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Economic and Environmental Implication of Net-Zero Emission Strategy in Residential Sector of Bagmati Province

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 **"Economic and Environmental Implication of Net-Zero Emission Strategy in Residential Sector of Bagmati Province"** submitted by Subash K.C., in partial fulfilment of the requirements for the degree of Master of Science in Energy system planning and management.

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ABSTRACT

With the growing concern of the rise in global temperatures, and in support of the Paris Climate Agreement, countries around the world have set national targets to cut down their emissions. The government of Nepal too has pledged to achieve net zero emissions by year 2045 and put into effect several plans and policies. These has their effect on the country's energy demand and economy. Using Bagmati province of the country as study area, energy demand and scenario analysis is conducted using LEAP framework. One business-as-usual (BAU) and two net zero scenarios are analyzed, with existing (NZE) and additional measures (NZA). The energy demand, emissions, social costs of the scenarios are studied. Significant emission reductions are estimated in NZE scenario. However, existing measures alone are not found to be sufficient to achieve the targets. In terms of social costs, considerable benefits are estimated in implementing these scenarios.

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LIST OF ABBREVIATIONS

BAU	Business as Usual
CBS	Central Bureau of Statistics
GHG	Greenhouse Gas
GWP	Global Warming Potential
ICS	Improved Cooking Stove
LEAP	Low Emissions Analysis Platform
LPG	Liquified Petroleum Gas
MAED	Model for Analysis of Energy Demand
MARKEL	Market Allocation
MOEWRI	Ministry of Energy, Water Resources, and Irrigation
MOPE	Ministry of Population and Environment
MT	Metric Tons
NDC	Nationally Determined Contributions
NMVOC	Non-Methane Volatile Organic Compounds
NPHC	Nepal Population and Housing Census
NPR	Nepalese Rupee
NPV	Net Present Value
NZA	Net Zero with Additional Measures
NZE	Net Zero with Existing Measures
O&M	Operation and Maintenance
SCC	Social Cost of Carbon
SDG	Sustainable Development Goals
TCS	Traditional Cooking Stove
TSP	Total Suspended Particles
WECS	Water and Energy Commission Secretariat

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CHAPTER ONE: INTRODUCTION

1.1 Background

Energy consumption is an important indicator of development of the country. A country's economic growth and its energy consumption are interrelated with each other (Apergis & Payne, 2009). Energy consumption and efficiency measures should go hand in hand in order to achieve economic benefits and promote long term sustainability. Also, a country's energy supply situation should be able to address its demand and there are environmental implications to be considered as well. Nepal is a landlocked, developing country and is subdivided into three geographic regions – mountain, hilly and terai. Most of the energy used in Nepal comes from non-commercial resources. However, in recent years the share of modern energy is gradually increasing. Electricity, petroleum and renewable, account around 20 % of total energy consumption of Nepal (Sanjel et al., 2022). To provide energy access, and for improving energy efficiency, various subsidy mechanisms are in effect in Nepal. Along with that, the government has also set various milestones on the federal level to be met in different time frames (WECS, 2022b). Ministry of Energy, Water Resources, and Irrigation (MOEWRI) has set the target to increase per capita electricity consumption from the current value of 700kWh to 1500kWh in the coming decade. Ministry of Forest and Environment (MOPE) has prepared a Low Carbon Economic Development Strategy, which promotes the use of clean renewable energy in all sectors. The second NDCs, which are the national commitments to address climate change, targets to implement energy efficient clean technologies in residential sector (Ministry of Population and Environment, 2020). The SDGs by National Planning Commission, in order to encourage switching to electric cooking in residential sector, targets to limit the use of LPG to less than 40% (NPC, 2017).

Nepal is divided into seven provinces by the Constitution of Nepal (2015), among which Bagmati is one, which is also the major economic region of the country. The country is subdivided into seven economic sectors – residential, industrial, commercial, transport, agriculture, construction, and mining. With over 63% of total energy consumption, residential sector is the major consumer of energy in Nepal (WECS, 2022b). According to WECS (2022), total energy consumption of Bagmati province is

83.53PJ. Containing major cities and industries, it has the highest province wise contribution to GDP, 36.15% (CBS, 2022).

1.2 Problem Statement

Most of the energy in residential sector comes from biomass, which is one of the most inefficient sources of energy and a major contributor to GHG emissions. Although, the growth of economic activities has resulted in decrease in percentage share of residential energy consumption from 89% in 2009 to 63% in 2021 (WECS, 2022b), it is still increasing in absolute terms. The increase in energy consumption rate in residential sector of Nepal, is 2.2% per annum in the last two years which is higher than the population growth rate. In the province under consideration, numerous efficiency improvement measures for residential sector are available through which energy consumption can be minimized without reducing the quality of lifestyle. The use of inefficient fuels such as biomass, which remains a major source of energy in rural areas of developing countries is undoubtably one of the major causes of health-related problems (Elbayoumi & Albelbeisi, 2023; Fullerton et al., 2008; Kyayesimira & Muheirwe, 2021; Shindell et al., 2021). Considerable quantity of emissions can be reduced from implementing net-zero targets set by the Nepali government. The social-cost benefits of these targets need to be studied. There are economic benefits of reduced externalities by implementing these targets. There is a lack of literature which quantify these benefits at sectoral level. Projection of the cost of demand technology required in residential sector on implementing net zero targets is not conducted on existing literatures. The future energy demand necessitated by the net-zero targets and the required technology changes should be assessed based on the economic and geographic conditions of the country.

1.3 Research Question

The aim of this research is to answer following questions related to energy consumption in the province:

- What is the expected energy demand of residential sector of Bagmati region up to year 2050?
- What are the economic implications of implementing net-zero targets in residential sector?

- How much reduction in emissions will be actually achieved in the process?

1.4 Objectives

The main objective of this study is to conduct scenario analysis of residential sector of Bagmati province using LEAP framework.

The specific objectives of this study are:

- To prepare different scenarios which can meet targets set by government and to conduct energy demand analysis for the developed scenarios.
- To analyze environmental benefits in implementing different scenarios.
- To evaluate the cost of implementing the scenarios and review net zero emission targets in residential sector.

1.5 Limitations of the Study

This study is conducted from secondary data which is taken from the study by WECS. In formulating the scenario, the same net-zero targets set by the government of Nepal for the whole country are applied as they are, in Bagmati province without considering the provincial contribution. The energy demand projection is made based on the population growth and urbanization. The effect of income elasticity is not included in the projection. The externality cost and demand technology cost are estimated based on the base year prices.

CHAPTER TWO: LITERATURE REVIEW

There have been several studies which studied the sectoral energy demand and performed scenario analysis of the country. Shrestha & Malla (1996) studied sectoral energy use patterns to study the associated emissions, however the study did not use comprehensive energy system model to estimate the future energy demand. Shrestha & Rajbhandari (2010) analyzed the sectoral energy consumption pattern and emissions for five different economic sectors, viz. – agriculture, residential, commercial, industrial and transport – using MARKAL framework. They found that the overall energy consumption per capita in the Kathmandu Valley would increase from 12.7 GJ/capita in 2005 to 25.6 GJ/capita in 2050, while the residential energy consumption per capita would decrease from 6.5 GJ/capita to 5.9 GJ/capita during the study period 2005-2050. Malla (2013) examined the household energy consumption patterns and its environmental implications of whole Nepal, dividing the country in 13 analytical sectors and energy consumption in three end-uses. By developing 4 different scenarios in LEAP model, he also concluded on environmental implications. Rajbhandari & Nakarmi (2014) conducted a study to understand the energy consumption pattern of residential sector of Kathmandu valley using MAED and MARKAL. Shakya (2016) conducted a study to analyze the benefits of low carbon strategies in case of Kathmandu. The study analyzed energy, environmental and economic implications of adopting low carbon strategies. Shakya et al., (2023) studied environmental, energy security and energy equity benefits of net zero-emission strategy in the country and found substantial reduction in emissions and drastic improvement in energy security and energy equity.

A study conducted of household sector in Panauti municipality by Dhaubanjar et al. (2019) found that electrification of all the sectors can significantly reduce final energy demand and GHG emissions all the while saving considerable cost on fuel import. Dulal & Shakya (2020) found that by increasing the share of electricity in residential cooking, heating, industrial boiler, motive power, and transport, the energy intensity can be significantly lowered. Maharjan & Bhattrai (2022) performed energy consumption, energy demand and scenario analysis of the residential sector of Province 1 over the period 2019-2030 using the LEAP model. The study used four different scenarios - Business-as-usual (BAU), LPG substitution scenario, Improved Cooking Stove (ICS) scenario and Sustainable Energy Development Scenario (SEDS) and concluded that the substitution of inefficient devices and technologies in residential sector significantly reduces final energy demand while reducing GHG emissions. WECS (2022) conducted study on sectoral energy demand of Bagmati province and studied the environmental and cost implications for four different scenarios. This study lacks the detailed consideration of residential sector of Bagmati province and effects of various mitigations measures on residential sector specifically. The results of this study are also required to be recalculated based on the recent census data.

CHAPTER THREE: METHODOLOGY

3.1 Study Area

The Bagmati province is located at 26^0 55’ to 28^0 23’ north latitude and 83^0 55’ to 86^0 34’ east longitude. It constitutes major cities of the country such as the capital Kathmandu, Bhaktapur, Lalitpur, Hetauda and Narayengadh. The province is geographically distributed into hilly, mountainous and terai regions. The map of Bagmati province according to physiographic region is as shown in Figure 3.1.

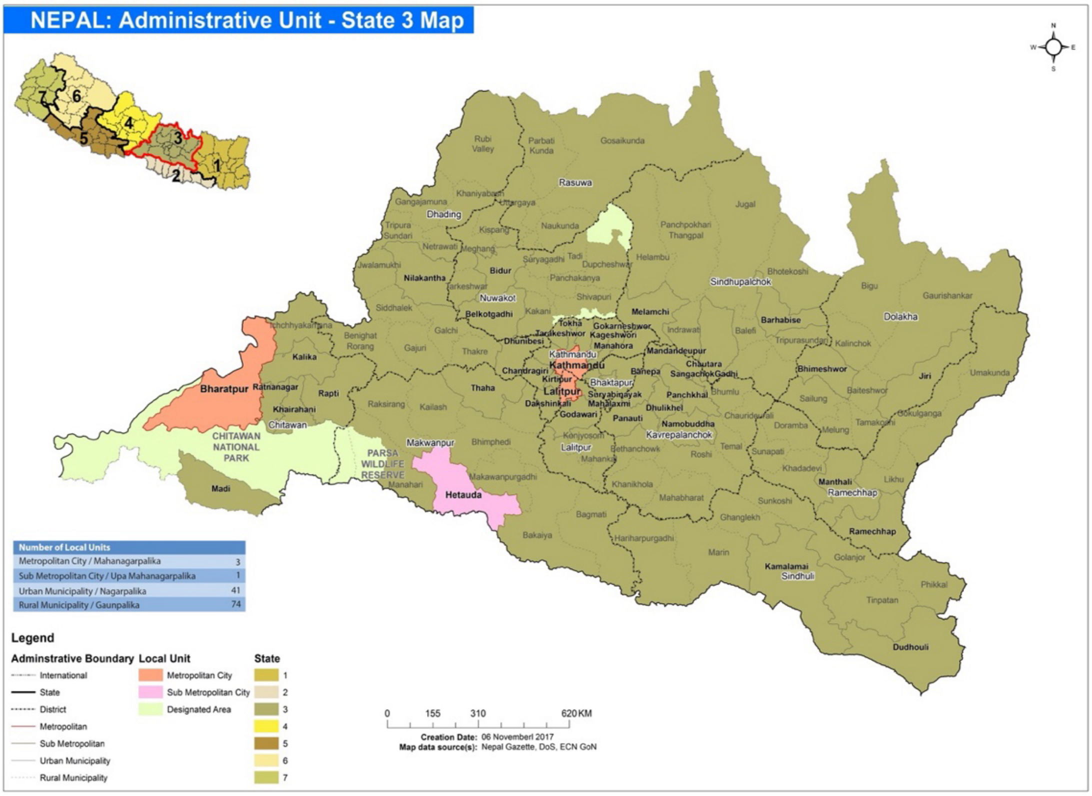

Figure 3.1: Map of Bagmati Province (UN, 2020)

The energy consumption for six different economic sectors of the province is shown in Figure 3.2. Residential sector is the highest energy consuming sector with 42.26% of energy consumption out of the total 82.53 PJ.

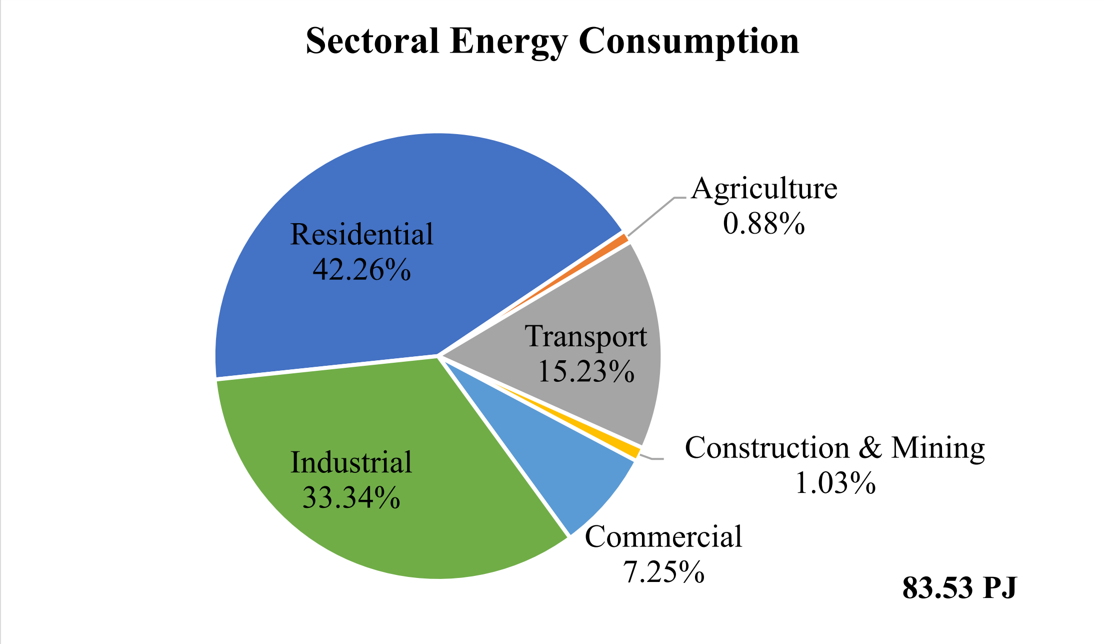

Figure 3.2: Sectoral energy consumption of Bagmati province (WECS, 2022a)

The total consumption of energy for residential sector is about 35.3 PJ. The share of final energy demand by end-uses is shown in Figure 3.3. Cooking consumes most of the energy, nearly 65% of 35.3 PJ, animal fed preparation comes second followed by electrical appliances.

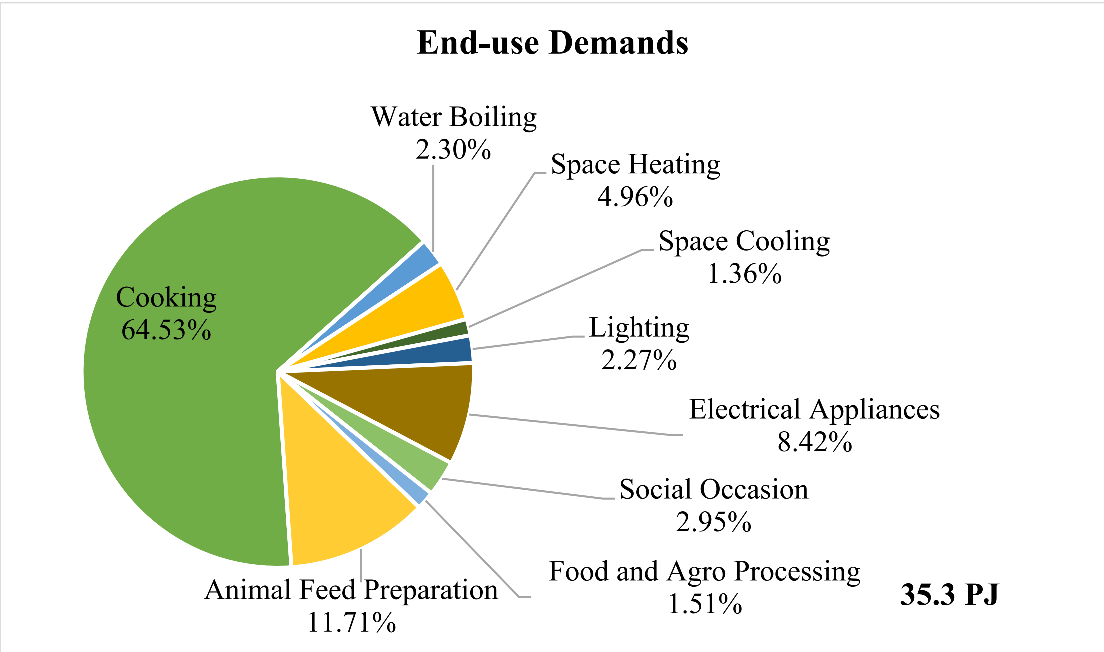

Figure 3.3: Share of final energy demand of residential sector by end-use (WECS, 2022a)

Figure 3.4 shows the energy mix in residential sector. Most of the energy comes from fuelwood, followed by LPG. The share of electricity is only 13%.

