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Residential Sector Energy Demand and Scenario Analysis: A case study on Province 1 of Nepal

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Abstract
This paper presents the energy consumption, energy demand and scenario analysis of the residential sector of Province 1 over the period 2019-2030 using the LEAP model. Four scenarios were developed, Business as usual (BAU), 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 1 is expected to be 30.15 PJ, whereas in the SEDS, the final energy demand is expected to be 12.6 PJ such that the total energy demand in cooking decreases by 58% in year 2030. Hilly region has a potential of energy saving compared to other region such that about 64% of energy saving can be achieved in hilly region in SEDS. The electricity consumption per capita in residential sector increases upto 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 due to technology policy intervention. 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 promoting renewable energy systems and energy efficient technologies rather than use traditional firewood and fossil fuels systems.

Keywords
Emission, Energy Demand, LEAP and Scenario

1. Introduction

The Constitution of Nepal, 2015 has restructured the nation into the Federal Democratic Republic and has divided the nation into seven provinces [1]. In the energy sector, various target and milestones have been set by federal level government for different time frame to achieve the goal [2]. Access to clean, reliable and affordable energy services will help in control of environment degradation, emission control, increase productivity and optimum utilization of hydropower energy [3]. A well-organized energy database helps in the formulation of policy and sustainable energy planning of the provinces to meet the national target. Provincial government system has come in practice recently, so there has not been enough study carried out on the provincial level. Energy mix and scenario analysis would help to have a best picture of energy consumption and formulation of planning and policy making towards sustainable energy development.

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 firewood, agricultural residue, and animal waste. The energy consumption patterns in all economic sectors are mainly classified as residential sector,commercial sector,industrial sector, transport sector, agricultural sector and construction & mining sector.

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.

Province 1 lies in the eastern region of Nepal ranging from mountainous and hilly to terai region. It covers an area of 25,905 km^2. The province comprises of 14 districts with one metropolitan city, two sub-metropolitans, 46 municipalities, and 88 rural municipalities. Biratnagar has been declared capital of the province. According to the 2011 census, there were around 4.5 million people in the province.[8]

1.1 Energy consumption in Province 1 by sector

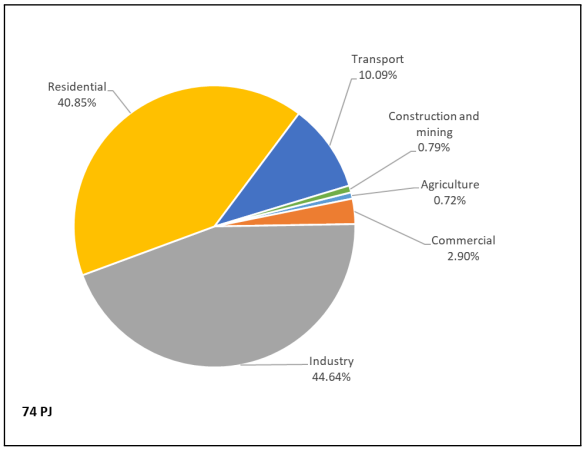

Figure 1: Energy Consumption Share in Province 1 by Sectors [8]

The total energy consumption in province 1 in the year 2019 is 74 PJ. Due to highly industrial activities in this province, the energy consumption in the industrial sector has highest share (44.6%) followed by residential sector (40.8%).Energy Consumption Share in province 1 by Sectors is shown in Figure 1.

