International Journal of Engineering Applied Sciences and Technology, 2024
Vol. 9, Issue 03, ISSN No. 2455-2143, Pages 16-23
Published Online July 2024 in IJEAST (http://www.ijeast.com)

LONG-TERM ENERGY DEMAND THROUGH BOTTOM-UP ANALYSIS AND PROJECTION FOR KUWAIT

Naser Hussain
Energy and Building Research Center,
Kuwait Institute for Scientific Research, Kuwait

Abstract: **In this study, an energy demand projection and analysis were conducted for the State of Kuwait, which has an oil-based economy. A bottom-up approach was used to conduct energy demand projection and analysis by utilizing the Model for Energy Demand Analysis (MAED), which is a software package developed by the International Atomic Energy Agency (IAEA). The energy demand projection was conducted until 2050, with 2019 as the base year. The total demand is expected to grow from 210.9 TWh in 2019 to 373.07 TWh in 2050. The industrial sector dominates final energy demand, with a percentage of 45.1% in 2019 and is expected to reach 55.8% by 2050. Reliance on fossil fuels for energy demand will persist with an annual growth rate of 4% throughout the projection period. The electricity demand in the household and service sectors has the highest share of space cooling during the long summer months. Policy implications in response to energy demand consumption patterns are discussed to achieve national sustainable economic growth and environmental requirements. The implementation of rules and regulations to deploy and use equipment and machinery with high energy efficiency ratings will assist in energy savings in the industrial sector. Providing incentives to use building materials with high insulation can significantly reduce the energy demand for space cooling. Setting high-efficiency rating standards for engine specifications for vehicles imported to Kuwait will help reduce the consumption of motor fuels in the transportation sector.**

Key words: **Energy demand, bottom-up, economic growth, sustainability.**

I. INTRODUCTION

The need for energy is crucial for economic development and enhancing quality of life. Therefore, the energy sector's strategic development critically depends on the demand profile trends that are driven by economic, technological, and demographic factors. Accordingly, long-term energy demand forecasting plays a key role in a country's energy value chain planning and development.

Kuwait is an oil-based economy. All sales are managed and organized by the Kuwait Petroleum Corporation (KPC). KPC sells oil products locally, which contribute to energy consumption in different sectors within the country. In order to realize the flow and usage of energy, it is necessary to conduct an energy demand analysis to investigate and understand energy consumption patterns. This will help tackle the different sectors with excessive energy consumption and make appropriate recommendations for proper energy saving and usage.

Various sectors in Kuwait, such as residential, industrial, power, petroleum, etc. demand energy in different types and forms. The residential and service sectors require energy mainly in the form of electricity for space cooling, heating, and operating electrical appliances. On the other hand, the industrial and petroleum sectors demand energy in the form of heat and electricity to operate their businesses.

Analyzing and knowing the energy demand patterns of various sectors can help pinpoint where excessive energy consumption occurs. This will allow us to understand the reasons for excessive energy usage in these sectors and determine the seasons for excessive energy usage. Hence, proper solutions and policies can be put in place to reduce excessive energy use.

II. LITERATURE REVIEW

The barriers to adopting energy efficiency technologies are presented in aggregate and simplified format in most bottom-up approaches to modeling energy demand [1]. This is done in the form of the adjusted discount rate. Diffusion modeling is used to obtain a more accurate representation of the barriers faced by energy efficiency technologies to deliver better models for energy demand.

The advantage of using the MAED model (model for analysis of energy demand) for final energy demand forecasting is the comprehensive analysis of energy sector development. The model considers the mutual relationships among the factors affecting the long-term energy consumption. The model also considers social, economic, and technological factors that affect energy demand, leading to better forecast accuracy [2].

Energy demand modeling for developing countries differs from that for developed countries in terms of population and economy. The developing countries have higher growth rates for both the economy and population. Growth is accompanied by expansion in different sectors of the economy (i.e., industries, services, etc.), leading to an increase in the demand for energy. Moreover, an increase in the population in a country is translated into a demand for energy. Hence, the combination of the socio-economic status of a country ultimately affects the demand for energy [3].

