Analysis of Bhutan's Long-Term Energy Demand Projection Using the End-Use Methodology

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Received: 14 April 2025; Revised: 10 June 2025; Acceptance: 17 July 2025; Published: 17 August 2025

Abstract

This paper addresses the pressing need to project Bhutan's long-term energy demand by considering crucial factors like socioeconomic dynamics, demographic trends, technological advancements, and emerging policies, which are essential for informed policymaking. It employs two scenarios: Business as Usual (BAU) which assumes a normal economic growth rate and follows historical trends in energy demand, while the Policy Motivated Scenario (PMS) scenario takes into account the potential impact of the EV (electric vehicle) Road Map 2035 policy, which aims to promote the use of electric vehicles in Bhutan. The Model for Analysis of Energy Demand (MAED_D) was utilized and the results projection shows that by 2040, the total energy of Bhutan will increase by about 121% (2,194.703 ktoe) under BAU and about 173% under PMS with respect to base year of this study (2017). Under BAU, by 2040, the industrial sector remains the largest consumer (59%), followed by households (21%), transportation (13%) and service (7%). The demand analysis by energy form projects a stable biomass demand at 533.9 ktoe and substantial electricity growth at 747.8 ktoe by 2040. Fossil fuel is anticipated to account 29% of the total energy in 2040 from 12 % in 2017. The motor fuel is expected to reach 286.9 ktoe by 2040. Under the PMS scenario, the electricity consumption will increase consistently reaching 9,866.19 GWh by 2040, which accounts to 44% share of the total fuel mix. Notably the electricity as a transportation fuel is anticipated to grow significantly to 39.42 ktoe by 2040 to represents 19.33% share of the fuel mix in the transportation sector. Furthermore the population and GDP are projected to reach 0.86 million and 5.789 billion US dollars, respectively, by 2040. Per capita GDP is expected to increase from 3477.547 US dollars in 2017 to 6732.48 US dollars by 2040, while final energy per capita and per GDP will account for 22.36 toe/cap and 0.069 kgoe/US$, respectively, by 2040, indicating the evolving energy landscape in Bhutan

Key Words: *Model for Analysis of Energy Demand (MAED, Energy Projection, Base Year, Business as Usual (BAU), Policy Motivated Scenario (PMS), Energy Demand*

1. INTRODUCTION

Energy is regarded as one of the most important parts of social well-being and long-term growth (Kumar, 2020). As society has evolved from hunting-gathering to growing own food, industrialization and digitalization, the need for and use of energy also grows (Suurs et al., 2010). Due to changes in the social, economic, and technological fields, the energy industry is growing quickly, especially in developing economies (Sieed et al., n.d.). The increasing global population has resulted in a corresponding rise in the need for energy, which is a fundamental requirement for facilitating diverse aspects of contemporary society such as transportation, communication, and manufacturing (United Nations, 2021). Energy is essential for economic and social development and improved quality of life (Kanté et al., 2021a) and access to clean, affordable energy and its growing use have often been linked directly to social and economic growth (Bhattacharyya & Timilsina, 2010a). As the population increases and economies continue to advance, the demand for energy rises, and it is more crucial than ever to have access to energy sources that are dependable, cost-effective, and environmentally friendly. According to projections made by the International Energy Agency (IEA), the demand for energy around the world would increase by 25% by the year 2040 (International Energy Agency, 2017).

Bhutan has an abundance of renewable energy sources for various capacities, such as mini, small, large and mega hydro (IRENA, 2019) and the country currently has 2326 MW of installed capacity (MoEA, 2021). In addition to the abundance hydropower potential, Bhutan is also endowed with renewable resources for solar

and wind (MoEA, 2021).With the government prioritizing climate actions for reducing greenhouse gas emissions by focusing on the EV vehicle project by designing numerous policies such as EV Road Map 2035 policy which aims to replace 70 percent of the vehicles with electric vehicles by 2035 is expected to increase the electricity demand in the transportation sector (UNDP, 2023). Furthermore while heavy industries primarily rely on electricity, they have shown an increasing dependence on diesel and coal (UNESCAP, 2021).

Such changes in social, economic, and technological conditions influence the rapid expansion of the energy industry, particularly in developing economies (Sieed et al., n.d.). The combination of a growing population and a stronger national economy increases energy consumption (Hainoun, 2009). Additionally, technological advancements and government policies significantly influence the energy demand of a nation. In order to analyse energy demand pattern and meet the growing demand and moreover to keep pace with the development trend, Sieed et al. asserts that sectoral demand energy growth projection for long term planning and execution is essential. The proper demand forecasting is significant considering current socio-economic growth patterns to identify and explores alternate options (Ardakani & Ardehali, 2014a). Modelling future energy demand ensures effective and efficient energy infrastructure and technology development. Thus, assisting government, policy makers, energy suppliers to effectively plan for the future. Good energy planning reduces the likelihood of supply disruptions and price increases by ensuring adequate power production to meet demand (EIA, n.d.) and moreover projecting the future energy demand is essential for optimizing energy infrastructure, achieving energy security and planning resource allocation.

The current state of study on Bhutan's long-term energy projections shows that there is a remarkable gap in the research that is already out there. In particular, there aren't enough complete studies about how energy usage is shown through sectoral decomposition, considering all important factor unique to Bhutan, such as socioeconomic, technological, demographic factors and emerging policies. Furthermore, the limited available study in this area has conducted in collaboration with the foreign consultants, highlighting the dearth of national expert in this area. Thus, these gaps project the significance of study and can ensure in filling the knowledge gap and provide insights to policymakers and stakeholders and enhance the overall nation's capacity in energy planning. To fill the gap of lack of research stated above by giving a full picture of Bhutan's long-term energy projections is the main goal of this study. By taking into account socioeconomic factors like population growth, and changes in lifestyle, as well as technological factors, energy-efficient technologies, and demographic factors like population age structure and urbanization patterns, it is possible to get a complete picture of Bhutan's energy landscape.

Considering the socioeconomic factors, this study aims to provide reliable and accurate estimates for the future energy landscape of Bhutan. This, in turn, will make it easier to handle energy well and help Bhutan make policies through facts and figures. This study hopes to help Bhutan have a sustainable and resilient energy future by giving policymakers and decision-makers a full understanding of the complex dynamics of energy demand and consumption.

