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An Integrated National Energy Demand Model with Provincial-Level Disaggregation for the Residential Sector

by

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A THESIS

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ABSTRACT

The residential sector in Nepal shows significant regional variation in energy consumption due to differences in population, urbanization, and access to modern energy services. This study develops an integrated national energy demand model with provincial-level disaggregation using the LEAP framework to analyze energy use and project future demand and greenhouse gas (GHG) emissions. The model is calibrated for the base year 2024, with total residential energy consumption estimated at 320 PJ, incorporating key factors such as demographic trends, technological change, and energy efficiency.

The results indicate clear disparities across provinces. Under the Business-as-Usual (BAU) scenario, total energy demand increases to 404 PJ by 2050, growing at an annual rate of 0.89%. Madhesh remains the highest energy-consuming province, rising from 64 PJ to 86 PJ, followed by Bagmati (60 PJ to 77 PJ), reflecting higher urbanization and population density. In contrast, provinces such as Karnali and Gandaki maintain relatively low demand, reaching around 33 PJ by 2050.

Under alternative scenarios, energy demand declines significantly across all provinces. The Net Zero Emission scenario reduces total demand to 172 PJ by 2050 (a 46% reduction), while the NDC 3.0 scenario reaches 205 PJ (36% reduction). The All Electrification scenario shows the greatest impact, lowering demand to 121 PJ (62% reduction), with substantial declines across all provinces, particularly in high-demand regions such as Madhesh and Bagmati. The findings also indicate that the per capita electricity consumption grows substantially in all the provinces, especially in ambitious cases, and GHG emission decreases dramatically even to zero in the case of complete electrification. But in the NDC scenario, the emission level is stable, then the impact is limited by 2035 and it requires more stringent policy implementation.

A similar trend is observed in GHG emissions, where BAU results in the highest emissions, particularly in Bagmati and Madhesh. Emissions decrease considerably under the Net Zero and NDC scenarios due to electrification and efficiency improvements, while the All

Electrification scenario achieves complete decarbonization across all provinces. In general, the paper demonstrates the significance of provincial-level analysis in the national energy planning because the existence of regional differences is critical in influencing the energy transitions. The results indicate that province-specific policies, especially in the less developed areas are necessary to speed up the electrification, enhance energy efficiency and to meet the long-term climate and sustainability aspirations of Nepal.

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LIST OF ABBREVIATIONS

AE	All Electrification
AEPC	Alternative Energy Promotion Center
CBS	Central Bureau of Statistics
CO2	Carbon Dioxide
GHG	Greenhouse Gases
GVA	Gross Value Added
GWh	Gigawatt-hour
HH	House Holds
ICS	Improved Cooking Stove
IEA	International Energy Agency
kWh	kilowatt-hour
LPG	Liquefied Petroleum Gas
LEAP	Long-range Energy Alternatives Planning System
MAED	Model for Analysis of Energy Demand
MMT	Million Metric Ton
NDC	Nationally Determined Contribution
NEA	Nepal Electricity Authority
NREP	National Rural Energy Programme
NZE	Net Zero Emission
PJ	Peta Joule
SDG	Sustainable Development Goals
SE4ALL	Sustainable energy for all
WECS	Water and Energy Commission Secretariat

CHAPTER ONE: INTRODUCTION

1.1 Background

Nepal's energy landscape is characterized by a heavy reliance on traditional energy sources, with biomass including firewood, agricultural residues, and animal dung still dominating the national energy mix. Despite the country's significant hydropower potential, only a small fraction has been harnessed, leading to seasonal imbalances and continued dependence on imported fossil fuels during dry months. Electricity contributes a modest share to the total energy supply, although recent years have seen significant improvements in generation capacity and electrification coverage. However, the energy transition remains uneven across provinces, with disparities in access, affordability, and usage patterns particularly within the residential sector. This scenario underscores the need for integrated, data-driven energy planning approaches that consider regional variations to inform national strategies.

In Nepal, residential sector is the biggest energy consumer sector with a share of around 60% of national energy consumption. In this sector, the energy is used for cooking, lighting, heating and other household tasks. Traditional biomass is the main source of energy used, even after more than 98% of households have access to electricity. Modern energy carriers such as liquefied petroleum gas (LPG) and electricity are increasingly becoming more popular in urban areas, but limited in uptake due to cost, infrastructure, and cultural preferences. These dynamics illustrate the complexities and the divergent pattern of energy use among households in the provinces of Nepal.

Nepal's energy planning is increasingly influenced by its Pledges to international sustainability goals and national climate policies. The country is working towards achieving Sustainable Development Goal (SDG) 7 which seeks to ensure access to affordable, reliable, sustainable and modern energy for all, a goal which is well aligned with Nepal's domestic development agenda. The country has the target of achieving Sustainable Development Goal (SDG) 7 under which the world aims to ensure access to affordable, reliable, sustainable and modern energy for all which is closely linked with its domestic development agenda. Nepal also has committed to a substantial increase in the use of clean energy and improving energy efficiency, and a decrease in the use of traditional biomass, through its Third Nationally Determined Contribution (NDC 3.0) submitted under the Paris Agreement, by promoting electric cooking and renewable energy technologies. Most importantly, the government has promised a big target of becoming a net-zero carbon nation by 2045. These ambitious targets require a comprehensive knowledge of energy use, particularly residential energy use, which is still a significant fraction of energy consumption and a prime space for action in a low carbon and inclusive energy future.

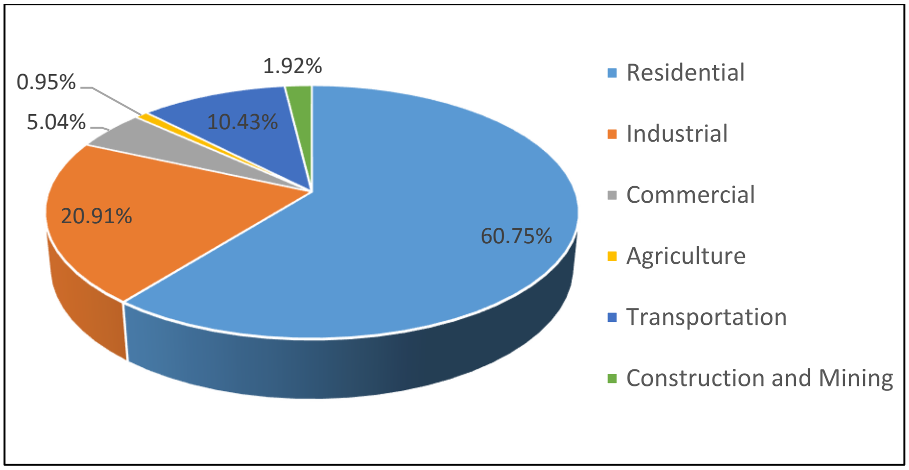

Figure 1.0.1: Total Energy Consumption of Nepal Sector wise

The total Consumption of Nepal is estimated to be 532.45 PJ in 2023, which is 16.81% lower than the consumption in previous year and residential sector dominated energy consumption with 60.75%. Industrial sector has the second dominance consuming 20.91% of the energy followed by transportation sector which accounts for 10.43%, while other sectors like Commercial uses 5.04%, Construction and Mining uses 1.92% and remaining 0.95% of energy is being used by Agriculture Sector. (WECS, 2024)

Nepal's energy mix in the residential sector is 323.46 PJ (Figure 1.2) in 2023. Firewood accounts largest share of 79.52% of the total. LPG (5.62%), electricity (4.99%), and biogas (3.31%) are further noteworthy contributions. Agricultural residue (2.75%), animal dung (2.93%), solar (0.68%), micro/Pico hydro (0.14%), wind (0.0053%), kerosene (0.03%), and coal (0.01%) all contribute less. (WECS, 2024)

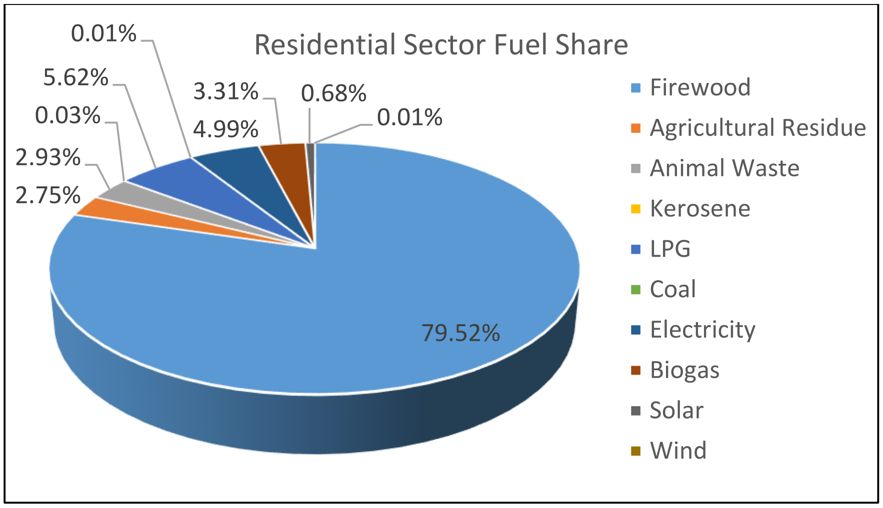

Figure 1.0.2 Fuel Share in Residential Sector

1.2 General Overview of Nepal:

Nepal is a landlocked country situated in South Asia, bordered by China to the north and India to the east, west, and south. The country covers a total area of approximately 147,516 square kilometers and is characterized by diverse topography, ranging from the lowland Terai plains to the high Himalayan mountain range, which includes Mount Everest, the highest peak in the world. The geographical differences contributes to significant variations in climate, settlement patterns and socio-economic conditions in whole country.

The latest projections for the Nepalese population are approximately 30 million, of which most live in rural areas. The country is divided into seven Provinces administratively - Koshi Province, Madhesh Province, Bagmati Province, Gandaki Province, Lumbini Province, Karnali Province and Sudurpashchim Province. The provinces vary greatly in population distribution, population density, degree of urbanization and infrastructure. Bagmati and Madhesh are more densely populated and relatively urbanized provinces while Karnali and Sudurpashchim are less populated and remote in nature. Nepal has a growing population with a gradual urbanization trend over the past few years. The average household size has been declining over time, indicating changes in social structure and living patterns. The geographical and demographic characteristics have a significant influence on regional development and planning throughout the country.

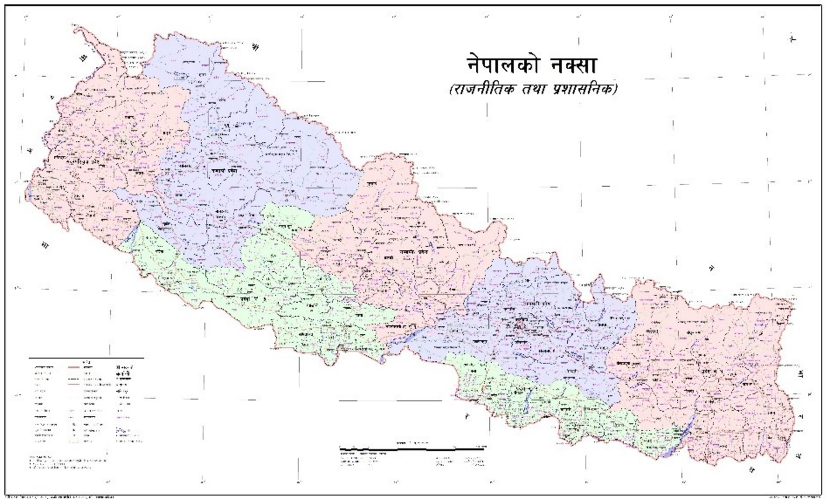

Figure 1.0.3: Map of Nepal

1.3 Problem Statement:

The energy demand study have been conducted at the provincial level in Nepal, there is a huge gap in making the localized energy demand studies in a coherent national framework. The lack of a national-level energy demand model prevents capturing of the overall energy demand dynamics while not losing the important regional variations across provinces. Consequently, energy planning and energy policy formulation become segmented, weaker the impact of the investments and strategies taken to realize a clean energy transition.

In addition, currently no standardized model is available for provincial or national energy demand forecasting and scenario analysis. Due to this, there is a problem in coordinated planning to meet long-term energy and climate goals. Considering the significant share of energy use in the residential sector of the Nepalese energy market, an in-depth and comprehensive modeling framework is needed. Hence, this study aims to fill this gap and develop an integrated model of the energy demand of the country with a disaggregation at the provincial level in order to assist in the effective planning and policy development for the energy sector, specifically the residential sub-sector in the country.

1.4 Objective

The main objective of this research is to develop an integrated energy demand model with Provincial level disaggregation for the residential sector.

Specific Objectives:

1. To assess and integrate provincial level residential energy demand data into a national modelling framework
2. To analyze future residential energy demand for different policy scenarios across different provinces
3. To estimate residential sector emissions for different policy scenarios at the provincial level
4. To evaluate provincial energy and emission indicators and determine policy measures to support national energy and climate targets

CHAPTER TWO: LITERATURE REVIEW

2.1 Energy Classification Trend

Energy use has changed a lot over time and so has been changed by various classification methods of energy. Energy has been traditionally classified as primary energy and secondary energy. Primary energy is energy derived from the natural resources like biomass, coal, hydropower, solar radiation, etc., and secondary energy is refined or converted energy like electricity and petroleum products. This classification enables us to understand the production and transformation of energy, and its final usage.

There is a common distinction between renewable and non-renewable energy resources. Renewable energy consists of energy sources that replenish naturally like solar, wind, hydro, or biomass, while non-renewable energy sources, like fossil fuels, are finite and will run out over time. The use of renewable energy is increasing in recent years, due to the growing awareness of the need to be more environmentally sustainable now and in the future, and the risk of climate change.

Besides these categories, energy can be categorized by the degree of technological development, especially in relation to developing countries. There is a widespread use of traditional energy sources (firewood, agricultural residues etc.) in rural households, and a high level of modern energy sources (electricity, LPG and other clean fuels) are linked to the enhancement of efficiency and quality of life. This change from traditional energy use to modern use is accentuated by the underlying socio-economic development and urbanization.

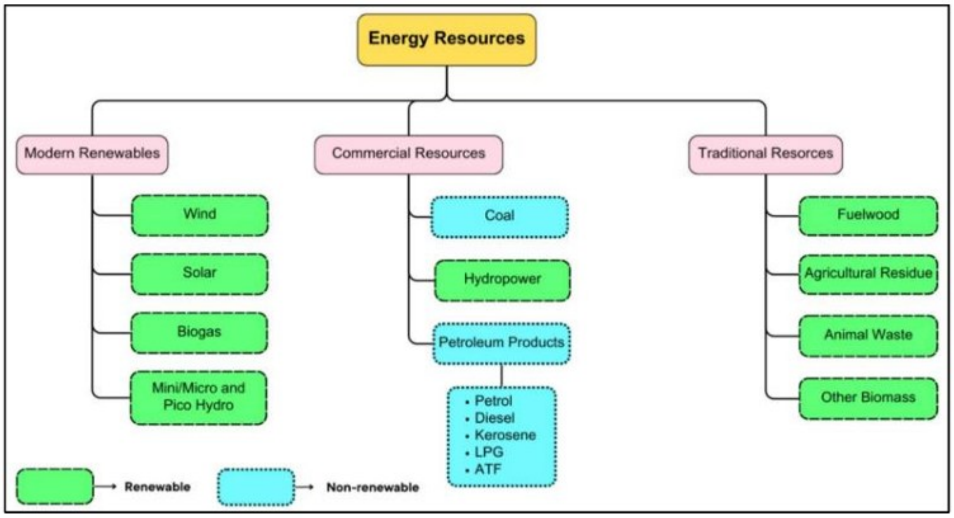

Figure 2.0.1: Energy Source of Nepal

2.2 Overview of Energy Consumption in the Residential Sector and past trends

Residential buildings are responsible for about 20–30% of the global energy consumption of the energy used for the end users (IEA, 2022). This proportion is frequently higher in developing countries where energy has to be used for basic domestic needs like cooking, heating and lighting. In Nepal, the residential sector is the largest energy consumer, representing over 60% of the country's final energy consumption (WECS 2024). This high percentage can be attributed mainly to population growth, rural settlement and traditional energy consumption.

Traditional biomass fuels such as firewood, agricultural residues, and animal wastes have traditionally been the main source of energy used in Nepal's homes. The Water and Energy Commission Secretariat (WECS, 2024) indicates that almost 80% of energy use in the residential sector comes from biomass. These fuels are mainly fuelled by the rural households as they are accessible and inexpensive, but the usage of these fuels is associated with low efficiency and environmental and health issues. However, with time, the changes in socio-economic conditions and infrastructure have had an impact on energy consumption patterns.

In the last few years, it has been observed that the trend is toward modern energy sources like LPG and electricity. Examples of this include the growing share of LPG in the residential segment, especially in urban areas, and the steady growth in electricity use from the expansion of grid connections and hydropower projects (CBS, 2021; IEA, 2022). Even with these advances, traditional biomass energy is still significant in many rural areas and the shift to cleaner energy is still continuing.

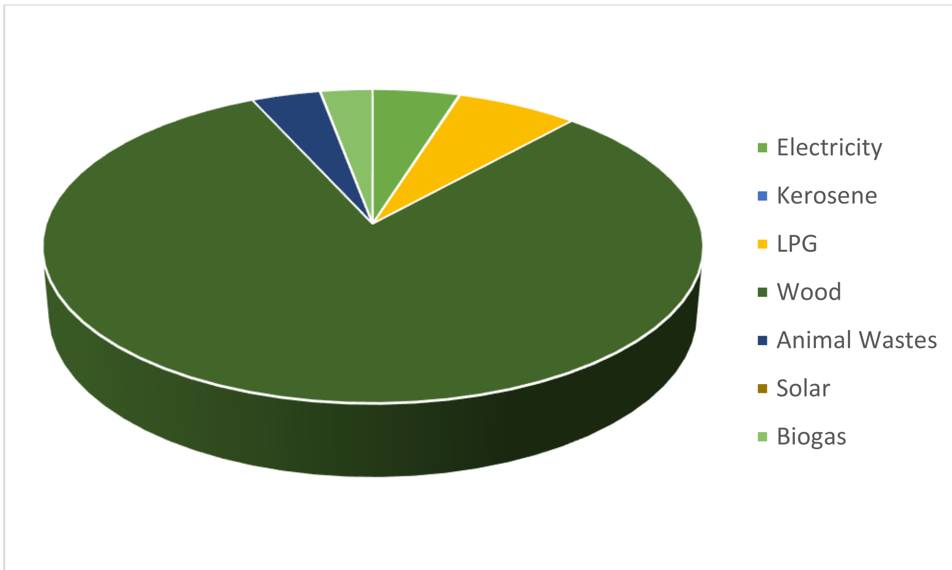

Figure 2.0.2 Energy Mix in Residential sector, 2024

The estimated breakdown of fuel consumption in Nepal for 2024, derived from historical consumption trends is around 320 PJ in residential sector. The estimation is clearly showing the dominance of traditional biomass use with the firewood energy use at around 81%, or 261 PJ, of total energy use in the residential sector, reflecting continued use of traditional fuels. LPG represents approximately 7%, a sign of progressive shifts toward cleaner fuels, especially in urban areas, for cooking. Electricity (5%) and animal waste (4%) are smaller, but significant contributors. Other fuels like coal, kerosene, briquettes, solar PV and solar thermal have negligible or zero percentages in the projection of biogas. Overall, the Figure 2.2 highlights that although some diversification is expected, Nepal's energy mix will remain largely biomass-based in the future, with implications on its greenhouse gas emissions and energy policy planning.

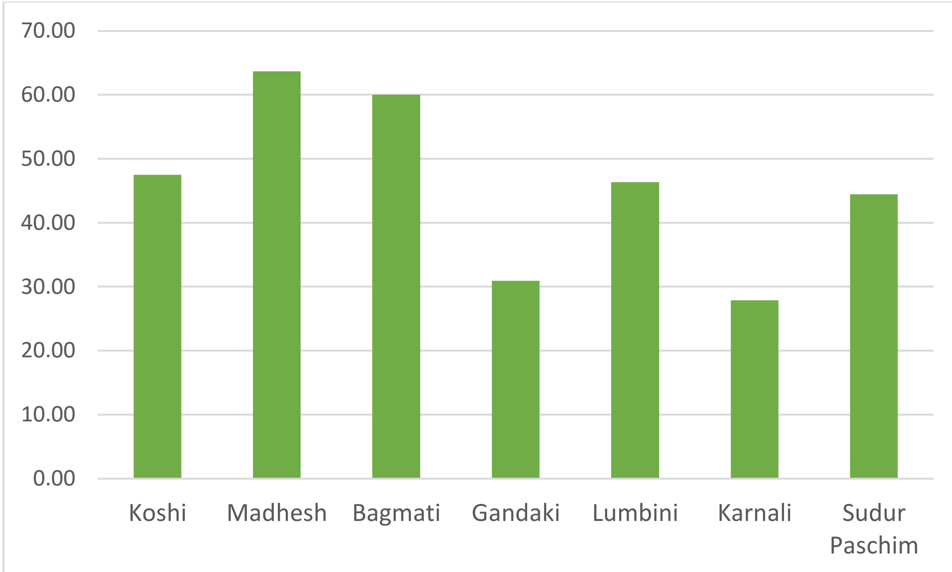

Figure 2.0.3: Province wise total energy consumption in Residential sector

The best, similar estimation of energy consumption in different provinces of Nepal will show that the highest consumption of energy is in Madhesh Province, which is 64 PJ followed by the Bagmati Province (60 PJ). Due to the smaller population in Karnali and Gandaki they experience a lowest energy consumption of around 28 PJ and 30 PJ respectively. The figure can be used to calculate all other Province energy consumption.

2.3 Nepal's Energy-Related Plans and Policies

In Nepal energy sector has been guided by diverse policies and legislative frameworks to foster sustainable development and enhance energy access. One of the early milestones was the Nepal Electricity Authority Act 1984 that provided the institutional framework for electricity generation, transmission and distribution. This was followed by the Water Resources Act of 1992, which focused on the balanced utilization and conservation of water resources and laid the foundation for the development of hydropower.

In the development run to promote hydropower, the Hydropower Development Policies of 1992 and 2001 has been published to encourag private sector participation, recognizing the need for investment and technological advancement. The Local Self-Governance Act of 1998 also played a key role by empowering local governments to manage small-scale energy projects such as mini and micro hydropower systems. NEA Community Electricity

Distribution Bye-Laws of 2003 also came to support community-based electrification initiatives, improving access in rural areas.

The policies were developed to focus on expanding energy access and promoting renewables. The National Water Plan (2005) was also targeted at rural electrification, while the Rural Energy Policy (2006) encouraged the use of renewable energy technologies in rural communities. Financial support mechanisms, such as the Renewable Energy Subsidy Policy (2000–2016) and the Renewable Energy Subsidy Delivery Mechanism (2018), have played an important role in promoting off-grid electrification. In addition, the National Energy Efficiency Strategy (2018) aims to improve the overall energy performance, with a target to double energy efficiency by 2030.

In recent times, Nepal has introduced strategic frameworks to guide long-term energy planning and sustainability. The 15th and 16th Five-Year Plans emphasize energy security, expansion of electricity access, and increased reliance on clean energy sources. The Energy Development Roadmap 2081 outlines a forward-looking strategy for achieving sustainable energy, increasing electricity generation capacity, and promoting electrification across sectors. Nepal's Nationally Determined Contributions (NDC 3.0) highlight commitments to climate change mitigation, including increased use of renewable energy, promotion of electric cooking, and reduction of greenhouse gas emissions. These policy initiatives reflect Nepal's strong commitment toward a sustainable, low-carbon, and energy-efficient future.

2.3.1 Energy Development Roadmap 2081

Energy Development Roadmap 2081 is a forward looking plan to guide long term development of the electricity sector. The roadmap is mainly directed towards augmenting generation capacity, modernising the transmission and distribution system and providing reliable and affordable access to electricity across the country. It mirrors Nepal's aspiration to harness its vast hydropower potential for not only domestic use but also regional energy trade.

An important characteristic of the roadmap is its focus on achieving energy independence and cutting the reliance on imported fossil fuels. It encourages development of hydropower projects and incorporation of other renewable energy sources. The road map also underscores the importance of electrification in different sectors especially in households, transport and industries as a path to sustainable development.

2.3.2 Nepal's Third Nationally Determined Contribution (NDC 3.0)

Nepal's Nationally Determined Contributions (NDC 3.0) are the country's updated commitments under the Paris Agreement to address climate change. This document spells out Nepal's commitments to reduce greenhouse gas emissions and achieve sustainable development. This is a more ambitious and bolder approach than earlier commitments, aligning national targets with global climate goals.

The clean energy transition is one of the main priorities of NDC 3.0. The country seeks to augment the share of renewable energy sources, especially hydropower, and encourages the use of electricity in applications such as residential energy use and transportation. The policy also focuses on the adoption of electric cooking technologies, expanding access to clean energy and reducing reliance on traditional biomass and fossil fuels. NDC 3.0 also highlights the importance of climate adaptation, recognizing Nepal's vulnerability to climate impacts such as floods, landslides, and changing weather patterns. Overall, the document serves as a strategic framework guiding Nepal toward a low-carbon and climate-resilient future while balancing development needs.

2.3.3 Sixteenth Five Year Plan

The 16th Five-Year Plan of Nepal emphasizes on the development of a reliable, sustainable and efficient energy system to support the overall economic growth of the country. The plan emphasizes the importance of increasing the capacity of power generation, especially hydropower, to satisfy the growing domestic demand and to generate opportunities for export of power. It envisages improving energy security by reducing reliance on imported fossil fuels and encouraging utilization of indigenous energy resources.

The policy focuses to enhance access to electricity across all regions of the country, including remote and rural areas. This includes strengthening transmission and distribution infrastructure to ensure a stable and uninterrupted power supply. The plan also promotes the increased use of electricity in various sectors, including households, transportation, and industries, as part of a broader strategy for electrification.