The modeling method using the accounting approach (i.e. MAED) is better than the economic modeling approach for developing countries. Models that use an economic approach are not suitable for developing countries because of the required amount of data and the inability to capture specific features such as informal sectors and non-monetary transactions. The developing countries face challenges in applying energy demand models due to a lack of sufficient data and institutional capacity. In addition, their energy systems' characteristics does not have formal sector categorizations and lack energy supply technologies [4].

In some situations, energy modeling tools do not capture the features and issues of the country under study. Inappropriate modeling assumptions can create complexities instead of solving the problem in consideration, which ultimately leads to unrealistic modeling results. Hence, it is important that the assumptions made by the respondents from the country under study reflect the actual conditions and issues [5].

The bottom-up approach was deployed in various studies to forecast energy demand using various modeling tools for the countries under consideration. This approach allows researchers to study and forecast energy demand for major sectors and subsectors, facilitating a more in-depth analysis for policymakers and decision makers. Economic factors can also be considered in energy demand forecasting using a bottom-up approach [6].

It is important, during the modeling of energy demand, to consider greenhouse gas emissions mitigation policies and to include their economic effects on generation cost. It is crucial to assess the power expansion pathways by considering a wide range of scenarios rather than a limited set [7].

MAED can be integrated with other software to perform in-depth analysis of energy systems. In this regard, MAED was used along with MARKAL to study and analyze the energy system of Nepal. The outputs of MAED, which represent the useful energy demand for multiple sectors, were input to MARKAL for energy supply analysis. The integration of MAED and MARKAL allowed the assessment of various pathways for future energy development [8].

The end-use models do not have the capacity to capture price signals for price-based policy analysis. Hence, the matter of consistency with macro-economic performance for the countries in consideration cannot be verified. On the other hand, the rich scenario capabilities allow end-use models to analyze structural changes in energy systems in detail [9].

III. METHODOLOGY

Demand analysis can be performed using various tools. In this study, the software Model for Analysis of Energy Demand (MAED), which was developed by the International Atomic Energy Agency (IAEA), was used to generate an energy demand model and analyze it. The input data were collected from various official authorities to simulate the desired scenario along with the demand forecast and analysis. The local authorities that provided the needed data included the Ministry of Electricity and Water and Renewable Energy (MEWRE), Central Statistical Bureau (CSB), Public Authority for Industry (PAI), Kuwait Petroleum Corporation (KPC), and Public Authority for Civil Information (PACI). In addition, the World Bank database was used to obtain some data unavailable from local authorities.

The demand analysis method used in MAED is a bottom-up or disaggregated approach. In this approach, the projection of energy usage patterns is deduced by end users. Therefore, the energy demand of the country can be analyzed. The end-use of energy considers the sectors and sub-sectors that consume all forms of energy. It starts with each sub-sector's energy demand to build the evolution of the total final energy demand for the whole country. The major sectors are as follows:

- Industries: This sector covers different types of industries, such as manufacturing, construction, and agriculture.
- Transport: This sector covers different types of transportation, such as private and public transportation.
- Residential: This sector includes private villas, building apartments, and commercial buildings in urban and rural areas.
- Service: This sector includes areas and buildings providing services to customers.

MAED was designed to reflect structural changes in energy demand by analyzing social, economic, and technological factors. In addition, it considers the evolution of different forms of energy, such as electricity, motor fuels, fossil fuels, and renewable resources. It is worth noting that MAED considers the economic development and demography of a country when analyzing and forecasting energy demand.

