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Scenario Analysis on Energy Transition & Energy Security: A Case Study on Madhesh Province of Nepal

by

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A THESIS

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ABSTRACT

The paper has taken Madhesh province as the area of study and it presents the study of energy demand emission analysis along with the energy security state of the province. The Government's Net-zero targets had been taken into account to create the scenarios where the overview of the province-level energy security indicators is calculated in the time frame taking 2019 as the base year and 2050 as the final year of analysis. The energy demand and emission of different sectors of Madhesh province are compared in the different scenarios and their impact on the energy security indicators are compared. The elasticity of the different sectors based on GDP is used to determine the baseline scenario of the study which is then compared with the Government scenario to observe fuel savings and reduction of import of fuel can be seen. The energy intensity in the base year is 16.2 GJ/$1000. In the baseline scenario, it is projected to decrease by 55.06% by 2050. In the intervention scenarios, the decrease is even more significant, with a reduction of 66.88% in the NZE scenario and 71.02% in the NZA scenario by 2050, compared to the baseline scenario. On the other hand, the electricity consumption per capita was 308.2 kWh/capita in the baseline scenario, and it is expected to reach 691.4 Kwh/capita by 2050 in the baseline scenario. In the NZE scenario, it is projected to increase 1291.2 Kwh/capita, and in the NZA scenario, it is expected to increase 2693.4 Kwh/capita by 2050, compared to the baseline scenario. These findings highlight the significant improvements in energy intensity and the substantial increase in electricity consumption per capita in the different scenarios. Under the baseline scenario, energy consumption is projected to increase by approximately 200% by 2050 compared to the value of energy consumption of 64072.36 TJ in the base year. The NZE and NZA scenarios demonstrate a shift towards more efficient fuel types for energy consumption in the residential sector, with respective shares of 25.75% and 23.80% in 2050. Implementing the NZE scenario can lead to a significant reduction in energy consumption by 25.86% by the year 2050, accompanied by a corresponding decrease in GHG emissions by 56.75%. NZA scenario achieves an even more substantial reduction in energy consumption, reaching 35.92%, which makes to a remarkable reduction by 87.01% in GHG emissions in the year 2050. These impressive reductions demonstrate the potential of the NZE and NZA scenarios to mitigate climate change and transition towards a low-carbon economy.

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LIST OF ABBREVIATIONS

WECS	Water and Energy Commission Secretariat
MOEWRI	Ministry of Energy, Water Resources, and Irrigation
NDC	Nationally Determined Contributions
SDG	Sustainable Development Goals
CBS	Central Bureau of Statistics
LPG	Liquid Petroleum Gas
UNFCCC	United Nations Framework Convention on Climate Change
LEAP	Low Emissions Analysis Platform
NZE	Net-zero with existing measure
NZA	Net-zero with additional measure
MOF	Ministry of Finance

CHAPTER ONE: INTRODUCTION

1.1 Background

The development of the country is indicated by energy consumption. The energy-related database provides critical information for designing specialized strategies, setting provincial goals, and combining them to achieve the national goal (WECS, 2022). As a result, a well-organized energy database serves as a foundation for policy development and long-term energy planning. As constitution of Nepal 2015 has divided the nation into seven provinces (GON, 2015). Along with various targets and milestones set by the government to be met in the energy sector. The use of biomass, a non-commercial energy type in Nepal, dominates the country's entire energy consumption. Traditional energy sources (fuel wood, agri-residue, and animal waste) continue to dominate. However, there is a clear move toward commercial energy (coal, petroleum products, and electricity), and renewable energy sources are expanding. Consumption of electricity has also recently increased at a rapid pace (GON, 2010).

Energy transition towards cleaner sources improves individual living conditions and the economic growth of the nation, Nepal has a lot of water that could be used to make electricity, especially from hydropower. But because of various social and economic challenges, the country is finding it hard to tap into this potential. This is why people in Nepal use less electricity per person compared to other places (Pokharel & Rijal, 2021).

Energy mix helps to understand energy balance and the status of energy in the country. The energy security indicators derived from the energy data will further expand the scenario, which will finally be used as a resource for drafting policies and action plans for energy sector improvement, leading to the province's energy sustainability (Dulal & Shakya, 2018). Although considerable work has been done in this area of research, the number of indicators employed is quite limited. Numerous articles and publications that were published at the time described the crisis's potential causes and solutions. The energy crisis has had a significant impact on every economic sector, including commercial, industrial, residential sectors, etc, which has slowed down the country's economic growth.

The energy consumption continues to rise in terms of absolute values. The increase in energy consumption growing at the rate of 4% over the last two years which is higher than the population growth rate (WECS, 2022). As a result, there is still some potential for further research into the energy mix and energy security utilizing a wider number of relevant indicators. To comply with the national level target it is necessary to analyze the provincial status of energy demand and its transition in different scenarios which will be beneficial federal government to make a plan and policy for achieving the target set by it. Thus, the study of issues relating to the energy sector has been the main topic of study in the case of Madhesh province.

1.2 Status of Energy mix of Madhesh province

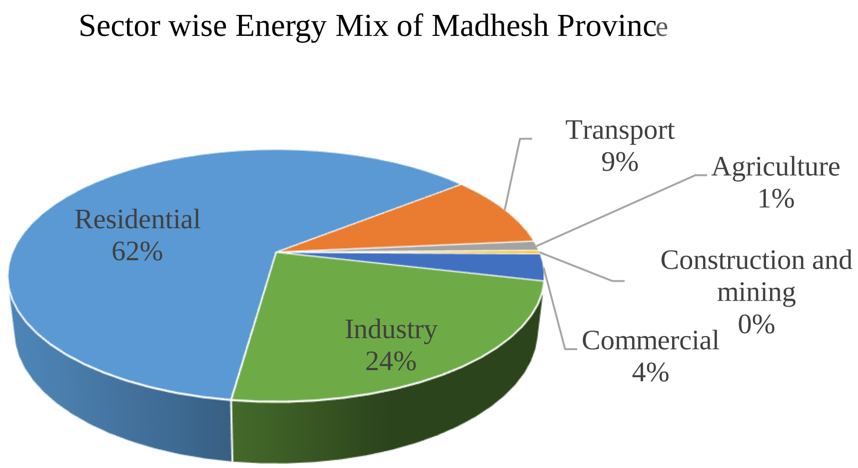

Figure 1.1: sector wise energy mix of Madhesh province (WECS, 2021)

Figure 1.1 shows the total energy consumption in Madhesh Province is about 64 PJ in the year 2019. Energy is mostly consumed in 6 sectors Residential, Industry, Transport, Commercial, Agriculture, Construction, and mining. Among them Residential sector consumes 62.11% share of total energy consumption after the residential, Industrial, and Transport sector's contribution to energy consumption 23.58% and 9.20% respectively. Madhesh province is the economic hub for industry and trade so consumption in the Industrial is large after the residential sector. Whereas, commercial, Agriculture, and construction mining are the least energy-consuming sector having a share of 3.45%, 1.25%, and 0.42% in total energy respectively.

Various types of fuels that are being supplied and used to meet various energy demands of different sectors. Fuel Wood is the main source of energy type in the residential sector while 64% of energy comes from conventional renewables. The Commercial sector mainly used electricity and Transport, Industry and Agriculture sector mainly depend on fossil fuels, however shifting from solar water pumping is seen in the Agriculture sector. (WECS, 2021)

1.3 Statement of Problem

Countries are competing for energy resources, which are becoming scarce due to the growth of industries in countries like India and China. Climate change is also making it harder to find and use energy. These factors threaten the ability of countries to meet their energy needs, which is important for their economies to grow. Therefore, all countries need to find ways to secure their energy supplies for the future. The energy crisis has had a significant impact on every economic sector, including commercial, industrial, residential sectors etc., which has slowed down the country's economic growth.

Madhesh province heavily depends on imported fossil fuels, has inadequate infrastructure, limited energy access in remote areas, environmental degradation from fossil fuel use, vulnerability to natural disasters, energy inefficiency, lack of diversification, and insufficient awareness. These challenges hinder socioeconomic development, disrupt services, and pose environmental and health risks.

To eliminate GHG emissions is crucial for Nepal to meet its commitments under the Paris Agreement. Nepal is particularly vulnerable to climate change, and it has outlined specific goals in its second NDC to reduce emissions (GON, 2020). Additionally, the country has set a long-term strategy to achieve net-zero carbon emissions by 2045 (GON, 2021). National and provincial goals need to align for a coordinated effort in reaching these targets by implementing a net zero emission strategy and conducting scenario analysis which can guide effective solutions for ensuring energy security and sustainable development.

1.4 Objectives

The main objective is to study potential pathways for transitioning to sustainable energy sources while ensuring energy security for the Madhesh Province.

Specific objectives

- To assess the aggregate energy needs within various sectors of Madhesh Province
- To develop different scenarios for energy transition and study the effects of Net zero emission strategy on energy security.
- To study the GHG emission & ambient air pollution.

1.5 Limitations of Study

Secondary data has been taken for the study from WECS report and analysis is done for Madhesh Province in the Residential, Industrial, Commercial, Transport, and Agriculture sectors. The different scenario is based on Net-zero target set by the Government of Nepal's Long-term Strategy for Net-zero Emission, 2021. Non-energy sector's calculation is not included.

CHAPTER TWO: LITERATURE REVIEW

Nepal relies completely on imported petroleum fuels and this reliance is increasing rapidly. The amount of petroleum products Nepal imports has grown much faster than the amount of goods it exports (MOF, 2020). The report highlights the share of Nepal's energy consumption is gradually increasing shifting from traditional fuels to modern fuels is seen in residential due to urbanization and living standards, The energy consumption share of petrol is 65% while the share of electricity consumption is only 15% and the Nepal energy consumption is shifting towards unsustainability though agreed to SDGs no.7 (Sanjel, Sharma, Bhat, & Manandhar, 2022). This is the reason to ensure energy security by prioritizing indigenous hydro resources. This paper highlights the energy imports ratio of Nepal has increased from 18.5% to 34.5% between the period of 2015 to 2030 (Gautam, Nakarmi, & Shakya, 2023). The author used five economic growth scenarios i.e. Normal Growth (NOR), Low growth (Low), High growth (Hig), Accelerated growth (ACC), and Intervention scenario on normal growth using these scenarios author compared energy consumption and energy security indicators in these scenarios find out if intervention is done energy intensity GHG emission, and oil imports will reduce while securing the energy security of that region (Dulal & Shakya, 2018). The author used the LEAP framework to analyze the GHG mitigation potential in different economic sectors of Kathmandu city implementing intervention scenarios can reduce 35.2% of total GHG emissions from energy to base case scenario in 2030 (Shakya,2016). This paper shows the share of the electricity-based transport sector increased by 10 percent in 2015 the hydropower generation would have to increase by 7.86 TW by 2050 compared to the base case scenario which can reduce GHG emissions, local environment, and improvement in energy security in Nepal (Shakya & Shrestha, 2011). The author used Major two policy intervention scenarios has included WEM and WAM using LEAP software both measures lead to a high reduction in GHG emission and energy security improvement compared to reference scenarios at the national level (Shakya, et al., 2023). Nepal submitted its NDC to UNFCCC in 2016 which aims to reduce climate change impact by adaption and mitigation actions in different sectors like agriculture, transport, and renewable energy, second NDC is more ambitious than the first NDC in terms of sectoral coverage and net zero emission target, it also set plan to increase hydropower plant to export electricity to neighboring countries (MOPE, 2016), (GON, 2020).

After the oil crisis of the 1970s, countries that rely on oil imports became more aware of the need for energy security. This led to a worldwide effort to plan for future energy needs. Energy security is still a major global issue today (Shakya, et al., 2023). Nepal scores low ranking in the Energy Trilemma Index reflects its deficiencies in energy security and equity. Without prompt and effective policy changes to address the country's energy challenges, the current situation is likely to persist. (Bhattarai, Marasaini, Devkota, & Apan, 2022).

Scenario analysis and energy security research are crucial for Madhesh Province, Nepal, as to provide insights into future energy needs, potential emissions reductions, and policies for economic growth. By understanding energy demand, and GHG mitigation, the province can plan effectively, aligning with national targets and global climate goals. Considering past energy crises and emerging challenges, addressing energy security becomes essential for sustained development and stability.

2.1 Energy Security Indicators

The IEA defines energy security as the uninterrupted availability of energy sources at an affordable price. It classifies energy security into two aspects term which mainly deal with timely investments to supply energy in line with economic developments and environmental needs and short-term Energy security emphasizes the resilience of the energy system to effectively adapt to sudden shifts in the supply-demand equilibrium (IEA, 2023). For the sustainable development of a country energy security indicators become important aspects of the country or regions as energy security indicators analyze the advancement of energy which leads to improvement of energy efficiency in power consuming sectors (Selvakkumaran & Limmeechokcha, 2013). For oil-importing countries like Nepal energy security became a hot topic after the energy crisis hit the world in 1970-73 after that every country became aware of energy security and energy planning, now energy security has become a global issue, and ensuring the supply of energy and to provide affordable, clean and sustainable energy are urgencies for a country like Nepal (Gautam, Nakarmi, & Shakya, 2023). For developing countries, energy security means getting energy demand fulfilled by all citizens at an affordable and suitable price with a better quality of life without harming the environment (Lu & Su, 2013).

Some following energy security for Nepal are used by the Water and Energy Commission Secretariat (WECS, 2021)

- Final energy demand/capita
- Final electricity demand/capita
- GHG emission
- Share of renewable energy in final total energy demand

- Share of electricity used/household
- Share of non-carbon energy in the primary supply
- Net import to total primary energy supply

Other research national journals highlight and discuss the different dimensions of energy security in Nepal (Darlamee & Bajracharya, 2021).

