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The impact of reducing electric energy consumption and peak load through the implementation of energy conservation policies

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Abstract

Electric energy stands as one of the most critical pillars of modern civilization, playing a fundamental and indispensable role in various social and life activities. The rate of electric energy consumption is widely regarded as a key indicator for assessing the level of economic and civilizational progress across nations.

In recent years, the demand for electric energy has accelerated significantly, particularly in developing countries and emerging economies, driven by industrial development and rapid economic growth. This trend has placed policymakers and decision-makers in developing nations in a challenging predicament, as limited investments are available to meet the escalating energy demand at an acceptable cost. Failure to address this issue may impede economic growth and lead to a decline in living standards [1].

Consequently, the global focus on enhancing energy efficiency has intensified, with this issue taking precedence on the agendas of policymakers and decision-makers. The importance of this topic lies in its potential to deliver numerous benefits, including stabilizing energy demand, conserving energy resources, meeting growing energy needs without compromising consumer requirements, generating substantial economic returns, and addressing climate change concerns.

In this study the energy produced and the peak load for the study period from 2015 to 2024 were calculated based on demographic,

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economic, and electrical data from previous years (historical). In this step, two energy scenarios were assumed: a baseline energy scenario, which assumes the continuation of past energy consumption patterns (the conventional energy scenario), and a guided energy scenario, which reflects the impact of adopting policies to promote rational energy use and conservation.
The demand for electric energy was analyzed according to the assumed scenarios baked on the data collected from the General Electricity Company and National Oil Corporation, using Excel by applying the same reliability criteria to both scenarios, the results were compared to determine the expected impact of implementing electric energy conservation and load management policies [2].

Keywords: Consumption, energy demand, energy resources, conventional energy, guided energy.

تأثير خفض استهلاك الطاقة الكهربائية وتحقيق تقليل الأحمال القصوى من خلال تطبيق سياسات ترشيد الطاقة

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الملخص

تُعد الطاقة الكهربائية من الركائز الأساسية والحيوية للحضارة الحديثة، إذ تلعب دوراً جوهرياً لا غنى عنه في مختلف الأنشطة الاجتماعية والحياتية. ويُعد معدل استهلاك الطاقة الكهربائية مؤشراً مهماً يُستخدم على نطاق واسع لتقييم مستوى التقدم الاقتصادي والحضاري في الدول.

شهدت السنوات الأخيرة تسارعاً ملحوظاً في الطلب على الطاقة الكهربائية، لا سيما في الدول النامية والاقتصادات الصاعدة، وذلك نتيجة للنمو الصناعي والتطور الاقتصادي

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السريع. وقد وضع هذا الاتجاه صانعي السياسات ومتخذي القرار في هذه الدول أمام تحدٍ كبير، يتمثل في محدودية الاستثمارات المتاحة لتلبية الطلب المتزايد على الطاقة بتكلفة مقبولة. ويُعد الفشل في معالجة هذه القضية عائقاً محتملاً أمام النمو الاقتصادي وقد يؤدي إلى تراجع في مستويات المعيشة [1].

ونتيجة لذلك، تزايد الاهتمام العالمي بتحسين كفاءة استخدام الطاقة، وأصبحت هذه القضية من أولويات جداول أعمال صانعي السياسات ومتخذي القرار. وتكمن أهمية هذا الموضوع في قدرته على تحقيق فوائد متعددة، منها استقرار الطلب على الطاقة، والحفاظ على الموارد الطاقية، وتلبية الاحتياجات المتزايدة دون الإضرار بمصالح المستهلكين، وتحقيق عوائد اقتصادية كبيرة، فضلاً عن الإسهام في معالجة قضايا التغير المناخي.

في هذه الدراسة، تم حساب الطاقة المُنتجة والطلب الأقصى خلال فترة الدراسة الممتدة من عام 2015 إلى عام 2024، وذلك بالاعتماد على بيانات ديموغرافية واقتصادية وكهربائية سابقة (تاريخية). وفي هذه المرحلة، تم افتراض سيناريوهين للطاقة: الأول هو سيناريو الطاقة الأساسي، الذي يفترض استمرار أنماط الاستهلاك السابقة (سيناريو الطاقة التقليدي)، والثاني هو سيناريو الطاقة المُوجّه، الذي يعكس تأثير تبنّي سياسات ترشيد استخدام الطاقة والحفاظ عليها.

