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Residential Sector Energy Demand and Scenario Analysis for Province One of Nepal

by

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A THESIS

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled "Residential Sector Energy Demand and Scenario Analysis for Province One of Nepal" submitted by Karshan Maharjan in partial fulfillment of the requirements for the degree of Master of Science in Energy Systems Planning and Management (MSESPM).

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ABSTRACT

A reliable future energy demand projection is a prerequisite condition for sustainable utilization of local energy resources of a nation. The purpose of this study is to project and analyze the long term energy demand in residential sector of Province One. In this study, the residential sector is disaggregated into physiographic region and each region is divided into rural and urban area and into end use fuel type. Primary data was used for base year analysis and a Low Emission Analysis Platform (LEAP) model was used to calculate an energy demand and perform scenario analysis of the Residential sector of Province One over the period 2019-2030. Four scenarios were developed, Business as usual (BAU) scenario, LPG substitution scenario, Improved Cooking Stove (ICS) scenario and Sustainable Energy Development Scenario (SEDS). The study shows that in the BAU scenario, the final energy demand of the residential sector of Province One is expected to increase from 30.5 PJ (Peta Joule) to 34.6 PJ, whereas in the sustainable energy development scenario, the final energy demand is expected to be 12.6 PJ such that the electricity demand increases from 1.8 PJ to 9.4 PJ by 2030. The electricity consumption per capita in residential sector increases from 99 kWh to 449.2 kWh in the year 2030 in SEDS scenario. In BAU scenario, the GHG emission increases to 534 kt (kiloton) of CO_2 equivalent from 462 kt of CO_2 equivalent in 2030 in SEDS scenario, the GHG emission drops to 56 kt of CO_2 equivalent. The study also shows that electricity consumption per capita in residential sector increase to 292 kWh in 2030 if LPG is substituted with electricity resulting to higher consumption of electrical power thus enhancing the energy security of nation. However, above results can only be achieved with the coordinated action of both provincial and federal government and promoting renewable energy systems and energy efficient technologies instead of traditional fuel woods and fossil fuels systems.

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LIST OF ABBREVIATIONS

AEPC	Alternative Energy Promotion Center
CBS	Central Bureau of Statistics
CO_2	Carbon Dioxide
FY	Fiscal Year
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GVA	Gross Value Added
GW	Gigawatt
GWh	Gigawatt-hour
HH	House Holds
ICS	Improved Cooking Stove
IEA	International Energy Agency
kWh	kilowatt-hour
LPG	Liquefied Petroleum Gas
LEAP	Long-range Energy Alternatives Planning System
MAED	Model for Analysis of Energy Demand
MToE	Million Tonnes of Oil Equivalent
NEA	Nepal Electricity Authority
NREP	National Rural Energy Programme
PJ	Peta Joule
SDG	Sustainable Development Goals
SE4ALL	Sustainable energy for all
SEDS	Sustainable Energy Development Scenario
WECS	Water and Energy Commission Secretariat

CHAPTER ONE: INTRODUCTION

1.1 Background

Energy is one of the essential drivers for social and economic development. A sustainable energy supply, both in the short and the long term, is needed for enhancing economic development, people's quality of life and protecting the environment. An energy supply and demand balance shall always be maintained for the better quality and reliability of energy system. Access to reliable and affordable energy services is fundamental to reducing poverty and improving health, increasing productivity, enhancing competitiveness and promoting economic growth.

Energy consumption, specifically electricity consumption per capita, is one of the significant indicators of the development status of the country. It indicates the current situation of economic activities as well as how well a country is progressing towards development. The overall energy consumption of Nepal is largely dominated by usage of non-commercial forms of energy, such as fuel wood, agricultural residue, and animal waste. The energy consumption patterns in all economic sectors are mainly classified as residential sector, industrial sector, transport sector, commercial sector, agricultural sector and construction & mining sector.

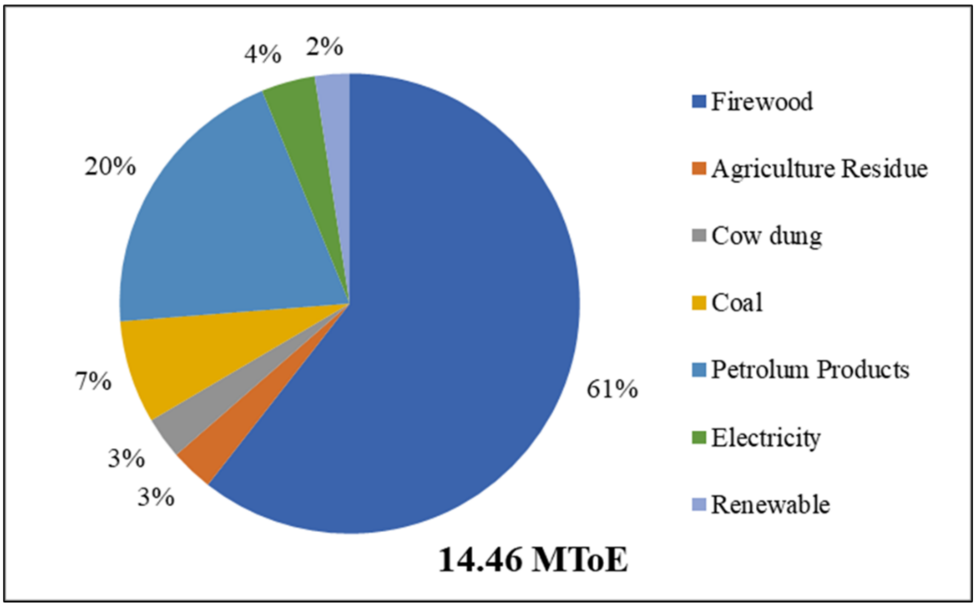


Figure 1.1: Total energy consumption of Nepal

The total energy consumption of nation is 14.46 MToE (Million Tonnes of Oil Equivalent) or 605 PJ (Peta Joule) in year 2021 as shown in above Figure 1.1. The total energy consumption is mostly dominated by traditional energy i.e., firewood (61%) followed by petroleum products (20%), coal (7%), electricity (4%) and renewable energy (2%) only (MoF, 2021).

1.2 General Overview of Province One

The Constitution of Nepal, 2015 has restructured the nation into a Federal Democratic Republic and has divided the nation into seven provinces. Province One lies in the eastern region of Nepal ranging from mountainous and hilly to terai region. It covers an area of 25,905 km^2. Under the newly reformed local bodies, the province encompasses a total of 1 metropolitan city, two sub-metropolitans, 46 municipalities, and 88 rural municipalities. Biratnagar has been declared capital of the province by the provincial assembly in 2019. According to the 2011 census, there were around 4.5 million people in the province. The administration boundaries of Province One is shown in Figure 1.2 below.

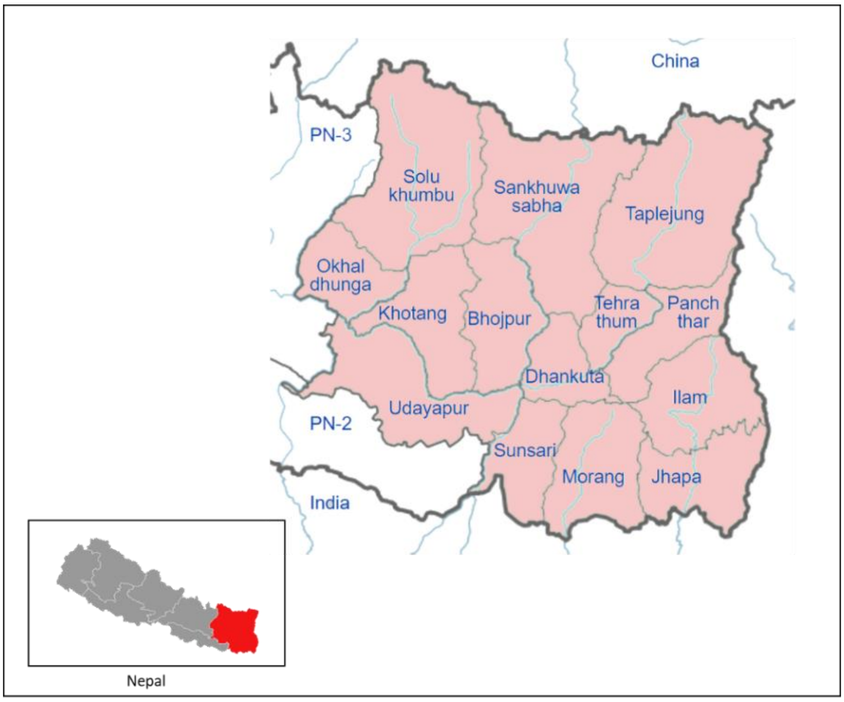


Figure 1.2: Province One – Location and Administrative Boundaries (WECS, 2021)

In terms of economic activity, Province One is the second-most active province with a GDP share of 17.5% (NRB, 2018). The economic sectors diversify according to the geographic conditions. Terai and hilly regions in the border area are the corridor for international trade. The Terai regions dominate in industrial as well as agricultural activities, wherein hilly and Terai regions, other commercial activities such as tourism and small enterprises are concentrated. In terms of energy, this province has the most diversified energy resources as well as energy demand pattern due to varying geographical situations. The mountain regions are known to be remotely accessible. Thus, there are a lesser number of industries, and primary energy resources are traditional biomass. However, due to mountainous geography, there is a significant potential for hydro and solar energy. As moving towards Terai, the energy pattern differs, as there is more commercial energy consumption than in mountainous and hilly regions. It is not only due to easy accessibility, but also the presence of industrial, commercial, and transport activities.

According to National Economic census, among the registered institutions in Province One, more than 80% are commercial institutions, around 12% are industries, 3% of institutions involved in agriculture while construction and mining account for less than 1%. Meanwhile, in economic terms, the largest share of GDP is from the commercial sector (46%) followed by agriculture (37%), construction and mining (9.5%) and industry (7.8%) in 2019.

Province One can be further categorized into the physiographic region i.e. Mountain Hilly and Terai region. The Hilly region consists of 8 districts, Terai region has 3 districts and Mountain region has 3 districts. The lists of districts according to the geographic region are shown in Table 1.1.

Table 1.1: Districts as per geographic region of Province One

Geographical Region	District
Mountain	Sankhuwasabha, Solukhumbu, Taplejung
Hill	Bhojpur, Dhankuta, Ilam, Khotang, Okhaldhunga, Panchthar, Terhathum, Udayapur
Terai	Jhapa, Morang, Sunsari

1.3 Problem Statement

Residential sector is one of the major contributors in the total energy consumption among all other sectors in Province One. Nearly 80% of the energy comes from traditional energy i.e., fuelwood whereas the contribution of electricity is nearly 6% only. The high use of firewood is primarily for cooking (58%) and animal feed preparation (33%). Most of the previous research has been carried out in the federal level only and very few researches have been carried out at provincial level. Fossil fuels like LPG and Petroleum etc. are imported in the significant amount which has a negative impact on energy security. Meanwhile, install capacity of hydropower is increasing and surplus power has become key issue for management. Various policies, SDG goals and Sustainable Energy for all (SE4ALL) program target to achieve access to reliable, affordable, improvement in energy efficiency and increasing the share of renewable energy in the energy mix by 2030. Also, government has set a target of full electrification in Bagmati, Gandaki, Province Two and Lumbini within this fiscal year 2078/79, and Province One, Karnali and Sudurpaschim within fiscal year 2079/80.

Hence, energy demand forecasting and scenario analysis needs to be carried out for the sustainable development of all Province but this study is mainly focus on the Residential sector of Province One.

1.4 Research Objective:

The main objective of this research is to find the energy consumption, energy demand and scenario analysis of the Residential sector of Province One over the period 2019-2030.

The specific objective is:

- To determine the energy consumption pattern of Province One according to physiographic region (Mountain, Hilly and Terai Region).
- To determine the final energy demand in Business As Usual scenario, Improved Cooking Stove scenario, LPG substitution scenario and Sustainable Energy Development scenario up to year 2030.
- To evaluate the change in electricity demand and traditional energy demand.
- To determine the per capita electricity consumption and per capita energy consumption.
- To determine the GHG emission under aforementioned scenario.

CHAPTER TWO: LITERATURE REVIEW

2.1 National Energy Scenario

The energy source is mainly classified as commercial and non-commercial forms of energy (Vikas Khare, C. K., 2019). The overall energy consumption of Nepal is highly dominated by the use of non-commercial forms of energy, like fuelwood, animal waste and agricultural residue. Economic survey 2015/16 indicates that the total energy consumption increased to 11 MToE in 2015/2016 (MOF, 2016) with an annual growth rate of 3%. The National Survey of Energy Consumption and Supply situation of Nepal by WECS in the year 2011/12 has determined the energy consumption patterns in all economic sectors i.e. (residential sector, industrial sector, transport sector, commercial sector, agricultural sector), and others by physiographic and development regions. According to the survey, the residential sector accounts for a significant share of energy consumption (80.4%) followed by industrial (7.9%), transport (7.1%), commercial (3.4%), and agriculture (1.2%) in 2011/12.

The primary source of energy in the residential sector is fuelwood, agriculture residue, animal waste, biogas, and other biomass energy resources. Electricity by hydropower and solar energy substitute traditional energy in urban residential area, mainly for cooking and lighting. The industrial sector consumes coal, fuelwood, diesel, and electricity as major sources of energy with a 63% share of non-renewable energy consumption. Transport sector consumes 99% of gasoline and 87% of diesel imported in the nation (Malla 2014). Diesel, petrol, and Aviation Turbine Fuel (ATF) are major fuel sources in the transport sector with minimal contribution from electricity. The National Survey of Energy Consumption and Supply Situation in Nepal, 2013 shows fuelwood, LPG, coal and grid electricity as major fuel energy sources in the commercial sector with 34% share of non-renewable energy consumption. Agriculture sector mainly uses fuel for water pumping and farm machinery that consume diesel as major fuel source.

The total energy consumption of Nepal in year 2009 is about 400 PJ and in year 2019 it is about 586 PJ while it , with an annual average growth rate of 4% (WECS, 2010; MoF, 2020). Also, consumption of traditional energy has decreased from 82% in 2009 to 69% in 2019. Meanwhile, there's an improvement in consumption of commercial energy from 12% in 2009 to 29% in 2019, with a growth rate of 13% per annum. Similarly, the consumption of renewable energy is increasing at the rate of 17% per annum, constituting 2% share in energy mix in 2019. In 2009, electricity consumption was 2% of total energy consumed in the country and it was increased to 4% by 2019 with the annual average growth rate of 10%.

2.2 Energy Policy

Energy- related documents and programs of Nepal have a clear policy of maximizing hydropower utilization to meet domestic demand for electricity and to accelerate the renewable energy service in the country. To provide access to energy and energy efficient technologies, various subsidy mechanisms are in effect. National Rural Energy Programme (NREP) provided a framework for the implementation in local communities across the country. Under this policy, Nepal intends to expand its energy mix prioritizing on renewable energy by 20% by diversifying its energy consumption pattern to more industrial and commercial sectors.

As per the Policy and Programs ratified by the Parliament, The Federal Government of Nepal, in June 2020, the government of Nepal has amply put focus on the development of hydropower in Nepal. Especially upper Tamakoshi Hydropower project will be commissioned during the fiscal year 2020-21, Budhigandaki and West Set storage hydropower projects will be propelled for further development through external financial resources. The GoN will be prioritizing development of effective and reliable infrastructure development in the transmission and distribution systems. There will be full electrification in Bagmati, Gandaki, Provinces Two and Lumbini Province within the fiscal year 2078/79, and Province One, Karnali and Sudur Paschim Province will have full electrification within the fiscal year 2079/80.

2.2.1 Ministry of Energy, Water Resources, and Irrigation White Paper 2075

Ministry of Energy, Water Resources and Irrigation (MoEWRI) had released white paper 2075 in July 2018 with the objectives to elevate hydropower and renewable energy generation in the coming decade to take the country towards the path of sustainable development. It has set the target to improve per capita electricity consumption from current 700 kWh to 1,500 kWh in the coming ten years. It requires the penetration of electricity in all the sectors, including electrification in residential, commercial, transport, industry and agriculture. The white paper focuses on optimum generation and utilization of clean energy resources, including efficiency improvement in the country.

The Energy White Paper (2018) has set some ambitious targets as follows:

Within Year 3	• Additional 3,000 MW capacity will be installed • Country will be self-sufficient in terms of electricity • For management and utilization of water resources river basin plan and other useful schemes will be developed
Within Year 5	• Additional 5,000 MW capacity will be installed • Transmission and distribution lines will be developed to ensure all households have access to electricity. Where central grid access is not possible, micro-hydro, solar and wind energy systems with battery storage will be used • Per capita electricity consumption will reach 700 kWh
Within Year 10	• Additional 10,000 MW capacity will be installed • Per capita electricity consumption will reach 1500 kWh

2.2.2 Nepal's Intended Nationally Determined Contribution (INDC)

The Government of Nepal - Ministry of Population and Environment has, in February 2016, communicated its INDC to the UNFCCC as a national pledge to contribute its parts to the promotion of renewable energy services across the nation. Most of the mitigations strategies and targets included in the INDC report adheres to the existing policies and plans. One of the key strategies includes the formulation of Low-Carbon Economic Development Strategy (LCEDS) that provides the framework for the promotion of renewable energy across the country in all economic sectors. As per Climate Action Tracker, NDC submitted by Nepal could not be rated as it did not quantify Nepal's contribution in GHG emissions target. As per National Action Plan for Electric Mobility of Nepal Government in 2018 and as per afforestation activities in Nepal– the growth in forest areas has increased to 45% of land area in 2016 from

26% in 1992, the Climate Action Tracker projects that the Nepal's emissions in 2030 will be "1.50 C Paris Agreement compatible".

2.2.3 Nepal: Sustainable Development Goals Status and Roadmaps 2016-2030

The National Planning Commission prepared the status and roadmaps to achieve sustainable development goals by 2030. It envisions Nepal to graduate from the list of Least Developed Countries which requires the rapid economic growth of at least 7% over the decades. It highlights significant issues and challenges along with the path to achieving the targets of SDGs. It emphasizes thee sectors mainly clean energy, agriculture, and tourism for the sustainable prosperity of the nation.

2.2.4 National Energy Efficiency Strategy, 2075

Owing to the lack of a separate strategy related to promotion energy efficiency, National Energy Efficiency Strategy, 2075 was formulated with the vision to assist in energy security by increasing the energy access through efficient use of energy available in the country. Its specific target is to double the average improvement rate of energy efficiency in Nepal from 0.84% per year, between 2000 -2015 AD to 1.68% per year in 2030 AD. It aims to do so by massive inclusion of stakeholders – from consumers to policy makers and establish all required frameworks for resources management, resources mobilization, infrastructure development and human resources development required for energy efficiency. Additionally, it also ought to develop national standard regarding energy efficiency as well as develop equipment's and means for measuring energy efficiency.

2.3 Energy Consumption pattern of Province One

The total energy consumptions in six economic sectors in Province One in 2019 are summed to about 74 PJ. The energy consumption in the industrial sector has the highest share in this province followed by residential sector. Nearly 45% of the total energy demand is in industrial sector and 55% of energy coming from renewable and non-renewable at around 45% respectively as shown in Figure 2.1 (WECS, 2021).

