Libyan Open University Journal of Applied Sciences (LOUJAS)
Volume 2 - Issue 1 - 2026 - Pages 71-79

A Comparative Study Between Conventional Power Generation Plants and Renewable Energy Generation Technologies Using Solar (PV) Panels and Wind Energy in Libya

Ali Ahmed Aboukra [1*], Khaled Al Hadi Lekhmaisi [2]
[1,2] Libyan Center for Engineering Research and Information Technology, Bani Walid, Libya
* **Email (for reference researcher):** aliaboukra@gmail.com

دراسة مقارنة بين محطات توليد الطاقة التقليدية مع تقنيات توليد الطاقة المتجددة باستخدام طاقة الألواح الشمسية والرياح في ليبيا

علي أحمد أبوكراع [1*]، خالد الهادي الخميسي [2]
[1،2] المركز الليبي للبحوث الهندسية وتقنية المعلومات، بني وليد، ليبيا

Received: 25-12-2025; Accepted: 12-02-2026; Published: 01-03-2026

Abstract:
Energy systems in Libya share many of the same characteristics found across developing countries, relying heavily on traditional electricity generation methods such as fossil fuels and natural gas. This dependence results in high electricity costs, significant fuel consumption, and increased pollution and carbon emissions. In recent years, advancements in renewable energy technologies have created an opportunity to address these challenges and enhance the affordability and sustainability of the national energy system.
This study highlights the comparison between conventional power generation plants and renewable energy technologies, outlining the advantages and disadvantages of each in order to adopt the most suitable option and incorporate it into future expansion plans to meet the growing demand for energy and reduce the costs of its production and transmission to load centers.

Keywords: Renewable Energy, Gas Turbine Power Plant, wind power plants, 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 فرضية إضافة طاقات مركبة للشبكة العامة مولدة باستخدام محطات الرياح والشمس لتغطية الأحمال السنوية المتزايدة والطلب على الطاقة وإجراء بعض الحسابات في هذه الدراسة لمعرفة مقدار الخفض في تكاليف الوقود المستخدم غي التوليد والوفر الممكن للنفقات في حال دمج التقنيات الحديثة للتوليد المعتمدة على الطاقات المتجددة مع محطات التوليد التقليدية.

الكلمات المفتاحية: الطاقات المتجددة، محطة الغاز الطبيعي لتوليد الطاقة، محطة توليد رياح، استهلاك الوقود.

1. Introduction

1.1. Background on energy systems in Libya

The energy crisis in Libya has significantly hindered the country's development, as prolonged civil unrest has caused widespread electricity shortages and frequent power outages. Before 2011, Libya relied extensively on conventional fossil-fuel power generation thanks to its abundant oil and gas resources. However, after the Arab Spring and the subsequent uprising and civil war, the nation's power grid faced immense challenges. The conflict caused extensive damage, destruction, sabotage, and vandalism across power plants and transmission infrastructure, especially in the eastern and western regions. A lack of maintenance, financial limitations, and reduced foreign support further worsened the situation, resulting in a power supply that consistently fell short of national demand. To prevent a total grid failure, authorities implemented rolling blackouts, and although some individuals relied on portable diesel generators as a temporary solution, many Libyans continued to experience limited access to electricity. This situation highlights the urgent need to address the weaknesses within Libya's energy system by considering alternative and innovative approaches, including the integration of renewable energy sources such as solar and wind. Conducting a comprehensive analysis of fuel quantities and costs associated with electricity generation from traditional fossil-fuel and gas-turbine plants—combined with contributions from solar and wind power—can provide crucial insights. Such an analysis would support assessments of cost-effectiveness, potential fuel savings, and regulatory requirements, helping inform future policy decisions and guiding Libya

toward a more sustainable and resilient energy future. Fig. (1) shows the existing national transmission grid. See reference Almaktar et al., 2021 [1].

