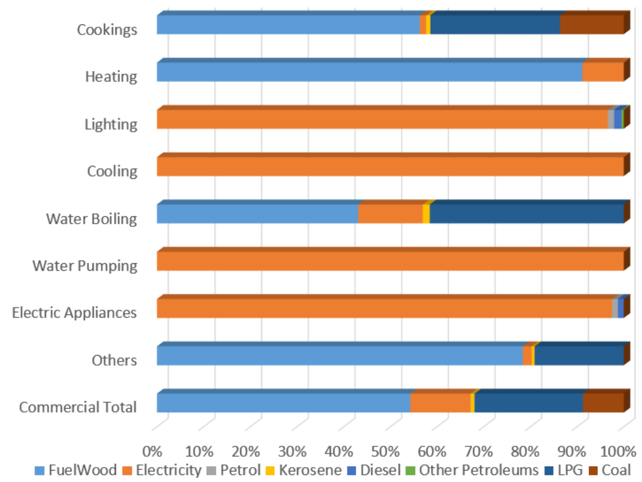

Figure 6: Commercial Energy Consumption

6.4 Transport Energy Consumption

Figure 7 illustrates that the contribution of diesel is above 60% in case of transport sectoral energy consumption. Petrol's fuel share is around 25% in transport sector's energy consumption whereas Aviation turbine fuel contributes to 1% fuel share. LPG and electricity also contribute in transport energy consumption but the shares are below 1% in both fuels.

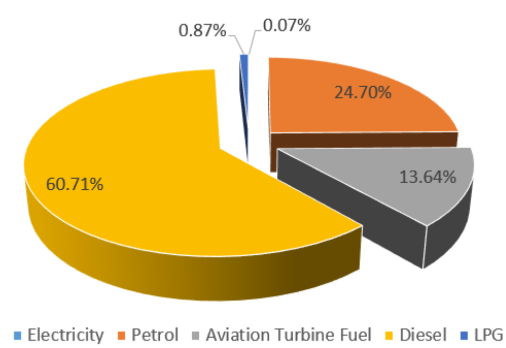

Figure 7: Transport Energy Consumption

The public transports (bus, minibus, microbus and three wheelers) consume over 25% of total fuels of Transport sector. The Cars/Jeep/Van consume around 25% of total fuels of Transport sector. The trucks and lorries also consume around 25% of total fuels of Transport sector. The aviation sector consume over 13% of the fuel of total fuel consumption whereas two wheelers consume over 8% of fuel consumption of Transport sector.

6.5 Agricultural & Other Energy Consumption

Figure 8 illustrates the agricultural sector's energy consumption which shows that the fuel share of Diesel is just above 75% whereas that of electricity and petrol is 23% and just above 1% respectively.

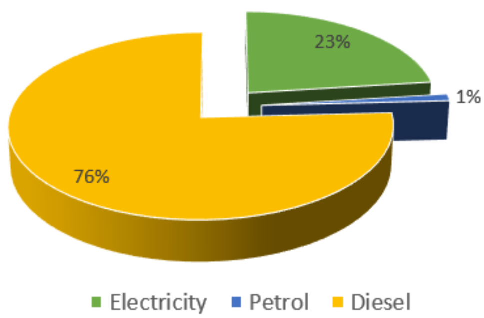

Figure 8: Agricultural & Other Energy Consumption

7. Energy System Modelling

In order to determine the probable effective DSM options to be implemented, it is necessary to determine the futuristic energy demand and supply. [11] stress that energy models are used to project the future energy demand and supply of a country or a region. They are mostly used in an exploratory manner assuming certain developments of boundary conditions such as the development of economic activities, demographic development, or energy prices on world markets. They are also used to simulate policy and technology choices that may influence future energy demand and supply, and hence investments in energy systems, including energy efficiency policies.