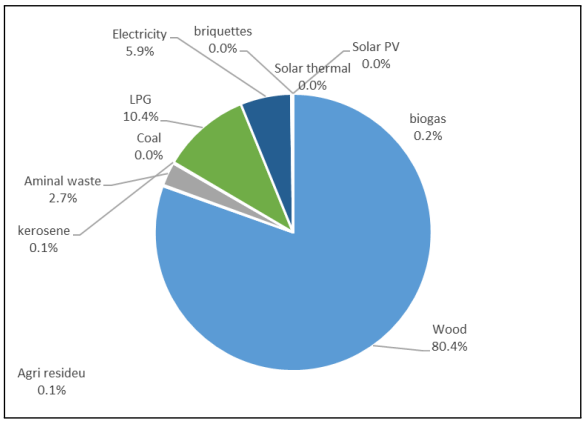

Figure 2: Energy Mix in Residential Sector in Province 1 [8]

The total energy consumption in the residential sector of province 1 is about 30 PJ as shown in Figure 2. Nearly 80% of the energy comes from firewood followed by LPG. The share of LPG fuel is 10% and 6% electricity in the residential sector. Modern renewables like solar PV, biogas and briquettes are also consumed whose share is less than 1% of total residential energy consumption.

1.2 Status of Electrification in Provincial Level

The total install capacity of hydropower in Nepal is about 1386 MW in which province 1 has a share of about 280 MW. The national electrification by household in year 2021 is about 93%. Madhesh Province has electrification of 99.05%, Karnali province has lowest electrification of 34.75% and province 1 has electrification of 82.43% [4].

1.3 Need and Importance of Study

Residential sector is one of the major contributors in the total energy consumption among all other sectors in province 1. About 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 research has 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 [18]. As government has set a target of full electrification in Bagmati, Gandaki, Madhesh and Lumbini Province within this fiscal year 2078/79, and Province 1, Karnali and Sudurpaschim within fiscal year 2079/80 [2]. Energy consumption pattern and target set by government are not aligned to each other. Hence, energy demand forecasting and scenario analysis needs to be carried out for the sustainable development of all provinces but this study is mainly focus on the residential sector of province 1.

2. Methodology

2.1 Modeling software LEAP (Long-range Energy Alternatives Planning System)

The LEAP is a simplified modeling tool which is basically used for energy policy analysis and climate change mitigation assessment. The demand program can be further divided into levels: sectors, sub-sectors, end -uses and devices. Under certain assumptions such as GDP, population growth and scenario, LEAP can be used to represent the present energy condition/consumption and to forecasts the future energy demand for a different time interval. Greenhouse gas (GHG) emissions of all energy sectors and non-energy sectors can be estimated. Initial data requirements for the analysis are quite low and scenarios can be developed based on targets and policy [19].

A residential sector's energy demand model is developed in the LEAP model which is shown in Figure 4. Then it is disaggregated into the physiological region (Terai, Hilly and Mountain). Further, each geographical region is divided into urban and rural areas and these areas are further divided into end-use service demand i.e. cooking, water heating,lighting, space heating and cooling, electrical appliances, animal food processing and social events. Again, each end-sue service demand is further disaggregrated into its end use fuel type like Cooking includes the branches of fuels like firewood, agriculture residue, animal residue, LPG, electricity and biogas etc.

In developing the scenario analysis in LEAP model, target set by federal and provincial government is considered like substitution of LPG by e-cooking, increase the share of renewable energy in the energy mix, use of energy efficient technology and focus on clean, reliable and affordable energy by 2030.