The generic mathematical formula used by MAED to determine the energy demand for the sector under consideration is as follows:

$$ED_t = SEC_t \times DF_t$$

Here, ED_t is the energy demand at time t, SEC_t is the specific energy consumption (or energy intensity EI_t) at time t, and DF_t is the driving factor at time t. This general formula is used to determine the energy demand of sectors and subsectors, but the terms SEC_t and DF_t differ depending on the sectors in consideration. The specific energy consumption (or energy intensity) was calculated using the following equation:

$$SEC_t = EI_t = \frac{\text{specific energy consumtion in year t}}{\text{unit of deriving parameter in year t}}$$

In a MAED model, identifying and setting the base year correctly is essential. The base year is a year with typical conditions of activities without abnormal situations, such as pandemics and economic instabilities. The base year should be selected from a recent year in which reliable and consistent energy and economic information is available. The base year must also represent stable conditions for energy use. The base year selected for this study was 2019 because it is the most recent year with the full set of data. After the COVID-19 pandemic, many authorities suffered from delays in data gathering in2020 until the writing of this paper due to administrative challenges.

Since MAED analyzes energy demand based on socioeconomic conditions, this requires data on demography and gross domestic product (GDP) for the region to be considered. The demographic information needed is the census, which counts the entire population and housing stock of a given country and collects information on its main characteristics (geographic, demographic, social and economic, plus household and family characteristics). The model considers total population, potential labor force, and actual labor force. The GDP is the total monetary or market value of all finished goods and services produced within a country's borders during a specific period. GPD is needed to determine the economic state of the region.

Data for the consumed energy within the sectors are obtained from the energy balance for the country. The energy balance presents the balance between input energy flows by source and output energy flows by consumer type. The energy balance data were obtained from the relevant authorities.

The final energy demand in MAED is significantly driven by the energy intensity of each sector considered. The energy intensity of each sector is calculated according to the nature of the consumed energy by each sector.

IV. RESULTS

The results of the simulation consider the base year to be 2019 because it was a normal year in terms of economic and life activities, whereas 2020 had the COVID-19 pandemic. The forecast was set for every five years from 2019 to 2050. According to figure 1, Kuwait's GDP is expected to reach USD 265.9 billion by year 2050 which is approximately an increase of approximately 104% compared to the base year of 2019. The increase in GDP is explained by a significant increase in the service sector's GDP, which is mainly driven by population growth and demand for various services. The share of the agricultural sector is very limited in Kuwait's GDP is very limited compared to other sectors. Therefore, it cannot be seen in figure 1. The agricultural sector's GDP share is expected to remain constant throughout the projection period at a value of KD 441.7 million.

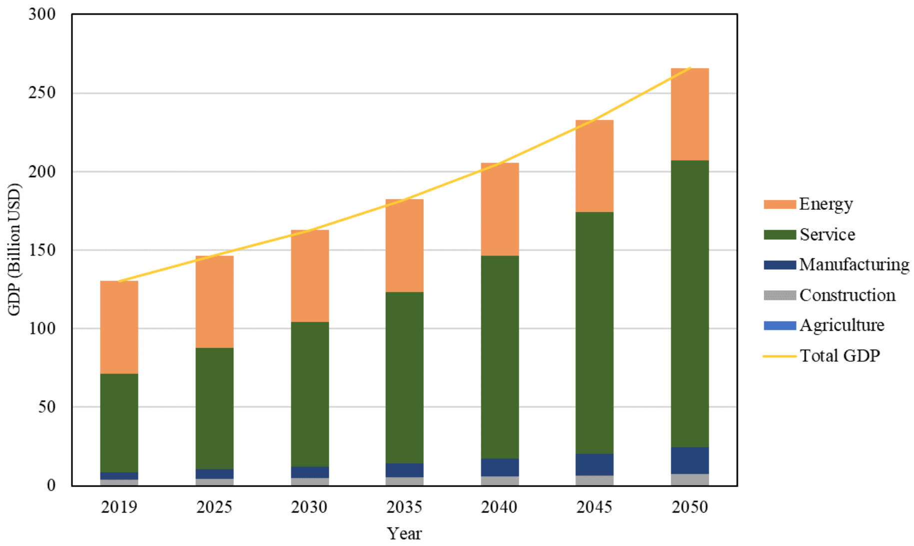

Figure 1. Kuwait's GDP structure by sectors.