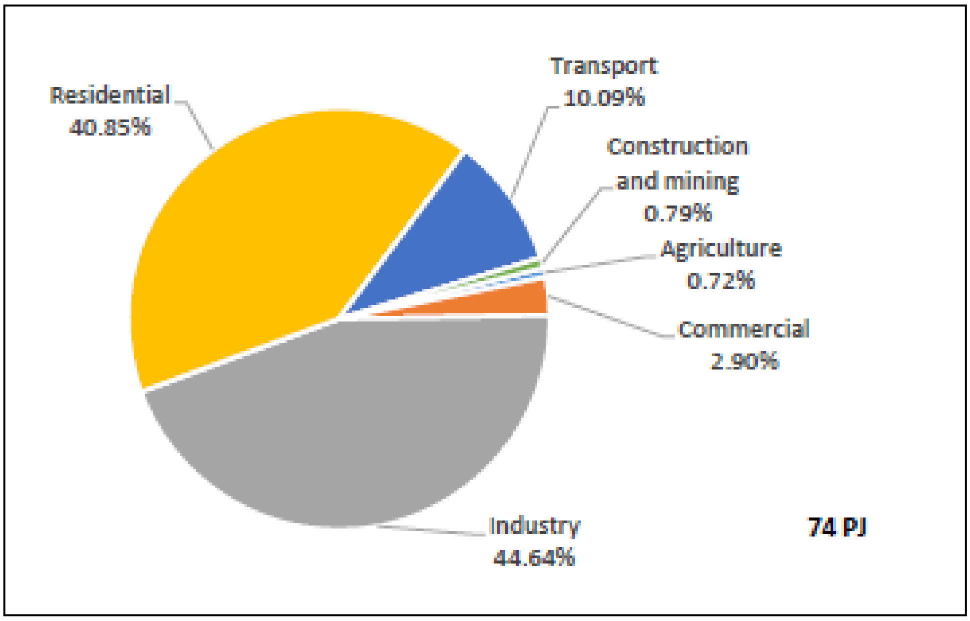


Figure 2.1: Energy Consumption share in Province One by Sectors.

Energy mix in residential sector is as shown in Figure 2.2. It shows that wood is the major source of fuel in this sector consuming 80% of total energy consumed followed by LPG. There is consumption of 10% LPG fuel and 6% electricity in this sector. Modern renewable like biogas, briquettes, solar PV, solar thermal is also consumed; however, the share is less than 1% of total residential energy consumption.

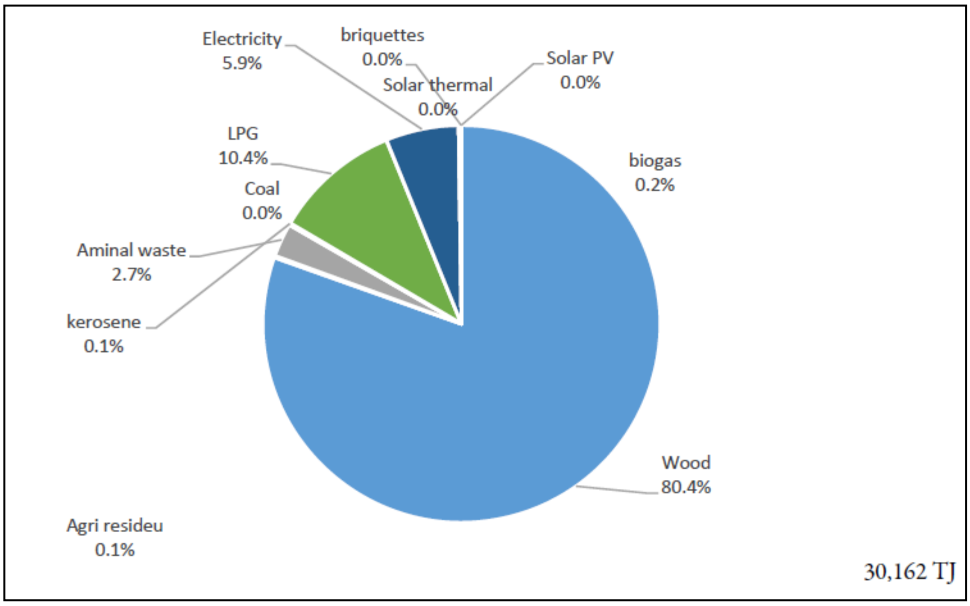


Figure 2.2 : Energy mix in Residential Sector in Province One (WECS, 2021)

2.3.1 Electricity Consumption Status

Nepal has abundant hydropower resources and switching to electricity in energy access could be a better option in context of economic efficiency, energy efficiency, sustainability, and energy security. Nepal Electricity Authority (NEA) is responsible for developing, operating hydropower and transmission and distribution of power in Nepal. Currently, the install capacity of Hydropower and solar in Nepal is about 1451 MW and the peak demand of 1481 MW of electricity. During the wet season, Nepal imports about 727 MW from India to meet the national demand. The total demand of electricity is balanced through 65% of it is supplied by from domestic generation, and the remaining 35% is imported to fulfill the demand (NEA 2020). The total install capacity of Hydropower and under construction hydropower in Nepal is shown in

Table 2.1 and Table 2.2 below.

Table 2.1: Install capacity of Hydropower in Nepal

S.N.	Power Plant Description	Capacity In MW
1.	Total Major Hydro(NEA)-Grid Connected	577.39
2.	Total Small Hydro(NEA)-Isolated	4.53
3.	Total Hydro(IPP)	814.65
4.	Total Hydro(Nepal)	1396.58
5.	Total Thermal	53.41
6.	Total Solar	1.35
7.	Total Installed Capacity	1451.35

Table 2.2: Hydropower Projects Under-construction in Nepal

S.N.	Power Plant Under Construction	Capacity In MW
1.	Upper Tamakoshi Hydropower Project	456.00
2.	Tanahu Hydropower Project	140.00
3.	Rahuganga HEP	40.00
4.	Upper Sanjen	14.6
5.	Sanjen	42.5
6.	Rasuwagadi	111.00
7.	Madhya Bhotekoshi	102.00
8.	Upper Trishuli 3B	37.00
	Total	943.100

The system load curve (maximum demand) of Nepal is shown in Figure 2.3 below. It shows that during the Peak load, the power imported from the India is significantly high than the power generation within the nation (NEA, 2021). The base load is supported from the Independent Power Producer (IPP) and few by NEA power plants.

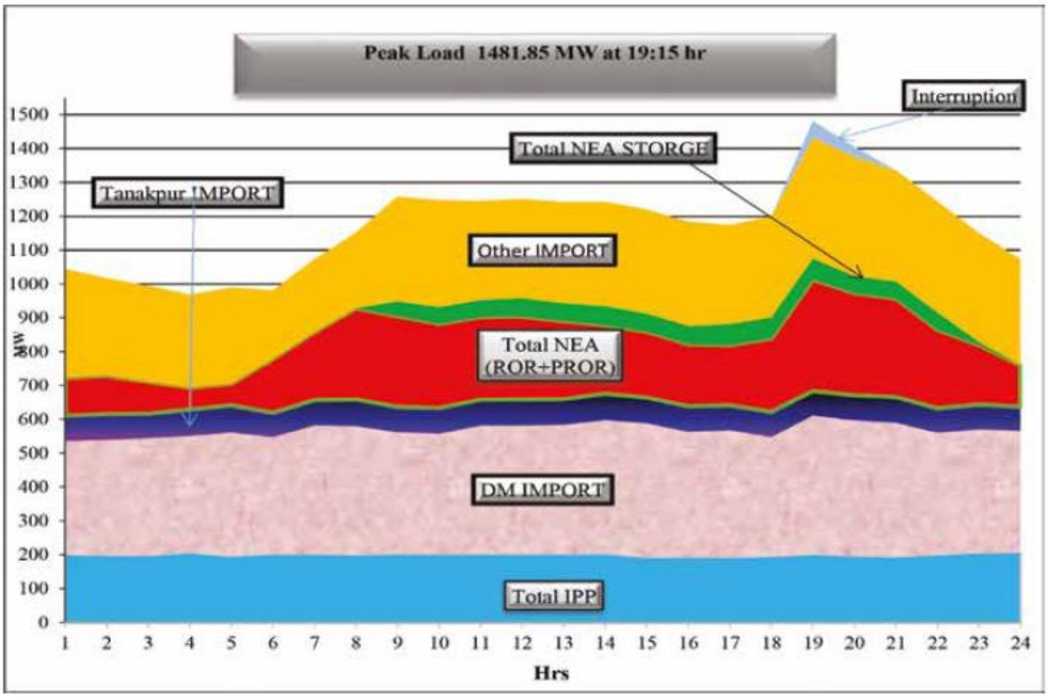


Figure 2.3: System Load curve of Nepal

The province wise electrification in Nepal is shown in Figure 2.4 below. It shows that the Province No. 2 has highest household electrification about 99.05% which is followed by Bagmati and Gandaki Province. The Province One has about 83 % of household electrification (NEA, 2018).

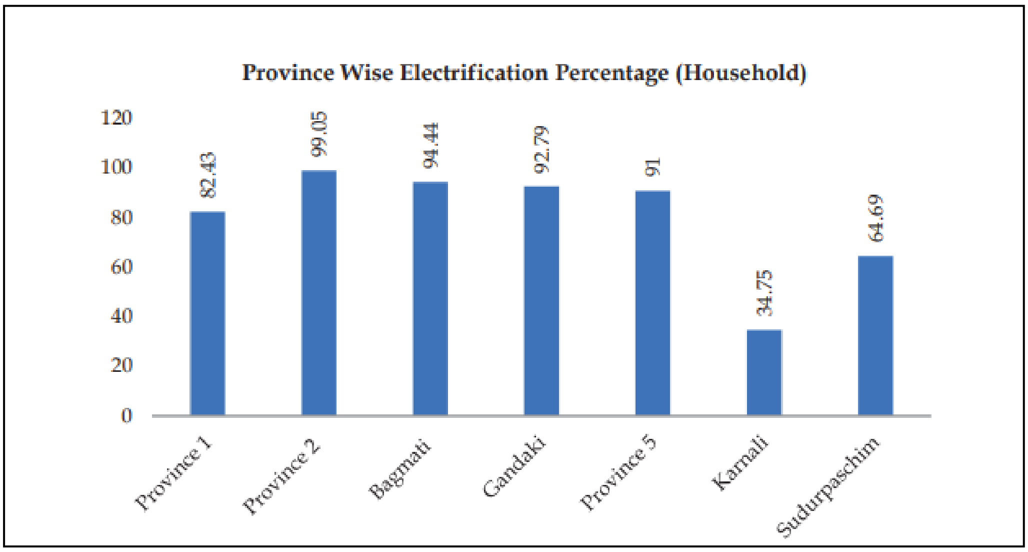


Figure 2.4: Province wise electrification in Nepal

Bagmati Province has the highest electrification rate of 90% of the total population, whereas Karnali province has the lowest with 27%. Province One has around 76% of its population electrified (NEA, 2019).

Province One, which has mountains and hills, has abundance of water resources and there are several potential sites for hydropower development. The average potential for hydropower plant is around 20,500 MW in Province One (Kandel, 2018). In addition to that, 66 MW of small hydropower potential from 84 and nearly 70 sites for 1 MWp of solar PV sites has been identified for decentralized generation of electricity (NPC, 2018). There are 29 IPPs hydropower projects, 4 major hydro power plants and 5 small hydropower plants in Province One (NEA 2019). There is 237.59 MW (226.796 MW from IPPs and 10.794 MW from NEA generation) installed capacity in the province is attached in Appendix-E.

With the increasing investment in hydropower plants, Ministry of Electricity, Water Resources, and Irrigation has plans to generate 3,751 MW of electricity from different hydropower plants of Province One in next 15 years. As per NEA 2019, the planned and proposed hydropower plants are Dudhkoshi storage plant (635 MW) and Upper

Arun Hydroelectric plant (1,061 MW) in Sankhuwasabha in Solukhumbu districts (NEA, 2019).

The district - wise electricity supply status of Province One as per is as shown in Figure 2.4. Province One consumed 1,011 GWh of electricity including all economic sectors (NEA database 2020). The three districts of Terai Jhapa, Morang and Sunsari consume about 79% of the total electricity in Province One mainly due to high industrial activities. However, due to poor access to electricity in remote area electricity consumption in the mountainous regions is extremely low. Comparatively, electricity consumption in Hilly region is lower than in Terai region.

Peak demand in 2019 in Nepal was 1,320 MW in wet season (NEA 2019). National sales data in the same show that there was demand of almost 6,340 GWh electricity in Nepal. Industry and household sectors consume 39% and 42% of total supply respectively in Nepal.

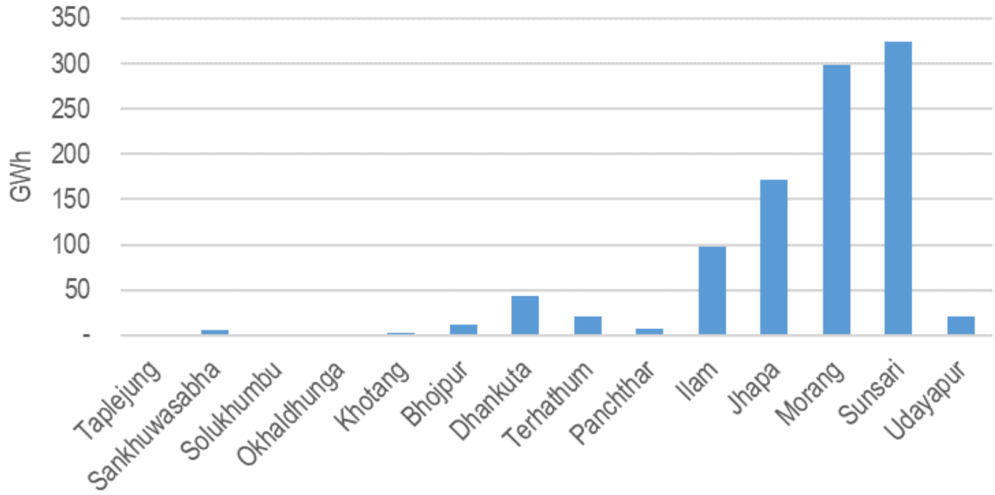


Figure 2.4: District wise electricity consumption in Province One (NEA, 2019)

The sectoral electricity consumption in economic sectors in Province One is as shown in Figure 2.5. Industrial sector consumed 42% of total electricity consumed in the Province One whereas its consumption in household sectors (43%), commercial 6%, agriculture 3% and others including non-commercial sector 6% respectively. (NEA, 2019)

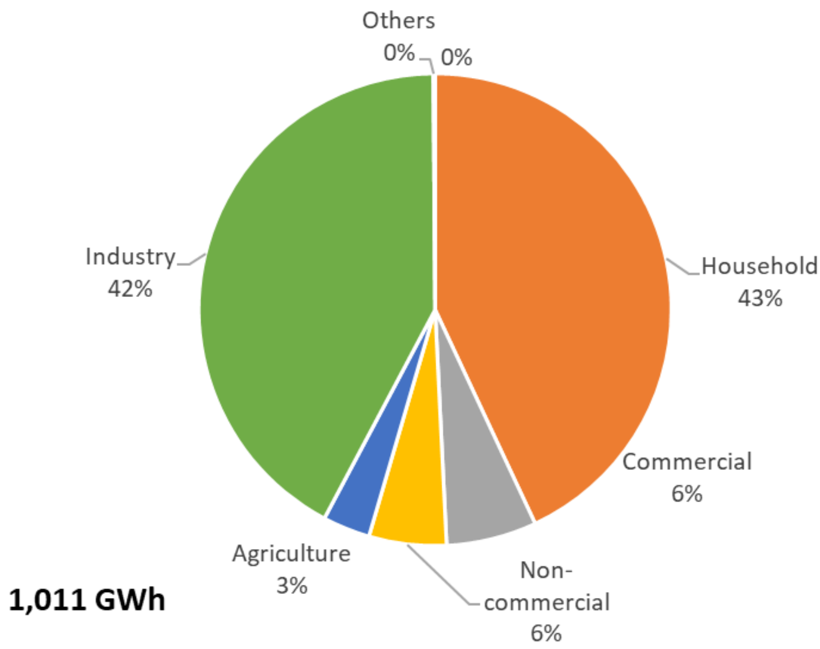


Figure 2.5: Economic Sector wise Electricity Consumption in Province One

As per NEA domestic consumption data, the electricity connection as per ampere capacity of households is about 90% of the households lies within minimal amperage capacity of 5A, 7% are connected with 6-15A connection. Less than 1% has electricity connection above 16A. In Province One, 76% of household have access to electricity (NEA, 2075).

2.3.2 Modern Renewable Energy Sources

Modern Renewable energy sources can be categorized into the wind, biogas, solar, micro hydro, and other renewables. Alternative Energy and Promotion Centre (AEPC) is the leading organization working in the promotion of renewable energy in Nepal. The modern energy access is gradually increasing in Nepal with the current status of electricity access from renewables reaching 25% population. There has been a contribution of 32 MW of electricity from mini and micro hydro schemes, 15 MWp from solar PV system and around 20 kW from wind energy. More than 1.5 million households have been benefited from different renewable energy sources for cooking, lighting and productive end uses (MoPE, 2016).

2.3.3 Petroleum Products

Till date, the source of feasible petroleum products has not been found in Nepal. All the petroleum products which are consumed in the nation are imported from India. The only company that deals with import and sales of petroleum products – that include mainly diesel, petrol, kerosene, and LPG. The furnace oils and other oil residues are imported by the industries themselves. Thus, the supply of petroleum products is obtained from regional offices of Nepal Oil Corporation. District- wise sales data for 2075-76 are as shown in Table 2.3. All the units for MS, Diesel and SKO are in kiloliters except for LPG in metric ton (MT). These sales data represent the sales to depots at each district. However, it is to be noted that neither the sales from these depots are bound within the district only nor the supply in each district is bound by the capacity of depots only – there are inter-boundary trade and transportation of petroleum fuels. Hence, the supply of petroleum products and their consumptions may not tally properly.

Table 2.3: Petroleum sales in 2075-76 in Province One (NOC, 2020)

Districts	**MS**	**Diesel**	**SKO**	**LPG**
	kL	**kL**	**kL**	**tons**
Taplejung	234	1,980	-	-
Sankhuwasabha	948	4,441	-	-
Solukhumbu	288	1,576	282	-
Okhaldhunga	816	5,722	168	-
Khotang	306	1,904	-	-
Bhojpur	288	3,113	-	-
Dhankuta	1,371	7,399	39	-
Terhathum	192	1,032	-	-
Panchthar	929	7,109	-	-
Ilam	2,245	6,487	-	-
Jhapa	27,102	66,017	777	20,824
Morang	25,507	71,727	1,528	9,358
Sunsari	21,557	59,436	1,019	51,994
Udayapur	3,622	15,950	-	-
Total	**85,405**	**253,891**	**3,813**	**82,176**

2.3.4 Population of Province One

Population and Households for 2019 are estimated based on population growth rate and household size of each province. In Province One, the population growth rate of 1.35% per annum, and household size of 4.6 are used. The district wise population and households in each province for 2011 and 2019 is as shown in Table 2.4 (WECS, 2021).