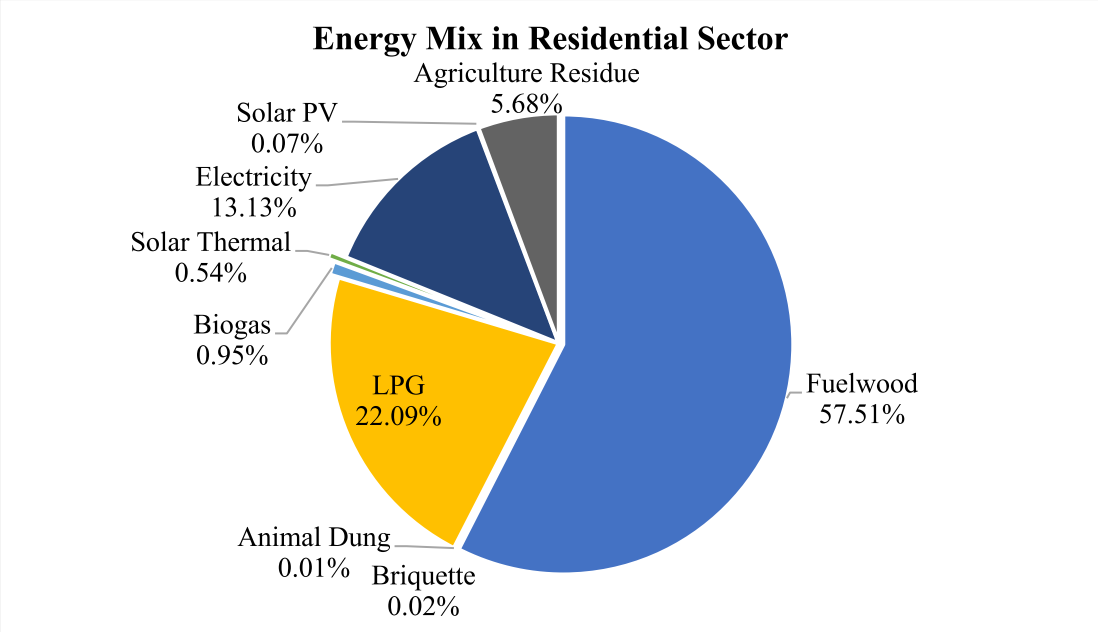

Figure 3.4: Energy mix in residential sector (WECS, 2022a)

3.2 Data Collection

The data used in this study comes from secondary sources. The household size and population of the province used for energy demand projection is obtained from CBS and NHPC reports (National Statistics Office, 2021; NPHC, 2021). The base year energy demand for different end-uses, and energy mix used to create technology branches in LEAP are taken from WECS reports (WECS, 2022b, 2022a) which is provided in Annex C and Annex D. The base year demand technology cost is taken from market study and is provided in Annex E and Annex F.

3.3 Research Framework

This study uses LEAP, which is a modeling tool used for energy policy analysis and climate change mitigation assessment. The overall research framework is as shown in Figure 3.5. The base year energy consumption data, macroeconomic parameters, population, changes in technology and technology costs are fed into the model. The appropriate growth rates are applied for the business-as-usual scenario. A scenario is then created based on net-zero targets. The model calculates the future energy demand and quantifies emission reductions. The emissions data are obtained from various sources. By applying appropriate social cost of emissions, the benefits of reduced emissions are evaluated. The relative cost of scenarios is also calculated from the entered values of different technologies. The future energy demand and the required technology changes will then be analyzed to assess the implications of the targets.

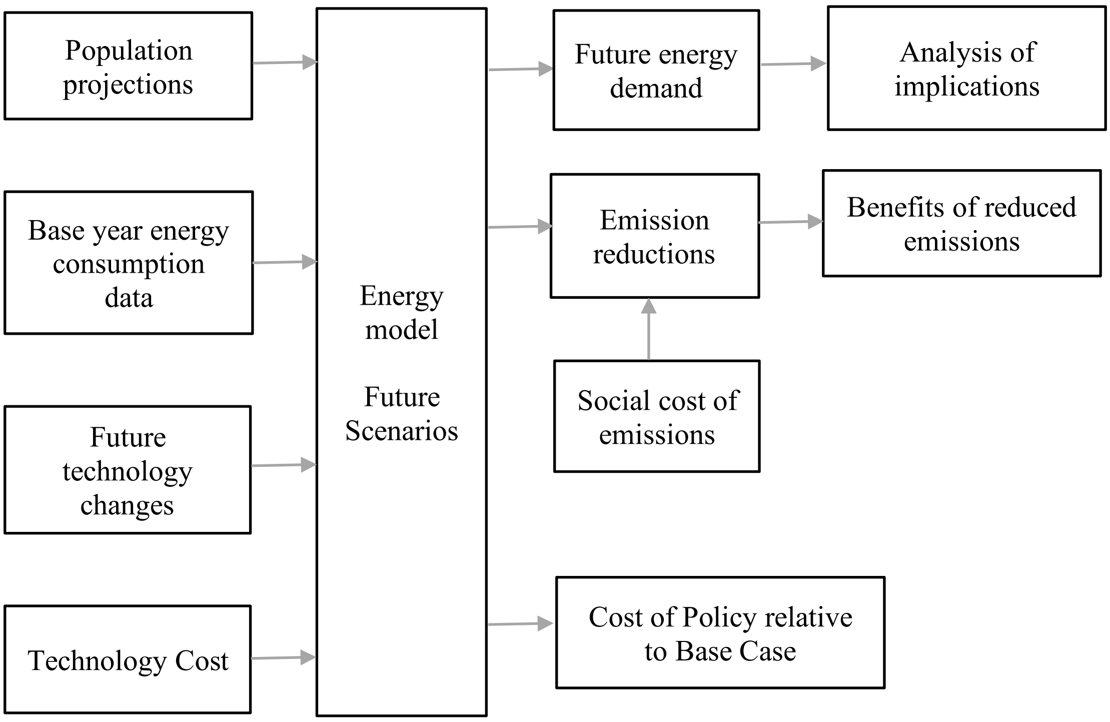

Figure 3.5: Research Framework (Heaps, 1980)

To develop the energy model in LEAP, the residential sector is disaggregated into three geographic regions (Terai, Hilly and Mountain). Each of these geographic regions are divided into urban and rural areas each of which are then subdivided into nine end-use service demands, i.e., cooking, lighting, animal fed preparation, electrical appliances, space heating, space cooling, social occasion, water boiling and food and agro-processing. Each of the end-use is further subdivided into different fuel types. The disaggregation of residential sector and the disaggregation of end-use sector by fuel types used in LEAP is shown in Annex A and Annex B respectively.

3.4 Energy Demand Analysis

For each end-uses of residential sector, both in urban as well as rural, aggregate energy intensities and fuel shares, taken from WECS report (WECS, 2022a) and energy efficiencies taken from various sources (Adhikari et al., 2020; Pokharel, 2004; Wang & Mendelsohn, 2003; WECS, 2022c) are specified in LEAP. These data are then used to calculate the overall useful energy intensity of the aggregate energy intensity branch and the activity shares for each technology by using following relations:

For each end-use technologies,

$$UE_{b,0} = EI_{AG,0} \times FS_{b,0} \times EFF_{b,0} \qquad \text{…………… (1)}$$

Where,

$UE_{b,0}$ is useful energy intensity of 'b' end-use technology in time '0'.

$EI_{AG,0}$ is the final energy intensity of 'b' end-use in time '0'.

$FS_{b,0}$ is fuel share and $EFF_{b,0}$ is efficiency of 'b' end-use in time '0'.

The useful intensity of the aggregate energy intensity branch is the sum of the useful intensities for each technology, i.e.,

$$UE_{AGG,0} = \sum UE_{b,0} \qquad \text{…………… (2)}$$

The activity share (AS) of an end-use technology is its individual useful energy intensity divided by useful intensity of aggregate energy intensity branch, i.e.,

$$AS_{b,0} = \frac{UE_{b,0}}{UE_{AGG,0}} \qquad \text{…………… (3)}$$

For the scenarios, the final energy intensity of each technology is estimated by:

$$EI_{b,s,t} = UI_{AGG,s,t} \times \frac{AS_{b,s,t}}{EFF_{b,s,t}} \qquad \text{…………… (4)}$$

Where,

$EI_{b,s,t}$ is final energy intensity of 'b' end-use technology in time 't' for scenario 's'.

$AS_{b,s,t}$ is activity share of 'b' end-use technology in time 't' for scenario 's'.

$EFF_{b,s,t}$ is energy efficiency of 'b' end-use technology in time 't' for scenario 's'.

The overall energy demand for each technology is calculated as:

$$D_{b,s,t} = TA_{b,s,t} \times EI_{b,s,t} \quad \text{.............. (5)}$$

Where,

$D_{b,s,t}$ is overall energy demand of 'b' end-use technology in time 't' for scenario 's'.

$TA_{b,s,t}$ is total activity of 'b' end-use technology in time 't' for scenario 's'.

$EI_{b,s,t}$ is energy intensity of 'b' end-use technology in time 't' for scenario 's'.

3.5 Economic Analysis

Economic analysis is conducted by considering externality cost and demand technology costs. For the analysis the discount rate 10% is used whereas the inflation rate is taken as 6.32% (Nepal Rastra Bank, 2022). Real costs are used during the analysis of externalities and technology cost. Discounted costs are used to calculate the NPV. NPV is calculated of the cumulative costs from the base year to end year.

3.5.1 Environment Externality Cost

The externality cost of greenhouse gases (Carbon dioxide, methane, and Nitrous Oxides) emissions (Institute for Policy Integrity, 2023; The White House, 2016) are used to calculate the cost of total GHG emissions. These costs are the monetized values of the net harm to the society due to the addition of GHG gases into the atmosphere in a given year. It includes the value of all climate change impacts, including effects on human health, energy system disruptions, environmental mitigations, risk of conflict, changes in net agricultural productivity, property damage from increased flood, risk from natural disasters, and the value of ecosystem services (United States Government, 2021).

3.5.2 Demand Technology Costs

Based on the capital cost, O&M cost and the lifetime of individual technology, the technology costs incurred in different scenarios are calculated.

$$Annualized\ Cost = (CRF \times Capital\ Cost) + O\&M\ Cost \quad \text{........... (6)}$$

Where; $CRF = \frac{Discount\ Rate}{1-(1+Discount\ Rate)^{-useful\ life}}$ (Heaps, 2023)

The O&M cost for each end-use devices is calculated based on the base year energy consumption by that device and the cost of fuel. The cost of devices is taken from market survey and various commercial websites.

$$O\&M\ Cost = \frac{Energy\ Consumption\ (MJ)}{Energy\ Density\ \left(\frac{MJ}{Kg}\right)} \times Cost\ per\ Kg \qquad \text{............ (7)}$$

For electric devices, the O&M cost depends on the cost of annual consumption of electricity. The cost for electricity is calculated based on the NEA tariff rates (Nepal Electricity Authority, 2023). The technologies used, their cost and efficiencies are provided in Annex E and Annex F.

3.6 Structure of Emissions

The emission factors used in this analysis are taken from national and international documents, and as much as possible, these are selected to be country and technology specific (Alternative Energy Promotion Center, 2023; IPCC, 1996; Leach & Gowen, 1987).

3.7 Description of the Scenarios

The energy demand from the base year 2022 to 2050 is studied. Based on historical trends, population and GDP growth rates, business-as-usual scenario (BAU) is created. The Scenario, Net Zero with Existing Measures (NZE) is created based on the targets set by government to achieve net zero emission. An additional scenario, Net Zero with Additional Measures (NZM) in which penetration of the technology is calculated based on the SDG and second NDC goals is also used.

Considerations for business-as-usual (BAU) scenario:

- The household income is assumed to grow at a rate of 1.4%, population at 0.97% (National Statistics Office, 2021).
- The maximum urbanization expected of the province, considering its current progress, population distribution and in comparison, with other countries (United Nations, 2019), is assumed to be 90%.

- For the sake of simplicity, the urbanization is assumed to grow at a uniform rate from current value to maximum in 2050.

Considerations for Net-Zero with Existing Measures (NZE) scenario:

This scenario is based on following considerations taken from the net-zero emission strategy of government of Nepal (Ministry of Forests and Environment, 2021) :

- In urban areas, by the year 2050, 70% of the cooking will be done by electricity, 20% will be done by LPG and the rest being other fuels.
- The share of other fuels for cooking (i.e., remaining 10%) is assumed to occupy the same proportions as in base year.
- 75% of the space heating requirement in final year will be met by electricity.
- In rural areas, by the year 2050, 40% of cooking will be done by electricity and 40% by LPG.
- 10% of the cooking will be done by ICS by year 2050.

The share of other end-uses in end year, which are not mentioned in the policies, are assumed to occupy the proportionate share of total intensity as in the base year.

Considerations for Net-Zero with Additional Measures (NZA) scenario:

In order to further curtail the emissions to meet the net-zero target, an additional scenario is created in which the penetration of energy is calculated based on second NDC (Ministry of Population and Environment, 2020) and SDG (NPC, 2017) of Nepal. The assumptions for this scenario are formulated based on all possible technology intervention that can be made in every end-use of residential sector. These assumptions are as follows:

- 90% electrification will be achieved in cooking, water heating and space heating in urban areas by the year 2050.
- Other end-use sectors such as social occasion, agriculture, and food processing as well as animal feed preparation, in which the penetration is not exclusively mentioned are assumed to have 90% electrification, as most of the activities in those sectors are related to cooking.
- In rural areas, by the year 2050, 60% electrification will be achieved in cooking. Space heating and water boiling activities will be done by 50% and 80% electricity respectively.

- Similar assumptions are used for other end-use sectors, in which penetration is not exclusively mentioned.
- In urban areas, the end-use devices responsible for major chunk of pollutant and GHG emissions such as wood, agriculture residue, animal wastes and biogas stoves, are assumed to be replaced completely by electric and LPG stoves.
- Similar technology changes are also assumed for the rural areas. Fuelwood, which is difficult to omit completely for cooking, is assumed to be used with ICS.
- Fuels such as kerosene, animal wastes, agriculture residue are assumed to be replaced completely by the year 2050.

CHAPTER FOUR: RESULTS AND DISCUSSION

The final energy demand, emissions and social costs are calculated for the BAU scenario and two net zero scenarios. The results of two net zero scenarios are then compared for their deviation with BAU scenario. The energy demand, emission and cost results are obtained for three scenarios separately, and their variation and comparative benefits are described.

4.1 Business-As-Usual (BAU) Scenario

4.1.1 Final Energy Demand

Bagmati province's final energy demand of residential sector in year 2022 was 35.3 PJ, with 19.7 PJ from urban and 15.6 PJ from rural areas, which is expected to rise to 39.1 PJ in year 2050, with 29.9 PJ from urban and 9.2 PJ from rural areas, which is slightly less as compared to previous estimate (WECS, 2022a). The share of urban demand is expected to increase because of urbanization and the consequent rise in energy demand. Nearly 52% increase in final energy demand is expected in urban areas, whereas 41% decrease is expected in rural areas. Overall, about 10.6% increase in total demand is expected.

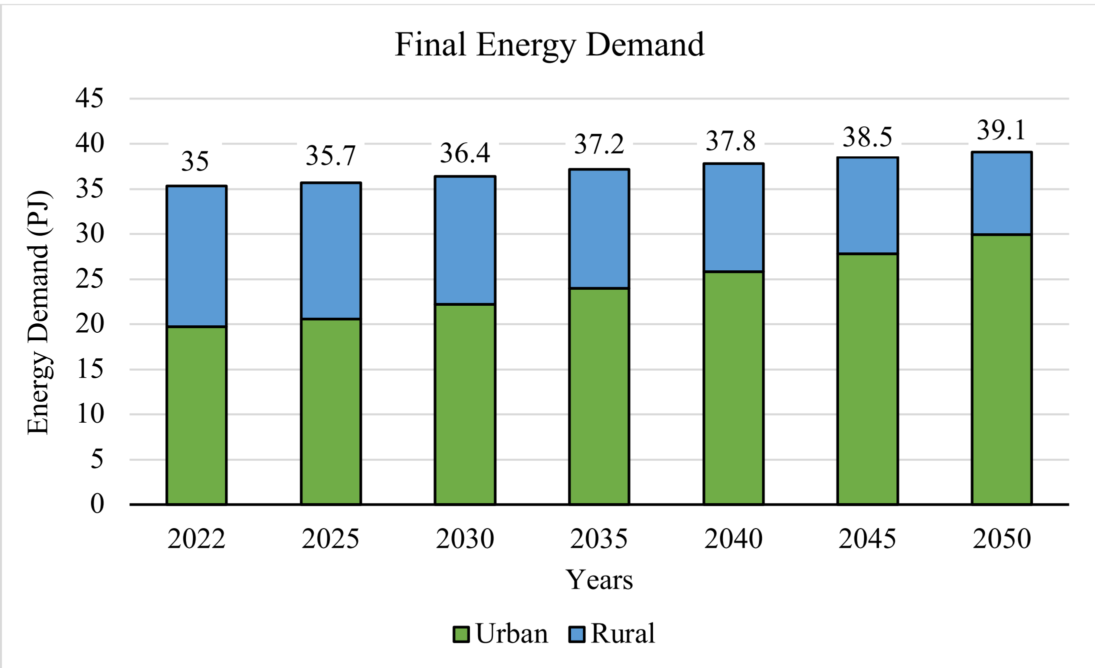

Figure 4.1: Energy Demand Final Units

The final energy demand of Bagmati province in rural and urban sector is presented in Figure 4.1. The expected energy demand in different end-use sectors is shown in figure 4.2 and Annex G. Energy demand is primarily dominated by cooking. Electrical appliances are also expected to have increased demand, whereas significant decrease in demand is expected in space heating due to the use of efficient electricity as fuel.

