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A Comparative Study of Gas Turbine Power Plant and Renewable Solar Energy and Regulatory Frameworks in Libya

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دراسة مقارنة بين محطات توليد الطاقة باستخدام الغاز الطبيعي والطاقة الشمسية المتجددة والأطر التنظيمية في ليبيا

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Abstract
Energy systems in Libya present inherent characteristics like any energy systems in the third-world countries which meanly depend on classical generation systems of electricity such as fossil and gas. This leads to high electricity prices, heavy dependence on fuel, pollution and carbon emissions. In recent years, the development of renewable energy technologies has presented an opportunity to counter these challenges and improve the affordability and sustainability of energy systems. This study focuses on a gas turbine power plant compared to a solar PV power station. the uptake of this has been constrained by various factors. These include consumption quantities of fuel, installations, operations and maintenance cost-effective, CO2 emissions, and available land area. This study compares the gas turbine power plant and renewable solar energy systems in Libya, analyzing their impact on electricity prices, fuel dependence, pollution, and carbon emissions.

Keywords: Renewable Energy, Gas Turbine Power Plant, CO2 Emissions, Pollution, Fuel Consumption.

الملخص
تعتبر أنظمة توليد الطاقة الكهربائية العاملة في ليبيا والتي تم بناؤها خلال الخمسة عقود الماضية مشابهة لتلك الأنظمة العاملة في بعض الدول المتقدمة ومعظم دول العالم الثالث من حيث اعتمادها الرئيسي على الوقود الأحفوري والغاز الطبيعي والذي من شأنه إطلاق كميات هائلة من الغازات الدفيئة والانبعاثات السامة المسببة في ظاهرة الاحتباس الحراري والاعتماد الكلي على هذا الوقود يفرض تكاليف باهظة على عمليات إنتاج الطاقة. خلال العقدين الأخيرين التطور الهائل الذي حصل على أنظمة توليد الطاقة باستخدام المصادر المتجددة كالشمس والرياح فرض فرص هائلة لاستخدامها والتغلب على التحديات وتحسين إدامتها ورخص مكوناتها. هذه الدراسة تركز على المقارنة بين محطة توليد الطاقة باستخدام الغاز الطبيعي مع نظيرتها المستخدمة للطاقات الشمسية المتجددة مع التركيز على عدة جوانب في المقارنة منها كميات الوقود المستهلكة، أعمال الإنشاءات والتركيبات، أعمال التشغيل والصيانة، كفاءة الأسعار، الانبعاثات الكربونية، مساحات الأرض اللازمة لتركيب المحطة.

الكلمات المفتاحية: الطاقات المتجددة، محطة الغاز الطبيعي لتوليد الطاقة، انبعاثات أول أكسيد الكربون، التلوث، استهلاك الوقود.

1. Introduction

1.1. Background on energy systems in Libya

The energy crisis in Libya has had a profound impact on the country's progress, as ongoing civil unrest has led to severe electricity shortages and power outages. Before 2011, Libya heavily relied on traditional fossil fuel-based power generation due to its abundant oil and gas reserves. However, following the Arab Spring protests, a full-fledged rebellion and subsequent civil war ensued, presenting numerous challenges to the nation's power grid infrastructure. The conflict resulted in significant damage, destruction, sabotage, and vandalism to power plants and transmission network assets, particularly in the eastern and western regions of Libya. The lack of maintenance, coupled with financial constraints and limited foreign involvement, exacerbated the electricity supply issues. With actual electricity generation falling below demand levels, rolling blackouts were

implemented to prevent a complete system collapse. While some individuals resorted to using mobile diesel generators as a temporary fix, many Libyans continued to have limited access to grid electricity.

This situation underscores the critical need for addressing energy system deficiencies in Libya by exploring innovative solutions such as integrating renewable energy sources like solar power. A comprehensive analysis comparing gas turbine power plants with renewable solar energy will offer valuable insights into cost-effectiveness, environmental implications, and regulatory frameworks to inform policy decisions for a more sustainable energy landscape in Libya. See references: (Almaktar et al., 2021) [2], (Kassem et al., 2020) [3].