Table 2.4: District Wise Population and Household Status in Province One

Geographical Region	**District**	**2019**	
		Population	**Households**
Mountain	Sankhuwasabha	176,718	38,417
	Solukhumbu	117,877	25,625
	Taplejung	141,895	30,847
Hill	Bhojpur	203,121	44,157
	Dhankuta	181,917	39,547
	Ilam	323,123	70,244
	Khotang	229,675	49,929
	Okhaldhunga	164,742	35,813
	Panchthar	213,539	46,422
	Terhathum	113,080	24,583
	Udayapur	353,490	76,846
Terai	Jhapa	904,677	196,669
	Morang	1,074,692	233,629
	Sunsari	849,947	184,771
	Total	**5,048,494**	**1,097,499**

2.4 Energy Planning Model

Energy planning is defined as a process of assessing the supply and demand for energy and attempting to balance them from present to future (Kahen G., 1995). The energy planning is the process of managing the available resources and is a process-oriented activity. According to Van Beeck (2003), a planning process is a process of creating a choice between available alternatives. Planning for the future is basically done through projecting the scenarios based on present and past information. Energy planning is a dynamic and complex approach, which takes the policies and strategies of energy systems, therefore, energy models are used for the planning process. For energy planning purpose, energy models were first developed in 1970s as a result of the increasing availability of computer and the growing concern of environmental consciousness (Shukla, P.R., 1995).

The importance of developing countries in energy planning began after the first oil crisis in 1973, when the high oil prices suddenly caused trade unbalance of many oil importing countries (Van Beeck Nicole 2003, Sanchez-Sierra, Gabrie 1991). Only after the crisis, the sufficient attention was given to the rational utilization of energy resources and felt the necessity of long-term energy planning (Mathur.J, 2001). Literatures show, energy planning is done for different time horizons like for four years or less as short term, from five to nine years as medium term and ten or more than ten years as long term respectively (Klein, et al. 1984).

Energy models have two types of approaches and they are the top-down and bottom-up approaches. These are the two basic approaches to examine the linkage between the economy and specific GHG-emiting sectors such as the energy system. Top-down model evaluates the system from aggregate economic variables and they come from the way the energy modelers apply macroeconomic variables theory and economic techiniques to historical data on energy consumption, prices, income to model the final demand for goods and services, and supply it to the main sector (Pachauri rt al., 2014).

On the other hand, bottom-up models work at a disaggregated level and thus require extensive database of emperical data to be able to build up the desired energy model (Kavgic et al., 2010). However, the application of the bottom-up model is a more inclusive assessment and analysis of the energy technologies, policies, fuel mix, energy mix and the entire energy system (Lkhagva 2014a,b). The Figure 2.6 shows the classification of energy models in Top-down and Bottom-up approcahes (Brizard N., 2015).

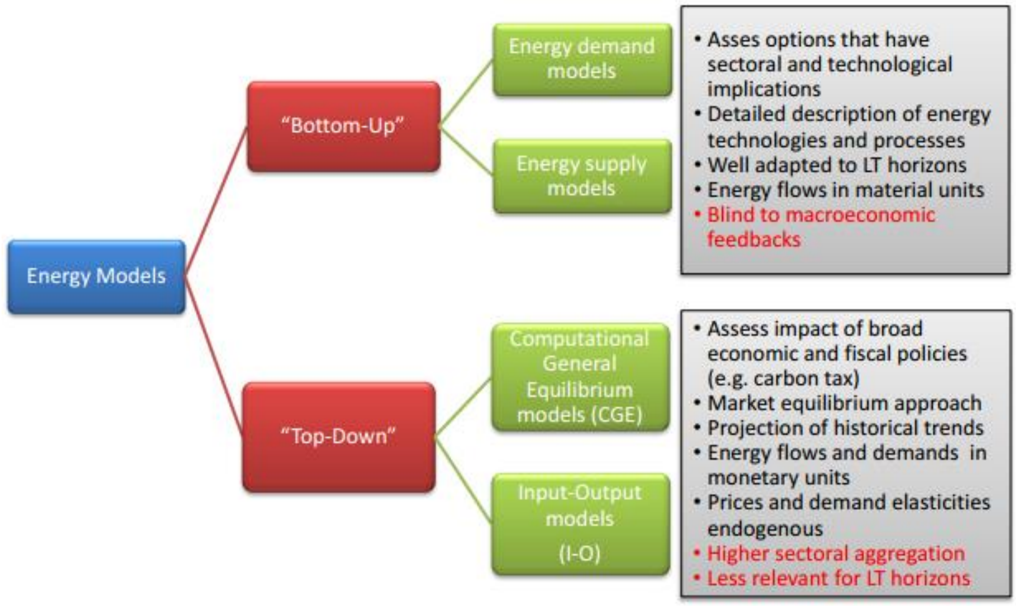


Figure 2.6: "Top-down" and "Bottom-up" energy models

Similarly, the Bottom-up models has been further disaggregated into End-use accounting models, Optimization models and Simulation models which is shown in the Figure 2.7 below (Brizard N.,(2015).

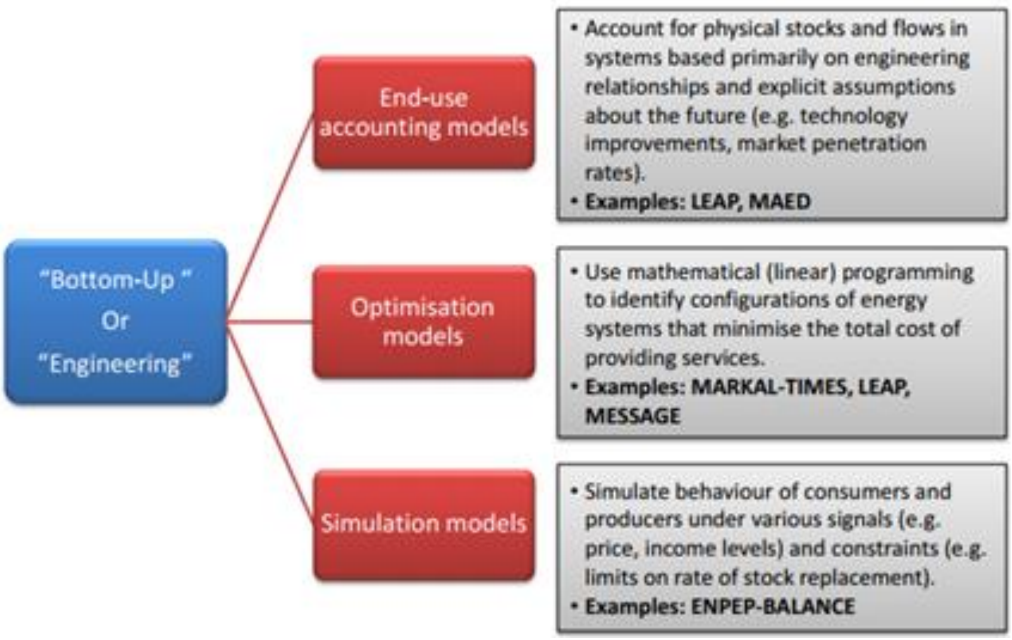


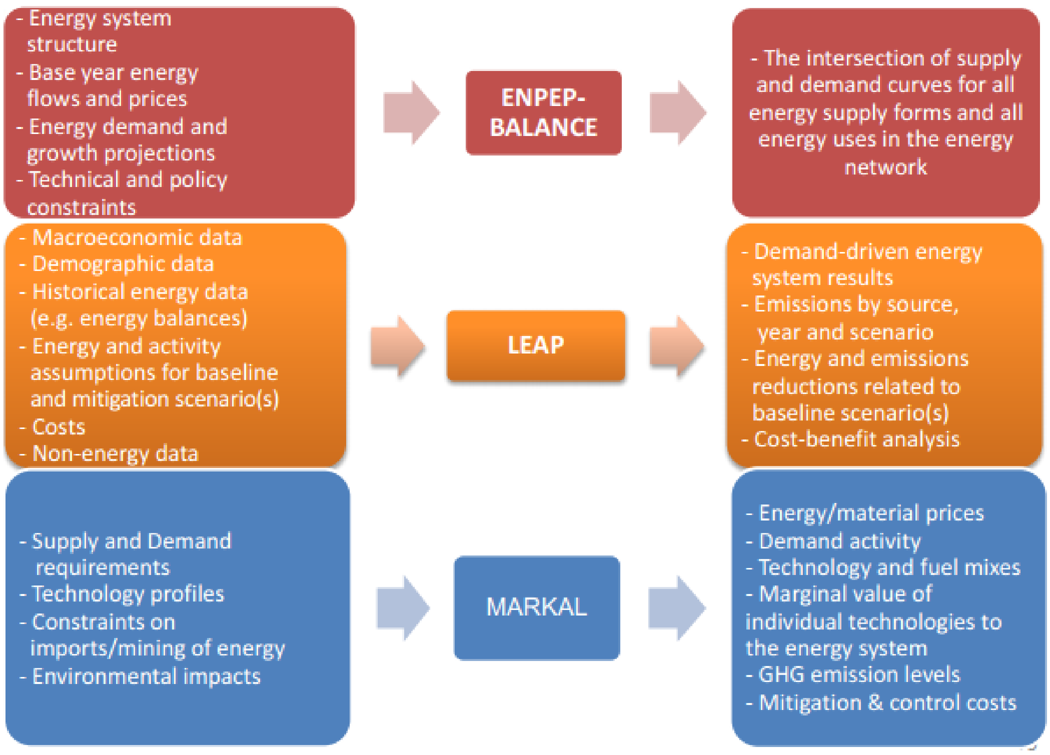
Figure 2.7: A typology of "bottom-up" energy models

Different models have come in practice for addressing the energy system planning like MESSAGE, WASP and MARKAL for supply side, whereas MADEE for demand side.

It has been found that about 80% contribution of the total global greenhouse effect was due to energy related activities (WRI, 1999). Knowing the fact, the scope of environmental planning together with energy and economics rose - up and also the importance of the new dimension of planning was realized and afterward, the environmental dimension was also consider into the planning process. Therefore, the existing energy planning tools are continuously enhanced to address the energy, economic and environment aspects of the energy planning process.

2.4.1 Models Input and Results

Different energy models are used in the analysis depending upon their specific purpose. Following are the different energy model which requires the different input parameters and final results are obtained which are shown in the Figure 2.8 below (Brizard N., 2015).



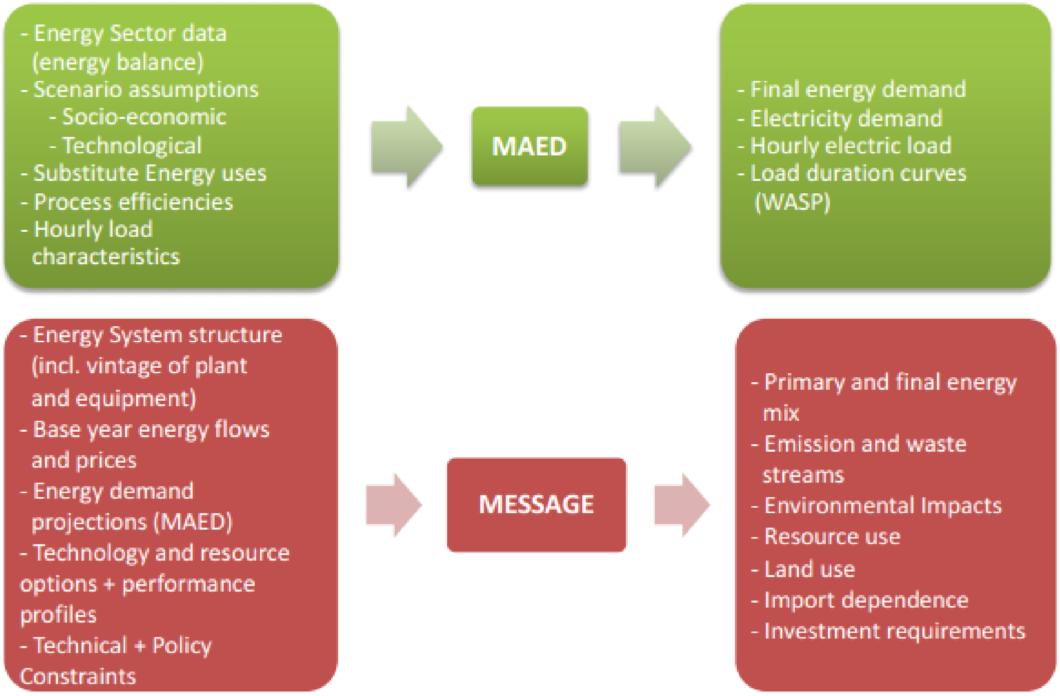


Figure 2.8: Input and Results of energy models

2.4.2 Energy-economy models and energy efficiency policy evaluation for the household sector

Followings Heaps (2002), Hourcade et al, (2006), Jaccard et al, (1996) and Worrell et, (2004), four methodological categories of energy-economy models were identified;

(i) Simulation,

(ii) Optimization,

(iii) Accounting and

(iv) Hybrid models

They are described below (Mundaca, 2009);

2.4.2.1 Simulation model

Simulation models attempts to provide a descriptive, quantitative illustration of energy production and consumption based on exogenously determined scenario. The methodological approach aims to represent observed and expected microeconomic decision-making behavior that is limited to an optimal pattern. These models try to replicate end-user behavior for technology choice considering different drivers (e.g.

income, energy security, public policies and endogeneous energy prices). Thus, and despite that economic data can be of high significance, drivers and often linked to other aspects of energy systems (e.g. CO_2 constraints). Under this category, there are following models: Residential End-Use Energy Planning System (REEPS); World Energy Model (WEM); Mesured' Utilisation Rationnelle de I' Energie (MURE) and the National Energy Modelling System-Residential Sector Demand Model (NEMS-RSDM).

2.4.2.2 Accounting Models

The main purpose of accounting models is to account for the physical flos=ws of energy. They often use spreadsheets to arrange in tabular form the efficiency in a prescriptive (e.g. impacts from high-efficient technology adoption by end-users) or descriptive manner (e.g. portfolio od technologies resulting from one or various policy instruments). Instead of identifying the behavior of market agents and resulting outcomes in an energy system, accounting models require users to determine and introduce outcomes beforehand (e.g. technology adoption rates). End-use service demands and change over time due to aggregate macroeconomic and demographic drivers (e.g. population, GDP). Under this, taxonomy, there are the following models: Long-Range Energy Alternatives Planning (LEAP), National Impact Analysis (NIA), Bottom-Up Energy Analysis System (BUENAS), Model for Analysis of Energy Demand (MAED) and Policy Analysis Modelling System (PAMS).

2.4.2.3 Optimization models

Optimization models are prescriptive by definition. They attempt to find least-cost solutions of technology choices for energy systems based on various policy and market constraints. Based on the rational model of consumer behavior, the allocation of energy supplies to energy demands is based on minimum life cycle technology costs at given discount rates and determined by an optimization approach (linear programming). Constraints can be related, for example, to atmospheric emissions, fuel supply, technological development and capacity utilization. Under this taxonomy there are following models: Market Allocation (MARKEL)model generator, PRIMES Energy System Model and Model of Energy Supply Strategy Alternatives and their General Environmental Impacts (MESSAGE).

2.4.2.4 Hybrid models

Hybrid models basically merge different methodological components from the above-mentioned types of models. In addition, some hybrid models are also integrated with top-down or general equilibrium models. That is, there is no need for exogenously determined macro-economic scenario (employment, income effects, economic growth rate, competitiveness etc.) but endogenous relationships between the economy and energy system take place instead. Some of the reviewed models fall into this taxonomy.

2.4.3 Selection of Energy Modeling Tool

Long-term energy modelling systems integrate and capture various interactions of economic changes and energy supply, population, demand, and costs. For that reason, many researchers have carried out their work on integrated energy planning for sustainable development. Although there are different types of models available for energy planning purpose, but the selection of a proper modelling tool for developing nations is a difficult task.

For the selection of a model for planning purposes, Rath-Nagel (1981) suggested that there are no such models which can give the solution to all questions due to the complexity of energy policy and energy strategy issues; therefore, it will be required several models with different objectives and specifications in order to effectively support the development of energy policies and planning. Van Beeck (2003) has highlighted the impossibility to put each and every aspect of reality in a model and told that the best model addresses the maximum degree of a simplified representation of reality.

The selection of a proper model for the energy planning process is determined by the availability of planning models and their characteristics and capabilities. Shukla (1995) mentioned that most of the energy models were developed in industrialized countries and it was assumed that the energy systems of developing countries would follow the same pattern as of industrialized countries. The required data for the different models are also challenging for developing countries like Nepal. Worrell et al. (2004) identified a number of modelling challenges like data quality, capturing technological potential and technological penetration. The main issues for developing countries' energy system are the informal economy, supply shortages, poor performance of power sector, structural economic change, electrification, traditional bio-fuels and urban-rural division (Urban et al., 2007). Being a developing country, those characteristics can be easily seen in Nepalese energy system too. In addition, the unavailability of appropriate database is also a crucial issue for long term Nepalese energy sector's modeling and planning.

Urban et al. (2007) highlighted that based on the different types of characteristics of developing countries address per model, the LEAP model addresses a large number of characteristics whereas MARKAL model address a medium number of characteristics. It has been found that none of the energy models fulfill all requirements satisfactory by addressing the energy systems and economics of developing countries. Seebregts et al. (2001) emphasized that the MARKAL model is the most widely used optimization model for supply-side planning.

In the context of Nepal, some authors (Shailendra Bhusal, A. M. 2019, Sujan Dulal, S. R., October 2019) have used the LEAP model, whereas others (WECS,2021, WECS,2017) have used MAED to evaluate the future energy demand for the medium to long term, focusing more specifically on demand for specified energy services. Shrestha et al. (2010) analysed the potential implications of adopting a policy of CO_2 emission reduction from Kathmandu Valley using Market Allocation (MARKAL) framework from 2005 to 2050 (Shrestha R.M et al., 2010). In the study, the end use service demands of residential and road transport sectors were forecasted by using population and GDP. Similarly, GDP only was used to determine the demands of air passengers, air freight and road fright whereas, sectoral GDP was used in agriculture, commercial, industrial and service sectors demand projections. Shakya et al. (2011) have used a MARKAL model/framework to study the road transport systems electrification over a time period of the year 2015 to 2050 in Nepal. In this study, the methodology developed by Shrestha et al. has been used for the service demand projections. In both of the study, the MARKAL framework was used exogenously for supply-side energy planning with analysing considering the implications of technology, economy and environment respectively.

Although there exists a variety of computer-based energy modelling tools, the LEAP system is chosen. The main reasons for doing so are given below:

1. LEAP is a user friendly, integrated energy modelling tool that can be used to create models of different energy system, where each requires its own data structures. By relaying on simpler accounting principles and since many aspects of the tool are optional (in accordance with the supporting data), it requires a week of training to conduct a typical analysis.
2. LEAP can account for energy consumption, production and resource extraction calculations at all sectors of an economy and can be used to track both energy and non-energy sector GHG emission sources and sinks at a regional, national or global scale. The software is designed to conduct long-range scenario analysis. Most of its calculations occur on an annual time-step and obtained results are combined into scenario of typically 20 to 50 years.
3. LEAP is notable for the transparency and flexibility that offers to users in respect to the wide range of different modelling methodologies that supports for both demand and/or supply side analysis.
4. LEAP includes Technology and Environmental Database (TED) which provides qualitative information on the technical characteristics, costs and environmental effects of wide range of energy technologies as well as qualitative information in respect to the availability, cost-effectiveness and key environment issues of energy technologies. This database offers to analysts in developing countries, where data structures are in sparse and poor quality, a complete and up-to-date data library.
5. LEAP is free to download for certified users from developing countries and students.