In this study, MAED model has been used to anticipate Bhutan's energy consumption with sectoral decomposition (industry, transportation, service and households) considering socioeconomic, technological, and demographic development based on the current policies scenarios and data until 2040. As shown in Fig 1 the MAED provides a comprehensive comprehension of the dynamics of energy consumption by systematically relating specific energy demands to socioeconomic and technological factors. Through the disaggregation of energy demand into different end-use categories and the consideration of influencing factors such as population growth, transportation modalities, and national priorities, the model provides valuable insights into sector-specific energy consumption patterns.

MAED employs a corresponding set of equations to calculate the energy consumption for each group of end uses. However, these equations are identical in form. Energy demand (ED) in any future year is calculated using the MAED_D generic equation (Kichonge et al., 2014b), where energy demand in future year is determined and could be simplified as in equation 1.

$$ED_t = \frac{ED_b}{DP_b} \times CH_t \times DP_t \quad (1)$$

Where

ED_t represents energy demand in future analysis year, t
$\frac{ED_b}{DP_b}$ is the specific energy demand per unit of the driving parameter.
CH_t is the Coefficient to reflect evolution of specific energy demand due to socio-techno-economic changes per unit of driving parameter in future year, t
DP_t is the Driving parameter creating energy demand in future year
From the equation 1, the key two variables are specific energy demand and the driving parameter. The product of these two parameter is the generic fundamental equation used in the MAED model (Kichonge, n.d.)

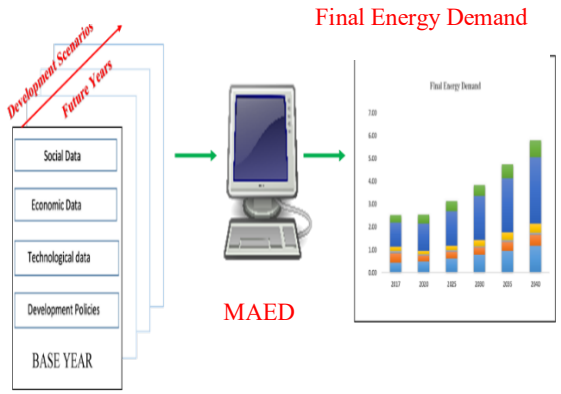

***Fig.1**: Structure of MAED Model for Energy and Electricity Demand (Abdel-Aal, 2008)*

2. METHODOLOGY

The research methodology framework was built based on the actual MAED methodology, and the methodology was devised to answer the research question and objectives while considering data availability and limits. Figure 3 summarizes the research approach through a pictorial representation. Many formula and equation in the model are not revealed in this paper.

2.1 Selection and reconstruction of base year

Selection of the base year forms the first and the crucial step in MEAD (IAEA, 2006). The application of MAED model requires, at first stage, the selection of a base year for the study, chosen among the recent past years to represent the economic and energy background of the country. Furthermore, the selected year should be as near as possible to the present for which reliable and consistent energy and economic information is available. The other objective of selecting a base year in energy consumption analysis is to establish a reference point from which to measure and evaluate future energy consumption trends. Considering the above the criterions the year 2017 was selected as the base year for this study as it is the most recent year with the sufficient data and information for modelling

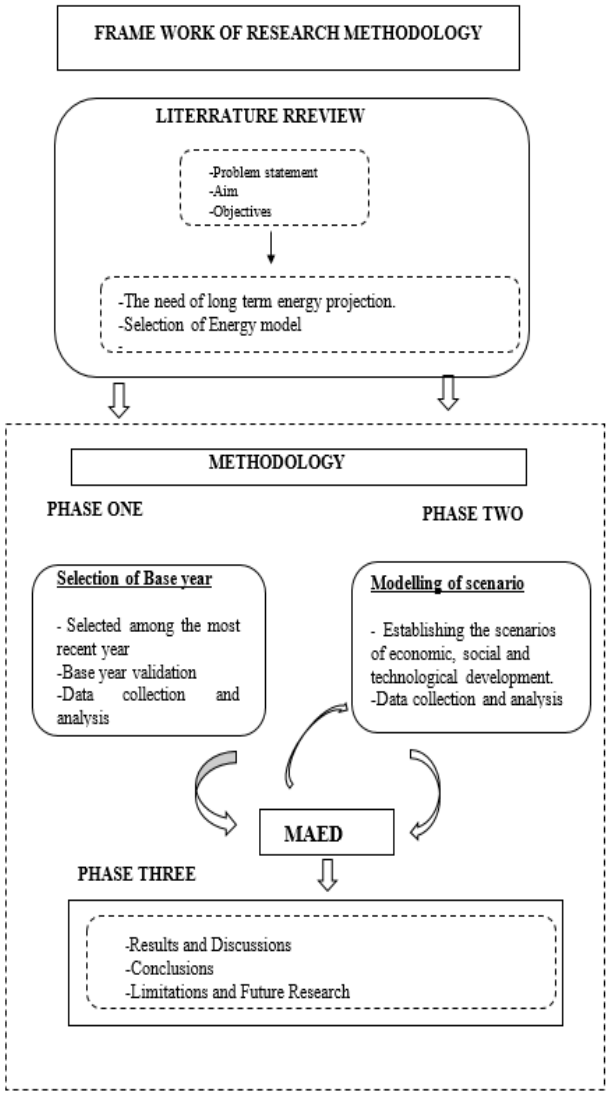

***Fig.2**:Summary of research processes undertaken*

2.2 Base year Validation

After selecting the base year and collecting the data, next step is to reconstruct and calibrate the base year. The 2017 is reconstructed and validated by adopting the following iterative process.

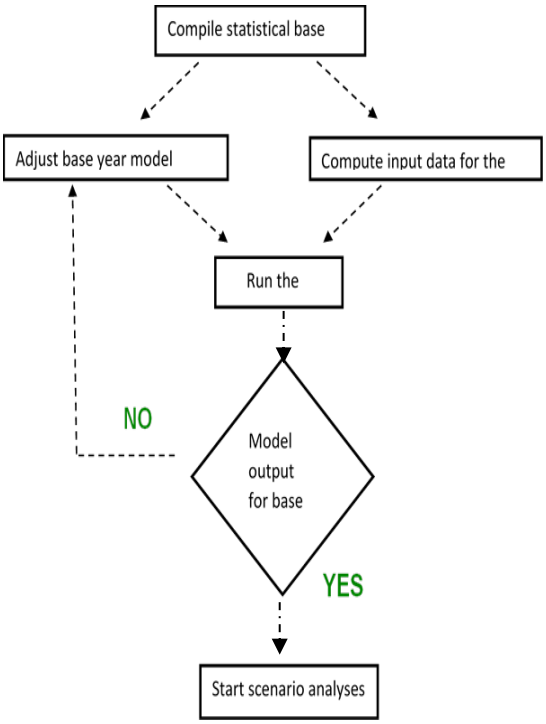

***Fig.3**:Flow chart of base year validation*

3. Input data Overview

As is the case with all models of this disaggregated type the amount of data that must be input into MAED is of a relatively large scale (Nakarmi et al., 2016). All input data belong to one of four groups: economy, demography, lifestyle and the technology as shown in the fig 4