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

The Ministry of Energy, Water Resources, and Irrigation (MoEWRI) White Paper 2075 serves as a strategic document outlining Nepal's vision for the development of the energy sector. It was introduced with the aim of addressing long term challenges such as energy shortages, limited infrastructure, and dependence on energy imports. The white paper emphasizes the need to accelerate electricity generation, particularly through hydropower. During which transmission and distribution systems are enhanced to ensure reliable and efficient energy supply across the country.

The primary aim of this white paper is to emphasize the concept of energy self-sufficiency through efficient use of its natural water resources. It also emphasizes the need to expand electrical services, encourage private sector involvement, and create an attractive investment climate. In addition, the document promotes increased electrification within several sectors, such as household and transport, as a means to achieve sustainable development. The white paper thus lays down the framework within which Nepal's energy sector will be transformed into a more sustainable one.

2.3.5 Nepal: Sustainable Development Goals Status and Roadmaps (2016–2030)

The SDG for Nepal is an important national document that captures Nepal's strategy towards the fulfillment of the United Nations' Sustainable Development Goals (SDGs). The document analyzes the progress made in this area and establishes concrete objectives for the country in the process of attaining sustainable development by 2030. The roadmap is focused on issues of inclusive growth, poverty reduction, and improving access to basic amenities like education and healthcare, among others, without compromising environmental sustainability.

With regard to energy issues, this roadmap underscores the importance of achieving sustainable development goals in this sector by ensuring access to affordable, reliable, and modern energy services for all people, in line with SDG 7. The document advocates for greater electricity access, promotion of renewable energy sources, and improvement in energy efficiency. There is a recognition in the document that concerted efforts are required in order to achieve these objectives.

2.4 Electricity Status

As of fiscal year 2024/25, Nepal has made significant progress in electricity generation and consumption. The total installed electricity generation capacity reached 3,591 MW, with an addition of 434 MW within the year, indicating steady growth in the power sector. The system peak demand was recorded at 2,901 MW, while the national peak demand stood at 2,409 MW, reflecting increasing electricity consumption across the country. Annual electricity availability reached 15,641 GWh (56.3 PJ) , out of which a majority was supplied by Independent Power Producers (55%), followed by the Nepal Electricity Authority and its subsidiaries (34%), while 11% was imported from India. The total domestic electricity consumption was recorded at 11,343 GWh (40.8 PJ), showing a notable increase compared to the previous year, with the residential sector accounting for the largest share of consumption at 42.3% which is around 4525 GWh (16.3 PJ (NEA, 2025).

In addition, Nepal has emerged as a net exporter of electricity, with total exports reaching 2,380 GWh and a net export of 699 GWh during the year (NEA, 2025). Per capita electricity consumption also increased significantly to 465 kWh, reflecting improved access and growing demand for electricity services. These trends indicate a transition toward increased electricity generation, higher domestic consumption, and expanding regional energy trade, highlighting the growing importance of electricity in Nepal's overall energy system.

2.5 Demography of Nepal

Population and Households for 2024 are estimated based on population growth rate and household size of each province. In Nepal, the overall population growth rate of 0.92% per annum, and household size of 4.37 are used. The Province wise population and households in both rural and urban area for 2024 is as shown in Table (*National Population and Housing Census 2021. Volume 01*, 2023).

Table 1: Province wise Population and Household Status

Name of Province	Rural		Urban	
	Population	No. of Households	Population	No. of Households
Koshi	1,722,123	413,972	3,368,397	809,711
Madhesh	1,710,585	323,362	4,624,914	874,275
Bagmati	2,109,361	542,252	4,187,238	1,076,411
Gandaki	827,670	222,485	1,657,749	445,638
Lumbini	2,386,109	531,386	2,912,407	648,685
Karnali	808,651	175,421	888,848	192,801
Sudurpashchim	1,704,520	364,968	1,027,769	220,104
Nepal	**11,269,019**	**2,573,846**	**18,667,322**	**4,267,625**

2.6 Energy Planning Model

Energy is a major factor in the modern economy, modeling and simulation of energy systems has drawn a lot of research interest. The energy system, however, is part of a larger economic framework that encompasses a number of players from both the energy sector and other economic sectors (Subramanian et al., 2018). Energy planning can be understood as a process that evaluates both energy supply and demand with the aim of maintaining a balance between them over time (Kahen, 1995). It involves the effective management of available resources and is inherently a continuous and decision-oriented activity. As noted by Van Beeck (2003), planning essentially involves selecting the most appropriate option from a set of available alternatives. In this context, future energy planning is often carried out by developing scenarios based on historical trends and current data. Due to the complexity and dynamic nature of energy systems, energy models have become essential tools to support planning and policy analysis. The development of energy models dates back to the 1970s, driven by advancements in computing technologies and increasing global awareness of environmental issues (Shukla, 1995).

Over the past few decades, the specifications for energy system models have evolved. The use of large percentages of renewable energy has created new difficulties. The national greenhouse gas strategies of developed nations include a complete overhaul of their energy systems in addition to the climate objectives of the Paris Agreement (Lopion et al., 2018).

Additionally, advanced models that take into account the unique features, practical requirements, and uncertainties of isolated locations must be developed (Liu et al., 2018).

Energy modeling approaches are generally categorized into two main types: top-down and bottom-up models. Top-down models analyze the energy system using aggregated economic indicators and are based on macroeconomic theories that link energy demand with variables such as income, prices, and economic growth (Pachauri et al., 2014). In contrast, bottom-up models operate at a more detailed level, incorporating specific technologies, end-use activities, and fuel types. Although these models require extensive data, they provide a more comprehensive understanding of energy systems and are particularly useful for analyzing energy technologies, fuel transitions, and policy impacts (Kavgic et al., 2010; Lkhagva, 2014). Similarly, the Bottom-up model is further categorized into End-use accounting model, optimization models and simulation models (Brizard N., 2015).

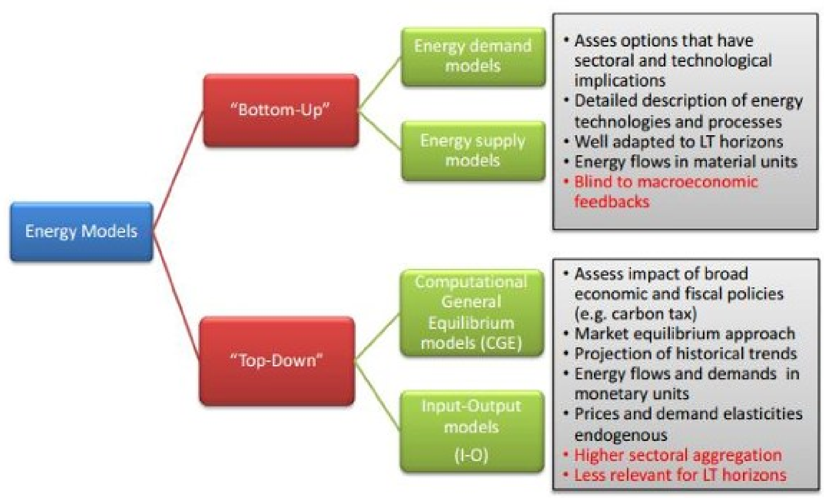

Figure 2.0.4: Energy Modeling Approaches

2.7 Modeling Energy Demand in Nepal

The energy planning of Nepal's consumption pattern can be modeled based on scenario approaches using software such as MAED and LEAP (Rajbhandari & Nakarmi, 2014). The scenarios are helpful in determining the future energy needs through different assumptions related to population growth, economy, technology, and policy change. For example, the

MAED software can be used to predict the energy demand per sector by the year 2050. It is also helpful in analyzing the effects of changes in income, urbanization, and electrification rates on energy demands in the country. LEAP software is also important for analyzing renewable energy policies, fuel switching strategies, and GHG mitigation approaches.

The choice of energy models depends on the availability of different modeling software and their features. Shukla (1995) asserts that most existing energy models were developed in industrialized nations, where they made assumptions that other developing nations will follow the same pattern when it comes to energy development. This is not always the case because each country differs when it comes to energy development. Another challenge associated with the application of these models relates to the availability of data, especially in developing nations such as Nepal.

Several studies have highlighted key challenges in energy modeling, including issues related to data quality, representation of technological potential, and the rate of technology adoption (Worrell et al., 2004). Developing countries often face structural challenges such as informal economic activities, energy supply shortages, inefficiencies in the power sector, ongoing economic transitions, and disparities between urban and rural areas (Urban et al., 2007). These characteristics are clearly reflected in the energy system of Nepal. Due to the lack of comprehensive and reliable database, there will be a significant barrier to effective long-term energy planning and modeling in the country. After reviewing so many papers, LEAP Software is chosen for this study because of its suitable features.

Low Emissions Analysis Platform (LEAP) is an integrated energy environment modeling software widely used for energy policy analysis, scenario development, and greenhouse gas (GHG) mitigation assessment. Developed by the Stockholm Environment Institute (SEI), LEAP is designed to support medium- to long-term energy system planning by simulating energy production, transformation, and consumption across different sectors of an economy. It is well suited for developing countries, such as Nepal, where data availability may be limited but policy-relevant insights are crucial. The major features of LEAP are described briefly:

- **Scenario-Based Modeling Approach**: LEAP operates on a scenario-driven framework where a base year is established using historical data disaggregated by sectors, fuels, and technologies. Based on baseline, future projections are developed for various scenarios by considering assumptions such as population growth, economic development, technological changes, fuel switching, and policy interventions.
- **Demand and Supply Representation:** The model follows an accounting approach in which energy demand is calculated as a function of activity levels (such as number of households or appliance ownership) and energy intensity. On the supply side, LEAP represents key components such as electricity generation, fuel processing, and energy transmission, allowing a comprehensive analysis of the entire energy system.
- **Environmental Impact Assessment:** LEAP also includes an environmental module that estimates GHG emissions and local pollutants based on fuel consumption and emission factors consistent with IPCC guidelines. This enables the evaluation of environmental implications of different energy pathways.
- **Scenario Comparison and Policy Analysis:** LEAP allows comparison between multiple scenarios, such as Business-as-Usual and Net Zero pathways. This helps to assess the impacts of different strategies on energy demand, emissions, and sustainability making it a valuable tool for supporting policy analysis and decision-making.

In this study, LEAP is used to model residential energy consumption and project future energy demand and GHG emissions at both provincial level which is integrated to develop national level model. By incorporating demographic trends, technological transitions, and policy directions, it provides a systematic and transparent framework for evaluating energy strategies and supporting evidence based planning in Nepal.

2.8 Findings from past Energy Planning Studies

Table 2: Literature Reviewed on different energy planning studies

S.N.	Title of paper	Result

1.	Energy Consumption and Scenario Analysis of Residential Sector Using Optimization Model-A Case of Kathmandu Valley	The energy model was developed using MAED and MARKEL. It was demonstrated that energy use can be reduced by 27% with optimization. (Rajbhandari & Nakarmi, 2014).
2.	Current Energy Consumption in Bhaktapur District	The energy usage of Bhaktapur is presented in the study. It is shows that 25% of households use energy for water heating; in rural areas, the majority 70% use firewood, while in urban areas, 755 use LPG (Bajracharya & Nakarmi, 2014).
3.	National Energy Demand Projections and Analysis of Nepal	This study project and analyze the national demand for each sector. The modeling tool utilized was the LEAP model in which four growth rate scenarios are taken into consideration. Demand is thought to be influenced by GDP and population (Bhattrai, 2015).
4.	Residential Sector Energy Demand and Analysis of Resunga Municipality, Gulmi, Nepal	The research on residential consumption is done where questionnaire is used for the survey. The LEAP model was applied and ICS scenarios was done (Panthi & Bhattarai, 2016).
5.	Sustainable Energy Planning for Nepal in The Federal Structure	This study looked at social cost-benefit analysis in the energy industry from 2017 to 2050, sustainable technology policy interventions in the energy demand, and energy planning in each province. (Bhusal & Nakarmi, 2019).
6.	Energy Security and Scenario Analysis of Province One of Federal Democratic Republic of Nepal	Five economic growth scenarios are analyzed with current status of energy consumption in Province One of the Federal Democratic Republic of Nepal for the years 2017–2040 (Dulal & Shakya, 2019).
7.	Residential Sector Energy Demand and Scenario Analysis for Province One of Nepal	In this study, the energy consumption and scenario analysis of Province One's residential sector for the years 2019–2030 were calculated using a Low Emission Analysis Platform (LEAP) model. Business as usual (BAU), LPG

		substitution, improved cooking stove (ICS), and sustainable energy development (SEDS) are the four scenarios that were created (Maharjan & Bhattarai, 2021).

CHAPTER THREE: METHODOLOGY

This study employs an energy system modeling approach to analyze the current and future energy consumption patterns of the residential sector in Nepal. The analysis is conducted using the Low Emissions Analysis Platform (LEAP), which is a widely used scenario-based energy modeling tool for evaluating energy demand, supply, and environmental impacts.

The methodology involves developing a residential energy demand model using demographic and energy consumption data. The model simulates future energy demand under different scenarios to evaluate potential changes in fuel consumption and greenhouse gas emissions. The analysis focuses on comparing a Business-as-Usual (BAU) scenario, Net-Zero Emission scenario, NDC 3.0 Scenario in order to understand the impact of clean energy transitions in the residential sector.

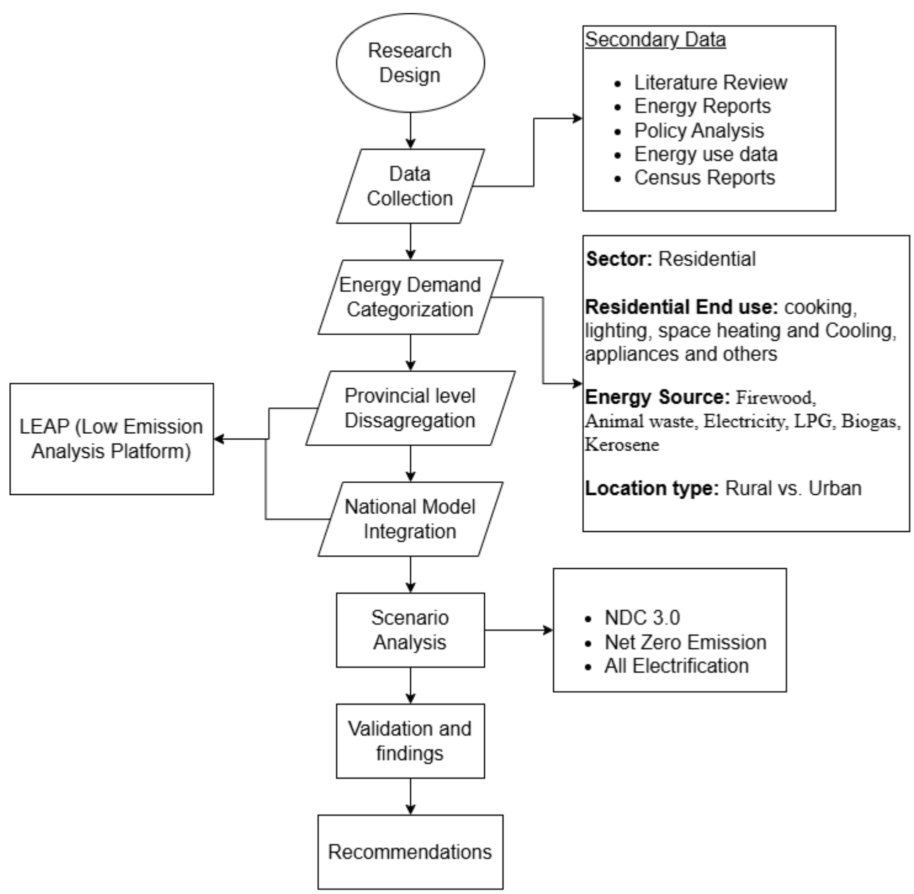

Figure 3.0.1: Methodology Flowchart

3.1 Study Areas

The study area for this research encompasses the entire country of Nepal, which is administratively divided into seven provinces:

Table 3.1: Province wise Population, household and population growth rate status, NSO 2021

Name of Province	Population (2021)	Household Size	Number of Household	Population Growth Rate (%)	Population (2024) Calculated	Number of Household (Calculated)
Koshi	4,961,412	4.16	1,191,556	0.86	5,090,520	1,223,683
Madhesh	6,114,600	5.29	1,156,715	1.19	6,335,499	1,197,637
Bagmati	6,116,866	3.89	1,570,927	0.97	6,296,599	1,618,663
Gandaki	2,466,427	3.72	662,480	0.25	2,485,419	668,123
Lumbini	5,122,078	4.49	1,141,902	1.24	5,298,516	1180,070
Karnali	1,688,412	4.61	366,255	0.70	1,697,500	368,221
Sudurpashchim	2,466,427	4.67	577,102	0.52	2,732,289	585,073
Nepal	**29,164,578**	**4.37**	**6,666,937**	**0.92**	**29,936,342**	**6,841,470**

Each province has its unique features in terms of population density, number of households, urbanization, and availability of modern energy sources. The Provinces like Bagmati and Madhesh, having high population density and urbanization, tend to use more electricity and LPG than other provinces. On the contrary, provinces like Karnali and Sudurpashchim, being more rural and distant, rely heavily on biomass energy sources.

Taking into account the above differences among regions, this paper evaluates residential energy demand in each of the seven provinces of Nepal. It is expected that considering the geographical division within the nation will help to understand how residential energy demand might develop in future. Such an approach will enable researchers to conduct better policy analysis and suggest ways to transition to cleaner energy sources in households in various regions of Nepal.

3.2 Data Collection

The analysis carried out in this study is basically conducted using secondary data gathered from different national and international sources. Secondary data was used for developing the model of residential energy demand and for establishing baseline scenarios for the study period as well as projections for the future energy demand. This includes demographic variables, energy use statistics, technology variables, and emissions factors for use in the LEAP modeling tool.

The use of variables like population level, population growth rate, household sizes, and numbers of households was important because they formed the core of the residential energy demand. All these secondary data were gathered from statistical reports published by the national and government authorities on the population levels. The population projections provided a basis for projecting future increases in the number of households.

Energy consumption data for different fuels used in the residential sector, including firewood, LPG, electricity, kerosene, biogas, animal waste, and solar energy, were collected from national energy balance reports and energy statistics published by relevant governmental organizations. These reports provide detailed information on sectoral energy consumption and fuel distribution across the country. More information such as efficiency of cooking stoves, lighting devices, and other household appliances, was obtained from existing literature, international energy databases, and previously published energy studies. Emission factors for different fuels were also collected from internationally recognized sources such as the Intergovernmental Panel on Climate Change (IPCC) guidelines, which are commonly used in energy and environmental modeling studies.

Overall, the use of secondary data from multiple credible sources ensures the reliability and consistency of the data used in the model. These datasets were integrated into the LEAP modeling framework to simulate residential energy demand and evaluate future energy and emission scenarios for Nepal.

- **National Statistics Office (NSO)**: for household-level data from the National Population and Housing Census and Nepal Living Standards Survey (NLSS), including energy access, fuel usage, and demographic indicators.
- **Alternative Energy Promotion Centre (AEPC)**: for data on the deployment of clean cooking technologies, renewable energy systems, and off-grid electrification programs.

- **Nepal Electricity Authority (NEA)**: for province-wise electricity access rates and consumption statistics in the residential sector.
- **Ministry of Energy, Water Resources, and Irrigation (MoEWRI)**: for national energy policies, demand projections, and progress reports.
- **Previous provincial studies and academic literature:** for region-specific demand estimates, energy use patterns, and modeling methodologies.
- **Water and Energy commission secretariat (WECS):** Energy synopsis report and the provincial energy consumption pattern report

3.2.1 End Use

Residential sector is further sub categorized on the basis of their end uses such as Cooking, Heating and Cooling, Lighting, Electric Appliances and Other (Animal feed, social purpose)

Table 3.3: Province wise Energy consumption for different end use

Name of Province	Cooking	Heating and Cooling	Lighting	Electric Appliance	Other	Total
Koshi	32.52	1.14	0.31	1.09	12.45	47.51
Madhesh	56.86	2.40	0.66	0.24	3.53	63.69
Bagmati	44.01	4.90	0.76	2.75	7.57	59.99
Gandaki	26.60	2.32	0.13	0.70	1.16	30.91
Lumbini	41.73	1.68	0.39	1.20	1.36	46.36
Karnali	27.60	0.036	0.05	0.10	0.11	27.89
Sudurpashchim	42.13	1.73	0.09	0.45	0.03	44.43
Total	**271.45**	**14.21**	**2.30**	**6.52**	**26.23**	**320.80**
Share	**78.90%**	**4.26%**	**1.15%**	**3.12%**	**12.57%**	**100.00%**

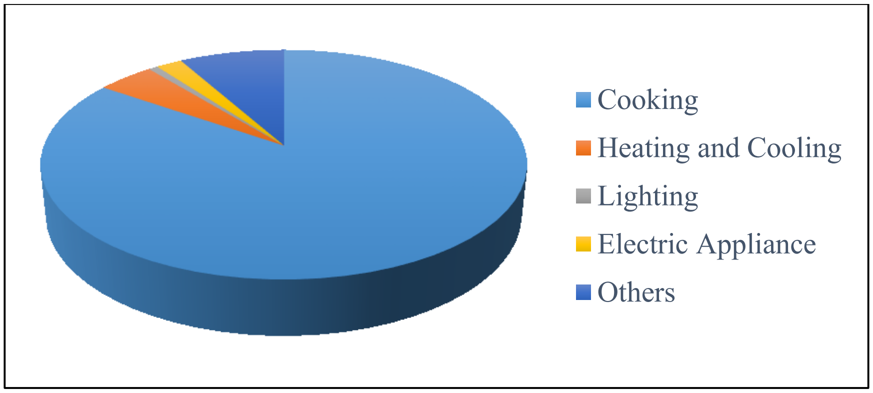

Figure 3.0.2: Energy End Use Share

3.3 LEAP Model Structure

The residential energy demand model in this study was developed using the demand module of the Low Emissions Analysis Platform (LEAP). The model structure was designed to represent the hierarchical organization of residential energy consumption across Nepal, allowing for detailed analysis of energy use by region, settlement type, end-use activity, and fuel type.

At the highest level of the model, the demand structure was divided into the seven administrative provinces of Nepal. These include Koshi, Madhesh, Bagmati, Gandaki, Lumbini, Karnali, and Sudurpashchim. This provincial disaggregation enables the analysis of regional variations in residential energy demand across the country.

Within each province, the residential sector was further categorized into two settlement types: Rural and urban areas. This distinction is important because energy consumption patterns differ significantly between rural and urban households. Rural households tend to rely more heavily on traditional biomass fuels such as firewood and animal waste, while urban households generally have greater access to modern energy sources such as electricity and liquefied petroleum gas (LPG).

The next level of the model structure represents the major household end-use activities. These end uses include cooking, lighting, heating and cooling, electric appliances, and other miscellaneous energy services. Each of these end-use categories reflects specific household energy requirements and allows for a more detailed representation of how energy is consumed within the residential sector.

At the lowest level of the model structure, the different fuels used to meet these energy service demands were defined. The fuels considered in this study include firewood, LPG, animal waste, electricity, kerosene, biogas, and solar energy. These fuels represent both traditional and modern energy sources commonly used by households in Nepal. The Figure below represents the model of this study in LEAP software

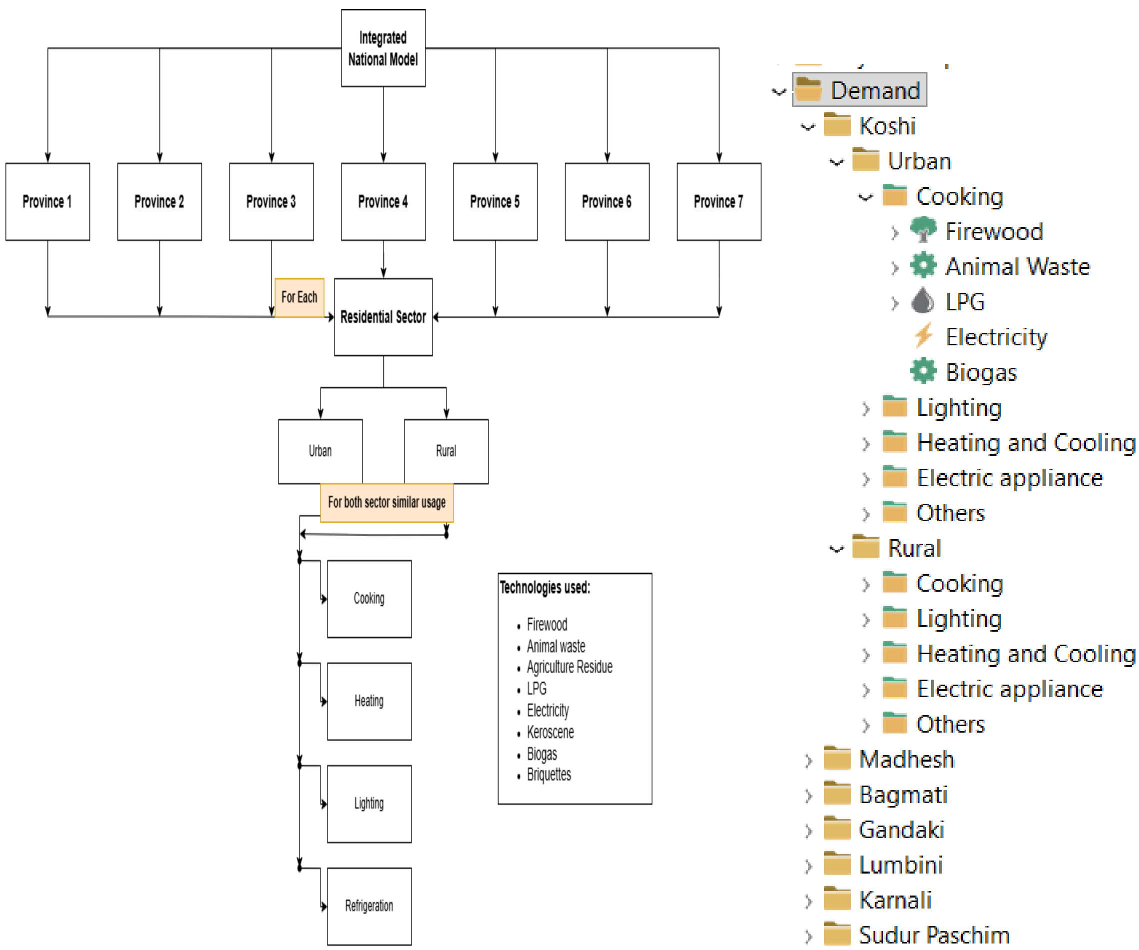

Figure 3.0.3: Detailed tree structure in LEAP

3.4 Demand Calculation Method

The estimation of residential energy demand in this study was carried out using the demand calculation framework available in the Low Emissions Analysis Platform (LEAP). The

LEAP model calculates energy demand based on the relationship between activity level and energy intensity. This approach allows the model to represent how different socio-economic drivers influence energy consumption within the residential sector.