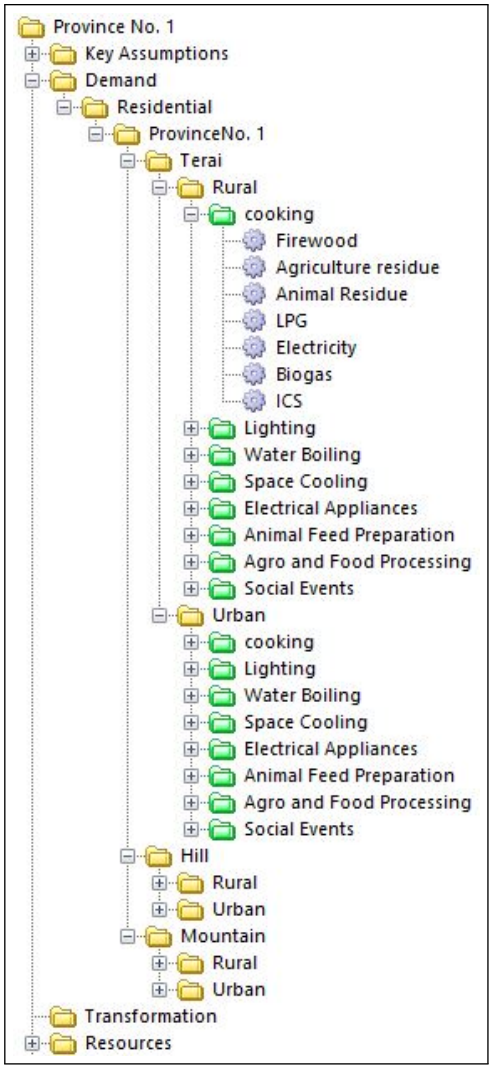

Figure 3: Disaggregation of residential sector

2.2 Data Collection

Secondary data is used to determine the base year energy mix and end use service demand of province 1. Most of the data used in this study is recently published in year 2021. So, this helps to find the actual condition of energy consumption pattern of province 1. In addition to it, different targets and plans set by both federal and provincial government in sector of energy is identified to used in model.

2.3 Description of Scenarios

Four different scenarios are carried out in the study: Business as usual, ICS scenario, LPG substitution scenario and Sustainable energy development scenario.

2.3.1 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 new activities will occur such that there will be no significant change in the energy consumption pattern in future. The natural change in the energy consumption pattern in the system is considered in this study. In this scenario, population growth rate is considered to be same as base year.

2.3.2 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 [20]. So, in this scenario, all traditional stoves which use firewood as fuel are replaced by the energy efficient Improved cooking stoves.

2.3.3 LPG Substitution Scenario

Currently, many new hydropower plant 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 [3]. Therefore, in this scenario, non-renewable energy LPG is completely replaced by electricity and annual decrement of firewood by 1.5% in energy mix in residential sector by 2030.

2.3.4 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 [12].

3. Results and Discussion

4.1 BAU Scenario

Following assumptions are considered in this scenario analysis shown in Table 1 [3].

Table 1: Assumption in BAU scenario

End Use Activity	Fuel Switching		Technology Switching	
	Existing	BAU scenario	Existing	BAU scenario
Cooking	Firewood, LPG, Biogas, Electricity	Annual average decrement of Firewood by 2.5%, increment of LPG uses by 2% and Eelctricity by 5%	LPG stove, Traditional Cooking stoves, Improved cooking stove and Induction cooker	LPG stove, Traditional Cooking stoves, Improved cooking stove and Induction cooker
Lighting	Hydro electricity, solar electricity	Solar and Hydro electricity	Incandescent Bulb, CFL and LED	LED
Water Boiling	LPG, Boigas and Firewood	Annual average decrement of Firewood by 2.5%, increment of LPG uses by 2% and Eelctricity by 5% and Biogass uses remain same	Traditional Cooking stoves, Improved cooking stove	LPG stove,Traditional Cooking stoves and Improved cooking stove
Space Cooling	Hydro electricity		-	-
Electrical Appliances	Hydro electricity		-	-
Animal Feed Preparation	Firewood		Traditional Cooking stoves	Traditional Cooking stoves, Improved cooking stove
Agro and Food Preparation	Firewood		Traditional Cooking stoves	Traditional Cooking stoves, Improved cooking stove
Social Events	Firewood, LPG, Biogas, Electricity		-	-

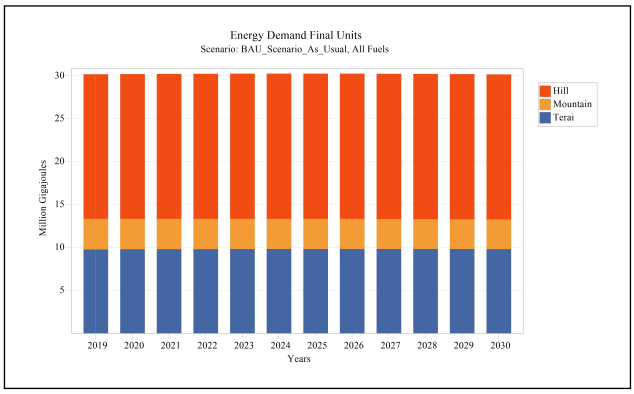

Figure 4: Energy demand projection under physiographic region

The Figure 4 represents the energy demand projection under physiographic region upto year 2030 in the BAU scenario. 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.