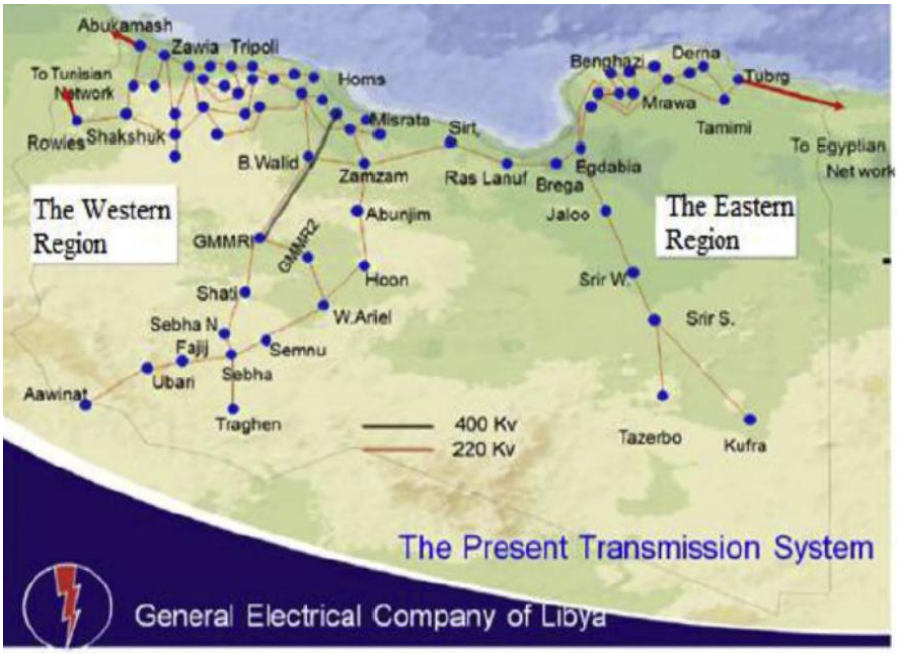

Figure 1: Libyan national transmission grid (220 kV & 400 kV). (source: reference (Almaktar et al., 2021) [**1**])

1.2. Significance of Comparing Gas Turbine Power Plants and Solar Energy

The shift toward sustainable energy in Libya is increasingly important, making it essential to evaluate gas turbine power plants alongside solar energy. Gas turbines are known for their reliability and high efficiency; however, they are associated with substantial fuel consumption and significant CO_2 emissions. In contrast, solar energy is a clean and widely available resource, though it involves high initial investment costs and is highly dependent on weather conditions.

In the pursuit of diversifying Libya's energy mix, policymakers must assess key factors such as fuel consumption, capital costs, operational and maintenance requirements, CO_2 emissions, and land use. Addressing challenges to renewable energy deployment—including high fuel usage, installation complexities, and economic feasibility—is critical for successful adoption. Regulatory frameworks play a vital role in supporting the development of both gas turbine power plants and solar energy projects. A thorough understanding of the existing regulations governing each system can help ensure a smoother transition toward renewable energy. Additionally, case studies of energy projects in Libya can offer valuable insights into their performance, practicality, and suitability within the local context. Ultimately, a thorough comparative assessment of gas turbine power plants and solar energy in Libya can yield valuable insights to guide future development initiatives. The resulting recommendations should emphasize expanding the adoption of renewable energy, lowering CO_2 emissions, and strengthening the country's overall energy security.

1.3. Significance of Study

A comparative analysis of gas turbine power plants, solar and wind energy systems in Libya is essential for addressing the nation's ongoing energy challenges, including frequent power outages and deteriorating infrastructure. Solar and wind energy offers a promising pathway to minimizing blackouts, enhancing system reliability, and reducing environmental impacts. To effectively support the transition toward renewable energy, it is important to understand the key differences between these generation options, particularly in terms of operational costs, fuel requirements, and potential financial savings. This study will compare key factors such as the initial installation costs, operation and maintenance costs, associated fuel consumptions, pollutions, and the expected land area needed. Ultimately, the research aims to provide policymakers with meaningful insights that can support informed decisions and encourage the widespread adoption of renewable energy in Libya, contributing to a more stable and sustainable national energy system.

2. Overview of gas turbine power plant

2.1. Description of gas turbine systems

Gas turbine technology is a key component of Libya's power generation infrastructure, offering high efficiency, rapid start-up capability, and relatively low emissions. Nevertheless, it is associated with high fuel consumption

and significant maintenance costs. These systems depend heavily on Libya's natural gas resources and require a continuous fuel supply to operate reliably. Despite the costs related to installation and upkeep, gas turbines remain a dependable source of electricity. A clear understanding of their advantages and limitations is essential when evaluating renewable energy alternatives, such as solar power, within Libya's evolving energy landscape. The total installed power plants are 16, with total installed generation capacity around 9000 MW. Table (1) illustrate the installed power plants and their capacity and fuel types [**2**].

Table (1) The Existing power plants (source: reference (Al-Hashmi, S.A., (2017) [2])

No.	PLANT	CAPASITY	TYPE	FULE
1	Alzawia	990 MW	GT	Gas
2	Alzawia	450MW	ST	Gas
3	Bengazi	1131MW	GT	Oil
4	Bengazi	550MW	GT	Gas
5	Musrata	570MW	GT	Gas
6	Musrata steel	504MW	ST	Gas
7	Tripoli south	648MW	GT	Gas
8	Khomes	600MW	GT	Gas
9	Khomes	480MW	ST	Gas
10	West mountain	936MW	GT	Gas
11	Zewitena	770MW	GT	Oil
12	Serrier	570MW	GT	Oil
13	Derana	130MW	GT	Oil
14	Tobruk	130MW	GT	Oil
15	Sirat	1400MW	ST	Gas
16	Tripoli west	500MW	ST	Oil