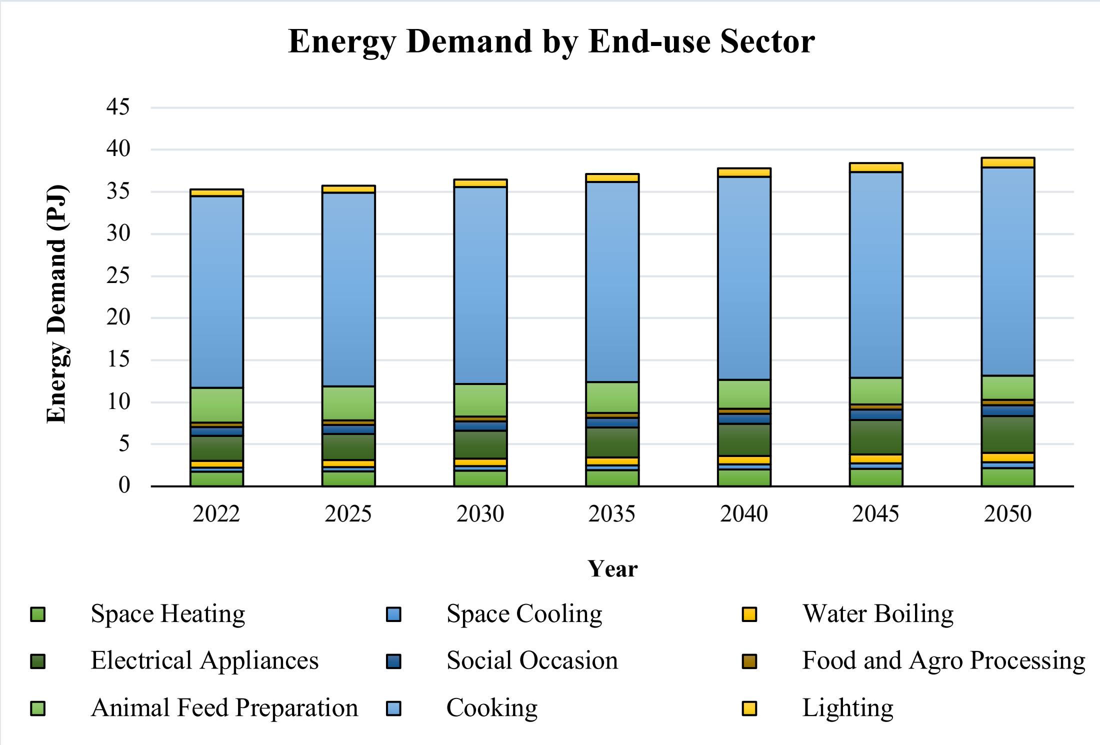

Figure 4.2: Energy Demand by End-use Sector

The fuel demand in BAU scenario in different years is shown in Figure 4.3 and Table 1. The demand for electricity and LPG which are used in greater quantities in urban areas compared to rural, are expected to increase. Electricity demand is expected to increase by nearly 47%, from 4.6 PJ in year 2022 to 6.8 PJ in year 2050. The LPG demand is also expected to rise by 47%, from 7.8 PJ to 11.4 PJ. The fuel mix is dominated by wood, followed by LPG and electricity.

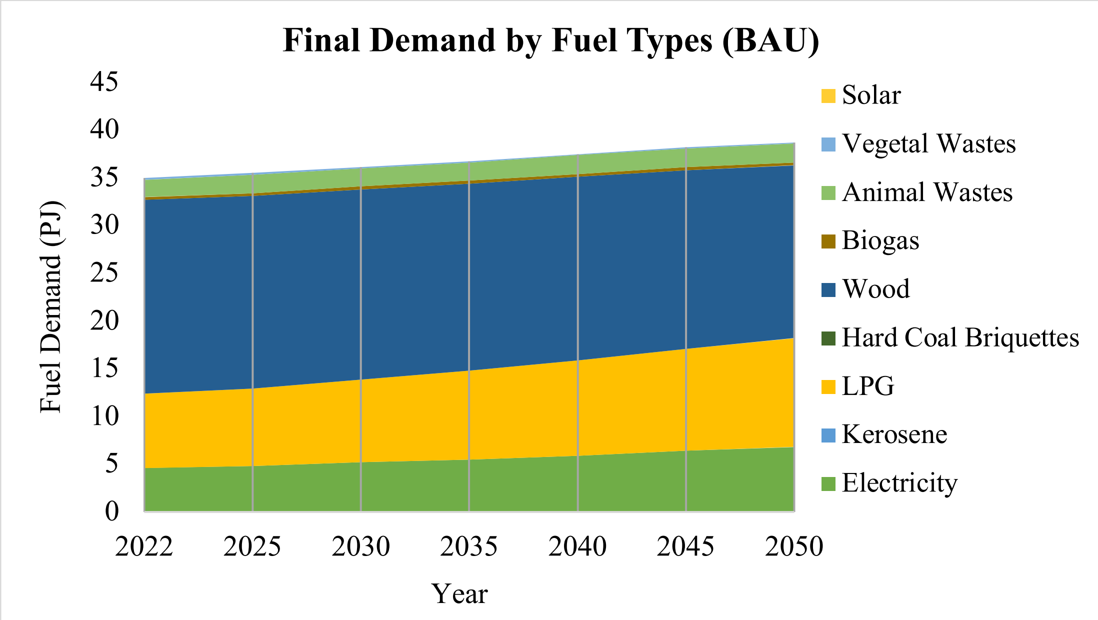

Figure 4.3: Final Demand by Fuel Types (BAU)

The demand for wood and biogas, being primarily used in rural areas, is expected to decline by 11% and 12% respectively. Cooking remains the most energy intensive activity in residential sector, with wood providing highest share (46.2%) of energy demand.

Table 1: Fuel demand in BAU Scenario (in PJ)

Fuel	**2022**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Electricity	4.6	4.8	5.2	5.5	5.9	6.4	6.8
Kerosene	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LPG	7.8	8.1	8.7	9.3	10.0	10.7	11.4
Hard Coal Briquettes	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wood	20.3	20.2	19.9	19.6	19.2	18.7	18.1
Biogas	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Animal Wastes	1.8	1.9	1.9	1.9	2.0	2.0	2.0
Vegetal Wastes	0.2	0.2	0.1	0.1	0.1	0.1	0.1
Solar	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Heat	0.2	0.2	0.2	0.2	0.2	0.3	0.3
Total	**35.3**	**35.7**	**36.5**	**37.1**	**37.8**	**38.5**	**39.1**

4.1.2 Emissions

The emissions of GHGs based on 100-Year GWP in thousand MT of CO_2 equivalent is expected to vary as shown in Table 2 for different end-use sectors.

Table 2: GHG Emissions (in '000 MT of CO_2 Equivalent)

Branch	2022	2025	2030	2035	2040	2045	2050
Urban	**601**	**629**	**678**	**730**	**787**	**847**	**910**
Water Boiling	27	28	30	32	35	37	40
Social Occasion	33	35	37	40	43	47	50
Food and Agro Processing	16	17	18	20	21	23	25
Animal Feed Preparation	10	10	11	12	13	14	15
Cooking	515	539	581	626	674	726	780
Rural	**218**	**212**	**199**	**184**	**168**	**150**	**129**
Water Boiling	2	2	2	2	2	1	1
Social Occasion	4	4	3	3	3	3	2
Food and Agro Processing	2	2	2	2	2	1	1
Animal Feed Preparation	79	76	72	67	61	54	47
Cooking	132	128	120	111	102	90	78
Total	**819**	**840**	**877**	**915**	**955**	**996**	**1039**

Majority of GHG emission is expected from cooking. Nearly 79% of GHG emission is from cooking in base year, which is expected to increase by 83% in year 2050. The urban and rural emissions in base year are nearly 601 MT and 218 MT of CO_2 equivalent respectively. In year 2050, urban GHGs are expected to increase by 52% compared to base year, whereas nearly 41% decrease in rural emissions are expected. Overall, 27% increase in GHG emissions is expected, final year GHG emissions being 1039 thousand MT of CO_2 equivalent.

The environmental emissions of GHG and other pollutants is shown in Table 3. Huge chunk of emissions is from carbon dioxide biogenic. The biogenic CO_2 arisen from biomass comes from recent carbon fixation, which is a part of short term and natural carbon cycle (Harris et al., 2018). This emission according to IPCC should not be counted in national GHG because it is already included fully in AOFL sector (IPCC, 2019). CO_2 biogenic account for nearly 76% of the emissions in base year, which are expected to decrease by nearly 9% in year 2050. Compared to base year, CO_2 emissions are expected to increase by nearly 47% in year 2050. The emissions N_2O, NO_X and TSP are expected to increase by 18%, 8.9% and 9.5% respectively, whereas CO and CH_4 emissions are expected to decline by 6% and 14% respectively. SO_2 and PM10 emissions are insignificant in terms of quantity, compared to other pollutants.

Table 3: Environmental Emissions in Physical Units (BAU)

Years	2022	2025	2030	2035	2040	2045	2050
Emissions (in '000 MT)							
CO_2 Biogenic	2085	2076	2054	2026	1989	1944	1890
CO_2	525	547	586	628	672	719	769
CO	110	110	109	108	107	106	104
CH_4	7.4	7.3	7.2	7.0	6.9	6.6	6.4
NMVOC	14.4	14.5	14.6	14.7	14.7	14.8	14.7
TSP	2.9	3.0	3.0	3.1	3.1	3.2	3.2
N_2O	0.20	0.21	0.21	0.22	0.22	0.23	0.24
NO_X	0.27	0.28	0.28	0.29	0.29	0.29	0.30
Emissions (in Kg)							
SO_2	2.5	2.5	2.7	2.8	3.0	3.1	3.3
PM10	2.2	2.3	2.4	2.5	2.7	2.8	2.9

4.1.3 Social Costs

The externality cost by end-use sector in BAU scenario is shown in Figure 4.4 and Annex H. With the increase in emissions in urban areas, the externality cost is expected to increase. In urban areas, nearly 52% increase in externality cost is expected in year 2050 compared to base year. Whereas 41% decrease is expected in rural areas.

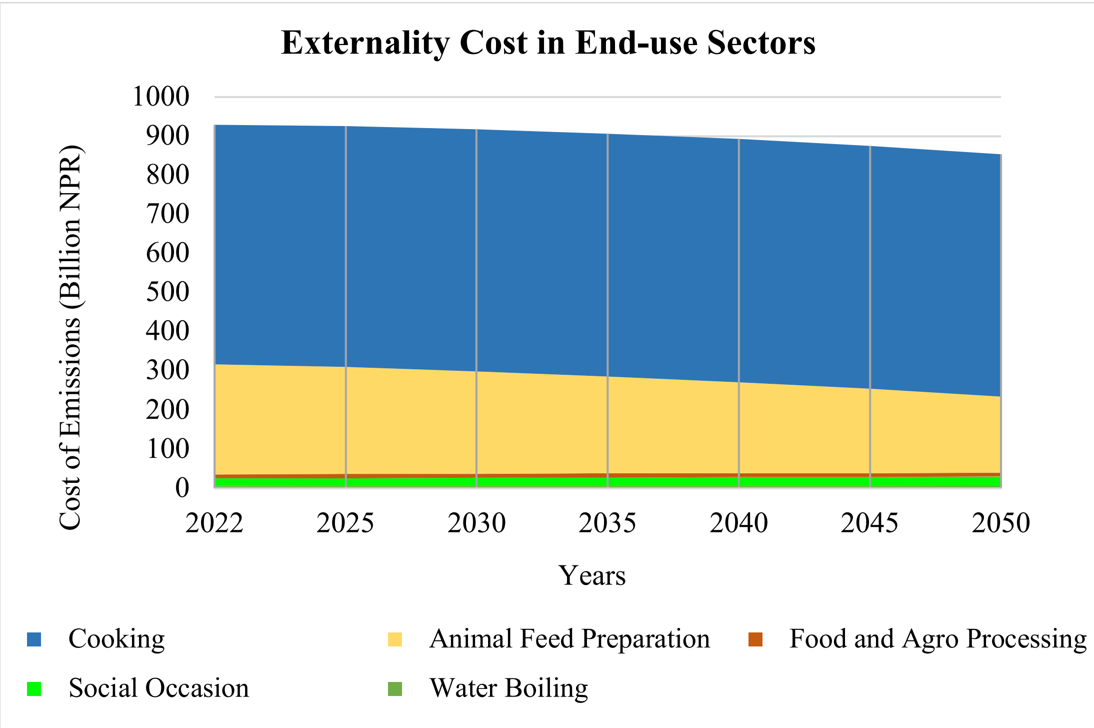

Figure 4.4: Externality Cost by End-use Sector in BAU

The net externality cost in base year is nearly 929 billion NPR, which is expected to decline by 8% in year 2050, reaching a value of 853 billion NPR. Animal feed preparation and cooking are the major contributors to externality costs. The contribution of animal feed preparation in year 2050 is expected to be 31% less compared to base year, whereas slight increase (1.01%) is expected from cooking sector.

The demand technology cost for different end-use sectors in BAU scenario is shown in Figure 4.5 and Annex I. This cost includes the investment cost of the technology and the O&M cost calculated from fuel used. The base year demand technology cost is nearly 51 billion NPR, which is expected to increase by 47% in final year, reaching nearly 74 billion NPR. In base year, urban areas hold nearly 94% share of total demand technology cost, which is expected to increase to nearly 98% in final year. Cooking occupies most of the technology cost, nearly 44%, which is followed by electrical appliances occupying 17% of the total technology cost.

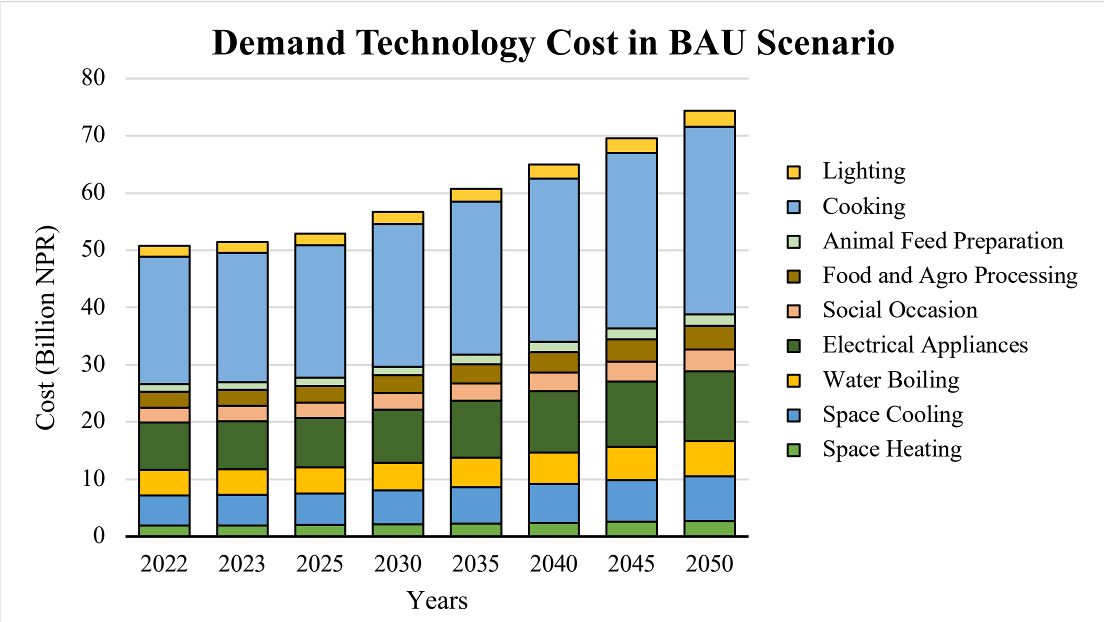

Figure 4.5: Demand Technology Cost in BAU Scenario

4.2 Net Zero with Existing Measures (NZE) Scenario

4.2.1 Final Energy Demand

Urban areas occupy nearly 56% share of residential energy demand in base year, which is expected to increase to 80.48% in year 2050. The final energy demand in NZE scenario in urban areas is shown in Figure 4.6 and for rural areas is show in Figure 4.7. The highest energy demand in both areas is in cooking sector. In base year, 62% share of total urban demand (19.69 PJ) is from cooking. The electrical appliances occupy 2.83 PJ, nearly 14% of total urban demand. In year 2050, the urban energy demand from cooking is expected to decline by nearly 9%. In terms of share of total urban demand, the share of cooking sector is expected to reduce to nearly 52%. Space heating is another end-use sector which is will experience decrease in energy demand. All other end-use sectors of urban areas are expected to experience increase in demand. The replacement of wood and other inefficient fuels by electricity in cooking and space heating is the cause of decrease in demand in those end-use sectors.