تم تحليل الطلب على الطاقة الكهربائية وفقاً للسيناريوهات المفترضة بالاستناد إلى البيانات التي تم جمعها من الشركة العامة للكهرباء والمؤسسة الوطنية للنفط، باستخدام برنامج إكسل. ومن خلال تطبيق نفس معايير الموثوقية على كلا السيناريوهين، تمت مقارنة النتائج لتحديد الأثر المتوقع لتطبيق سياسات ترشيد الطاقة الكهربائية وإدارة الأحمال [2].

الكلمات المفتاحية: الاستهلاك، الطلب على الطاقة، الموارد الطاقية، الطاقة التقليدية، الطاقة المُوجّهة.

1. Introduction:

In Libya, the electricity sector holds significant importance. Like many nations, Libya aspires to achieve rapid and steady progress. The electricity sector witnessed notable development during the latter part of the 20th century, with per capita electricity consumption doubling to more than 1.16 times by the end of 2024 (3.2 kWh) compared to 2015 (2.75 kWh). Additionally, the peak load of the public grid was nearly 1.36 during the period from 2015 to 2024 (Source: General Electricity Company data).

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To accommodate the growing demand for electric energy and supply all consumption sectors, relatively large power plants of various types were constructed. In 2024, the installed capacity of electricity generation plants reached 10 megawatts, necessitating the development of an extensive transmission and distribution network capable of delivering the energy produced by these plants to various consumption points.

Problem Statement

Given the continuous rise in future demand for electric energy, it is imperative to add new generation capacities to address this growth. However, since the costs of constructing new generation units of various types are substantial, it has become essential to explore methods to reduce the required generation capacities without adversely affecting the productive capacity of economic activities or individual livelihoods.

Therefore, this study aims to examine the anticipated impact of reducing electric energy consumption and peak load through the implementation of energy conservation policies. and as a developing nation, Libya seeks to harness its depleting oil and natural gas resources for economic and social development. The country utilizes its oil and gas wealth to meet the growing energy needs of various economic sectors. Libya exports oil, natural gas, and their derivatives to numerous countries worldwide to secure the necessary funding for its economic and social development plans. Simultaneously, it strives to conserve energy and promote rational consumption within a broader strategy aimed at achieving sustainable development and environmental protection Such measures would lead to a decrease in the required generation capacities, thereby lowering the overall costs of the electrical system (both capital and operational expenses), reducing polluting emissions, and positively contributing to the national economy.

2. Study Methodology

This study represents an integrated analysis of produced energy, maximum generation capacity, and exports and imports of crude oil, diesel, and natural gas during the period from 2015 to 2024. The study focused on exploring the impact of these factors on the local market and assessing the ability of available resources to meet local demand, based on demographic, economic, and electrical data collected from reliable sources such as the General Electricity Company, the National Oil Corporation, and OPEC. By utilizing

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Excel, sustainable policies aimed at rationalizing electricity consumption and improving load management were applied, enhancing resource efficiency and achieving an optimal balance between supply and demand.

3. Energy Resources

Energy resources are vital for modern societies, divided into non-renewable sources (e.g., fossil fuels), which are finite and environmentally harmful, and renewable sources (e.g., solar, wind), which are sustainable and eco-friendly. Rising global energy demand and environmental concerns necessitate a transition to renewable energy to ensure sustainability and energy security. This shift is critical for addressing climate change and fostering long-term development [3].

3.1 Crude Oil and Natural Gas

Oil and natural gas are the primary sources of energy in Libya, given the absence of alternative resources such as coal and hydroelectric power.

Proven discoveries on land and in submerged areas have revealed that the entirety of Libya constitutes an oil-rich region with extensive sedimentary basins both onshore and offshore. By the end of 2024, cumulative crude oil production since 2015 reached approximately 3.1 billion barrels, predominantly extracted from onshore sedimentary basins [4].