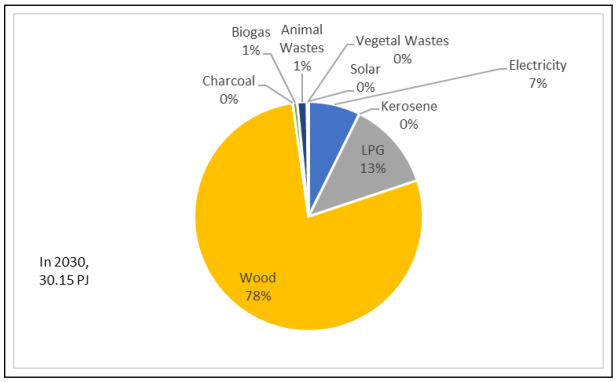

Figure 5: Final energy demand by Fuel type

The Figure 5 represents the energy demand of

residential sector of province 1 w.r.t. fuel type upto year 2030 is 30.15 PJ. Wood has the highest share about 78% of the total energy demand which is followed by LPG (13%), electricity (7%) and others in this BAU scenario.

4.2 ICS Scenario

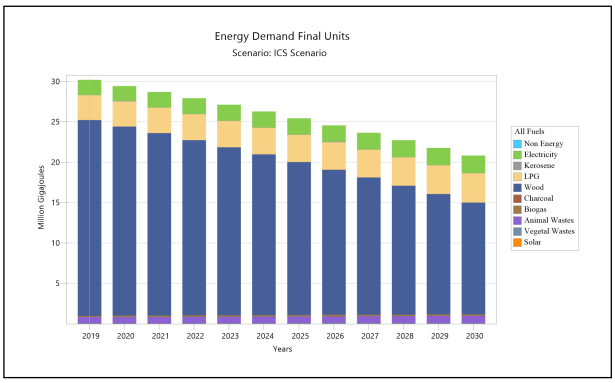

Figure 6: Energy Projection under ICS substitution Scenario

The Figure 6 shows the projection of final energy demand under ICS scenario upto year 2030. 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. It is found that with implementation of improved cooking stoves the final energy demand decreases to 20.78 PJ in year 2030 which was 30.16 PJ in base year.

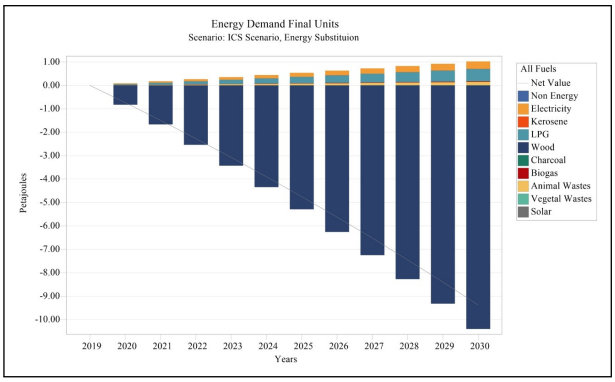

Figure 7: Energy saving in ICS Scenario

The Figure 7 shows the final energy demand compared to the base year in ICS scenario. It shows that about 10.5 PJ of firewood could be saved by 2030 with the implementation of improved cooking stove.