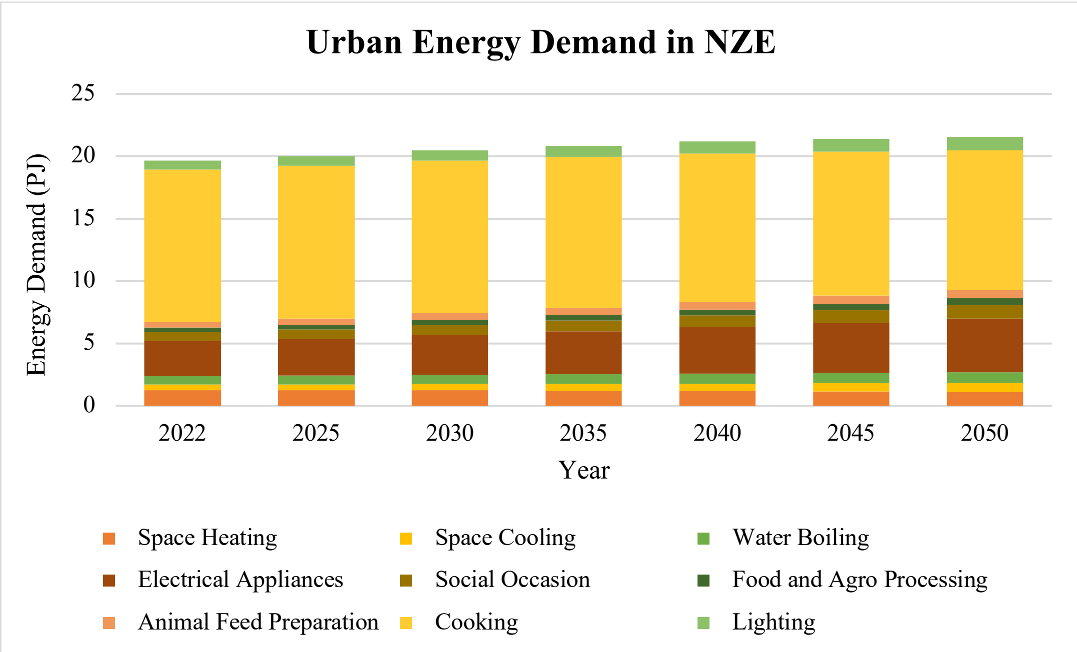

Figure 4.6: Urban Final Energy Demand in NZE

In rural areas, cooking and animal feed preparation are two end-use sectors which occupy major share of total rural energy demand, occupying nearly 68% and 23% share respectively.

The decline in rural population and increase in electric cooking are expected to cause significant decline in cooking demand by the year 2050. Cooking demand is expected to decline significantly by nearly 77%. All other end-use sectors are expected to have some decline in energy consumption. In year 2050, the share of cooking reduces to nearly 46% of total rural demand, whereas animal feed preparation occupies second highest share (41%) which presents further potential for reduction in energy consumption. The urban/rural energy demand in NZE scenario is shown in Annex J.

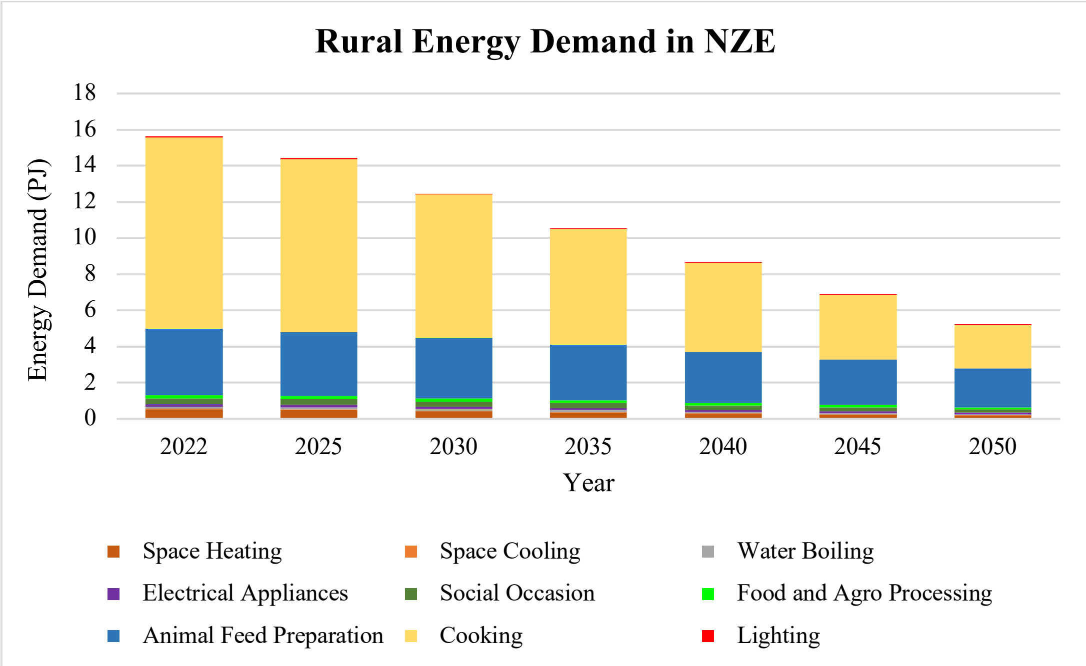

Figure 4.7: Rural Final Energy Demand in NZE by end-use

With the implementation of electric cooking technologies in net zero scenario, the energy demand by wood decreases considerably by nearly 71%, whereas large increase in electricity demand, nearly 3 times of base year is expected.

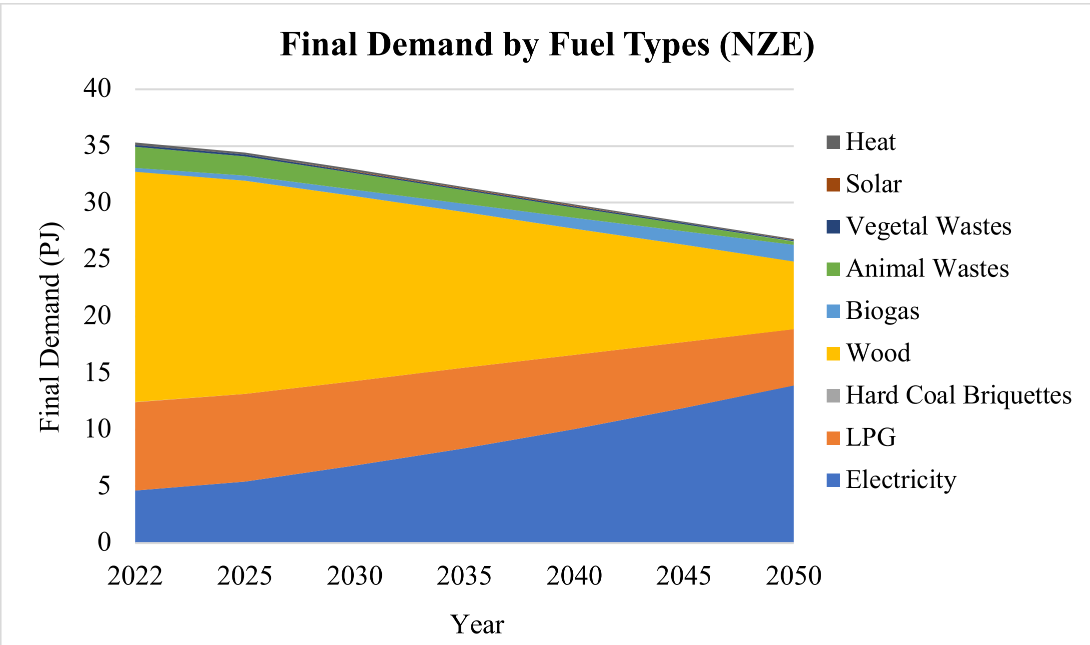

Figure 4.8: Final Demand by Fuel Types (NZE)

Demand for LPG is expected to decline by 36%. Electric fuels will gradually replace all other inefficient fuels in year 2050. This can be seen from Figure 4.8 and Table 4.

Table 4: Final Demand by Fuel Types in NZE (in PJ)

Fuel	**2022**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Electricity	4.6	5.4	6.8	8.4	10.0	11.9	13.9
LPG	7.8	7.7	7.5	7.1	6.6	5.9	5.0
Hard Coal Briquettes	0.01	0	0	0	0	0	0
Wood	20.3	18.8	16.3	13.7	11.1	8.5	6.0
Biogas	0.3	0.4	0.6	0.8	1.0	1.2	1.5
Animal Wastes	1.9	1.7	1.4	1.2	0.9	0.6	0.3
Vegetal Wastes	0.2	0.2	0.2	0.1	0.1	0.1	0.1
Solar	0.03	0	0	0	0	0	0
Heat	0.2	0.2	0.2	0.2	0.1	0.1	0.1
Total	**35.3**	**34.4**	**32.9**	**31.4**	**29.9**	**28.3**	**26.8**

4.2.2 Emissions

The GHG emissions of end-use sectors in NZE scenario, based on 100-Year GWP in thousand MT of CO_2 equivalent is shown in Table 5.

Table 5: GHG Emissions in NZE ('000 MT of CO_2 Equivalent)

Branch	**2022**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Urban	**601**	**585**	**552**	**510**	**458**	**394**	**318**
Water Boiling	27	26	24	22	19	16	13
Social Occasion	33	35	37	40	43	47	50
Food and Agro Processing	16	17	18	20	21	23	25
Animal Feed Preparation	10	10	11	12	13	14	15
Cooking	515	497	461	416	361	294	216
Rural	**218**	**211**	**197**	**182**	**165**	**146**	**125**
Water Boiling	2	2	2	2	1	1	1
Social Occasion	4	4	3	3	3	3	2
Food and Agro Processing	2	2	2	2	2	1	1
Animal Feed Preparation	79	76	72	67	61	54	47
Cooking	132	127	119	109	98	87	74
Total	**819**	**796**	**749**	**692**	**622**	**540**	**443**

In year 2050, emissions from cooking, water boiling, and animal feed preparation are expected to decline by nearly 55%, 53% and 31% respectively compared to base year.

The urban and rural emissions are expected to decline by 47% and 43% respectively. Overall, 46% decrease in GHG emissions is expected, final year GHG emissions being 443.1 thousand MT of CO_2 equivalent. Apart from cooking, emissions from animal feed preparation are significantly higher even in end year.

The environmental emissions in physical units are shown in Table 6. In year 2050, biogenic CO_2 emissions are expected to decline by 64%, whereas CO_2, and CH_4 emissions are expected to decline by 46% and 62% respectively. Other emissions experience similar decline. SO_2 and PM10 emissions which are emitted from the burning of wood, animal wastes and LPG, become almost zero in final year.

Table 6: Environmental Emissions in Physical Units (NZE)

Years	2022	2025	2030	2035	2040	2045	2050
Emissions (in '000 MT)							
CO_2 Biogenic	2085	1940	1694	1446	1198	952	709
CO_2	525	519	503	478	442	395	334
CO	110	102	90	77	63	50	36
CH_4	7	7	6	5	5	4	3
NMVOC	14	14	12	11	9	7	5
TSP	3	3	2	2	2	1	1
N_2O	0.2	0.2	0.2	0.2	0.2	0.1	0.1
NO_X	0.3	0.3	0.2	0.2	0.2	0.1	0.1
Emissions (in Kg)							
SO_2	2.5	2.3	1.9	1.5	1.1	0.6	0.0
PM10	2.2	2.0	1.7	1.4	1.0	0.5	0.0

4.2.3 Social Costs

Figure 4.9 and Annex K shows the externality cost in different end-use sectors in NZE scenario. The total externality cost expected in year 2050 is 346.28 billion NPR, in which 40% is from urban whereas, 60% is from rural areas. In year 2050, the expected decline of urban and rural externality cost compared to base year is 58% and 66% respectively. Nearly 81% reduction in externality cost of emissions from cooking and 31% reduction from animal feed preparation is expected. As lighting is done entirely by electricity, 100% reduction is expected from lighting. Externality cost from water boiling is nearly 62% less in final year.

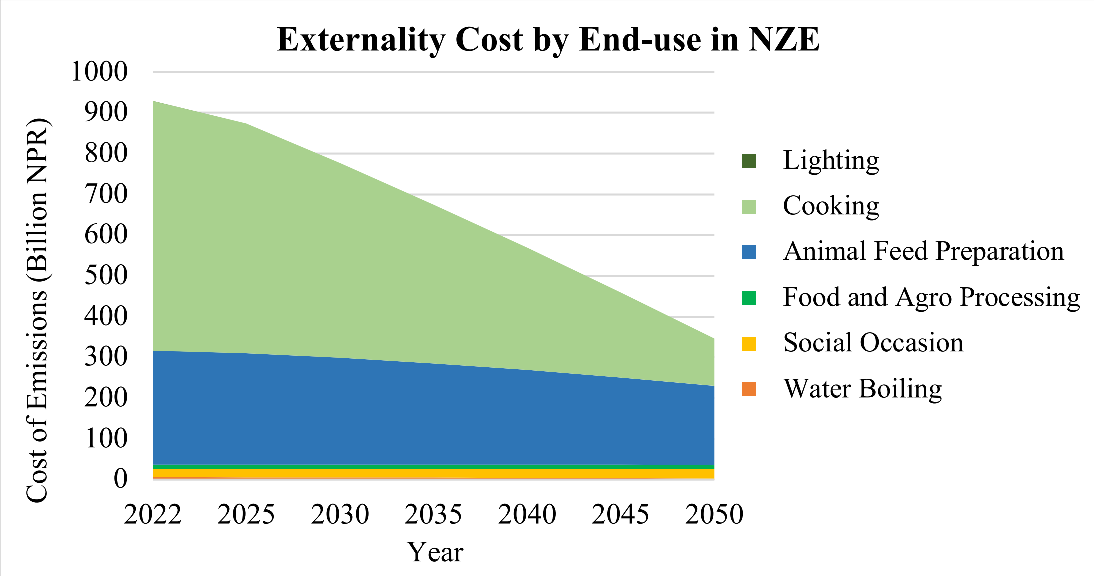

Figure 4.9: Externality Cost by End-use in NZE Scenario

The demand technology cost in NZE scenario for different end-use sectors is shown in Figure 4.10 and Annex L. The use of electric water heaters in place of wood and LPG stoves is expected to reduce the cost of water boiling by nearly 30% compared to base year. With the investment in efficient technologies, the cost is expected to increase in all other end-use sectors. Highest increase is expected in space heating (nearly 120%), due to the investment in electric heating technologies. Cost in lighting, cooking, animal feed preparation, food and agro processing, social occasion, electrical appliances, and space cooling are expected to increase by 44%, 31%, 51%, 51%, 45%, 48% and 47% respectively.

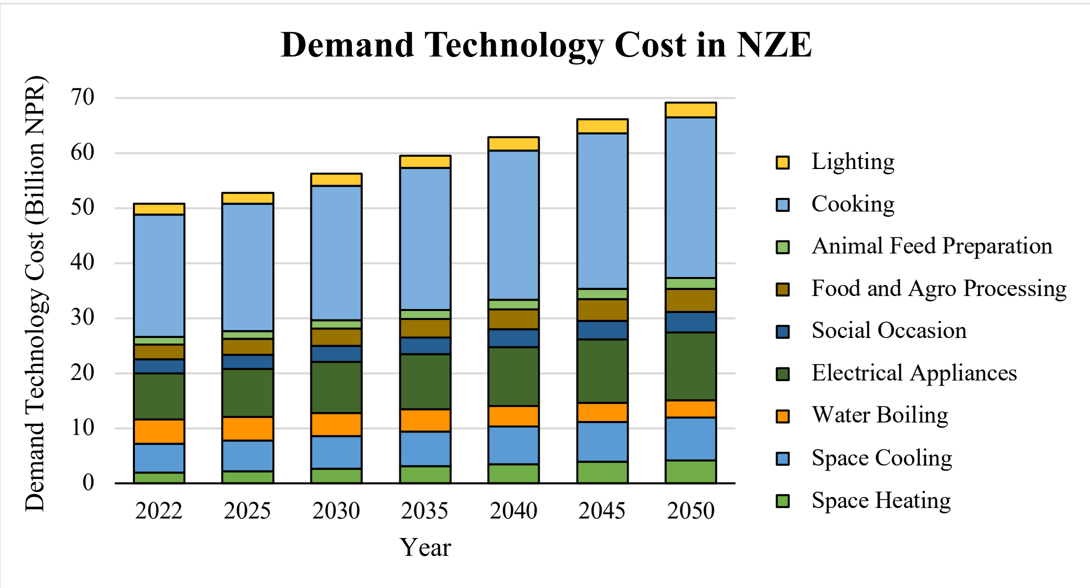

Figure 4.10: Demand Technology Cost (Real) in NZE

4.3 Net Zero with Additional Measures (NZA)

4.3.1 Final Energy Demand

The final energy demand for NZA scenario for urban and rural areas is shown in Figure 4.11 and Figure 4.12 respectively. In year 2050, the final energy demand is 21.88 PJ, the share of urban and rural areas being 83% and 17% respectively. More than half of the demand is from cooking activities.