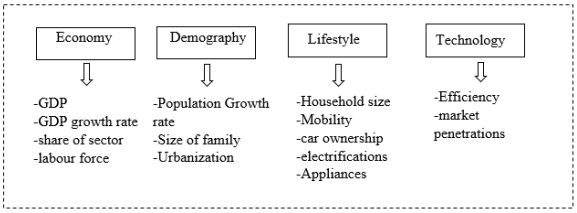

***Fig.4:** Overview of input data*

Each input data category corresponds to a distinct set of input data. Economy data includes the Gross Domestic Product (GDP), its growth rate, and the structural composition of the economy, including the distribution of GDP across various sectors and the size of the labor force. Population size, population growth rate, the proportion of urban and rural populations, and average family size are examples of demographic data. Lifestyle data includes information on dwelling sizes, mobility patterns, vehicle ownership rates, electric technology adoption, and appliance usage. The input data for technology consists of energy intensities in various sectors, the efficiency of end-use equipment and processes, and the market penetration levels of various technologies and energy sources.

2.4 Base year results and validation

As stated in the methodology, the MAED model is run for all sectors after the input data has been prepared according the MAED methodology. The results are then compared to the year's statistical data. If there is a significant difference, the process is done again with the MAED parameter adjusted until the results match the statistical data.

The following figures shows the results of base year obtained from MAED, which are then compared to the statistical value in all four sectors.

2.4.1 Industry sector

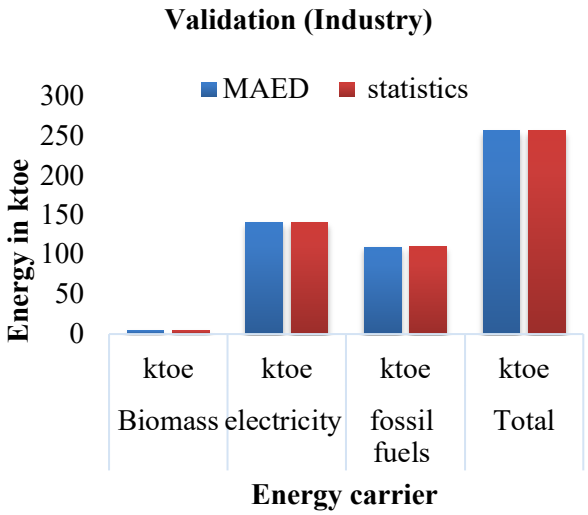

***Fig.5:** Validation results for industry sector*

As shown in the fig.5, the error percentage for each energy carrier is close to 0%, indicating that the base year data for the industry has been reconstructed and validated, and can therefore be utilized for the energy forecast

2.4.2. Household sector

As shown in the figure 6 the error percentage for each energy carrier is not more than 5%. Hence the base year data for the household is validated and reconstructed.

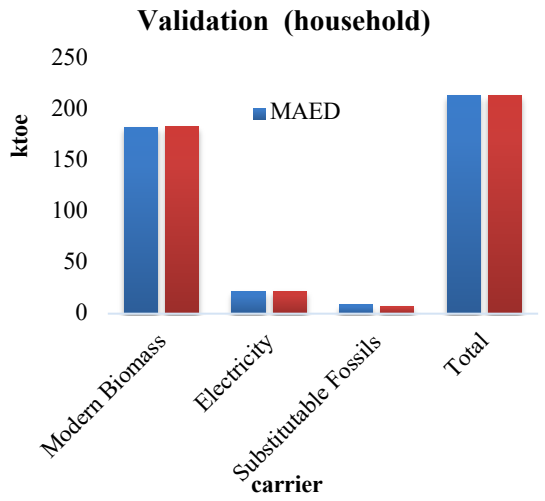

***Fig.6**: Validation results for household sector*

2.4.3. Service sector

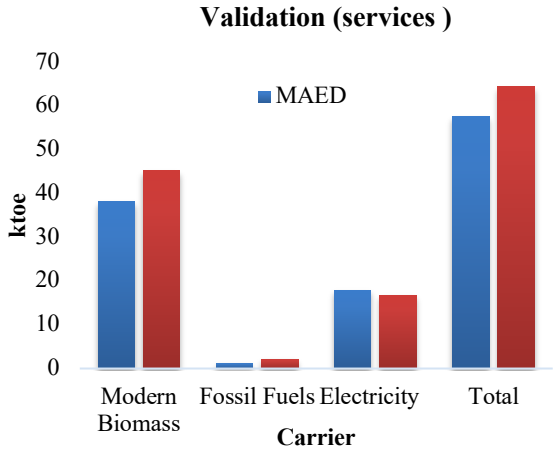

***Fig 7:** Validation results for service sector*

2.4.4. Transport sector

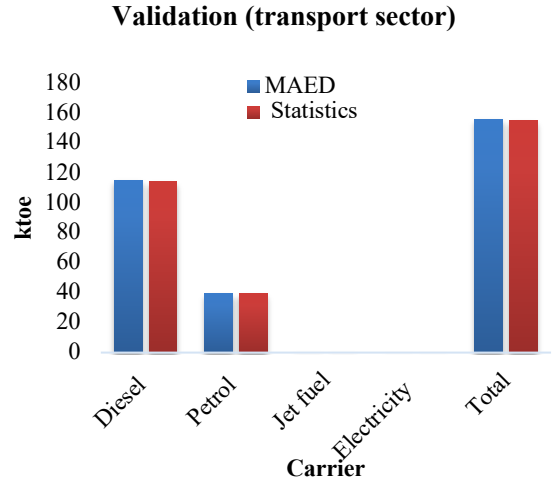

***Fig.8:** .Validation results for transport sector*

2.5. Scenario introduction

The MAED model belongs to a family of models which are based on the scenario approach (Hainoun et al., 2006). Hence the term scenario in MAED is regarded as a consistent description of a possible long-term development pattern of a country, primarily characterized by the long-term direction of government socio-economic policy. For this study, two basic energy demand scenarios are defined and elaborated namely Business as Usual (BAU) scenario or reference scenario and the policy motivated scenario (EV road map 2035). The BAU was developed to assume the normal economic growth rate and follows the historical trends in the demand which is based on the growth projections. Policy motivated scenario (PMS) is designed to project country's future energy demand, considering the potential influence by the particular policy or a combinations of policies of a country. By incorporating the key variables of the policy such as economic indicators and other considerations, this scenario aims to assess the potential outcomes on energy consumptions for the study period. For this study, EV road map 2035 policy, has been used as the policy to examine its possible energy scenario within the PMS framework

2.6. Scenarios overview

The Table 1 shows modelled scenarios at a glance, while highlighting quantitative key parameters and their differences the text.