4.3 LPG Substitution Scenario

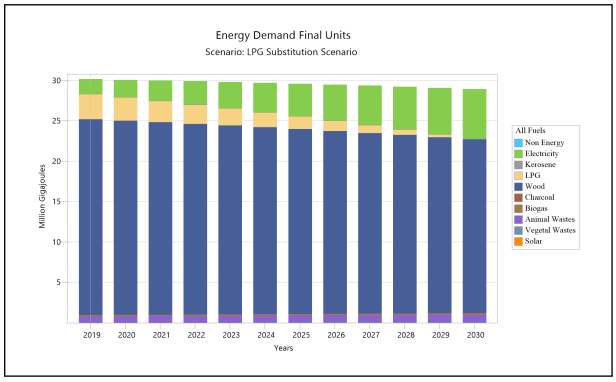

Figure 8: Energy Projection under LPG substitution scenario

The Figure 8 shows the projection of final energy demand under LPG substitution scenario upto year 2030. In this scenario, the use of LPG has been substituted by the electricity. This results to decrease in final energy demand in year 2030 to 28.9 PJ which was 30.16 PJ in base year.The study shows that electricity demand increases to 6.2 PJ in year 2030 from 1.8 PJ in base year.

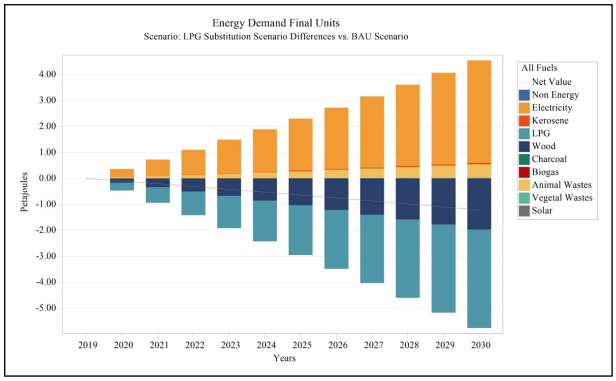

Figure 9: Energy saving in LPG substitution scenario

The Figure 9 shows the energy saving of fuel type in LPG substitution scenario compared to the BAU scenario. It shows that about 2 PJ of firewood could be saved and electricity demand can be increased by 4 PJ in 2030 with the substitution of LPG.

4.4 SEDS Scenario

Following assumption is considered in this scenario analysis shown in Table 2 [3].

Table 2: Assumption in SEDS scenario

End Use Activity	Fuel Switching		Technology Switching	
	Existing	SEDS scenario	Existing	SEDS scenario
Cooking	Firewood, LPG, Biogas, Electricity	Hydro electricity	LPG stove, Traditional Cooking stoves, Improved cooking stove and Induction cooker	Induction Cooker
Lighting	Hydro electricity, solar electricity	Solar and Hydro electricity	Incandescent Bulb, CFL and LED	LED
Water Boiling	LPG, Boigas and Firewood	Solar and Hydro electricity	Traditional Cooking stoves, Improved cooking stove	Electric Water Heater
Space Cooling	Hydro electricity	Hydro electricity	-	-
Electrical Appliances	Hydro electricity	Hydro electricity	-	-
Animal Feed Preparation	Firewood	Hydro electricity	Traditional Cooking stoves	Electric Cooking
Agro and Food Preparation	Firewood	Hydro electricity	Traditional Cooking stoves	Electric Cooking
Social Events	Firewood, LPG, Biogas, Electricity	Hydro electricity	-	-