In urban areas, electrical appliances are expected to consume nearly 24% of total urban energy demand. The energy demand from space cooling, electrical appliances and lighting uses is expected to increase by nearly 52%, 24% increase is expected on water boiling. Whereas decrease in energy demand by 32%, 20%, 17%, 46% and 24% is expected in space heating, social occasion, food and agro processing, animal feed preparation and cooking respectively.

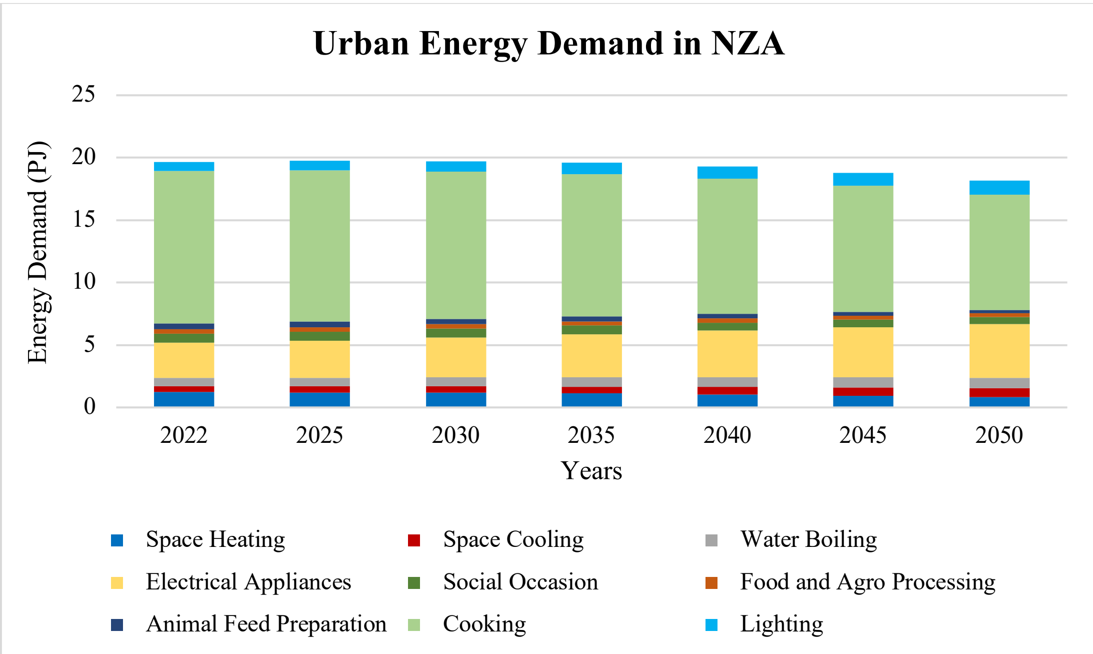

Figure 4.11: Urban Final Energy Demand in NZA

In rural areas, apart from cooking, animal feed preparation is expected to occupy second largest share of total energy demand (nearly 30%). Decrease in energy demand in year 2050, is expected of all applications. Cooking and water boiling applications are expected to consume nearly 80% less energy. Fuel switching and urbanization are the main factors responsible for this decline in energy consumption. The urban/rural energy demand in NZA scenario is shown in Annex M.

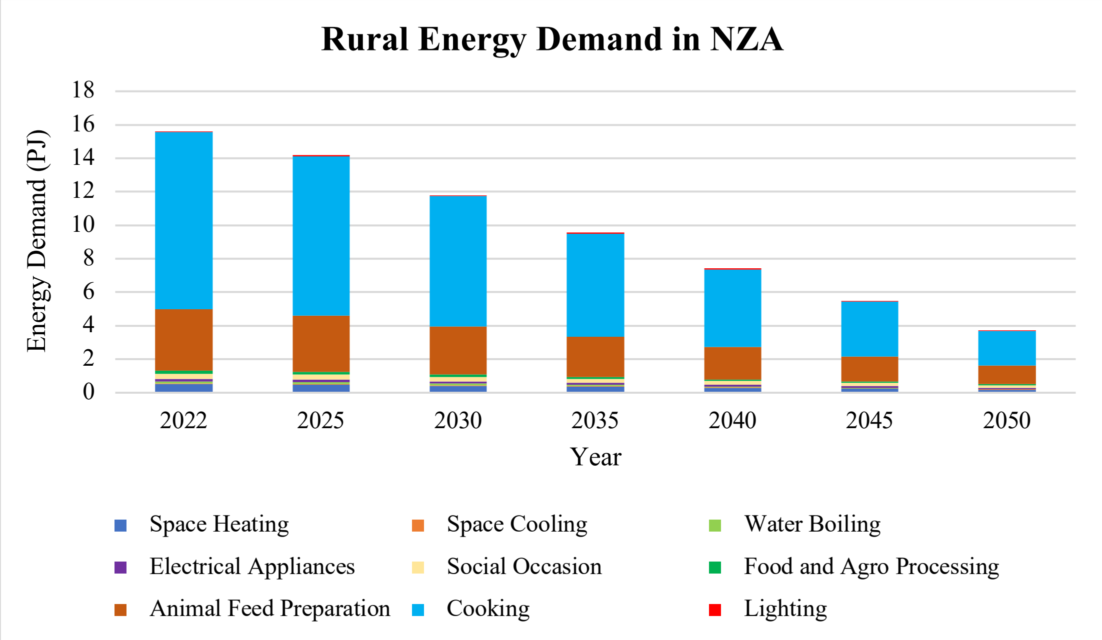

Figure 4.12: Rural Final Energy Demand in NZA

The final energy demand by fuel types in NZA scenario is shown in Figure 4.13 and Table 7. In NZA scenario, 79% of total residential energy demand is supplied from electricity, nearly 8% is from LPG and 12% from wood.

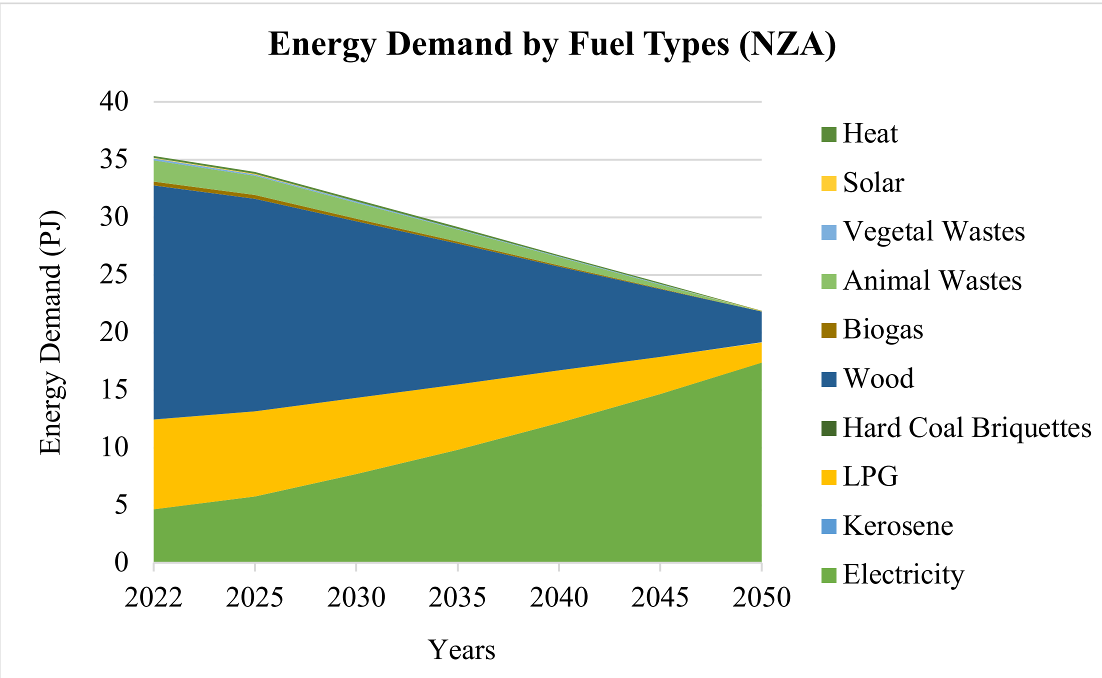

Figure 4.13: Final Demand by Fuel Types (NZA)

Solar energy in the form of electricity and heat contribute to a small percentage of total demand. All other inefficient and polluting fuels are replaced. In year 2050, the expected growth in electricity consumption is nearly 4 times, whereas nearly 78% and 87% decline in use of LPG and wood is expected.

Table 7: Final Demand by Fuel Types in NZA Scenario (in PJ)

Fuel	2022	2025	2030	2035	2040	2045	2050
Electricity	4.6	5.7	7.7	9.8	12.1	14.6	17.4
LPG	7.8	7.4	6.6	5.7	4.5	3.2	1.7
Hard Coal Briquettes	0.01	0.0	0.0	0.0	0.0	0.0	0.0
Wood	20.3	18.5	15.4	12.2	9.0	5.8	2.7
Biogas	0.3	0.3	0.2	0.2	0.1	0.1	0.0
Animal Wastes	1.8	1.7	1.4	1.0	0.7	0.4	0.0
Vegetal Wastes	0.2	0.1	0.1	0.1	0.0	0.0	0.0
Solar	0.03	0.0	0.0	0.0	0.0	0.0	0.0
Heat	0.2	0.2	0.2	0.1	0.1	0.1	0.0
Total	**35.3**	**33.9**	**31.5**	**29.1**	**26.7**	**24.3**	**21.9**

4.3.2 Emissions

The GHG emissions based on 100-Year GWP in thousand MT of CO_2 equivalent in NZA scenario is shown in Table 8. In year 2050, GHG emissions is expected to be 170.29 thousand MT of CO_2 equivalent, nearly 79% less compared to base year.

Table 8: GHG Emissions in NZA Scenario (in '000 MT of CO_2 Equivalent)

Branch	**2022**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Urban	**601**	**570**	**509**	**434**	**345**	**239**	**115**
Water Boiling	27	25	22	19	15	10	4
Social Occasion	33	31	28	24	19	13	6
Food and Agro Processing	16	15	14	12	9	6	3
Animal Feed Preparation	10	9	9	7	6	5	3
Cooking	515	488	436	372	296	205	99
Lighting	0	0	0	0	0	0	0
Rural	**218**	**199**	**166**	**136**	**107**	**80**	**55**
Water Boiling	2	2	1	1	1	0	0
Social Occasion	4	4	3	3	3	3	2
Food and Agro Processing	2	2	2	1	1	1	0
Animal Feed Preparation	79	71	60	48	37	28	19
Cooking	132	120	101	82	65	48	34
Lighting	0.01	0	0	0	0	0	0
Total	**819**	**768**	**675**	**570**	**451**	**318**	**170**

Emissions from cooking are expected to decline by nearly 80%, whereas nearly 85%, 77%, 81% and 76% decline is expected in water boiling, social occasion, food and agro processing and animal feed preparation applications. Emissions from lighting applications are expected to be zero since all lighting is expected to be done from electricity.

Pollutant emission is shown in Table 9. Biogenic CO_2 emissions in year 2050 are nearly 63% of total, whereas 31% and 5.22% of total emissions are from CO_2 and CO. Significant decrease in emission is expected in NZA scenario. Biogenic CO_2 emissions are expected to decline by nearly 88%. CO_2, CO and CH_4 emissions are expected to decline by 78%, 82% and 80% respectively. NMVOC, N_2O, NO_X and TSP emissions decline by 84%, 76%, 88% and 86% respectively, whereas SO_2 and PM10 emissions are reduced to zero.

Table 9: GHG Emissions in Physical Units in NZA Scenario

Years	**2022**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Emissions (in '000 MT)							
CO_2 Biogenic	2085	1893	1567	1238	905	572	241
CO_2	525	498	444	381	306	218	117
CO	110	101	86	70	54	37	20
CH_4	7	7	6	5	4	3	1
NMVOC	14	13	11	9	7	5	2
TSP	3	3	2	2	1	1	0
N_2O	0.2	0.2	0.2	0.1	0.1	0.1	0.1
NO_X	0.3	0.3	0.2	0.2	0.1	0.1	0.0
Emissions (in Kg)							
SO_2	2.5	2.3	1.9	1.5	1.1	0.6	0.0
PM10	2.2	2.0	1.7	1.4	1.0	0.5	0.0

4.3.3 Social Costs

Figure 4.14 and Annex N show the externality cost in end-use sectors in NZA scenario. The total externality cost expected in year 2050 is nearly 169 billion NPR, out of which 3% is from urban whereas, 97% is from rural areas. The decline of urban and rural externality cost compared to base year is 98% and 73% respectively. The expected decline in externality cost in water boiling, social occasion, food and agro processing, animal feed preparation and cooking are nearly 89%, 78%, 86%, 79% and 83% respectively.

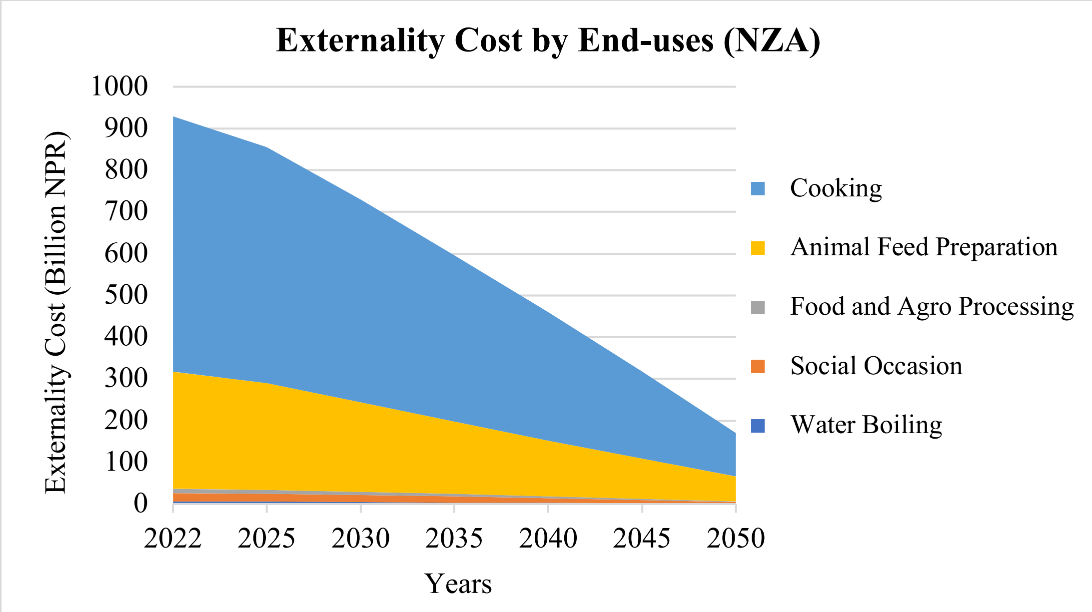

Figure 4.14: Externality Cost by End-uses in NZA Scenario

The demand technology cost in NZA scenario for different end-use sectors is shown in Figure 4.15 and Annex O. In year 2050, the technology cost in social occasions and food and agro processing applications is expected to decrease by nearly 88% and 95% respectively. Whereas due to the investment in efficient technologies, the cost is expected to increase on all other applications. Nearly 24% increase in technology cost is expected in cooking application. 44% increase is expected in lighting. Similarly, cost of space cooling and electrical appliances is expected to increase by 47% and 48% respectively. The cost of space heating applications is expected to increase by 129%. Animal feed preparation, which is done mostly by freely available firewood as primary fuel, is expected to have significant increase in terms of technology cost.