In general, the total final energy demand is calculated using the following relationship:

Demand = Activity Level × Energy Intensity

Where the activity level represents the magnitude of the energy-consuming activity, and the energy intensity represents the amount of energy required per unit of activity. In the residential sector, the activity level is typically defined by the number of households or population, while energy intensity represents the amount of energy required to meet household energy services such as cooking, lighting, and appliance use.

In this study, the useful energy approach was adopted to more accurately represent household energy consumption and technology efficiency. Under this approach, energy demand is first estimated in terms of useful energy required for specific household services. The final energy demand is then calculated by considering the efficiency of the technologies used to deliver these services.

The relationship between useful energy and final energy can be expressed as:

Final Energy Demand = Useful Energy Demand / Technology Efficiency

In useful energy method, the model is able to reflect the impacts of advances in technology and changes in fuel types on energy demands. For instance, technological efficiencies such as electricity cookers and light-emitting diode lamps consume less final energy than their respective inefficient counterparts for example, wood stoves and kerosene lamps to produce similar useful energy services. This technique facilitates the evaluation of the impact that changing household technologies, fuels, and efficiency gains have on energy consumption in the future.

3.5 Emission Calculation Method

Greenhouse gas (GHG) emissions from residential energy consumption were estimated using the environmental assessment capabilities in Low Emissions Analysis Platform (LEAP). The model calculates emissions based on the quantity of fuel consumed and the corresponding emission factors associated with each fuel type.

The general relationship used for emission estimation can be expressed as:

$$\textbf{Emissions} = \textbf{Fuel Consumption} \times \textbf{Emission Factor}$$

In this formula, fuel use is the measure of the total energy consumed by households through various types of fuels, such as firewood, LPG, kerosene, biogas, dung, electricity, and solar power. The emission factor measures the quantity of greenhouse gas emissions per unit of fuel use. Emission factors are normally expressed in terms of the weight of gas per unit of energy (kg CO_2/GJ).

In this research, the major greenhouse gases, such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), were taken into consideration. The emission factors of the aforementioned gases were taken from globally recognized protocols, such as the IPCC emission factor database. The factors were then incorporated in the LEAP model to determine the quantity of emissions produced using each fuel in the domestic sector.

The LEAP model automatically multiplies the projected fuel consumption by the corresponding emission factors to calculate total emissions for each fuel type, end-use category, and scenario. The emissions of different gases can also be aggregated and converted into carbon dioxide equivalent (CO_2e) using global warming potential (GWP) values, which allows for the comparison of total climate impacts across scenarios.

3.6 Key Assumptions

For Various assumptions concerning demographic behavior, energy use behavior, efficiency improvement, and emission factors were needed for the development of the residential energy demand model. This is because various assumptions help to forecast future energy demand and emissions based on different scenarios. The starting year used in the development of the model is 2024, indicating the state of energy use conditions in the residential energy sector at present in Nepal. The population and the characteristics of households were regarded as the main determinants of residential energy demand. Projections of population and average household size helped in determining the number of households in each province.

Another vital assumption concerns the use of energy technologies within homes. Distinct technologies were considered for cooking, lighting, heating and cooling, and electrical gadgets. Each technology was assigned a unique efficiency rating based on how much final energy is needed to generate useful energy services. Biomass stoves and kerosene lamps were among the traditional energy technologies considered and assumed to be less efficient than modern energy technologies such as LPG stoves, electric cookers, and LED lights. In addition, distinct fuel sources are considered for the residential energy consumption, namely firewood, LPG, animal waste, electricity, kerosene, biogas, and solar energy. Different percentages of these energy sources are assumed within each province and for different households (rural and urban).

Emission factors were another important assumption used in the model. These factors represent the amount of GHG emitted per unit of fuel consumed. Standard emission factors obtained from the Intergovernmental Panel on Climate Change (IPCC) guidelines were applied to estimate emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) from different fuels.

These key assumptions provide the foundation for projecting residential energy demand and associated greenhouse gas emissions under the Business-as-Usual and Net-Zero Emission scenarios analyzed in this study.

Table 3: Assumption in the LEAP Model

Parameter	Value/Description
Base Year	2024
Population Driver	Population & Household Size
Modeling Approach	Useful Energy Approach
End Uses	Cooking, Lighting, Heating & Cooling, Appliances
Fuels	Wood, LPG, Electricity, Kerosene, Biogas, Animal Waste, Solar
Emission Factors	IPCC Default Factors

3.7 Scenario Description

Scenario analysis is an important component of energy modeling, in which evaluation of future energy demand and emissions may evolve under different development pathways. In this study, four scenarios were developed using the LEAP modeling framework to analyze the future energy consumption in residential sector and associated greenhouse gas emissions in Nepal.

3.7.1 Business-as-Usual (BAU)

The Business As Usual scenario refers to the current trend of energy consumption and technology adoption in the residential sector that would happen under the absence of significant changes in policies. In this scenario, the traditional sources of energy like firewood and dung will remain the major sources of energy used by households. The modern energy sources like electricity, LPG, and biogas will keep increasing gradually because of better availability and socio-economic development; nevertheless, this process will be quite slow. Therefore, the BAU scenario depicts the future energy consumption trend provided that the present policies will persist.

3.7.2 Net Zero Emission

This scenario is created based on the With Existing Measure approach, and it outlines the pathways through which the residential sector will switch from energy sources that cause high amounts of carbon emissions to other sources, which are relatively clean. These pathways include electrification of household energy services, increased efficiency in cooking and lighting systems, among others. Also, there is a reduction in the amount of fossil fuel and traditional biomass used. Electricity and biogas are examples of cleaner energy sources, which will replace other fuels during the period under study. In addition, technology efficiency also contributes towards a decrease in the overall final energy demand of households.

Comparing this approach to the Business-as-Usual case will help understand the effect that the With Existing Measures approach will have on energy consumption. Specifically, it helps to gauge how the existing policy framework and technological changes could affect the demand for residential energy and emissions in the future. The target of the net-zero emission scenario is to reduce the Emissions by 9% by 2030 and 47 % by 2050 (Government of Nepal, 2021).

3.7.3 All Electrification

The All Electrification scenario is developed as a With Additional Measures (WAM) scenario, representing an ambitious pathway. It goes beyond existing policies to accelerate the transition toward a fully electrified residential energy system. This scenario assumes a complete shift from traditional biomass and fossil fuels to electricity for meeting household energy needs, particularly in cooking, lighting, and appliance use. It also incorporates strong policy interventions, rapid technological adoption, and improved access to reliable electricity across all provinces, including rural and remote areas.

3.7.4 Third Nationally Determined Contribution

This scenario designed as a WAM scenario that symbolizes the greater commitments from Nepal for its renewed Nationally Determined Contributions to mitigate the impacts of climate change. The current scenario assumes that greater policy measures will be taken compared to what is currently being implemented, especially in regards to the development of clean/renewable energy within the household sector. There is an encouragement to promote electric cooking, enhance modern energy technology utilization, and improve energy efficiency within household energy use.

3.8. Model Calibration

Calibration plays an important role in energy modeling by ensuring that the results generated by the models are comparable to those obtained through observation or reporting. In this case, calibration of the energy model was done through the use of national energy balance data collected by the Water and Energy Commission Secretariat (WECS). The accuracy of the modeling process in estimating energy consumption patterns can be improved by adjusting some correction factors for the different end uses. The correction factor for cooking was set at 1.6, allowing for higher energy consumption than what could be estimated from the baseline data. The LPG correction factor was adjusted to 0.6, while the electricity correction factor was increased to 2.

CHAPTER FOUR: RESULT AND DISCUSSION

The most important chapter presents the results obtained from the LEAP energy model developed for the residential sector of Nepal, focusing on four scenarios: Business-as-Usual (BAU), Net Zero Emission, All Electrification, and NDC 3.0. The analysis evaluates key indicators such as final energy demand, fuel consumption patterns, and greenhouse gas emissions over the study period to understand the impact of different energy transition pathways in the residential sector.

4.1 Business-as-Usual (BAU) Scenario

The Business-as-Usual (BAU) scenario is a continuation of current energy consumption patterns and energy technologies in the residential sector without significant policy action. Current rates of fuel consumption, technological efficiency and energy consumption patterns are assumed to change little over the period of study, while the energy demand is principally projected to result from changes in population, household numbers etc.

The overall residential energy demand is expected to continue to grow in the BAU scenario. This is the reason that the amount of energy consumed has increased, partly due to the increasing number of houses and increased consumption of energy services like cooking, lighting and using appliances. The assumptions made for this are that the Population growth rate is constant, the Size of household is also constant and the % of Rural and Urban are also constant throughout the period.

4.1.1 Final Energy Demand

The projected final energy consumption of the residential sector in the seven provinces of Nepal is shown in Figure 4.1. The findings reveal that the overall energy demand in all provinces increased gradually during the study period. The population growth, the growth in household population and the improvement of living standards are the major factors behind such growth, leading to an increase in demand for household energy services, including basic energy services such as lighting and cooking and non-essential energy services like appliances.

The Madhesh province has the largest energy demand among the provinces during the study period, rising from around 64 PJ in 2024 to about 86 PJ in 2050. The increased demand is due to the relatively large population and urbanization rate in this province. And in Bagmati province also demonstrates a substantial increase in energy consumption, from around 60 PJ in 2024 to about 77 PJ by 2050, reflecting robust energy consumption growth in the residential sector in this region.

The energy demand in the Koshi and Lumbini province has grown consistently up to moderate level. Koshi grows from around 48 PJ in 2024 to around 60 PJ in 2050 and Lumbini expands from nearly 46 PJ to about 64 PJ in the same timeframe. These increases are due to a constant growth in the energy consumption of households which is a consequence of the demographic changes.

Karnali and Gandaki have relatively lower energy demand during the study period. The increase of Power Potential from the year 2024 to 2050 is just 2.6 PJ for Gandaki and 5.4 PJ for Karnali. This is due to differences in population size, household energy consumption level, which may be associated with the lower demand in these provinces.

Sudurpashchim also has a moderate increase in energy demand from approximately 44 PJ in 2024 to approximately 51 PJ in 2050. The rise is moderate when compared to other more populous provinces but the trend is an upward one that signifies an ongoing growth in residential energy demand.

Overall Energy consumption of Nepal is estimated to be 320 PJ in 2024 and it increases with the rate of 0.89% annual and reaches 404 PJ in 2050 which shows the similar trend from the previous study by WECS. Among all provinces, Lumbini increases with high rate of 1.24% and Gandaki increases with lowest rate of 0.25% annually.

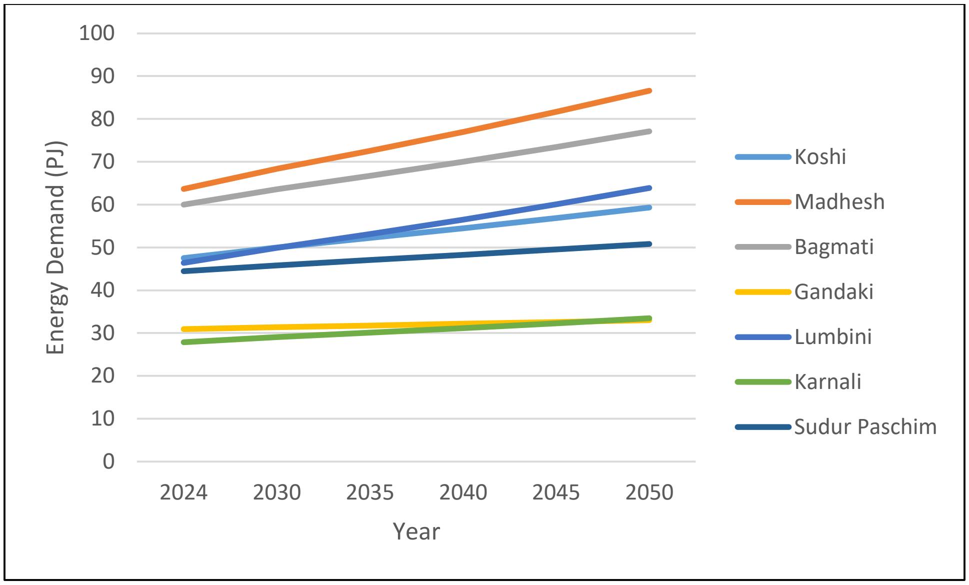

Figure 4.0.1: Projected Provincial Residential Final Energy Demand for BAU

4.1.2 Fuel Energy Mix

The fuel-wise distribution of residential final energy demand has been estimated in the 2024-2050 period for each provinces under the Business-as-Usual scenario as shown in Figure 4.2. The findings show that traditional biomass fuels remain the main energy sources for residential sector during the study period while the contribution of modern energy sources gradually rises over the time.

Firewood is the single biggest fuel used in households. Firewood demand grows from around 261 PJ in 2024 to some 327 PJ in 2050. Firewood is still the main source of energy in the residential sector, although this is starting to change as the energy sector becomes gradually 'modernized'. LPG is the second most important energy source for households. The consumption steadily grows from 21.8 PJ in 2024 to 28 PJ in 2050. Urbanization, better access to modern cooking fuels, and changing preferences for cleaner and more convenient energy options are all factors in this growing demand for LPG.

The residential sector also has a slight uptick in electricity use over the study period. The demand for electricity is expected to increase from about 16 PJ in 2024 to 20 PJ in 2050. It is an upward trend due to enhanced electricity coverage and increased consumption of electrical appliances and lighting systems in homes. If the trends continues the share of Renewable Energy will be less than the share in 2050.

In the residential sector, energy consumption from animal waste is a minor and growing source, with a growth from ~12 PJ in 2024 to ~16.8 PJ in 2050. Likewise, the amount of kerosene use increases slightly from approximately 0.21 PJ to approximately 0.27 PJ and is still quite low in comparison to other fuels.

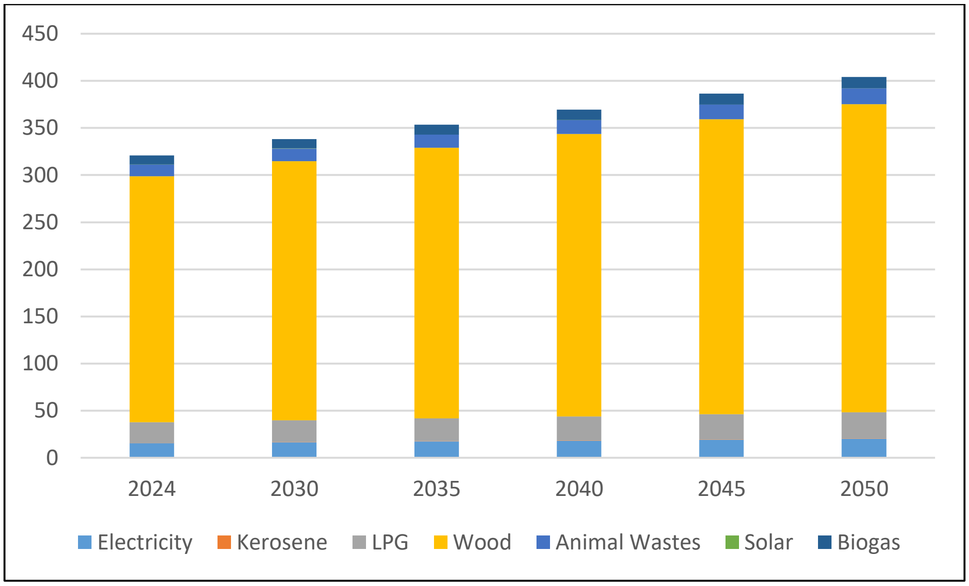

Figure 4.0.2: Energy Mix for BAU Scenario

Figure 4.3 illustrates the provincial energy mix, clearly showing a strong dependence on firewood across all provinces. Among them, Karnali exhibits the highest reliance, with firewood accounting for more than 98% of its total energy consumption. In contrast, Madhesh shows the lowest dependence on firewood, contributing less than 70% of its total energy demand.

The figure also indicates that Madhesh has the highest share of animal waste usage, comprising approximately 18% of its total energy consumption. Electricity use is most prominent in Bagmati Province; however, its share remains relatively low at around 8%. Similarly, Lumbini Province demonstrates the highest adoption of biogas, contributing about 9% to its overall energy mix.

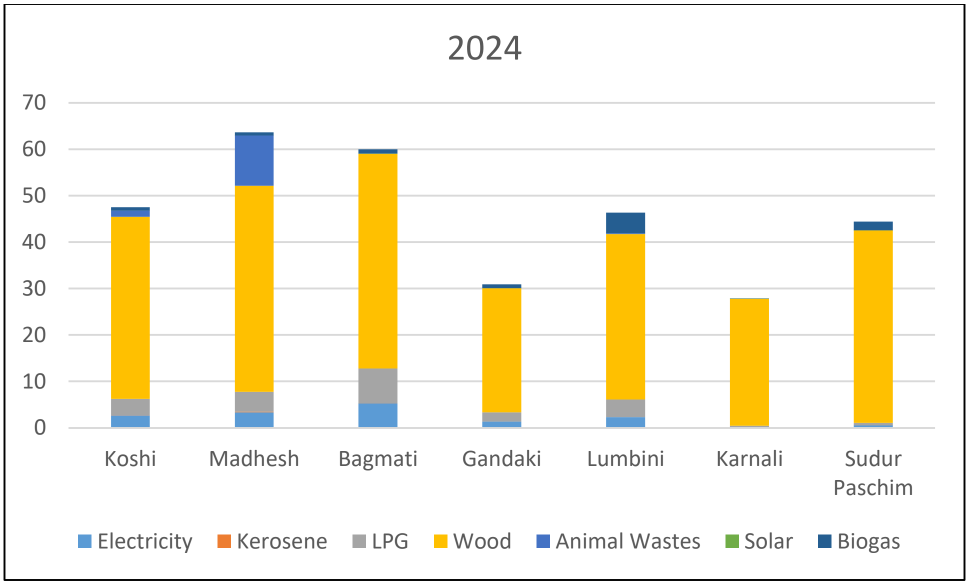

Figure 4.0.3: Provincial Energy Mix

4.1.3 Greenhouse Gas Emissions

Figure 4.4 presents the projected Province wise emission of residential sector from 2024 to 2050 under the Business-as-Usual Scenario. The result indicate that Bagmati has the maximum emission of around 1 million Metric Ton (mMT) and continue to dominate over year and year. The total emission in year 2024 is 4.2 mMT and it reaches to 5.35 mMT in 2050 which shows 27% increase. We can also find the line Gandaki is most flat which shows there is the minimum increase in emission over a period at the same time the line of graph for Bagmati and Madesh is more inclined showing the maximum GHG Emissions.

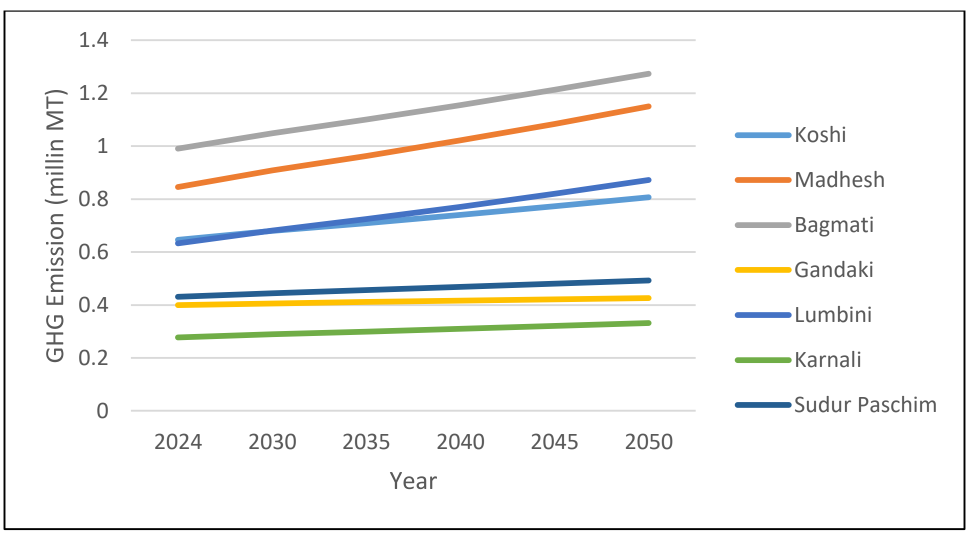

Figure 4.0.4: Province wise GHG Emission of Residential Sector in BAU Scenario

Figure 4.5 presents the projected fuel wise emission of residential sector from 2024 to 2050 under the Business-as-Usual scenario. The result shows main four fuels as responsible for the emission, they are Wood, LPG, Kerosene, and Animal Wastes. The result indicate that Wood has the maximum share in GHG emission of more than 50% throughout the study period and is constant over time. Among all fuels, Wood accounts the largest emission in residential sector, it increases from approximately 2.47 mMT to about 3.1 mMT by 2050. And this share of emission is followed by LPG and other two fuels don't have a significant share in GHG Emission.

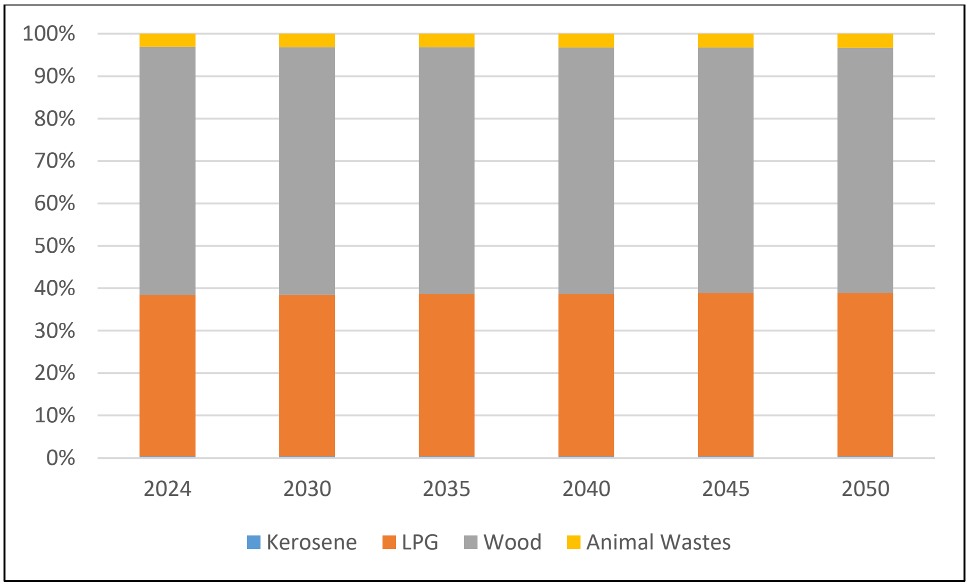

Figure 4.0.5: Fuel wise GHG Emission in BAU

4.1.4 Energy Balance

Figure 4.6 present the Sankey diagrams illustrating the flow of energy in the residential sector across the seven provinces of Nepal for the base year 2024 under the BAU scenario. In the base year 2024, the residential energy system is dominated by biomass resources. Biomass production accounts for approximately 262 PJ of energy supply, which represents the largest share of the residential energy mix. Oil product imports also contribute around 34.49 PJ, mainly representing fuels such as LPG and kerosene used in household activities. Electricity supply in the residential sector is relatively limited in comparison to biomass-based energy sources. It also illustrates the distribution of energy consumption across the seven provinces. Provinces with higher population and urbanization levels, such as

Madhesh and Bagamti, show relatively larger energy flows compared to other provinces. In contrast, provinces with smaller populations and more rural characteristics, such as Karnali and Gandaki, exhibit lower levels of residential energy consumption.

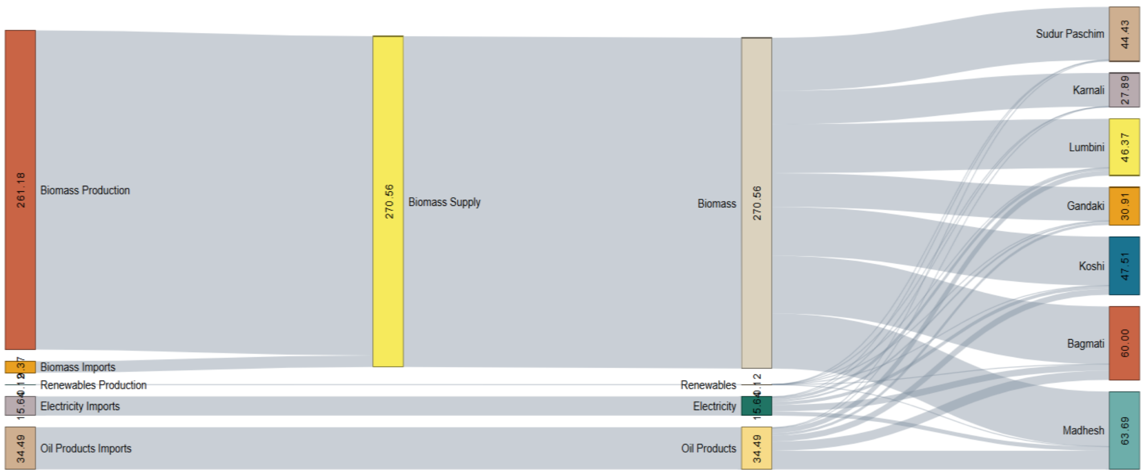

Figure 4.0.6: Sankey Diagram for BAU Scenario

4.1.5 Energy Indicators

Energy indicators are metrics used to assess the performance of the energy system, including aspects such as energy demand, efficiency, and emissions. It helps in understanding trends of energy consumption and evaluates the impact of different scenarios and policy interventions. In this study, energy indicators are used to analyze changes in energy use and emissions across provinces and scenarios.