2.4.4 Major Findings from Different Energy Demand Projection Studies

Following are the major findings from the literature review shown in Table 2.5 below.

Table 2.5: Literature reviewed on different energy related studies

S.N.	Author	Title of Paper	Result/Conclusion
1.	Bhattarai (2015)	National Energy Demand Projections and Analysis of Nepal	This research projects and analyzes national demand for each sector by taking in data from different sources. LEAP model was used as modeling tool. Four different growth rate scenarios are considered. Population and GDP are taken as factors affecting the demand.
2.	Rajbhandari & Nakarmi (2014)	Energy Consumption and Scenario Analysis of Residential Sector Using Optimization Model-A Case of Kathmandu Valley	MAED and MARKEL was used for energy system evaluation. It was shown that with optimization energy demand reduction by 27% was possible. It also points out that the consumer prioritized cost over other factors.
3.	Bhusal & Nakarmi (2019)	Sustainable Energy Planning for Nepal in The Federal Structure	This paper examined the energy planning in each province, sustainable technology policy interventions in the energy demand and social cost benefit analysis in energy sector over the period 2017 -2050. LEAP-IBC model was used with four different growth rates.
4.	Dulal & Shakya (2019)	Energy Security and Scenario Analysis of Province One of	The paper presents the current energy security status of the Province One of Federal Democratic Republic Nepal

		Federal Democratic Republic of Nepal	over the period 2017-2040 and five economic growth scenarios are considered.
5.	Bajracharya & Nakarmi (2014)	Current Energy Consumption in Bhaktapur District	The paper presents the energy consumption of Bhaktapur. It is found that 25% of urban and rural household uses water heating but in rural, majority 70% of them uses firewood whereas in urban, 755 uses LPG for water heating.
6.	Hamal, Shrestha & Jha (2014)	Strategizing Demand side Management on Residential Sector of Nepal and its impact on Electricity Planning	LEAP is used to analyze residential energy profile and variation in it with inclusion of various national plans. Electricity generation and requirement of proper planning is emphasized as there is increasing peak load demand.
7.	Panthi & Bhattarai (2016)	Residential Sector Energy Demand and Analysis of Resunga Municipality, Gulmi, Nepal	This paper focuses on the research relating to Residential Consumption and the survey is done by using the questionnaire. LEAP model was used. ICS scenario analysis was carried out.
8.	Maharjan & Nakarmi (2019)	Sustainable Energy Planning at Municipal Level: A case study of Residential sector at Kirtipur Municipality	Two scenarios EHE and SDG were developed using LEAP model with the fuel switching to clean energy and energy efficient technology i.e. Hydro Electricity, Solar electricity and Solar energy.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Methodological Flowchart

The methodology followed for doing the study can be understood from the flowchart as shown in Figure 3.1.

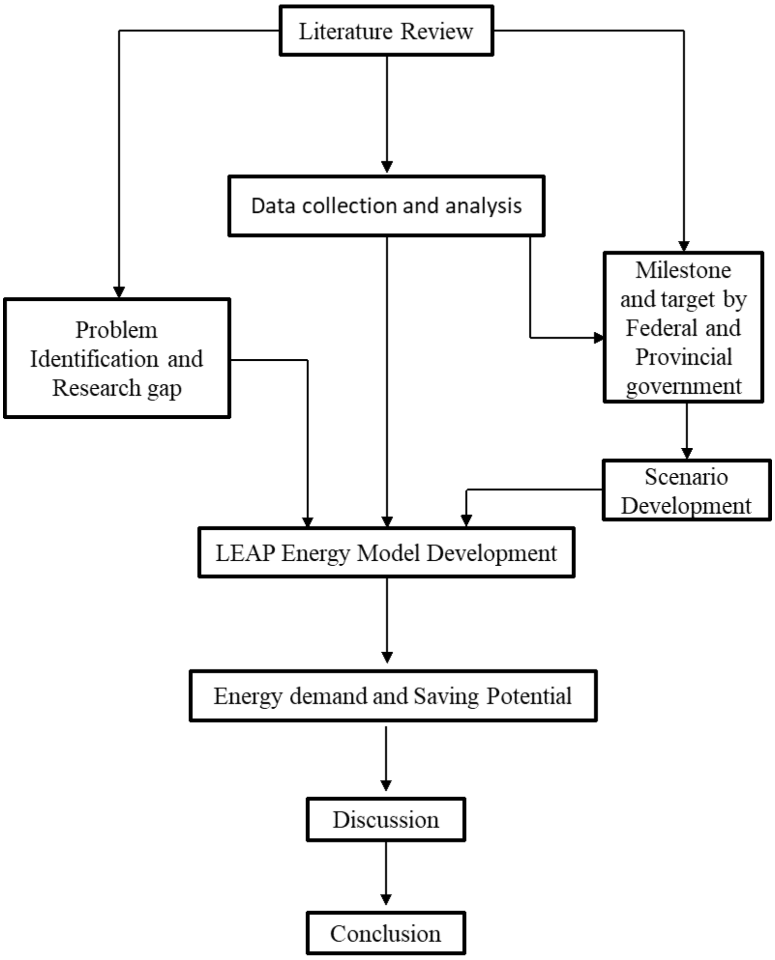


Figure 3.1: Methodological Flowchart of the Research

3.2 Data Collection

To know the current energy pattern on the energy mix of Province One, the reports of different governmental organizations were used for reference. Since most of the data are taken from published reports of the Government authorities and agencies, it's difficult to get the data and information at the level of disaggregation from the government offices exactly as required for this study. However, the data obtained from the Water and Energy Commission Secretariat (WECS) through their various publications were really helpful. Also, while creating the scenarios analysis population growth of Province One is taken into consider i.e. annual average growth rate of 1.35%.

The data and information collected are presented below:

- Province One information about demographic, political and geographical.
- Population of Province One
- Efficiencies of end use fuel type i.e. (Electricity, firewood, LPG etc.)
- Energy consumption at different physiographic region and further disaggregation level.
- Energy supply data from different government authorities
- Fuel prices projections

3.3 Modeling:

LEAP (Long-range Energy Alternatives Planning System) follows an end use, demand-driven approach, which means that the analysis starts from the end use of energy. The demand branch of the LEAP is further divided into the many levels: sectors, sub-sectors, end -uses and devices. LEAP is a simulation model which presents the current energy situation of a particular area and forecasts the future energy demand under certain assumptions such as population growth, GDP, etc. In beginning, the present status of the energy system should be developed by specifying data for the base year, and a basic scenario can be developed assuming a continuation of current trends. LEAP is an integrated modeling tool that can be used in all economic sectors which helps to identify energy production, consumption, and resource extraction. It can be used in different sectors like the energy sector and non-energy sector, greenhouse gas (GHG) emission sources and sinks. Besides tracking GHGs, LEAP is also used for analyzing the effect of local and regional air pollutants which can be further used in the studies of the climate co-benefits of local air pollution reduction.

LEAP has developed a good image among its users for processing complex energy analysis concepts in a simpler and easy learning way. In addition to it, LEAP is widely used by users of various levels of expertise: from global experts who wish to advise on policies and highlight the benefits and final output to decision-makers to trainers those who want to develop their skills in the sectors of the energy system and presenting the findings in a simpler and user-friendly way (Charlie Heaps Slides, 2005)

A long-term residential sector's energy demand model has been formulated for the study using the LEAP framework as shown in Figure 3.1. The residential sector is disaggregated into the different physical region (Mountain, Hill and Terai). Then, each physical region is disaggregated into rural and urban and is further disaggregated to end-use service demand (Cooking, Water Boiling, Space Heating, Space Cooling, Animal Feed, Agriculture, Electrical Appliances, Lighting and Social Services). These service demands are further disaggregated to fuel type (Firewood, LPG, Electricity, Biogas, Solar, Biomass etc).

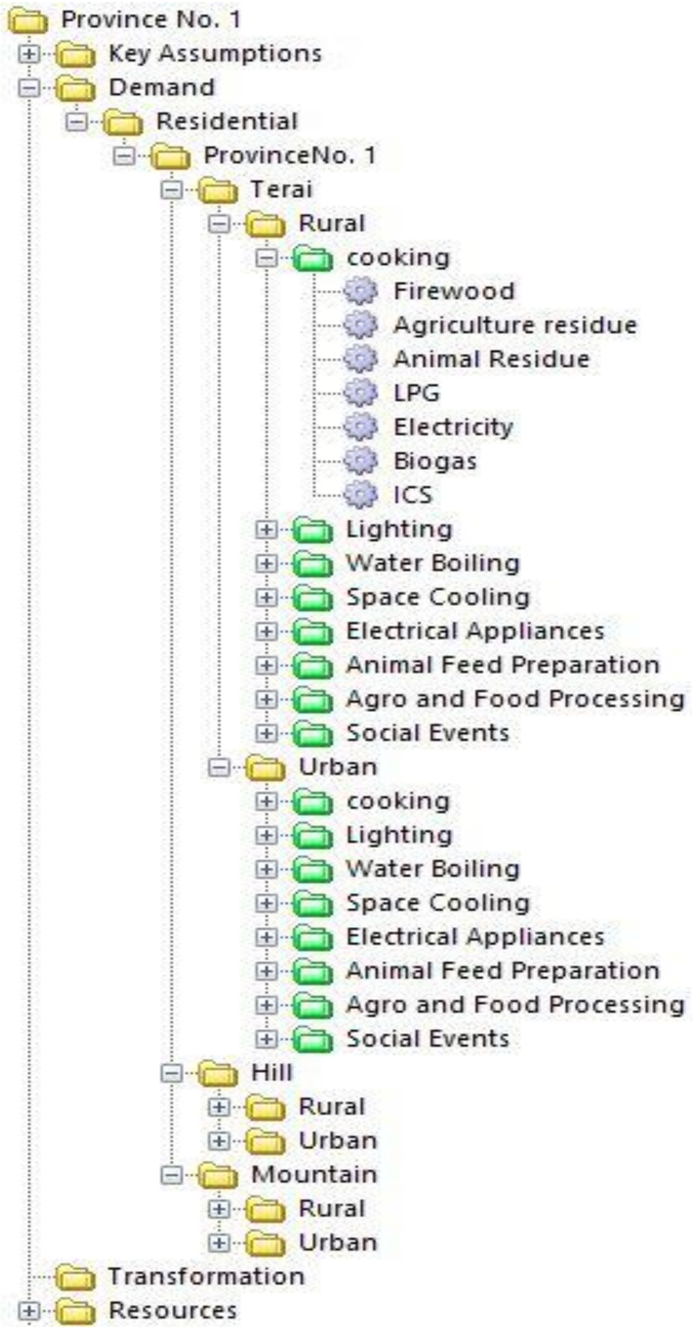


Figure 3.1: Disaggregation of residential sector

3.4 Description of Scenarios

Four different scenarios are carried out in the study i.e., Business as Usual (BAU), Improved Cooking Stove (ICS) scenario, LPG substitution scenario and Sustainable Energy Development Scenario (SEDS).

3.4.1 Business as Usual (BAU) Scenario

Business as usual scenario is the base line scenario which assumes that the past trends will continue in the near future and no additional measurement will be put into practice. Thus, the share of each demand technology in the energy supply in future will be same as in the base year. In this scenario, population growth rate and GDP growth rate will be same as base year.

3.4.2 Improved Cooking Stove (ICS) Scenario

Nepal's 20 Year Renewable Energy Perspective Plan has made a target of increasing the use of improved cooking stoves. Similarly, National Energy Efficiency Strategy has set a target to double the average improvement rate of energy efficiency by 2030. So, in this scenario, all traditional stoves which use firewood as fuel are replaced by the energy efficient improved cooking stoves.

3.4.3 LPG Substitution Scenario

Currently, many new hydropower plants are connected to the national grid and during wet season surplus power management has become a great challenge. On the other hand, import of LPG is increasing annually. Also, Provincial Periodic Plans and renewable energy policy has made a target of reducing use of LPG by e-cooking. Therefore, in this scenario, non-renewable energy LPG is completely replaced by electricity and decrement of firewood by rate 1.5 % to 2030 in residential sector.

3.4.4 Sustainable Energy Development Scenario (SEDS)

In this scenario, various policies and targets are considered while performing analysis. In cooking activity of rural area, fuel wise energy mix is 70% Electric, 10% Fuel wood, 10% ICS and 10% LPG by 2030. 100% use of electricity in cooking and space heating in urban area by 2030. Similarly, lighting, space cooling, and electrical appliances will be 100% electric in 2030 for both rural and urban. For water heating, share of electricity and solar thermal is 60%and 20% respectively in rural area and 100% electrification in the urban area by 2030.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Energy Demand Projection

The final energy demand of residential sector of Province One in four different scenarios (Business as Usual scenario, ICS scenario, LPG substitution scenario and SEDS scenario) is obtained from the prepared energy balance of base year 2019.

4.2 Business as Usual Scenario

Figure 4.1 shows the projection of final energy demand in residential sector of Province One in BAU scenario. In this scenario, the final energy demand is estimated to be 34.6 PJ in year 2030 which was 30 PJ in base year. There is a gradual increase in the final energy demand due to the high consumption of the traditional energy for different service demand which has very low efficiency.

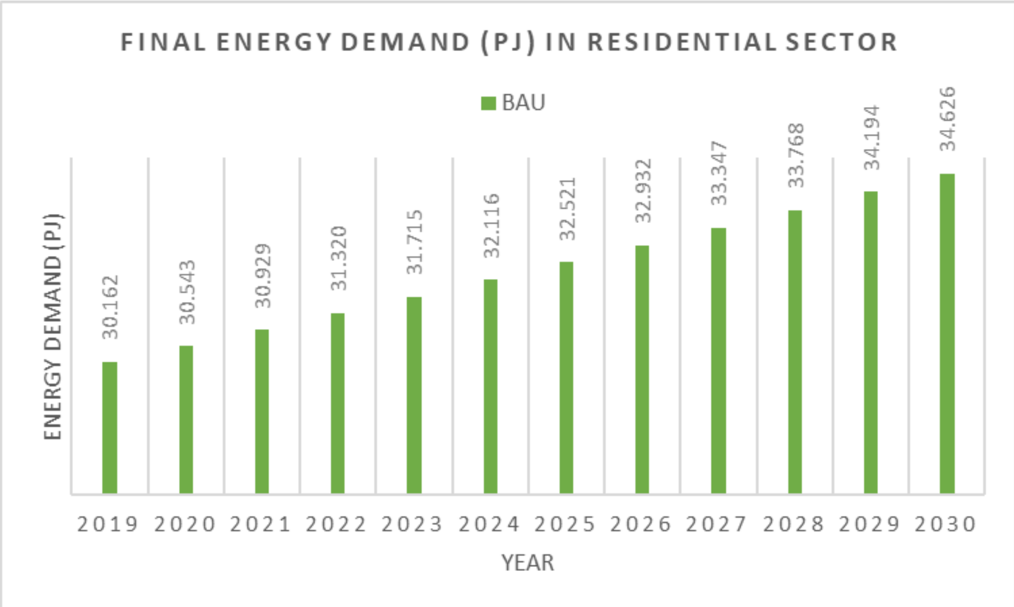


Figure 4.1: Final energy demand in residential sector in BAU scenario

The projection of final energy demand by fuel type in residential sector of Province One in BAU scenario is shown in Figure 4.2. In this scenario, firewood is highly dominated in the energy mix which is found to be in increasing trend. LPG holds the second position in energy consumption followed by electricity.

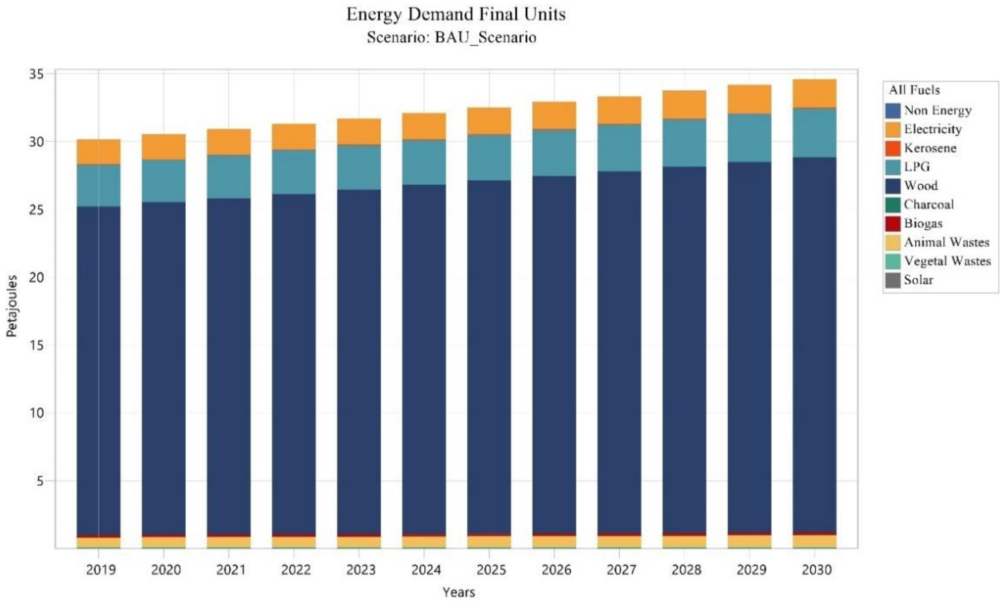
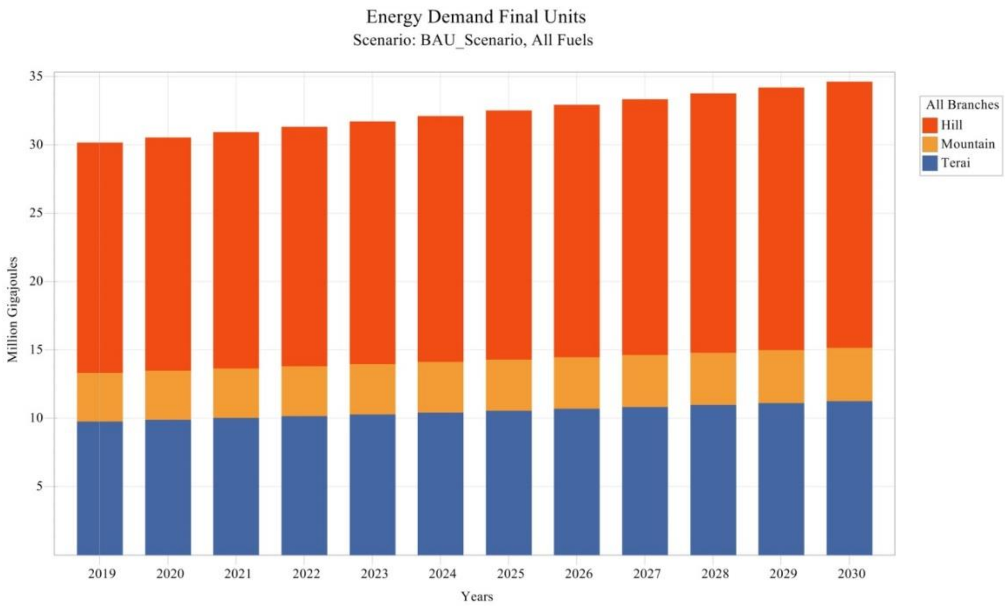


Figure 4.2: End use fuel type demand in BAU scenario

The energy demand projection under physiographic region upto year 2030 in the BAU scenario is shown in Figure 4.3. It is found that the Hilly region has highest energy demand of 19.5 PJ, Terai region has an energy demand of 11.26 PJ and Mountain region has a lowest energy demand of 3.9 PJ in year 2030. The study shows that traditional fuel, firewood is mostly used for cooking and animal feed preparation. In Terai region, consumption of fuels like LPG and Electricity more than that of other two region.