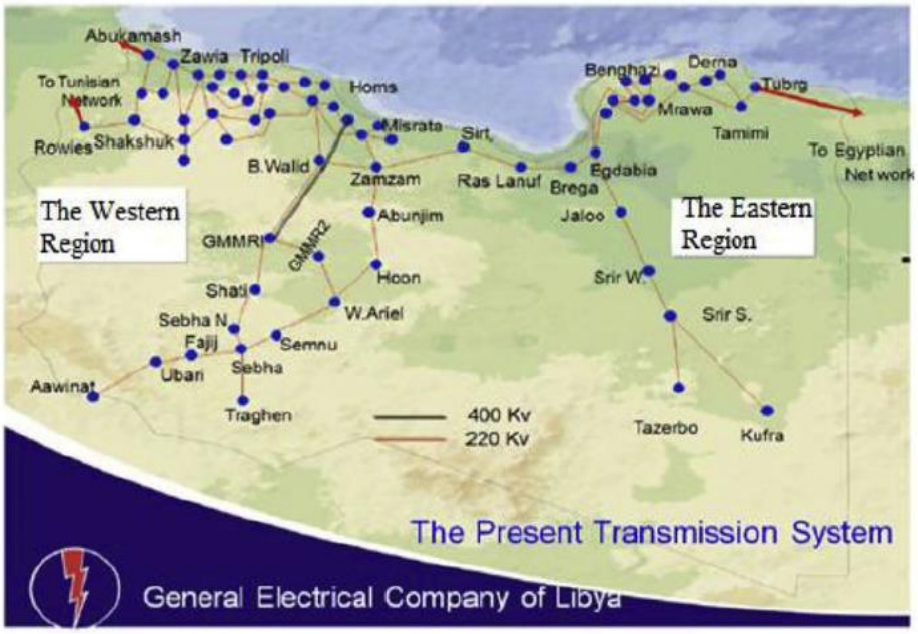

Figure 1: Libyan national transmission grid (220 kV & 400 kV). (source: reference (Almaktar etal.,2021) [2])

1.2. Significance of Comparative Study

A comparative analysis between gas turbine power plants and renewable solar energy in Libya is crucial to address energy difficulties caused by frequent power outages and infrastructure issues. Solar energy presents a hopeful solution to prevent blackouts, improve dependability, and reduce environmental impact. Understanding the distinct characteristics of each option regarding costs, environmental effects, and land requirements is essential for policymakers to promote renewable energy utilization effectively. The analysis will focus on factors such as installation, operation, maintenance expenses, CO2 emissions, pollution levels, and land space needed for each type of power plant. Ultimately, this research aims to provide valuable insights for policymakers to encourage the adoption of renewable energy in Libya, enabling well-informed decisions to tackle the nation's energy challenges efficiently. See references:(Kassem et al., 2020) [7], (Almaktar et al., 2021) [2], (Ailleret, 2004, pages 51-55) [8], (Alshalwy etal., 2020) [6].

1.3. Overview of gas turbine power plant

The gas turbine power plant plays a vital role in Libya's energy systems, serving as a key element in the country's reliance on oil and gas for electricity generation. Furthermore, a comparison between gas turbine power plants and renewable solar energy systems in Libya uncovers intriguing insights. While gas turbines rely on fossil fuels for operation, solar energy systems offer independence from non-renewable sources, impacting fuel dependence, pollution levels, and carbon emissions. Gas turbines release higher levels of CO_2 compared to solar energy systems due to their reliance on fossil fuels. When it comes to installation and operation, gas turbine power plants demand meticulous maintenance and monitoring for optimal performance. In contrast, solar energy systems offer a simpler operation with minimal maintenance requirements post-installation. Additionally, the cost-effectiveness of gas turbines versus solar energy systems plays a critical role in evaluating energy options in Libya. In conclusion, gaining an understanding of gas turbine power plants in Libya provides valuable insights into the country's energy landscape. As efforts persist to balance decarbonization with energy security in regions like Libya, exploring alternative energy sources like solar power becomes increasingly significant for sustainable development. See references: (Alshalwy et al.,2020) [6], (Seyed Mehdi Arabi, 2019) [4].

1.4. Overview of renewable solar energy

Renewable solar energy has emerged as a pivotal solution to energy challenges in Libya. The country's strategic roadmap, Renewable Energy Strategic '2013-2025', sets a target of achieving 7% of electricity generation from renewable sources by 2050, focusing on solar photovoltaics, wind, and solar thermal technologies. Despite facing obstacles due to political turmoil, both private initiatives and public entities have stepped forward to invest in the solar PV sector for power generation. Solar PV technology has been effectively utilized in Libya since 2003, especially in remote regions were connecting to the main power grid is cost-prohibitive. These systems have demonstrated their feasibility by offering reliable electricity solutions without relying on traditional off-grid energy sources like diesel generators. Furthermore, the General Electricity Company of Libya has deployed numerous solar PV systems in rural areas, highlighting their dependability and cost-efficiency. The potential for large-scale solar projects in Libya is substantial. Research indicates that the country possesses extensive solar energy resources that can be tapped into for generating electricity.