In figure 2, it is expected that electricity consumption will increase from 58.2 TWh in 2019 to 91.9 TWh in 2050. The increase in electricity demand is mainly driven by population growth and the increase in facilities that require electric power to operate. The household and service sectors together have the highest electricity consumption in Kuwait. This is due to the need to run air conditioning to cool the spaces for long periods of time during the summer when the temperature reaches the extreme highest (i.e. greater than 50^{o} degrees Celsius).

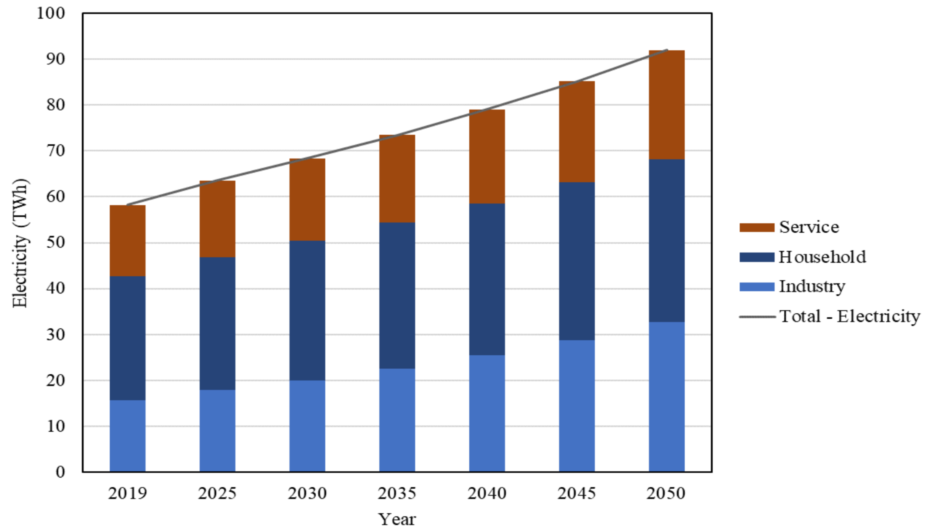

Figure 2. Electricity consumption in Kuwait by sectors.

Gasoline and diesel dominate the transportation sector(see figure 3). The expected annual growth rates for gasoline and diesel demand are 1.16% and 1.79%, respectively. The total energy demand for the transportation sector is expected to reach 99.96 TWh, with a growth rate of 1.4% annually.

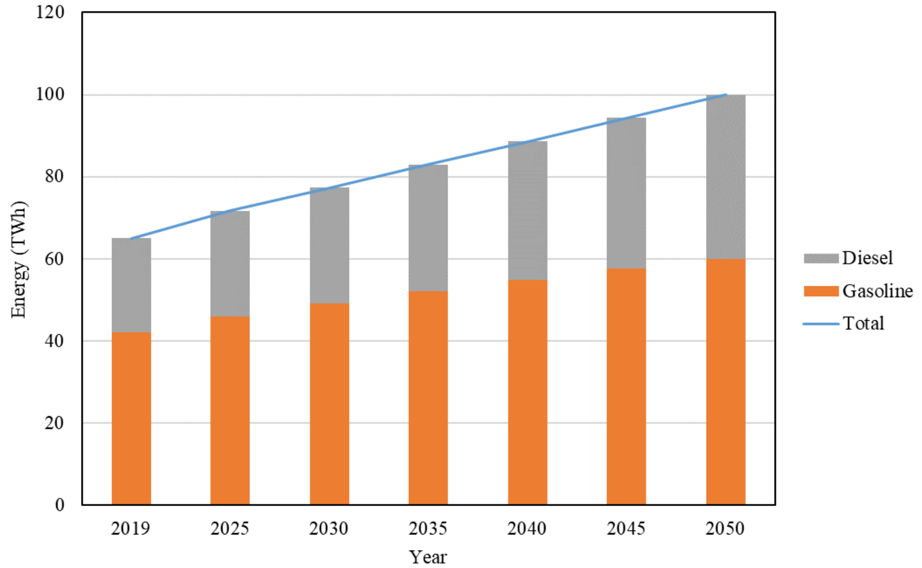

Figure 3. Final energy demand in transportation sector by fuel types.