Figure 1 illustrates the daily average of crude oil production and exports in Libya during the period (2015–2024)

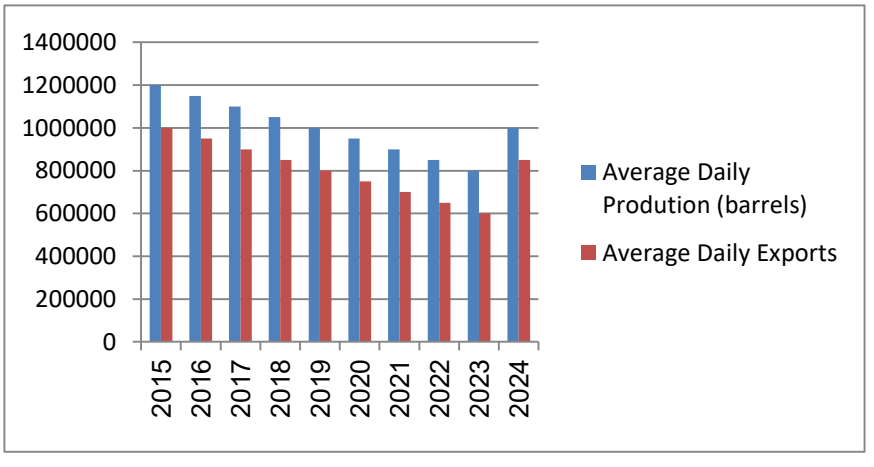

Figure 1: Daily Average of Crude Oil Production and Exports in Libya (2015–2024) [2]

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Libya exports the surplus of its crude oil and natural gas production to global markets after refining a portion domestically to meet local demand for petroleum products [1].
In addition, Figure 2 presents the daily average of liquefied natural gas production and exports during the period (2015–2024).

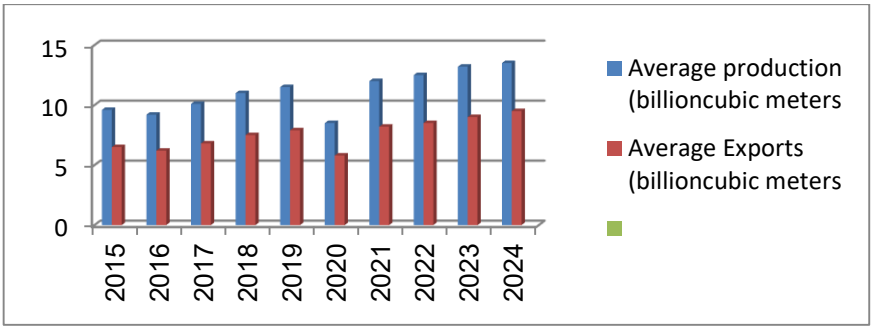

Figure 2: Daily Average of Liquefied Natural Gas production and Exports (2015–2024)

Additionally, certain petroleum products are imported to satisfy domestic market needs, with gasoline accounting for approximately 20% of total imports in 2024. Figures 3 and 4 illustrate the evolution of petroleum product exports and imports during the period 2015–2024 [5].