Table 4 Energy Indicators for BAU Scenario

Province	Final Energy Demand Per Capita (GJ)	Total Electricity Demand Per Capita (kWh)	GHG Emission Per Capita (Kg)
Koshi	9.33	144.46	126.90
Madhesh	10.05	146.14	133.53
Bagmati	9.53	232.78	157.23
Gandaki	12.44	150.36	160.54
Lumbini	8.75	119.73	119.47
Karnali	16.43	31.94	163.18
Sudurpashchim	16.26	57.26	157.74
Nepal	10.72	145.17	141.03

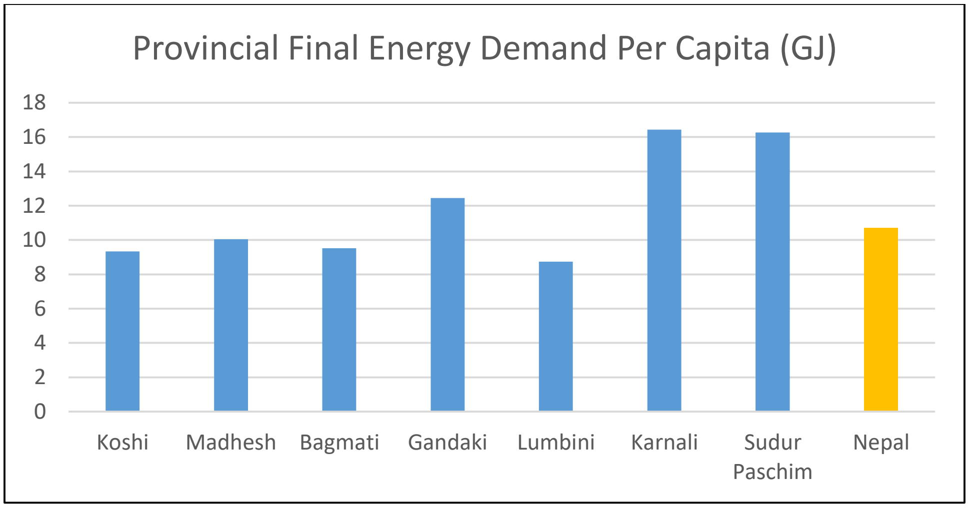

Figure 4.0.7: Provincial Final Energy Demand per Capita (GJ)

There are significant inter-provincial differences in the final energy demand per capita, which is driven by energy access, demand and living standards. The average energy demand is estimated as 10.72 GJ per capita at national level. Also, per capita energy demand is observed to be highest in Karnali (16.43 GJ) and Sudurpashchim (16.26 GJ) out of all the Provinces, which could be explained by inefficient utilization of energy and the use of traditional fuel. In contrast, Lumbini has the lowest value 8.75 GJ per capita, while Koshi has 9.33 GJ and Bagmati 9.53 GJ. Madhesh (10.05 GJ) and Gandaki (12.44 GJ) are very close to or higher than the national average. Such differences show that regional differences in energy use exist and indicate the importance of developing energy plans tailored to individual provinces.

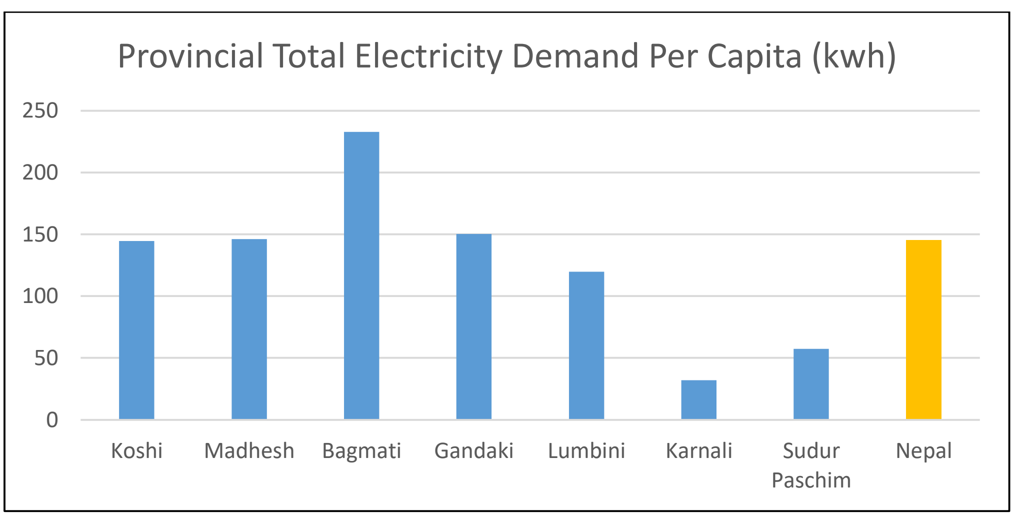

Figure 4.0.8: Provincial Total Electricity Demand per Capita (kWh)

The total electricity demand per capita also shows significant variation across provinces, reflecting differences in electrification levels and access to modern energy services. At the national level, the average electricity consumption is estimated at 145.17 kWh per capita. Bagmati records the highest electricity demand at 232.78 kWh per capita, indicating higher urbanization and better access to electricity. Provinces such as Gandaki (150.36 kWh), Madhesh (146.14 kWh), and Koshi (144.46 kWh) are close to or slightly above the national average. In contrast, Lumbini has a relatively lower consumption at 119.73 kWh, while Karnali (31.94 kWh) and Sudurpashchim (57.26 kWh) show significantly lower values, highlighting limited access to electricity and lower levels of electrification. These disparities emphasize the need for targeted interventions to improve electricity access in less developed provinces.

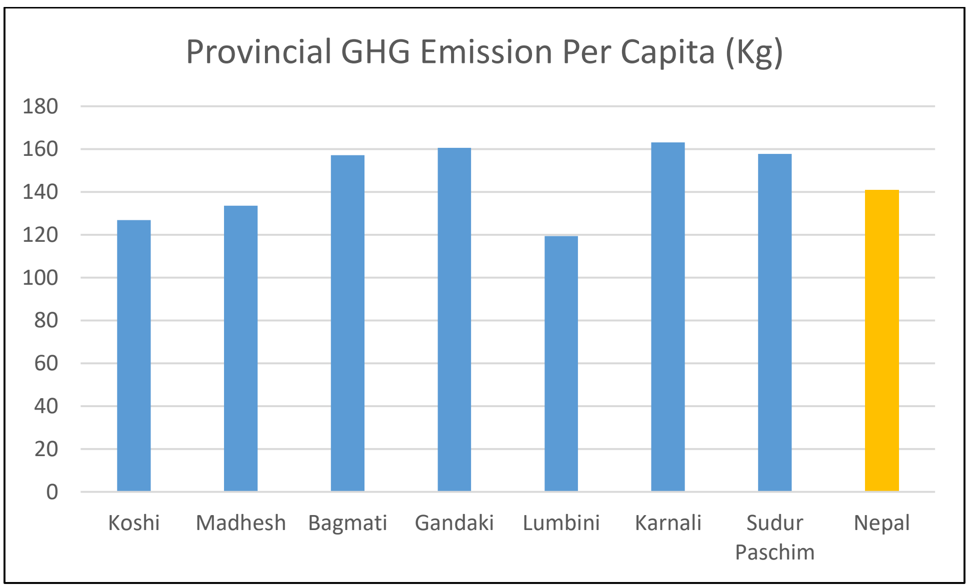

Figure 4.0.9: Provincial GHG Emission per Capita (Kg)

The per capita greenhouse gas (GHG) emissions also exhibit noticeable variation across provinces, reflecting differences in energy consumption patterns and fuel use. At the national level, the average emission is estimated at 141.03 kg per capita. Among the provinces, Karnali records the highest emissions at 163.18 kg per capita, followed by Gandaki (160.54 kg) and Sudurpashchim (157.74 kg), indicating higher reliance on traditional and less efficient energy sources. Bagmati also shows relatively high emissions at 157.23 kg per capita despite higher electrification levels. In contrast, Lumbini has the lowest emissions at 119.47 kg per capita, followed by Koshi (126.90 kg) and Madhesh (133.53 kg). These variations highlight regional disparities in energy use and suggest that provinces with higher dependence on traditional fuels tend to have higher per capita emissions, emphasizing the need for cleaner energy transitions at the provincial level.

4.2 Net Zero Emission Scenario

The Net Zero Emission scenario, developed as a With Existing Measures (WEM) pathway, explores a gradual transition of the residential sector toward cleaner and more energy-efficient technologies to reduce greenhouse gas emissions. This scenario assumes increased electrification of household energy services, wider adoption of efficient cooking and lighting technologies, and a reduction in the use of traditional biomass and fossil fuels. Cleaner energy sources such as electricity and biogas progressively replace conventional fuels, while improvements in technology efficiency reduce the overall final energy demand required to meet household needs. As a result, the residential energy system undergoes a significant shift toward a low-carbon and more sustainable energy structure. The following are the major assumptions of this scenario:

- Urbanization up to 95% in Province 1, 2, 3 and 4
- Urbanization up to 85% in Province 5 and 6
- Urbanization up to 70% in Province 7

Table 5: Key Assumptions for Net Zero Emission (WEM)

End Use Activity	Urban (by 2050)	Rural (by 2050)
Cooking	30% LPG, 70% Electricity	55% Firewood with more efficient technology, 25% Electricity, 10% LPG, 10% Biogas
Lighting	80% Electricity, 20% RE	80% Electricity, 20% RE
Heating and Cooling	Min. 75% Electricity, Remaining LPG	Min. 75% Electricity, 10% LPG and Remaining with RE
Electric Appliance	100% Electricity with higher efficiency	100% Electricity with higher efficiency
Other	30% LPG, 70% Electricity	55% Firewood with more efficient technology, 25% Electricity, 10% LPG, 10% Biogas

4.2.1 Final Energy Demand

The projected final energy demand for the residential sector under the Net Zero Emission (NZE) scenario across the seven provinces of Nepal is presented in figure 4.7. Unlike the BAU scenario, the results for the NZE scenario demonstrate a significant and consistent decline in total energy demand across all provinces from 2024 to 2050. This downward trend is primarily driven by the aggressive adoption of high-efficiency electric cooking appliances, the implementation of energy-efficient building codes, and the transition toward advanced lighting and electrical appliances, which significantly reduce the energy intensity per household.

Among the provinces, Madhesh has the highest energy demand in year 2024 but due to its high negative rate throughout the period, it shows a notable decrease from approximately 64 PJ to about 33 PJ in 2050. This reduction, despite high urbanization, reflects the substantial impact of fuel switching and efficiency measures in densely populated urban centers. Similarly, Bagmati experiences a decline in energy requirements, falling from 60 PJ in 2024 to approximately 37 PJ by 2050, representing one of the most significant reductions in absolute terms due to the displacement of inefficient traditional fuels.

Koshi and Lumbini also exhibit clear downward trajectories in the NZE pathway. Koshi sees its demand drop from approximately 48 PJ in 2024 to about 25 PJ in 2050, while Lumbini decreases from 46 PJ to roughly 32 PJ over the same horizon. In contrast, Gandaki and Karnali continue to represent the lowest energy demand profiles, but with accelerated reductions compared to the baseline. Gandaki shows a decrease from about 31 PJ in 2024 to approximately 14 PJ by 2050. Karnali, starting at 28 PJ, reaches the lowest provincial demand of roughly 12 PJ by the end of the study period. These figures suggest that in less populous provinces, the transition to modern energy services can lead to very low per-capita energy footprints.

Sudurpashchim follows a similar pattern of reduction, with energy demand falling from approximately 44 PJ in 2024 to about 20 PJ in 2050. Overall, the total residential energy demand under the NZE scenario is projected to decrease from 320 PJ in 2024 to 172 PJ in 2050, illustrating that a net-zero pathway can achieve nearly a 46% reduction in total energy consumption through aggressive efficiency and electrification which is similar to the provincial study done by WECS under the SEDS Scenario.

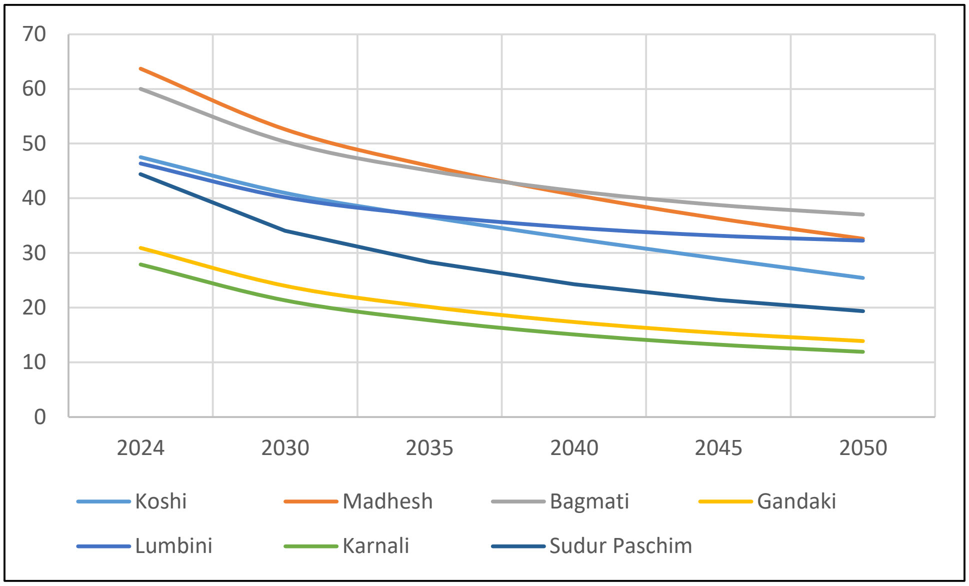

Figure 4.0.10: Projected Provincial Final Energy Demand for NZE Scenario

4.2.2 Energy Mix

The projected fuel mix for the residential sector under the Net Zero Emission (NZE) scenario from 2024 to 2050 is presented in Figure. The results indicate a transformative shift in the energy consumption pattern, characterized by a rapid transition from traditional biomass and fossil fuels toward clean, renewable energy sources. This evolution is a direct result of aggressive policy interventions aimed at decarbonizing the residential sector through large-scale electrification and the promotion of modern renewable technologies.

Among the various fuel types, Electricity shows the most significant growth, more than three times its share over the study period. Demand for electricity increases from approximately 16 PJ in 2024 to 64 PJ by 2050. This surge reflects the successful implementation of "electricity-first" policies, where electric induction stoves, high-efficiency lighting, and modern appliances become the primary drivers of household energy services. In stark contrast, Wood (firewood), which is the dominant fuel in 2024 at 261 PJ, undergoes a dramatic decline to just 62 PJ by 2050. This sharp reduction highlights the massive displacement of traditional cooking methods by cleaner alternatives, significantly reducing the pressure on forest resources and improving indoor air quality.

LPG and Animal Wastes also demonstrate a downward trend under the NZE pathway. LPG consumption increases gradually from 21.5 PJ to 34.5 PJ, suggesting that while it remains a transition fuel, it is increasingly phased out in favor of electricity. Similarly, the use of Animal Wastes and Kerosene virtually disappears by 2050, with kerosene usage hitting zero and animal waste dropping from 12 PJ to negligible levels. These trends underscore a total move away from inefficient and high-emission energy carriers.

On the other hand, modern renewable sources like Biogas and Solar exhibit steady growth, albeit from a smaller baseline. Biogas demand rises from 9 PJ to 12 PJ, while solar energy demand increases from 0.1 PJ to approximately 0.6 PJ by 2050. These increases represent the diversification of the renewable energy portfolio, particularly in rural and off-grid areas where decentralized energy solutions complement the national grid.

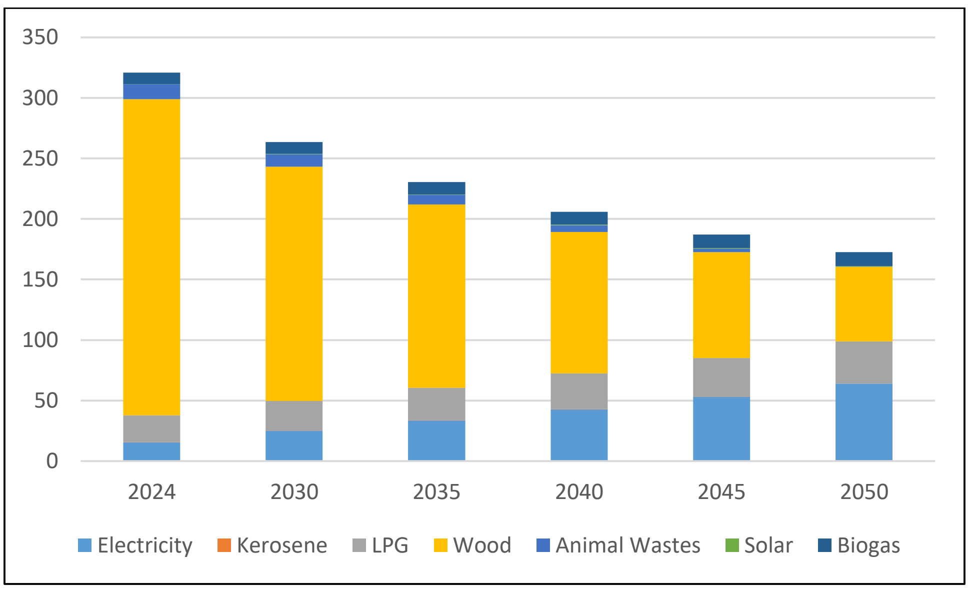

Figure 4.0.11: Fuel Share in residential sector over a period

4.2.3 Greenhouse Gas Emission

The projected greenhouse gas (GHG) emissions for the residential sector under the Net Zero Emission (NZE) scenario across the seven provinces of Nepal are presented in Figure 4.9. The results indicate a significant and steady decline in total CO_2 equivalent emissions over the study period, falling from 4.2 million Metric Tons (mMT) in 2024 to 3.1 mMT by 2050, This is a direct consequence of the aggressive fuel-switching strategies and energy efficiency measures analyzed in the previous sections, which prioritize the displacement of high-emission fossil fuels like LPG and kerosene with clean electricity and modern renewables.

Among the provinces, Bagmati begins with the highest emission levels at 1.0 mMT in 2024 but achieves the most substantial absolute reduction, reaching 0.65 mMT by 2050. This downward trend reflects the successful decarbonization of urban household energy use, particularly through the transition to electric cooking in high-density areas. Similarly, Koshi, Madhesh and Lumbini all demonstrate consistent decreases in their carbon footprints. Madhesh for instance, reduces its emissions from 0.85 mMT to 0.65 mMT, while Koshi declines from 0.64 mMT to 0.42 MMT by the end of the study horizon.

Karnali GHG emission reaches 0.22 mMT in 2050 from 0.27 mMT and then reaches 0.22 mMT, and Sudurpashchim decreases from 0.43 mT to 0.34 mMT and then rises to 0.37 mMT in 2050. This growth in emissions, despite the overall national decline, can be attributed to the expansion of energy access and the initial transition from traditional biomass to transition fuels (such as LPG) in previously underserved rural regions before full electrification is realized.

Finally, Gandaki maintains a relatively low and stable emission profile, decreasing from 0.4mMT in 2024 to 0.26 mMT by 2050. Overall, the national total reduction is more than 25% in GHG emissions under the NZE scenario underscores the residential sector's vital role in meeting Nepal's international climate commitments. The convergence of declining emissions in major urban provinces and the stabilization of energy related carbon output in developing regions highlights a balanced path toward a carbon-neutral residential sector.

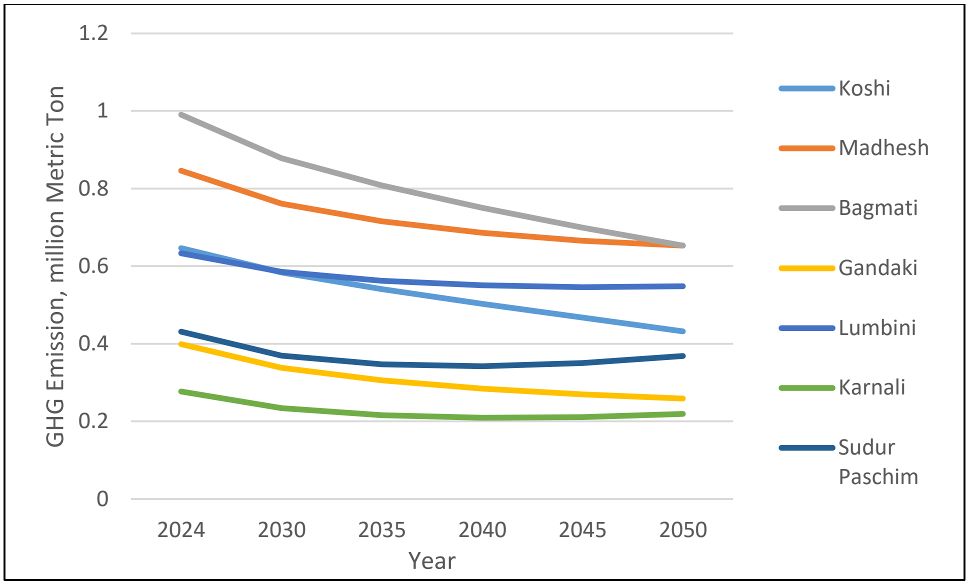

Figure 4.0.12: Province wise GHG emission of Residential sector for NZE Scenario

4.2.4 Energy Balance

Figure 4.10 present the Sankey diagrams illustrating the flow of energy in the residential sector across the seven provinces of Nepal for the projected year 2050 under the Net Zero Emission scenario.

In the base year 2024, the residential energy system is dominated by biomass resources. Biomass production accounts for approximately 261 PJ of energy supply, which represents the largest share of the residential energy mix. Oil product imports also contribute around 35 PJ, mainly representing fuels such as LPG and kerosene used in household activities. Electricity supply in the residential sector is relatively limited in comparison to biomass-based energy sources. It also illustrates the distribution of energy consumption across the seven provinces. Provinces with higher population and urbanization levels, such as Bagmati and Madhesh, show relatively larger energy flows compared to other provinces. In contrast, provinces with smaller populations and more rural characteristics, such as Karnali and Sudurpashchim, exhibit lower levels of residential energy consumption.

The Sankey diagram for the year 2050 under the Net Zero Emission scenario demonstrates a significant transformation in the residential energy system. One of the most notable changes is the substantial increase in electricity supply, which rises to approximately 64 PJ. This reflects the growing electrification of household energy services, including cooking, lighting, and appliance use. The increased reliance on electricity represents a key strategy for reducing greenhouse gas emissions in the residential sector. At the same time, the role of biomass in the energy mix declines considerably. Biomass supply decreases to approximately 61 PJ in 2050, indicating a gradual transition away from traditional biomass fuels such as firewood and animal waste. Oil product remains almost constant to around 35 PJ, reflecting reduced dependence on fossil fuels such as LPG and kerosene in the Net Zero developed With Existing Measures (WEM) pathway.

Overall, the comparison between the 2024 and 2050 Sankey diagrams clearly illustrates the transformation of the residential energy system in Nepal under the Net Zero Emission scenario. The results highlight a shift from biomass-dominated energy use toward increased electrification and reduced reliance on fossil fuels and traditional biomass. This transition plays a crucial role in achieving long-term emission reduction targets and promoting a more sustainable residential energy system.

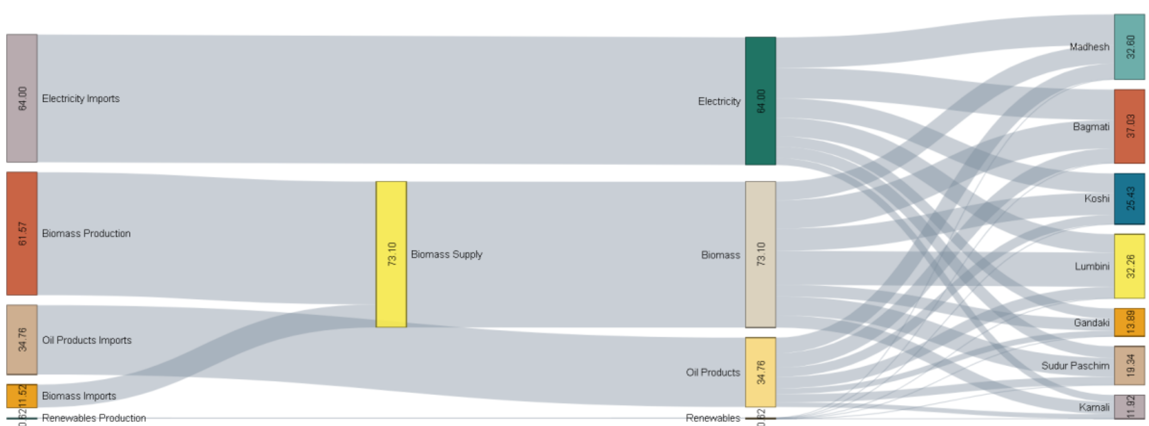

Figure 4.0.13: Sankey Diagram for Net Zero Emission in 2050

4.2.5 Energy Indicators in Net Zero Emission Scenario

Table 5 presents the projected residential energy indicators under the Net Zero Emission scenario from 2024 to 2050. The results show a gradual decline in final energy demand per capita from 10.72GJ/capita in 2024 to 4.52 GJ/capita by 2050, indicating improvements in energy efficiency and the adoption of more efficient technologies. At the same time, electricity consumption increases significantly, with final electricity demand rising from 145 kWh per capita in 2024 to 448 kWh per capita in 2050. Similarly, total household electricity consumption grows from 635 kWh per household to 1970 kWh by 2050, reflecting increased electrification of household energy services such as cooking, lighting, and appliance use.