***Table 1:** Scenario overview*

Parameter	Business As Usual(BAU)	Policy Motivated Scenario (PMS)
Base year	2017 (the latest year for which most of the data points are available and the year with stable conditions of energy consumption.)	
Demography	Projection of population in Bhutan from 2017 to 2040 was agreed as follows: 2017 - 727150 2040 – 860000	
Household size (persons per household)	2017: 4 2040: 3.7	
Urban / rural (%)	2017: 37.8% / 62.18% 2040: 52.52% / 47.47%	
GDP (us$ billion)	2017: 2.52870 2040: 5.78997	
GDP per capita (us$/capita)	2017: 3477.54934 2040: 6732.48584	
Transport activity	Not influenced by EV Road Map 2035	Influenced by EV Road Map 2035 (70 % vehicles to be replaced with electric vehicles.

3. RESULTS AND DISCUSSIONS

After defining the basic information and the assumptions for both the scenarios, it is run in the MAED model. The modelling results for the two

scenarios formulated to represent the possible development of Bhutan based on the social, economic, and technological development

3.1 Business as Usual (BAU) results

a. Population and the GDP

Table 2 shows the basic information on macroeconomic environment of Bhutan for the study period. The prediction is done based on the

Table 2: *Population and GDP result*

Item	Unit	2017	2020	2025	2030	2035	2040
Population	Million	0.72715	0.74363	0.79700	0.82100	0.84300	0.86000
Population growth rate	% per annum	-	0.75000	1.39587	0.59513	0.53028	0.40011
Urban Population	%	37.81460	39.00000	42.01408	45.26109	48.75905	52.52735
Person/ urban Household	cap	4.00000	3.80000	3.78104	3.76217	3.74340	3.72472
GDP	US$ Billion	2.52870	2.54109	3.12803	3.83847	4.72960	5.78997
GDP Growth rate	% p.a.	-	0.16300	4.24385	4.17833	4.26370	4.12869
GDP per capita	US$/Cap	3477.54934	3417.11903	3924.74089	4675.33964	5610.40701	6732.48584
Sectorial shares of GDP							
Agriculture	%	17.37174	19.20000	20.06003	20.20741	20.20741	20.20741
Construction	%	15.87159	9.99000	9.02605	8.18079	8.18079	8.18079
Mining	%	4.22042	2.70832	2.20013	1.79292	1.79292	1.79292
Manufacturing	%	7.25073	5.85637	6.36657	6.94302	6.94302	6.94302
Service	%	42.06421	46.60000	48.31479	50.25042	50.25042	50.25042
Energy	%	13.22131	15.64531	14.03243	12.62544	12.62544	12.62544

The population of Bhutan is expected to grow consistently from 2017 to 2040. The population in 2017 stood at 0.72715 million and by 2040 it is projected to reach 0.86 million. In 2020 the population growth rate was 0.75% which indicates a moderate increase in population. However between the year 2020 and 2025, the growth rate is expected to rise to around 1.39% and from 2025 onwards, the population growth rate begins to decrease gradually. By 2040, the growth is expected to reach 0.40011% indicating the modest growth rate in the later years.

Similarly GDP shows a steady upward trend with the projected increase from 2.5387 billion US$ in 2017 to 5.789 billion US$ by 2040. It was observed a slow growth rate between 2017 and 2020 mainly because of the slow economic activity because of COVID 19. However GDP growth rate is expected to rise significantly from 2020, suggesting an improvement in economic activity. Moreover per capita GDP also expected to increase from 3477.547 US$/cap in 2017 to 6732.48 US$/cap by 2040.

b. GDP formation by sector

The results of the shares of GDP reveals a significant shift towards the service sector with 50.25% (2.91 billion US$) by 2040 from 42.06% (1.06 billion US$) in 2017. Hence the service sector is expected to be the dominant contributor to the overall GDP of Bhutan.

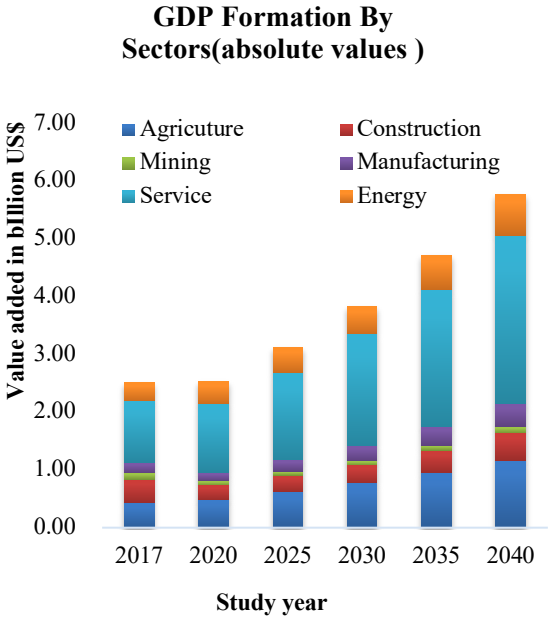

Fig.10: *GDP formation by sector*

The agriculture and manufacturing sector is expected to maintain the relatively stable share in the GDP composition with 20.2% and 1.79% respectively by 2040. The constructions sector shows a declining contribution to the GDP share of a country with 15.87% in 2017 to 8.18% in 2040. As far as mining and energy sector are concerned, it plays a smaller yet consistent roles in the overall GDP formation of the country. It is expected that in the BAU scenario the mining would occupy 1.79% and the energy sector will contribute 12.6% by 2040.

c. Energy Demand

Using the validated base year and the BAU scenario, the energy demand is projected until 2040. A numerous projection results are obtained. The projection includes the comprehensive estimation of total final energy demand by energy form as well as the total final energy demand segmented by defined sector. Furthermore, it also includes energy demand and its share within each sector and many other important findings.