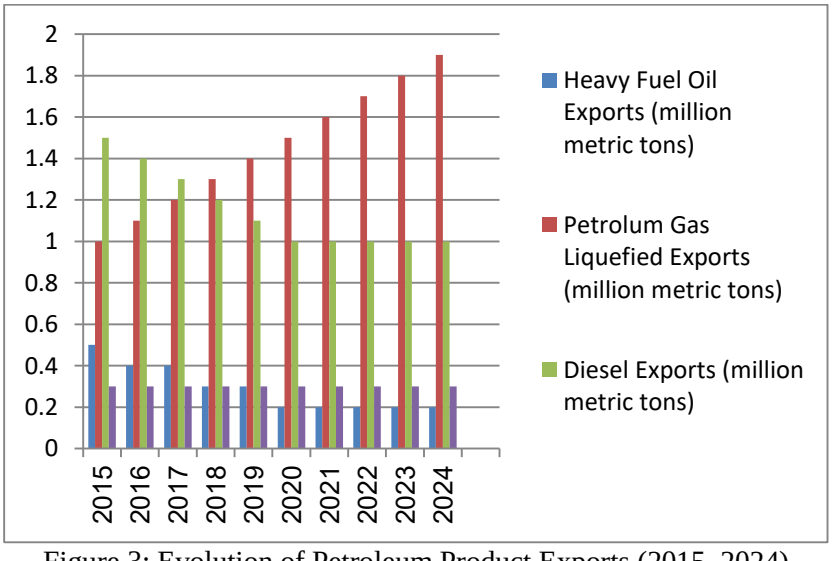

Figure 3: Evolution of Petroleum Product Exports (2015–2024)

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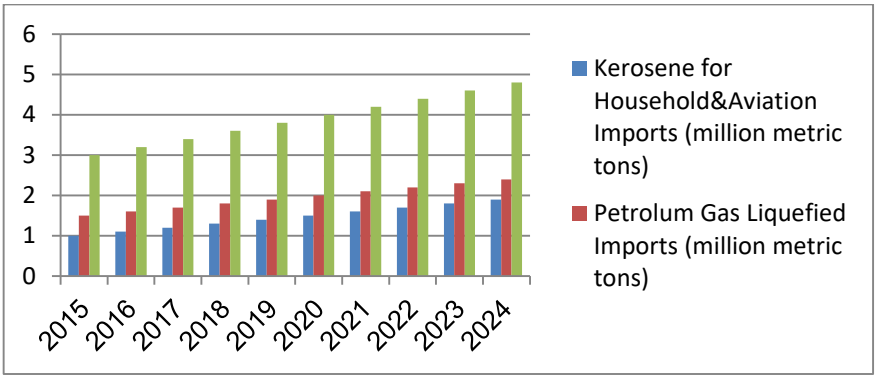

Figure 4: Evolution of Petroleum Product Imports (2015–2024)

3.2 Renewable Energy

Libya's geographical location in North Africa, bordering the Mediterranean Sea with a coastline of 1,900 kilometres and an area of approximately 1,775,500 square kilometres, renders it a predominantly desert region, with 88% of its landmass classified as desert due to the Tropic of Cancer traversing its southern territory. This geographical positioning endows Libya with a hot desert climate characterized by intense sunlight for over ten hours daily throughout the year. Consequently, Libya possesses significant potential for renewable energy, particularly solar and wind energy, which can be harnessed to meet the energy needs of rural and remote areas not connected to the national grid. In such a way, Solar energy is widely regarded as one of the most important renewable energy sources for the coming century. Numerous countries are directing efforts and allocating substantial funds toward developing technologies and research initiatives aimed at harnessing solar energy as a viable alternative to oil and gas. Solar energy offers numerous advantages, including its abundance, sustainability, and environmental benefits [6].

Solar energy can be converted into electrical energy through photovoltaic (PV) systems and into thermal energy through solar thermal conversion. Photovoltaic systems utilize solar cells to generate electricity, with numerous models of solar cells having been developed for practical applications. Solar cells are characterized by their lack of fuel consumption, minimal environmental pollution, and low maintenance requirements. Moreover, electricity generation from solar energy does not necessitate centralized production; instead, energy can be generated and utilized locally, significantly reducing transmission and

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distribution costs. Solar cells are also employed in various applications, including communication systems, cathodic protection, and water pumping. Solar thermal conversion, on the other hand, involves the use of solar collectors and thermal materials to convert solar radiation into thermal energy, which can be utilized for heating, cooling, water heating, and electricity generation. Solar water heaters are among the most widely adopted applications of solar thermal technology [7].

Studies on solar radiation in Libya have revealed exceptionally high levels of solar irradiance on horizontal surfaces, as illustrated in Figure 5, The total solar energy received on a horizontal surface exceeds 7.1 kWh/m²/day, with an average annual sunshine duration ranging from 3,000 to 4,000 hours. Figure 6 provides a map of Libya indicating solar radiation levels.