Figure 4.3: Energy demand projection under physiographic region in BAU scenario



Energy mix in residential sector is as shown in Figure 4.4. It shows that wood is the major source of fuel in this sector consuming 80% of total energy consumed followed by LPG. There is consumption of 10% LPG fuel and 6% electricity in this sector. Modern renewables like biogas, briquettes, solar PV, solar thermal is also consumed, however the share is less than 1% of total residential energy consumption. In national scenario in 2011/12, fuelwood had the largest share of 84%, other biomass at 11%, LPG 2% and electricity at 1.6% (WECS, 2013). Comparing that to the Province One at current situation, the consumption of wood is still high, but the share of other biomass has decreased and is replaced by use of electricity and LPG.

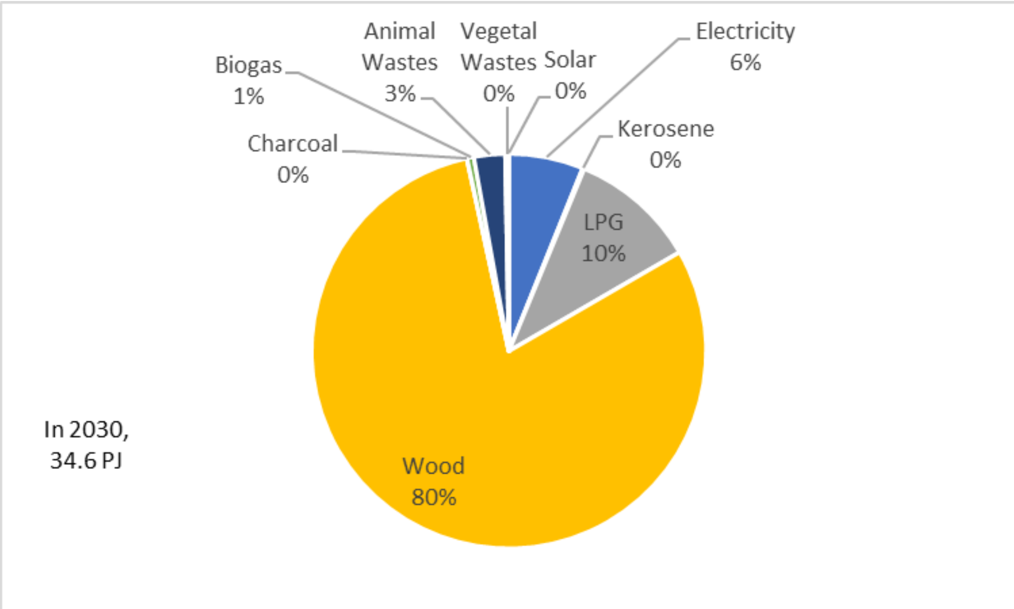


Figure 4.4: Energy mix in residential sector in BAU scenario in year 2030

The Figure 4.5 shows the end use service demand in residential sector in BAU scenario. In residential sector, cooking and animal feeding has the largest share in energy consumption. In base year the consumes 17 PJ of energy which is increased to 20 PJ in the year 2030. Similarly, the energy consumption in animal feed is increased upto 11 PJ by 2030. This mainly due to the use of inefficient technology and traditional energy i.e., fuelwood.

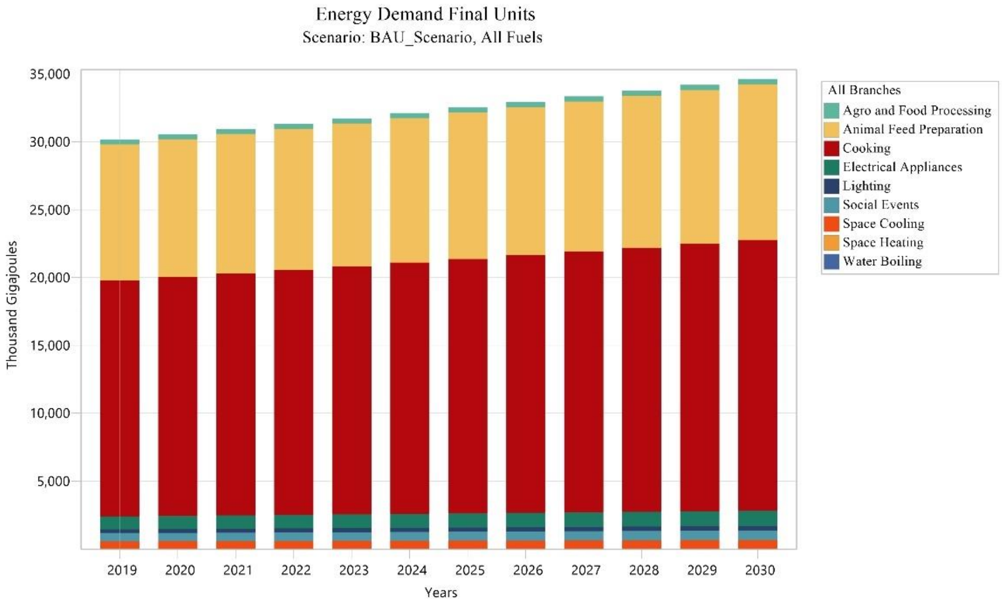


Figure 4.5: End use service demand in residential sector in BAU scenario

The final energy demand in Residential sector of Province One by its fuel type (Solar, Wood, LPG, Electricity, etc.) and its end use service., (Cooking, Heating, Water Boiling, etc.) in BAU scenario in year 2030 is shown in the Table 4.1. It is seen that firewood is still the predominant energy source. Nearly 80% of the energy comes from firewood. The high use of firewood is primarily for cooking and animal feed preparation. The consumption of LPG for cooking is on increasing pattern due to increase in accessibility while electricity consumption is used in household electrical appliances as well as space cooling and lighting.

Table 4.1: Final energy demand in Residential sector of Province One in BAU in 2030 (PJ)

Branch\Fuel Type	Solar	Vegetal Wastes	Animal Wastes	Biogas	Charcoal	Firewood	LPG	Kerosene	Electricity	Total
Agro and Food Processing	-	0.048	-	-	-	0.330	0.002	-	0.000	0.380
Animal Feed Preparation	-	0.014	0.236	-	-	1.146	0.063	-	0.010	11.470
Cooking	-	0.026	0.653	0.175	0.008	5.754	0.275	0.001	0.071	19.963
Electrical Appliances	-	-	-	-	-	-	-	-	1.124	1.124
Lighting	0.011	-	-	-	-	-	-	0.046	0.262	0.319
Social Events	-	-	-	0.015	-	0.433	0.259	-	0.000	0.707
Space Cooling	-	-	-	-	-	-	-	-	0.629	0.629
Space Heating	-	-	-	-	-	-	-	-	0.010	0.010
Water Boiling	-	0.000	0.000	0.002	-	0.013	0.004	-	0.006	0.025
Total	0.011	0.088	0.889	0.191	0.008	27.67	3.60	0.047	2.11	34.62

4.3 Improved Cooking Stove (ICS) Scenario

The final energy demand in residential sector of Province One in ICS scenario is 20.8 PJ in year 2030 which was 30 PJ in base year as shown in Figure 4.6. There is a gradual decrease in total energy demand due to the replacement of traditional cooking stoves used for cooking, water heating, etc. by energy efficient system ICS.

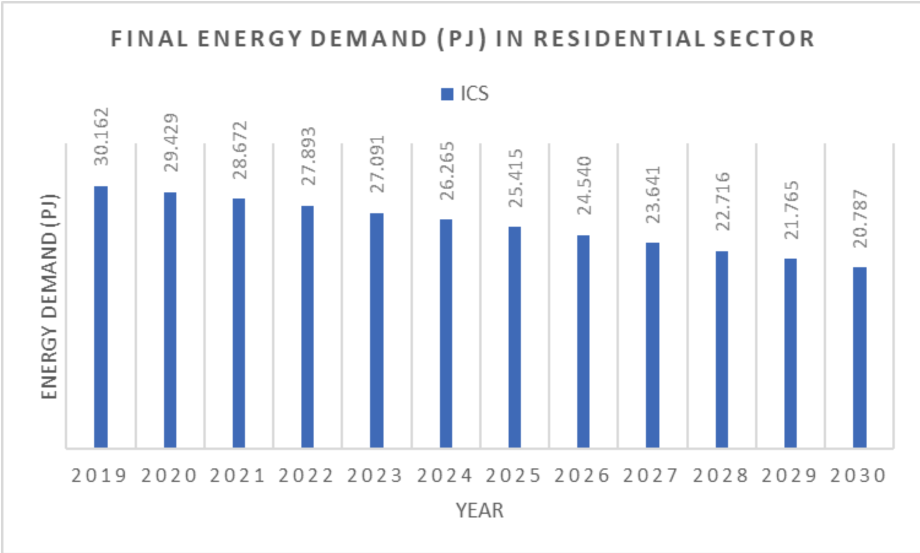


Figure 4.6: Final energy demand in residential sector in ICS scenario

Figure 4.7 shows the final energy demand of end use fuel type in ICS scenario. Firewood consumption has decreased to 14 PJ in year 2030 which was 24 PJ in base year. This decrement in the fuel consumption is mainly due to the implementation of ICS whose efficiency is 30% which is more than three times than traditional cooking stoves.

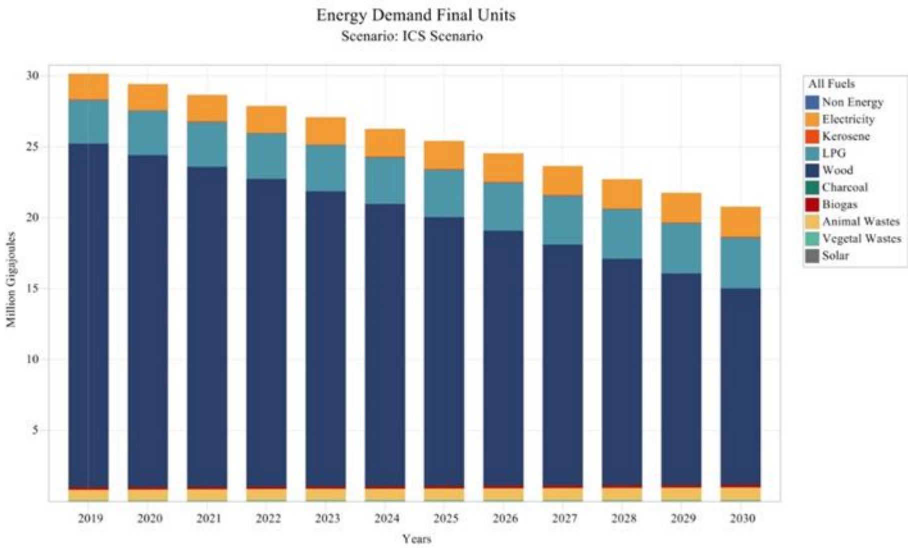


Figure 4.7: End use fuel type demand in ICS Scenario

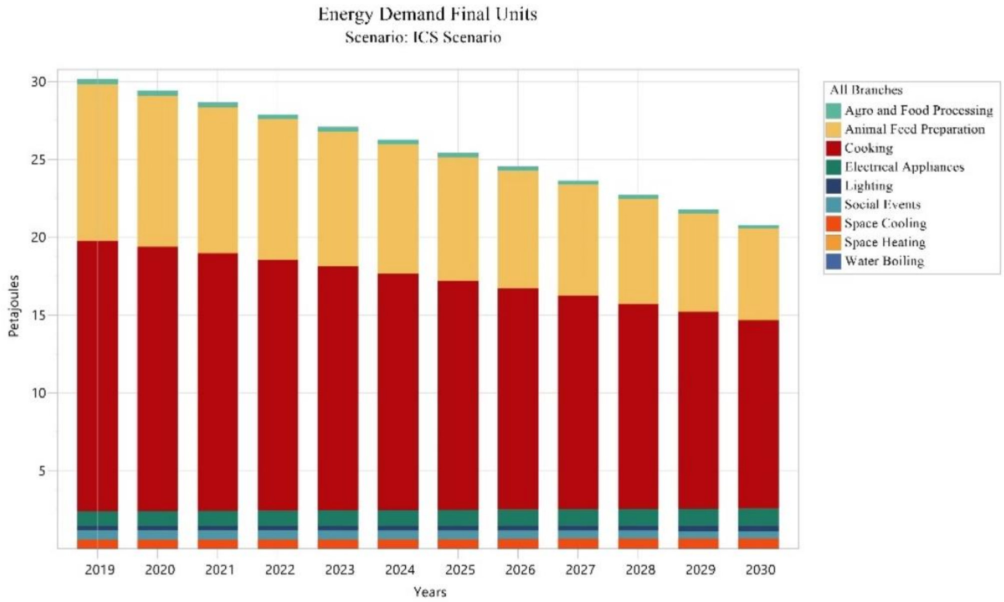


Figure 4.8: End use service demand in ICS Scenario

Figure 4.8 represents the end use service demand in residential sector in ICS scenario i.e. cooking, heating, water boiling, animal feeding etc. Cooking has a highest energy demand of 12 PJ followed by Animal Feed (5.8PJ) and Electrical appliances (1.12 PJ) in year 2030.

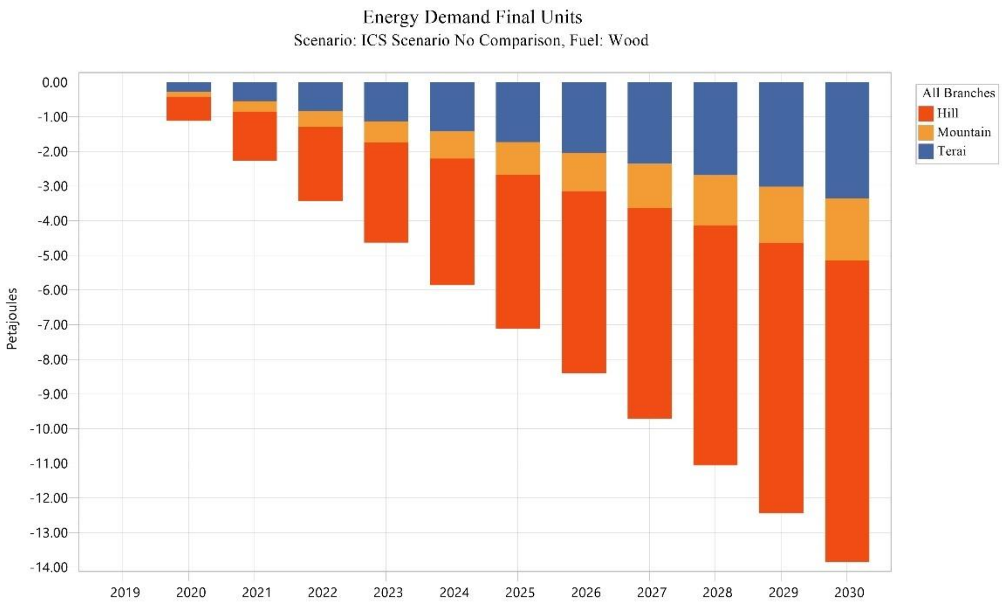


Figure 4.9: Firewood demand in ICS scenario and BAU scenario

Figure 4.9 shows the comparison on demand of firewood in ICS scenario and BAU scenario based on Physiographic region. The study shows that with the implementation of the energy efficient technology i.e. improved cooking stoves in residential sector, about 14 PJ of firewood could be saved in year 2030. In Hilly region, consumption of firewood can be significant reduced than other two regions by replacing the traditional cooking stoves.

4.4 LPG Substitution Scenario

Final energy demand in residential sector of Province One in LPG substitution scenario is shown in Figure 4.10. In this scenario, the final energy demand is expected to be 28.9 PJ in 2030 which was 30 PJ in the base year. As the efficiency of the LPG and Electricity are nearly equal, so the final energy demand is not significantly changed yet the penetration of electricity is gradually increasing in the energy mix and contribution of LPG is null by 2030.

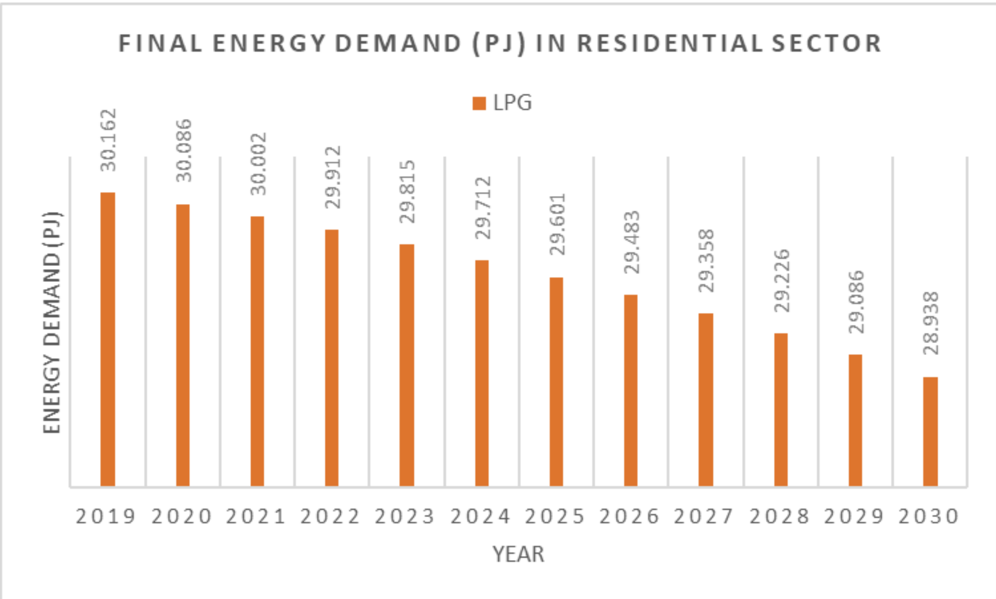


Figure 4.10: Final energy demand in residential sector in LPG substitution scenario

Figure 4.11 shows the projection of end use fuel type in LPG substitution scenario. In this scenario, the demand of electricity is just 1.8 PJ in base year which is then gradually increased upto 6 PJ in year 2030. Also, the demand of firewood is expected to be 21 PJ in 2030 which was 24 PJ in base year.