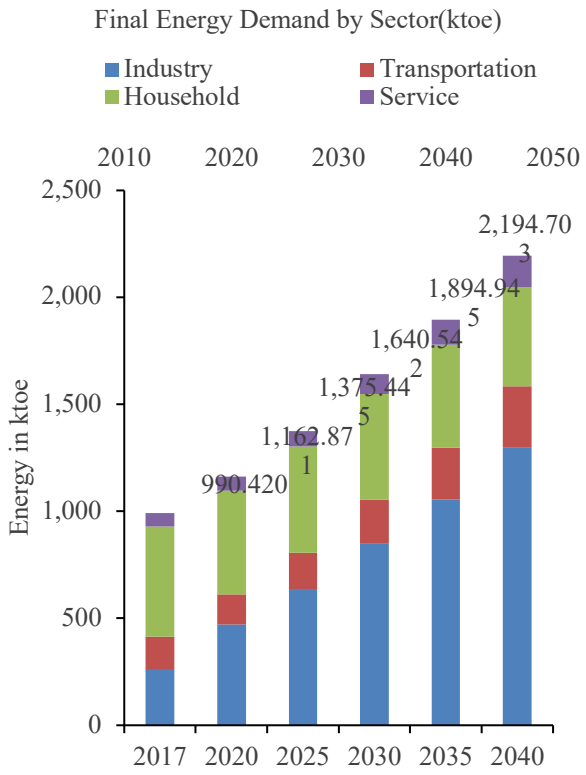

Fig. 11: *GDP formation by sector*

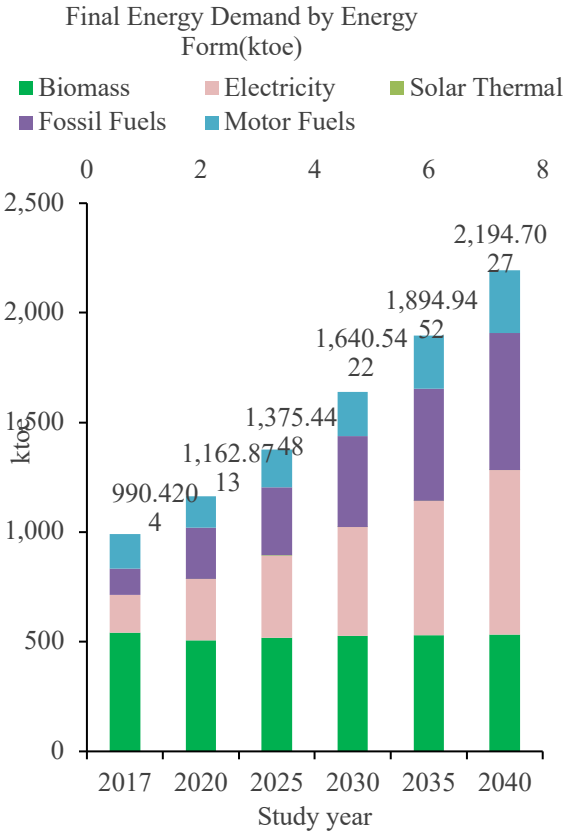

Fig. 12: *Final energy demand by energy form*

The Fig. 12 shows the final energy demand by sector in ktoe. The energy demand of industrial sector in the BAU shows a steady rise over the years with 257.771 ktoe in 2017 and 1,297.866 ktoe by 2040. This suggests a significantly increase of energy demand in the industrial sector due to the expanding manufacturing activities. For transportation sector, there is a slightly dip between 2017 and 2020, however from 2020 the energy demand in the transportation sector is expected to grow from 142.212 ktoe in 2020 to 287.461 ktoe in 2040.

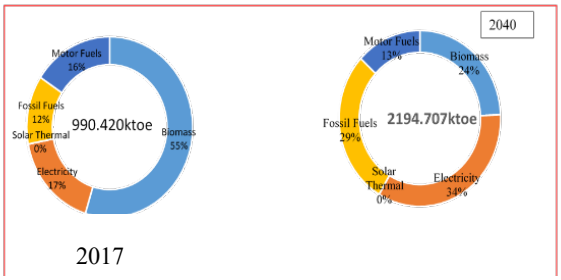

Fig.13: *Final Energy demand by energy form in percentage*

The Fig. 13 shows the final energy demand by energy form under BAU scenario. The demand for biomass is expected to be remained relatively stable over the years with a slight increase projected in the future year. In 2017 it was accounted for 542.3 ktoe (55% of total energy in 2017) and it is expected to grow 533.9 ktoe by 2040 which is around roughly 24% of the total energy of 2040. According to the results, the demand for electricity has shown significant growth with 170.7 ktoe in 2017 and is expected to grow steadily to 747.8 ktoe in the projected year of 2040. The increased trend in the electricity indicates a greater reliance on electricity and the transition from biomass based fuel for the various purposes. The solar thermal as an energy source was negligible in 2017 but it is expected to reach 0.7 ktoe by 2040. Fossil fuel have been the dominant energy source with 12% of the total energy in 2017 and it is expected to account 29% of the total energy in 2040. As for the motor fuel, the results shows the fluctuation over time but it is projected to grow steadily with 286.9 ktoe by 2040.

d. Electricity demand

As electricity directly contributes to the quality of people's life, it gets special attention in this analysis. As shown in the figure 22 the total electricity demand is expected to grow consistently over the years. From 1,985.26 GWh in 2017, it is projected to grow 8,697.49 GWh by 2040 which is the growth of around 338%. The analysis shows that the electricity demand is

dominated by the industry sector in all study years.

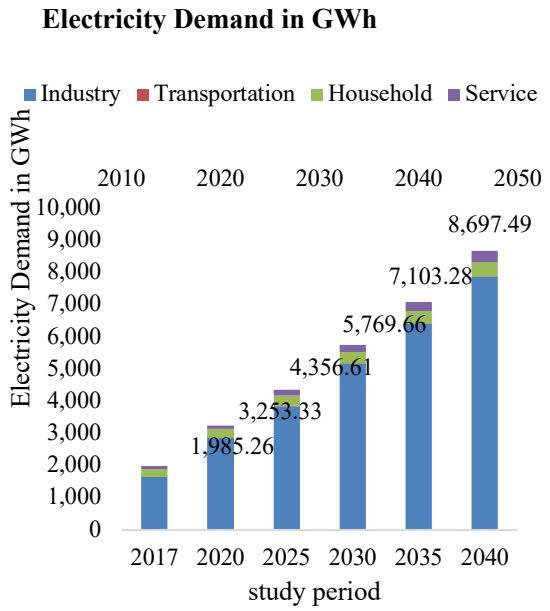

Fig.14: *Electricity demand*

3.2. Final energy demand by energy form in four major sectors

The final energy demand is further examined by breaking it down into its respective energy forms across four main sectors.