The energy system models aim to replicate the energy demand scenario using the interrelationship among various system elements like income, population, living standards, government policies, energy prices etc. The following equations have been developed by [12] to determine the end use service demands in the residential sector and other sectors based on population and GDP growth.

$$ESD_{i,t} = (POP_t/POP_0)^{\alpha 1i} * (GDP_t/GDP_0)^{\alpha 2i} * ESD_{i,0} \quad (1)$$

(For residential and land transport end use demand)

$$ESD_{i,t} = (GDP_t/GDP_0)^{\alpha 2i} * ESD_{i,0} \quad (2)$$

(For Air freight transport end use demand) and

$$ESD_{i,t} = (VA_t/VA_0)^{\alpha 3i} * ESD_{i,0} \quad (3)$$

(For Other sector demand) where,
$ESD_{i,t}$ = level of service demand type i in year t for a sector or sub-region
POP_t = Population in year t
GDP_t = aggregate GDP in year t
VA_t = value added in the relevant sector in year t
$\alpha 1i$ = population elasticity of service demand type i
$\alpha 2i$ = GDP elasticity of demand for service type i
$\alpha 3i$ = sectoral value added elasticity of demand for service type i

8. LEAP Model

The LEAP (Long Range Energy Alternatives Planning) model (Windows-based) has been developed by the Stockholm Environment Institute (SEI-Boston) in 1997. LEAP is a general purpose energy modelling tool that can be used for a wide variety of tasks ranging from the preparation of energy balances and energy forecasts, to policy analyses such as integrated energy planning and GHG mitigation analysis. It is a scenario-based energy-environment modelling. Its scenarios are based on comprehensive accounting of how energy is consumed, converted and produced in a given region or economy under a range of alternative assumptions on population, economic development, technology, price and so on [13].

The data are assembled in a hierarchical format based on different levels; sector level (Residential, Industrial, Commercial etc.) and further end-use (cooking, lighting, heating, etc.) and fuel use (fuelwood, coal, diesel, electricity, etc.). In the energy demand program, the energy intensity values along with the type of fuel used in each device are required to estimate the energy requirements at sector, sub-sector and end- use level. Projections for energy including electricity utilization in Residential, Industrial, Commercial, Agricultural and other sectors are made over a long-term planning horizon (2015–2050). The effects of the key variables population, number of households, GDP, GDP per capita, Value added share by sector (for industrial, commercial and agricultural sectors) based on BAU and fuel-switch (electricity)scenarios are assessed in LEAP. A demand analysis is performed for the economic sectors which is discussed in following section.

9. Future Demand Prediction

The demand of each sector is forecast using the equations 1, 2 and 3. The elasticities required by the equations are determined using historical data of energy consumption along with demographic and economic factors. Regression analysis was performed using log linear model as mentioned in [14], [12] with the sectoral energy consumption as independent variable and the demographic factor (population), GDP and GDP/Capita as dependent variables.

Table 2: Elasticities for year 2014/15

	Elasticity	R Square	P Value
Population	1.053	0.997	0.0030
GDP	0.1315	0.991	0.0863
GDP/Capita	0.776	0.885	0.0015
VA (Indst.)	2.472	0.793	0.0061
VA (Comm.)	1.807	0.854	0.0017
VA (Agr.)	1.372	0.857	0.0015

The values of elasticities calculated are comparable with the values mentioned in other studies by [12] and [14]. The efficiency of fuels for end-use activities such as cooking, boilers has been adopted from [15], [16] and [17]. The transmission losses of electricity at the year 2015 is calculated to be 25.21% [1]. In the past decade, annual growth rate of NEA's transmission loss was found to be -0.91%. This factor was also considered in determining the demand and supply requirement of electricity over the study period of 2015-2050.

The hourly demand data (including the load shedding) of the year 2014/15 which was obtained from Load Dispatch Center, NEA was fed into LEAP in order to calculate the peak power requirements over the study period. The reserve margin was taken as 25%.

9.1 BAU Scenario

The future energy demand for each sector was calculated for Business as Usual (BAU) scenario using the aforementioned equations and tabulated in Table 3. The values of GDP, GDP/Capita and Population were referred from [18] and the population index, GDP growth rate, value added for related sectors were referred from [19] and [9] for the calculation of future demand.