1. Affordability dimension

2. Availability dimension

   i. oil imports value per unit of GDP
   ii. Oil Consumption /capita
   iii. Total Final Energy Consumption/capita
   iv. Share of domestic production of primary energy
   v. Import Dependency
   vi. Shannon- Weiner Index (SWI)
   vii. Annual electricity deficit
   viii. Average annual price of petroleum products
   ix. Electricity Consumption/capita
   x. Strategic Fuel Stock is the number of days of stock of petroleum products
   xi. Electricity Consumption /capita
   xii. The average annual price of electricity

3. Efficiency dimension

   i. Intensity of Residential energy consumption
   ii. Total final energy Intensity
   iii. Intensity of Industrial Energy Consumption
   iv. Intensity of commercial energy consumption
   v. Oil consumption /GDP
   vi. Transmission and Distribution losses

4. Acceptability dimension

   i. Annual Co2 emission/capita
   ii. Carbon fuel portfolio

5. Accessibility dimension

   i. Access to modern cooking fuel

ii. Access to electricity

Although there are many different energy security indicators, in this study following ten different significant indicators have been used

a) Energy consumption Per Capita

Energy consumption per capita is in GJ/ Capita, it measures the amount of energy used by each person in total a population of the region. It helps to understand energy demand and the region's ability to provide sustainable energy sources.

b) Electricity consumption per capita

Electricity consumption per capita in Kwh/Capita, measure the amount of electricity used by each person in total population of the region. It helps to understand electricity demand in different intervention scenarios.

c) Energy Intensity

Energy Intensity in GJ/$1000, shows that amount of energy required to produce a unit of GDP. It helps to understand the relationship between economic growth and energy consumption also it shows the efficiency of energy use in the economy.

d) Electricity Intensity

Electricity Intensity in Kwh/$1000, it shows the amount of Electricity required to produce a unit of GDP. It helps to understand the relationship between economic growth and electricity consumption.

e) Share of Renewable Energy in Final Energy Consumption

The share of Renewable Energy in Final Energy consumption in percent shows the proportion of renewable energy sources in the region to total energy consumption. It helps to understand region's commitment to sustainable energy sources and to reduce dependence on fossil fuels.

f) GHG Emission

GHG Emission GHG in KG/ per capita, measure the GHG emission produced by each person in the population of this region. It helps to understand the region's contribution to GHG emission and guides to make emission reduction policies.

g) GHG Intensity

GHG Intensity GHG in KG/$1000, measure of GHG emission per unit of GDP. It helps to understand the relationship between GHG emissions and the economic growth of the region.

h) Shannon-Wiener Index (SWI)

It shows the diversity of energy sources in the region. It measures energy security by considering a variety of available energy sources.

i) Total Energy Used/ Household

Total Energy used/ Household in GJ/HHI, measures the amount of energy consumed per household. It helps to understand the energy consumption pattern in households in the region.

j) Environmental effects in physical unit

Environmental effects in physical unit in KG/ Capita, It measures the environmental impact of energy consumption per person in the population of the region. It helps to understand the ability to minimize the environmental impact of the region by using different intervention scenarios.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Study Area

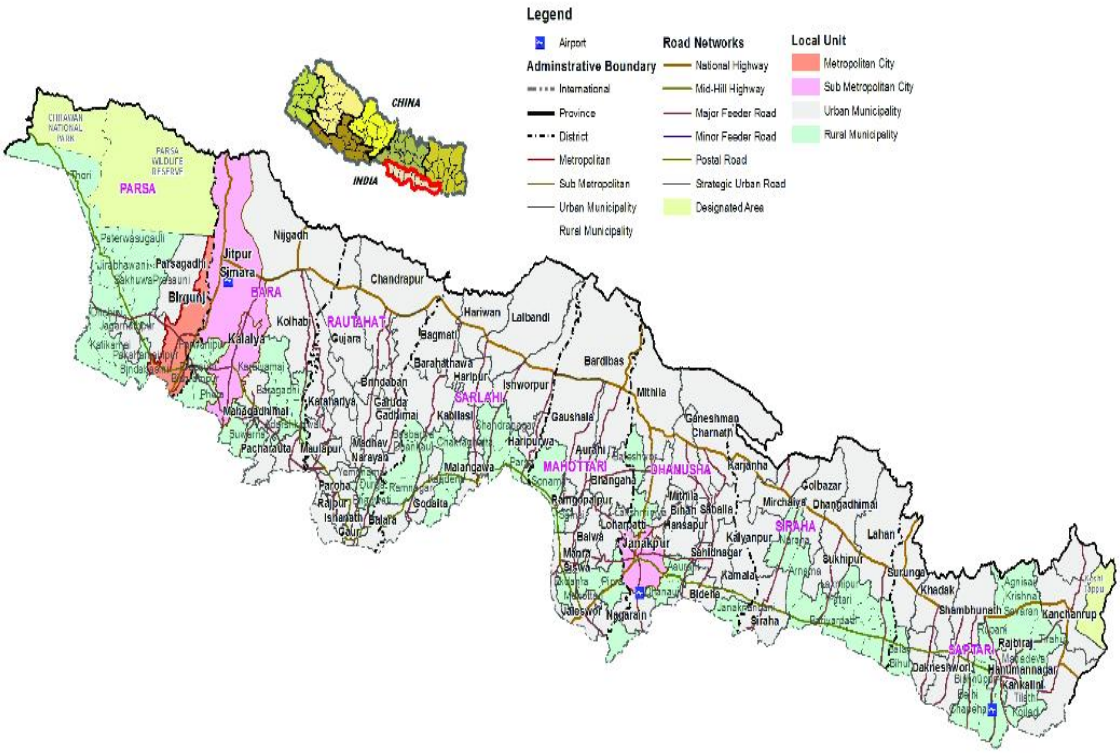

Figure 3.1: Map of Madhesh Province

Source: https://un.org.np/map/nepal-administrative-unit-province-2-map

Madhesh Province is located in the southeastern Terai region of Nepal, bordered by Koshi province to the east, Bagmati Province to the north, and India's Bihar state to the south. It has eight districts and the capital of Madhesh province is Janakurdham. It covers an area of 9,661 km2 (3,730 sq mi), which is about 6.5% of Nepal's total land. Despite being the smallest province in terms of area, it has a high population of 6,126,288 according to the 2021 census (CBS, 2021), making it the most densely populated province in Nepal.

3.2 Data Collection

Madhesh province energy mix data is collected from WECS and different organization reports. For economic growth during developing scenarios, the data is taken from reports of economic survey (MOF, 2020). The types of data collected are as follows:

- Total Energy demand in different sectors
- GDP of Madhesh Province
- GDP growth rate.
- GDP contribution from different sector
- Population of Nepal
- Household Size

3.3 Research Framework

This study uses the LEAP modeling tool used for energy policy analysis and climate change mitigation assessment which is capable of monitoring energy consumption, production, and resource extraction across all economic sectors. Also, the initial data requirements are quite low, which helps in getting the maximum insight despite having a low volume of data. Hence, a lot of future scenarios can be modeled on the basis of limited data and whose results can be used for gaining a better understanding of the interventions and policies undertaken. LEAP is used to calculate the energy mix of Madhesh province under various scenarios. The software is easy to use and the interface of the software enables the user to easily input data and generate scenarios.

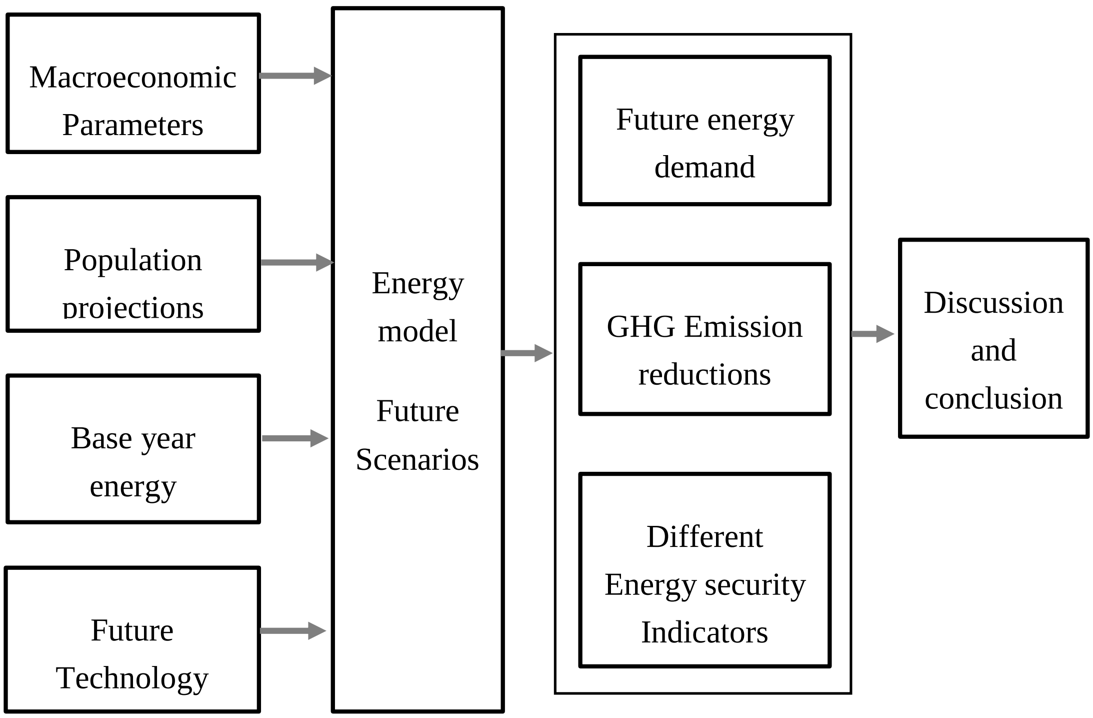

Figure 3.2 Research Framework

In the Key Assumptions section of the LEAP Model, the following parameters are used based on compiled data (WECS, 2021).

- Population: 6.125 million
- Average Household Size: 5.8
- Number of Households: 1.06 million
- GDP of Madhesh Province: 3939.1 million US$
- Share of Agriculture GDP: 40% of province GDP
- Share of Commercial GDP: 47.5% of province GDP
- Share of Industrial GDP: 7.8% of province GDP

For the input of data, a proper disaggregation level was used. To develop the energy model in LEAP, the Energy demand in the residential, Industrial Commercial, and Agriculture sectors is disaggregated into different end-use service demands from which each of the end-use is further subdivided into different fuel types. The disaggregation of the sector and the disaggregation of the end-use sector by fuel types used in the LEAP.

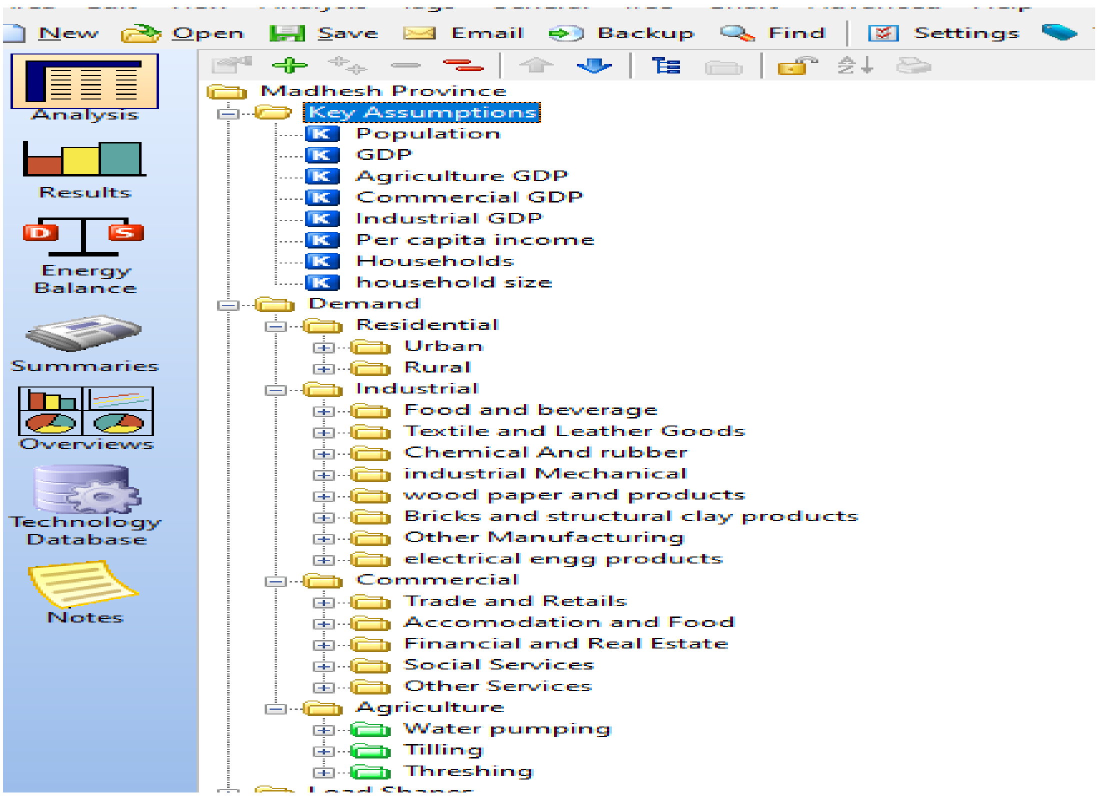

Figure 3.3 Division of different Energy Demand Sector in LEAP

3.4 Energy Demand Calculation

Energy Demand has been formulated using the LEAP framework, the methodology involves a fundamental equation that serves as the basis for estimating energy demand in different sectors.

$$Energy\ Demand = Total\ Activity * Energy\ Intensity \qquad \ldots\ldots\ldots\ldots\ldots\ldots 1$$

Equation 1 highlights the essential connection between the scope of a specific activity and its energy consumption. For the residential sector, the parameter "Total Activity" is defined as household size. Conversely, in the agricultural, commercial, and industrial sectors, "Total Activity" corresponds to the proportionate contribution of each sector to the provincial Gross Domestic Product (GDP). This approach establishes a direct and evident link between the scale of an activity and its energy requirements, thereby presenting valuable insights into the energy dynamics across these sectors.