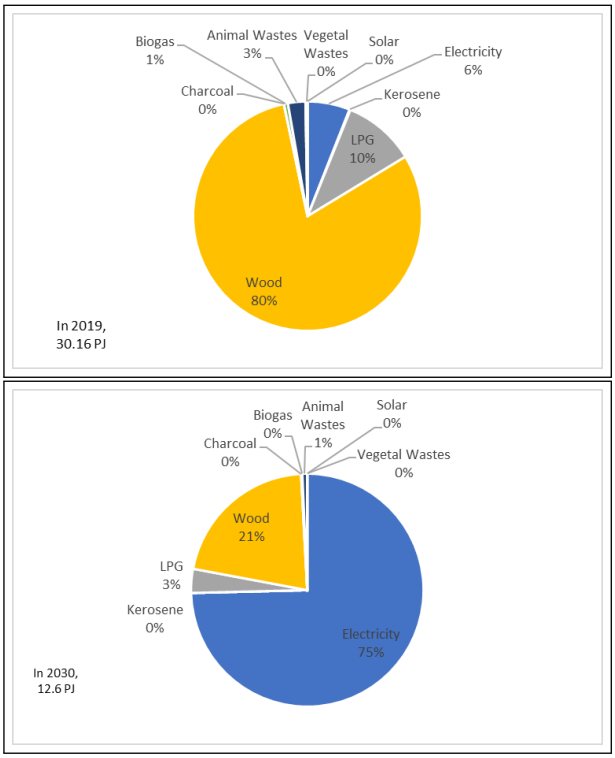

Figure 10: Energy Projection under SEDS Scenario

The Figure 10 shows the final energy demand under SEDS scenario is 12.6PJ in 2030. 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.

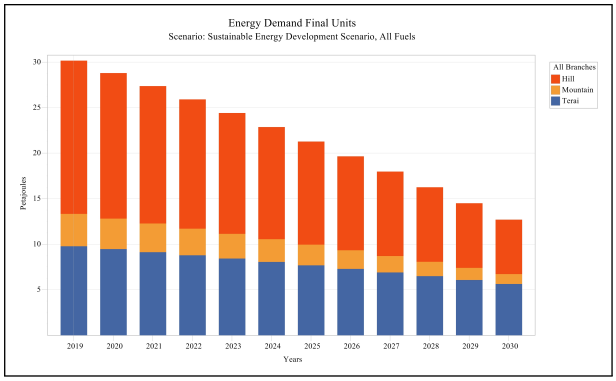

Figure 11: Energy demand projection under physiographic region in SEDS Scenario

The Figure 11 represents the energy demand projection under physiographic region upto year 2030 in the SEDS scenario. It is found that the Hilly region has highest energy demand of 16.8 PJ in base year. With the implementation of the energy efficient technology and clean energy, the energy demand in this region can be decreased by 10 PJ. Similarly, energy demand in Terai and mountain region can be decreased by 2.4 PJ and 4 PJ respectively.

4.5 Final Energy Demand

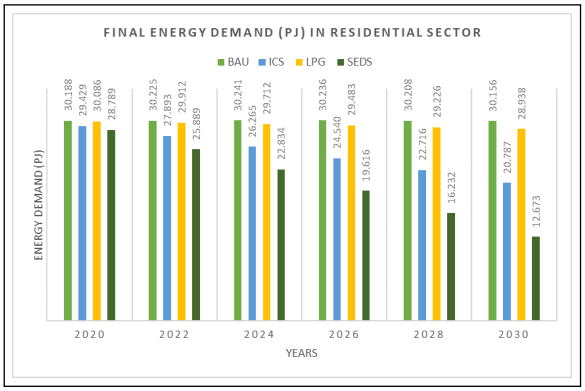

Figure 12: Final energy demand BAU, ICS, LPG and SEDS scenario

The Figure 12 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 30.15 PJ by 2030. Similarly, report of WECS shows that the final energy demand of residential sector of Province 1 in 2030 under BAU scenario is found to be 34.95 PJ [8]. Difference on energy demand is 15% due to the consideration of fuel switching in this study.