Table 3: Energy Demand (PJ) in BAU Scenario

Sector	Year				
	2015	2025	2035	2045	2050
Residential	379	449	1325	1592	1745
Industrial	39	50	65	85	97
Commercial	17	19	23	28	31
Transport	32	39	47	56	61
Agriculture	5	6	7	8	9
Other	1	1	2	2	2
Total	473	585	1469	1771	1945

Table 4: Electricity, Fossil fuel and Fuelwood Demand forecast in BAU Scenario

Year	Electricity (PJ)	Fossil Fuel (PJ)	Fuelwood (PJ)
2015	15	75	341
2025	25	92	398
2035	48	191	1140
2045	58	234	1371
2050	64	258	1504

Table 4 shows the growth of electricity demand and fossil fuel over the study period. As seen from Figure 9, the peak demand for the year 2050 is 5252 MW in case of BAU scenario. So, by the year 2050, Nepal must have developed generating plants at least of 5252 MW in order to meet the demand.

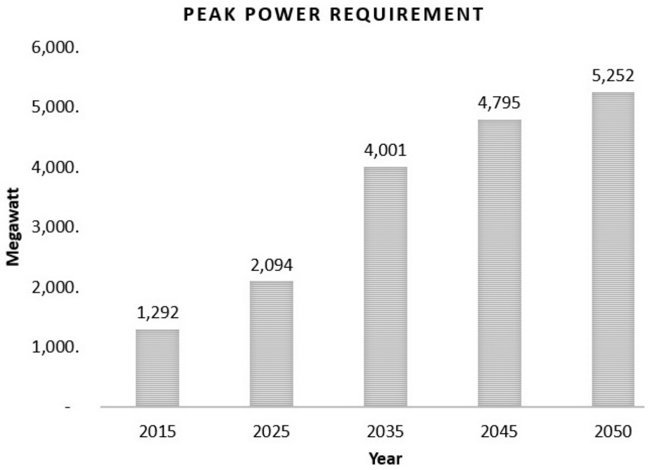

Figure 9: Peak Power Requirement (BAU Scenario)

9.2 Fuel Switch Scenario

In total 67% of population of Nepal has access to electricity [20]; 56% being connected to grid whereas 9% via other sources. According to 13th National Plan [20], Nepal targets to increase the access of electricity to 100% of population of Nepal by the year 2027.

Table 5: End use wise Fuel Switch Scenario

Economic Sector	End-use Activity	Electricity usage by		
		2015	2030	2050
Residential	Cooking	2.47%	50%	100%
	Heating	0.41%	15%	50%
	Lighting	53.9%	60%	100%
	Water boil	2.72%	50%	100%
Industrial	Power	43.47%	75%	100%
	Heating	2.14%	25%	75%
	Boiler	9.47%	50%	100%
	Lighting	28.92%	50%	100%
	Other	21.66%	50%	100%
Commercial	Cooking	3.62%	100%	100%
	Heating	8.88%	50%	100%
	Lighting	96.59%	100%	100%
	Water boil	20.95%	50%	100%
Transport	Elec. Vehicle	<1%	25%	50%
	3 Wheeler	<1%	25%	50%
	2 Wheeler	<1%	25%	50%
Agriculture	Tractor	0%	25%	50%
	Thresser	7.72%	25%	50%
	Water Pump	15.97%	100%	100%

The cost of fossil fuels increment, depletion of fossil fuels and environment concern will lead to switch over of fuels to electricity. Similarly, traditional fuels will also be switched over to electricity due to modernization or technology advancement and efficient and clean energy concerns.

Hence, in this scenario, the traditional fuels and fossil fuels in the activities of different economic sectors are assumed to get switched to electricity as shown in Table 5 over a span of the study period.

Table 6 depicts the future energy demand forecast sector-wise in case of fuel-switch scenario. Compared to BAU scenario, the total energy demand drastically decreased in this scenario. In fact, in case of residential sector, the energy demand is decreasing with the increase of year. This is due to switching over to more efficient fuel and technology in place of inefficient fuels like fuelwood, animal and vegetable wastes etc.

Table 6: Energy Demand (PJ) Forecast in fuel-switch Scenario

Sector	Year				
	2015	2025	2035	2045	2050
Residential	379	366	347	323	302
Industrial	39	50	65	84	96
Commercial	17	15	15	18	19
Transport	32	39	47	56	61
Agriculture	5	6	7	8	9
Other	1	1	2	2	2
Total	473	477	482	491	490

And Table 7 shows the growth of electricity demand and fossil fuel demand over the study period in the fuel-switch scenario. It clearly shows the reason behind decrements in total energy in fuel switch scenario compared to that in BAU scenario. The fuelwood and fossil fuel demands are decreased and hence electricity demand increased immensely.