In transportation subsector, the energy demand for urban transport exceeds that for freight, as indicated in figure 4. In 2019, the energy demand for urban transport was 51.2 TWh, representing 78.7% of the total energy demand. This percentage is expected to decline to 73.1%. On the other hand, the percentage share of energy demand for freight from total energy demand is expected to increase from 21.3% to 26.9% by 2050, reaching 26.85 TWh.

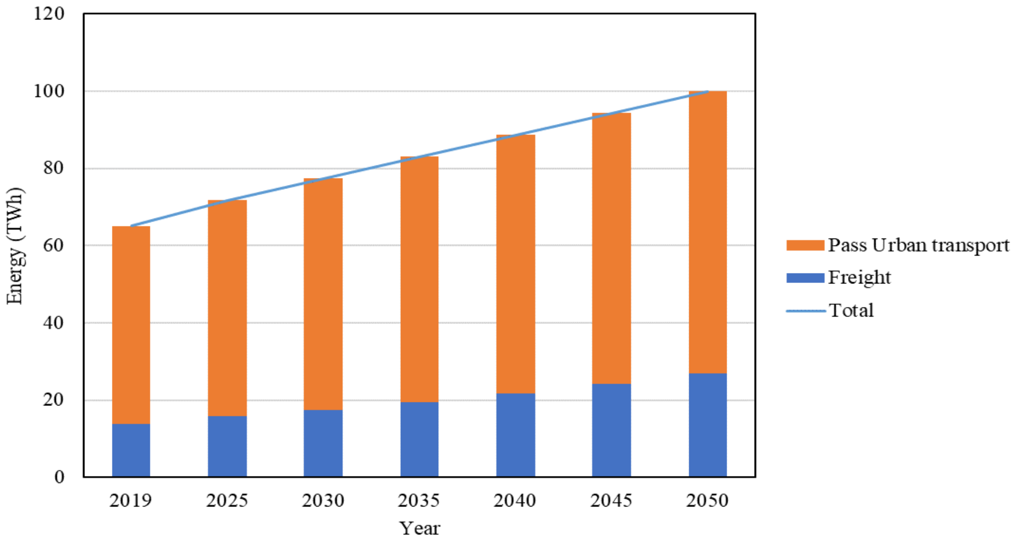

Figure 4. Final energy demand in transportation (by subsector) [TWh].

The electricity demand in the households, as indicated in figure 5, is mainly dominated by air conditioning due to the extremely hot climate in Kuwait, which lasts long periods throughout the year. The electricity demand is expected to increase from 18.9 TWh in 2019 to 20.99 TWh in 2050. The electricity demand for water heating has the smallest share due to the very short winter in Kuwait. In addition, the temperature levels in Kuwait do not drop significantly during the winter. The electricity demand share for water heating was 5% in 2019, and it is expected to increase to 5.7% in 2050.