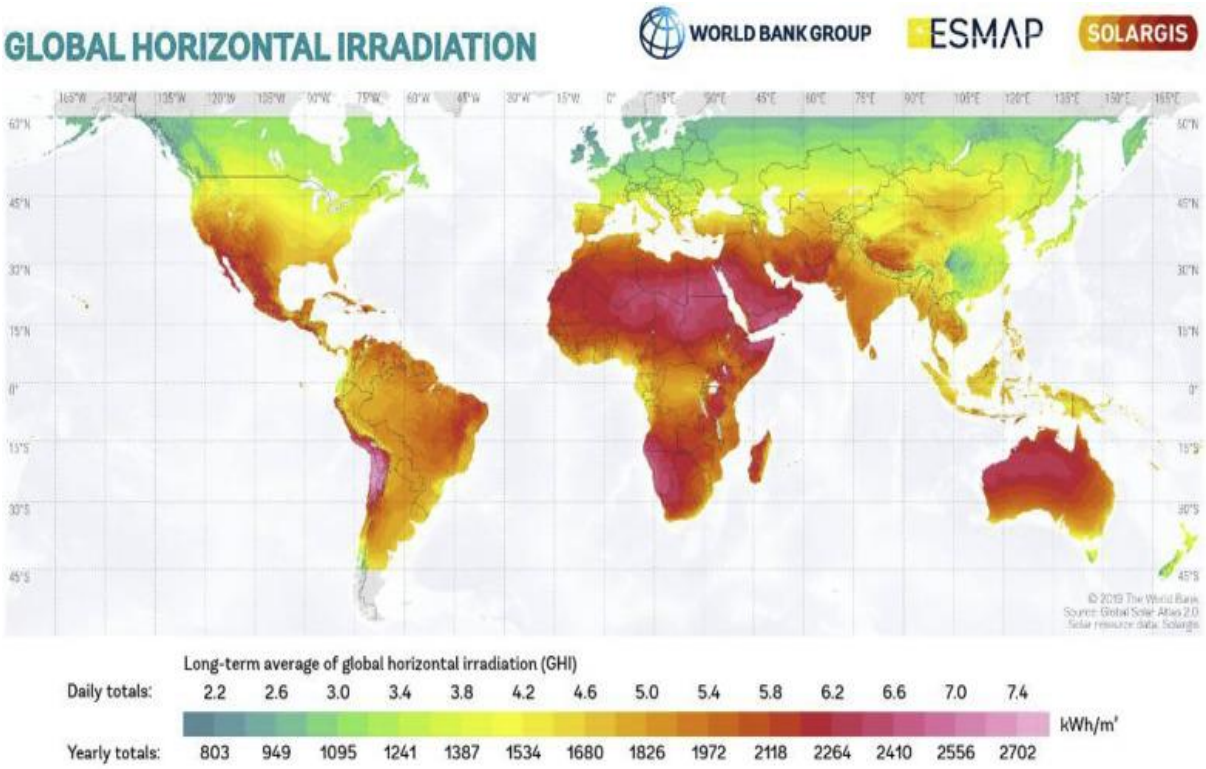

Figure 2: Global horizontal irradiation (kWh/m2/year) (source: reference (Almaktar et al., 2021) [2]

Collaborative efforts with other nations, such as the desert technology project, aim to export solar power produced in Libya to Europe. This ambitious initiative could supply Europe with a significant amount of clean energy and substantially decrease carbon emissions. In essence, solar PV technology presents a sustainable and eco-friendly answer to Libya's energy requirements. By investing in solar energy systems, the nation can diminish its reliance on fossil fuels, alleviate pollution levels, and reduce carbon emissions. With continuous advancements in solar technology and a growing global emphasis on renewable energy sources, Libya stands at a unique juncture to leverage its abundant solar resources for a more sustainable energy future. See reference (Maka et al., 2021) [**1**].