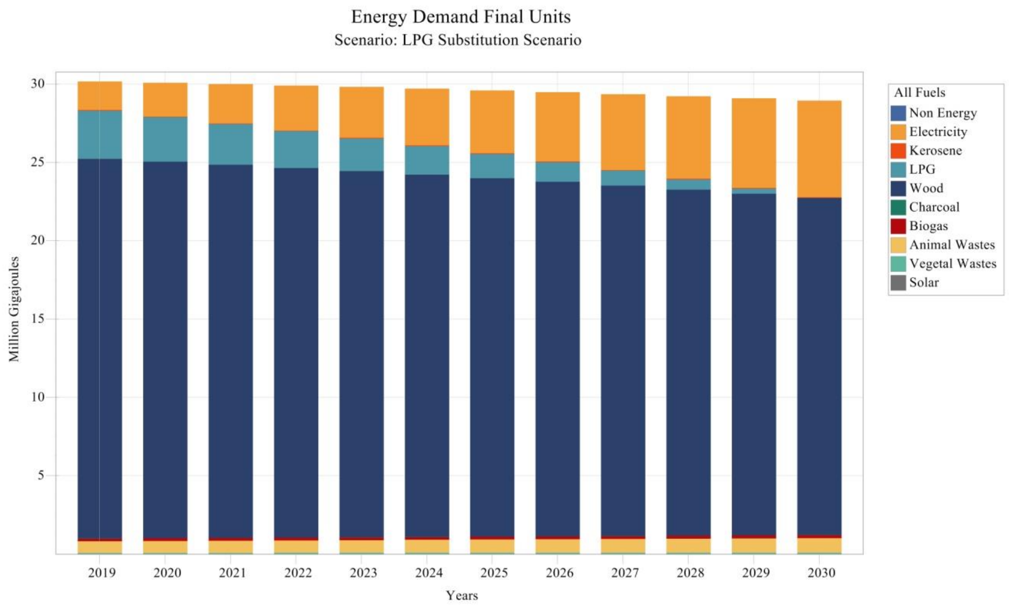


Figure 4.11: End use fuel type demand in LPG Substitution scenario

Energy saving with the substitution of LPG and firewood by Electricity in LPG substitution and BAU scenario is shown in the Figure 4.12. It is found that electricity demand increases to 6.2 PJ in year 2030 from 1.8 PJ in base year. Also, the consumption of firewood is decreased to 21.5 PJ in 2030 which was 24.3 in base year.

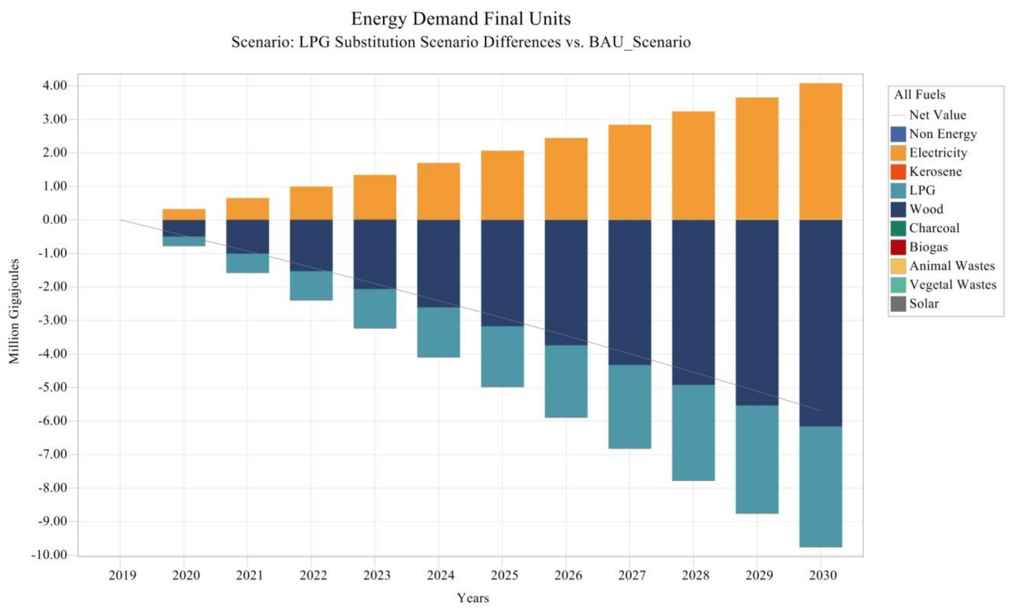


Figure 4.12: Comparison on fuel uses in LPG substitution and BAU scenario

4.5 Sustainable Energy Development Scenario (SEDS)

Final energy demand in the residential sector of Province One in SEDS scenario is shown in Figure 4.13 below. In this scenario, the final energy demand is expected to be 12.6 PJ in 2030 which was 30 PJ in the base year. There is a significant change in the final energy demand mainly due to the replacement of traditional and inefficient technology by renewable and energy efficient technology in the energy system.

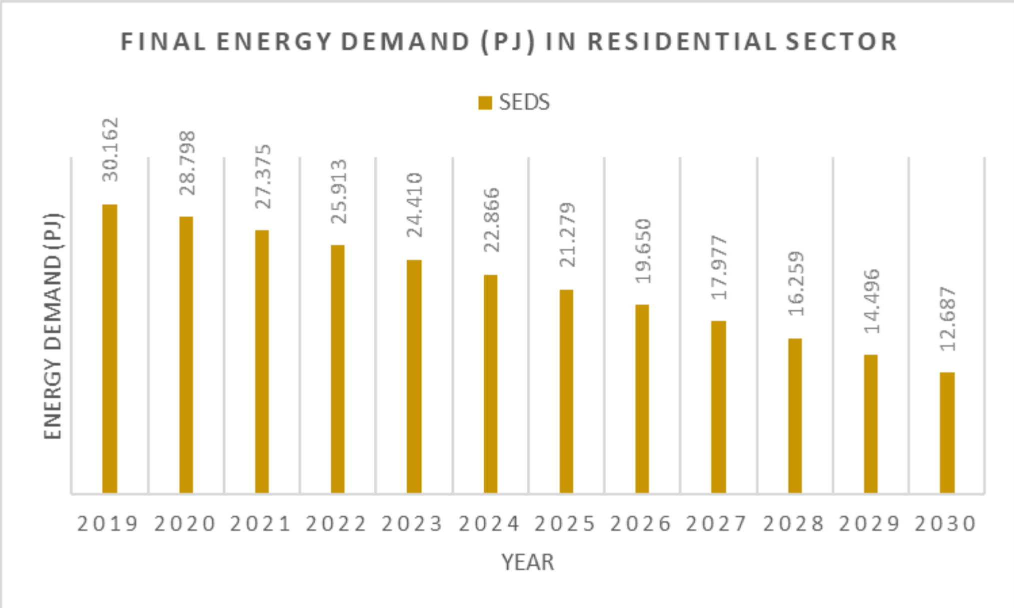


Figure 4.13: Final energy demand in residential sector in SEDS scenario

The Figure 4.14 shows that the energy mix in 2019 is Wood (80%), LPG (10%) and followed by electricity (6%), animal waste (3%) and others. With the implementation of energy efficient technology and renewable energy, the energy mix by 2030 is dominated by electricity (75%) and followed by Wood (21%), LPG (3%) and others. Hence, SEDS scenario, shows that the share of electricity increases by 69%, fuel import decreases by 7% and use of traditional fuel decreases by 60% promoting the use of clean and renewable energy.

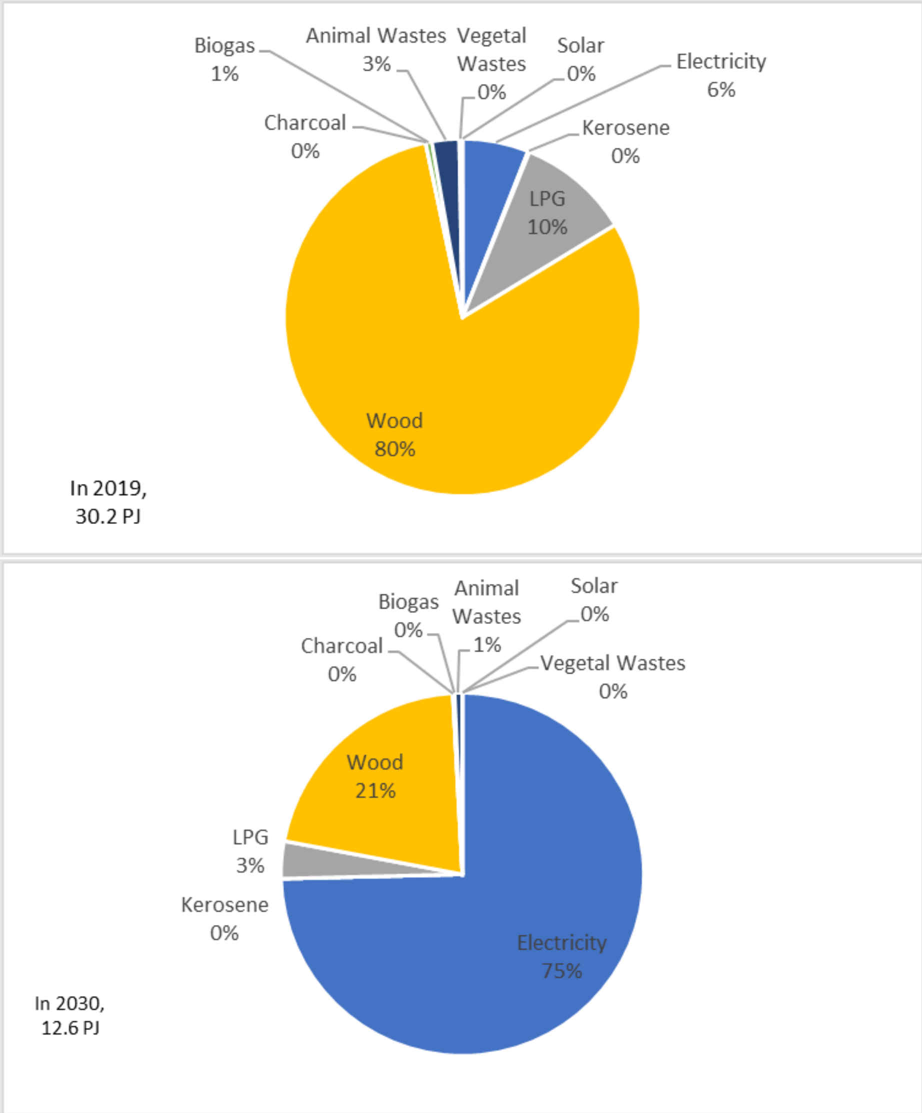


Figure 4.14: Energy mix in residential sector of Province One in SEDS scenario

The Figure 4.15 represents the energy demand projection under physiographic region upto year 2030 in the SEDS scenario. It is found that the energy demand in the Hilly region has decreased significantly in year 2030 than base year. This is mainly due to the high consumption of firewood for cooking and animal feed.

Similarly, the final energy demand in Residential sector of Province One by its fuel type (Solar, Wood, LPG, Electricity, etc.) and end use service demand i.e., (Cooking, Heating, Water Boiling, etc.) in SEDS scenario in year 2030 is shown in the Table 4.2 below. It is seen that electricity is dominant energy source followed by firewood. The high use of electricity is mainly for cooking and animal feed preparation and electrical appliances.

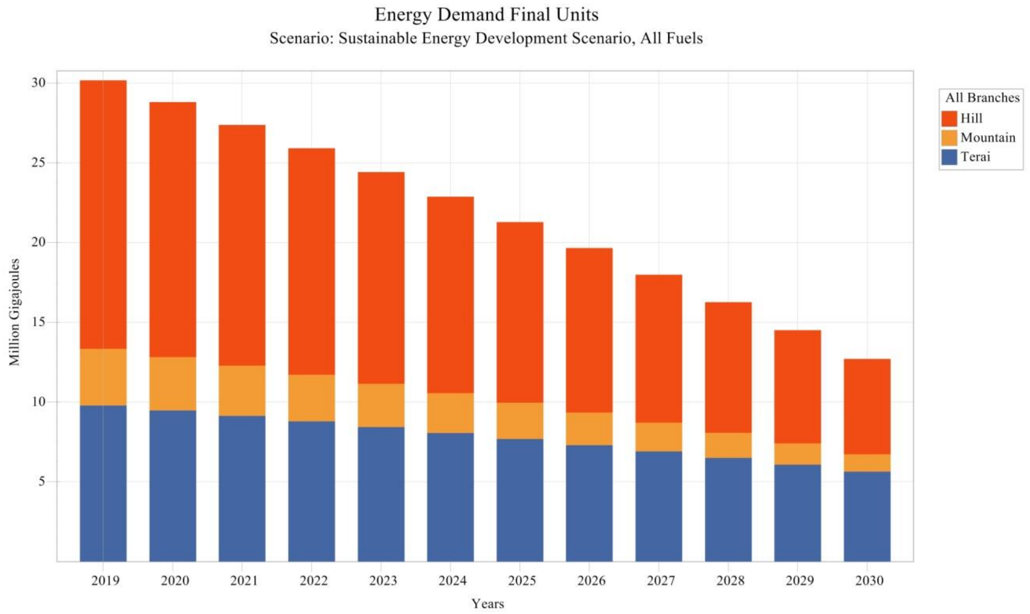


Figure 4.15: Final energy demand in physiographic region in SEDS scenario

The Figure 4.16 shows the end use service demand in residential sector in SEDS scenario. In base year, cooking and animal feeding have an energy consumption of 17 PJ and 10 PJ respectively. By the implementation of the energy efficient technology demand of energy for cooking and animal feeding has decreased significantly to 7.2 PJ and 2.9 PJ respectively satisfying all the needs.

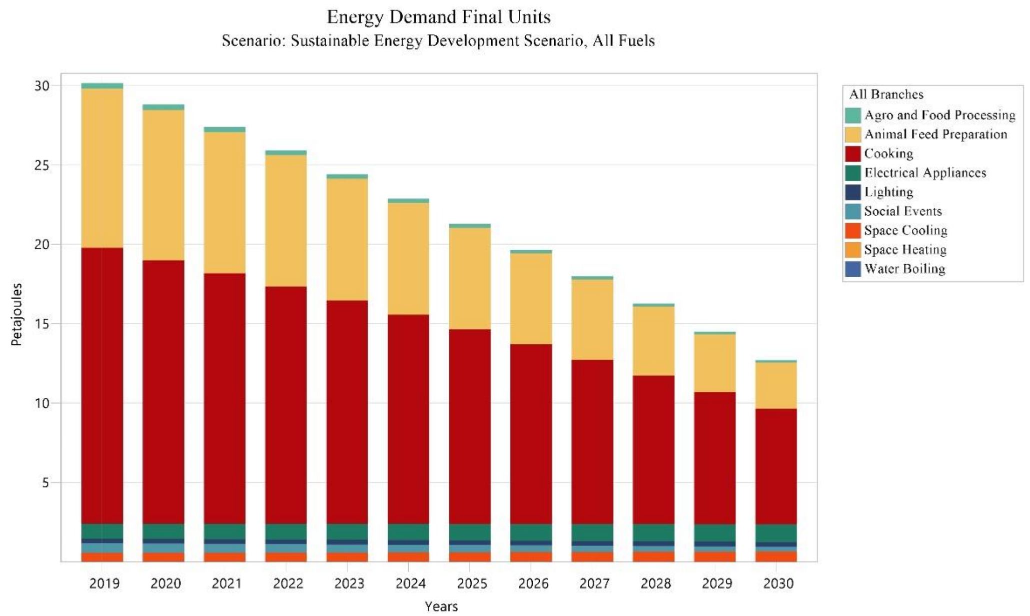


Figure 4.16: End use service demand in residential sector in SEDS scenario

Table 4.2: Final energy demand in Residential sector of Province One in SEDS in 2030 (PJ)

Branch\Fuel Type	Solar	Vegetal Wastes	Animal Wastes	Biogas	Charcoal	Firewood	LPG	Kerosene	Electricity	Total
Agro and Food Processing	-	-	-	-	-	0.068	0.001	-	0.055	0.124
Animal Feed Preparation	-	-	0.087	-	-	0.933	0.028	-	1.870	2.918
Cooking	-	-	-	0.019	-	1.689	0.394	-	5.172	7.274
Electrical Appliances	-	-	-	-	-	-	-	-	1.125	1.125
Lighting	-	-	-	-	-	-	-	-	0.293	0.293
Social Events	-	-	-	-	-	-	-	-	0.300	0.300
Space Cooling	-	-	-	-	-	-	-	-	0.630	0.630
Space Heating	-	-	-	-	-	-	-	-	0.010	0.010
Water Boiling	0.000	-	-	0.001	-	0.000	-	-	0.012	0.013
Total	0.00	-	0.087	0.020	-	2.691	0.43	-	9.466	12.687

4.6 Final Energy Demand

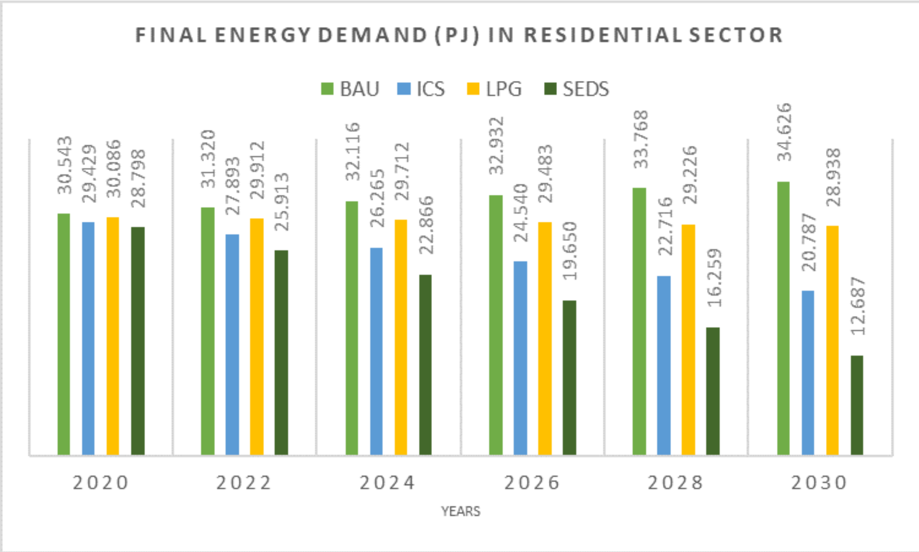


Figure 4.17: Final energy demand BAU, ICS, LPG and SEDS scenario

The Figure 4.17 shows that the final energy demand in BAU, ICS, LPG and SEDS scenario which shows the final energy demand can be reduced to 12.6 PJ in 2030 by policy intervention. In BAU scenario, the final energy demand of residential sector is 34.6 PJ by 2030.Similarly, report of WECS shows that the final energy demand of residential sector of Province One in 2030 under BAU scenario is found to be 34.95 PJ (WECS, 2021). Difference on energy demand is less than 1% which validate the result of this study.