Energy demand forecast in the baseline scenario is carried out taking the elasticity of each sector GDP as shown in equation 2 below;

$$Energy\ Demand_{(t)} = Energy\ Demand_{(0)} \times (\frac{GDP_t}{GDP_0})^{\wedge elasticity} \qquad \ldots\ldots\ldots\ldots\ldots\ldots 2$$

Each sector elasticity is based on (Shrestha & Raj Bhandari, 2010),(Shakya & Shrestha, 2011), (Burke & Csereklye, 2016),

3.5 Emission calculation

The emission from each sector in the net-zero and baseline scenarios is calculated through LEAP using IPCC guidelines for the Asian subcontinent.

3.5 Scenarios Description

Analyzing energy demand from 2019 to 2050, the study considered past trends, population growth, and economic growth (GDP) by which baseline scenario is created in which the population and GDP growth rates are 1.35% and 6.3% taken from the WECS report (WECS, 2021). The household size growth rate is taken the same as the population growth rate.

For Net-zero with existing measures and net-zero with additional measures are based on Low carbon technology penetration targets of energy sector analysis done by (Shakya, et al., 2023) and Long-term strategy for Net-zero emission by (GON, 2021).

The assumption for the baseline scenario

- Urbanization of Madhesh province is expected to be 90 % (UN , 2019).
- Urbanization is considered a uniform growth rate for easy calculation.

The assumption for Net- Zero with existing measures scenario

Residential Sector

- In urban households: The fuel mix is 20% LPG, 70% electric cooking, and 75% Electrification in space heating and water heating.
- In rural households: The fuel comprises of 10 % ICS, 40% LPG, 40% electric cooking, 50% electric space heating, and 25% electric water heating.

Industrial Sector

- In food and beverage 100% electrification in process heat and motive power, 50% in electric boiler.
- In Textile and leather products 100% electrification in process heat, motive power, boiler.
- In Industrial Chemical rubber and plastics 50% electrification in process heat, 100% in motive power, 50% in boiler.
- In Mechanical engineering process heat 50% electrification, and motive power electrification is 100%.
- In Electrical engineering Products: Process heat and motive power 100% electrification.
- In Wood products and paper, Process heat 50%, motive power 100%, and 50% boiler electrification.

Transport Sector

Due to the unavailability of specific data on intercity and intracity transportation in Madhesh province, Made the simplifying assumption that intracity transportation dominates the transportation landscape. Consequently, scenario analysis for public passenger and private transport is based on intracity transportation patterns.

In public transport and private transport, the study considers the following distribution: 35% electric buses, 20% electric cars, and 5% electric motorbikes.

Commercial Sector

100 % electrification in all sectorial demand.

Agriculture sector

In water pumping 40% electric, 40 % by solar PV Pumping, and 25% electricity in farm machinery.

The assumption for Net- Zero with additional measures scenario

Residential Sector

100% electric cooking and lighting in both urban and rural areas.

Industrial Sector

In food and beverage, Textile and leather products, Industrial Chemical rubber and plastics, Mechanical engineering, Electrical engineering Products, Wood products and paper 100% electrification.

Transport Sector

In Public transport and Private Transport 48% in electric bus, 20% electric car, 10% Electric motorbike.

Commercial Sector

100 % electrification in all sectorial demand.

Agriculture sector

In water pumping 60% from electricity, 40 % by solar PV Pumping and 100% electricity in farm machinery.

CHAPTER FOUR: RESULTS AND DISCUSSION

Final energy demand and emissions were calculated for the Baseline, NZE, and NZA scenarios. This comparison quantifies the differences in emissions and energy demand across various sectors under each scenario.

Energy security indicators were calculated for the Baseline, NZE, and NZA scenarios in the base year 2019 and the final year 2050. These indicators were compared to identify deviations from the Baseline scenario.

4.1 Baseline Scenario

In the baseline scenario energy consumption in the industrial sector has the highest consumption in the year 2050 though the share of energy consumption of residential is highest in the base year.

4.1.1 Sector-wise comparison of energy consumption

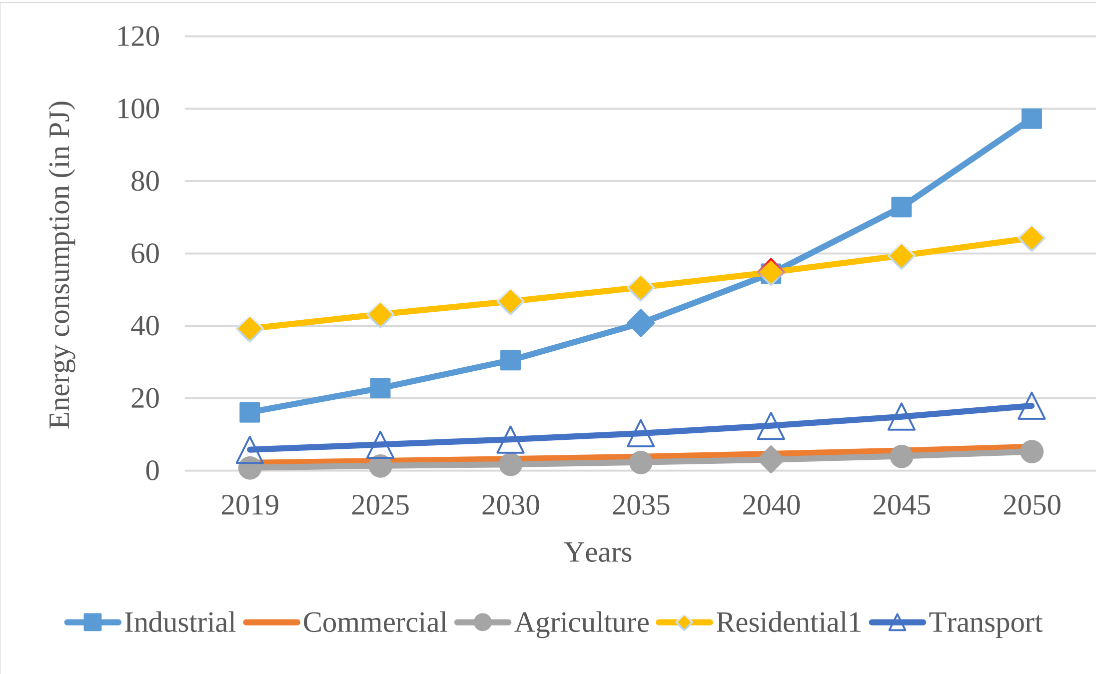

Figure 4.1 Sector wise energy consumption in baseline scenario

Figure 4.1 shows that in Madhesh province total final energy demand is 64.074 PJ in the base year, the highest energy consumption in the residential sector in the base year. All sectors are expected to grow significantly over the next 30 years, the industrial sector led in energy consumption, utilizing 16.0969 PJ in the base year and this consumption steadily increases throughout the projection period, reaching 97.3076 PJ by 2050. This shows energy consumption annual growth rate in the industrial sector is 5.97% whereas the growth rate in the residential is 1.60% annually. The Commercial sector, starting at 2.1867 PJ in 2019, also experiences a consistent rise, reaching 6.5593 PJ by 2050. Similarly, the Agriculture sector starts at 0.78946 PJ in 2019 and climbs to 5.2515 PJ by 2050. Residential energy consumption, beginning at 39.2503 PJ in 2019, shows a gradual increase, reaching 64.3181 PJ by 2050. Lastly, the Transport sector, with an initial consumption of 5.749 PJ in 2019, seen a notable escalation, reaching 17.9106 PJ by 2050.

4.1.2 Fuel mix comparison

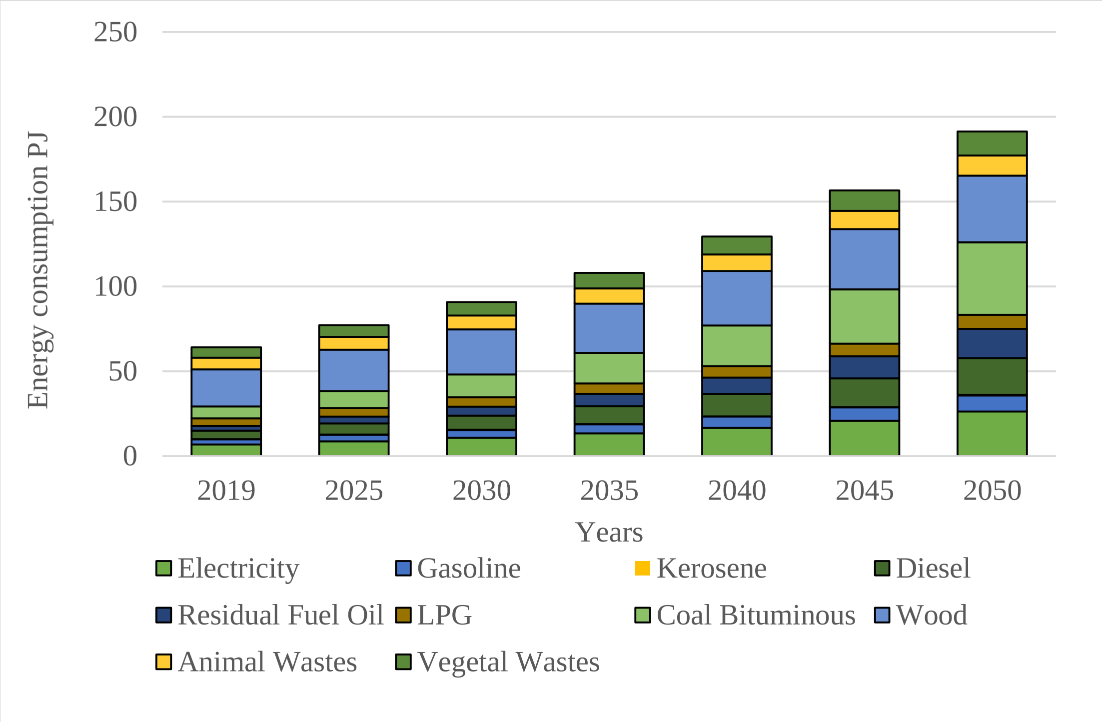

Figure 4.2 Energy consumption by fuel type in the baseline scenario

Fuel consumption in petajoules (PJ) across diverse categories from 2019 to 2050 in the baseline scenario is shown in Figure 4.2. Electricity consumption experiences consistent growth, starting at 6.9 PJ in 2019 and reaching 26.2 PJ by 2050. Gasoline consumption follows a steady upward trajectory, ascending from 3.01 PJ in 2019 to 9.4 PJ in 2050. Diesel consumption increases significantly, starting at 4.7 PJ and reaching 21.6 PJ by 2050. Residual Fuel Oil consumption rises from 2.8 PJ to 17.2 PJ over the same period. LPG consumption increased from 4.6 PJ in 2019 to 8.3 PJ in 2050. Coal Bituminous sees substantial growth, escalating from 7.0 PJ to 42.9 PJ. Wood consumption rises gradually from 21.9 PJ to 39.3 PJ. Animal Wastes and Vegetal Wastes consumption also show upward trends, reaching 11.8 PJ and 14.2 PJ, respectively, by 2050.

4.2 Net-zero existing measure scenario

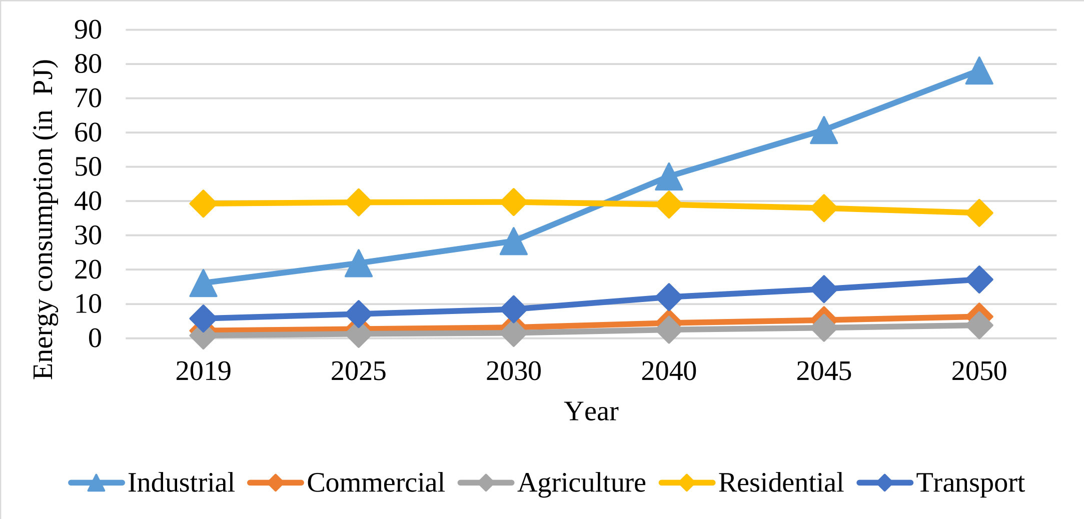

Figure 4.3 Net-zero with existing measure different sector comparison

Figure 4.3 shows the Net-zero with the existing measure scenario in which different sectors' energy consumption is shown in PJ. The graph shows that the industrial sector has the highest energy consumption which has an annual growth rate of 5.23% and reached 78.09 PJ in the end year from 16.09 PJ in the base year. Residential energy consumption share in this scenario has decreased to 25.75 % in 2050. Similar share decreasing pattern is seen in other sectors as well. This is because energy consumption in industrial sectors is increasing due to less use of efficient fuels and demand increases.

4.2.1 Fuel mix energy consumption in Net-zero with existing measures

Figure 4.4 shows the fuel mix energy consumption in net-zero with existing scenarios, the fuel type electricity highest consumption in the period 2019 to 2050 which reached to 49.05 PJ in the end year from 6.83 PJ in the base year because of electrification in every sector. Wood, animal waste, and vegetable waste decreased by 58.73%, 63.39% and, 38.93% in the end year because lower of consumption in residential from these fuel types and replaced by electricity fuel types.