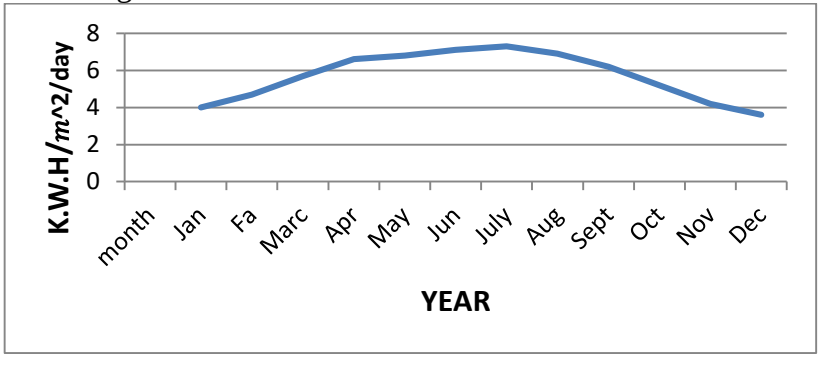

Figure 5: Average Solar Radiation in Libya on a Horizontal Surface (kWh/m²/day)

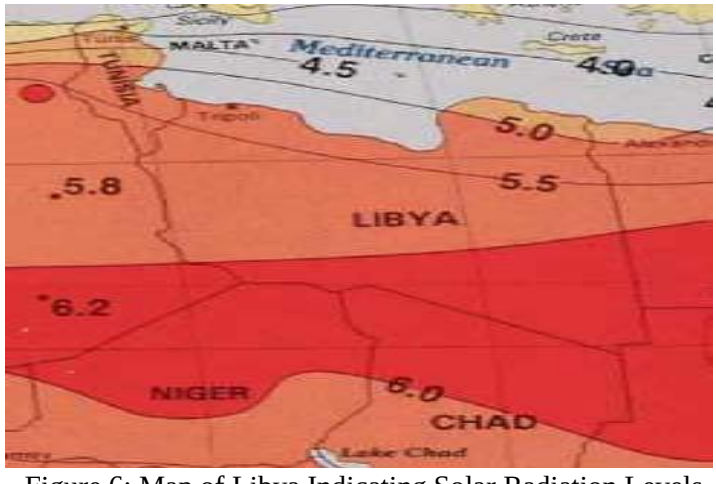

Figure 6: Map of Libya Indicating Solar Radiation Levels

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Solar energy applications have been implemented in Libya across various sectors. Photovoltaic systems have been utilized for cathodic protection of oil pipelines, operation of communication stations, and water pumping in remote rural areas. In terms of solar thermal applications, numerous solar water heaters have been installed in hotels and residential buildings, with further installations anticipated in the near future [7].

In addition, Libya is situated in a region with moderate wind speed distribution, particularly along its Mediterranean coastline, which presents favorable conditions for wind energy utilization. Wind energy can be harnessed to generate electricity, offering a sustainable alternative to conventional energy sources.

Measurements indicate significant potential for wind energy in Libya, with annual average wind speeds at a height of 40 meters ranging between 6 and 7.5 meters per second. Figure 7 illustrates wind speeds along the Libyan coastal region [7].

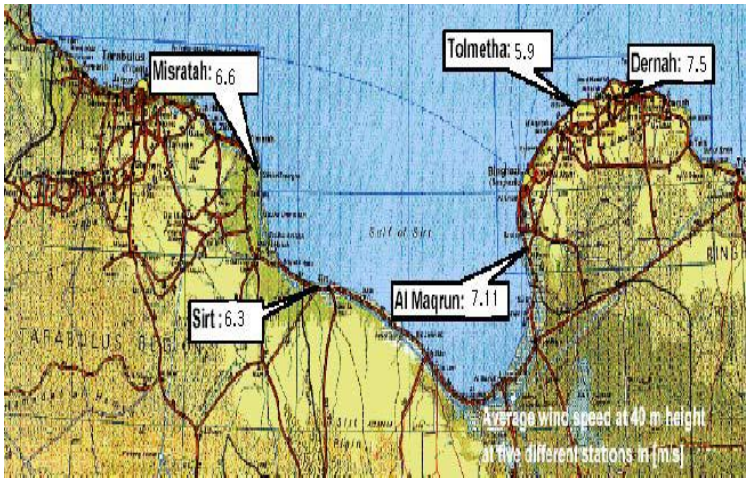

Figure 7 Wind Speeds in the Libyan Coastal Region [7]

Wind energy has been historically utilized for water pumping in various oases since the early 1940s, with capacities ranging from 50 to 1,000 watts. However, the use of wind energy for electricity generation has yet to be implemented in Libya.