The transition toward electricity and cleaner energy sources also results in substantial reductions in greenhouse gas emissions. GHG emissions decrease from 141 kg per capita in 2024 to 78 kg per capita by 2050. This decline is mainly due to the gradual replacement of traditional biomass fuels and fossil fuels with cleaner and more efficient energy technologies. Overall, the indicators demonstrate that the Net Zero scenario promotes improved energy efficiency, increased electrification, and significant emission reductions in the residential sector.

Table 6: Energy Indicator for Residential Sector in NZE Scenario

		2024	2030	2035	2040	2045	2050
Final enrgy Demand/ Capita	GJ/capita	10.72	8.15	6.74	5.71	4.91	4.52
Final Electricity Demand	KWh/Capita	145.17	215.65	274.14	332.41	390.46	448.31
Total Electrcity Used/HH	KWh/HH	635.21	944.62	1201.83	1458.49	1714.67	1970.37
GHG Emission	GHG in Kg/Capita	141.03	116.27	102.57	92.32	84.32	77.86

The final energy demand per capita under the Net Zero Emission (NZE) scenario shows a consistent declining trend across all provinces, reflecting improvements in energy efficiency and increased adoption of cleaner technologies. At the national level, energy demand decreases significantly from 10.72 GJ per capita in 2024 to 4.52 GJ by 2050. Provinces with initially high energy demand, such as Karnali and Sudurpashchim, experience the most substantial reductions, declining from 16.43 GJ to 5.86 GJ and from 16.26 GJ to 6.19 GJ, respectively. Similarly, Madhesh and Koshi show notable decreases, reaching 3.78 GJ and 4.00 GJ by 2050. Although Bagmati and Gandaki maintain relatively higher values compared to other provinces, they also demonstrate steady reductions over time. Overall, the declining trend across all provinces highlights the effectiveness of electrification and efficiency improvements in reducing per capita energy demand under the NZE pathway.

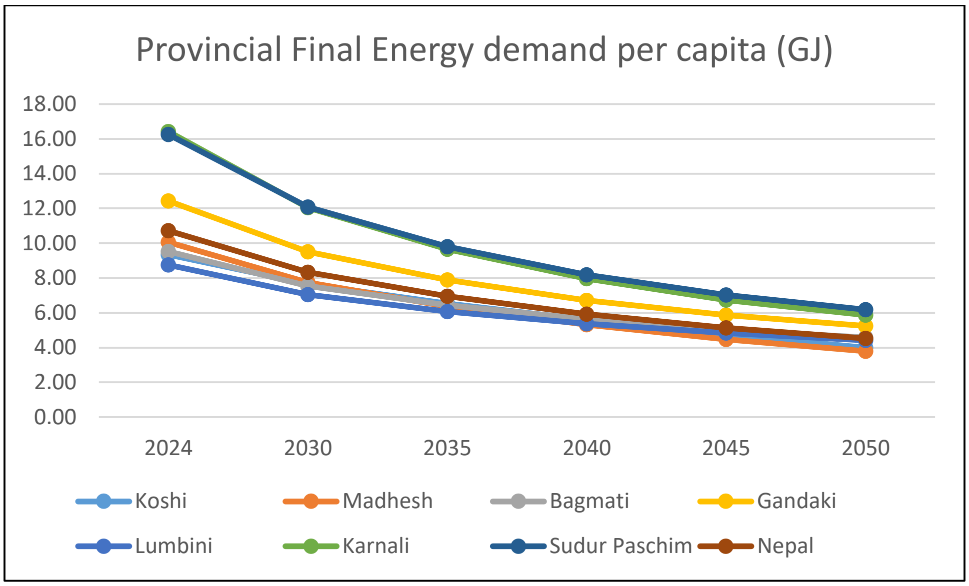

Figure 4.0.14: Provincial Final Energy Demand Per Capita

The total electricity demand per capita under the Net Zero Emission (NZE) scenario shows a substantial and continuous increase across all provinces, reflecting rapid electrification of the residential sector. At the national level, electricity consumption rises from 145.17 kWh per capita in 2024 to 465.61 kWh by 2050, representing more than a threefold increase. Among the provinces, Karnali and Sudurpashchim exhibit the highest growth rates, increasing from very low base values of 31.94 kWh and 57.26 kWh to 476.11 kWh and 512.45 kWh, respectively, indicating significant expansion in electricity access. Madhesh and Gandaki also show strong growth, reaching 495.01 kWh and 538.37 kWh by 2050, while Bagmati maintains the highest absolute consumption throughout the period, increasing from 232.78 kWh to 523.41 kWh. In contrast, provinces like Koshi and Lumbini show relatively moderate growth. Overall, the sharp increase in electricity demand across all provinces highlights the critical role of electrification in achieving emission reductions and transitioning toward a cleaner energy system.

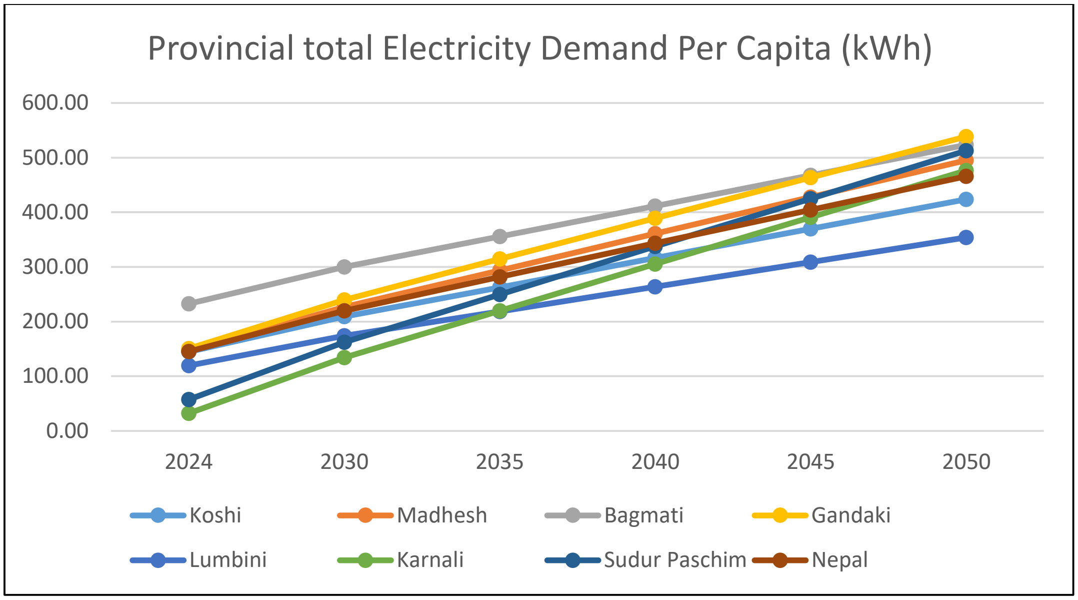

Figure 4.0.15: Provincial Total Electricity Demand per Capita (kWh)

The per capita greenhouse gas (GHG) emissions under the Net Zero Emission (NZE) scenario show a consistent declining trend across most provinces, reflecting the impact of electrification and improved energy efficiency. At the national level, emissions decrease significantly from 141.03 kg per capita in 2024 to 82.00 kg by 2050. Provinces such as Bagmati and Madhesh experience substantial reductions, declining to 80.69 kg and 75.78 kg respectively, due to higher adoption of clean energy technologies. Similarly, Koshi and Lumbini show steady decreases, reaching 67.92 kg and 75.07 kg by 2050. Although Gandaki also demonstrates a gradual decline, it remains relatively higher at 97.66 kg. In contrast, Karnali and Sudurpashchim show slower reductions, with emissions stabilizing or slightly increasing toward the later years, reaching 107.61 kg and 117.69 kg respectively. This trend indicates that while the NZE pathway effectively reduces emissions overall, provinces with limited access to modern energy technologies may require additional targeted interventions to achieve deeper emission reductions.

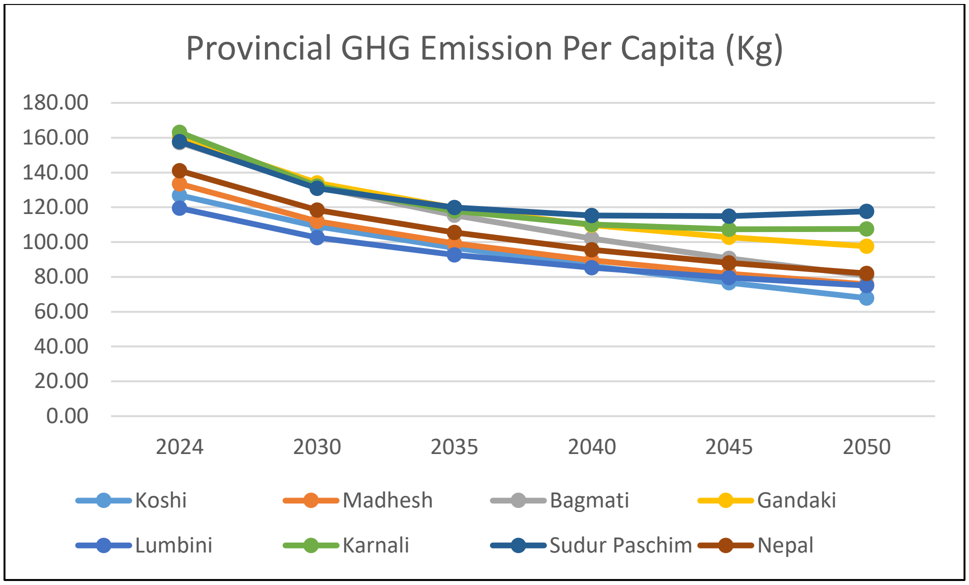

Figure 4.0.16: Provincial GHG Emission per Capita (kg)

4.3 All Electrification Scenarios

The All Electrification Scenario is developed With Additional Measures (WAM) to achieve net-zero emissions by 2050 in the residential sector of Nepal. Under this scenario, all conventional fuels including traditional biomass (firewood, agricultural residues, and animal dung) and fossil fuels such as LPG and kerosene are completely replaced by electricity across all end-use applications. Electricity is assumed to be predominantly generated from hydropower, reflecting Nepal's abundant renewable energy potential and its central role in the future energy system. The transition involves large-scale adoption of electric technologies for cooking, heating, and other household energy needs, resulting in a fully electrified residential sector.

The urbanization trend in this scenario is assumed to follow the same trajectory as in the net-zero emission scenario, ensuring consistency in demographic and structural changes. While this pathway significantly reduces emissions and enhances energy efficiency, it also leads to a substantial increase in electricity demand, requiring robust expansion of generation capacity and grid infrastructure to ensure reliability and sustainability.

4.3.1 Final Energy Demand

The projected final energy demand for the residential sector under the All Electrification scenario across the seven provinces of Nepal is presented in figure 4.11. Unlike the BAU scenario, the results for this scenario demonstrate a complete fuel switch in total energy demand across all provinces from 2024 to 2050. This downward trend is primarily driven by the aggressive adoption of high-efficiency electric cooking appliances, the implementation of energy-efficient building codes, and the transition toward advanced lighting and electrical appliances, which significantly reduce the energy intensity per household.

Among the provinces, Madhesh has the highest energy demand in year 2024 but due to its high negative rate throughout the period, it shows a notable decrease from approximately 64 PJ to about 24 PJ in 2050. This reduction, despite high urbanization, reflects the substantial impact of fuel switching and efficiency measures in densely populated urban centers. Similarly, Bagmati experiences a decline in energy requirements, falling from 60 PJ in 2024 to approximately 27 PJ by 2050, representing the highest demand and one of the most significant reductions in absolute terms due to the displacement of inefficient traditional fuels.

Koshi and Lumbini also exhibit clear downward trajectories in this pathway. Koshi sees its demand drop from approximately 48 PJ in 2024 to about 18 PJ in 2050, while Lumbini decreases from 46 PJ to roughly 21 PJ over the same horizon. In contrast, Gandaki and Karnali continue to represent the lowest energy demand profiles, but with accelerated reductions compared to the baseline. Gandaki shows a decrease from about 31 PJ in 2024 to approximately 10 PJ by 2050. Karnali, starting at 28 PJ, reaches the lowest provincial demand of roughly 8 PJ by the end of the study period.

Sudurpashchim follows a similar pattern of reduction, with energy demand falling from approximately 44 PJ in 2024 to about 13PJ in 2050. Overall, the total residential energy demand under the NZE scenario is projected to decrease from 320 PJ in 2024 to 121 PJ in 2050, illustrating an emission reduction pathway can achieve nearly a 62% reduction in total energy consumption through aggressive electrification for all end use.

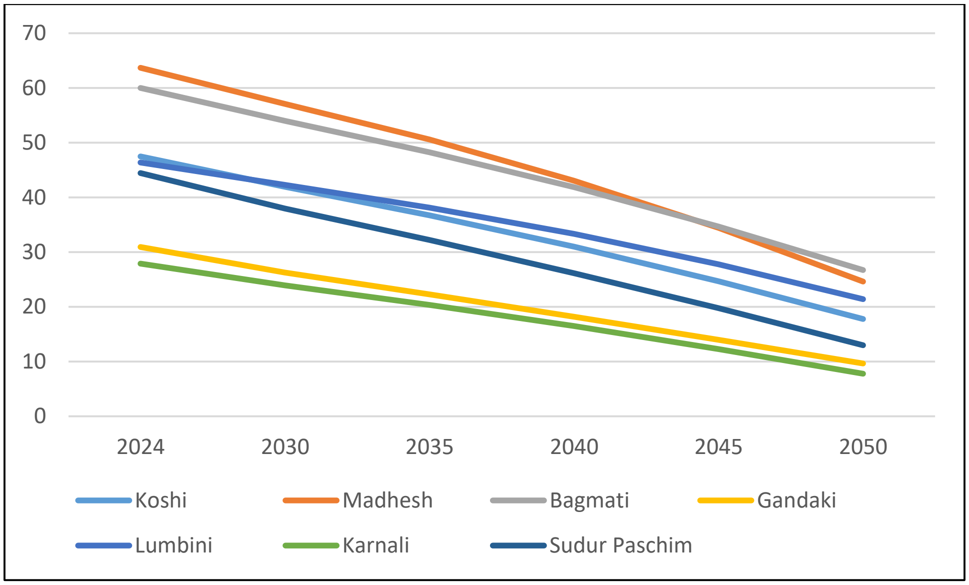

Figure 4.0.17: Final Energy Demand for All Electrification Scenario

4.3.2 Energy Mix

The projected fuel Share transition for the residential sector under the all electrification scenario from 2024 to 2050 is presented in Figure. The results indicate a transformative shift in the energy consumption pattern, characterized by a rapid transition from traditional biomass and fossil fuels toward Electricity. This evolution is a direct result of aggressive policy interventions aimed at decarbonizing the residential sector through large-scale electrification and the promotion of modern renewable technologies.

Among the various fuel types, Electricity overtakes all other fuel sources the study period. Demand for electricity increases from approximately 16 PJ in 2024 to 121 PJ by 2050 full filling all the end uses. This surge reflects the successful implementation of "electricity-first" policies, where electric induction stoves, high-efficiency lighting, and modern appliances become the primary drivers of household energy services. In stark contrast, Wood (firewood), which is the dominant fuel in 2024 at 261 PJ, undergoes a dramatic decline to zero by 2050. This sharp reduction highlights the massive displacement of traditional cooking methods by cleaner alternatives, significantly reducing the pressure on forest resources and improving indoor air quality.

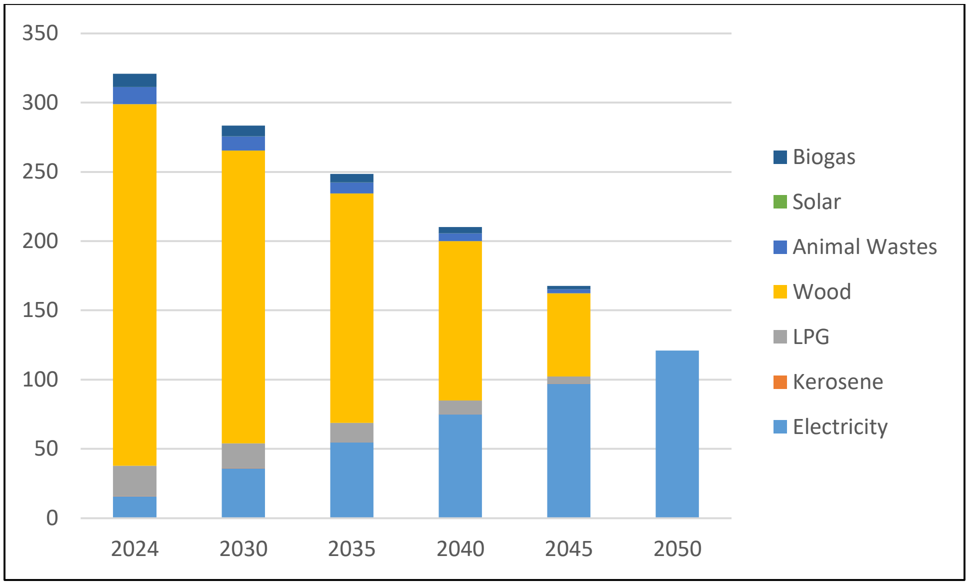

Figure 4.0.18: Fuel Share in residential sector over Period

In this Figure 4.13 the provincial Fuel projection is represented the residential final energy demand of all seven Provinces. It is clear that, Madhesh has the maximum energy consumption in 2024 and it decreases over a period of year and in year 2050 Bagmati Province has maximum Energy Demand. It also shows how the share of electricity increases over a period of year and in 2050 electricity is only fuel source responsible for all the end uses.

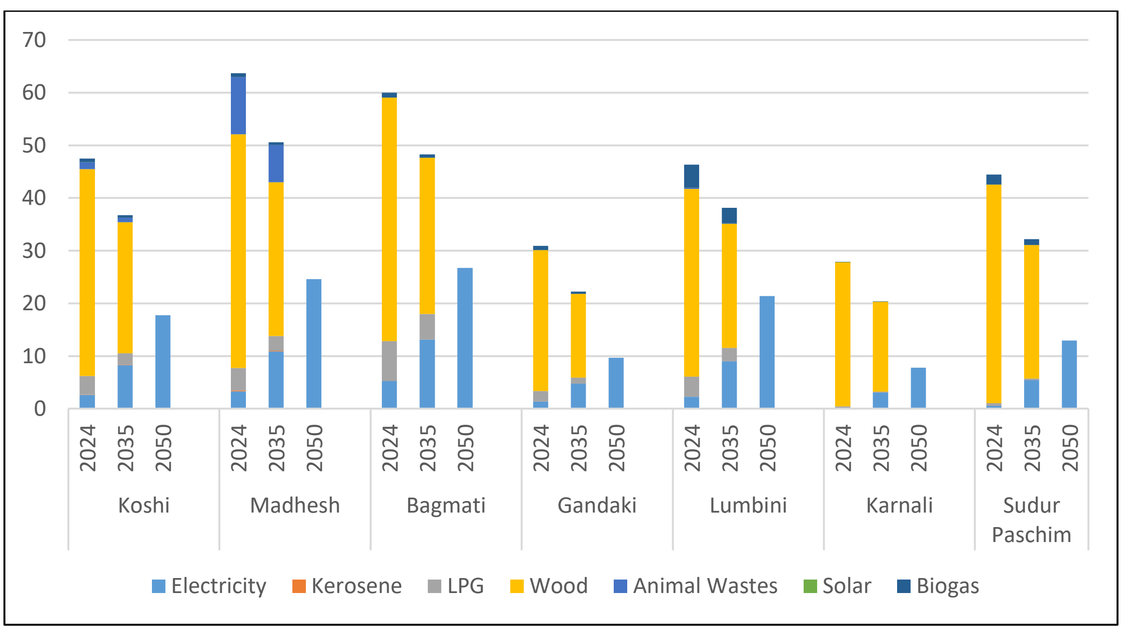

Figure 4.0.19 Provincial fuel share over period of year

4.3.2 Greenhouse Gas Emission

Figure 1.14 represents the decrease in GHG emission over a period and finally it gets eliminated in 2050. By all electrification the net GHG emission gets eliminated by 2050 and for this there should be high interventions. The maximum GHG emission was seen from Bagmati followed by Madhesh in 2024 this shows the maximum intervention is needed in Bagmati to eliminate the GHG Emission but to electrify more focus should be done on Sudurpashchim and Karnali. Upto 2045 the total GHG emission reduces by 6.70% annually and it is found that Gandaki has highest rate of reduction and Lumbini has lowest rate of reduction.

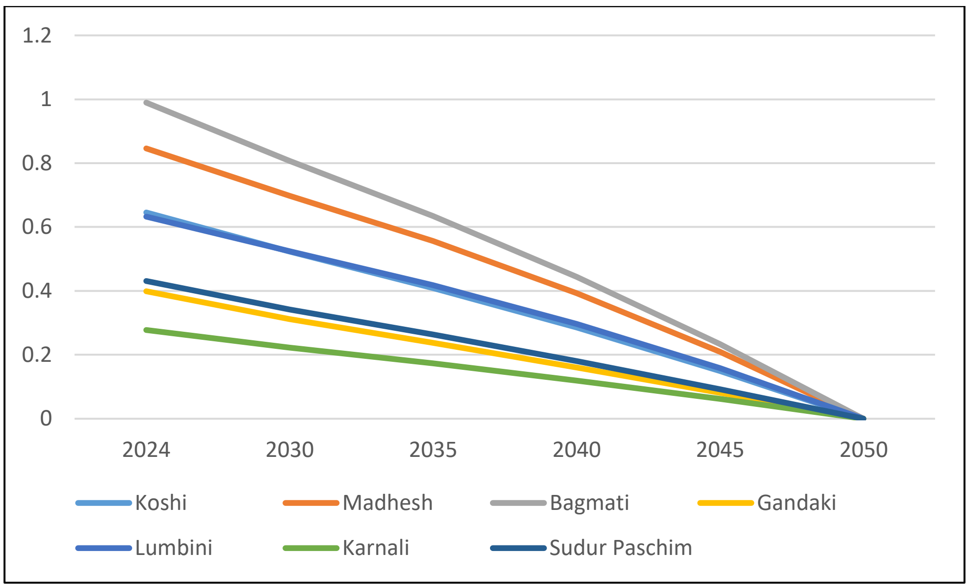

Figure 4.0.20: GHG Emission for All Electrification

4.3.4 Energy Balance

This Sankey diagram shows the Energy mix of total energy consumption in residential sector of Nepal. The total demand of energy which is around 121 PJ is supplied form Electricity over a period, in 2024 Bagmati has the maximum share of electricity consumption which remains similar over a period of year. The thickness shows the value of energy consumption.

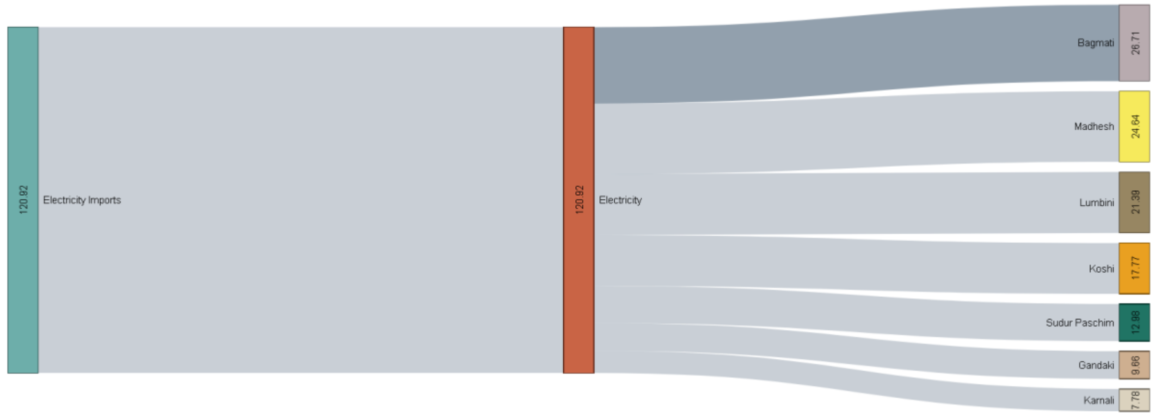

Figure 4.0.21: Sankey Diagram for All Electrification

4.3.5 Energy Indicators in All Electrification Scenario

Table 6 presents the projected residential energy indicators under All Electrification scenario from 2024 to 2050. The results show a gradual decline in final energy demand per capita from 10.72 GJ/capita in 2024 to 3.02 GJ/capita by 2050, indicating improvements in energy efficiency and the adoption of more efficient technologies. At the same time, electricity consumption increases significantly, with final electricity demand rising from 145 kWh per capita in 2024 to 840 kWh per capita in 2050. Similarly, total household electricity consumption grows from 635 kWh per household to 3690 kWh by 2050, reflecting increased electrification of household energy services such as cooking, lighting, and appliance use.

The transition toward electricity results in substantial reductions in greenhouse gas emissions. GHG emissions gets eliminated in 2050 from 141 kg per capita in. This elimination is mainly due to the gradual replacement of traditional biomass fuels and fossil fuels with cleaner and more efficient energy technologies. Overall, the indicators demonstrate that the All Electrification scenario promotes improved energy efficiency, increased electrification, and complete emission elimination in the residential sector due to the transition from dirty energy source to cleaner fuel source.

Table 7: Energy Indicators in Residential Sector for All Electrification

		2024	2030	2035	2040	2045	2050
Final enrgy Demand/ Capita	GJ/capita	10.72	8.92	7.43	5.95	4.48	3.02
Final Electricity Demand	KWh/Capita	145.17	306.56	440.49	573.92	706.87	839.35
Total Electrcity Used/HH	KWh/HH	635.21	1342.81	1931.08	2518.14	3104.1	3689.01
GHG Emission	GHG in Kg/Capita	141.03	108.34	81.15	54.05	26.99	0.00

The final energy demand per capita under the All Electrification scenario shows a sharp and consistent decline across all provinces, reflecting significant improvements in energy efficiency and complete reliance on electricity. At the national level, energy demand decreases from 10.72 GJ per capita in 2024 to 3.17 GJ by 2050, representing a substantial reduction. Provinces with initially high energy demand, such as Karnali and Sudurpashchim, experience the most pronounced declines, dropping from 16.43 GJ to 3.82 GJ and from 16.26 GJ to 4.15 GJ, respectively. Similarly, Madhesh and Koshi show strong reductions, reaching 2.86 GJ and 2.79 GJ by 2050. Bagmati and Gandaki, although relatively higher in the early years, also decline significantly to 3.30 GJ and 3.64 GJ, respectively. Overall, the steep reduction across all provinces highlights the effectiveness of full electrification and advanced technologies in minimizing final energy demand while maintaining energy services.