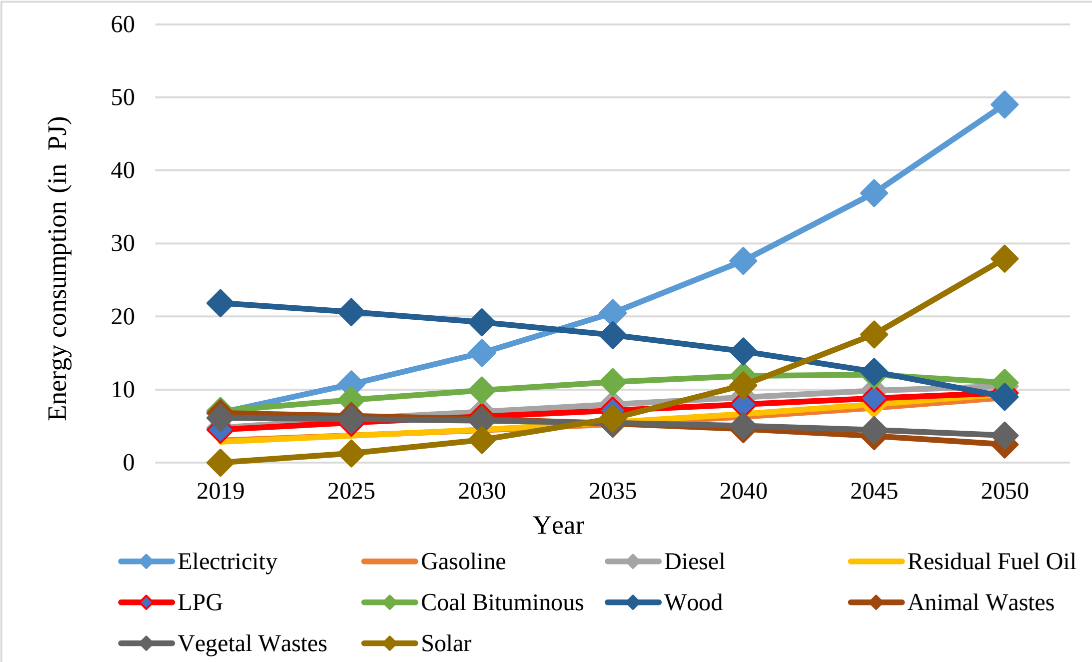

Figure 4.4 Fuel mix energy consumption in NZE

4.3 Net-zero with additional measures scenario

Figure 4.5 shows the energy consumption in net-zero with additional measures. The total energy consumption in end year is 122.61 PJ. The Highest energy consumption is seen in the industrial sector occupying the share of 56.69% in total energy consumption after residential, transport, commercial, and agriculture having the share of 23.80%, 12.83%5.14%, and 1.54% respectively. The average growth of total final energy consumption is 2.12% in this scenario. It shows that the energy consumption annual growth rate is lower than NZE and Baseline scenarios.

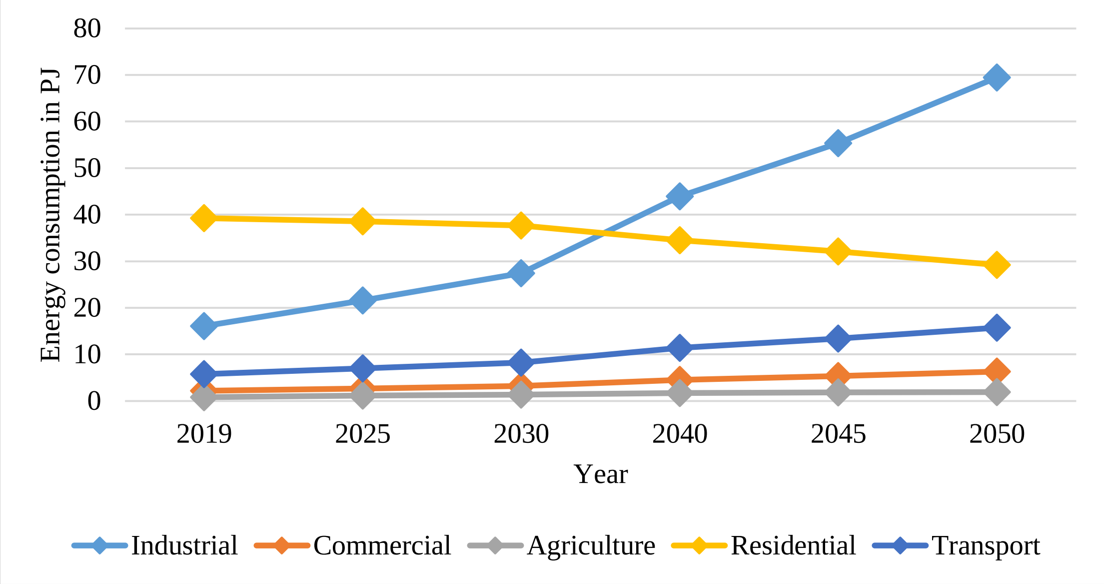

Figure 4.5 Sectorial energy consumption in net-zero with additional measure scenario

4.3.1 Fuel mix energy consumption in Net-zero with additional measures

Figure 4.6 shows that net-zero with additional measure scenario. Fuel-type electricity has the highest consumption in the end year because high implementation of fuel-type electricity in all sectors. The average annual consumption growth rate of electricity is 9.137%. Residual fuel oil has decreased at the rate of 7.79% and other fuels animal wastes, vegetable wastes, LPG, coal bituminous, and wood consumption have decreased annually.

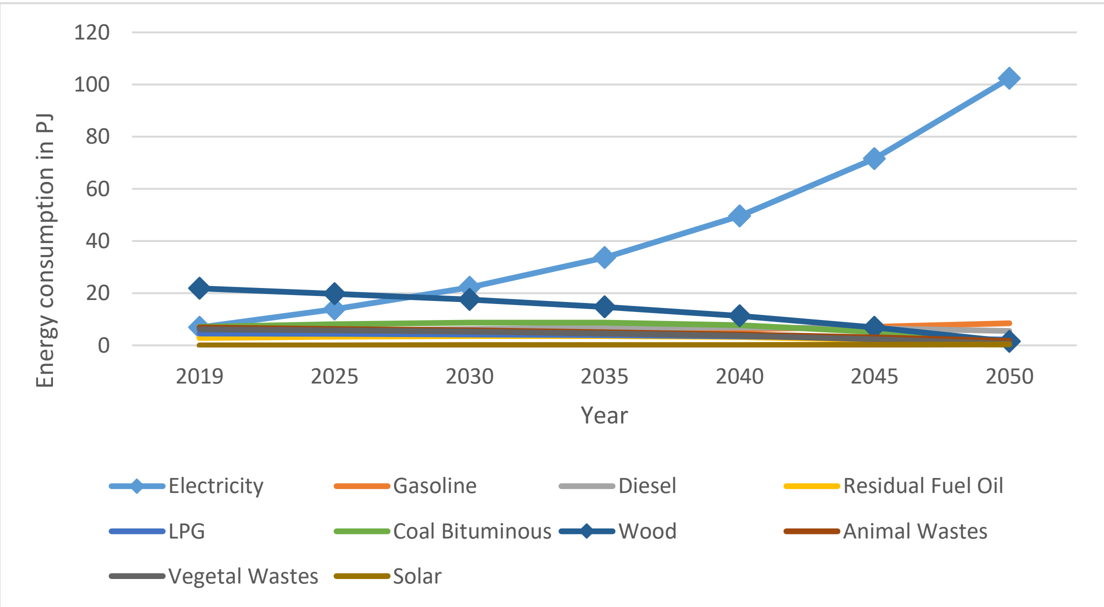

Figure 4.6 Fuel mix in net-zero with additional measures scenario

4.4 Comparison in total energy consumption between different scenarios with the baseline scenario

The Figure 4.7 shows energy consumption patterns in petajoules (PJ) across three distinct scenarios Baseline, Net Zero with Additional Measures, and Net Zero with Existing Measures from the years 2019 to 2050. In the Baseline scenario, there is a consistent upward growth in energy usage, commencing at 64.07 PJ in 2019 and it is forecasted to 191.34 PJ by 2050. Conversely, the Net Zero with Additional Measures scenario, despite initiating with the same energy consumption as the Baseline in 2019, exhibits a distinguishable reduction, reaching 122.61 PJ by 2050, which indicates the uses of additional measures and efficiency improvement in selected fuel type in additional measures. In contrast, the Net Zero with Existing Measures scenario, while still achieving a reduction compared to the Baseline, concludes with higher energy consumption at 141.86 PJ in 2050.

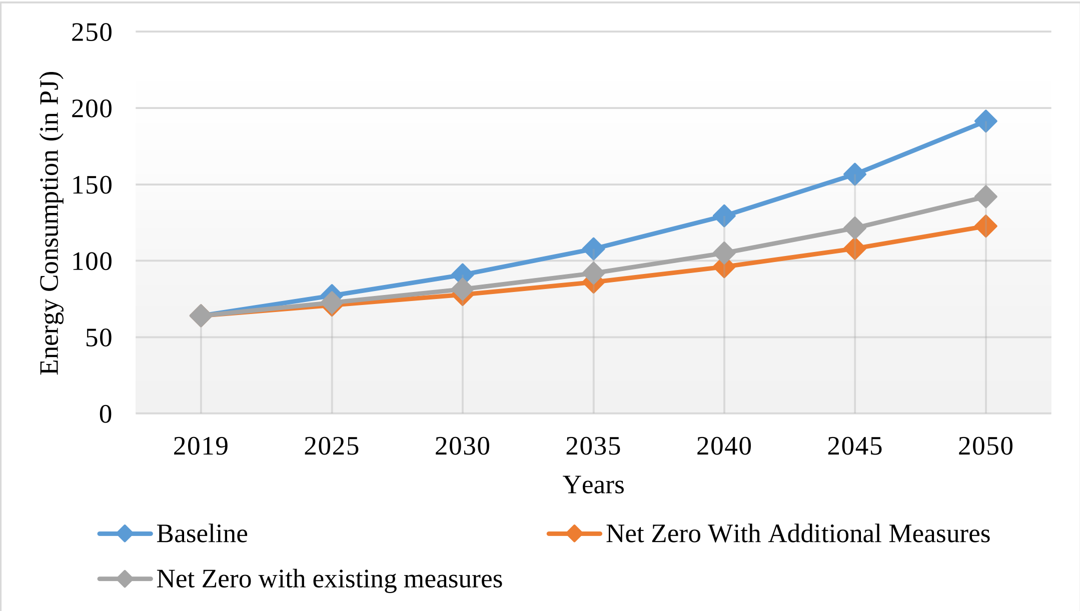

Figure 4.7 Comparison between different scenarios

4.5 Sectorial GHG Emission in Baseline Scenario

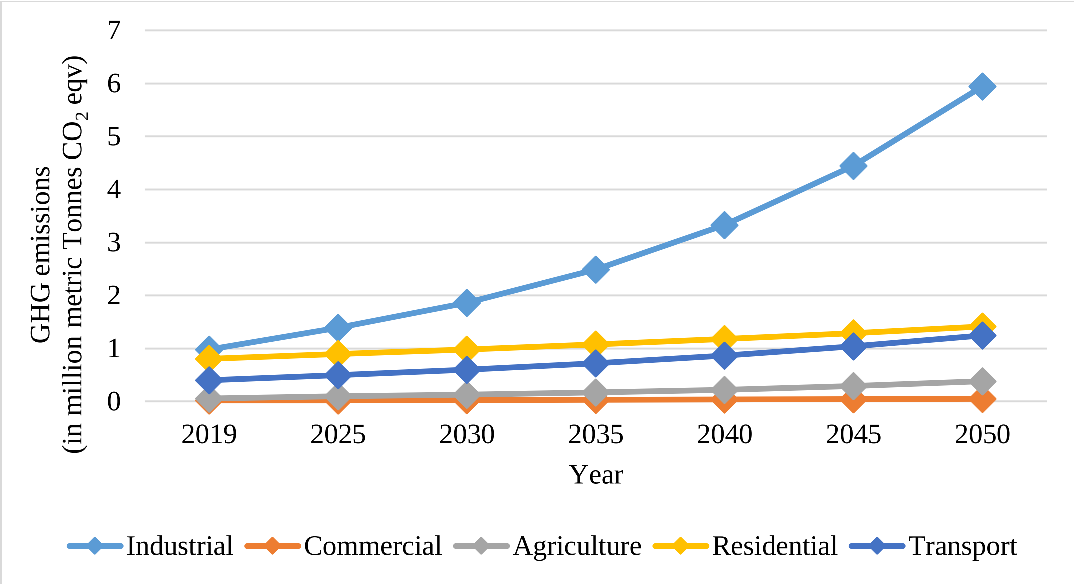

Figure 4.8 Sectorial GHG Emission in Baseline Scenario

Figure 4.8 shows the sectorial GHG emission in million Metric tonnes of CO_2 Equivalent. The annual average growth rate of GHG emission by all sectors is 4.55%. The Industrial sector emits more GHG in the base year 0.98 million metric tonnes of CO_2 Equivalent and a growth rate of 5.97% annually reached to 5.94 million metric tonnes of CO_2 Equivalent in the end year. This is due to the industrial sector having the highest energy consumption growth rate and the sector has high energy consumption via fossil fuel compared to other sectors.

4.6 Comparison of GHG Emission with different scenarios

Figure 4.9 shows GHG emissions in million metric tons of CO_2 equivalent from the base year 2019 to 2050 across three distinct scenarios. The baseline scenario exhibits significant growth in GHG emissions, characterized by an annual average growth rate of 5%. In contrast, the Net-Zero with Existing Measures scenario reveals a decline in emissions by the end of 2050, despite starting with the same GHG emission levels as the base year. This reduction is attributed to the implementation of existing measures aimed to control emissions, particularly by promoting the use of renewable energy sources emissions are even lower in the Net-Zero with additional Measures scenario compared to the Net-Zero with Existing Measures scenario. In the Net-Zero with additional measures scenario, emissions do not reach a 100% reduction. This is because the calculation only considers emissions from the energy sector, and those originating from non-energy sectors are not considered.