Table 7: Electricity, Fossil fuel and Fuelwood Demand and forecast in fuel-switch Scenario

Year	Electricity (PJ)	Fossil Fuel (PJ)	Fuelwood (PJ)
2015	15	75	341
2025	80	81	287
2035	166	83	216
2045	278	75	129
2050	349	70	69

Figure 10 shows that the peak demand for the year 2050 is 27.4 GW in case of fuel switch scenario. In order to decrease the dependency over fossil fuels and decrease fuelwood consumption and switching over to electricity and related technologies, Nepal must have developed generating plants at least of 27.4 GW by the year 2050 to meet the demand or import to meet the peak demand or else implement load shedding.

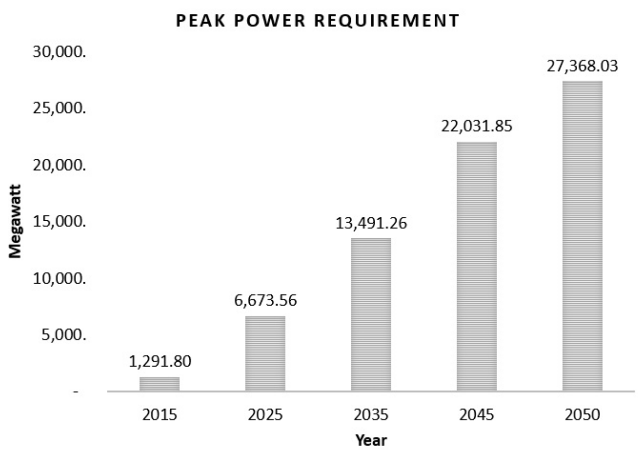

Figure 10: Peak Power Requirement (Fuel-switch Scenario)

10. Conclusion

The energy demand always is dependent on the number of population, income level, GDP of nation and technology advancement. Subsequently, the fuel demand also increases. In order to limit the import of fossil fuels and lessen the tradition fuels, the only option Nepal has is to increase the hydro generation. As seen from Table 4 the increment in electricity demand in the year 2050 is 64 PJ whereas the fossil fuel demand is 258PJ and fuelwood demand is 1504 PJ in BAU scenario. The peak demand of electricity for the year 2050 is 5252 MW in BAU scenario.

In another fuel-switch scenario, where switching to electricity from the fossil fuels and traditional fuels is done to avoid fossil fuel import cost, environment security and efficient fuels, the electricity demand will be immense. In such scenario, the electricity demand in the year 2050 is 349 PJ whereas the fossil fuel demand is 70 PJ and fuelwood demand is 69 PJ. The peak demand of electricity for the year 2050 is 27.4 GW in this scenario. It is evident that with the technological advancement and increase in income level of people, people will switch to electricity eventually due to efficient and environment friendliness of electricity. To meet this growing future demand of electricity, installation of new hydropower plants or thermal plants or solar plants seems inevitable in the near future or increase the import from India else huge load shedding is unavoidable. Hence, to control this electricity demand growth, there is much need of Demand side management (DSM) of electricity in Nepal, which must be adopted as soon as possible.

11. Recommendation

Nepal being hydro-potential nation will have to develop hydro generation plants. But the construction of these hydropower plants and its associated components consume huge investments and time. The demand growth is inevitable. Hence, the demand growth should be controlled in such a way that the demand does not surpass the supply. For this, the utility and the nation must invest in DSM. The need of DSM is paramount in today's world. There are many DSM options available which have been adopted in various parts of world successfully. All of these DSM options may not be applicable or feasible in case of Nepal. Different analysis like B/C ratio, or Multi-Criteria Decision Model should be adopted in order to evaluate the effective DSM options. The government, utility, and the end user must work in close co-ordination in developing and implementing the necessary policy in order to narrow the gap between the supply and demand of electricity in the nearing future.

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