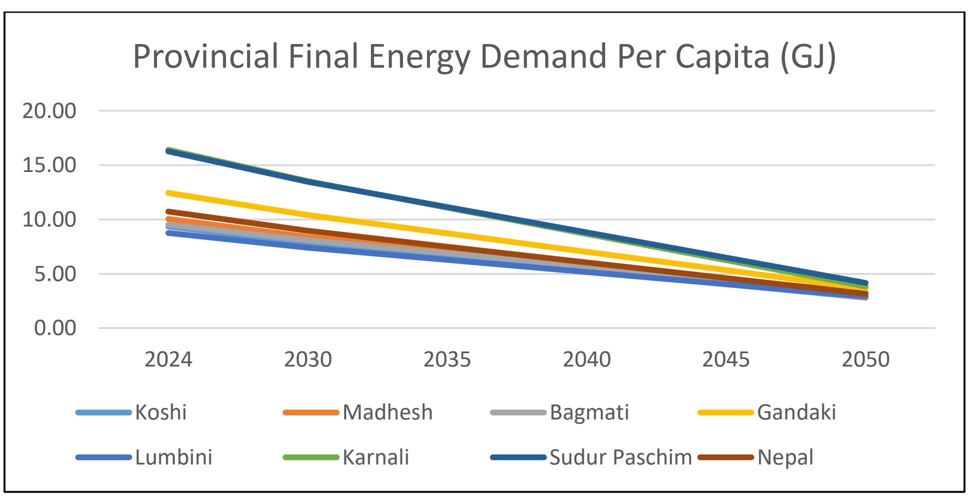

Figure 4.0.22: Provincial Final Energy Demand Per Capita

The total electricity demand per capita under the All Electrification scenario shows a rapid and substantial increase across all provinces, reflecting the complete shift toward electricity as the primary energy source. At the national level, electricity consumption rises significantly from 145.17 kWh per capita in 2024 to 879.67 kWh by 2050. Provinces such as Karnali and Sudurpashchim exhibit the highest growth rates, increasing dramatically from 31.94 kWh and 57.26 kWh to 1062.21 kWh and 1152.83 kWh, respectively, indicating a major expansion in electricity access and usage. Similarly, Gandaki and Madhesh show strong growth, reaching 1011.82 kWh and 794.18 kWh by 2050, while Bagmati maintains the highest absolute consumption throughout the period, increasing from 232.78 kWh to 916.88 kWh. Koshi and Lumbini also experience steady increases, though at relatively moderate levels compared to other provinces. Overall, the sharp rise in electricity demand across all provinces highlights the critical role of full electrification in transforming the residential energy system and enabling deep decarbonization.

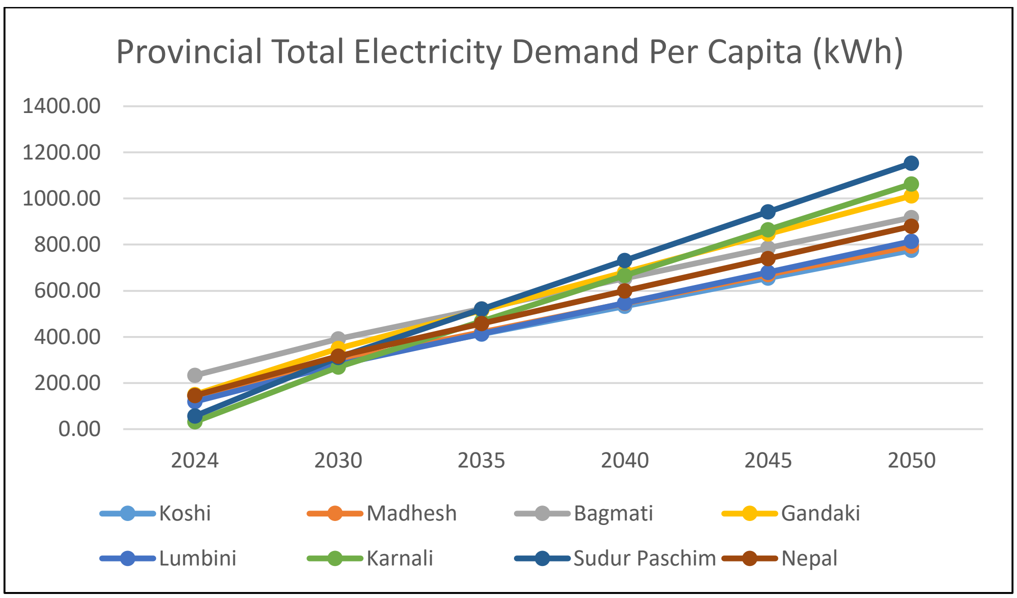

Figure 4.0.23: Provincial Total Electricity Demand per Capita

The per capita greenhouse gas (GHG) emissions under the All Electrification scenario show a rapid and complete decline across all provinces, ultimately reaching zero by 2050. At the national level, emissions decrease significantly from 141.03 kg per capita in 2024 to 0 kg by 2050, reflecting full decarbonization of the residential sector. Provinces such as Bagmati, Gandaki, and Karnali, which initially exhibit higher emission levels (above 150 kg per capita), experience sharp reductions over time, falling below 30 kg by 2045 before reaching zero. Similarly, Madhesh, Koshi, and Lumbini show steady declines, with emissions reducing to minimal levels by the mid-2040s. Even provinces with slower transitions, such as Sudurpashchim, follow the same downward trajectory and achieve complete elimination of emissions by 2050. This trend clearly demonstrates that full electrification, combined with the elimination of fossil fuels and traditional biomass, can entirely decarbonize the residential energy system across all provinces.

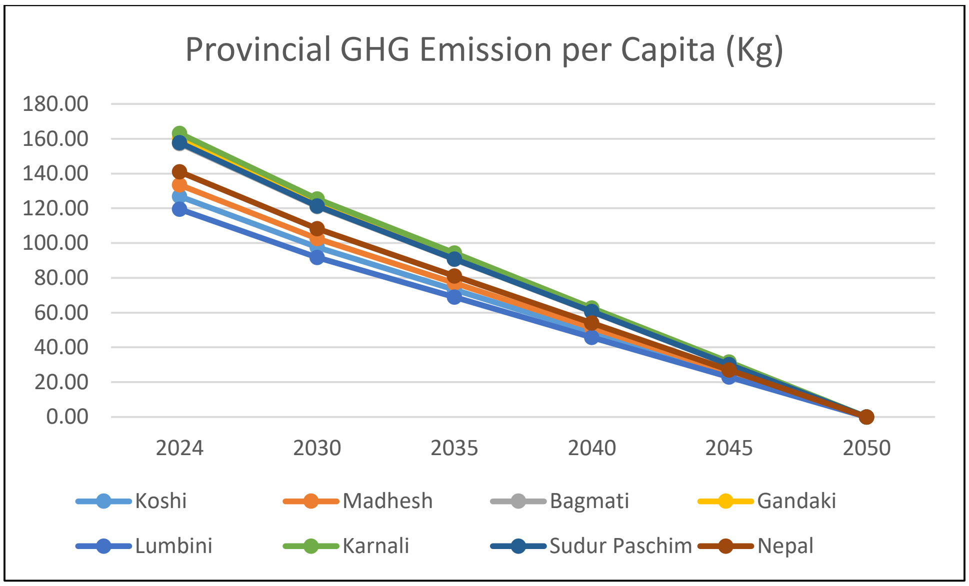

Figure 4.0.24: Provincial GHG Emission per Capita

4.4 Third Nationally Determined Contribution (NDC 3.0) Scenario

The NDC 3.0 scenario represents a more ambitious transition aligned with Nepal's updated climate commitments. This scenario assumes accelerated adoption of clean and modern energy technologies, increased electrification of household energy services, and significant improvements in energy efficiency. Traditional fuels such as firewood and animal waste are progressively replaced by cleaner energy sources including electricity and biogas, supported by stronger policy interventions and implementation measures. As a result, the residential energy system shifts more rapidly toward a low-carbon pathway, leading to substantial reductions in greenhouse gas emissions while supporting sustainable development goals. The urbanization trend in this scenario is assumed to follow the same trajectory as in the net-zero emission scenario, ensuring consistency in demographic and structural changes.

Table 8: Key Assumptions for NDC 3.0 Scenario

End Use Activity	By 2035
Cooking	40% Firewood (efficiency 35%), 25% LPG, 25% Electricity, 10% Biogas
Lighting	90% Electricity, 10% RE
Heating and Cooling	100% Electricity
Electric Appliance	100% Electricity with higher efficiency
Other	40% Firewood (efficiency 35%), 25% LPG, 25% Electricity, 10% Biogas

4.4.1 Final Energy Demand

The projected final energy demand for the residential sector under the NDC 3.0 scenario across the seven provinces of Nepal is presented in figure 4.16. Unlike the BAU scenario, the results for the NDC 3.0 scenario demonstrate a significant and consistent decline in total energy demand across all provinces from 2024 to 2035 and then continues the same trend up to 2050. This downward trend is primarily driven by the aggressive adoption of high-efficiency electric cooking appliances, the implementation of energy-efficient building codes, and the transition toward advanced lighting and electrical appliances, which significantly reduce the energy intensity per household.

Among the provinces, Madhesh has the highest energy demand in year 2024 but due to its high negative rate throughout the period, it shows a notable decrease from approximately 64 PJ to about 42 PJ in 2050. Similarly, Bagmati experiences a decline in energy requirements, falling from 60 PJ in 2024 to approximately 43 PJ by 2050, representing significant reductions in absolute terms due to the displacement of inefficient traditional fuels.

Koshi and Lumbini also exhibit clear downward trajectories in this scenario. Koshi sees its demand drop from approximately 48 PJ in 2024 to about 30 PJ in 2050, while Lumbini decreases from 46 PJ to roughly 37 PJ over the same horizon. In contrast, Gandaki and

Karnali continue to represent the lowest energy demand profiles, but with accelerated reductions compared to the baseline. Gandaki shows a decrease from about 31 PJ in 2024 to approximately 17 PJ by 2050. Karnali, starting at 28 PJ, reaches the lowest provincial demand of roughly 14 PJ by the end of the study period. These figures suggest that in less populous provinces, the transition to modern energy services can lead to very low per-capita energy footprints.

Sudurpashchim follows a similar pattern of reduction, with energy demand falling from approximately 44 PJ in 2024 to about 23 PJ in 2050. Overall, the total residential energy demand under the NDC scenario is projected to decrease from 320 PJ in 2024 to 179 PJ in 2035 and following the constant share thereafter it reaches 205 PJ in 2050, illustrating that a it can achieve nearly a 36% reduction in total energy consumption through aggressive efficiency and electrification similar to the scenarios developed in previous studies.

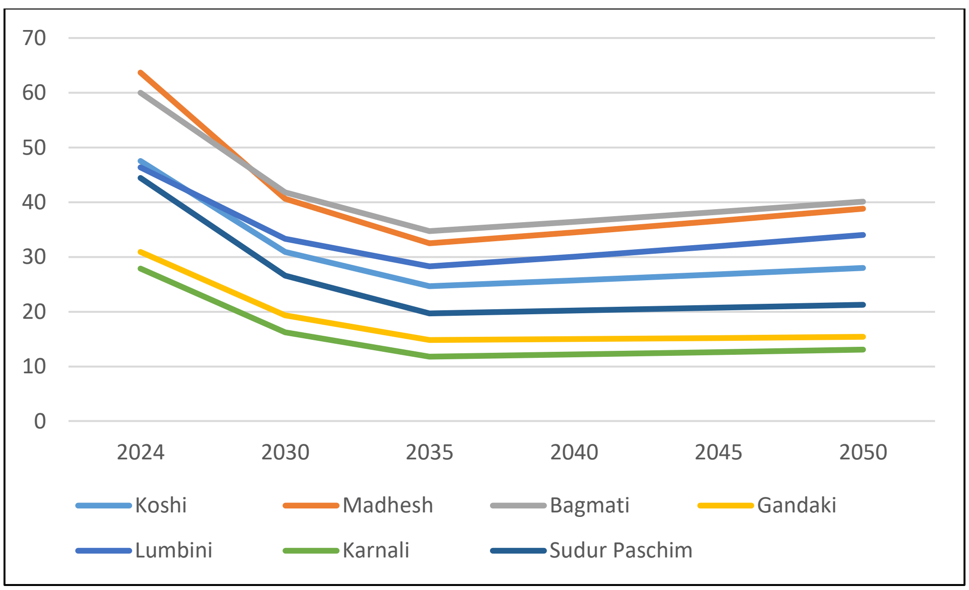

Figure 4.0.25: Projected Provincial Final energy demand for NDC 3.0 Scenario

4.3.2 Energy Mix

The projected fuel mix for the residential sector under the NDC 3.0 scenario from 2024 to 2050 is presented in Figure. Since the NDC targets are made for 2035 only the study continues the trend constant after that. The results indicate a transformative shift in the energy consumption pattern, characterized by a rapid transition from traditional biomass and fossil fuels toward clean, renewable energy sources.

Among the various fuel types, Electricity shows the most significant growth, more than three times its share over the study period. Demand for electricity increases from approximately 16 PJ in 2024 to 40 PJ by 2035 and following the same trend it reaches 46 PJ by 2050. In stark contrast, Wood (firewood), which is the dominant fuel in 2024 at 261 PJ, undergoes a dramatic decline to just 90 PJ by 2035 by intervening with improved cook stoves and efficient technologies. This sharp reduction highlights the massive displacement of traditional cooking methods by cleaner and better alternatives.

Animal Wastes and Kerosene also demonstrate a downward trend under the NDC pathway and are eliminated by year 2035. LPG consumption increases gradually from 22 PJ to 35 PJ by 2035 and reaches 41 PJ in 2050, suggesting that while it remains a transition fuel, it is increasingly because of urbanization and still has a significant share. Modern renewable sources like Biogas and Solar exhibit steady growth, albeit from a smaller baseline. Biogas demand rises from 9 PJ to 13 PJ, while solar energy demand increases from 0.1 PJ to approximately 0.2 PJ by 2035. These increases represent the diversification of the renewable energy portfolio, particularly in rural and off-grid areas where decentralized energy solutions complement the national grid.

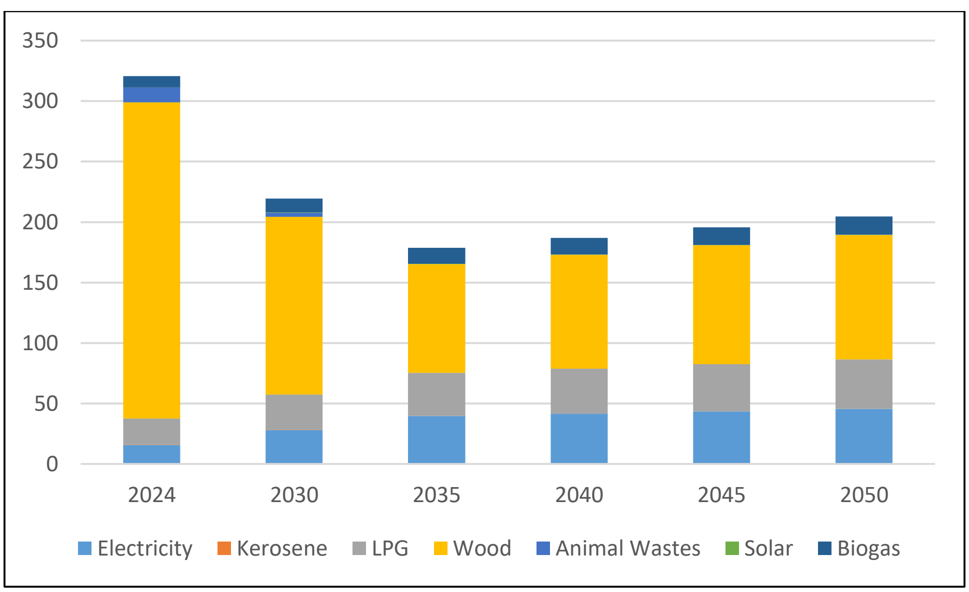

Figure 4.0.26: Fuel share in residential sector

Since the NDC 3.0 targets are sets up to 2035, the energy consumption scenario of all seven provinces are demonstrated in figure 4.18. In 2035, Bagmati demands the highest energy consumption of around 37 PJ followed by Madhesh whose total energy demand will be 35 PJ. Each Province Energy share are balanced my 40% Firewood with most efficient cookstoves and 25% shares of LPG and Electricity each. Karnali has the lowest energy demand of 13 PJ only. In 2035, still the Share of Wood is maximum around 50% followed by Electricity 22%, LPG 20% and Renewable Energy 8%.

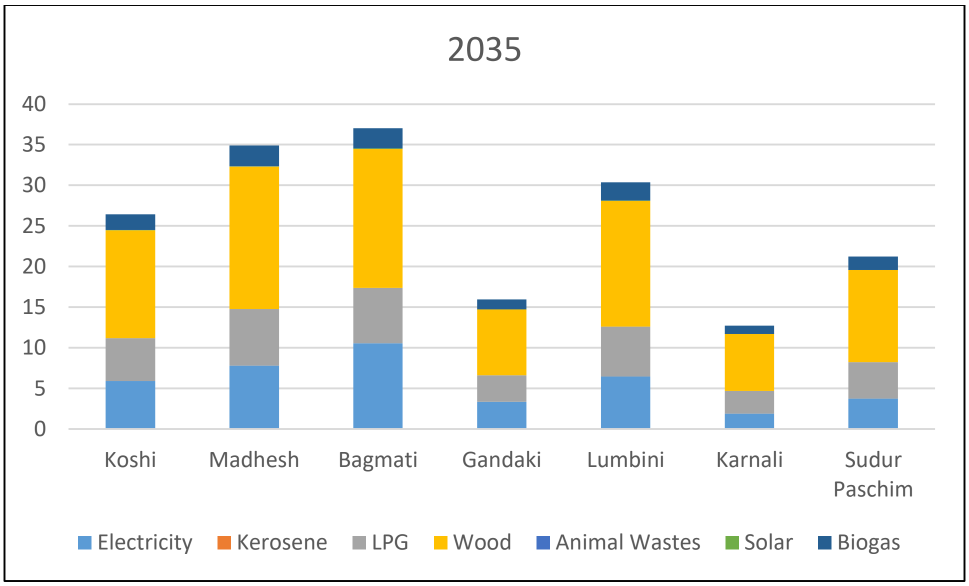

Figure 4.0.27 Provincial Energy mix in residential sector

4.3.3 Greenhouse Gas Emission

The projected greenhouse gas (GHG) emissions for the residential sector under the NDC 3.0 scenario across the seven provinces of Nepal are presented in Figure 4.19. The results indicate a significant and steady decline in total CO_2 equivalent emissions over the study period, falling from 4.2 million Metric Tons (mMT) in 2024 to 3.5 mMT in 2035, and again increases to 4.0 by 2050. This initial decreases shows the adaption of cleaner and efficient technologies and later increase in the GHG emission is due to the population growth and following a constant trend.

Among the provinces, Bagmati begins with the highest emission levels at 1.0 mMT in 2024 but achieves the most substantial absolute reduction, reaching 0.66 mMT in 2035. This downward trend reflects the successful decarbonization of urban household energy use, particularly through the transition to electric cooking in high-density areas. Similarly, Koshi, Madhesh and Lumbini all demonstrate consistent decreases in their carbon footprints. Madhesh for instance, reduces its emissions from 0.85 mMT to 0.67 mMT, while Koshi declines from 0.65 mMT to 0.51 mMT by the end of the 2035 and again increases from 2035 to 2050.

There is very slight decrease in GHG emission in Karnali and Sudurpashchim province by 2035 and after that a rise in emission makes it higher than from the base year. Karnali GHG emission reaches 0.25 mMT in 2030 from 0.28 mMT and then reaches 0.3 mMT by 2050, and Sudurpashchim decreases from 0.43 mT to 0.4 mMT in 2030 and then rises to 0.47 mMT in 2050. This growth in emissions, despite the overall national decline, can be attributed to the expansion of energy access and the initial transition from traditional biomass to transition fuels (such as LPG) in previously underserved rural regions before full electrification is realized.

Finally, Gandaki maintains a relatively low and stable emission profile from 2035 to 2050, initially decreasing from 0.4mMT in 2024 to 0.31 mMT in 2035 to 0.33mMT by 2050. Overall, the national total reduction is more than 17% GHG emissions by 2035 under the NDC 3.0 scenario underscores the residential sector's vital role in meeting Nepal's international climate commitments. The convergence of declining emissions in major urban provinces and the stabilization of energy related carbon output in developing regions highlights a balanced path toward a carbon-neutral residential sector.

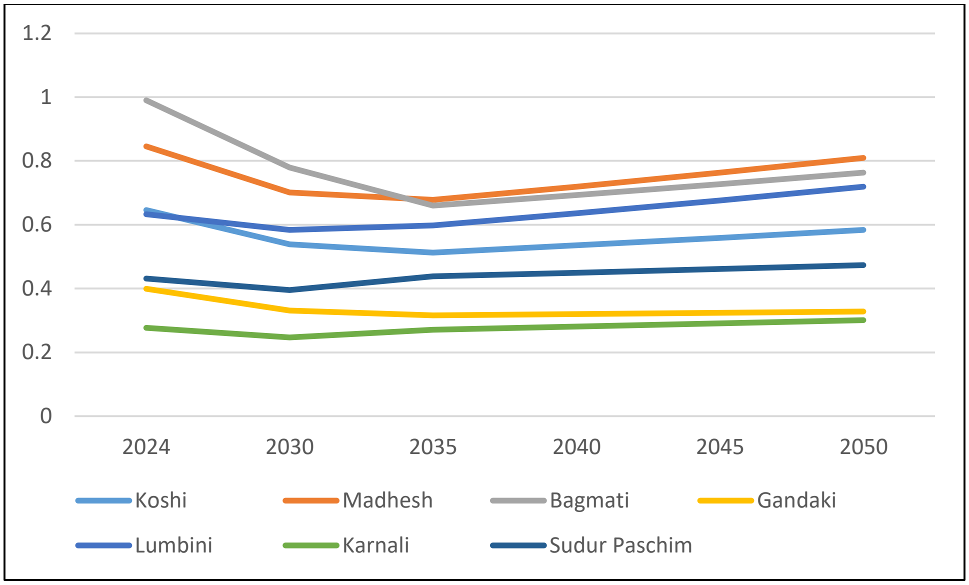

Figure 4.0.28: GHG Emission in residential sector

4.3.4 Energy Balance

Figure 4.20 present the Sankey diagrams illustrating the flow of energy in the residential sector across the seven provinces of Nepal for the projected year 2035 under NDC 3.0 scenario.

In the base year 2024, the residential energy system is dominated by biomass resources. Biomass production accounts for approximately 261 PJ of energy supply, which represents the largest share of the residential energy mix. Oil product imports also contribute around 35 PJ, mainly representing fuels such as LPG and kerosene used in household activities. Electricity supply in the residential sector is relatively limited in comparison to biomass-based energy sources. It also illustrates the distribution of energy consumption across the seven provinces. Provinces with higher population and urbanization levels, such as Bagmati and Madhesh, show relatively larger energy flows compared to other provinces. In contrast, provinces with smaller populations and more rural characteristics, such as Karnali and Sudurpashchim, exhibit lower levels of residential energy consumption.

The Sankey diagram for the year 2035 under the NDC 3.0 scenario demonstrates a significant transformation in the residential energy system. One of the most notable changes is the substantial increase in electricity supply, which rises to approximately 40

PJ. This reflects the growing electrification of household energy services, including cooking, lighting, and appliance use. Biomass supply decreases to approximately to 90 PJ in 2035, indicating a gradual transition away from traditional biomass fuels such as firewood and animal waste. Oil product remains almost constant to around 35 PJ, reflecting reduced dependence on fossil fuels such as LPG.

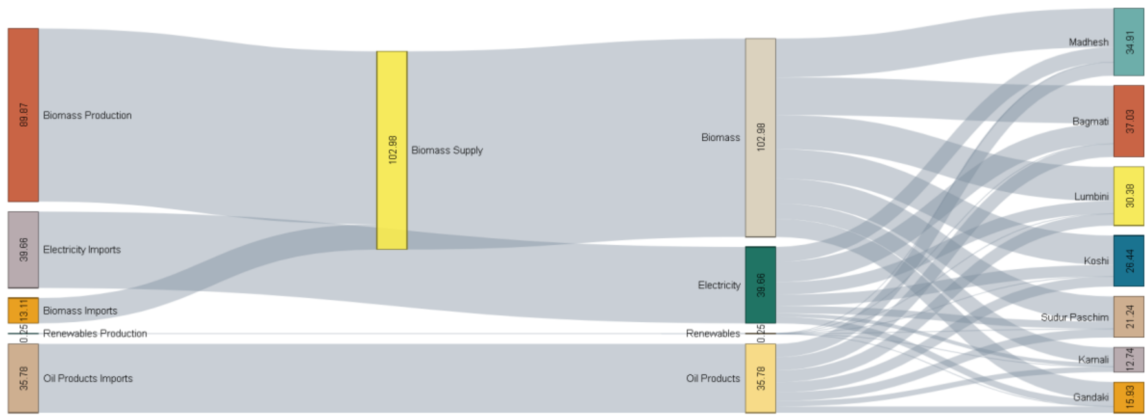

Figure 4.0.29: Sankey Diagram

4.3.5 Energy Indicators

Table 8 presents the projected residential energy indicators under the NDC 3.0 scenario from 2024 to 2050. Since the NDC targets are made for year 2035, there is gradual change from 2024 to 2035 and then it continues to 205. The results show a gradual decline in final energy demand per capita from 10.72GJ/capita in 2024 to 5.4 GJ/capita by 2035, indicating improvements in energy efficiency and the adoption of more efficient technologies. At the same time, electricity consumption increases significantly, with final electricity demand rising from 145 kWh per capita in 2024 to 332 kWh per capita in 2035. Similarly, total household electricity consumption grows from 635 kWh per household to 1457 kWh by 2035, reflecting increased electrification of household energy services such as cooking, lighting, and appliance use.