2. Comparison of gas turbine powerplant and solar energy

2.1. Consumption quantities of fuel

An essential factor to consider when comparing gas turbine power plants and solar energy systems in Libya is the fuel consumption rates. In Libya, the electricity sector heavily depends on fossil fuels, specifically natural gas and oil, for generating power. The country's power stations mostly utilize light and heavy oil, with a growing reliance on natural gas as well. This heavy reliance on fossil fuels presents challenges related to fuel transportation expenses, safety issues, and environmental consequences. On the contrary, solar energy systems provide a sustainable and renewable alternative to traditional fuel-based power generation. A study focusing on solar energy applications in Libya emphasized the country's abundant solar energy potential due to its proximity to the Sahara Desert (International Journal of Thermodynamics). Solar power can be harnessed through concentrated solar power (CSP) systems that use sunlight to produce electricity without the need for fossil fuels.

By utilizing this renewable resource, Libya can significantly decrease its fuel consumption for electricity production. The fuel consumption rates of gas turbine power plants are substantial due to their reliance on fossil fuels like natural gas and oil. In contrast, solar energy systems operate without any fuel requirements, making them a cleaner and more sustainable choice for power generation in Libya. Transitioning towards increased use of solar energy could aid in reducing the country's dependence on imported fossil fuels and mitigating the environmental impacts associated with fuel-based electricity generation. Overall, when considering the fuel consumption rates of gas turbine power plants versus solar energy systems, it becomes clear that shifting towards renewable energy sources such as solar power can provide a more sustainable and environmentally friendly solution for meeting Libya's electricity demands. See references: (Ehtiwesh et al., 2023) [11], (Maka et. al., 2021) [1].

Table **1**: The cost of the fuel quantities (M$) consumed by GECOL for power generation (source: reference (official GECOL letter dated 06/11/2023) [16].

Category	2020	2021	2022	2023
Diesel	534	885	2,115	2,837
Heavy fuel	139	285	295	315
Crude oil	144	239	368	573
Natural gas	1,326	1,794	3,326	3,015
TOTAL	**2,143**	**3,203**	**6,104**	**6,740**

2.2. Installations and operations

Gas turbine power plants are widely utilized in Libya for electricity production due to their efficiency and reliability. The setup of these power plants involves turbines, compressors, combustors, and generators that work together to convert fuel into electricity. These plants rely on a continuous supply of fuel, typically natural gas or diesel, which is burned in the combustor to create high-pressure, high-temperature gas. The resulting hot gases pass through the turbine, spinning the generator and generating electricity. Conversely, solar energy systems have seen increased use in Libya, particularly in critical facilities like hospitals and health clinics. The installation process for solar energy systems includes placing photovoltaic modules on rooftops or open areas to capture sunlight and convert it into electricity using the photovoltaic effect. These systems are connected to inverters that convert the DC electricity produced by the panels into AC electricity for building use. When it comes to operation, gas turbine power plants require regular maintenance to ensure optimal performance. This involves monitoring fuel levels, inspecting combustion chambers and turbines, and conducting routine electrical checks. It is also important to operate these powerplants within specific temperature and pressure ranges to prevent damage and maintain efficiency. In contrast, solar energy systems have minimal operational requirements compared to gas turbine power plants. Once installed, solar panels need little maintenance aside from occasional cleaning to remove dust or debris that could impact their efficiency. Solar energy systems operate quietly and without emissions during use, making them a clean and sustainable energy choice. Overall, while gas turbine power plants offer high efficiency and reliability in electricity generation, they rely on fossil fuels and can emit CO2 during operation. On the other hand, solar energy systems provide a renewable and emission-free source of electricity with low operational needs. Both systems have their advantages and drawbacks that should be taken into account when comparing energy options in Libya. See references: (Almaktar et al., 2021) [2], (Beitelmal et al., 2022) [9], (Maka et al., 2021) [1].

2.3. Cost-effectiveness

The economic feasibility of energy systems in Libya is heavily influenced by their cost-effectiveness. A detailed analysis of gas turbine power plants and solar energy provides valuable insights into their economic viability. Gas turbine power plants, which rely on fossil fuels, come with substantial installation and operational expenses. The ongoing costs associated with fuel consumption significantly impact the cost-effectiveness of these plants. Moreover, the high levels of CO2 emissions produced by gas turbines contribute to their environmental and social costs. On the contrary, solar energy systems present a more sustainable and economically efficient alternative. Studies on the feasibility of solar power generation within local communities suggest that providing financial incentives, such as Feed-in Tariffs (FiT) exceeding 7 $/kWh, can result in positive Net Present Value (NPV) and shorter payback periods for solar projects. The availability of higher FiT rates and incentives leads to