4.7 Energy Demand Per Capita

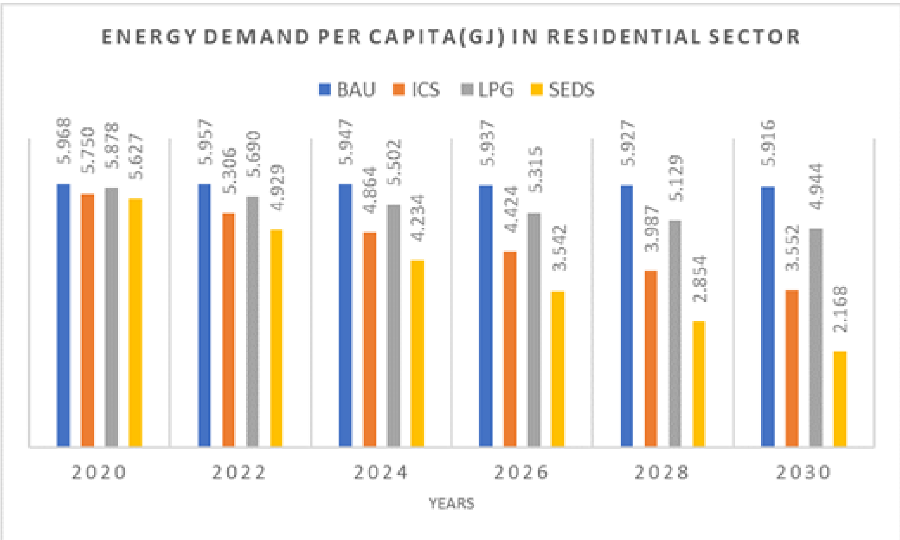


Figure 4.18: Energy Demand Per capita BAU, ICS, LPG and SEDS scenario

Above Figure 4.18 shows that the energy demand per capita can be reduced up to 2.1 GJ in SEDS scenario from 5.9 GJ in BAU scenario in year 2030 by the use of energy efficient technology and renewable energy. Energy demand per capita under SEDS scenario in 2030 is 2.1 GJ which is 12% lesser than that of Kirtipur Municipality (2.4 GJ) under SDG scenario in 2030 (Jenish Maharjan, A. M. , 2019). This reduction in energy demand is mainly due to use of energy efficient technology (ICS).

4.8 Electricity Demand Per Capita

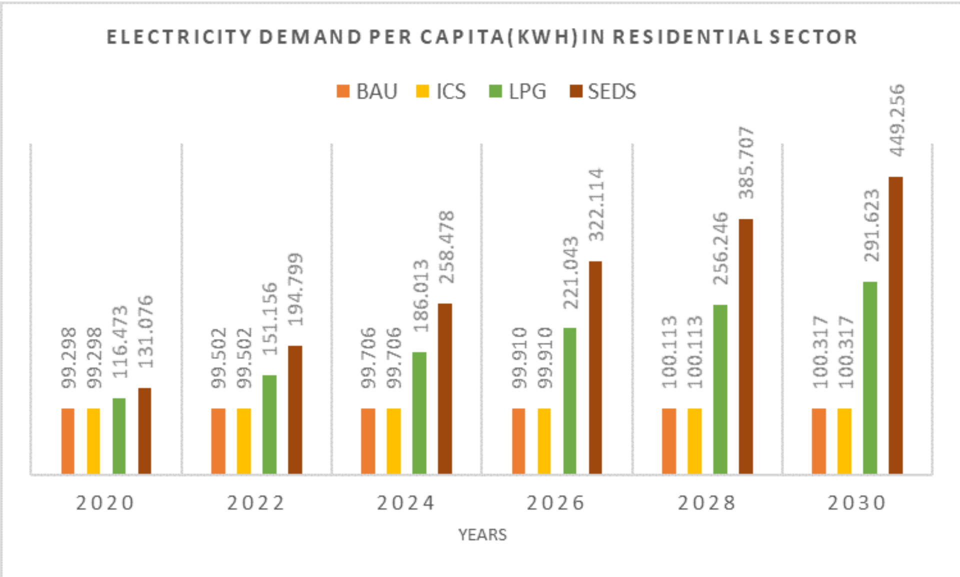


Figure 4.19: Electricity Demand Per capita BAU, ICS, LPG and SEDS scenario

Above Figure 4.19 shows that the electricity demand per capita can be increased up to 449.2 kWh in SEDS scenario over 100.31 kWh in BAU scenario in 2030. Also, on substitution of LPG with electricity, the electricity demand per capita can be increased up to 291 kWh from 100 kWh in year 2030. The electricity demand per capita of Province One considering all economic sector (residential, transport, industrial, commercial and agriculture etc) is found to be 574kWh (Sujan Dulal, S. R., 2019). It is 27% more than electricity demand per capita under SEDS scenario. This difference is due to the consideration of residential sector only in this study and with the use of efficient technology.

4.9 GHG Emission

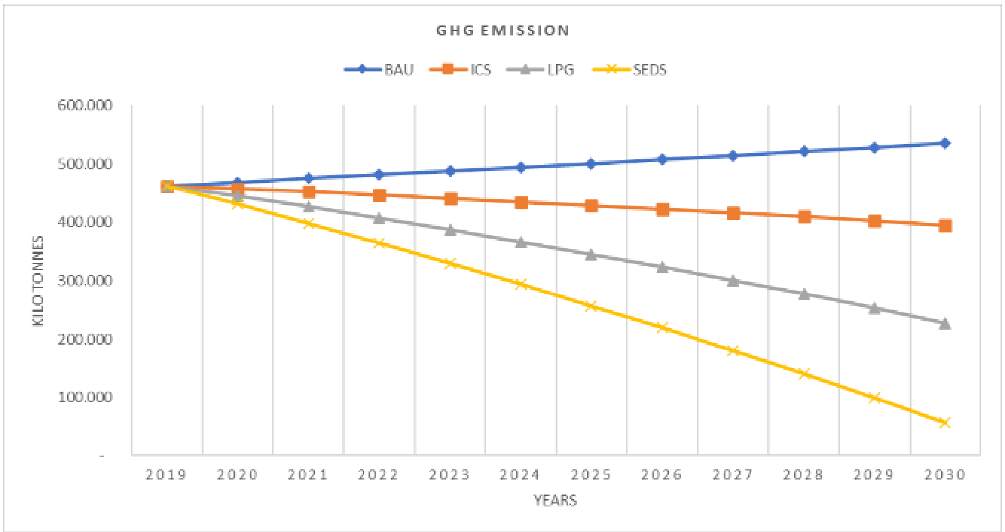


Figure 4.20: GHG Emission at BAU, ICS, LPG and SEDS scenario

Above Figure 4.20 shows that GHG Emissions in residential sector of Province One can be gradually reduced from 462 kt (Kilo Tonnes) of CO_2 equivalent in base year to 56 kt of CO_2 equivalent in year 2030 in SEDS scenario by switching to Renewable energy and energy efficient technology. SEDS scenario has the least GHG emission followed by LPG and ICS scenario. In BAU scenario, GHG emission is higher mainly due to the use of firewood for cooking and animal feed. The efficiency of the traditional cooking stoves is also quite low.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The final energy demand of Residential sector of Province One is expected to reach a value of 34.6 PJ at 2030 in BAU scenario which is about 16% more than that of base year. The energy mix in BAU scenario by 2030 is fuel wood holding largest share (80%) followed by LPG (10%), Electricity (6%) and others. However, in a sustainable energy development scenario, the final energy demand will be 12.6 PJ by 2030 which is similar to that of base year. In case of sustainable energy development scenario, the final energy demand is 12.6 PJ by 2030. This energy demand is 63% less than that in BAU scenario. The reason behind the reduction of energy demand than BAU scenario is due to the penetration of high electricity (74%) in the energy system, energy efficient technology and renewable energy. In SEDS scenario, the demand of electricity in the fuel mix increases by five times than in base year whereas in BAU scenario, it is just 1.2 times than the base year.

The study shows that electricity demand per capita increases to 449.2 kWh in SEDS scenario and 100.31 kWh in BAU scenario in 2030. On substitution of LPG with electricity, the electricity demand per capita increases up to 291 kWh from 100 kWh in the year 2030. GHG emissions decreases from 462 kt of CO_2 equivalent in base year to 56 kt of CO_2 equivalent in year 2030 in SEDS scenario by switching to Renewable energy and efficient technology.

Hence, it can be concluded that with the substitution of LPG, traditional fuelwood and inefficient device with electricity, other renewable energy and energy efficient technology, the final energy demand can be significantly reduced meeting all the energy demand which ultimately reduces the GHG emission and saves the fuel expenditures. In addition to that the share of electricity in energy system increases with the increase in electricity demand per capita resulting to optimum utilization of surplus electrical power generated from hydropower.

5.2 Recommendations

Demand of electricity is raising each year in each scenario; thus, reliable and affordable supply of electricity shall be planned accordingly. Majority of households still use traditional cooking stoves, so the effective promotion of ICS should be initiated. Total GHG emission can be reduced significantly in SEDS scenario, so planning shall be carried out accordingly.

5.3 Future Research Work

This research is intended to find the residential sector energy demand and scenario analysis of Province One. Further research can be carried out to find the total energy demand of Province One including all the economic sectors like transport, industrial, commercial and others by preparing necessary energy database of all sectors. Eventually overall integrated energy planning of the whole county can also be done.

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APPENDIX A: Physiographic region wise energy demand in residential sector

Table A.1: In BAU scenario for base year (2019)

Branch	Solar	Vegetal Wastes	Animal Wastes	Biogas	Charcoal	Wood	LPG	Kerosene	Electricity	Total
Province One	0.010	0.077	0.747	0.165	0.007	24.234	3.079	0.040	1.803	30.162
Terai	0.000	0.076	0.736	0.136	-	5.907	1.919	0.000	1.006	9.781
Rural	0.000	0.035	0.053	0.044	-	3.386	0.481	0.000	0.173	4.171
Urban	0.000	0.041	0.683	0.092	-	2.521	1.439	0.000	0.833	5.610
Hill	0.009	0.000	0.001	0.026	0.002	15.028	0.957	0.039	0.760	16.823
Rural	0.004	0.000	-	0.021	0.001	9.463	0.251	0.026	0.326	10.092
Urban	0.005	-	0.001	0.005	0.002	5.565	0.706	0.014	0.434	6.731
Mountain	0.001	-	0.010	0.002	0.005	3.299	0.202	0.001	0.037	3.558
Rural	0.001	-	0.010	0.002	0.003	2.532	0.062	0.000	0.012	2.621
Urban	0.000	-	-	0.001	0.002	0.767	0.141	0.001	0.026	0.937
Total	0.010	0.077	0.747	0.165	0.007	24.234	3.079	0.040	1.803	30.162

Table A.2: In BAU scenario for year 2030

Branch	Solar	Vegetal Wastes	Animal Wastes	Biogas	Charcoal	Wood	LPG	Kerosene	Electricity	Total
Province One	0.011	0.088	0.889	0.191	0.008	27.676	3.602	0.047	2.114	34.626
Terai	0.000	0.088	0.877	0.159	-	6.709	2.249	0.000	1.187	11.269
Rural	0.000	0.039	0.057	0.048	-	3.685	0.523	0.000	0.188	4.540
Urban	0.000	0.049	0.820	0.110	-	3.024	1.726	0.000	0.999	6.729
Hill	0.010	0.000	0.001	0.030	0.003	17.367	1.115	0.045	0.883	19.455
Rural	0.005	0.000	-	0.024	0.001	10.842	0.288	0.029	0.373	11.562
Urban	0.005	-	0.001	0.006	0.002	6.525	0.828	0.016	0.509	7.893
Mountain	0.001	-	0.011	0.002	0.005	3.600	0.237	0.001	0.044	3.902
Rural	0.001	-	0.011	0.002	0.003	2.660	0.065	0.000	0.012	2.754
Urban	0.000	-	-	0.001	0.002	0.940	0.172	0.001	0.031	1.148
Total	0.011	0.088	0.889	0.191	0.008	27.676	3.602	0.047	2.114	34.626

Table A.3: In ICS scenario for year 2030

Branch	Solar	Vegetal Wastes	Animal Wastes	Biogas	Charcoal	Wood	LPG	Kerosene	Electricity	Total
Province One	0.011	0.088	0.889	0.191	0.008	13.838	3.602	0.047	2.114	20.787
Terai	0.000	0.088	0.877	0.159	-	3.354	2.249	0.000	1.187	7.914
Rural	0.000	0.039	0.057	0.048	-	1.842	0.523	0.000	0.188	2.697
Urban	0.000	0.049	0.820	0.110	-	1.512	1.726	0.000	0.999	5.217
Hill	0.010	0.000	0.001	0.030	0.003	8.683	1.115	0.045	0.883	10.771
Rural	0.005	0.000	-	0.024	0.001	5.421	0.288	0.029	0.373	6.141
Urban	0.005	-	0.001	0.006	0.002	3.263	0.828	0.016	0.509	4.630
Mountain	0.001	-	0.011	0.002	0.005	1.800	0.237	0.001	0.044	2.102
Rural	0.001	-	0.011	0.002	0.003	1.330	0.065	0.000	0.012	1.424
Urban	0.000	-	-	0.001	0.002	0.470	0.172	0.001	0.031	0.678
Total	0.011	0.088	0.889	0.191	0.008	13.838	3.602	0.047	2.114	20.787

Table A.4: In LPG substitution scenario for year 2030

Branch	Solar	Vegetal Wastes	Animal Wastes	Biogas	Charcoal	Wood	LPG	Kerosene	Electricity	Total
Province One	0.011	0.087	0.932	0.192	0.008	21.516	0.001	0.046	6.144	28.938
Terai	0.000	0.086	0.923	0.160	-	5.177	0.001	0.000	3.331	9.678
Rural	0.000	0.034	0.050	0.042	-	2.719	-	0.000	0.632	3.478
Urban	0.000	0.052	0.873	0.118	-	2.458	0.001	0.000	2.698	6.201
Hill	0.010	0.000	0.001	0.030	0.003	13.641	-	0.045	2.483	16.212
Rural	0.005	0.000	-	0.024	0.001	8.475	-	0.029	0.995	9.528
Urban	0.005	-	0.001	0.006	0.002	5.165	-	0.016	1.488	6.684
Mountain	0.001	-	0.009	0.002	0.005	2.698	-	0.001	0.331	3.047
Rural	0.001	-	0.009	0.001	0.002	1.908	-	0.000	0.100	2.021
Urban	0.000	-	-	0.001	0.002	0.791	-	0.001	0.231	1.026
Total	0.011	0.087	0.932	0.192	0.008	21.516	0.001	0.046	6.144	28.938

Table A.5: In SEDS scenario for year 2030

Branch	Solar	Vegetal Wastes	Animal Wastes	Biogas	Charcoal	Wood	LPG	Kerosene	Electricity	Total
Province One	0.000	-	0.087	0.020	-	2.691	0.423	-	9.466	12.687
Terai	0.000	-	0.087	0.000	-	1.271	0.149	-	4.134	5.642
Rural	0.000	-	-	0.000	-	0.830	0.120	-	1.049	1.999
Urban	-	-	0.087	-	-	0.441	0.029	-	3.085	3.642
Hill	-	-	-	0.001	-	1.173	0.239	-	4.540	5.953
Rural	-	-	-	0.001	-	1.008	0.239	-	2.180	3.428
Urban	-	-	-	-	-	0.165	-	-	2.360	2.525
Mountain	-	-	-	0.019	-	0.247	0.035	-	0.791	1.092
Rural	-	-	-	0.019	-	0.222	0.035	-	0.455	0.732
Urban	-	-	-	-	-	0.024	-	-	0.336	0.360
Total	0.000	-	0.087	0.020	-	2.691	0.423	-	9.466	12.687

APPENDIX B: Energy consumption in Urban and Rural -residential sector

Table A.6: Energy consumption in Urban-Residential Sector (TJ) (WECS,2021)

	Cooking	**Water boiling**	**Space heating**	**Space Cooling**	**Lighting**	**Electrical Appliances**	**Animal feed preparation**	**Agro and food processing**	**Social events**	
Firewood	5,119	7	4	-	-	-	3,447	131	161	**8,869**
Agricultural residue	1	0	-	-	-	-	-	2	-	**3**
Animal waste	488	0	-	-	-	-	275	-	-	**763**
Coal	0	-	-	-	-	-	-	-	-	**0**
kerosene	1	-	-	-	14	-	-	-	-	**15**
LPG	2,063	3	1	-	-	-	43	4	202	**2,316**
Diesel	-	-	-	-	-	-	-	-	-	**-**
Gasoline	-	-	-	-	-	-	-	-	-	**-**
Electricity	48	0	2	419	124	689	0	0	0	**1,281**
biogas	19	0	-	-	-	-	1	-	5	**25.3**
briquettes	0	-	-	-	-	-	-	-	-	**0.4**
Solar thermal	-	0	-	-	-	-	-	-	-	**0**
Solar PV	-	-	-	-	5	-	-	-	-	**5.0**
	7,741	**10.7**	**7**	**419**	**142**	**689**	**3,765**	**137.2**	**367**	**13,278**

Table A.7: Energy consumption in Rural-Residential Sector (TJ) (WECS,2021)

	Cooking	**Water boiling**	**Space heating**	**Space Cooling**	**Lighting**	**Electrical Appliances**	**Animal feed preparation**	**Agro and food processing**	**Social events**	
Firewood	8,714	2.91	-	-	-	-	6,254	202	220	**15,392**
Agri residue	26	0.02	-	-	-	-	13	-	-	**39**
Animal waste	63	-	-	-	-	-	-	-	-	**63**
Coal	3.59	-	-	-	-	-	-	-	-	**3.59**
kerosene	-	-	-	-	26	-	-	-	-	**26**
LPG	793	0.16	-	-	-	-	-	-	18	**811**
Diesel	-	-	-	-	-	-	-	-	-	**-**
Gasoline	-	-	-	-	-	-	-	-	-	**-**
Electricity	15	6	1.56	116	102	270	-	0.02	0.08	**510**
biogas	28	1.66	-	-	-	-	-	-	5.20	**35**
briquettes	-	-	-	-	-	-	-	-	-	**-**
Solar thermal	-	0.00	-	-	-	-	-	-	-	**0.00**
Solar PV	-	-	-	-	5	-	-	-	-	**4.9**
	9,642	**10.3**	**1.56**	**116**	**133**	**270**	**6,267**	**202**	**243**	**16,885**