The transition toward electricity and cleaner energy sources also results in substantial reductions in greenhouse gas emissions. GHG emissions decrease from 141 kg per capita in 2024 to 105 kg per capita by 2035. This decline is mainly due to the gradual replacement of traditional biomass fuels and fossil fuels with cleaner and more efficient energy technologies. Overall, the indicators demonstrate that the NDC 3.0 promotes improved energy efficiency, increased electrification, and significant emission reductions in the residential sector.

Table 9: Energy Indicators for Residential Sector

		2024	2030	2035	2040	2045	2050
Final enrgy Demand/ Capita	GJ/capita	10.72	6.93	5.39	5.38	5.37	5.36
Final Electricity Demand	KWh/Capita	145.17	247.45	332.27	332.04	331.81	331.57
Total Electrcity Used/HH	KWh/HH	635.21	1083.91	1456.66	1456.86	1457.08	1457.30
GHG Emission	GHG in Kg/Capita	141.03	112.99	104.77	104.58	104.36	104.18

The final energy demand per capita under the NDC 3.0 scenario shows a significant reduction in the early years, followed by a stabilization trend across all provinces. At the national level, energy demand decreases from 10.72 GJ per capita in 2024 to about 5.36 GJ by 2035, reflecting the impact of policy-driven efficiency improvements and partial electrification. Provinces such as Karnali and Sudurpashchim, which initially have the highest energy demand, experience substantial reductions, declining from 16.43 GJ to 6.95 GJ and from 16.26 GJ to 7.34 GJ, respectively. Similarly, Madhesh and Koshi reduce to 4.84 GJ and 4.73 GJ by 2035, after which their values remain relatively constant. Bagmati and Gandaki maintain comparatively higher energy demand levels, stabilizing at 5.29 GJ and 6.24 GJ, respectively. Overall, the trend indicates that while the NDC 3.0 scenario achieves notable reductions in per capita energy demand, the progress slows after 2035, suggesting the need for more aggressive measures to achieve deeper long-term reductions.

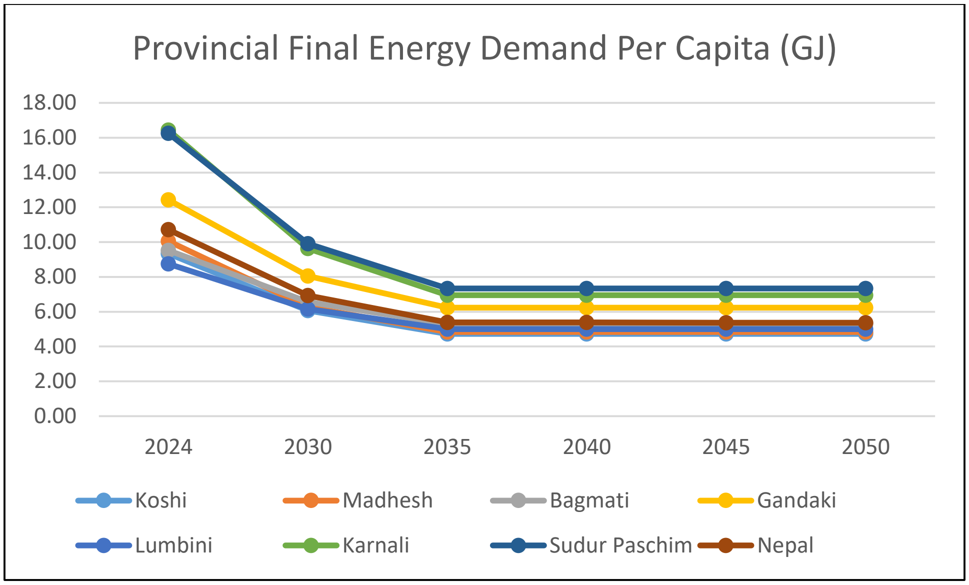

Figure 4.0.30: Provincial Final Energy Demand per Capita

The total electricity demand per capita under the NDC 3.0 scenario shows a steady increase up to 2035, followed by a stabilization trend across all provinces. At the national level, electricity consumption rises from 145.17 kWh per capita in 2024 to about 332 kWh by 2035, after which it remains nearly constant through 2050. Provinces such as Bagmati and Gandaki maintain the highest electricity demand levels, reaching 419.33 kWh and 363.80 kWh respectively, reflecting higher urbanization and access to modern energy services. Similarly, Madhesh and Koshi show moderate growth, stabilizing at around 299.62 kWh and 293.52 kWh. Notably, provinces with initially low electricity access, such as Karnali and Sudurpashchim, experience significant increases from 31.94 kWh to 284.67 kWh and from 57.26 kWh to 357.90 kWh respectively before leveling off. Overall, the trend indicates that the NDC 3.0 scenario promotes substantial electrification in the early years, but after 2035 suggests limited additional expansion without further policy interventions the advancement in the technology becomes constant.

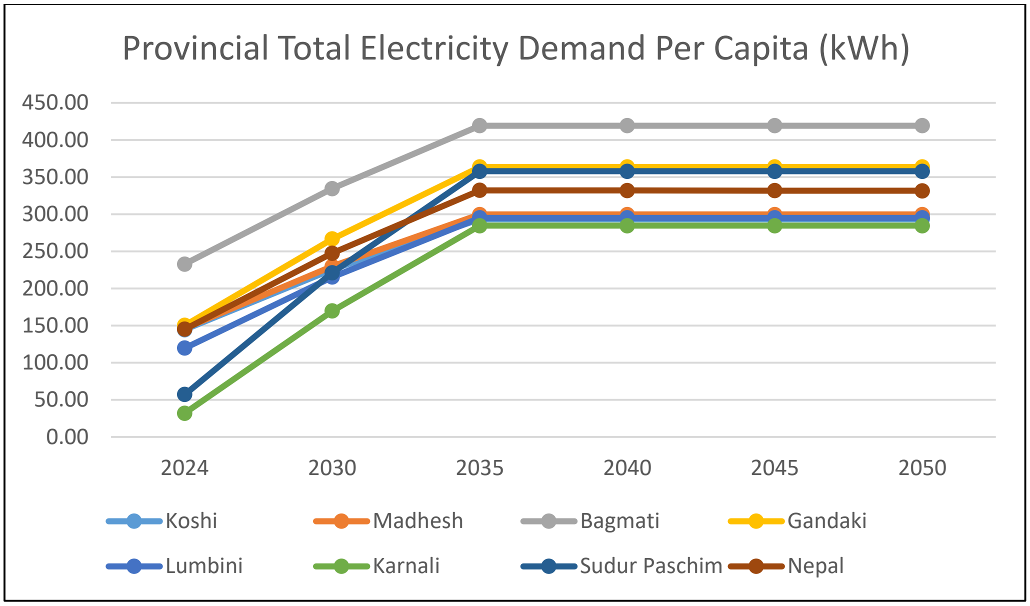

Figure 4.0.31: Provincial total electricity Demand per Capita

The per capita greenhouse gas (GHG) emissions under the NDC 3.0 scenario show an initial decline followed by a stabilization trend across most provinces. At the national level, emissions decrease from 141.03 kg per capita in 2024 to 104.18 kg by 2035, indicating a moderate reduction driven by policy interventions. Provinces such as Bagmati and Madhesh experience notable reductions, declining to around 94.28 kg and 93.88 kg respectively by 2035. Similarly, Koshi and Lumbini show gradual decreases, stabilizing at approximately 91.82 kg and 98.50 kg. However, provinces like Gandaki, Karnali, and Sudurpashchim maintain relatively higher emission levels, with Karnali and Sudurpashchim exceeding 147 kg and 151 kg per capita respectively in 2050, reflecting continued reliance on less efficient energy sources. Overall, the trend suggests that while the NDC 3.0 scenario achieves meaningful emission reductions in the early years, the plateau observed after 2035 highlights the need for more aggressive measures to achieve deeper and sustained decarbonization across all provinces.

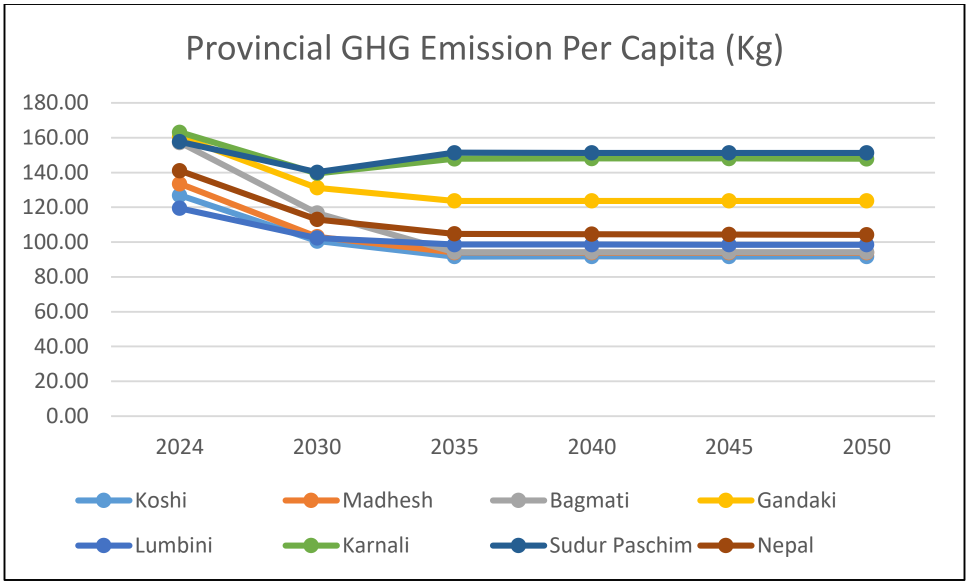

Figure 4.0.32: Provincial GHG Emission per Capita

4.5 Scenario Comparison

A comparison between different scenarios has been discussed in this section highlighting the significant impact that energy transition policies can have on the residential energy consumption. Under the BAU scenario, energy demand continues to grow while traditional fuels remain a major component of the energy mix. Consequently, greenhouse gas emissions from the residential sector continue to increase over time.

In contrast, the Net-Zero Emission (WEM) scenario demonstrates that the adoption of clean energy technologies and improved energy efficiency can substantially reduce emissions while still meeting the energy needs of households. Another Scenario which is all electrification highlights the complete elimination of GHG emission. The transition toward electricity and other low-carbon fuels reduces reliance on traditional biomass and fossil fuels, leading to a significant decline in greenhouse gas emissions. NDC 3.0 Scenario targets the government targets up to 2035 which mainly focuses on efficient technology intervention and use of electricity in residential sector. In NDC Scenario the intervention is made until 2035 and then it continues with the constant trend.

The comparison of these scenarios indicates that achieving a low-carbon residential energy system requires a combination of strategies including electrification, fuel switching, and improvements in energy efficiency. These measures not only contribute to climate change mitigation but also support sustainable energy development and improved energy access for households.

4.5.1 Final Energy Demand

The data reveals a stark contrast between different scenarios: Business As Usual (BAU), Net Zero Emission, All Electrification and NDC 3.0. While the BAU scenario projects a continuous rise in energy demand and reaches 404 PJ in 2050. On the other hand, due to the policy intervention the final energy demand decreases by 57 % and reaches 172 PJ for NZE scenario. Similarly for other two scenarios final energy demand will be 121 PJ and 205 PJ through all electrification and NDC 3.0 Scenarios. Policy intervention achieves a decoupling of household service needs from total energy consumption through aggressive efficiency gains and fuel switching. Through all electrification the demand is lowest around 70% below the BAU scenario because of the most efficient technology using electricity only. It can occur mainly due to the fuel switch and the use of more efficient technologies.

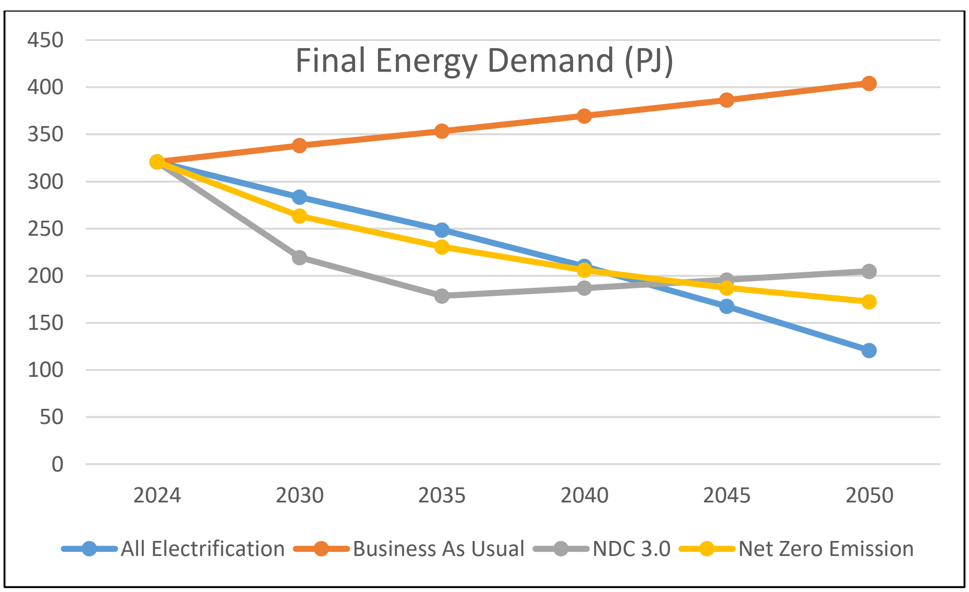

Figure 4.0.33: Final Energy Demand for different scenario in residential sector

4.5.2 Final Energy Demand Per Capita

The figure shows the final energy demand per capita for different scenarios: Business As Usual (BAU), Net Zero Emission, All Electrification and NDC 3.0. In this we can see as the trend remains constant for BAU the same value continues throughout the study period. Policy intervention through NDC 3.0 scenario decreases the final energy demand up to 2035 and after that it also continues constantly. The per capita final energy demand for BAU scenario is 10.72 PJ which is highest among all the scenarios. All electrification policy results in lowest final energy demand and reaches to 3.02 PJ per capita by 2050. Net Zero Emission scenario and NDC are other two scenario studied each having 4.29 PJ and 5.36 PJ respectively at the end of this study.

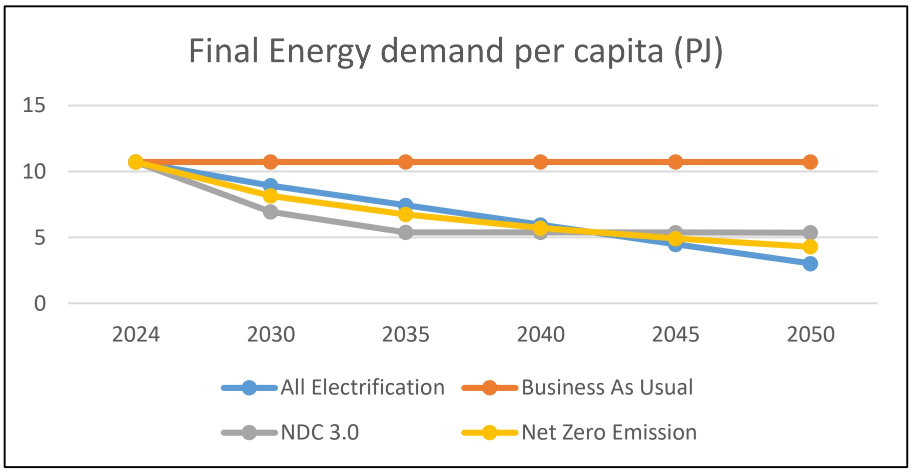

Figure 4.0.34: Final Energy Demand per capita in residential sector

4.5.3 Electricity Demand Per Capita

The electricity demand per capita under different scenarios is illustrated in the graph, highlighting the variation in consumption patterns over the study period. The results show that electricity demand per capita increases across all scenarios expect BAU, the rate of growth differs depending on the level of policy intervention and electrification. The Business-as-Usual scenario shows a flat line reflecting constant trends of 145 kWh per capita, while the Net Zero and NDC 3.0 scenarios demonstrate a more significant rise due to increased adoption of electric technologies and reaches 448 and 331 kWh per capita respectively. The All Electrification scenario exhibits the highest growth in per capita electricity demand reaching 840 kWh per capita by 2050 which is under the WECS Study for Bagmati which has the maximum electricity demand per capita around 4600 kWh for overall sector, indicating a strong shift toward electricity as the primary energy source in the residential sector.

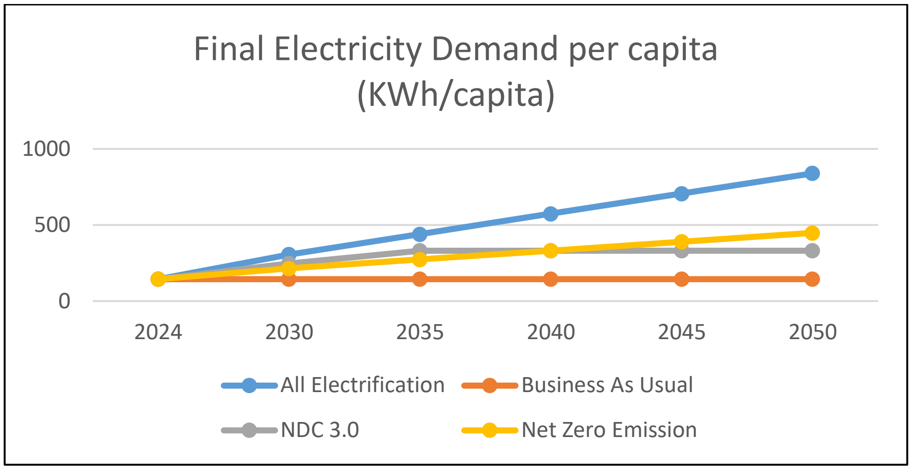

Figure 4.0.35: Electricity Demand Per Capita in residential sector

The electricity demand per household varies significantly across the different scenarios, reflecting the level of electrification and policy intervention. The Business-as-Usual scenario shows the lowest demand at 635.21 kWh per HH, indicating Constant trends. In contrast, the Net Zero scenario demonstrates a substantial increase to 1970.37 kWh/HH, driven by gradual electrification and improved energy efficiency. The NDC 3.0 scenario shows a moderate rise to 1457.3 kWh, reflecting the impact of additional policy measures promoting clean energy adoption. The All Electrification scenario exhibits the highest demand at 3689.01 kWh, highlighting a complete transition toward electricity as the primary energy source in the residential sector. These variations clearly indicate the strong influence of electrification strategies on household electricity consumption.

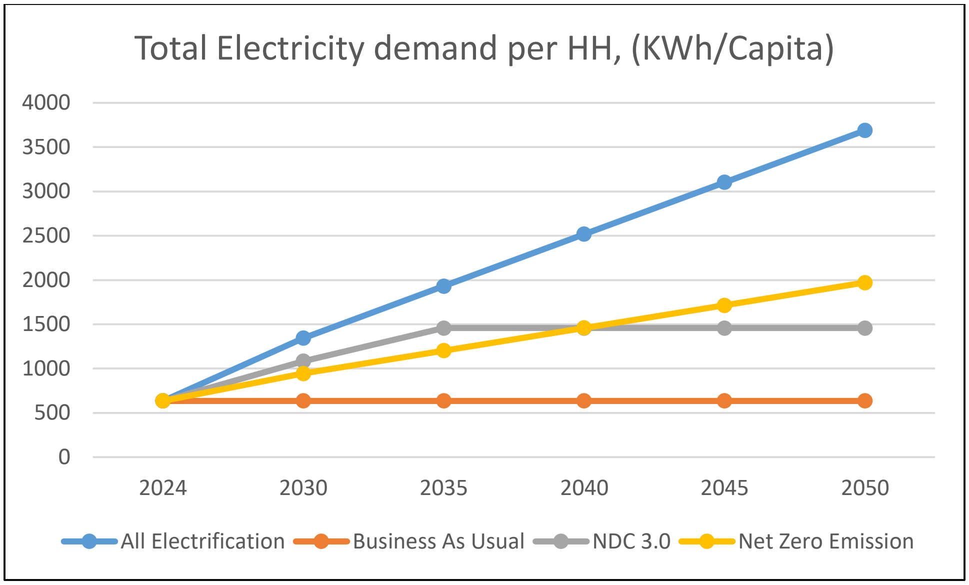

Figure 4.0.36: Total Electricity Demand per Household in Residential Sector

4.3.4 Greenhouse gas Emission

The comparison of the emission of greenhouse gas (GHG) under various scenarios is shown in the figure 4.25, where the values are in millions of metric tons. The scenario with the greatest amount of emissions is the Business-as-Usual (BAU) scenario, which is about 5.353 million metric tons, indicating the operation of the present energy consumption trends. The NDC 3.0 scenario shows significant drop up to 2035 and reaches 3.4 m MT and then moderate inrease to approximately 3.98 million metric tons, reflecting the effect of the extra policy actions. Further decrease is seen under the Net Zero Emission scenario where the emissions decrease to approximately 3.131 million metric tons under existing measures which represents the 15% reduction in 2030 and 42% reduction in 2050 from the refrence (BAU)scenario. Conversely, the All Electrification scenario attains full removal of emissions to zero, which emphasises the potential of full electrification in decarbonising the residential sector.

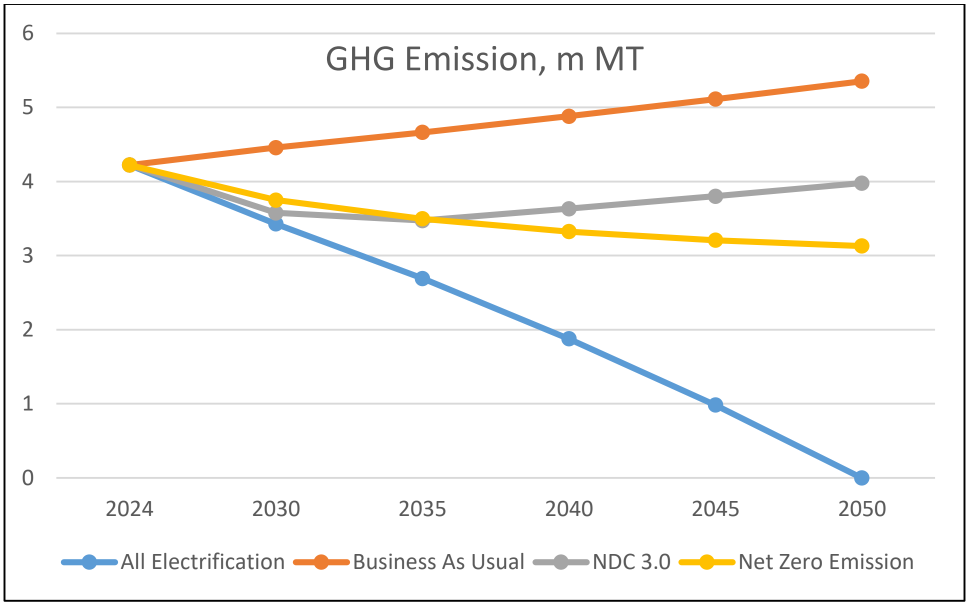

Figure 4.0.37: GHG Emission for different scenarios in Residential sector

A similar trend is observed in per capita emissions, where the BAU scenario records the highest value at 141.03 kg by 2050, followed by the NDC scenario at 104.18 kg in 2035 and it remains constant up to 2050 and the Net Zero scenario at 77.86 kg. The All Electrification scenario results in zero per capita emissions, further emphasizing its effectiveness in achieving complete decarbonization of the residential sector.

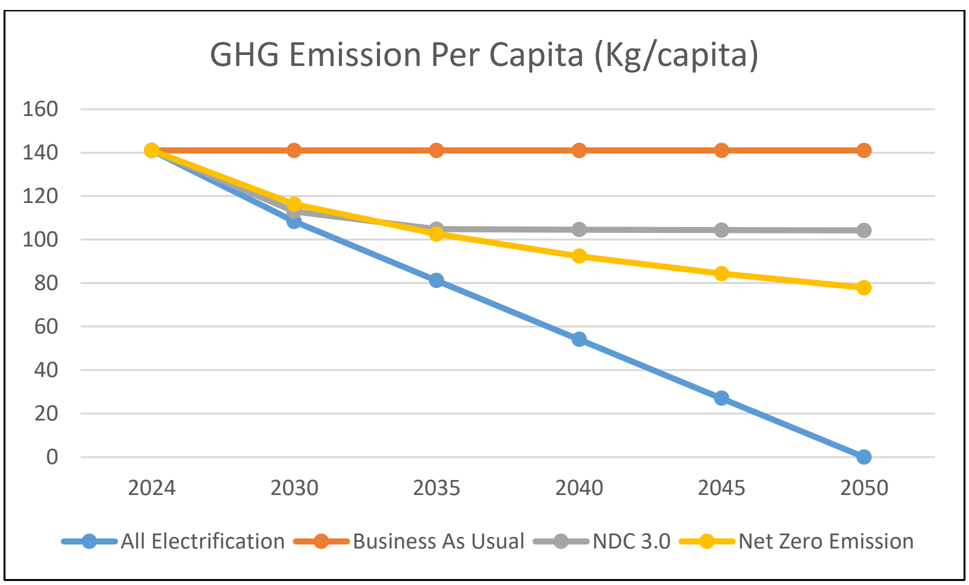

Figure 4.0.38: GHG Emission Per Capita in Residential sector

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study develops an integrated energy demand model for the residential sector of Nepal using the LEAP framework, incorporating provincial-level disaggregation to capture regional variations in energy consumption patterns. The analysis shows that the residential sector remains the largest energy-consuming sector and around 80% energy consumption is for cooking purpose, with a strong dependence on traditional biomass fuels.