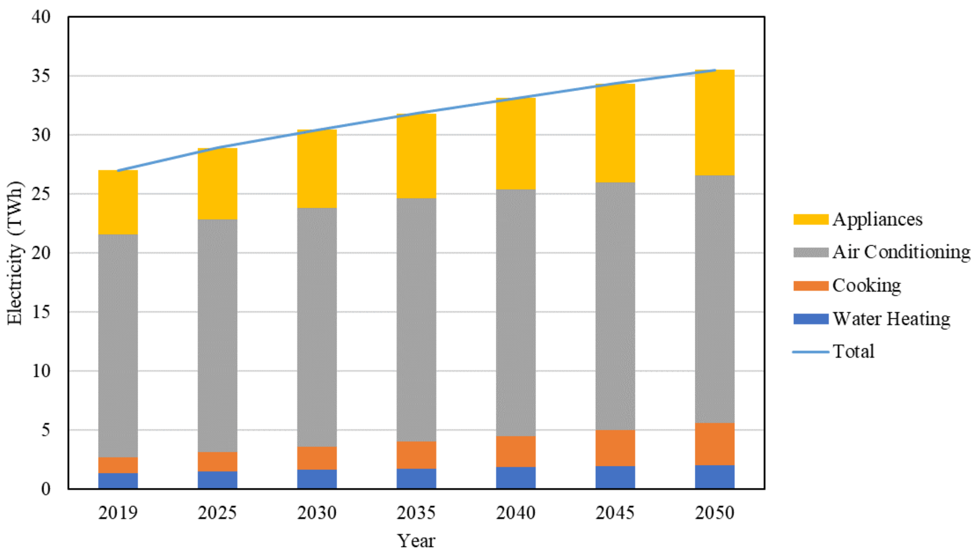

Figure 5. Electricity demand in the household sector.

In the service sector, air conditioning for space cooling has the highest share among other uses, as shown in figure 6. Space cooling has the highest share due to the extremely hot weather in Kuwait along with the long summer period. The share of electricity-specific uses is expected to increase over the years because of the expected increase in the services providing activities to meet the future demand resulting from the increased population. Thermal use takes the smallest share due to the short winter period in Kuwait, which leads to less heating need. The energy demand in the service sector is estimated to grow from 14.8 TWh in 2019 to 23.8 TWh by 2050, with an annual growth rate of 1.4%.

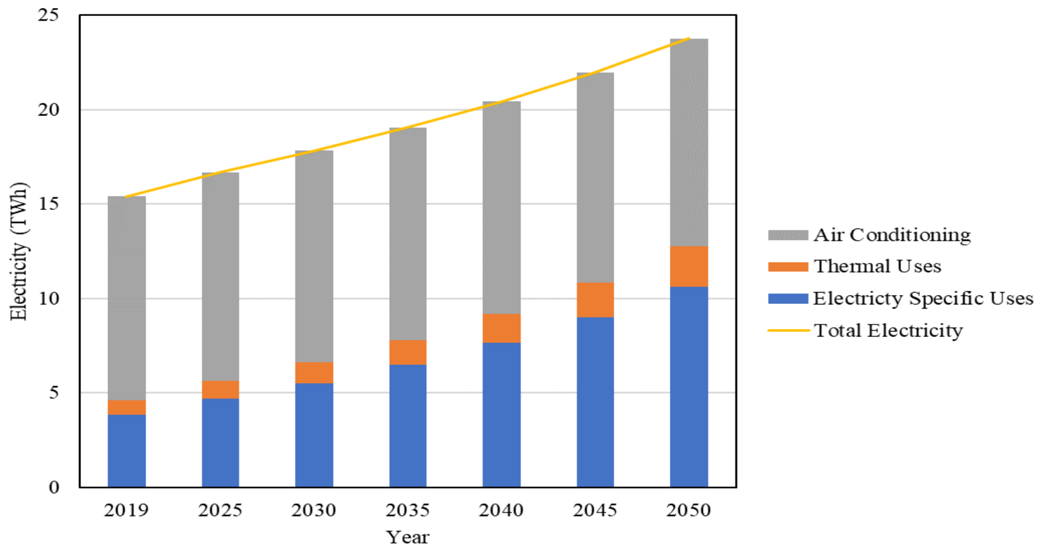

Figure 6. Final energy demand uses in service sector.

Energy demand in Kuwait originates from the service, household, transportation, and industrial sectors. Figure 7 illustrates the final energy demand for each sector. The industry sector accounts for the largest share of energy demand, while the service sector accounts for the least. In 2019, the energy demand share of the industry sector was 45.1% of the total energy demand of the country and was expected to reach 55.8% by 2050. This increase is expected due to the projected growth in industrial activities in the future. The transportation sector occupies the second position in terms of the share of total energy demand. The energy demand's share of the transportation sector from the total energy demand was 30.8% in 2019, but it is expected that this percentage will drop to 26.8% by 2050 due to the expected increase in public transport usage, which will lead to a reduction in motor fuel consumption.