a. Final energy consumption in industry

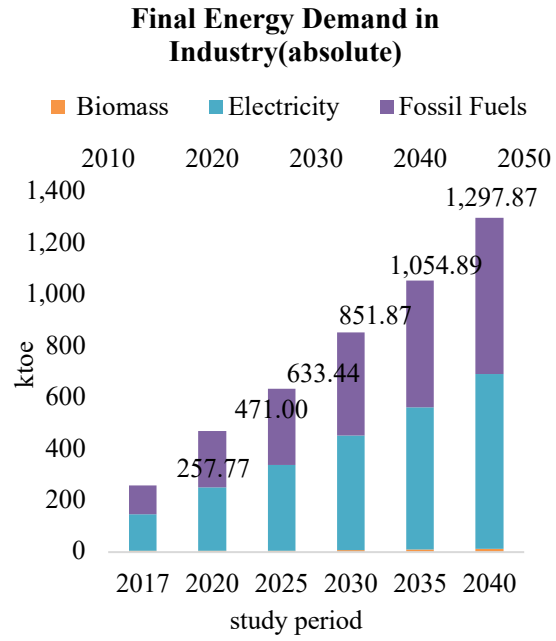

Fig.15: *Final energy demand in industry*

The biomass is expected to reach 12.44 ktoe by 2040 and occupies little share in the energy mix compared to electricity and fossil fuel. The staggering growth is seen in the electricity as a fuel source in the industry with the projection to reach 678.84 ktoe or 7,894.87 GWh by 2040. However fossil fuel consumption in industry sector remains substantial with projected 606.59 ktoe by 2040 from 110.82 ktoe in 2017

b. Final energy demand in transportation

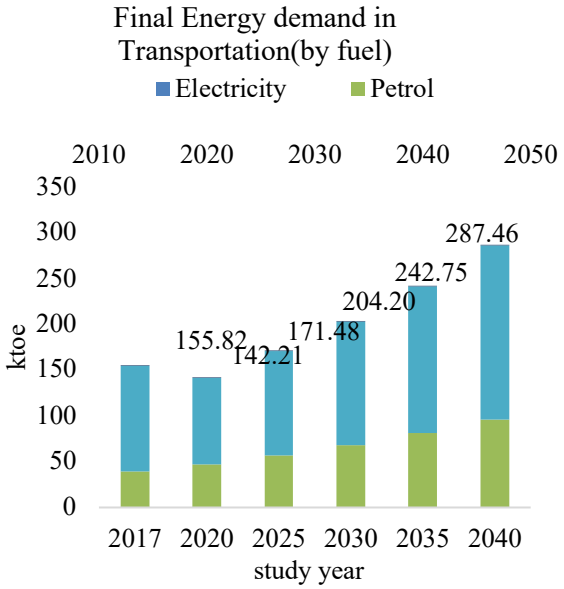

Fig. 16: *Final energy demand in transportation*

The energy consumption in the transport sector simulated under BAU has shown interesting results over the years. In the base year, the majority of energy consumption was dominated by diesel accounting for 115.41 ktoe, followed by petrol with 39.73 ktoe. At the same time, the electricity and jet fuel had relatively smaller shares with 0.03 ktoe and 0.65 ktoe, respectively. However from 2020 the electricity consumption is expected to rise significantly and reach 0.54 ktoe by 2040 but the jet fuel consumptions is expected to remain relatively stable. In the same time frame the consumption of petrol and diesel is projected to continue its upward trajectory reaching 95 ktoe and 190.25ktoe respectively by 2040.

c. Final energy demand in Household

The energy consumption pattern of rural and urban household shows a significant changes over the years. The biomass used for cooking and heating has shown the decreasing trend over the study years. In 2020 it has accounted for 447.43 ktoe, a decrease from its 2017 level of 483.53 ktoe. This trend indicates the shift towards the cleaner and more efficient alternative fuel in place of biomass.

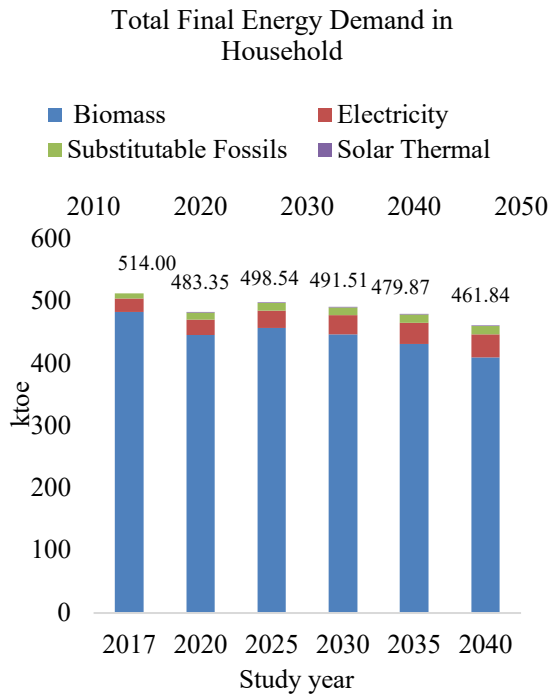

Fig. 17: *Final energy demand in Household*

d. Final energy demand in service sector

In the service sector, the total final energy consumed experienced a gradual increase from the base year under BAU scenario, reaching 60.74 ktoe in 2020 from 57.28 ktoe in 2017. From there the increasing trend is expected to continue with estimates of 68.27 ktoe in 2025, 88.09 ktoe in 2030, 111.06 ktoe in 2035, and 139.25 ktoe in 2040

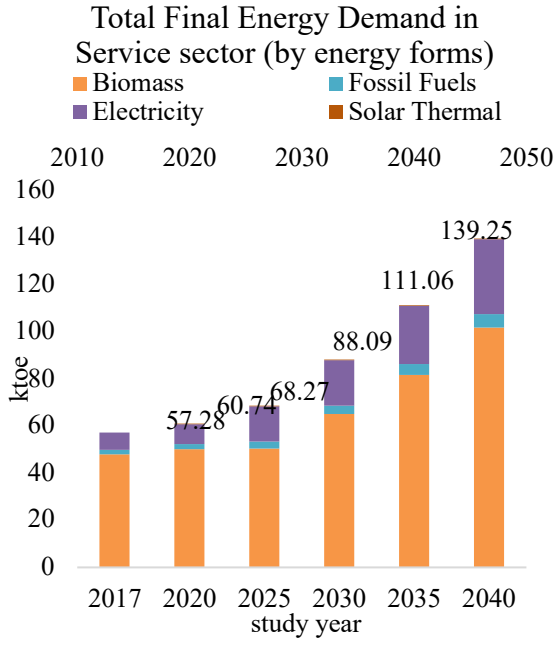

Fig. 18: *Final energy demand in service sector*

The results suggests the large portion of the energy consumed is from biomass sources followed by fossil fuel and electricity. The electricity is expected to show the substantial growth throughout the study year, indicating the expanding use of electrical appliances and technologies in the service sector as indicted in the Fig. 15.