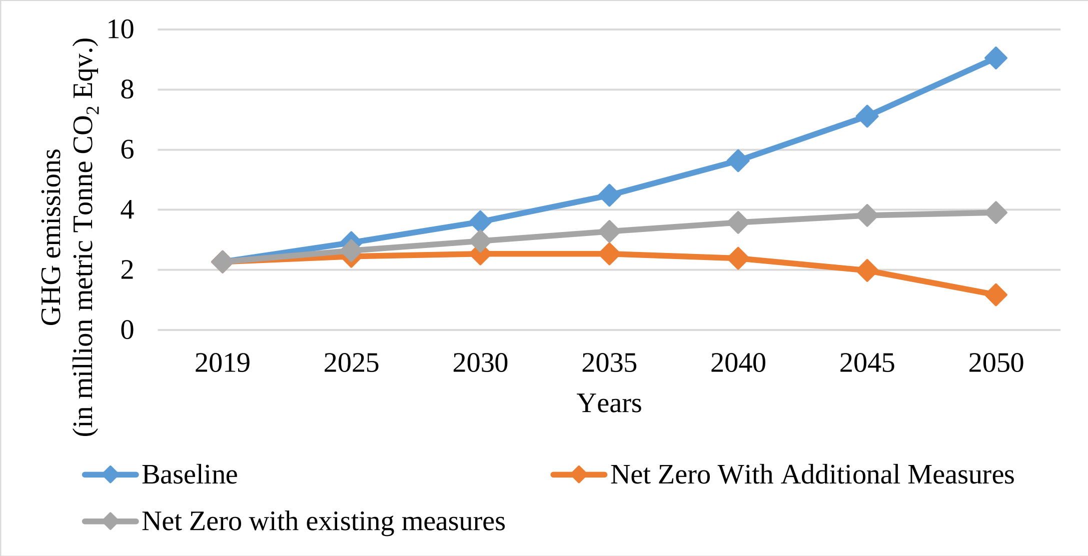

Figure 4.9 Comparison of GHG emission of the baseline with other scenarios

4.7 Environmental effects (Emission in Physical Units) Sector Wise in the baseline scenario

Table 1: Environmental emissions (in '000 metric tons)

Sectors	**2019**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Industrial	1212	1716	2294	3066	4099	5479	7324
Commercial	18	22	26	31	37	45	53
Agriculture	60	100	132	174	229	301	397
Residential	3903	4278	4617	4983	5377	5801	6259
Transport	434	540	649	780	937	1125	1351
Total	5626	6657	7719	9034	10679	12751	15383

Table 1 shows environmental effects in thousand metric tons which include emissions like Carbon Dioxide Biogenic, Carbon Dioxide, Carbon Monoxide, Methane Non-Methane Volatile Organic Compounds, Nitrogen Oxides, Nitrous Oxide, Tot Suspended Particulates, and Sulfur Dioxide. The highest emission in the base year is from the Residential sector which is 3903 thousand metric tons. The residential sector has the highest emission in comparison to other sector in the baseline scenario. This is because it has the highest energy consumption in the base year but, at the end year 2050 industrial sector emits more emissions due to the high energy consumption growth rate, and emissions is forecasted 7324 thousand metric tons in 2050.

4.8 Comparison of Environmental effects (Emission in Physical Units) in different scenarios

The Figure 4.10 shows environmental emissions in million metric tonnes from year base year 2019 to 2050 in three distinct scenarios. Among them baseline scenario has substantial growth in emissions with an annual average growth rate of 3%. In contrast to the baseline in Net-Zero with existing Measures scenario emission decrease at end year 2050 though it has the same emission in the base year. This is because it assumes to implement existing measures to reduce emissions such as promoting renewable sources of energy. Emission is even lower in Net-Zero with additional measures scenario than Net-Zero with existing Measures scenario due to implementing more efficient fuels in additional measures.

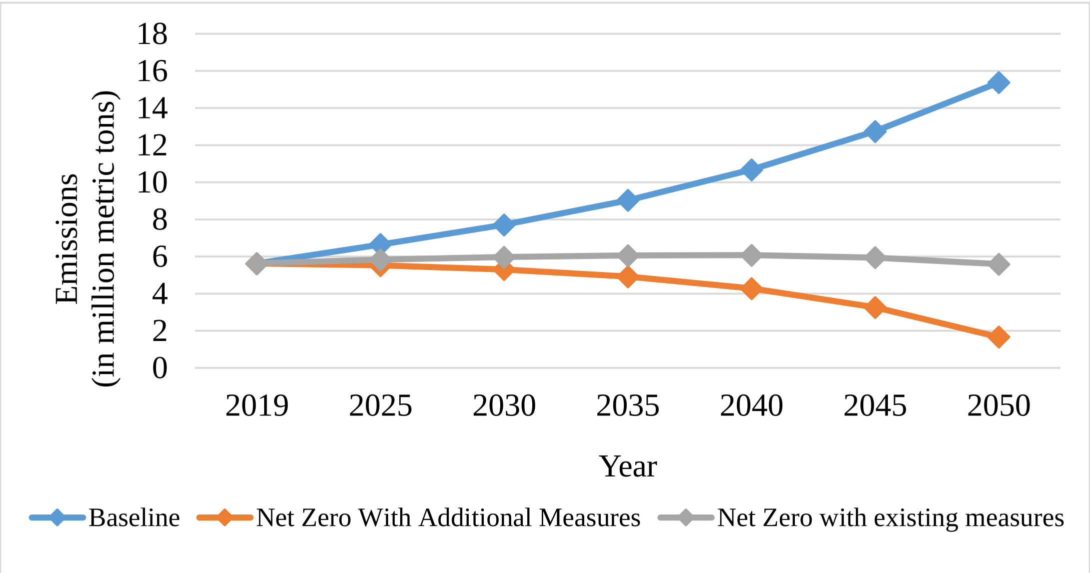

Figure 4.10 Environmental effects comparison in different scenarios

4.9 Energy security Indicators

Table 2: Energy security indicators

Indicators	Unit	Baseline		End Year (NZE)	End Year (NZA)
		Base Year	End Year		
Energy Consumption Per Capita	GJ/Capita	10.4	18.1	13.4	11.6
Electricity Consumption Per capita	Kwh/Capita	308.2	691.4	1291.2	2693.4
Energy Intensity	GJ/$1000	16.2	7.3	5.4	4.7
Electricity Intensity	Kwh/$1000	480.2	277.6	518.4	1081.2
Share of Renewable Energy in Final Energy consumption	Percent	0.6	0.5	0.7	0.9
GHG emission	GHG in KG/Capita	367.5	857.3	370.8	111.3
GHG Intensity	GHG in KG/$1000	572.6	344.2	148.8	44.7
Shannon -wiener Index (SWI)		2.0	2.1	2.0	0.7
Total energy used/Household	GJ/HH	36.9	35.3	20.1	16.0
Environmental effects in Physical unit	Kg/Capita	912.8	1457.7	529.8	158.0

Table 2 shows that the ten energy security indicators assessed in the Baseline, NZE, and NZA scenarios for the base year 2019 and the end year 2050 demonstrate the positive impacts of implementing net-zero emission strategies. While energy consumption per capita increases from 10.4 in the base year to 18.1 in the baseline scenario, it decreases to 13.4 and 11.6 in the NZE and NZA scenarios, respectively, by 2050. This reduction is attributed to the utilization of more efficient fuels in these scenarios. Similarly, electricity consumption per capita has increased in both NZE and

NZA scenarios in the year 2050. It shows that intervention scenarios uses more energy from electricity which results in reduction of GHG emission. Other indicators exhibit positive trends under these scenarios, except the SWI index, which suggests that diversification is not enhanced due to the shift toward renewable energy sources.

4.10 Overview of Energy security Indicators in different scenarios

Energy consumption per capita in three scenarios

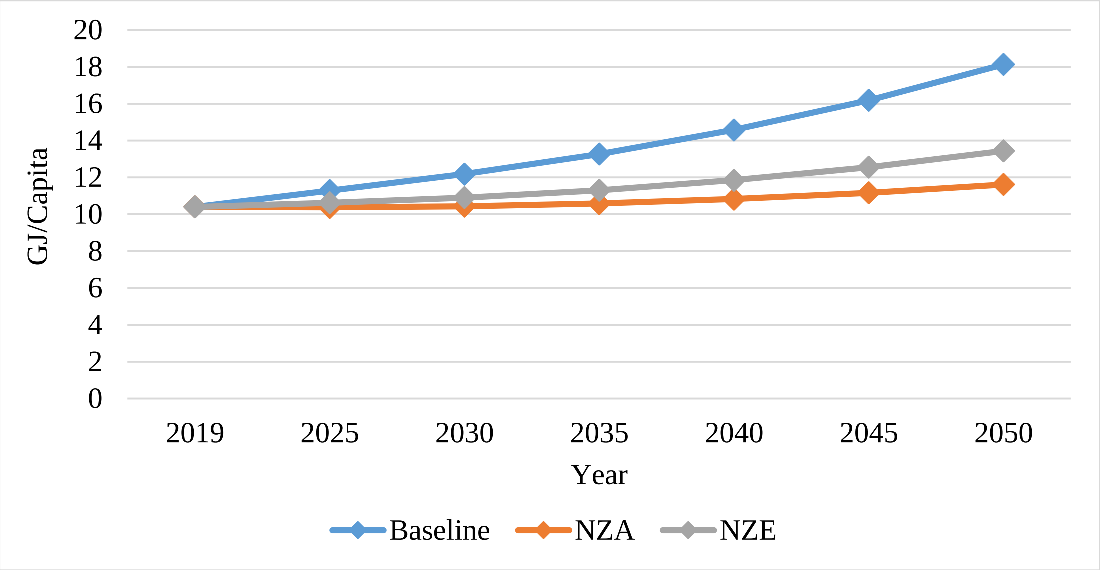

Figure 4.11 Energy consumption per capita in different scenarios

Figure 4.11 shows that Madhesh province exhibits the highest total energy consumption per capita in the baseline scenario. This is attributed to the lower utilization of efficient fuels like electricity across various sectors compared to the other two scenarios. In contrast, the Net-zero with existing and Net-zero with additional measure scenarios demonstrate lower energy consumption per capita due to their implementation of electricity as the primary fuel type across all sectors.

Within these scenarios, the Net-zero with additional measure scenario employs more efficient fuel sources, such as solar and electricity, compared to the Net-zero with existing measure scenario.

Electricity consumption per capita in three scenarios

Figure 4.12 shows total Electricity consumption per capita of Madhesh province. The energy consumption value is highest in NZA scenario. This is because in NZA scenario implements the use of more efficient fuels like electricity in every sector than the other two scenarios so in Net-zero with existing and Baseline scenario has lower electricity consumption per capita as compared to NZA scenario.

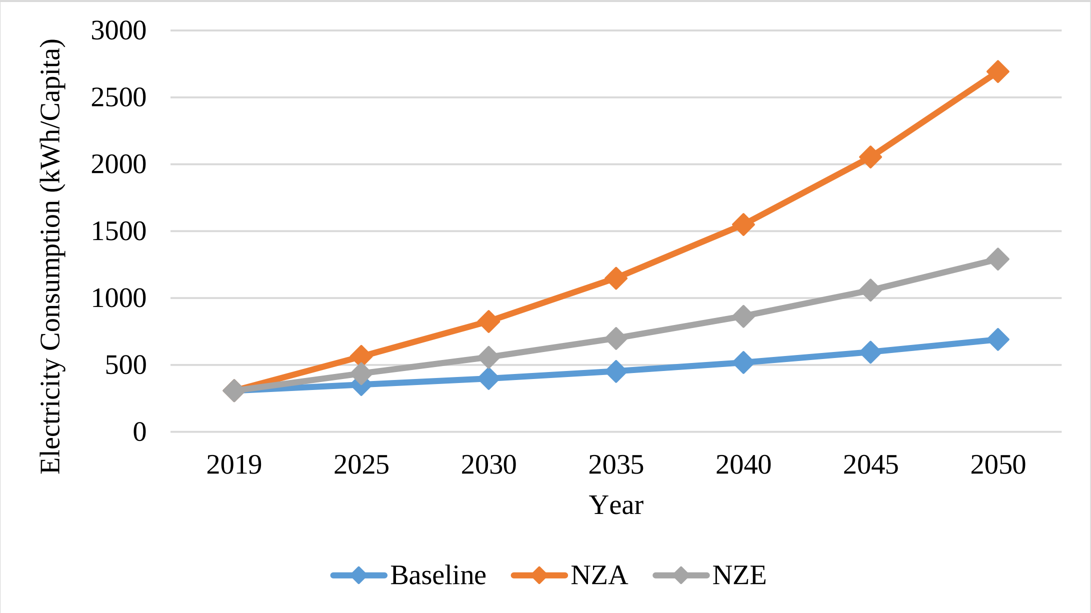

Figure 4.12 Electricity consumption per capita in three different scenarios

Energy Intensity in three scenarios

In Figure 4.13, the graph shows the variation trend of energy intensity of Madhesh province in the baseline scenario in the base year it has 16.19 GJ/$1000. And it decreases to 7.27 in the year 2050. Similar decreasing trend in the other two NZE and NZA scenarios. The decreasing trend shows that the share of renewable energy is increasing and there is a growing shift to electric vehicles in the Transportation sector.