increased profitability and faster breakeven points for solar initiatives. Inflation rates also play a crucial role in determining the cost-effectiveness of both gas turbine power plants and solar energy systems. While elevated inflation levels may make PV system projects unviable, lower inflation rates make them an attractive investment option due to reduced operating expenses and improved profitability. Overall, the cost analysis indicates that renewable solar energy systems represent a more economically feasible choice compared to gas turbine power plants in Libya. By offering lower operating costs, decreased environmental impact, and potential financial incentives, solar energy emerges as a promising solution for addressing the country's energy requirements in a sustainable and cost-effective manner. See reference (Almaktar et al., 2021) [2].

2.4. CO_2 emissions

Gas turbine power plants are notorious for their significant contribution to CO2 emissions as they burn fossil fuels like natural gas or oil for electricity generation. On the other hand, solar energy systems operate without emitting CO2 directly, as they harness energy from the sun. Opting for solar energy can contribute to lowering overall carbon emissions and alleviating the environmental impact caused by conventional gas turbine power plants. Research on renewable energy projects in Libya reveals that the solar energy system stands out for its remarkable reduction in carbon emissions compared to other hybrid energy systems. While gas turbine systems result in higher CO2 emissions due to diesel consumption in the generation process, the solar energy system boasts zero CO2 emissions, underscoring the environmental advantages of solar energy over fossil fuel-dependent systems. The heavy reliance on oil and gas in Libya's power generation sector has led to elevated levels of CO2 emissions per capita, highlighting an urgent need to transition towards more sustainable energy sources. With abundant solar resources available in Libya, there exists a promising opportunity to cut down on carbon emissions by implementing solar power systems on a large scale making a shift towards solar energy systems and decreasing reliance on gas turbine powerplants, Libya can make significant progress in reducing its carbon footprint and promoting environmental sustainability. Embracing renewable energy sources like solar not only aids in combating climate change but also leads to long-term cost savings and enhanced energy security for the nation. See references: (Almaktar et al., 2021) [2], (Beitelmal et al., 2022) [9], (Khalilet al., 2017)[5].

Table 2**:** Emissions from the two energy systems. (source: reference (Beitelmal et al.,2022) [9])

System type	Carbon dioxide CO2 (Kg/yr)	Carbon monoxide CO (Kg/yr)	Sulfur dioxide SO2 (Kg/yr)	Nitrogen dioxide NO2 (Kg/yr)
Solar energy systems	0.0	0.0	0.0	0.0
Gas turbine power plants	39.216	284	170	83.1

2.5. Available land area

The spatial needs for gas turbine power plants and solar energy systems are pivotal in determining their feasibility and influence. Gas turbine power plants typically demand a substantial land area for their setup due to the size of the infrastructure required to support them. This encompasses space for turbines, generators, cooling systems, fuel storage tanks, and other supplementary equipment. Additionally, gas turbine power plants necessitate access roads for maintenance and operational purposes. In contrast, solar energy systems have distinct land requirements. Solar panels can be situated on rooftops or open ground areas like deserts or unused lands. In Libya, with its expansive desert regions receiving high levels of solar irradiation throughout the year, there is a great opportunity to harness solar energy without significant land usage. Research indicates that every 1 square km of desert in the Middle East/North Africa region receives solar energy equivalent to 1.5 million barrels of crude oil annually. This underscores the vast potential for solar energy generation in Libya without compromising valuable land resources. The utilization of small-scale solar PV energy systems in local communities can help mitigate challenges faced by critical power grid infrastructure while utilizing minimal land area. In comparison to gas turbine power plants, which require extensive land use, solar energy systems offer a more efficient utilization of available land resources by effectively utilizing open spaces. By tapping into Libya's abundant solar energy potential, not only can local electricity needs be sustainably met but also make a significant contribution to global energy demands. Overall, the spatial requirements for gas turbine power plants and solar energy systems in Libya demonstrate diverging approaches to energy generation. While gas turbine power plants require larger land areas for their setup and operations, solar energy systems present a more environmentally friendly and resource-efficient solution with minimal impact on available land resources. See references: (Almaktar et al., 2021) [2], (Khalil et al., 2017) [5].