4. Environmental Considerations

The energy sector is a significant contributor to environmental pollution, particularly through the emission of carbon dioxide (CO_2), a primary driver of global warming and climate change.

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Consequently, it is imperative to adopt balanced development policies for the energy sector, integrating environmental considerations into development plans, promoting sustainable resource utilization, diversifying the economy, and establishing appropriate environmental standards (such as ISO standards) to achieve comprehensive sustainable development.

In Libya, oil and natural gas are the primary sources of CO_2 emissions, given their dominance in the energy mix. In 2024, CO_2 emissions were estimated at over 40% from oil combustion and approximately 60% from natural gas combustion. The distribution of CO_2 emissions by sector was as follows: 40% from the power generation sector, 25% from the transportation sector, 20% from the industrial sector, and 15% from other sectors. Figure 8 illustrates this distribution [6].

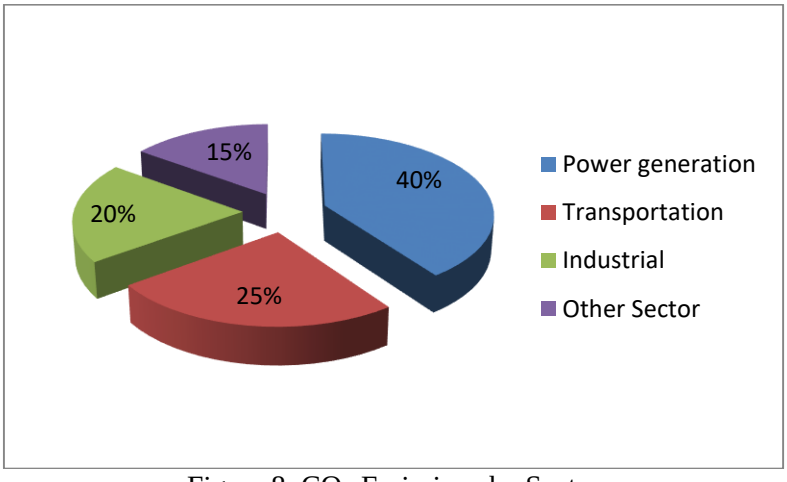

Figure 8: CO_2 Emissions by Sector

Figure 9 illustrates the fluctuation in carbon dioxide emissions between 2015 and 2024 as follows:

2015: Emissions peaked at 62.7 million metric tons .2020: Emissions dropped significantly to approximately 45 million metric tons, likely due to the impact of the COVID-19 pandemic, which caused reduced industrial activity and global mobility.(2020–2024)Emissions gradually rebounded as economies recovered and industrial activity resumed, reaching 62 million metric tons in 2024 close to 2015 levels but slightly lower by 0.7 million metric ton.

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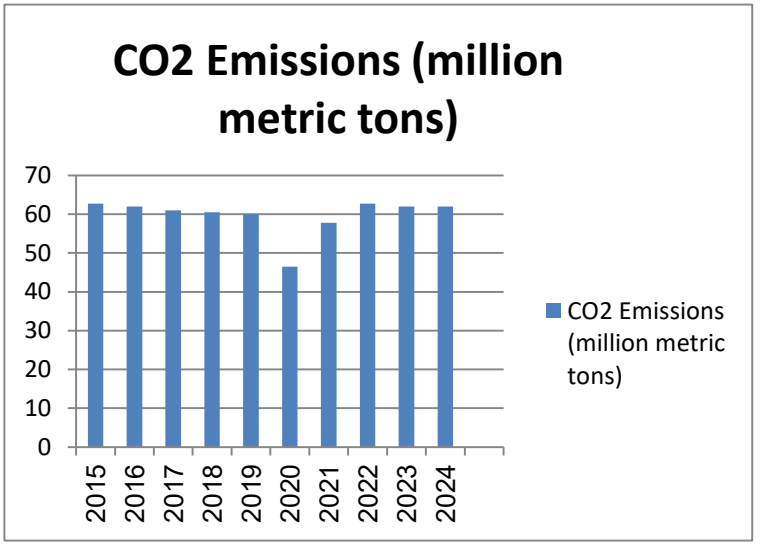