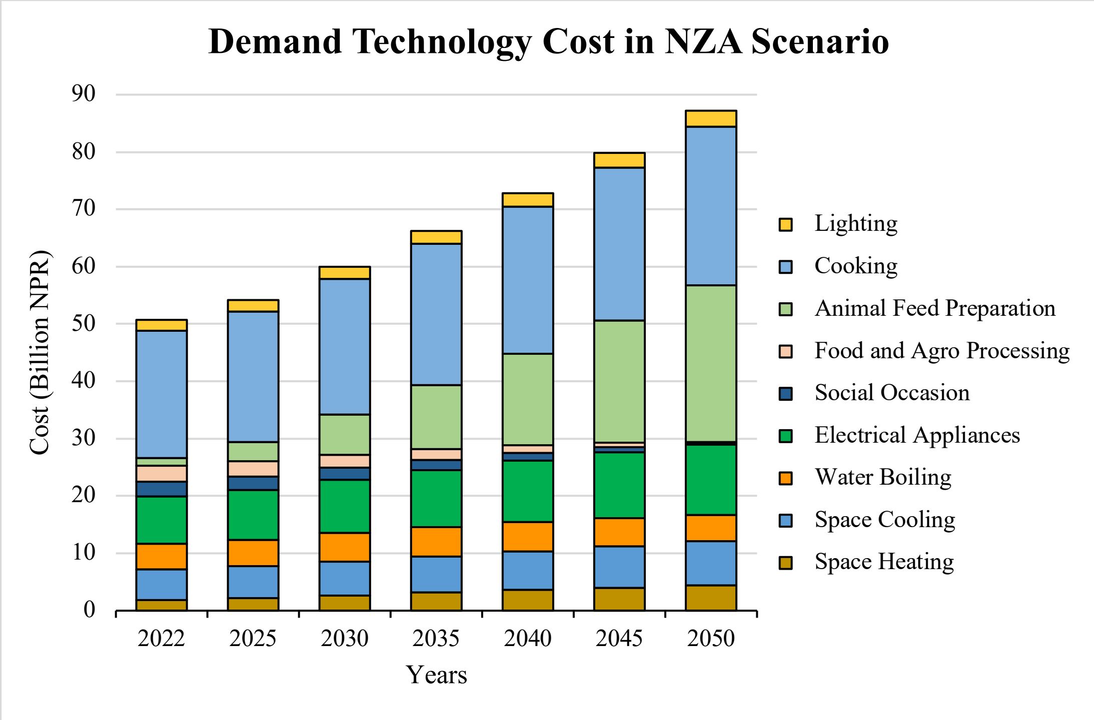

Figure 4.15: Demand Technology Cost (Real) in NZA

4.4 Benefits of Net Zero Scenarios

4.4.1 Environmental Benefits

Based on the 100-yr GWP, the GHG emissions of different scenarios is shown in Figure 4.16. GHG emissions from residential sector of Bagmati province in BAU scenario in year 2050 are expected to reach 1039 thousand MT of CO_2 equivalent. With the mitigation options as outlined in net zero strategy, i.e., in NZE scenario, 46% reduction in emissions is achievable by year 2045 reaching only 57% reduction in 2050, which does not fall in line with the aim of achieving net zero emissions by year 2045. In order to achieve the government target, implementation of additional mitigation options is essential. The NZA scenario, devised with a view to achieve this target, will further reduce the emission with 68% lesser emissions in year 2045 compared to BAU which will reduce by 84% by year 2050.

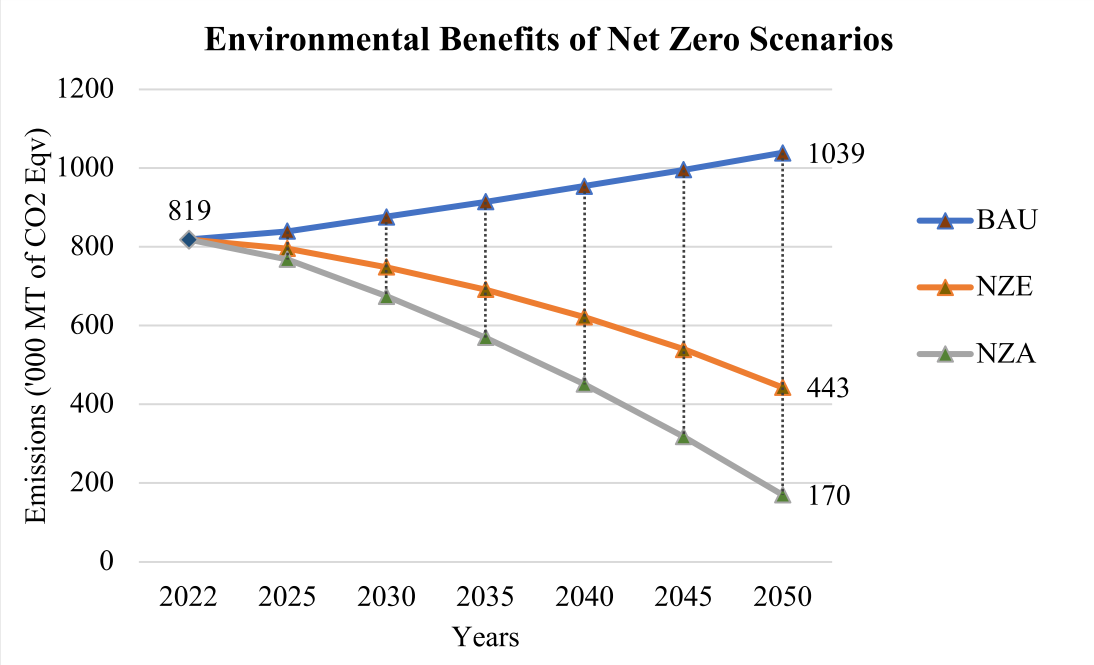

Figure 4.16: GHG emissions in different scenarios

Further measures such as 100% electrification (Shakya et al., 2023) can help to achieve net zero, whereas policies such as carbon tax can help curb the emissions (Pradhan et al., 2018). Considering geography of the region and societal needs, the feasibility of 100% electrification in Nepal may not be entirely plausible. However, considering large area of the country has forest cover, and taking into account of the sequestration by forest, the net zero target is within the capability of country.

The emissions of all pollutants in different scenarios from residential sector of Bagmati province is shown in Figure 4.17. With Existing measures, Biogenic CO_2 can be reduced by 62% in year 2050 compared to BAU. Additional measures are expected to further reduce these emissions by 87%. CO_2 emissions can be reduced by 57% by existing measures and by 85% by additional measures. Likewise, with existing measures, CO, CH_4, NO_X, N_2O, NMVOC and TSP emissions can be reduced by 65%, 56%, 68%, 53%, 63% and 71% respectively compared to BAS. Additional measures are expected to reduce these emissions by 81%, 77%, 89%, 79%, 84% and 87% respectively.

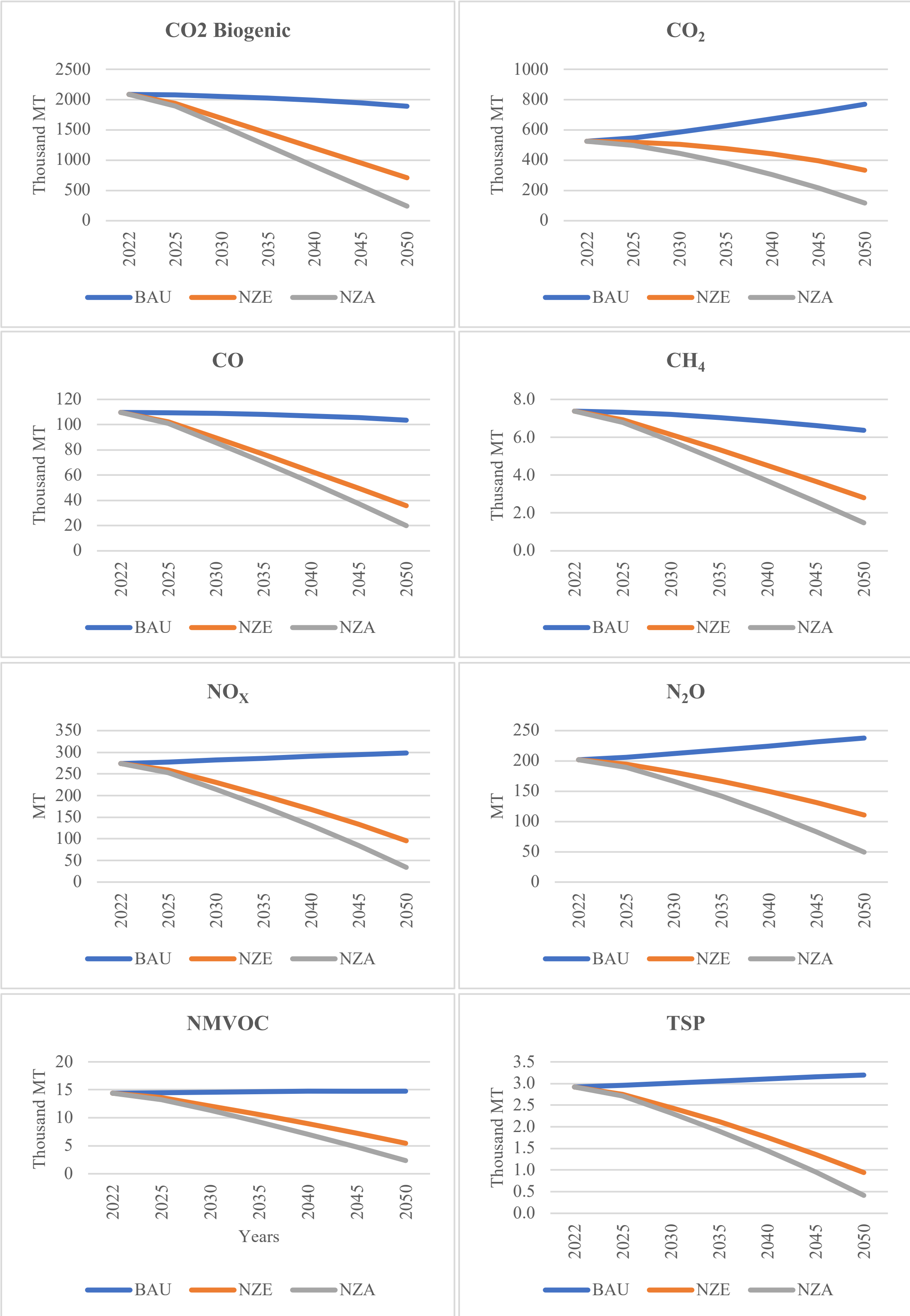

Figure 4.17: Pollutant Emissions in Different Scenarios

4.4.2 Economic Benefits

The implementation of net zero emission strategy has economic benefits in terms of reduced externalities as well as reduction in demand technology costs. The externalities of emissions in BAU scenario in year 2050 is expected to be 853.06 billion NPR, 8% lesser compared to base year, primarily due to urbanization. The existing measures of net zero strategy are expected to reduce these costs by 59% compared to BAU scenario. Whereas additional measures can further cut down these costs by 80%.

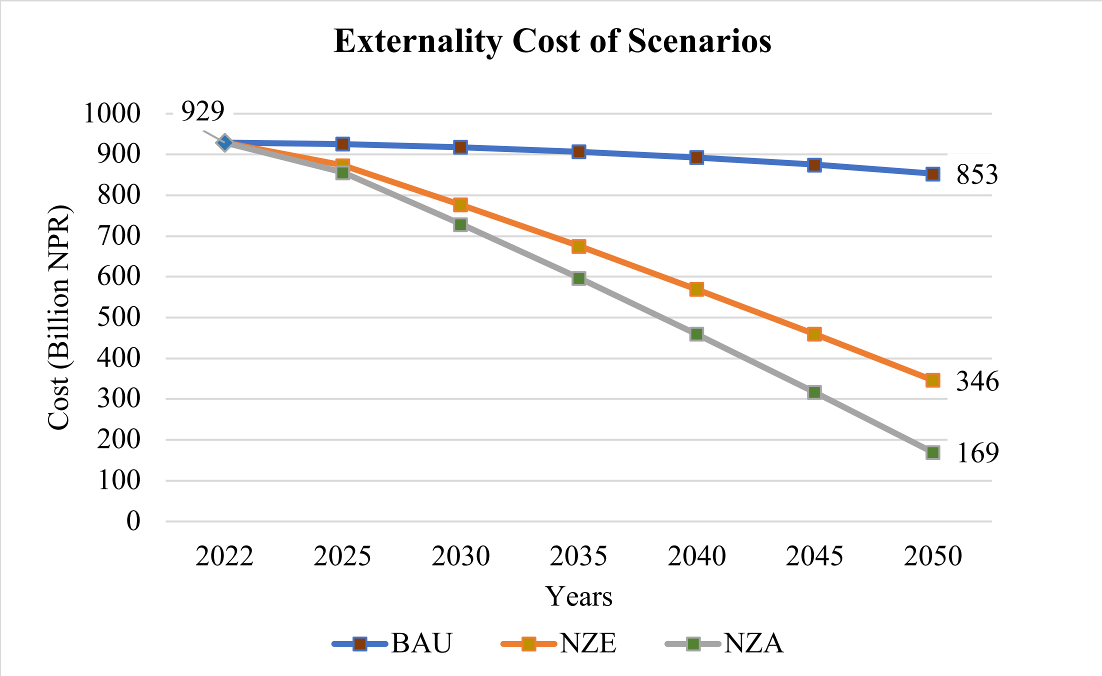

Figure 4.18: Externality Cost of Scenarios

The demand technology cost of different scenarios is shown in Figure 4.19. The expected demand technology cost in BAU scenario in year 2050 is expected to be 50.76 billion NPR, nearly 47% increase compared to base year value. The gradual shift to electric technologies and the subsequent cut down in fuel costs with existing net zero measures is expected to reduce the technology cost by 7% compared to BAU. However, Additional measures are expected to cause an increase the cost by nearly 16% due to the additional investment required in all end-use sectors.

The cumulative cost from 2022-2050 discounted at 10% to base year 2022 for different scenarios is shown in Table 10. In BAU scenario, the cumulative cost for demand technology is nearly 560 billion NPR, environmental externality is nearly 8,988 billion NPR, with total NPV being nearly 9,548 billion NPR.

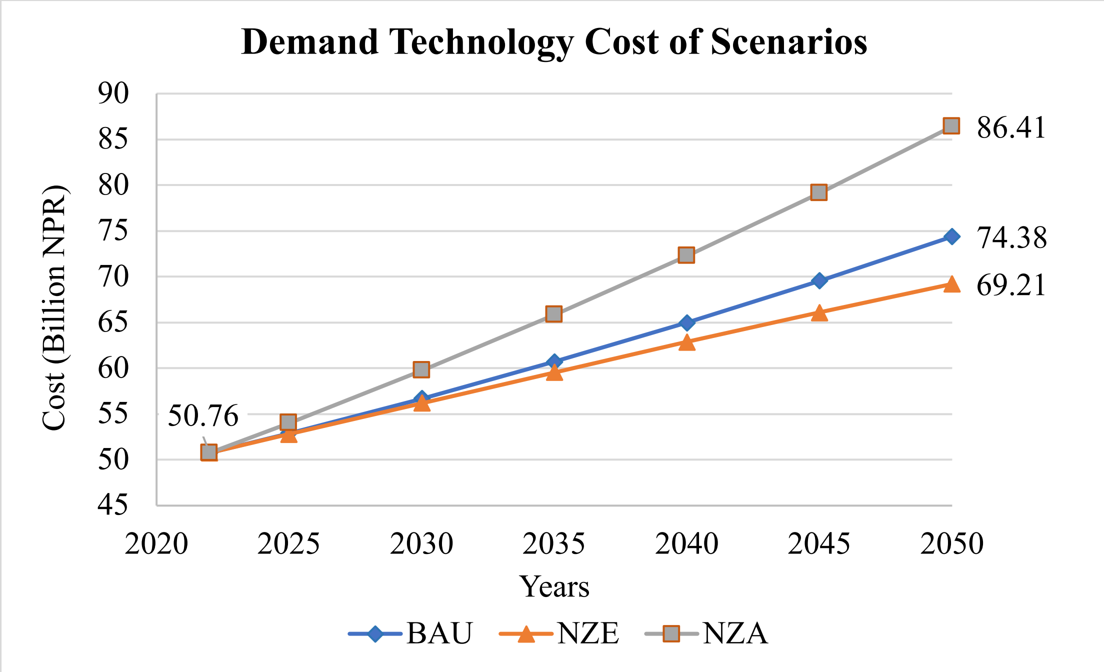

Figure 4.19: Demand Technology Cost of Scenarios

With existing measures, the demand technology and externality cost are expected to be 552 billion NPR and 7,578 billion NPR with total NPV being 8,130 billion NPR. Additional measures are expected to reduce cumulative demand technology cost to 591 billion NPR, externality costs to 7,100 billion NPR with total NPV being 7,691 billion NPR.

Table 10: Cumulative Cost 2022-2050 (in Billion NPR)

Sector	BAU	NZE	NZA
Demand Technology	560	552	591
Environmental Externalities	8,988	7,578	7,100
Total Net Present Value	**9,548**	**8,130**	**7,691**

The total NPV with existing measures is 14.85% less compared to BAU whereas, additional measures are expected to reduce NPV up to 19.45%. In terms of monetary value nearly 1,418 billion NPR is expected to be saved due to net zero measures. Additional measures are further expected to save the costs up to 1,857 billion NPR.

4.5 Additional Electricity Requirements

The electricity requirement for the residential sector of Bagmati province for different scenarios is shown in Figure 4.20 and Table 11.