3. Impact on electricity prices

3.1. Gas turbine power plant impact on electricity prices

The influence of gas turbine power plants on electricity costs in Libya is a crucial factor to take into account when examining different energy systems. Gas turbine power plants heavily rely on fossil fuels, leading to price fluctuations that directly impact electricity costs. The substantial fuel consumption required by these plants results in high operating expenses, which are then transferred to consumers through increased electricity prices. Additionally, the maintenance and fuel supply needed for the installations and operations of gas turbine power plants add to the overall costs incurred by these systems. Furthermore, the cost-effectiveness of gas turbine power plants plays a key role in determining their effect on electricity prices.

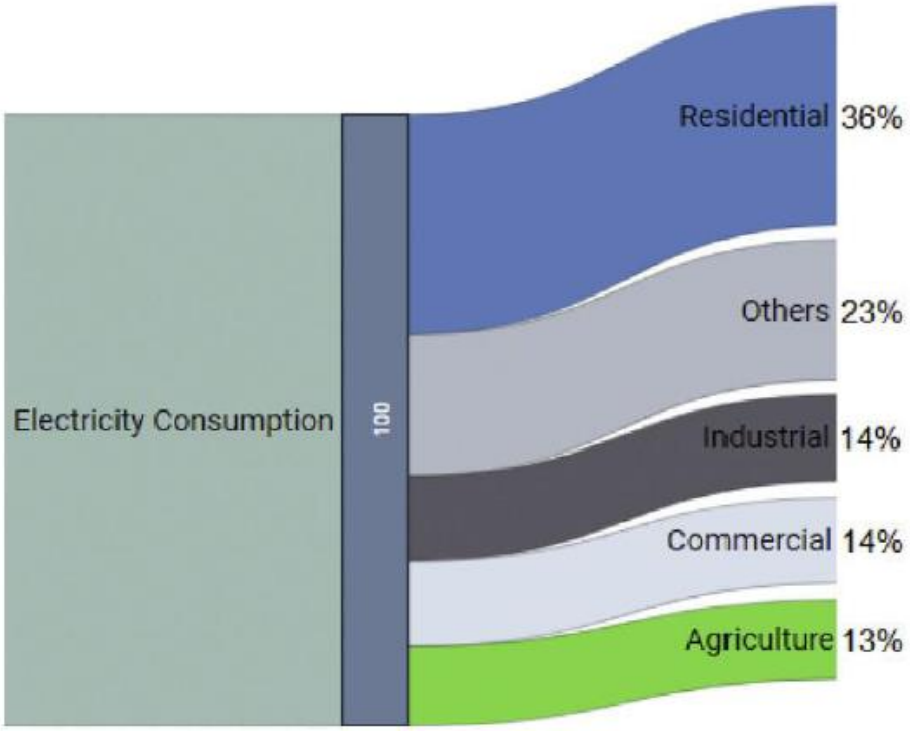

Figure 3: Sankey diagram of electricity consumption per sector (GECOL, 2012). (source: reference (Almaktar et al., 2021) [2])

The significant initial investment and ongoing operational costs associated with these power plants can lead to higher electricity prices for consumers. On the other hand, renewable solar energy systems offer a more sustainable and cost-efficient solution for electricity generation, with lower operational costs and minimal fuel needs. Additionally, gas turbine power plants contribute greatly to CO2 emissions due to their reliance on fossil fuels. These emissions not only have environmental impacts but also result in additional costs related to carbon offset credits or environmental compliance measures. In contrast, solar energy systems produce minimal to no CO2 emissions during operation, making them a cleaner alternative that can help decrease overall electricity prices by avoiding such extra expenses. In conclusion, the impact of gas turbine power plants on electricity prices in Libya tends to be negative due to their heavy dependence on fossil fuels, high operational costs, and significant carbon emissions. Conversely, renewable solar energy systems provide a more sustainable and cost-effective solution that can assist in alleviating the increase in electricity prices associated with conventional gas turbine power plants. See references: (Alshwawra et al., 2023) [10], (Pamucar et al., 2018) [12].