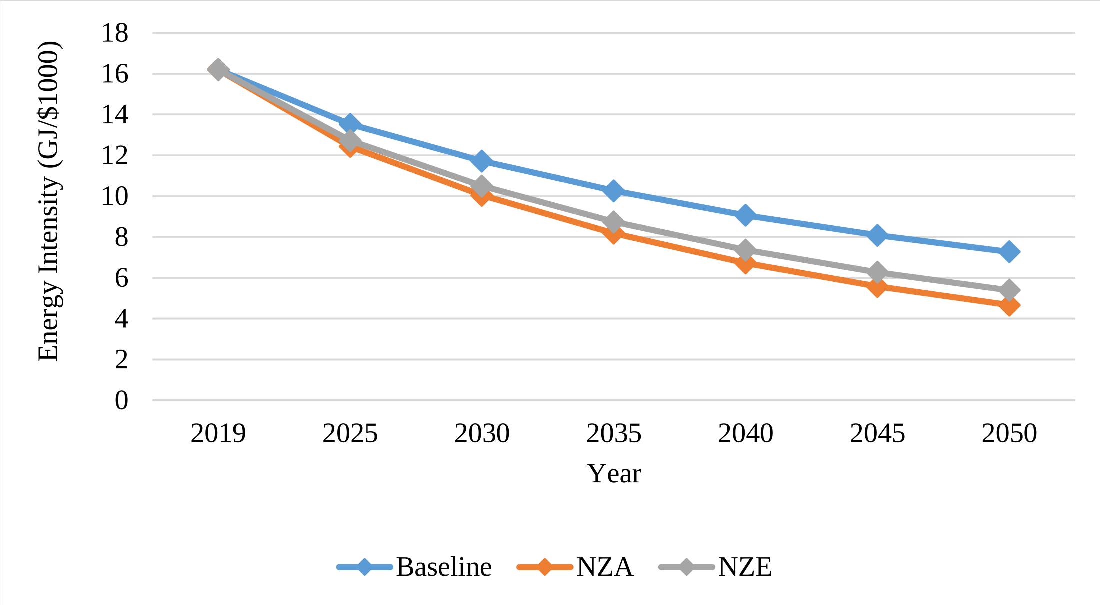

Figure 4.13 Energy intensity in three different scenarios

Electricity Intensity in three scenarios

The Figure 4.14 shows the electricity intensity variation in different scenarios. The value of electricity intensity in the baseline scenario in the base year 2019 is 480.19 kWh/$1000 and its value decreases to 277.56 kWh/$1000 in the end year 2050.

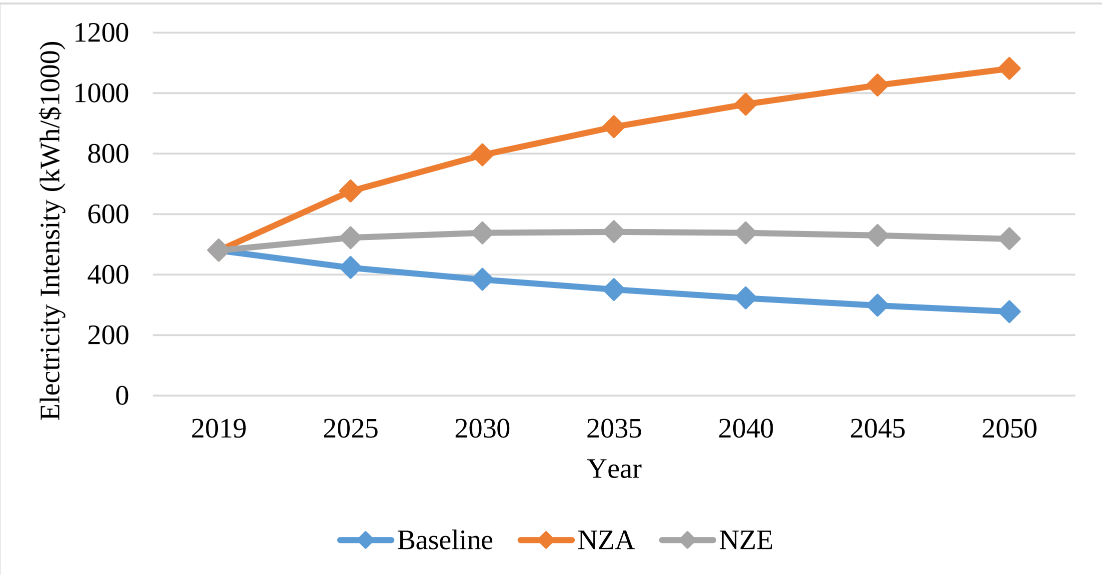

Figure 4.14 Electricity Intensity

In two NZE and NZA have a similar increasing trend in NZE electricity intensity is 518.35 kWh/$1000 and in NZA electricity intensity is 1081.22 kWh/$1000. This is because NZA scenario implements more electricity fuel type for energy demand in each sector.

Share of Renewable Energy Consumption

Figure 4.15 shows the share of renewable energy including traditional biomass in the total energy fuel mix. In the baseline scenario, it is in a decreasing pattern because the share of traditional biomass has decreased as the year exceeds in end year the share of renewable energy is 47.9% from the base year 64.9%. In NZA and NZE scenarios the share of renewable energy is increasing order the growth rate between the years 2040 to 2045 slightly decreases than previous year due to the share of traditional fuel use is high, after year 2045 again share of renewable energy increases, and its shows the increasing pattern.

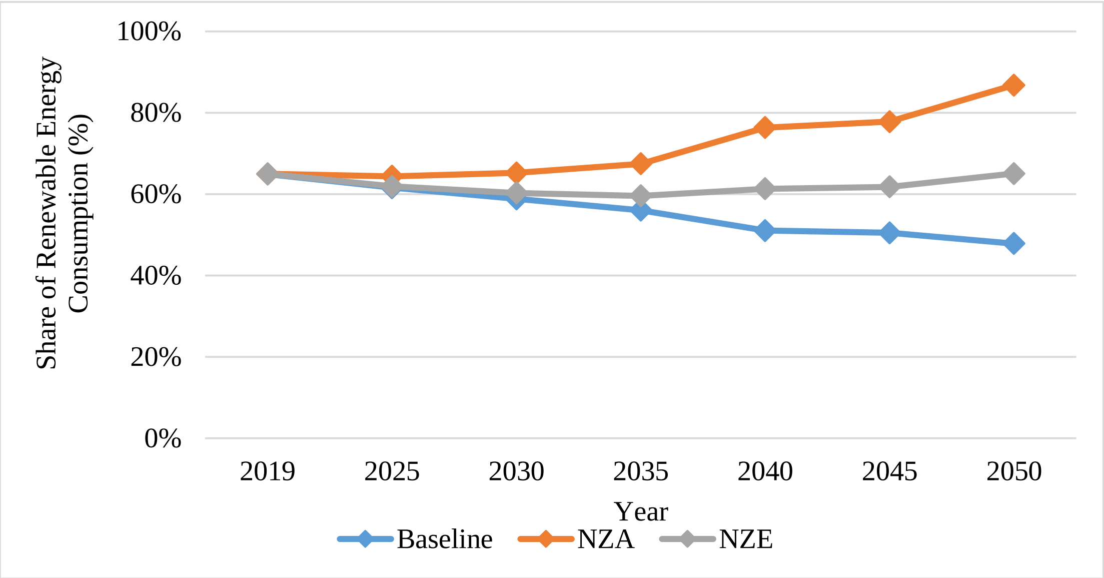

Figure 4.15 Share of Renewable energy consumption

GHG Emission per capita

The Figure 4.16 shows GHG emission (in kg) per capita in three distinct scenarios. The graph has upward trend in the baseline scenario while in NZA and NZE scenarios has downward trend because NZA and NZE scenarios use fuel type that produce less GHG emission like electricity, and solar energy. In the baseline scenario, it has 367.52 Kg per capita in the base year and it increases to 857.32 Kg per capita in the end year. Likewise, it decreases by 56.74% in comparison with baseline scenario in the end year in NZE scenario whereas in NZA scenario it decreases by 87.01% in comparison with the baseline scenario in the end year. It shows that implementing NZA scenario drastically can reduce GHG emission by 2050 year which help to get target Net-Zero emission set by the Government of Nepal.

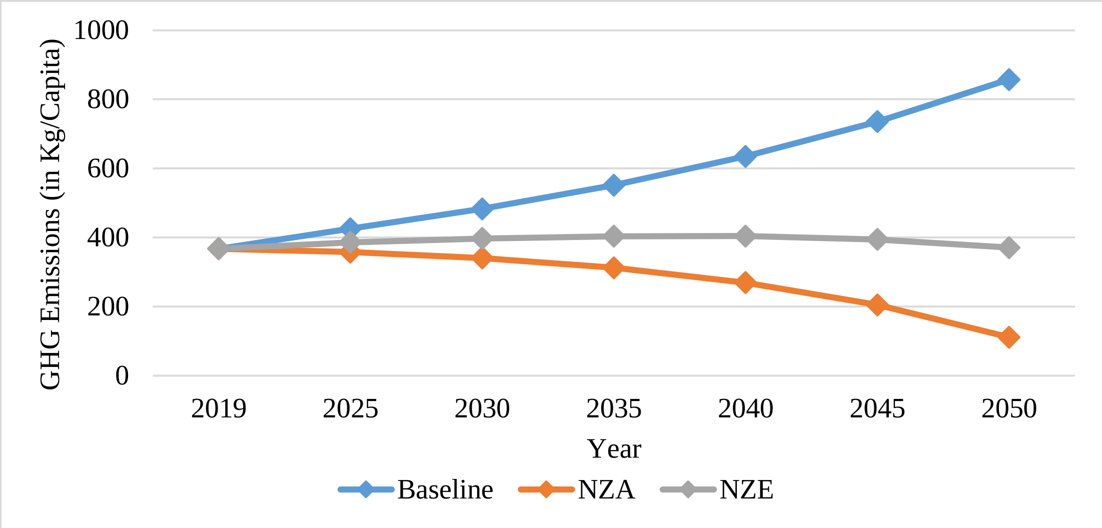

Figure 4.16 GHG Emission per capita

GHG Intensity

Figure 4.17 shows GHG intensity in GHG in kg per $1000. The graph shows the variation trend of GHG intensity of Madhesh province in the baseline scenario in the base year it has 572.62 kg/$1000. And it decreases to 344.15 kg/$1000 in the year 2050.

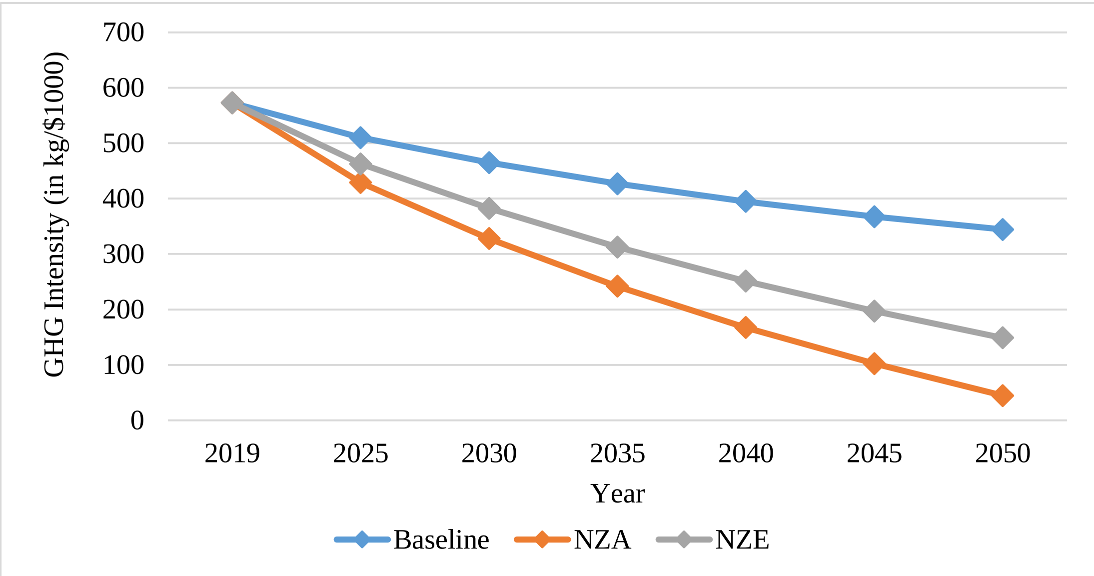

Figure 4.17 GHG intensity

Similar decreasing trend in other two NZE and NZA scenarios. The decreasing trend shows that the share of renewable energy is increasing and there is a growing shift to electric vehicles in the Transportation sector. So that GHG emissions are less than in both NZA and NZE than the baseline scenario which is 44.68 kg/$1000 and 148.83 kg/$1000 by the end year 2050 respectively.

Shannon –Weiner Index (SWI)

Figure 4.18 shows the Shannon-Weiner Index which represents the diversity of fuels in the Madhesh province. It indicates the greater the value higher the security in the province. In contrast in NZA and NZE scenarios, it is decreasing from base year 1.99 to 0.70 and 1.96 respectively. This means the diversity of fuel is not improved in both scenarios, but it shows improvement in diversity in the baseline scenario which increases to 2.05 from the base year 2019. Though NZE and NZA have good results and values in other security indicators.

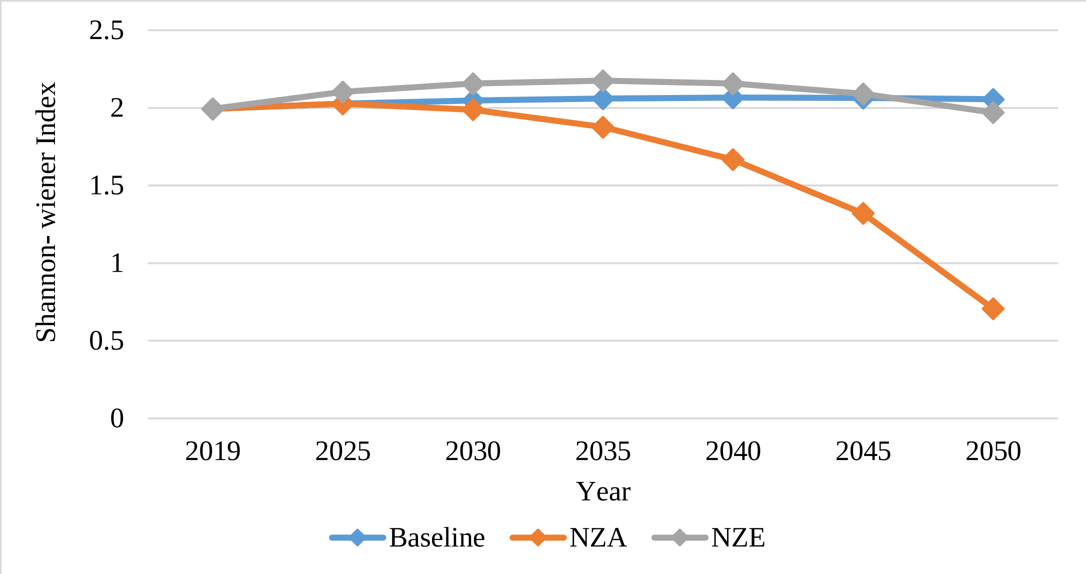

Figure 4.18 Shannon- wiener Index in different scenarios

Energy used /Households

Figure 4.19 shows the energy used/households in three distinct scenarios. The household energy consumption in decrease by 56.58 % by 2050 in net-zero with additional measures scenario because energy intensity is decrease and efficient fuels are implemented in this scenario.