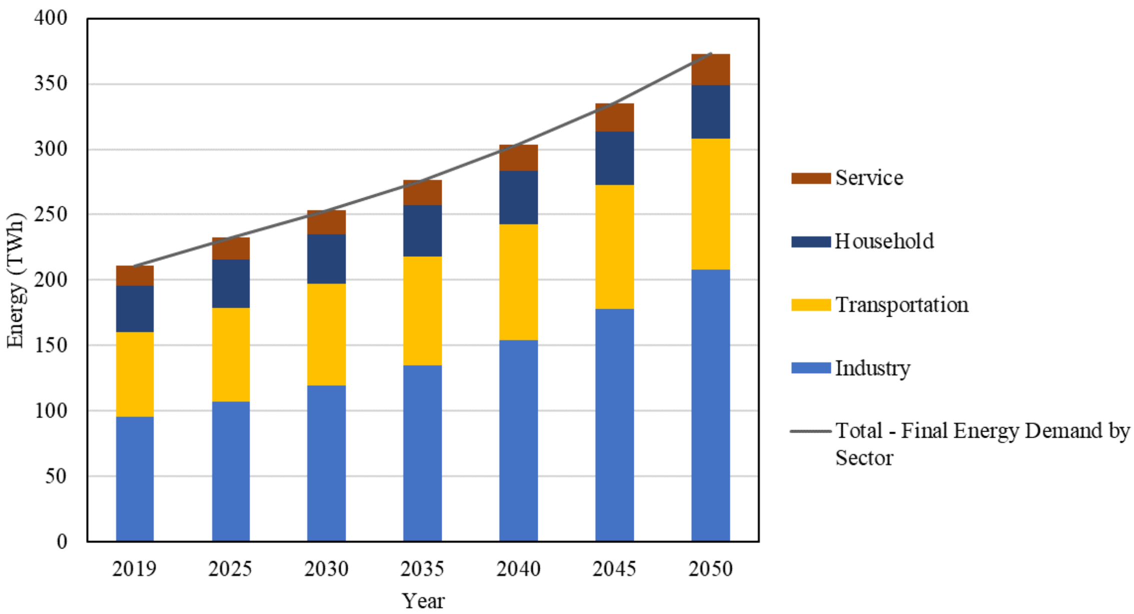

Figure 7. Final Energy Demand by Sector

V. CONCLUSIONS AND POLICY IMPLICATIONS

Kuwait's energy demand was modeled using the MAED software tool, which adopts a bottom-up approach. MAED reflects structural changes in energy demand with detailed analysis of social, economic, and technological factors. In addition, it considers the evolution of different forms of energy, such as electricity, motor fuels, fossil fuels, and renewable resources. Furthermore, it considers the economic development and demography of the country when analyzing and forecasting energy demand. The demand for four major sectors—industry, transportation, households, and services—are forecasted starting from the base year 2019 to 2050.

The energy demand for Kuwait is expected to grow from 210.9 TWh in 2019 to 373.07 TWh by 2050. The results indicate that the industry and transportation sectors are expected to have the highest energy consumption. Since the population is expected to increase in the upcoming years, the energy demand in the industry is expected to increase due to an increase in production for products to meet consumer demand. In addition, the energy demand in the transport sector will increase due to the increased demand for private andpublic transportation vehicles. Another source of the increase in energy demand in the transportation sector is the expected increase in freight due to the expected increase in imports, exports, and commercial activities. Proper policies must be enacted, and recommendations must be considered to be secure sustainable and available electricity. It is recommended that energy efficiency methods and policies be implemented for industry to reduce energy consumption. Some methods to reduce energy consumption in the industrial sector are the use of machinery and processes with high energy efficiency ratings that consume less energy to render the desired output. Another method is by setting tariff reforms to encourage companies in the industrial sector to develop energy-efficient machinery and processes. Energy demand in the transportation sector can be reduced by enhancing public transport services and infrastructure. Promoting the use of cars with engines with high energy efficiency ratings. Also, the government can enact policies and regulations that reduce the imports of vehicles with low fuel consumption ratings. Electric vehicles and hybrid electric cars can be promoted for passengers through incentives by the government to reduce both fossil fuel consumption and CO_2 gas emissions, leading to a significant reduction in energy demand.