Figure 9: Increase in CO_2 Emissions (2015–2024)

The power generation sector accounts for the largest share of CO_2 emissions, a trend attributed to the rising demand for electric energy in recent years due to factors such as population growth, increased per capita income, and overall economic expansion.

To mitigate these environmental impacts, a series of measures must be implemented, including:

- Conducting environmental impact assessments for all existing and planned power projects.
- Establishing appropriate environmental standards.
- Promoting the use of renewable energy sources due to their environmental benefits.
- Raising awareness about energy conservation and efficient energy use.
- Enhancing the efficiency of the electricity generation sector and transitioning to cleaner fuel sources, while supporting renewable energy programs and regional cooperation initiatives in grid interconnection and related areas.
- Incorporating renewable energy topics into educational curricula and encouraging the adoption of renewable energy technologies through public awareness campaigns.

5. Energy Demand

Rising global energy demand, driven by population growth and industrialization, relies heavily on non-renewable sources, leading

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to environmental and resource challenges. Transitioning to sustainable energy systems, including renewables and efficiency measures, is essential to meet demand while ensuring environmental and economic sustainability [8].

5.1 Demand for Petroleum Products

Domestic consumption of petroleum products increased from approximately 10.9 million metric tons in 2015 to 11.4 million metric tons in 2019 and 12.4 million metric tons in 2024, as illustrated in Figure 10. This growth in consumption is attributed to economic recovery

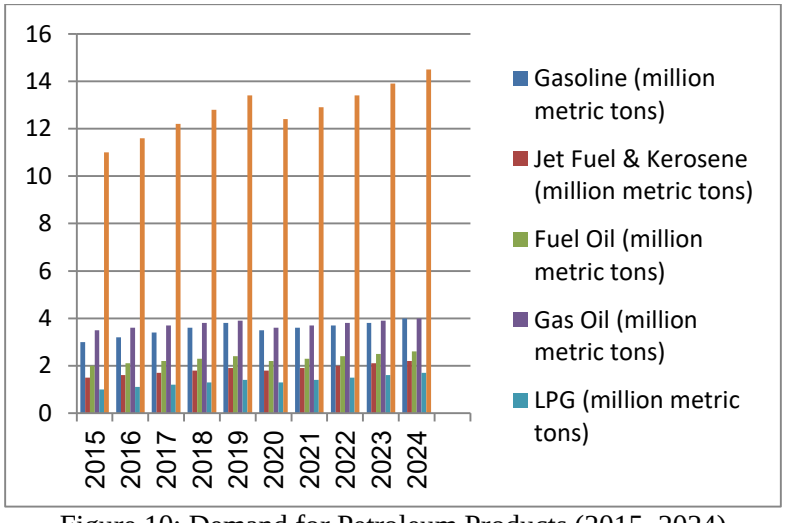

Figure 10: Demand for Petroleum Products (2015–2024)

5.2 Sectoral Demand for Petroleum Products

The primary economic sectors consuming petroleum products include transportation, electricity generation, industry, residential and services, and agriculture. Figure 11 illustrates the relative evolution of sectoral demand for petroleum products during the period 2015–2024. The transportation and electricity sectors collectively account for the majority of total consumption, with their combined share increasing from 70% to 90% during this period. The electricity sector is the largest consumer of petroleum products, accounting for 30% of total consumption in 2019, compared to 60% for the transportation sector and 10% for other sectors combined [9].