3.2. Renewable solar energy impact on electricity prices

Renewable solar energy has emerged as a vital alternative in Libya, particularly amidst the COVID-19 pandemic. The lockdowns and reduced industrial production have led to a significant increase in electricity costs, making solar energy a crucial solution. Solar power has played a key role in providing sustainable and reliable electricity to essential facilities like hospitals, clinics, and health centres. Numerous hospitals in Libya have already reaped the benefits of solar photovoltaic (PV) installations, ensuring continuous access to primary medical services even during electricity shortages. This reliance on solar systems not only offers a swift response to energy needs but also presents a long-term sustainable power generation solution. Extensive studies have highlighted the feasibility of utilizing solar energy sources across various applications. The Libyan

government's Renewable Energy Strategic plan aims to shift a substantial portion of electricity generation to renewable sources such as solar PV. Despite challenges related to political instability, private initiatives and public investments have set the stage for the widespread adoption of solar PV systems throughout the country. The successful implementation of numerous solar PV installations by the General Electricity Company of Libya for rural electrification underscores the reliability and cost-effectiveness of these systems. Furthermore, large-scale solar projects like the desert technology initiative showcase Libya's potential as a solar power exporter to Europe. These projects not only help reduce carbon emissions but also address critical needs such as water desalination in desert regions. With collaborations with various nations and advancements in solar technology, Libya is poised to become a major player in global renewable energy production. In summary, renewable solar energy holds great promise for positively influencing electricity prices in Libya by offering a sustainable and cost-effective alternative to traditional fossil fuel-based power generation methods. See references: (Beitelmal et al., 2022) [9], (Maka et al., 2021) [1].

4. Fuel dependence

4.1. Gas turbine dependence on fossil fuels

In Libya, gas turbines play a significant role in the country's energy infrastructure, as a majority of electrical energy is generated from fossil-fueled power plants. Data reveals that main gas turbines contribute 39.3% to electricity production, while combined cycle gas turbines (CCGT) make up 37% of the total. This heavy reliance on gas turbines underscores Libya's dependence on fossil fuels to meet the increasing electricity demand. The common use of gas turbines is not only due to their efficiency but also influenced by challenges in fuel transportation, particularly in regions like southern Libya where water scarcity poses a challenge. The high annual costs associated with fuel operation and transportation have led to a shift towards exploring the potential of solar energy to decrease fuel consumption. With favorable conditions for concentrated solar power plants near the Sahara Desert, there is a promising opportunity to reduce reliance on fossil fuels by integrating solar energy into existing power grids. By enhancing plant efficiency and lowering the fuel mass rate ratio through preheating air entering combustion chambers, it is feasible to lessen dependence on fossil fuels and transition towards cleaner and more sustainable energy sources. While gas turbines currently hold a significant position in Libya's energy sector, there exists an opportunity to diminish reliance on fossil fuels by embracing renewable energy sources like solar power. By harnessing the abundant solar resources available in the region, Libya can strive towards establishing a more sustainable and eco-friendly energy system. See references: (Almaktar et al., 2021) [2], (Ehtiwesh et al., 2023) [11].

4.2. Solar energy independence from fossil fuels

Solar power presents a remarkable degree of autonomy from fossil fuels, positioning it as a viable and dependable choice for energy systems in Libya. The potential of solar energy in Libya is virtually limitless, with solar resources surpassing the country's electricity demand by approximately 50 times. This surplus of solar power can be utilized to address the escalating electricity requirements in Libya without depending on exhaustible fossil fuels. Moreover, the utilization of solar energy can aid in decreasing the reliance on imported fuels, a critical aspect for ensuring long-term energy security and stability. By tapping into the extensive solar potential in Libya, the nation can enhance self-sufficiency in meeting its energy needs without having to lean on external fuel sources. Additionally, apart from its independence from fossil fuels, solar energy offers economic advantages. Solar panels entail lower operational and maintenance expenses compared to traditional fuel-based power plants, rendering them a cost-efficient option for electricity generation. By investing in solar energy infrastructure, Libya can not only diminish its carbon footprint but also save on fuel expenses and maintenance costs over time. In essence, the autonomy of solar energy from fossil fuels positions it as a promising substitute for powering energy systems in Libya. With abundant solar resources and economic benefits, embracing solar power can bolster energy security, reduce dependence on imported fuels, and pave the way for a more sustainable and environmentally friendly future for the country. See references: (IEA, 2021, pages 16-20) [13], (Supersberger et al., 2009, pages 136-140) [14], (Maka et al., 2021) [1].