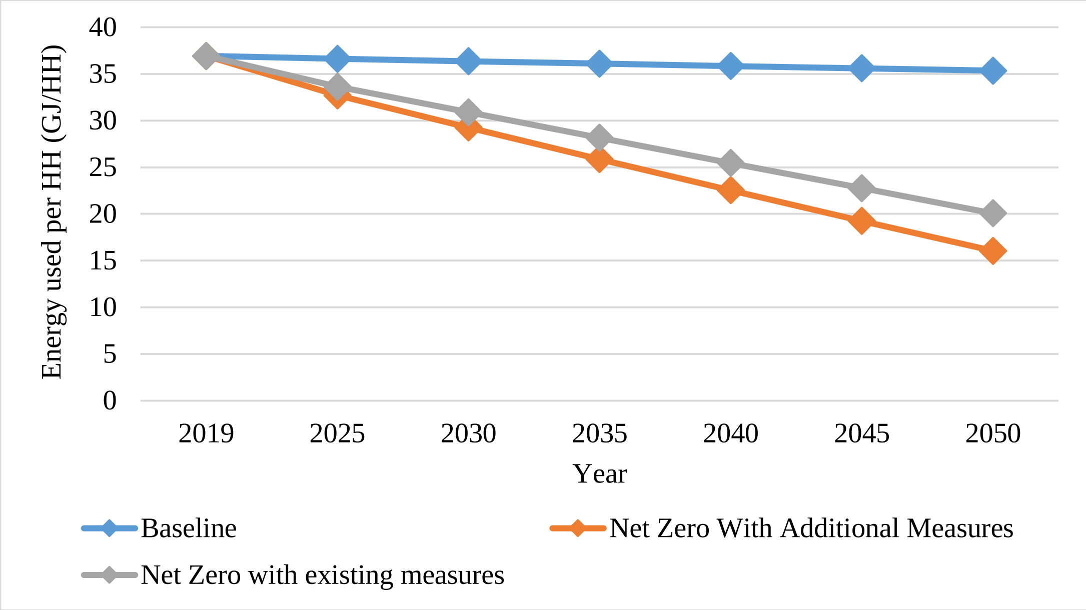

Figure 4.19 Energy used/Households

Environmental effects in Physical unit in KG per capita

In figure Figure 4.20 shows Environmental effects per capita in three different scenarios. In comparison to the baseline scenario, net zero with existing measure scenario effects decreases by about 41.96% in the end year whereas in net zero with additional measure it decreases to 82.69%. Shows that implementing these intervention scenarios significantly can reduce the environmental effects in comparison to the baseline scenario

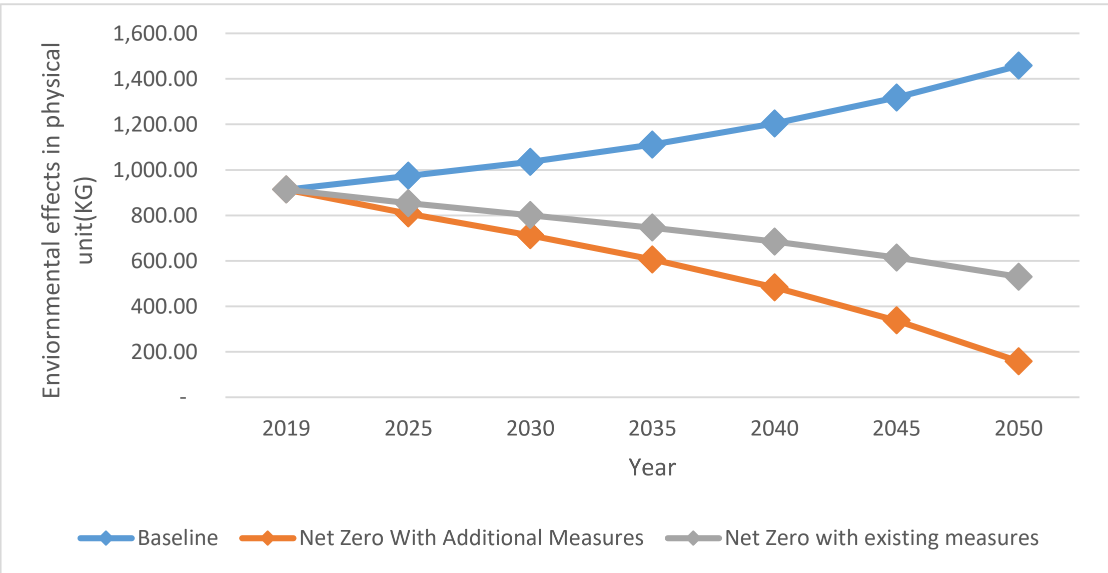

Figure 4.20 Environmental effects in physical unit (KG) per capita

4.11 Validation

As per the Energy Consumption and Supply Situation in Federal System of Nepal Province-02 report (WECS, 2021) total energy consumption from every sector in reference economic growth scenario projected in the year 2050 is 188.03 PJ excluding the construction and mining sector in this study it is forecasted 191.34 PJ in the year 2050 in the baseline scenario.

In case study of Nepal (Shakya, et al., 2023) the energy security indicator Shannon-Weiner Index’s growth rate is 19.76% and the energy intensity decrease by 66.16% in the REF scenario in a period of 2019 to 2050 whereas this study calculated the Shannon-Weiner index’s growth rate is 3.09% and Energy intensity decrease by 55.06% in baseline scenario in period of 2019 to 2050 in case of Madhesh province.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Energy consumption patterns in Madhesh Province reveal the significant impact of urbanization on residential energy demand, the growth in industrial and commercial sectors, and rising energy needs in agriculture. Importantly, addressing energy security challenges tied to fossil fuel reliance is highlighted, particularly in the context of achieving net-zero emissions. The study finds that energy consumption is highest in the residential sector with 62.11% followed by the industrial and transport sectors with a share of 23.58% and 9.20% respectively in the year 2019. The residential share changes to 33.61% whereas the industrial sector is forecasted to be the highest with the share of 50.85% in the year 2050. The different scenarios for energy transition was developed as NZE and NZA considering the national-level policies in Nepal. Analyzing the energy consumption pattern under the baseline scenario the energy consumption is 64,072.36 TJ in 2019 has an increment of about 200% in 2050. In the NZE and NZA scenarios for the residential sector, the share of energy consumption is 25.75% and 23.80%, respectively, in 2050. Likewise, in the industrial sector, the percentages are 55.05% in NZE and 56.66% in NZA scenarios. This indicates a clear shift towards more efficient fuel types for energy consumption in residential sectors under intervention scenarios.

In the baseline scenario, GHG emission is seen to increment by 300% by year 2050 on its value of 2,265 thousand metric tonnes of CO2 equivalent in 2019. Considering the NZE scenario, it is observed that energy consumption can be reduced by 25.86% in the year 2050 which will reduce GHG emissions by 56.75%, and in the NZA scenario energy consumption decrease by 35.92% which results in emission reduction of 87.01% in the year 2050. Analyzing the energy security indicators it is observed that the SWI index increases to 3.09% in 2050 from the base year value of 2.0 in the baseline scenario as it decreases in NZE and NZA scenario to 1.20% and 64.61% from the base year value showing that fuel diversification will reduce if these policies are implemented. Although other energy security indicators like energy intensity, and environmental effect in physical unit in kg per capita is reduced in NZE and NZA scenarios a positive effect is showing the use of more efficient fuel source.

It is observed that in the baseline scenario environmental effects in physical unit is 5.62 million metric tonnes in the base year has an increment of about 173.66% in 2050.

Considering the NZE and NZA scenario, it is seen that environmental effects decrease by 63.65% and 89.14% in comparison with the baseline scenario in 2050.

In this study, the analysis of the energy sector is carried out without analyzing the non-energy sector thus the state of the net-zero emission target is not seen in the year 2050 in this province.

5.2 Recommendation

This study is focused on energy transition in all sectors of the Madhesh province is carried out in this study considering the scenarios as per the policy of the government and the energy security indicators are analyzed. Further studies can be done on the environmental benefit cost of the different scenarios and their other socio-economic implications. Similarly, the study can be carried out to analyze the health effects of emissions in different scenarios. Carbon trade and financing opportunities on the national level can also be included in the research work. The study focused on energy sectors only further studies can incorporate non-energy sectors into scenario analysis which provides more comprehensive understanding of energy demand and GHG emission which identifies opportunities for improvement.

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ANNEXES

Energy demand by Industrial end use sectors in baseline scenario (in TJ)

Branch	2019	2025	2030	2035	2040	2045	2050
Food and beverage	1321.6	1872.2	2502.5	3345.1	4471.5	5977.0	7989.4
Textile and Leather Goods	276.0	391.0	522.7	698.6	933.9	1248.3	1668.6
Chemical And rubber	665.8	943.2	1260.8	1685.3	2252.7	3011.2	4025.1
industrial Mechanical	5384.2	7627.2	10195.2	13627.9	18216.4	24349.7	32548.2
wood paper and products	435.0	616.3	823.7	1101.1	1471.8	1967.4	2629.8
Bricks and structural clay products	7928.4	11231.2	15012.8	20067.5	26824.2	35855.8	47928.3
Other Manufacturing	83.8	118.7	158.6	212.0	283.4	378.8	506.3
electrical engg products	2.0	2.8	3.7	5.0	6.6	8.9	11.8

Energy demand by Industrial end use sectors in Net zero with existing measure scenario in TJ

Branch	2019	2025	2030	2035	2040	2045	2050
Food and beverage	1321.6	1779.0	2274.2	2901.2	3692.5	4687.9	5934.9
Textile and Leather Goods	276.0	346.5	413.6	486.6	561.9	632.7	687.4
Chemical And rubber	665.8	873.0	1088.8	1350.9	1666.0	2040.2	2477.6
industrial Mechanical	5384.2	7369.0	9562.6	12398.0	16058.6	20778.8	26857.1
wood paper and products	435.0	586.1	749.3	955.2	1213.9	1537.1	1938.6
Bricks and structural clay products	7928.4	10857.2	14096.2	18285.5	23697.8	30681.7	39682.2
Other Manufacturing	83.8	118.7	158.6	212.0	283.4	378.8	506.3
Electrical Eng. products	2.0	2.8	3.7	5.0	6.6	8.9	11.8

Energy demand by Industrial end use sectors in Net zero with existing measure scenario (in TJ)

Branch	2019	2025	2030	2035	2040	2045	2050
Food and beverage	1321.6	1693.5	2064.5	2493.5	2977.4	3504.3	4048.6
Textile and Leather Goods	276.0	346.5	413.6	486.6	561.9	632.7	687.4
Chemical And rubber	665.8	828.4	979.4	1138.3	1293.0	1423.0	1493.8
industrial Mechanical	5384.2	7118.5	8948.6	11204.2	13964.3	17312.7	21333.0
wood paper and products	435.0	557.8	678.5	814.6	962.1	1111.9	1247.4
Bricks and structural clay products	7928.4	10884.0	14161.9	18413.2	23921.8	31052.4	40273.0
Other Manufacturing	83.8	113.1	145.1	185.7	237.2	302.4	384.6
Electrical Eng. products	2.0	2.8	3.7	5.0	6.6	8.9	11.8

Energy demand by commercial end use sectors in baseline scenario (in TJ)

Branch	2019	2025	2030	2035	2040	2045	2050
Trade and Retails	465.1	575.3	686.8	819.9	978.8	1168.6	1395.1
Accommodation and Food	214.4	265.2	316.6	378.0	451.2	538.7	643.1
Financial and Real Estate	326.6	404.0	482.3	575.8	687.4	820.6	979.7
Social Services	782.5	967.8	1155.4	1379.4	1646.8	1966.0	2347.1
Other Services	398.1	492.5	587.9	701.9	837.9	1000.4	1194.3

Energy demand by commercial end use sectors in Net zero with existing measure scenario (in TJ)

Branch	2019	2025	2030	2035	2040	2045	2050
Trade and Retails	465.1	575.0	686.3	819.0	977.4	1166.5	1392.1
Accomodation and Food	214.4	252.9	289.7	331.2	378.0	430.4	489.0
Financial and Real Estate	326.6	408.6	492.5	593.5	715.1	861.6	1038.1
Social Services	782.5	957.3	1132.4	1339.4	1584.0	1873.3	2215.1
Other Services	398.1	490.8	584.3	695.5	828.0	985.7	1173.4

Energy demand by commercial end use sectors in Net zero with additional measure scenario (in TJ)

Branch	2019	2025	2030	2035	2040	2045	2050
Trade and Retails	465.1	575.0	686.3	819.0	977.4	1166.5	1392.1
Accomodation and Food	214.4	252.9	289.7	331.2	378.0	430.4	489.0
Financial and Real Estate	326.6	408.6	492.5	593.5	715.1	861.6	1038.1
Social Services	782.5	957.3	1132.4	1339.4	1584.0	1873.3	2215.1
Other Services	398.1	490.8	584.3	695.5	828.0	985.7	1173.4

Energy demand by agriculture end use sectors in baseline scenario (in TJ)