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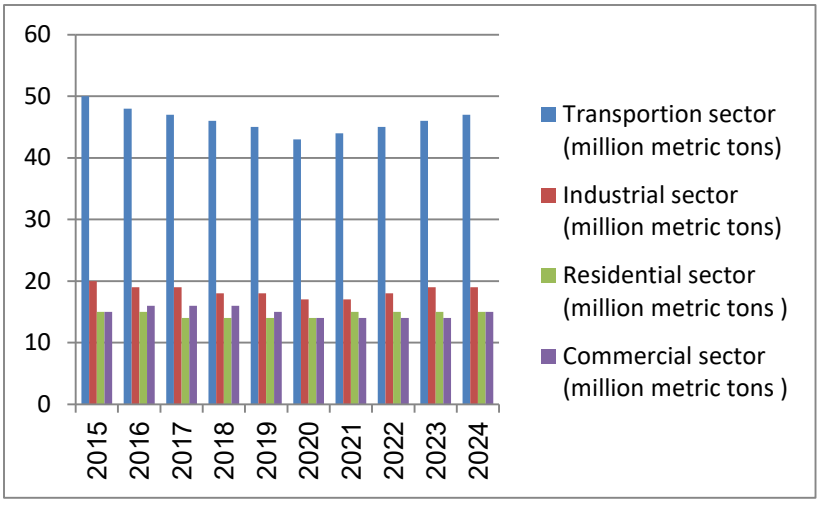

Figure 11: Sectoral Demand for Petroleum Products (2015–2024)

5.3 Demand for Natural Gas

Libya's natural gas demand is primarily driven by domestic power generation and industrial needs. Despite abundant reserves, production constraints—including infrastructure limitations and underinvestment—hinder supply reliability. While global markets shift toward LNG, Libya remains focused on meeting local demand, with limited export capacity. Energy security and infrastructure development are key challenges for future gas sector growth. Figure 12 illustrates the demand for natural gas during the period 2015–2024.

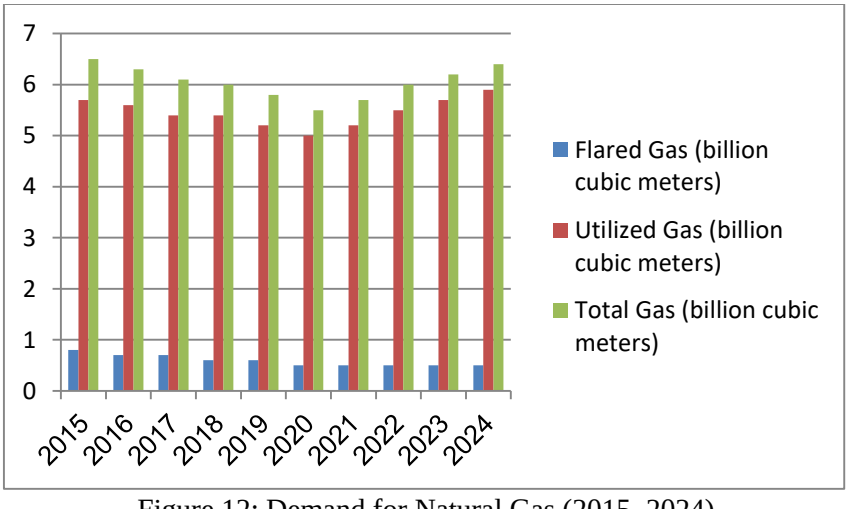

Figure 12: Demand for Natural Gas (2015–2024)

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5.4 Demand for Electric Energy

Global demand for electric energy is rising due to population growth, urbanization, and sector electrification. Meeting this demand requires sustainable energy generation, grid modernization, and a shift to renewables like solar and wind to ensure energy security and reduce emissions [9].

Conclusions

Through this research, it becomes evident that Libya primarily relies on conventional power plants for electricity generation, with sources such as diesel and natural gas constituting the majority of its energy mix. This heavy dependence on fossil fuels not only negatively impacts oil revenues but also leads to grid instability and increases thermal emissions, exacerbating both environmental and economic challenges.

Therefore, Libya must accelerate the adoption of renewable energy sources, such as solar and wind power, for electricity production. This transition will not only enhance grid stability but also reduce long-term energy production costs, decrease reliance on fossil fuels, and allow for increased oil exports, thereby boosting the national economy. Additionally, this shift will contribute to reducing carbon emissions, reflecting a greater commitment to environmental protection and

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