5. Pollution

5.1. Pollution levels from gas turbine power plants

The environmental impact of gas turbine power plants is substantial, particularly in terms of CO2 emissions. These plants heavily rely on fossil fuels as their primary energy source, resulting in a significant release of greenhouse gases into the atmosphere. In contrast to renewable energy options such as solar power, gas turbine power plants exhibit a much greater negative effect on the environment. Research has shown that the amount of CO2 emitted per unit of electricity produced by gas turbine power plants is markedly higher than that of renewable energy sources like solar power. This issue is alarming because CO2 emissions are major contributors to climate change and global warming. The continuous operation of gas turbine power plants in Libya only adds to the overall pollution levels in the country. Various studies have emphasized the necessity for

a transition towards cleaner and more sustainable energy sources. By reducing reliance on gas turbine power plants and shifting towards renewable energy alternatives like solar power, Libya can make strides in decreasing its pollution levels and lessening its environmental impact. This shift would also align with international efforts to combat climate change and foster a more environmentally conscious future for succeeding generations. See references: (Almaktar et al., 2021) [2], (Supersberger et al., 2009, pages 41-45) [14].

5.2. Pollution levels from solar energy systems

Solar energy systems are widely recognized for their eco-friendly characteristics and their contribution to sustainable development. In Libya, solar photovoltaic (PV) systems are commonly utilized in remote areas where connecting to the main power grid is costly, presenting a feasible alternative to traditional off-grid energy sources like diesel generators. The inclusion of storage in these solar PV systems allows them to meet the energy demands in these regions, ensuring a consistent power supply even during grid power shortages. A variety of applications for solar photovoltaic systems have been explored in Libya, such as powering mobile phone stations, PV-water desalination, solar PV operated LED lighting systems, photovoltaic water pumping, cathodic protection for oil pipelines, and standalone photovoltaic systems for household electrification. These examples showcase the versatility of solar energy in addressing diverse needs across different industries. A feasibility analysis conducted on a standalone solar-powered LED lighting system in Libya revealed significant advantages including reduced pollution, fuel savings, and cost-effectiveness. This system was able to cut down electricity consumption by 75% and eliminate 75% of CO2 emissions compared to conventional high-pressure sodium lamp systems. Furthermore, solar energy technology has demonstrated economic benefits through emission reduction and stable energy prices. In essence, solar energy systems play a pivotal role in minimizing pollution levels and carbon emissions while delivering a dependable source of electricity for various purposes in Libya. The utilization of solar energy not only supports sustainable development but also provides economic advantages and safeguards the environment. See references: (Maka&Alabid, 2022) [15], (Maka et al., 2021) [1].

6. Recommendations for Policy and decision-makers

6.1. Strategies to Promote Renewable Energy Adoption in Libya

In order to boost the uptake of renewable energy in Libya, it is imperative to leverage the country's abundant wind and solar energy resources. Research indicates that electricity produced from these sustainable sources can play a key role in reducing emissions and decreasing dependence on fossil fuels. The Libyan government has set targets to raise the proportion of renewable energy in electricity generation to 22% by 2030. Installing small-scale photovoltaic (PV) systems in local communities, particularly in areas prone to power outages and infrastructure damage, can offer a dependable alternative to traditional grid connections. By establishing microgrids that enable surplus energy sharing, these systems can enhance the overall reliability of the electricity supply network. Furthermore, it is vital to take into account financial incentives like Feed-in Tariff rates and electricity tariffs to ensure the economic feasibility of PV-grid setups. Through comprehensive feasibility studies and sensitivity analyses, policymakers can identify the most cost-efficient and sustainable approaches for promoting renewable energy integration in Libya. Embracing eco-friendly technologies such as solar power not only tackles the existing issues confronting the electricity sector but also lays the groundwork for a more robust and sustainable energy future in the nation.

7. Conclusion

In summary, the examination of gas turbine power plants versus renewable solar energy in Libya provides valuable insights into the nation's energy industry. While gas turbine technology offers flexibility and reliability, it is hampered by high costs and environmental considerations. On the contrary, solar PV technology presents advantages like sustainability and reduced operational expenses, but it encounters challenges related to intermittency and upfront investment. A thorough analysis of installation, operation, and maintenance expenses suggests that renewable solar energy could be more cost-effective in the long term compared to gas turbines. Furthermore, when taking into account environmental aspects such as CO2 emissions and pollution, solar energy emerges as a cleaner option that aligns with global sustainability objectives. Additionally, the land area requirements for solar energy tend to be lower than those for gas turbine power plants. Given these outcomes, policymakers in Libya need to prioritize the adoption of renewable energy sources by implementing supportive regulatory frameworks. By strengthening regulations that encourage the development of solar energy projects and stimulate investment in sustainable technologies, Libya can progress towards a more environmentally friendly and economically feasible energy environment. In essence, this comparative study emphasizes the significance of transitioning towards renewable sources like solar energy to secure a sustainable future for Libya's energy sector.

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