Branch	2019	2025	2030	2035	2040	2045	2050
Water pumping	352.4	490.1	645.1	849.3	1118.0	1471.8	1937.5
Tilling	301.0	648.9	854.2	1124.5	1480.4	1948.8	2565.5
Threshing	136.1	189.3	249.2	328.1	431.9	568.5	748.5

Energy demand by agriculture end use sectors in net zero with existing measure scenario (in TJ)

Branch	2019	2025	2030	2035	2040	2045	2050
Water pumping	352.4	447.1	541.4	650.6	774.7	912.3	1059.3
Tilling	301.0	626.5	800.1	1020.9	1301.3	1657.0	2107.4
Threshing	136.1	184.2	237.0	304.6	391.4	502.5	644.9

Energy demand by agriculture end use sectors in net zero with additional measure scenario (in TJ)

Branch	2019	2025	2030	2035	2040	2045	2050
Water pumping	352.4	436.1	514.8	599.8	686.9	769.1	834.6
Tilling	301.0	559.2	637.7	710.0	764.1	781.3	733.0
Threshing	136.1	168.9	200.0	233.8	269.0	303.1	331.8

Energy demand by residential end use sectors in baseline scenario (in TJ)

Branch	2019	2025	2030	2035	2040	2045	2050
All Others	415.2	420.5	422.0	420.3	414.8	404.9	389.8
Rural\Animal Feed Preparation	529.0	513.9	494.1	466.4	429.6	382.4	323.0
Rural\Cooking	11351.1	11027.7	10601.4	10007.3	9218.4	8204.4	6930.9
Rural\Social Event	407.0	395.4	380.1	358.8	330.5	294.2	248.5
Rural\Space Cooling	280.0	272.0	261.5	246.9	227.4	202.4	171.0
Urban\Animal Feed Preparation	1760.0	2047.9	2319.6	2623.7	2963.9	3344.3	3769.2
Urban\Cooking	22271.0	25913.6	29351.8	33200.4	37505.5	42318.1	47695.1
Urban\Eletrical Appliances	163.0	189.7	214.8	243.0	274.5	309.7	349.1
Urban\Lighting	416.0	484.0	548.3	620.2	700.6	790.5	890.9
Urban\Social Event	740.0	861.0	975.3	1103.2	1246.2	1406.1	1584.8
Urban\Space Cooling	918.0	1068.1	1209.9	1368.5	1546.0	1744.3	1966.0

Energy demand by residential end use sectors in net-zero existing measure scenario (in TJ)

Branch	2019	2025	2030	2035	2040	2045	2050
All Others	415.2	420.7	422.3	420.6	415.1	405.0	389.6
Rural\Animal Feed Preparation	529.0	513.9	494.1	466.4	429.6	382.4	323.0
Rural\Cooking	11351.1	10106.7	8978.1	7778.4	6523.6	5234.9	3940.0
Rural\Social Event	407.0	395.4	380.1	358.8	330.5	294.2	248.5
Rural\Space Cooling	280.0	272.0	261.5	246.9	227.4	202.4	171.0
Urban\Animal Feed Preparation	1760.0	2047.9	2319.6	2623.7	2963.9	3344.3	3769.2
Urban\Cooking	22271.0	23306.4	23937.9	24293.1	24298.7	23868.8	22902.8
Urban\Eletrical Appliances	163.0	189.7	214.8	243.0	274.5	309.7	349.1
Urban\Lighting	416.0	484.0	548.3	620.2	700.6	790.5	890.9
Urban\Social Event	740.0	861.0	975.3	1103.2	1246.2	1406.1	1584.8
Urban\Space Cooling	918.0	1068.1	1209.9	1368.5	1546.0	1744.3	1966.0

Energy demand by residential end use sectors in net-zero additional measure scenario (in TJ)

Branch	2019	2025	2030	2035	2040	2045	2050
All Others	415.2	414.5	411.4	405.7	397.1	385.1	369.6
Rural\Animal Feed Preparation	529.0	513.9	494.1	466.4	429.6	382.4	323.0
Rural\Cooking	11351.1	9644.4	8163.4	6659.8	5171.2	3744.8	2439.0
Rural\Social Event	407.0	395.4	380.1	358.8	330.5	294.2	248.5
Rural\Space Cooling	280.0	272.0	261.5	246.9	227.4	202.4	171.0
Urban\Animal Feed Preparation	1760.0	2047.9	2319.6	2623.7	2963.9	3344.3	3769.2
Urban\Cooking	22271.0	22706.3	22691.6	22242.6	21258.4	19621.6	17195.4
Urban\Eletrical Appliances	163.0	189.7	214.8	243.0	274.5	309.7	349.1
Urban\Lighting	416.0	471.2	521.6	576.3	635.5	699.6	768.8
Urban\Social Event	740.0	861.0	975.3	1103.2	1246.2	1406.1	1584.8
Urban\Space Cooling	918.0	1068.1	1209.9	1368.5	1546.0	1744.3	1966.0

Energy demand by transportation end use sectors in baseline scenario in TJ

Branch	2019	2025	2030	2035	2040	2045	2050
Public Passenger	987.0	1229.8	1477.2	1774.3	2131.3	2560.0	3074.9
Private Passenger	3011.0	3751.7	4506.4	5412.9	6501.7	7809.6	9380.6
Freight	1751.0	2181.8	2620.6	3147.8	3781.0	4541.6	5455.1

Energy demand by transportation end use sectors in net-zero with existing measure scenario in TJ

Branch	2019	2025	2030	2035	2040	2045	2050
Public Passenger	987.0	1198.9	1409.0	1655.3	1943.6	2280.9	2675.2
Private Passenger	3011.0	3720.9	4438.4	5294.1	6314.5	7531.2	8981.8
Freight	1751.0	2181.8	2620.6	3147.8	3781.0	4541.6	5455.1

Energy demand by transportation end use sectors in net-zero with additional measure scenario (in TJ)

Branch	2019	2025	2030	2035	2040	2045	2050
Public Passenger	987.0	1187.4	1383.7	1611.1	1873.9	2177.2	2526.7
Private Passenger	3011.0	3696.8	4385.6	5201.8	6168.9	7314.7	8671.7
Freight	1751.0	2111.2	2465.2	2876.2	3352.9	3904.9	4543.3

Environmental effects in Thousand Metric Tonnes in baseline scenario

Branch	2019	2025	2030	2035	2040	2045	2050
Industrial	1211.5	1716.1	2294.0	3066.3	4098.8	5478.8	7323.5
Commercial	17.7	21.9	26.2	31.3	37.3	44.6	53.2
Agriculture	59.6	100.3	132.0	173.8	228.8	301.3	396.6
Residential	3903.2	4278.1	4617.4	4983.0	5377.0	5801.5	6258.7
Transport	433.8	540.5	649.2	779.8	936.6	1125.0	1351.4

Environmental effects in Thousand Metric Tonnes in net-zero with existing measure scenario

Branch	2019	2025	2030	2035	2040	2045	2050
Industrial	1211.5	1489.0	1737.1	1983.4	2198.4	2333.1	2308.9
Commercial	17.7	18.4	18.5	17.9	16.4	13.6	9.2
Agriculture	59.6	91.5	110.9	133.3	158.8	187.0	217.3
Residential1	3903.2	3703.0	3474.1	3179.6	2810.3	2355.6	1803.7
Transport	433.8	532.8	632.3	750.2	890.0	1055.8	1252.1

Environmental effects in Thousand Metric Tonnes in net-zero with additional measure scenario

Branch	**2019**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Industrial	1211.5	1384.7	1481.4	1485.7	1324.6	885.6	0.0
Commercial	17.7	18.4	18.5	17.9	16.4	13.6	9.2
Agriculture	59.6	80.9	85.2	84.1	73.8	48.6	0.0
Residential1	3903.2	3522.4	3123.9	2641.6	2065.1	1383.2	583.2
Transport	433.8	519.1	602.1	697.5	806.9	932.1	1075.0

GHG emission in Thousand Metric tonnes CO2 equivalent in baseline scenario

Branch	2019	2025	2030	2035	2040	2045	2050
Industrial	983.6	1393.4	1862.6	2489.7	3327.9	4448.5	5946.2
Commercial	17.7	21.9	26.2	31.3	37.3	44.6	53.2
Agriculture	57.9	97.5	128.4	169.0	222.5	292.9	385.6
Residential	805.1	897.9	983.3	1076.8	1179.1	1291.2	1413.9
Transport	400.8	499.4	599.9	720.6	865.5	1039.6	1248.7

GHG emission in Thousand Metric tonnes Co2 equivalent in net zero with existing measure scenario

Branch	2019	2025	2030	2035	2040	2045	2050
Industrial	983.6	1202.7	1395.3	1581.4	1734.8	1812.5	1746.1
Commercial	17.7	17.7	17.0	15.2	12.2	7.4	0.4
Agriculture	57.9	89.0	107.8	129.7	154.5	182.1	211.6
Residential	805.1	838.3	857.1	865.5	860.9	840.1	799.5
Transport	400.8	492.2	584.0	692.7	821.6	974.3	1155.3

GHG emissions in Thousand Metric tonnes Co2 equivalent in net zero with additional measure scenario

Branch	2019	2025	2030	2035	2040	2045	2050
Industrial	983.6	1123.5	1201.3	1204.1	1072.9	716.9	0.0
Commercial	17.7	17.7	17.0	15.2	12.2	7.4	0.4
Agriculture	57.9	78.7	82.8	81.8	71.8	47.2	0.0
Residential	805.1	748.5	682.9	597.6	489.3	354.4	188.8
Transport	400.8	479.1	555.1	642.2	742.0	856.0	985.7

GHG emissions in Thousand Metric tonnes Co2 equivalent in baseline scenario

GHG	2019	2025	2030	2035	2040	2045	2050
Carbon Dioxide	1739.98	2316.44	2941.87	3755.99	4818.65	6209.20	8032.89
Methane	452.18	509.61	563.56	623.95	691.78	768.28	854.96
Nitrous Oxide	73.11	84.14	94.88	107.37	122.00	139.29	159.87

GHG emissions in Thousand Metric tonnes Co2 equivalent in net-zero with existing scenario

GHG	2019	2025	2030	2035	2040	2045	2050
Carbon Dioxide	1739.98	2140.48	2494.71	2863.57	3223.47	3534.20	3730.48
Methane	452.18	427.49	396.94	355.53	301.23	231.62	143.81
Nitrous Oxide	73.11	71.91	69.49	65.45	59.34	50.60	38.49

GHG emissions in Thousand Metric tonnes Co2 equivalent in net-zero with additional scenario

GHG	2019	2025	2030	2035	2040	2045	2050
Carbon Dioxide	1739.98	1963.19	2103.11	2169.08	2099.38	1799.44	1126.92
Methane	452.18	415.54	372.86	316.88	244.96	153.90	39.74
Nitrous Oxide	73.11	68.78	63.09	55.00	43.82	28.63	8.21

Environmental effects in Thousand Metric Tonnes in baseline scenario

Effect	2019	2025	2030	2035	2040	2045	2050
Carbon Dioxide Biogenic	3614.91	4028.39	4424.04	4877.04	5400.86	6013.04	6736.56
Carbon Dioxide	1739.98	2316.44	2941.87	3755.99	4818.65	6209.20	8032.89
Carbon Monoxide	198.18	224.83	250.57	280.40	315.21	356.15	404.68
Methane	15.07	16.99	18.79	20.80	23.06	25.61	28.50
Non Methane Volatile Organic Compounds	33.96	38.88	43.59	49.01	55.28	62.55	71.04
Nitrogen Oxides	11.08	14.34	17.75	22.10	27.71	34.94	44.29
Nitrous Oxide	0.28	0.32	0.36	0.41	0.46	0.53	0.60
Tot Suspended Particulates	0.67	0.78	0.87	0.98	1.11	1.24	1.40
Sulfur Dioxide	11.66	16.02	20.96	27.52	36.26	47.89	63.41

Environmental effects in Thousand Metric Tonnes in net-zero with exiting measure scenario

Effect	2019	2025	2030	2035	2040	2045	2050
Carbon Dioxide Biogenic	3614.91	3422.32	3207.58	2934.24	2591.11	2163.53	1631.96
Carbon Dioxide	1739.98	2140.48	2494.71	2863.57	3223.47	3534.20	3730.48
Carbon Monoxide	198.18	195.66	191.75	185.99	177.99	167.17	152.75
Methane	15.07	14.25	13.23	11.85	10.04	7.72	4.79
Non Methane Volatile Organic Compounds	33.96	34.11	33.87	33.24	32.13	30.43	27.99
Nitrogen Oxides	11.08	12.92	14.49	16.15	17.79	19.23	20.19
Nitrous Oxide	0.28	0.27	0.26	0.25	0.22	0.19	0.15
Tot Suspended Particulates	0.67	0.67	0.65	0.60	0.53	0.43	0.28
Sulfur Dioxide	11.66	14.07	16.24	18.48	20.57	22.15	22.63

Environmental effects in Thousand Metric Tonnes in net-zero with additional measure scenario

Effect	2019	2025	2030	2035	2040	2045	2050
Carbon Dioxide Biogenic	3614.91	3299.99	2957.54	2524.84	1979.59	1291.39	418.31
Carbon Dioxide	1739.98	1963.19	2103.11	2169.08	2099.38	1799.44	1126.92
Carbon Monoxide	198.18	189.33	178.85	164.99	146.85	123.18	92.25
Methane	15.07	13.85	12.43	10.56	8.17	5.13	1.32
Non Methane Volatile Organic Compounds	33.96	32.80	31.25	29.05	26.07	22.09	16.88
Nitrogen Oxides	11.08	12.34	13.14	13.64	13.57	12.50	9.80
Nitrous Oxide	0.28	0.26	0.24	0.21	0.17	0.11	0.03
Tot Suspended Particulates	0.67	0.63	0.57	0.49	0.37	0.22	0.03
Sulfur Dioxide	11.66	13.10	13.89	13.94	12.65	9.09	1.89

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