Regarding the household and service sectors, the highest energy demand in these sectors comes from the electricity demand for air conditioning and space cooling. This is due to the long summer in Kuwait, which has high temperatures. It is recommended to use air conditioning units and machines with high energy efficiency ratings along with the implementation of proper energy efficiency codes and procedures for buildings and houses. Building envelopes are highly effective for reducing energy consumption in buildings. It is recommended to promote new design concepts and building materials for future houses and buildings to help reduce energy consumption. Implementation of incentive plans for buildings that comply with energy efficiency requirements. Adding smart meters to existing buildings will help track consumption to analyze energy demand patterns in the households and the service sectors. This will help to investigate potential solutions for further energy savings in the household and service sectors.

The periodic implementation of energy demand analysis will help to assess and follow up energy consumption in the country to tackle sectors that excessively consume energy to resolve their shortcomings. This will guarantee sustainable energy availability for future generations and provide economic growth and prosperity.

Acknowledgment

I would like to acknowledge the team from EU155C for their contribution to the work of this paper. Also, I would like to thank Emmanuel Dountio, Loreta Stankeviciute, and Alenka Kinderman from IAEA for their contributions.

VI. REFERENCES

[1] T. Fleiter, E. Worrell, and W. Eichhammer, "Barriers to energy efficiency in industrial bottom-up energy demand models—A review," Renew. Sustain. Energy Rev., vol. 15, no. 6, pp. 3099–3111, Aug. 2011, doi: 10.1016/j.rser.2011.03.025.

[2] V. Miskinis, A. Galinis, and I. Konstantinaviciute, "Challenges and options for development of the Lithuanian energy sector," Int. J. Glob. Energy Issues, vol. 34, no. 1/2/3/4, p. 91, 2010, doi: 10.1504/IJGEI.2010.037396.

[3] J. Sieed, R. Komiyama, and Y. Fujii, "Energy Demand Modelling for Developing Economies Using MAED-2 with Sectoral Decomposition: Bangladesh Case Study," vol. 41, no. 5.

[4] S. C. Bhattacharyya and G. R. Timilsina, Energy Demand Models For Policy Formulation: A Comparative Study Of Energy Demand Models. in Policy Research Working Papers. The World Bank, 2009. doi: 10.1596/1813-9450-4866.

[5] A. G. Khaleel and M. Chakrabarti, "Energy modelling as a tool for curbing energy crisis and enhancing transition to sustainable energy system in Nigeria," Int. J. Sustain. Energy Plan. Manag., p. Vol 21 (2019), May 2019, doi: 10.5278/IJSEPM.2019.21.2.

[6] L. Suganthi and A. A. Samuel, "Energy models for demand forecasting—A review," Renew. Sustain. Energy Rev., vol. 16, no. 2, pp. 1223–1240, Feb. 2012, doi: 10.1016/j.rser.2011.08.014.

[7] X. S. Musonye, B. Davíðsdóttir, R. Kristjánsson, E. I. Ásgeirsson, and H. Stefánsson, “Integrated energy systems’ modeling studies for sub-Saharan Africa: A scoping review,” Renew. Sustain. Energy Rev., vol. 128, p. 109915, Aug. 2020, doi: 10.1016/j.rser.2020.109915.

[8] A. M. Nakarmi, T. Mishra, and R. Banerjee, “Integrated MAED–MARKAL-based analysis of future energy scenarios of Nepal,” Int. J. Sustain. Energy, vol. 35, no. 10, pp. 968–981, Nov. 2016, doi: 10.1080/14786451.2014.966712.

[9] S. C. Bhattacharyya and G. R. Timilsina, “Modelling energy demand of developing countries: Are the specific features adequately captured?,” Energy Policy, vol. 38, no. 4, pp. 1979–1990, Apr. 2010, doi: 10.1016/j.enpol.2009.11.079.