4. POLICY MOTIVATED SCENARIO (PMS) RESULTS

The PMS scenario is inherited from BAU with the modifications, particular focusing on the EV Road Map 2035 policy and investigating how it might affect the energy environment of the country in the future. Under this study it was assumed the results for GDP, demography, energy consumption in sector such as household, service, and industry remain same as BAU. The results in transportation sector and total final energy demand is analysed as presented in the following sections.

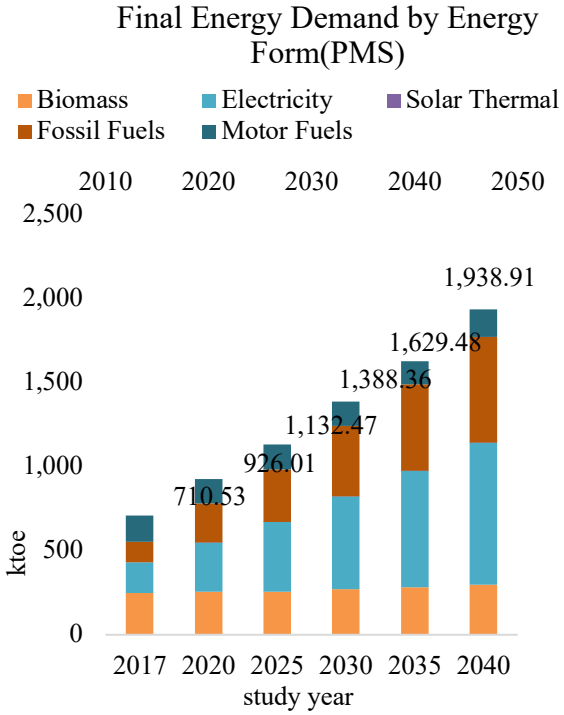

Fig.19: *Final energy demand by energy form (PMS)*

The final energy demand by energy from under PMS scenario which demonstrates a rather more sustainable energy profile. Under PMS the biomass consumptions follows a similar trend but a slower growth rate as compared to growth rate observed in BAU. The biomass consumption is expected to reach 296.810 ktoe by 2040 from 247.791 ktoe in 2017. As anticipated the electricity consumption has increased

significantly as the result of replacing 70 percent of the vehicles with electric vehicles in the next 14 years, by 2035 reaching to 848.339 ktoe by 2040. By 2040 electricity is expected to occupy 44% in the total fuel mix against 26% in 2017 under PMS. However as compared to BAU, under PMS fossil and motor fuel consumption is anticipated to experience slight decline from 2017 to 2035.

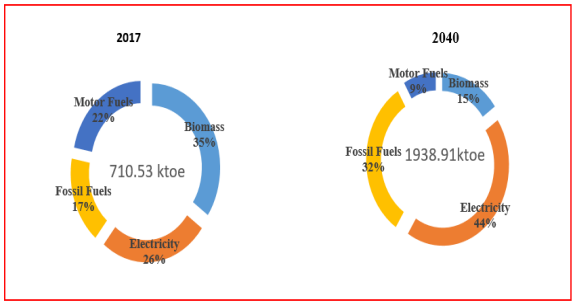

Fig. 20: *Final energy demand by energy form in percentage*

4.1 Energy Demand

Under the PMS scenario, the industrial sector is the largest consumer of electricity accounting for about 76.67% of the total consumption in 2017 followed by household and service sector with 11.74% 11.47% respectively. Meanwhile transportation accounts for smaller share with only 0.01%. However between 2030 and 2035, while industry sector continues to be the largest electricity consumer, with the shares of 80.23% and 79.61% respectively, the transportation sector exhibits the substantial growth in its share, reaching 4.81% in 2035 or 388.62 GWh. By 2040, the electricity consumption in transportation is expected to reach 458.44 GWh.

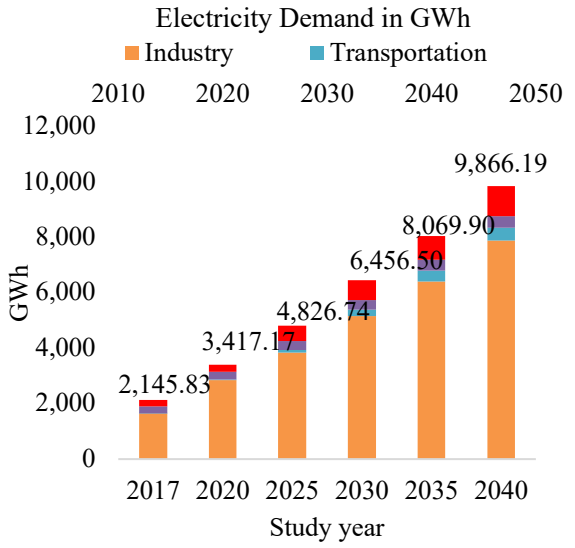

Fig. 21: *Electricity Demand in GWh in PMS*

Overall the total electricity consumption is projected to significantly increase from 2,145.83 GWh in 2017 to 9,866.19 GWh in 2040 which highlights the importance of addressing the energy demand and diversifying the electricity sources such as renewable energy sources to meet the rising the electricity needs across sectors.