Table 11: Capacity Requirements in Different Scenarios (in MW)

Scenarios	2022	2025	2030	2035	2040	2045	2050
BAU	209	218	234	250	268	287	307
NZE	209	244	307	377	453	537	628
NZA	209	258	347	443	547	661	784

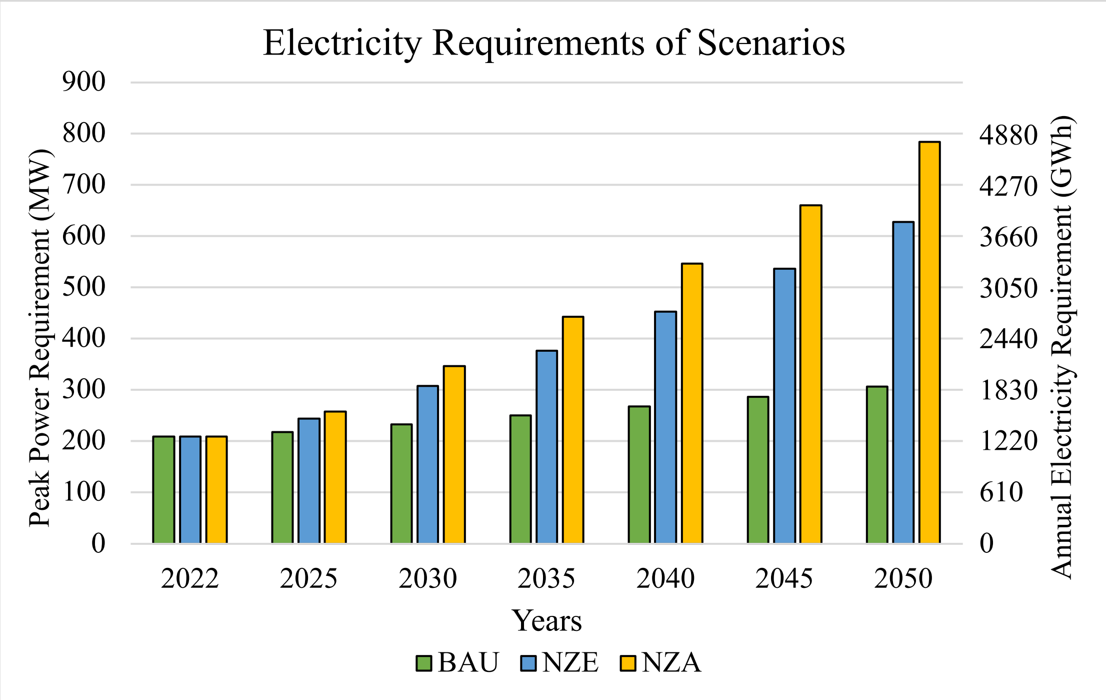

Figure 4.20: Electricity Requirement of Scenarios

The base year peak power requirement is 209 MW, annual requirement being 1,282 GWh. By the year 2050, urbanization and the subsequent preference to electric power by urban population, is expected to increase the required capacity up to 307 MW, with annual requirement of 1,881 GWh. With the penetration of electric technologies in existing measures (NZE), 628 MW plant capacity is required in year 2050, annual requirement reaching 3,849 GWh. Capacity requirement for the year 2045 is 536 MW, i.e., additional 327 MW is required in year 2045 for residential sector of Bagmati province to implement net zero strategy.

Additional measures in NZA scenario demand the plant capacity to be 784 MW in year 2050, with annual consumption of 4,809 GWh. With the province's existing capacity of 252.27 MW and 1,882 MW of capacity in pipeline (WECS, 2022a), this demand lies within the capability of the province.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study analyzed the energy demand, emissions, and social costs in residential sector of Bagmati province in three different scenarios and drew out following conclusions:

- Compared to BAU scenario, nearly 31% lesser energy demand is expected in NZE, whereas nearly 44% lesser energy demand is expected in NZA.
- With existing measures of net zero strategy indicated in government targets, nearly 57.4% reduction in GHG emissions is expected. Additional measures can reduce the emissions up to 84%.
- From the NPV calculated using environmental externalities and demand technology costs, nearly 1.4 trillion NPR can be saved with existing measures of net zero strategies, which can further be increased to 1.8 trillion NPR with additional measures.

The net zero emission strategy alone are not adequate to achieve total zero emissions. Considering the difficulty in entirely replacing polluting technologies used in different end-uses of residential sector by cleaner technologies, sequestration options should be encouraged. With significant forest cover available in the province, forestation may be the most viable option to curtail the emissions that cannot be reduced by technology changes alone.

In residential sector substantial emissions can be reduced by the electrification of all end-uses. Hence, government should encourage the use of electric technologies in residential sector. Switching from traditional to electric technologies requires investment and involves hesitation from the population. Awareness and incentives programs can be directed to encourage technology switching. Additional electricity required due to technology change can be met with existing and planned hydropower projects in the province. However, older homes need to have their current electrical system upgraded.

5.2 Recommendations

This study analyzed the demand, emissions, and costs only for the residential sector of Bagmati province. Further studies can be conducted for local levels. The environmental externality cost of pollutants and cost of demand technology used in this study is based on current prices. The energy demand forecast made on this study is based on the population growth and urbanization. The variation in future prices due to technology changes, and the effect of income elasticity in future energy demand can be included on further studies. This study uses energy demand projection and cost estimation only. Further studies can be conducted using cost optimization.

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ANNEXES

ANNEXE A: DISAGGREGATION OF RESIDENTIAL SECTOR

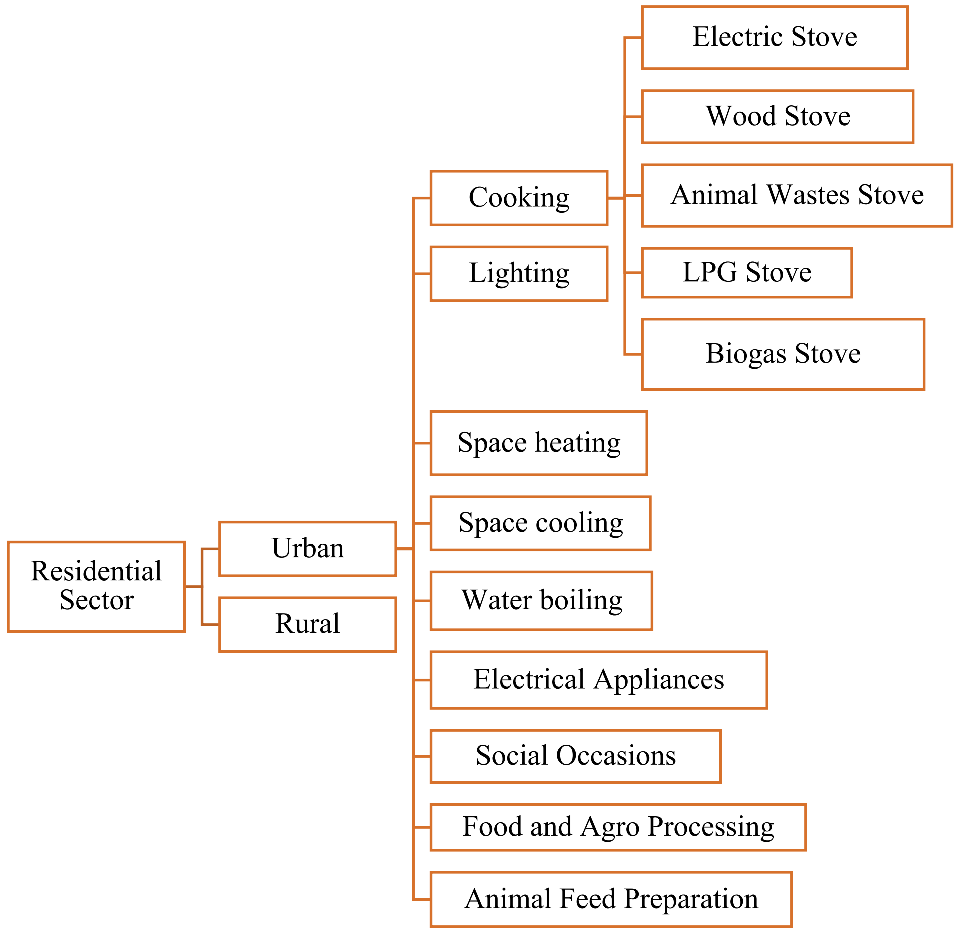

Figure A 1: Disaggregation of residential sector in LEAP

ANNEXE B: DISAGGREGATION OF END-USE SECTOR BY FUEL TYPES

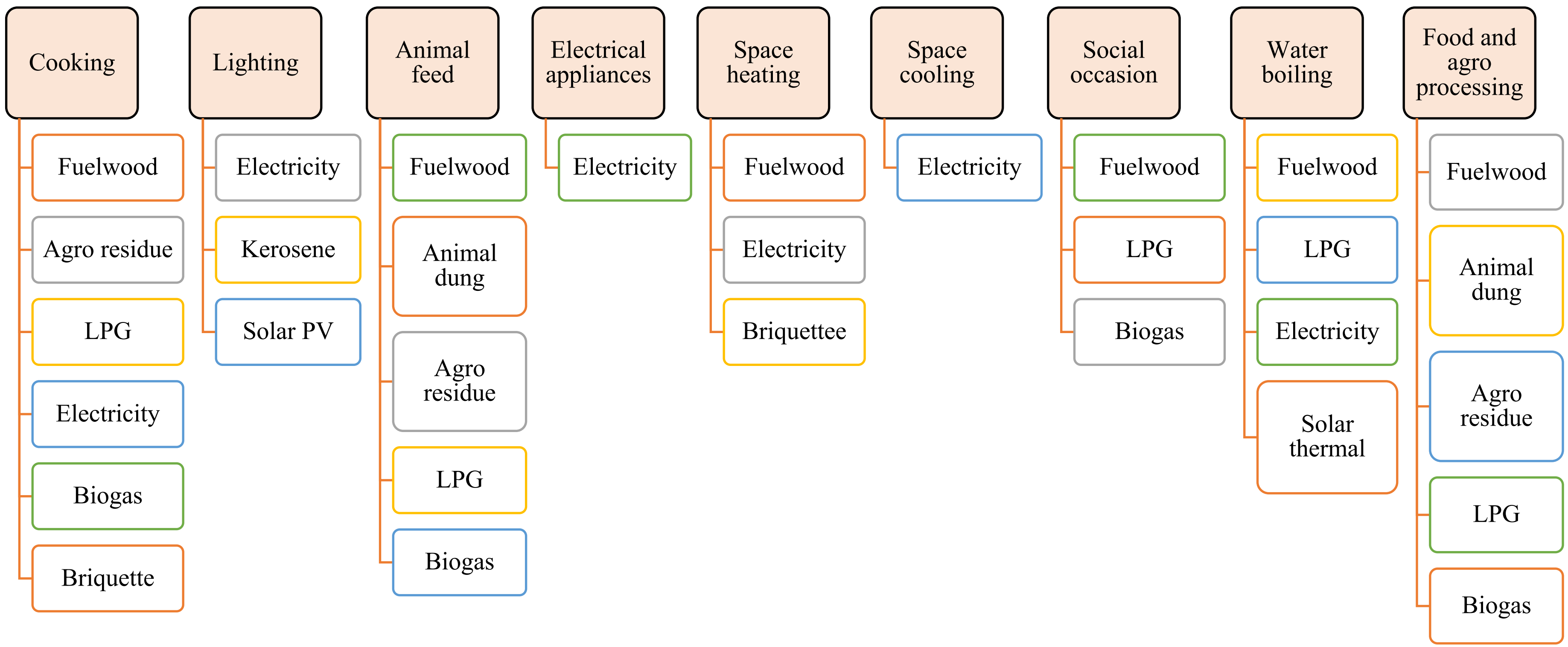

Figure A 2: Disaggregation of end-use sector by fuel types

ANNEX C: ENERGY CONSUMPTION IN RURAL-RESIDENTIAL SECTOR OF BAGMATI PROVINCE (IN TJ)

Energy Sources	Cooking	Water boiling	Space heating	Space cooling	Lighting	Electrical appliance	Social occasion	Food and agro processing	Animal feed preparation	Total
Fuelwood	9299.6	98.7	519.4	0	0	0	134	167	3512.7	**13731.4**
Animal dung	0	0	0	0	0	0	0.2	0	0	**0.2**
Agriculture residue	813.5	0	0	0	0	0	0	11	151.1	**975.6**
Kerosene	0	0	0	0	0.1	0	0	0	0	**0.1**
LPG	387.7	14.4	0	0	0	0	19.8	3.5	0	**425.4**
Electricity	3.2	3.3	3.8	32	61.2	140.3	0	0	0	**243.8**
Biogas	64.9	0	0	0	0	0	163.4	0	0	**228.3**
Briquette	0	0	0	0	0	0	0	0	0	**0.0**
Wax	0	0	0	0	0.1	0	0	0	0	**0.1**
Solar PV	0	0	0	0	4.3	0	0	0	0	**4.3**
Solar thermal	0	1	0	0	0	0	0	0	0	**1.0**
Total	**10568.9**	**117.4**	**523.2**	**32.0**	**65.7**	**140.3**	**317.4**	**181.5**	**3663.8**	**15610.2**

ANNEX D: ENERGY CONSUMPTION IN URBAN-RESIDENTIAL SECTOR OF BAGMATI PROVINCE (IN TJ)

Energy Sources	Cooking	Water boiling	Space heating	Space cooling	Lighting	Electrical appliance	Social occasion	Food and agro processing	Animal feed preparation	Total
Fuelwood	4630.4	56.1	1073	0	0	0	268.4	94.4	448.6	**6570.9**
Animal dung	0	0	0	0	0	0	0	3.2	0	**3.2**
Agriculture residue	1028.8	0	0	0	0	0	0	0.2	0	**1029.0**
Kerosene	0	0	0	0	0.4	0	0	0	0	**0.4**
LPG	6341.2	378.5	0	0	0	0	432.3	221.7	0.1	**7373.8**
Electricity	179	71.3	149	447.8	713.2	2830.6	0	0	0	**4390.9**
Biogas	32.7	0	0	0	0	0	21.9	30.8	21.1	**106.5**
Briquette	1.2	0	5.7	0	0	0	0	0	0	**6.9**
Wax	0	0	0	0	0	0	0	0	0	**0.0**
Solar PV	0	0	0	0	20.7	0	0	0	0	**20.7**
Solar thermal	0	188.1	0	0	0	0	0	0	0	**188.1**
Total	**12213.3**	**694.0**	**1227.7**	**447.8**	**734.3**	**2830.6**	**722.6**	**350.3**	**469.8**	**19690.4**

ANNEX E: COST OF TECHNOLOGIES USED IN URBAN-RESIDENTIAL OF BAGMATI PROVINCE

End-use Sector	Technology	Avg Life	Fuel consumed per HH/yr (in kg, kWh for electricity)	Capital Cost per TJ (in millions)	O&M Cost per TJ (in millions)
Space Heating	Electricity	3	33.94	9.70	1.44
	Wood Fireplace	2	43.98	0.85	0.75
	Briquette Stove	2	0.23	160.52	0.75
Space Cooling	Electricity	17.5	101.96	12.74	9.67
Water Boiling	Wood Stove	2	2.30	16.31	0.75
	LPG Stove	15	6.26	1.33	2.69
	Electric Stove	4	16.23	3.42	1.11
	Solar Thermal	20		23.30	7.78
Electrical Appliances	Electricity		644.50	0.00	2.82
Social Occasion	Wood Stove	2	11.00	3.41	0.75
	LPG Stove	15	7.14	1.16	2.69
	Electric Stove	10	0.0	0.00	0.00
	Biogas Stove	20	-	160.69	0.00
Food & Agro Processing	Wood Stove	2	3.87	9.69	0.75
	Animal Waste Stove	2	-	285.93	0.00
	Agriculture Residue Stove	2	-	4574.90	0.00
	LPG Stove	15	3.66	2.27	2.69
	Electric Stove	10	0.0	3.42	1.11
	Biogas Stove	20	-	114.26	0.00
Animal Feed Preparation	Wood Stove	2	18.39	2.04	0.75
	LPG Stove	15	0.00	2.27	2.69
	Electric Stove	10	0.0	0.00	0.00
	Biogas Stove	20	-	166.78	0.00
Cooking	Electric Stove	10	588.68	0.02	3.03
	Metal Wood Stove	2	1274.54	0.03	0.75
	Animal Waste Stove	2	-	0.00	0.00
	LPG Stove	15	125.13	0.07	2.69
	Biogas Stove	20	-	0.63	0.00
Lighting	Kerosene Lamp	25	9.72	0.11	3.24
	Electricity	10	164.37	0.58	2.35
	Solar	25	-	0.96	0.48