APPENDIX C: Final Energy Demand in Sankey Diagram in year 2030

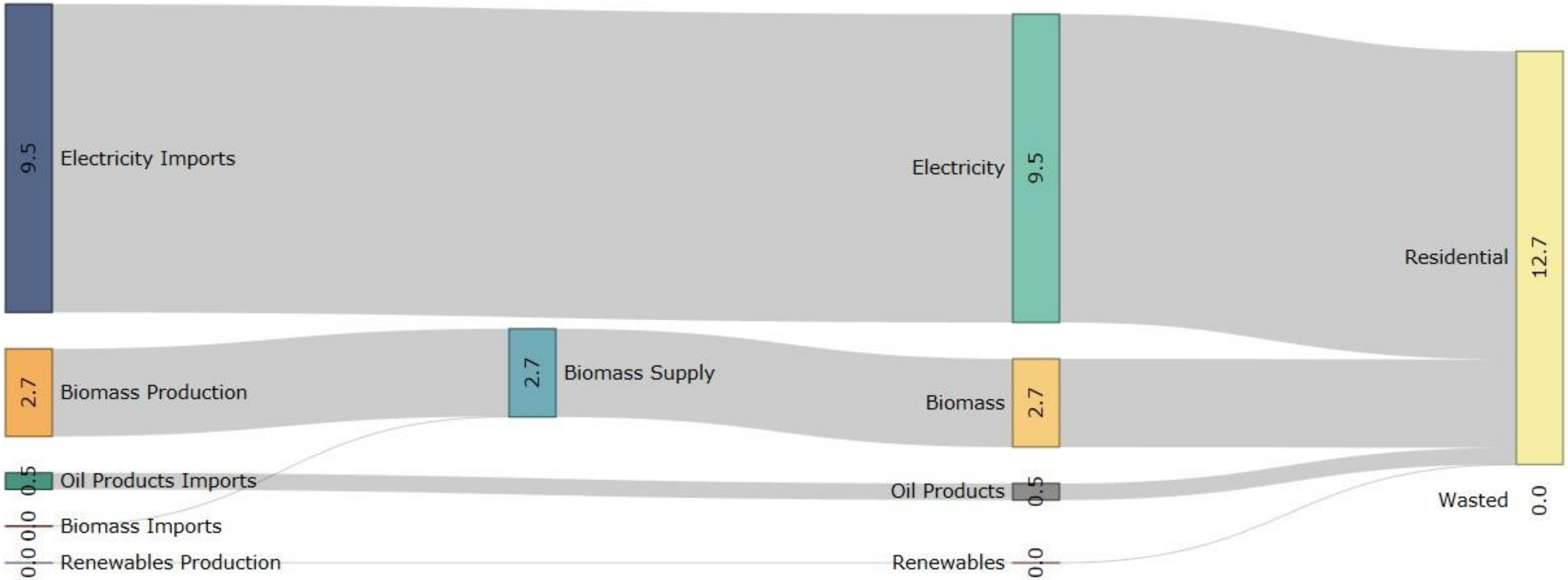


Figure A.1: Energy demand (PJ) in SEDS scenario in year 2030

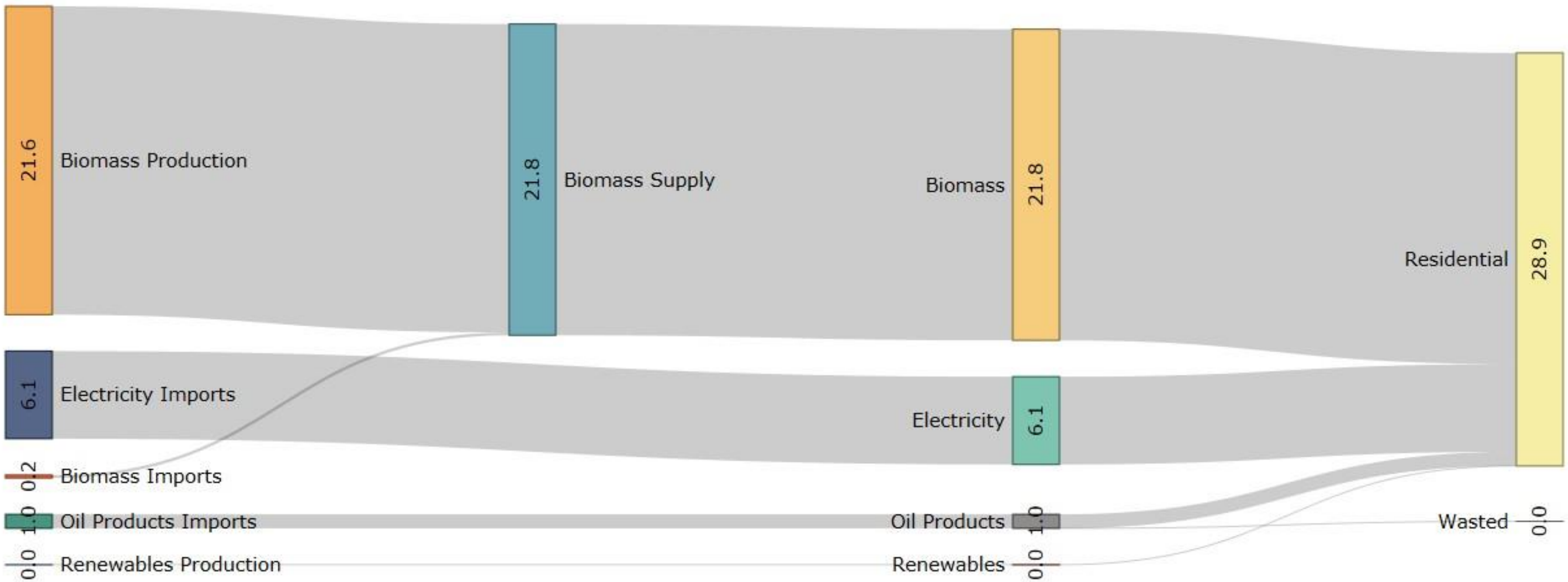


Figure A.2: Energy demand (PJ) in LPG substitution scenario in year 2030

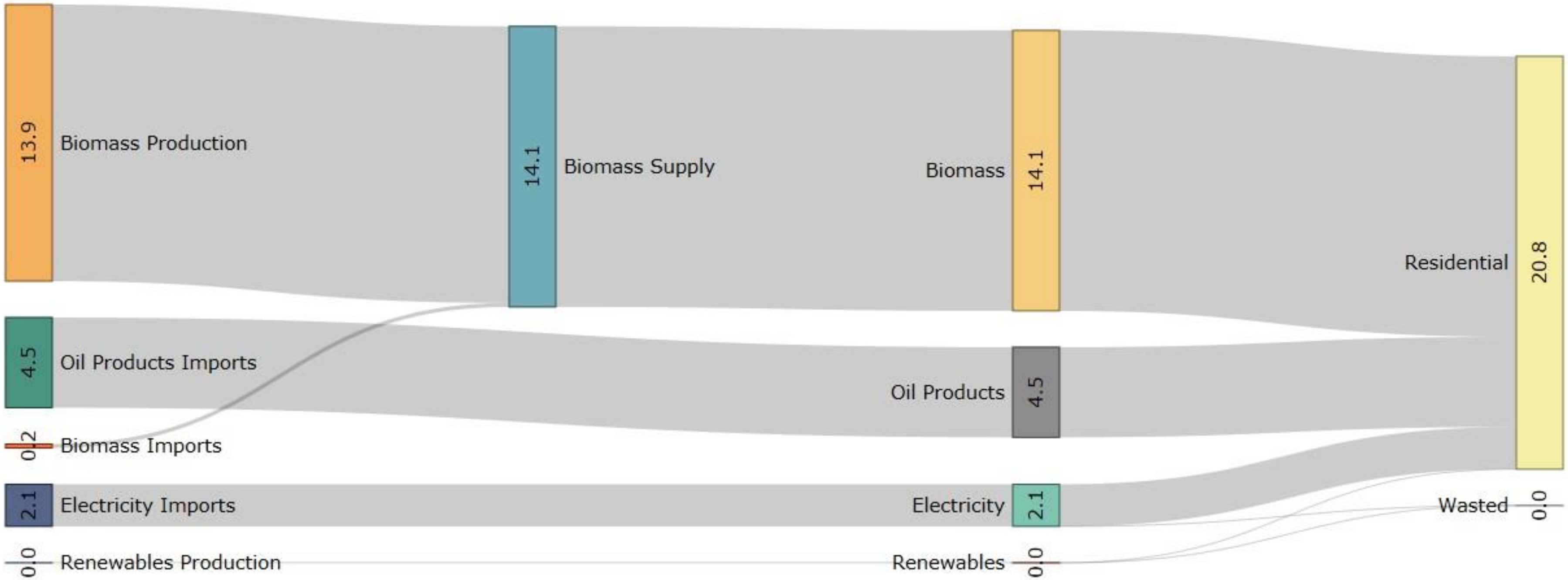


Figure A.3: Energy demand (PJ) in ICS scenario in year 2030

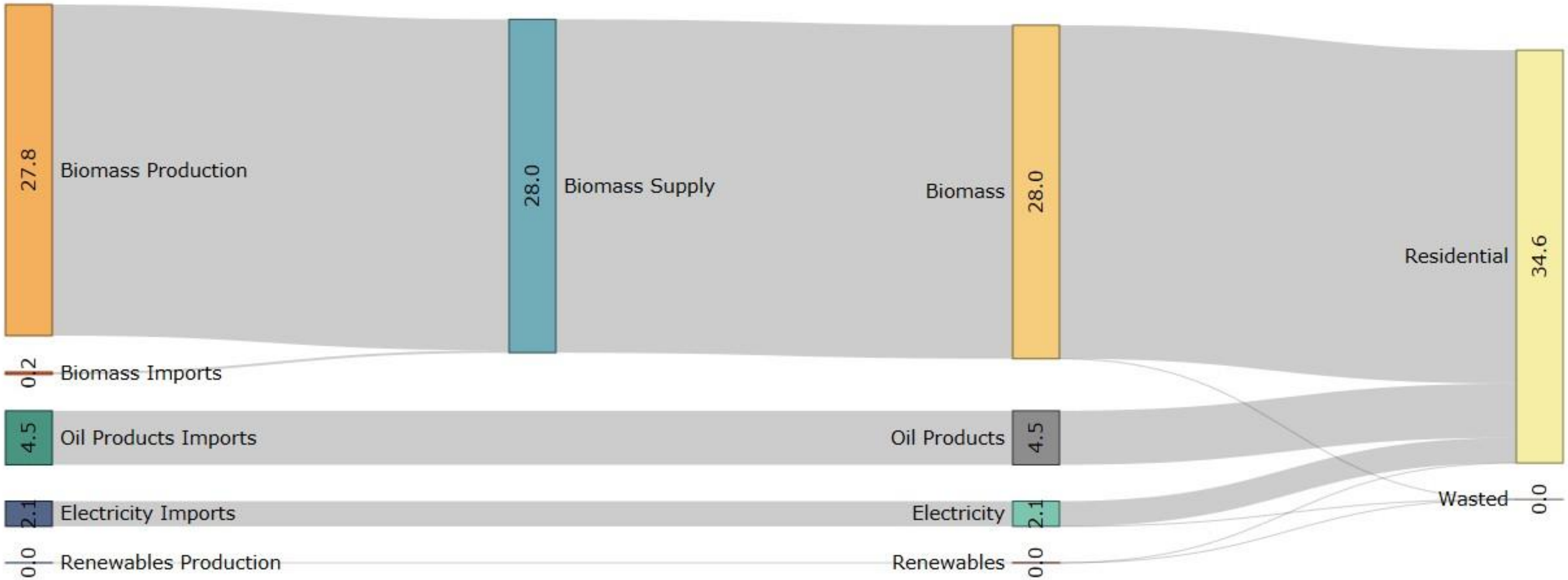


Figure A.4: Energy demand (PJ) in BAU scenario in year 2030

APPENDIX D: Electrification status of Province One

Table A.8: District wise electrification in Province One

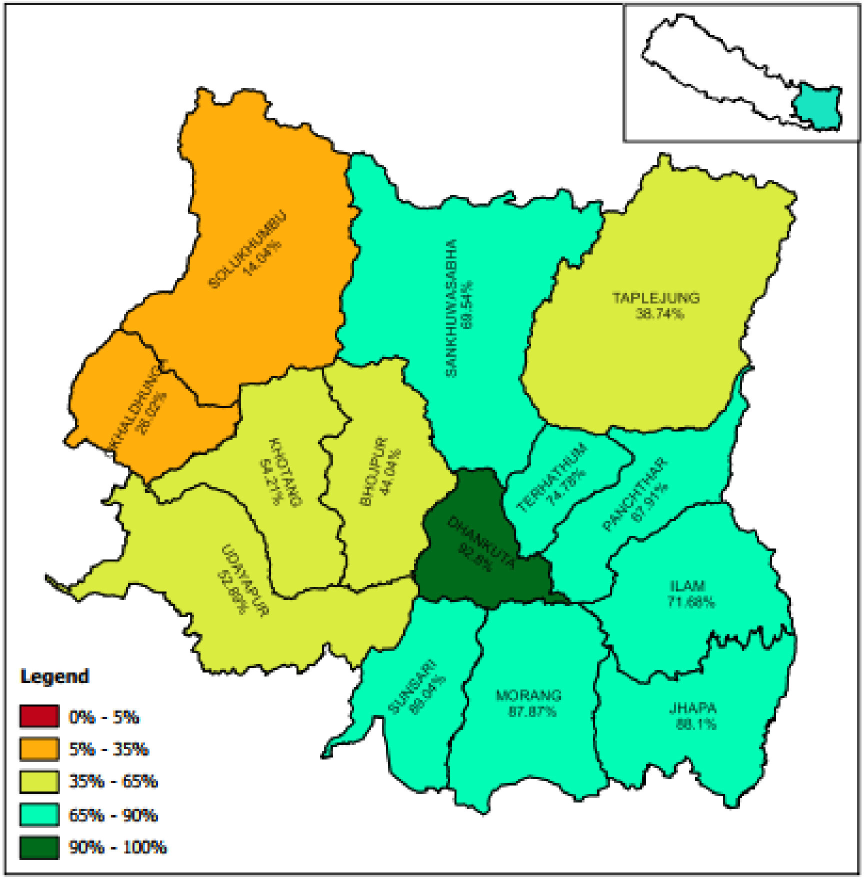
Province No. 1

S.N.	District	Households	Electrification (%)	33/11 kV Substation						33 kV Line		11 kV Line		LT Line		Dt. Transformer	
				Existing		Under Construction		Planned		Existing (km.)	Planned (km.)	Existing (km.)	Planned (km.)	Existing (km.)	Planned (km.)	Existing (Nos.)	Planned (Nos.)
				Nos.	Capacity (MVA)	Nos.	Capacity (MVA)	Nos.	Capacity (MVA)								
1	Taplejung	27099	38.74	1	1.50	1	3.00	1	3.00	82.50	23	41.48	267	102.14	852	26	235
2	Pachthar	42198	67.91	3	9.00	1	3.00	1	8.00	58.00	22	145.00	197	193.00	328	62	87
3	Ilam	68775	71.68	3	19.00	1	3.00	1	8.00	73.00	0	367.00	66	1330.00	188	320	145
4	Jhapa	207378	88.10	8	139.00	1	8.00	1	24.00	90.68	18	1396.16	464	4632.80	1271	1329	544
5	Morang	237747	87.87	4	98.40	2	16.00	2	41.00	117.00	40	1023.95	350	3693.72	1595	870	343
6	Sunsari	190662	89.04	4	97.80	0	0.00	2	48.00	100.51	22	887.82	113	2198.65	257	681	171
7	Dhankuta	39213	92.80	2	11.00	1	3.00	1	8.00	34.00	22	281.48	19	1276.03	34	293	24
8	Terathum	21940	74.78	1	3.00	1	8.00	1	8.00	15.00	0	285.00	17	480.00	51	133	9
9	Sankhuwasava	34433	69.54	1	8.00	1	3.00	1	3.00	45.94	57	312.85	368	577.53	654	202	105
10	Bhojpur	34326	44.04	1	3.00	2	11.00	1	3.00	45.00	18	226.00	162	340.00	254	309	99
11	Solukhumbu	23063	14.05	0	0.00	1	1.50	2	11.00	0.00	82	42.00	439	85.00	1267	44	108
12	Okhaldhunga	33176	26.02	1	0.75	0	0.00	2	6.00	33.20	60	314.00	547	473.00	1410	67	114
13	Khotang	36753	54.21	1	1.50	2	6.00	1	8.00	69.00	30	458.53	193	841.02	764	198	152
14	Udayapur	73756	52.89	2	28.00	1	8.00	1	8.00	51.71	87	349.69	255	732.45	510	287	172
	Total	**1070519**	**75.90**	**32**	**419.95**	**15**	**73.50**	**18**	**187.00**	**815.54**	**481**	**6130.96**	**3457**	**16955.34**	**9434**	**4821**	**2308**

Figure A.5: District wise household electrification status (%) in Province One

PROVINCE No. 1

Total Households	1070519
Electrification Status	75.90%
Existing	
132/11kV Substation	0 nos
132/11kV S/S Capacity	0 MVA
66/11kV Substation	0 nos
66/11kV S/S Capacity	0 MVA
33/11kV Substation	32 nos
33/11kV S/S Capacity	419.95 MVA
33kV Line	815.54 km
11kV Line	6130.96 km
LT Line	16955.34 km
Transformers	4821 nos
Under Construction	
33/11kV Substation	15 Nos
Substaion Capacity	73.5 MVA
Planned	
33/11kV Substation	18 nos
Substation Capacity	187 MVA
33kV Line	481 km
11kV Line	3457 km
LT Line	9434 km
Transformers	2308 nos



APPENDIX E: Hydropower and Renewable Projects in Province One

Table A.9: IPP's Hydropower Projects in Province One

IPPs' Hydropower Projects in Province One			
S.N.	**Hydropower Projects**	**Districts**	**Capacity (KW)**
1	Pikhuwa Khola	Bhojpur	5,000
2	Leguwa Khola	Dhankuta	40
3	Mai Khola	Illam	4,500
4	Upper Puwa-1	Illam	3,000
5	Mai Khola	Illam	22,000
6	Mai Cascade	Illam	7,000
7	Upper Mai	Illam	9,980
8	Jogmai	Illam	7,600
9	Upper Mai C	Illam	5,100
10	Puwa Khola-1	Illam	4,000
11	Mai sana	Illam	8,000
12	Super Mai	Illam	7,800
13	Super Mai 'A'	Illam	9,600
14	Super MaiCascade	Illam	3,800
15	Miya Khola	Khotang	996
16	Molung Khola	Okhaldhunga	7,000
17	Pheme Khola	Panchthar	995
18	Hewa Khola A	Panchthar	14,900
19	Tallo Hewa Khola	Panchthar	22,100
20	Piluwa Khola	Sankhuwasabha	3,000
21	Lower Piluwa Small	Sankhuwasabha	990
22	Hewa Khola	Sankhuwasabha	4,455
23	Sabha Khola	Sankhuwasabha	4,000
24	Solu Khola	Solukhumbu	23,500
25	Phawa Khola	Taplejung	4,950
26	Sobuwa Khola-2 MHP	Taplejung	90
27	lwa Khola	Taplejung	9,900
28	Kabeli B-1	Taplejung	25,000
29	Upper	Terhathum	7,500
	Total		**226,796**

Table A.11 : Major and Small Hydro Power Plants in Province One

Major and Small Hydro power plants in Province One			
S.N.	**Power Plants**	**Districts**	**kW**
1	Bhojpur**	Bhojpur	250
2	Dhankuta***	Dhankuta	240
3	Puwa Khola	Illam	6200
4	Gorkhe(Illam)***	Illam	64
5	Okhaldhunga	Okhaldhunga	125
6	Phidim	Panchthar	240
7	Khandbari	Sankhuwasabha	250
8	Chatara	Sunsari	3200
9	Taplejung**	Taplejung	125
10	Terhathum	Terhathum	100
	Total		**107,94**

** Leased to Private Sector ***Not in Normal Operation (NEA, 2019)

Table A.12 : Number of Modern Renewable Technologies Installed in Province One (AEPC, 2019)

District	SHS	SSHS	ISPS	MUD ICS	Domestic biogas
Bhojpur	12,348	321	2	163	225
Dhankuta	1,650	183	5	234	2,059
Illam	5,136	570	23	711	6,306
Jhapa	651	596	20	0	18,752
Khotang	12,833	865	23	137	100
Morang	1,365	776	32	8	10,800
Okhaldhunga	10,244	155	26	1,737	413
Panchthar	7,751	140	6	344	1,064
Sankhuwasabha	8,700	50	3	643	536
Solukhumbu	4,117	0	2	896	107
Sunsari	1,186	80	5	0	4,126
Taplejung	6,268	661	10	1,050	233
Terhathum	1,760	223	4	193	799
Udayapur	22,024	254	13	57	5,953
Total	**96,033**	**4,874**	**174**	**174**	**51,473**