4.2 Final energy demand in transportation (by fuels) under PMS Scenario

Under the PMS scenario, electricity as a transportation fuel is expected to grow significantly in the transportation sector over the time. Starting from the modest 0.03 ktoe in the base year electricity consumption is anticipated to reach 39.42 ktoe by 2040. From 2017 to 2020, the electricity consumption in transportation experiences a notbal jump from 0.03 ktoe to 0.27 ktoe which indicates the initial push of EV vehicles in the industry. By 2025, electricity consumption reaches 8.11 ktoe and this increasing trend continues for the future years. By 2040 the share of electricity will be around 19.33% against the 0.019% in the 2017 whereas the diesel share will fall down from 74.04% in 2017 to 17.21% by 2040. At the same time petrol consumption is likely to experience a slight decrease from 25.49% in 2017 to 17.21 % in 2040

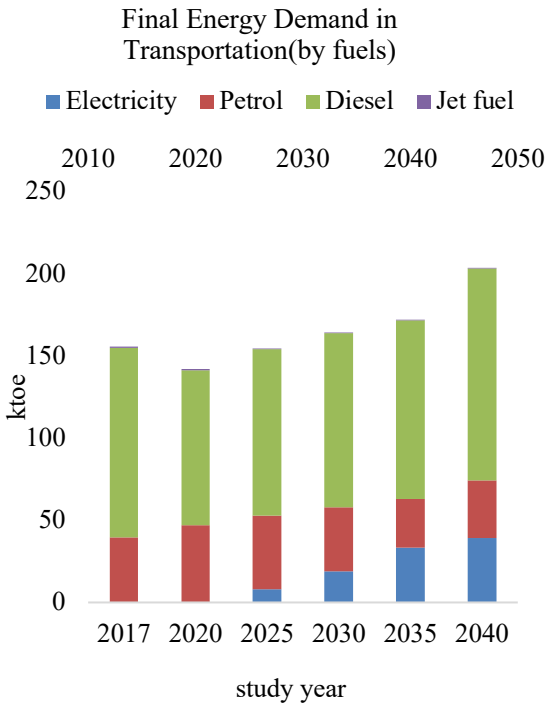

Fig. 22: *Final Energy Demand in Transportation (by fuels) in PMS*

5. CONCLUSION AND FUTURE SCOPE

5.1. Conclusion

By employing the end-use approach, the long term energy demand (2017-2040) of Bhutan has been projected according the two scenarios specified (BAU and PMS) which possibly represents the future socio-economic and the energy trends of the country. The year 2017 was chosen as the base year which was then validated in the MAED model to represent the economic and energy background of the country. The Business as usual scenario was developed to assume the normal economic growth rate and follows the historical trends in the demand which is based on the growth projections and Policy motivated scenario (PMS) on the other hand was designed to project country's future energy demand to assess the potential outcomes on energy consumptions because of the EV road map 2035 policy of Bhutan which is in line with the Low Emission Development Strategy (LEDS) for Surface Transport (2021-2050) policy.

The final energy per capita (toe/cap) and the final energy per GDP (kgoe/US$) for the base year was 11.93 and 0.072 respectively with the final electricity demand of 1,985.26 GWh. During the study period, the final energy per capita (toe/cap) is expected to rise to 22.36 by 2040 whereas the final energy per GDP (kgoe/US$) will slightly fall to 0.069 by 2040 under for the BAU scenario. However the electricity demand is anticipated to grow to 8,697.49 GWh by 2040 which is the growth of around 338% from the base year under BAU. Similarly for the PMS scenario final energy per capita (toe/cap) is projected to increase to 21.29 by 2040 and the final energy per GDP (kgoe/US$) will fall to 0.0662 by 2040 which indicates the using the energy more efficiently as well as the advancement of efficient technology. Meanwhile the electricity demand will be 9,866.19 GWh in 2040 under PMS which is due to the optimistic objectives of EV road map 2035 policy of Bhutan.

The total final energy demand in the both scenario is expected to increase over the study period. BAU shows a higher growth rate compared to PMS and hence resulting in higher energy consumption in every study period. The total final energy demand under the BAU sector is projected to grow over the years with 990.420 ktoe in 2017 to 2,194.703 ktoe by 2040. Comparing among the sectors the by 2040, the industrial sector as expected to consume the larger share of energy with 1,297.866 ktoe which is around 59% followed by household sector with 21% (461.837 ktoe). The transportation sector is projected to have 13% share (287.461 ktoe) and the service sector is anticipated have the least share with 7% which is around 147.538 ktoe. The analysis of final energy demand by energy form shows that biomass is expected to be remained relatively stable over the years reaching 533.9 ktoe by 2040 and electricity has shown significant growth and is expected to grow steadily to 747.8 ktoe by 2040. Fossil fuel will be the dominant energy source with 12% of the total energy in 2017 and it is expected to account 29% of the total energy in 2040 and the motor fuel is expected to reach 286.9 ktoe by 2040.

As anticipated the electricity consumption will increase significantly under PMS scenario, reaching 9,866.19 GWh by 2040 and expected to occupy 44% in the total fuel mix against 26% in 2017. Electricity as a transportation fuel will grow from 0.03 ktoe in the base year to 39.42 ktoe by 2040 and it is expected to contribute 19.33% share in the fuel mix in the transportation sector against the modest share of 0.019% in the 2017. The analysis also shows that the under PMS the electricity consumption will increase consistently as compared to BAU across all study year.

The demography results shows the the population of Bhutan is projected at 0.86 million by 2040 with the population growth rate of 0.40011% in that year. The GDP results also shows that the increasing trend with the projected GDP of to 5.789 billion US$ by 2040 from 2.5387 billion US$ in 2017 and subsequently the per capita GDP is also expected to increase from 3477.547 US$/cap in 2017 to 6732.48 US$/cap by 2040.

The output and the analysis of this study which was based on socioeconomic, technological, and demographic development and policy scenarios of Bhutan, establishes the connection between energy consumption against development and it would help facilitate policy and decision makers to plan for sustainable, reliable and affordable energy for the future.

5.2. Future scope

The final electricity demand results from the MAED_D model of this study can be further used in MAED_EL model to determine and

forecast the chronological sequence of the 8,760 hourly loads of the power system. MAED_EL is the second model under MAED which converts the projected annual electricity demand into the predicted hourly electricity demand curves which will be helpful in the power system expansion planning (Ardakani & Ardehali, 2014a). Load forecasting is generally accepted to be vital for the planning and operation of power transmission and distribution networks as well as for guiding the investment of capital in the energy sector. It is a central or integral component for managing power utilities and it acts as the critical mechanism or tool used by the policymakers and the decision-makers in the energy sector (Hahn et al., 2009; Trotter et al., 2017). Hence the final electricity demand results from the MAED_D module can be the vital input data for the MAED_EL which can be explored as the future work in continuation of this study.

The findings and results of this study have not been verified due to time constraints and the absence of similar study as well as the lack of report from the relevant stakeholder. Hence the verification analysis of this study could be considered as the future work to be undertaken as and when the reliable data is published. Furthermore by utilizing the result of the validated base year of this study, it becomes possible to investigate the impact of various policies and their effects.

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