4.6 Energy Demand Per Capita

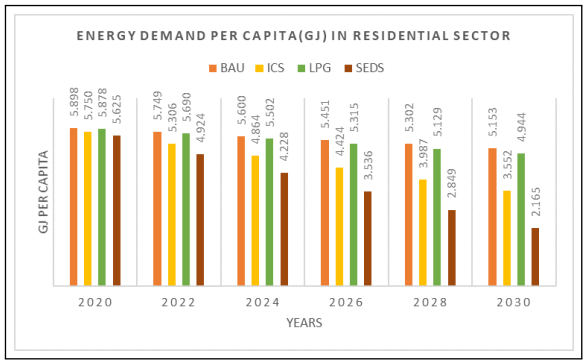

Figure 13: Energy Demand Per capita BAU, ICS, LPG and SEDS scenario

Above Figure 13 shows that the energy demand per capita can be reduced up to 2.1 GJ in SEDS scenario from 5.1 GJ in BAU scenario in year 2030. 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 [10]. This reduction in energy demand is mainly due to use of energy efficient technology (ICS).

4.7 Electricity Demand Per Capita

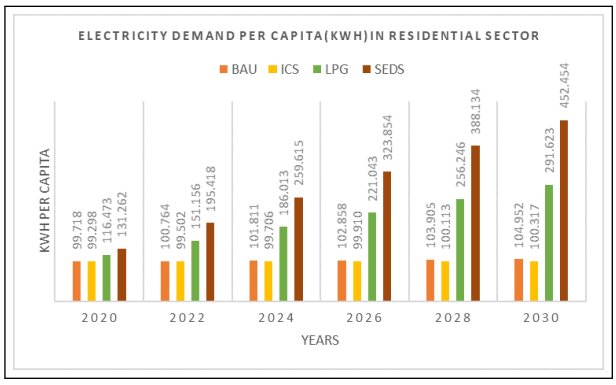

Figure 14: Electricity Demand Per capita BAU, ICS, LPG and SEDS scenario

Above Figure 14 shows that the electricity demand per capita can be increased up to 452.4 kWh in SEDS scenario over 104.9 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 116 kWh in year 2030. The electricity demand per capita of Province 1 considering all economic sector(residential, transport, industrial, commercial and agriculture etc) is found to be 574kWh [13]. 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.

4.8 GHG Emission

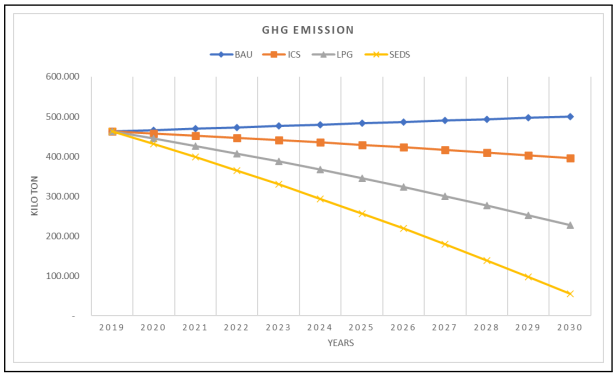

Figure 15: GHG Emission at BAU, ICS, LPG and SEDS scenario

GHG Emissions in residential sector can be gradually reduced from 462 kt of CO_2 equivalent to 56 kt of CO_2 equivalent by switching to renewable energy and energy efficient technology as shown in Figure 15. SEDS scenario has the least GHG emission followed by LPG and ICS sceanrio.

4. Conclusion

The final energy demand of residential sector of province 1 is expected to reach a value of 30.15 PJ at 2030 in BAU scenario which is nearly equal to the energy demand in base year. This is mainly due to the shifting of traditional cooking stove by efficient cooking stove. The energy mix in BAU scenario by 2030 is fuel wood holding largest share (78%) followed by LPG (13%), Electricity(7%) and others.

In case of SEDS scenario, the final energy demand is expected to be 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 high penetration of electricity (75%) 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. In Hilly region, about 64% energy can be saved with the implementation of the energy efficient technology and clean energy.

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 year 2019 to 56 kt of CO_2 equivalent in year 2030 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. Further Research Area

This paper presents the residential sector energy demand and scenario analysis of province 1. Total energy demand of Province 1 can be determined by further research on sectors such as transport, industrial, commercial and others. Cost benefit analysis can be carried out in these sectors.

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