The comparison of total final energy consumption across different scenarios shows a significant reduction relative to the Business-as-Usual (BAU) case. Under the BAU scenario, total energy demand reaches 404 PJ by 2050, serving as the reference baseline. In contrast, the NDC 3.0 scenario reduces total energy consumption to 205 PJ, representing a decrease of approximately 49% compared to BAU which is possible by intervention of 25% electricity, reducing firewood to 40%, 25 % LPG and around 10% of Renewable Energy. Further reduction is observed in the Net Zero Emission scenario, where energy demand declines to 172 PJ, corresponding to a reduction of about 57% as the energy mix looks like 70% Electricity and 30% LPG in urban and 25% Electricity and 50% Firewood with improved cook stove used for cooking. The most substantial decrease is achieved in the All Electrification scenario, with total energy consumption dropping to 121 PJ, which is nearly 70% lower than the BAU scenario as all the other fuels are switched to electricity. These results highlight the significant impact of electrification and energy efficiency improvements in reducing overall energy demand in the residential sector.

The results from the Business-as-Usual scenario indicate a continued reliance on traditional fuels, leading to a significant rise in greenhouse gas emissions, reaching approximately 5.35 million metric tons by 2050, with per capita emissions of about 141 kg. In comparison, the Net Zero Emission scenario demonstrates that emissions can be reduced to around 3.13 million metric tons (77 kg per capita) through increased electrification and efficiency improvements. The NDC 3.0 scenario further reduces emissions to approximately 3.98 million metric tons (104 kg per capita), reflecting the impact of additional policy measures. The All Electrification scenario presents the most ambitious pathway, achieving complete elimination of emissions, highlighting the transformative potential of full electrification in the residential sector.

The study also reveals clear provincial disparities in both energy consumption and emission reduction potential. Provinces such as Bagmati and Madhesh, which currently exhibit higher energy demand and emissions, require more focused mitigation efforts, while provinces like Karnali and Sudur pashchim need greater support in terms of electrification and access to modern energy technologies. These differences emphasize the need for region-specific strategies rather than a uniform national approach.

Overall, the findings demonstrate that a transition toward a cleaner and more sustainable residential energy system in Nepal is achievable, but it requires strong policy support, technological advancement, and targeted investments. The integrated modeling approach used in this study provides a robust framework for analyzing future energy demand and evaluating policy impacts. It offers valuable insights for policymakers to promote clean energy adoption, reduce emissions, and support Nepal's long-term goals of sustainable and low-carbon development.

5.2 Policy Recommendations

Based on the evidence provided by the study, the following policy interventions are recommended in different provinces:

i. Promote large-scale electrification of residential energy use, especially for cooking and heating in Bagmati and Madhesh due to their high energy demand and urbanization.
ii. Support adoption of clean cooking solutions such as electric stove and biogas systems in Koshi and Lumbini due to their moderate demand and transitioning region
iii. In Gandaki province, promotion of energy efficient technologies and fuel switching from biomass to clean fuel should be prioritize as it has relatively high emission
iv. Karnali and Sudurpashchim has low energy access and high potential growth, focus should be on improving energy access as high electricity in future

v. Integrating provincial-level planning into national energy strategies, supported by data-driven and scenario-based approaches, is essential for effective and long-term energy policy development.

5.3 Limitations of the Study

Although this study provides important insights into residential energy demand and emission trends in Nepal, several limitations should be acknowledged:

i. The study primarily relies on secondary data obtained from national reports, statistical publications, and previously published literature. The accuracy of the model therefore depends on the reliability and availability of these data sources.
ii. Some datasets used in the analysis may not fully reflect the most recent changes in household energy consumption patterns, particularly in rapidly developing urban areas.
iii. The study focuses only on the residential sector and does not incorporate interactions with other sectors such as industry, transportation, or commercial energy use. As a result, the analysis represents a sector-specific assessment rather than a complete national energy system analysis.
iv. Certain model parameters, such as technology efficiencies and emission factors, were derived from standard values and international literature. In practice, these values may vary depending on local conditions, user behavior, and technology performance.

Despite these limitations, the LEAP modeling framework provides a useful tool for understanding potential future energy pathways and evaluating the impacts of different energy transition strategies in the residential sector of Nepal.

REFERENCES

Adhikari, N. P., 2019. Integrating Renewable Energy and Energy Efficiency in mainstream energy to meet SDG Goals. s.l., Presentation at UNESCAP workshop on SDGs in Kathmandu in August 2019.

Bajracharya, Y., & Nakarmi, A.M. (2014). Current Energy Consumption in Bhaktapur District

Bhattarai, N. (2015). National energy demand projections and analysis of Nepal (Doctoral dissertation).

Bhusal, S., & Nakarmi, A. M. (2019). Sustainable Energy Planning for Nepal in the Federal Structure. Journal of Advanced College of Engineering and Management, 5, 127–145.

Brizard, N. (2015). Review of energy systems models. INOGATE Regional Seminar on Energy Planning.

CBS, 2022. Preliminary Results of National Population Census 2022, Kathmandu, Nepal: Center Bureau of Statistics, Government of Nepal.

Government of Nepal. (2021). Nepal's Long-term Strategy for Net-zero Emissions.

IEA (2022). World Energy Outlook 2022. International Energy Agency.

Jenish Maharjan, A. M. (2019-Summer), Sustainable Energy Planning at Municipal Level: A Case Study. IOE Graduate Conference.

Liu, Y., Yu, S., Zhu, Y., Wang, D., & Liu, J. (2018). Modeling, planning, application and management of energy systems for isolated areas: A review. Renewable and Sustainable Energy Reviews, 82, 460–470. https://doi.org/10.1016/j.rser.2017.09.063

Lopion, P., Markewitz, P., Robinius, M., & Stolten, D. (2018). A review of current challenges and trends in energy systems modeling. Renewable and Sustainable Energy Reviews, 96, 156–166. https://doi.org/10.1016/j.rser.2018.07.045

Maharjan, K., & Bhattarai, N. (n.d.). Residential Sector Energy Demand and Scenario Analysis: A case study on Province 1 of Nepal.

National population and housing census 2021. Volume 01: National report (Reprint). (2023). Government of Nepal, Office of the Prime Minister and Council of Ministers, National Statistics Office.

NEA. (2025). NEA Annual Report.

NPC, 2022. 16th Five Year Plan, Kathmandu, Nepal: National Planning Commission.
NPC, 2022.

Panthi, B., & Bhattarai, N. (2016). Residential Sector Energy Demand and Analysis of Resunga Municipality, Gulmi, Nepal.

Rajbhandari, U. S., & Nakarmi, A. M. (2014). Energy Consumption and Scenario Analysis of Residential Sector Using Optimization Model – A Case of Kathmandu Valley.

Subramanian, A. S. R., Gundersen, T., & Adams, T. A. (2018). Modeling and Simulation of Energy Systems: A Review. Processes, 6(12), 238. https://doi.org/10.3390/pr6120238

Sustainable Development Goals, Status and Roadmap: 2016-2030. Kathmandu, Nepal: National Planning Commission, Nepal Government.

WECS, 2024, Energy Sector Synopsis Report Nepal, Kathmandu: Secretariat, Water and Energy Commission, Ministry of Energy, Government of Nepal.

WECS, 2023, Energy Sector Synopsis Report Nepal, Kathmandu: Secretariat, Water and Energy Commission, Ministry of Energy, Government of Nepal.

WECS, 2022, Energy Sector Synopsis Report Nepal, Kathmandu: Secretariat, Water and Energy Commission, Ministry of Energy, Government of Nepal.

WECS, 2021a, Energy Consumption and Supply Situation in Federal System of Nepal - Province 1 (Koshi Pradesh).

WECS, 2021b Energy Consumption and Supply Situation in Federal System of Nepal - Province 2 (Madhesh Pradesh).

WECS, 2024, Energy Consumption and Supply Situation in Federal System of Nepal - Bagmati Province.

WECS, 2022, Energy Consumption and Supply Situation in Federal System of Nepal – Gandaki Province.

WECS, 2024, Energy Consumption and Supply Situation in Federal System of Nepal - Lumbini Province.

WECS, 2024, Energy Consumption and Supply Situation in Federal System of Nepal - Karnali Province.

WECS, 2024, Energy Consumption and Supply Situation in Federal System of Nepal – Sudurpashchim Province.

ANNEX-I

Table: Energy Consumption in Urban-Residential Sector of Province 1 (TJ)

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

(Survey 2019)

Table: Energy Consumption in Rural-Residential Sector of Province 1 (TJ)

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

(Survey 2019)

Table: Energy Consumption in Urban-Residential Sector of Province 2 (TJ)

	Cooking	Water boiling	Space heating	Space Cooling	Lighting	Electrical Appliances	Animal feed preparation	Agro and food processing	Social events	Total
Wood	12,866	0.4	0.7	-	-	-	571	-	67	13,506
Agricultural residue	3,023	0.0	-	-	-	-	240	1.4	-	3,264
Animal waste	4,230	0.0	-	-	-	-	722	-	-	4,952
Coal	-	-	-	-	-	-	-	-	-	-
kerosene	1.6	-	-	-	101	-	-	-	-	103
LPG	2,081	1.5	3.2	-	-	-	225	-	672	2,983
Electricity	68	0.6	81	918	314	163	-	0.0	0.1	1,544
biogas	-	-	-	-	-	-	-	-	0.2	0.2
briquettes	1.5	-	-	-	-	-	1.9	-	0.6	4.0
Solar thermal	-	-	-	-	-	-	-	-	-	-
Solar PV	-	-	-	-	0.9	-	-	-	-	0.9
	22,272	**2.5**	**85**	**918**	**416**	**163**	**1,760**	**1.4**	**740**	**26,357**

(Survey 2019)

Table: Energy Consumption in Rural-Residential Sector of Province 2 (TJ)

	Cooking	Water boiling	Space heating	Space Cooling	Lighting	Electrical Appliances	Animal feed preparation	Agro and food processing	Social events	Total
Wood	7,145	1.0	20	-	-	-	173	-	37	7,374
Agricultural residue	1,798	0.5	-	-	-	-	38	-	-	1,837
Animal waste	1,627	0.3	-	-	-	-	198	-	-	1,825
Coal	5.6	-	-	-	-	-	-	-	-	6
kerosene	3.9	-	-	-	44	-	-	-	-	48
LPG	765	0.1	-	-	-	-	103	-	369	1,236
Electricity	6.4	0.3	8.3	280	151	68	0.0	0.0	0.0	513
biogas	0.2	-	-	-	26	-	1.1	-	0.2	28
briquettes	-	-	-	-	-	-	16	-	0.8	17
Solar thermal	-	-	-	-	-	-	-	-	-	-
Solar PV	-	-	-	-	6.6	-	-	-	-	6.6
	11,350	**2.2**	**28**	**280**	**228**	**68**	**528**	**0.0**	**407**	**12,891**

(Survey 2019)

Table: Energy Consumption in Urban-Residential Sector of Province 3 (TJ)

Energy sources	Cooking	Water boiling	Space heating	Space cooling	Lighting	Electrical appliance	Social occasion	Food & agro processing	Animal feed	Total
Fuelwood	4,630.4	56.1	1,073.0	-	-	-	268.4	94.4	448.6	**6,570.9**
Animal dung	-	-	-	-	-	-	-	3.2	-	**3.2**
Agriculture residue	1,028.8	-	-	-	-	-	-	0.2	-	**1,029.0**
Kerosene	-	-	-	-	0.4	-	-	-	-	**0.4**
LPG	6,341.2	378.5	-	-	-	-	432.3	221.7	0.1	**7,373.7**
Electricity	179.0	71.3	149.0	447.8	713.2	2,830.6	0.0	0.0	-	**4,390.9**
Biogas	32.7	-	-	-	-	-	21.9	30.8	21.1	**106.4**
Briquette	1.2	-	5.7	-	-	-	-	-	-	**6.9**
Wax	-	-	-	-	-	-	-	-	-	-
Solar PV	-	-	-	-	20.7	-	-	-	-	**20.7**
Solar thermal	-	188.1	-	-	-	-	-	-	-	**188.1**
Total	**12,213**	**693.9**	**1,227.6**	**447.8**	**734.2**	**2,830.6**	**722.6**	**350.2**	**469.7**	**19,690.0**

(survey 2021)

Table: Energy Consumption in Rural-Residential Sector of Province 3 (TJ)

Energy sources	Cooking	Water boiling	Space heating	Space cooling	Lighting	Electrical appliance	Social occasion	Food & agro processing	Animal feed	Total
Fuelwood	9,299.6	98.7	519.4	-	-	-	134.0	167.0	3,512.7	**13,731.4**
Animal dung	-	-	-	-	-	-	0.2	-	0.0	**0.2**
Agriculture residue	813.5	-	-	-	-	-	-	11.0	151.1	**975.6**
Kerosene	-	-	-	-	0.1	-	-	-	-	**0.1**
LPG	387.7	14.4	-	-	-	-	19.8	3.5	0.0	**425.3**
Electricity	3.2	3.3	3.8	32.0	61.2	140.3	0.0	-	-	**243.6**
Biogas	64.9	-	-	-	-	-	163.4	-	-	**228.3**
Briquette	-	-	-	-	-	-	0.0	-	-	**0.0**
Wax	-	-	-	-	0.1	-	-	-	-	**0.1**
Solar PV	-	-	-	-	4.3	-	-	-	-	**4.3**
Solar thermal	-	1.0	-	-	-	-	-	-	-	**1.0**
Total	**10,568.9**	**117.4**	**523.2**	**32.0**	**65.7**	**140.3**	**317.4**	**181.4**	**3,663.9**	**15,610.0**

(survey 2021)

Table: Energy Consumption in Urban-Residential Sector of Province 4 (TJ)

	Cooking	Water boiling	Space heating	Space Cooling	Lighting	Electrical Appliances	Others	Total
Fuelwood	4,598.82	906.48	2.62	-	-	-	917.60	**6,425.52**
Agricultural residue	22.93	-	-	-	-	-	-	**22.93**
Animal waste	-	-	-	-	-	-	-	-
Coal	-	-	-	-	-	-	0.12	**0.12**
kerosene	-	-	-	-	-	-	2.20	**2.20**
LPG	1,436.39	29.25	-	-	-	-	90.61	**1,556.25**
Diesel	-	-	-	-	-	-	-	-
Gasoline	-	-	-	-	-	-	-	-
Electricity	134.02	-	-	18.80	99.35	650.54	4.64	**907.35**
Biogas	204.28	15.82	-	-	-	-	0.25	**220.35**
Briquettes	-	-	-	-	-	-	-	-
Solar thermal	-	0.05	-	-	-	-	-	**0.05**
Solar PV	-	-	-	-	1.22	-	-	**1.22**
Total	**6,396.45**	**951.60**	**2.62**	**18.80**	**100.57**	**650.54**	**1,015.42**	**9,136.00**

(survey 2022)\

Table: Energy Consumption in Rural-Residential Sector of Province 4 (TJ)

	Cooking	Water boiling	Space heating	Space Cooling	Lighting	Electrical Appliances	Others	Total
Fuelwood	9,115.06	219.18	122.85	-	-	-	130.39	**9,587.48**
Agricultural residue	3.07	-	-	-	-	-	-	**3.07**
Animal waste	-	-	-	-	-	-	-	-
Coal	0.45	0.91	-	-	-	-	-	**1.36**
kerosene	0.82	-	-	-	-	-	0.17	**0.99**
LPG	391.71	13.10	-	-	-	-	3.08	**407.89**
Diesel	-	-	-	-	-	-	-	-
Gasoline	-	-	-	-	-	-	-	-
Electricity	13.90	-	0.00	0.33	25.44	48.37	3.82	**91.87**
Biogas	101.33	-	-	-	2.20	-	-	**103.53**
Briquettes	-	-	-	-	-	-	-	-
Solar thermal	-	0.00	-	-	-	-	-	**0.00**
Solar PV	-	-	-	-	4.88	-	-	**4.88**
Total	**9,626.36**	**233.19**	**122.85**	**0.33**	**32.53**	**48.37**	**137.46**	**10,201.09**

(survey 2022)

Table: Energy Consumption in Urban-Residential Sector of Province 5 (TJ)

	Cooking	Water boiling	Space heating	Space Cooling	Lighting	Electrical Appliances	Others	Total
Wood	6,402.49	26.75	54.71	-	-	-	84.00	**6,567.95**
Agri residue	32.78	-	-	-	-	-	-	**32.78**
Animal waste	50.43	-	-	-	-	-	-	**50.43**
Coal	23.03	-	-	-	-	-	0.02	**23.05**
Kerosene	3.59	-	-	-	-	-	1.60	**5.18**
LPG	2,473.87	76.30	2.76	-	-	-	19.08	**2,572.01**
Electricity	70.29	-	0.03	159.18	260.54	1,042.17	5.34	**1,537.56**
Biogas	762.58	-	-	-	-	-	-	**762.58**
Briquettes	7.27	-	-	-	-	-	0.01	**7.28**
Solarthermal	-	0.02	-	-	-	-	-	**0.02**
	9,826.33	**103.07**	**57.51**	**159.18**	**260.54**	**1,042.17**	**110.05**	**11,558.84**

(Survey 2022)

Table: Energy Consumption in Rural-Residential Sector of Province 5 (TJ)

	Cooking	Water boiling	Space heating	Space Cooling	Lighting	Electrical Appliances	Others	Total
Wood	12,219.54	713.70	99.26	-	-	-	1,148.37	**14,180.88**
Agriresidue	136.77	8.58	-	-	-	-	-	**145.35**
Animal waste	70.10	-	-	-	-	-	-	**70.10**
Coal	-	-	-	-	-	-	0.44	**0.44**
Kerosene	0.38	-	-	-	-	-	0.45	**0.83**
LPG	942.88	99.78	-	-	-	-	66.48	**1,109.15**
Electricity	39.29	-	0.00	73.68	102.23	127.97	0.70	**343.86**
Biogas	1,438.23	9.76	-	-	2.05	-	0.17	**1,450.21**
Briquettes	-	-	-	-	-	-	0.02	**0.02**
Solar thermal	-	0.00	-	-	-	-	-	**0.00**
Solar	-	-	-	-	19.21	-	-	**19.21**
	14,847.19	**831.82**	**99.26**	**73.68**	**123.48**	**127.97**	**1,216.63**	**17,320.04**

(survey 2022)

Table: Energy Consumption in Urban-Residential Sector of Province 6 (TJ)

	Cooking	Water boiling	Space heating	Space Cooling	Lighting	Electrical Appliances	Others	Total
Fuelwood	6,569.71	8.38	1.30	-	-	-	76.63	**6,656.02**
Agricultural residue	11.22	-	-	-	-	-	-	**11.22**
Animal waste	-	-	-	-	-	-	-	-
Coal	-	-	-	-	-	-	-	-
Kerosene	-	-	-	-	-	-	0.78	**0.78**
LPG	163.71	2.08	3.08	-	-	-	-	**168.87**
Electricity	20.74	-	0.05	3.35	13.71	78.69	-	**116.53**
Biogas	3.33	-	-	-	-	-	-	**3.33**
Briquettes	-	-	0.23	-	-	-	-	**0.23**
Solar thermal	-	-	-	-	-	-	-	-
Solar PV	-	-	-	-	5.22	-	-	**5.22**
Total	**6,768.70**	**10.46**	**4.66**	**3.35**	**18.93**	**78.69**	**77.40**	**6,962.19**

(survey 2022)

Table: Energy Consumption in Rural-Residential Sector of Province 6 (TJ)

	Cooking	Water boiling	Space heating	Space Cooling	Lighting	Electrical Appliances	Others	Total
Fuelwood	9,640.48	-	-	-	-	-	35.50	**9,675.98**
Agricultural residue	10.43	-	-	-	-	-	-	**10.43**
Animal waste	-	-	-	-	-	-	-	-
Coal	0.08	-	-	-	-	-	-	**0.08**
Kerosene	-	-	-	-	-	-	-	-
LPG	72.96	-	-	-	-	-	-	**72.96**
Electricity	0.19	-	-	0.42	8.95	14.69	-	**24.25**
Solar PV	-	-	-	-	21.40	-	-	**21.40**
Total	**9,724.14**	-	-	**0.42**	**30.35**	**14.69**	**35.50**	**9,805.10**

(Survey 2022)

Table: Energy Consumption in Urban-Residential Sector of Province 7 (TJ)

	Cooking	Water boiling	Space heating	Space Cooling	Lighting	Electrical Appliances	Others	Total
Fuelwood	10,838.25	450.77	-	-	-	-	12.75	**11,301.77**
Agricultural residue	779.52	51.44	-	-	-	-	-	**830.96**
Animal waste	8.93	-	-	-	-	-	-	**8.93**
Coal	0.07	-	-	-	-	-	-	**0.07**
Kerosene	-	-	-	-	-	-	1.64	**1.64**
LPG	349.30	2.96	-	-	-	-	0.24	**352.50**
Electricity	11.74	-	0.00	20.28	56.72	362.67	-	**451.41**
Biogas	631.12	-	-	-	-	-	-	**631.12**
Briquettes	-	0.04	0.01	-	-	-	0.02	**0.07**
Solar thermal	-	0.01	-	-	-	-	-	**0.01**
Solar PV	-	-	-	-	3.52	-	-	**3.52**
Total	**12,618.93**	**505.22**	**0.01**	**20.28**	**60.25**	**362.67**	**14.65**	**13,582.00**

(Survey, 2022)

Table: Energy Consumption in Rural-Residential Sector of Province 7 (TJ)

	Cooking	Water boiling	Space heating	Space Cooling	Lighting	Electrical Appliances	Others	Total
Fuelwood	11,878.43	699.83	-	-	-	-	4.78	**12,583.03**
Agricultural residue	213.83	-	-	-	-	-	-	**213.83**
Kerosene	-	-	-	-	-	-	6.80	**6.80**
LPG	154.88	1.54	-	-	-	-	-	**156.41**
Electricity	2.07	-	-	1.18	16.26	78.92	-	**98.42**
Biogas	404.31	-	-	-	-	-	-	**404.31**
Solar PV	-	-	-	-	14.09	-	-	**14.09**
Total	**12,653.51**	**701.36**	**-**	**1.18**	**30.35**	**78.92**	**11.57**	**13,476.89**

(Survey, 2022)

Table: Energy Consumption under BAU Scenario (PJ)

	2024	2030	2035	2040	2045	2050
Koshi	47.513	50.018	52.207	54.49	56.874	59.362
Madhesh	63.691	68.376	72.542	76.963	81.652	86.628
Bagmati	59.998	63.576	66.72	70.019	73.482	77.115
Gandaki	30.914	31.381	31.775	32.174	32.579	32.988
Lumbini	46.365	49.924	53.096	56.471	60.06	63.878
Karnali	27.891	29.083	30.115	31.184	32.291	33.437
Sudurpashchim	44.429	45.834	47.038	48.274	49.542	50.843
Total	320.803	338.192	353.493	369.575	386.479	404.251

Table 5.19: Energy Consumption under Net Zero Emission Scenario (PJ)

	2024	2030	2035	2040	2045	2050
Koshi	47.513	40.979	36.551	32.622	28.965	25.435
Madhesh	63.691	52.599	45.912	40.637	36.299	32.602
Bagmati	59.998	50.339	45.045	41.343	38.766	37.027
Gandaki	30.914	23.988	20.138	17.378	15.365	13.89
Lumbini	46.365	40.177	36.862	34.623	33.152	32.262
Karnali	27.891	21.332	17.69	15.097	13.238	11.921
Sudurpashchim	44.429	34.055	28.33	24.276	21.383	19.339
Total	320.803	263.468	230.529	205.977	187.168	172.476

Table 5.20: Energy Consumption under All Electrification Scenario (PJ)

	2024	2030	2035	2040	2045	2050
Koshi	47.513	41.931	36.73	30.994	24.686	17.767
Madhesh	63.691	57.084	50.58	43.07	34.458	24.636
Bagmati	59.998	53.987	48.27	41.857	34.69	26.713
Gandaki	30.914	26.26	22.269	18.173	13.971	9.66
Lumbini	46.365	42.26	38.153	33.354	27.791	21.385
Karnali	27.891	23.933	20.339	16.46	12.28	7.782
Sudurpashchim	44.429	37.956	32.216	26.149	19.74	12.977
Total	320.803	283.411	248.558	210.057	167.616	120.921

Table 5.21: Energy Consumption under NDC 3.0 Scenario (PJ)

	2024	2030	2035	2040	2045	2050
Koshi	47.513	32.509	26.443	27.6	28.807	30.067
Madhesh	63.691	42.695	34.913	37.04	39.297	41.691
Bagmati	59.998	43.821	37.026	38.857	40.778	42.795
Gandaki	30.914	20.32	15.934	16.134	16.337	16.542
Lumbini	46.365	35.108	30.376	32.307	34.36	36.544
Karnali	27.891	17.058	12.735	13.187	13.655	14.14
Sudurpashchim	44.429	27.931	21.24	21.798	22.371	22.959
Total	320.803	219.442	178.667	186.923	195.605	204.738

ANNEX-II

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TRIBHUVAN UNIVERSITY
इन्जिनियरिङ्ग अध्ययन संस्थान
INSTITUTE OF ENGINEERING
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Pulchowk, Lalitpur

त्रिभुवन विश्वविद्यालय इन्जिनियरिङ्ग अध्ययन संस्थान पुल्चोक क्याम्पस

Date: May 8, 2026

To Whom It May Concern:

This is to certify that the paper titled "*An Integrated National Energy Demand Model with Provincial-Level Disaggregation for the Residential Sector*" (Submission ID #828), with **Rahul Kumar Jha** as the first author, was accepted through the peer-review process and has been presented at the 18th IOE Graduate Conference, organized at Pulchowk Campus, Lalitpur, Nepal, from May 7 to 9, 2026.

Please note that inclusion of the accepted manuscript in the conference proceedings is contingent upon timely compliance with any further editorial requirements during the publication process.

Prof. Sangeeta Singh
Convener
18th IOE Graduate Conference

ANNEX-III

Rahul Jha

An Integrated National Energy Demand Model with Provincial-Level Disaggregation for the Residential Sector.pdf

Tribhuvan University

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