ANNEX F: COST OF TECHNOLOGIES USED IN RURAL-RESIDENTIAL OF BAGMATI PROVINCE

End-use Sector	Technology	Avg Life	Fuel consumed per HH/yr (in kg, kWh for electricity)	Capital Cost per TJ (in millions)	O&M Cost per TJ (in millions)
Space Heating	Electricity	3	3.03	108.52	1.11
	Wood Fireplace	2	74.64		
Space Cooling	Electricity	17.5	25.55	50.84	1.26
Water Boiling	Wood Stove	2	14.18	-	-
	LPG Stove	15	0.83	9.96	2.69
	Electric Stove	4	2.63	21.09	1.11
	Solar Thermal	20	-	1249.88	417.53
Electrical Appliances	Electricity	-	112.01	-	2.22
Social Occasion	Wood Stove	2	19.26	-	-
	LPG Stove	15	1.15	7.24	2.69
	Electric Stove	10	-	-	-
	Biogas Stove	20	-	6.14	-
	Animal Waste Stove	2	-	-	-
Food & Agro Processing	Wood Stove	2	24.00	-	-
	Agriculture Residue Stove	2	-	-	-
	LPG Stove	15	0.20	40.97	2.69
	Electric Stove	10	0.0	-	-
Animal Feed Preparation	Wood Stove	2	-	-	-
	Agriculture Residue Stove	2	-	-	-
	Electric Stove	10	0.0	-	-
Cooking	Electric Stove	10	2024.80	0.07	-
	Mud Wood Stove	2	1707.37	-	-
	Animal Waste Stove	2	-	-	-
	LPG Stove	15	107.78	0.08	2.69
	Biogas Stove	20	-	0.10	-
	ICS	5	0	-	-
Lighting	Kerosene Lamp	25	1.87	0.55	3.24
	Electricity	10	53.0	0.63	1.75
	Solar	25	-	9.21	4.60

ANNEX G: ENERGY DEMAND BY END-USE SECTORS IN BAU SCENARIO (IN PJ)

Branch	2022	2025	2030	2035	2040	2045	2050
Urban	**19.7**	**20.6**	**22.2**	**24.0**	**25.8**	**27.8**	**29.8**
Space Heating	1.2	1.3	1.4	1.5	1.6	1.7	1.9
Space Cooling	0.5	0.5	0.5	0.5	0.6	0.6	0.7
Water Boiling	0.7	0.7	0.8	0.8	0.9	1.0	1.1
Electrical Appliances	2.8	3.0	3.2	3.4	3.7	4.0	4.3
Social Occasion	0.7	0.8	0.8	0.9	1.0	1.0	1.1
Food and Agro Processing	0.4	0.4	0.4	0.4	0.5	0.5	0.5
Animal Feed Preparation	0.5	0.5	0.5	0.6	0.6	0.7	0.7
Cooking	12.2	12.8	13.8	14.9	16.0	17.2	18.5
Lighting	0.7	0.8	0.8	0.9	1.0	1.0	1.1
Rural	**15.6**	**15.1**	**14.2**	**13.2**	**12.0**	**10.7**	**9.2**
Space Heating	0.5	0.5	0.5	0.4	0.4	0.4	0.3
Space Cooling	0.03	0.0	0.0	0.0	0.0	0.0	0.0
Water Boiling	0.12	0.1	0.1	0.1	0.1	0.1	0.1
Electrical Appliances	0.14	0.1	0.1	0.1	0.1	0.1	0.1
Social Occasion	0.3	0.3	0.3	0.3	0.2	0.2	0.2
Food and Agro Processing	0.2	0.2	0.2	0.2	0.1	0.1	0.1
Animal Feed Preparation	3.7	3.6	3.3	3.1	2.8	2.5	2.2
Cooking	10.6	10.2	9.6	8.9	8.1	7.2	6.2
Lighting	0.1	0.1	0.1	0.1	0.1	0.0	0.0
Total	**35.3**	**35.7**	**36.4**	**37.1**	**37.8**	**38.5**	**39.1**

ANNEX H: EXTERNALITY COSTS BY END-USE SECTORS IN BAU SCENARIO (IN BILLION NPR)

Branch	2022	2025	2030	2035	2040	2045	2050
Urban	48.0	48.7	50.2	54.2	58.4	62.9	67.6
Space Heating	1.7	1.8	1.8	2.0	2.1	2.3	2.5
Space Cooling	5.0	5.1	5.3	5.7	6.1	6.6	7.1
Water Boiling	3.8	3.8	4.0	4.3	4.6	5.0	5.3
Electrical Appliances	8.0	8.1	8.4	9.0	9.7	10.5	11.3
Social Occasion	2.4	2.4	2.5	2.7	2.9	3.1	3.3
Food and Agro Processing	2.8	2.8	2.9	3.1	3.4	3.6	3.9
Animal Feed Preparation	1.3	1.4	1.4	1.5	1.6	1.8	1.9
Cooking	21.2	21.5	22.2	23.9	25.8	27.8	29.9
Lighting	1.8	1.8	1.8	2.0	2.1	2.3	2.5
Rural	2.8	2.8	2.7	2.5	2.3	2.1	1.9
Space Heating	0.2	0.2	0.2	0.2	0.1	0.1	0.1
Space Cooling	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Water Boiling	0.7	0.6	0.6	0.6	0.6	0.5	0.4
Electrical Appliances	0.3	0.3	0.3	0.3	0.3	0.2	0.2
Social Occasion	0.2	0.2	0.2	0.2	0.2	0.2	0.1
Food and Agro Processing	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Animal Feed Preparation	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cooking	1.1	1.0	1.0	1.0	0.9	0.8	0.7
Lighting	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	**50.8**	**51.5**	**52.9**	**56.7**	**60.7**	**65.0**	**69.5**

ANNEX I: DEMAND TECHNOLOGY COSTS BY END-USE SECTORS IN BAU SCENARIO (IN BILLION NPR)

Branch	2022	2023	2025	2030	2035	2040	2045	2050
Urban	**48.0**	**48.7**	**50.2**	**54.2**	**58.4**	**62.9**	**67.6**	**72.7**
Space Heating	1.7	1.8	1.8	2.0	2.1	2.3	2.5	2.6
Space Cooling	5.0	5.1	5.3	5.7	6.1	6.6	7.1	7.6
Water Boiling	3.8	3.8	4.0	4.3	4.6	5.0	5.3	5.7
Electrical Appliances	8.0	8.1	8.4	9.0	9.7	10.5	11.3	12.1
Social Occasion	2.4	2.4	2.5	2.7	2.9	3.1	3.3	3.6
Food and Agro Processing	2.8	2.8	2.9	3.1	3.4	3.6	3.9	4.2
Animal Feed Preparation	1.3	1.4	1.4	1.5	1.6	1.8	1.9	2.0
Cooking	21.2	21.5	22.2	23.9	25.8	27.8	29.9	32.2
Lighting	1.8	1.8	1.8	2.0	2.1	2.3	2.5	2.7
Rural	**2.8**	**2.8**	**2.7**	**2.5**	**2.3**	**2.1**	**1.9**	**1.6**
Space Heating	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1
Space Cooling	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1
Water Boiling	0.7	0.6	0.6	0.6	0.6	0.5	0.4	0.4
Electrical Appliances	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2
Social Occasion	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.1
Food and Agro Processing	0.03	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Animal Feed Preparation	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cooking	1.1	1.0	1.0	1.0	0.9	0.8	0.7	0.6
Lighting	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	**50.8**	**51.5**	**52.9**	**56.7**	**60.7**	**65.0**	**69.5**	**74.4**

ANNEX J: FINAL ENERGY DEMAND BY END-USE SECTORS IN NZE SCENARIO

Branch	2022	2025	2030	2035	2040	2045	2050
Urban	**19.7**	**20.0**	**20.5**	**20.9**	**21.2**	**21.4**	**21.6**
Space Heating	1.2	1.2	1.2	1.2	1.2	1.2	1.1
Space Cooling	0.5	0.5	0.5	0.5	0.6	0.6	0.7
Water Boiling	0.7	0.7	0.8	0.8	0.8	0.9	0.9
Electrical Appliances	2.8	3.0	3.2	3.4	3.7	4.0	4.3
Social Occasion	0.7	0.8	0.8	0.9	1.0	1.0	1.1
Food and Agro Processing	0.4	0.4	0.4	0.4	0.5	0.5	0.5
Animal Feed Preparation	0.5	0.5	0.5	0.6	0.6	0.7	0.7
Cooking	12.2	12.2	12.2	12.1	11.9	11.6	11.2
Lighting	0.7	0.8	0.8	0.9	1.0	1.0	1.1
Rural	**15.6**	**14.4**	**12.5**	**10.5**	**8.7**	**6.9**	**5.2**
Space Heating	0.5	0.5	0.4	0.4	0.3	0.2	0.2
Space Cooling	0.03	0.0	0.0	0.0	0.0	0.0	0.0
Water Boiling	0.12	0.1	0.1	0.1	0.1	0.1	0.1
Electrical Appliances	0.14	0.1	0.1	0.1	0.1	0.1	0.1
Social Occasion	0.32	0.3	0.3	0.3	0.2	0.2	0.2
Food and Agro Processing	0.18	0.2	0.2	0.2	0.1	0.1	0.1
Animal Feed Preparation	3.7	3.6	3.3	3.1	2.8	2.5	2.2
Cooking	10.6	9.6	7.9	6.4	4.9	3.6	2.4
Lighting	0.1	0.1	0.1	0.1	0.1	0.0	0.0
Total	**35.3**	**34.4**	**32.9**	**31.4**	**29.9**	**28.3**	**26.8**

ANNEX K: EXTERNALITY COSTS BY END-USE SECTORS IN NZE SCENARIO (IN BILLION NPR)

Branch	2022	2025	2030	2035	2040	2045	2050
Urban	**329**	**318**	**295**	**266**	**232**	**189**	**140**
Water Boiling	3.4	3.2	2.9	2.5	2.1	1.5	0.9
Social Occasion	12.4	13.0	14.0	15.1	16.3	17.5	18.9
Food and Agro Processing	4.5	4.7	5.0	5.4	5.9	6.3	6.8
Animal Feed Preparation	31	33	35	38	41	44	47
Cooking	278	264	238	205	166	120	66
Lighting	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rural	**600**	**555**	**481**	**409**	**338**	**270**	**207**
Water Boiling	3.0	2.9	2.6	2.4	2.1	1.8	1.6
Social Occasion	7.2	7.0	6.5	6.1	5.5	4.9	4.2
Food and Agro Processing	5.8	5.7	5.3	4.9	4.5	4.0	3.4
Animal Feed Preparation	249	242	227	211	192	171	147
Cooking	334	298	240	185	134	89	50
Lighting	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**929**	**873**	**776**	**675**	**570**	**460**	**346**

ANNEX L: DEMAND TECHNOLOGY COSTS BY END-USE SECTORS IN NZE SCENARIO (IN BILLION NPR)

Branch	2022	2025	2030	2035	2040	2045	2050
Urban	**48.0**	**48.5**	**49.7**	**52.5**	**55.5**	**58.5**	**61.7**
Space Heating	1.7	1.8	1.9	2.1	2.3	2.6	2.8
Space Cooling	5.0	5.1	5.3	5.7	6.1	6.6	7.1
Water Boiling	3.8	3.8	3.8	3.7	3.5	3.3	3.1
Electrical Appliances	8.0	8.1	8.4	9.0	9.7	10.5	11.3
Social Occasion	2.4	2.4	2.5	2.7	2.9	3.1	3.3
Food and Agro Processing	2.8	2.8	2.9	3.1	3.4	3.6	3.9
Animal Feed Preparation	1.3	1.4	1.4	1.5	1.6	1.8	1.9
Cooking	21.2	21.4	21.8	22.8	23.8	24.8	25.8
Lighting	1.8	1.8	1.8	2.0	2.1	2.3	2.5
Rural	**2.8**	**2.9**	**3.2**	**3.7**	**4.1**	**4.4**	**4.4**
Space Heating	0.2	0.2	0.3	0.6	0.8	1.0	1.1
Space Cooling	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Water Boiling	0.7	0.6	0.6	0.6	0.5	0.4	0.4
Electrical Appliances	0.3	0.3	0.3	0.3	0.3	0.2	0.2
Social Occasion	0.2	0.2	0.2	0.2	0.2	0.2	0.1
Food and Agro Processing	0.03	0.0	0.0	0.0	0.0	0.0	0.0
Animal Feed Preparation	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cooking	1.1	1.1	1.3	1.7	2.0	2.3	2.4
Lighting	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	**50.8**	**51.4**	**52.8**	**56.2**	**59.6**	**62.9**	**66.1**

ANNEX M: FINAL ENERGY DEMAND BY END-USE SECTORS IN NZA SCENARIO

Branch	2022	2025	2030	2035	2040	2045	2050
Urban	**19.7**	**19.7**	**19.7**	**19.6**	**19.3**	**18.8**	**18.1**
Space Heating	1.2	1.2	1.2	1.1	1.0	1.0	0.8
Space Cooling	0.5	0.5	0.5	0.5	0.6	0.6	0.7
Water Boiling	0.7	0.7	0.7	0.8	0.8	0.8	0.9
Electrical Appliances	2.8	3.0	3.2	3.4	3.7	4.0	4.3
Social Occasion	0.7	0.7	0.7	0.7	0.7	0.6	0.6
Food and Agro Processing	0.4	0.4	0.3	0.3	0.3	0.3	0.3
Animal Feed Preparation	0.5	0.5	0.4	0.4	0.4	0.3	0.3
Cooking	12.2	12.1	11.8	11.4	10.8	10.1	9.2
Lighting	0.7	0.8	0.8	0.9	1.0	1.0	1.1
Rural	**15.6**	**14.2**	**11.8**	**9.6**	**7.4**	**5.5**	**3.7**
Space Heating	0.5	0.5	0.4	0.4	0.3	0.2	0.2
Space Cooling	0.03	0.0	0.0	0.0	0.0	0.0	0.0
Water Boiling	0.12	0.1	0.1	0.1	0.1	0.0	0.0
Electrical Appliances	0.14	0.1	0.1	0.1	0.1	0.1	0.1
Social Occasion	0.32	0.3	0.3	0.2	0.2	0.2	0.2
Food and Agro Processing	0.18	0.2	0.1	0.1	0.1	0.1	0.1
Animal Feed Preparation	3.7	3.4	2.9	2.4	1.9	1.5	1.1
Cooking	10.6	9.5	7.8	6.2	4.6	3.3	2.1
Lighting	0.1	0.1	0.1	0.1	0.1	0.0	0.0
Total	**35.3**	**33.9**	**31.5**	**29.1**	**26.7**	**24.3**	**21.9**

ANNEX N: EXTERNALITY COSTS BY END-USE SECTORS IN NZA SCENARIO (IN BILLION NPR)

Branch	2022	2025	2030	2035	2040	2045	2050
Urban	**329**	**308**	**266**	**216**	**157**	**87**	**5**
Water Boiling	3.4	3.2	2.8	2.4	1.9	1.2	0.5
Social Occasion	12	12	10	8	6	3	0
Food and Agro Processing	4	4	4	3	2	1	0
Animal Feed Preparation	31	29	25	20	15	8	0
Cooking	278	260	225	182	132	73	4
Lighting	0.01	0.0	0.0	0.0	0.0	0.0	0.0
Rural	**600**	**548**	**463**	**381**	**303**	**230**	**164**
Water Boiling	3.0	2.6	2.0	1.5	1.0	0.6	0.2
Social Occasion	7.2	6.9	6.4	5.9	5.3	4.7	4.0
Food and Agro Processing	5.8	5.3	4.4	3.5	2.7	2.0	1.3
Animal Feed Preparation	249	226	189	153	119	87	60
Cooking	334	307	261	217	175	135	99
Lighting	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	**929**	**856**	**729**	**597**	**459**	**317**	**169**

ANNEX O: DEMAND TECHNOLOGY COSTS BY END-USE SECTORS IN NZA SCENARIO (IN BILLION NPR)

Branch	2022	2025	2030	2035	2040	2045	2050
Urban	**48.0**	**51.0**	**56.3**	**62.2**	**68.5**	**75.4**	**82.9**
Space Heating	1.7	1.9	2.1	2.4	2.6	3.0	3.3
Space Cooling	5.0	5.3	5.7	6.1	6.6	7.1	7.6
Water Boiling	3.8	3.7	3.5	3.3	3.1	2.7	2.3
Electrical Appliances	8.0	8.4	9.0	9.7	10.5	11.3	12.1
Social Occasion	2.4	2.2	2.0	1.6	1.3	0.8	0.3
Food and Agro Processing	2.8	2.6	2.3	1.8	1.4	0.8	0.1
Animal Feed Preparation	1.3	3.3	6.8	10.9	15.6	21.0	27.0
Cooking	21.2	21.9	23.0	24.1	25.2	26.4	27.5
Lighting	1.8	1.8	2.0	2.1	2.3	2.5	2.7
Rural	**2.8**	**3.2**	**3.7**	**4.1**	**4.3**	**4.4**	**4.3**
Space Heating	0.2	0.3	0.6	0.8	1.0	1.1	1.1
Space Cooling	0.2	0.2	0.2	0.2	0.2	0.2	0.1
Water Boiling	0.7	1.0	1.4	1.8	2.0	2.2	2.2
Electrical Appliances	0.3	0.3	0.3	0.3	0.2	0.2	0.2
Social Occasion	0.2	0.2	0.2	0.1	0.1	0.1	0.1
Food and Agro Processing	0	0	0	0	0	0	0
Animal Feed Preparation	0	0.1	0.2	0.3	0.4	0.4	0.4
Cooking	1.1	0.9	0.7	0.6	0.4	0.2	0.1
Lighting	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total	**50.8**	**54.1**	**60.0**	**66.2**	**72.8**	**79.8**	**87.2**

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