2.2. Benefits and Limitations

The integration of diverse renewable energy technologies—such as biogas derived from cow dung, solar thermal energy, and kinetic energy—into hybrid systems offers significant advantages. Diversifying energy sources enhances overall power output and system efficiency while reducing waste and lowering greenhouse gas emissions. This approach supports sustainable development objectives and promotes a more environmentally responsible future. Hybrid systems that combine these technologies deliver cost-effective and eco-friendly power generation solutions for communities. When comparing the advantages and disadvantages of gas turbine power plants and solar energy in Libya, gas turbines are recognized for their high efficiency but are constrained by high installation costs, dependence on fossil fuels, and associated emissions. In contrast, solar energy is environmentally friendly and benefits from Libya's abundant solar resources, though it faces challenges related to intermittent power generation and substantial initial investment requirements. Overall, solar energy is more sustainable and inexhaustible than gas turbines, offering lower maintenance costs and significantly reduced CO_2 emissions. In summary, gas turbine power plants and solar energy each present distinct advantages and limitations for application within Libya's energy sector. The choice between these technologies depends on considerations such as environmental impact, economic viability, and regulatory policies. Incorporating renewable energy technologies into hybrid systems is essential for overcoming energy challenges, advancing sustainability, and strengthening resilience in Libya's evolving energy landscape.

3. Overview of Renewable Solar Energy

3.1. Description of solar PV technology

Solar photovoltaic (PV) technology is a method of generating electricity directly from sunlight using semiconductor materials. It is based on the photovoltaic effect, where solar radiation striking a PV cell excites electrons, creating an electric current. A typical solar PV system consists of solar panels, which are made up of many individual PV cells, commonly manufactured from silicon (monocrystalline, polycrystalline, or thin-film).

When sunlight hits these cells, direct current (DC) electricity is produced. Fig. (2) below shows structure of a single mono-crystal cell. See reference Hamza A. S., Mohamed M. A., Ali A. A., 2022 [**5**].

Figure 2: Mono-crystalline Solar cells [**5**].

This DC power is then converted into alternating current (AC) using an inverter so it can be used by homes, industries, or fed into the electrical grid. Solar PV systems can be installed in various configurations, including grid-connected**,** off-grid, and hybrid systems with battery storage. They require relatively low maintenance, have no moving parts, and produce electricity without fuel consumption or greenhouse gas emissions during operation. An on-grid solar system is shown in Fig. (3). See reference Telugu M., Likhithasree, C., 2019 [3].

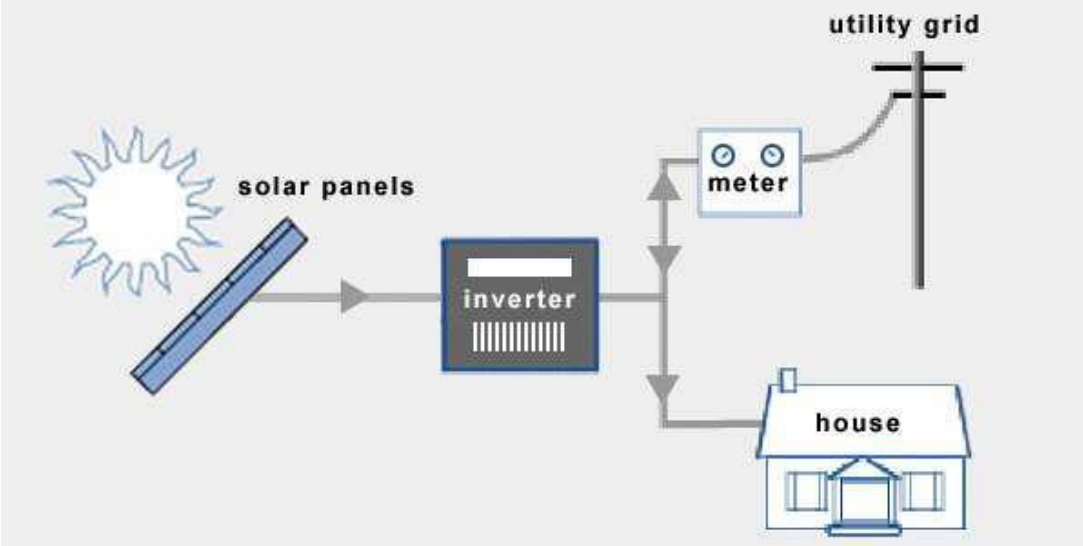

Figure 3: On-grid solar energy system [3]

Overall, solar PV technology is a clean, renewable, and sustainable energy solution, particularly suitable for regions with high solar irradiation, such as Libya, where abundant sunlight makes it an attractive option for reducing reliance on fossil fuels and lowering CO_2 emissions. Renewable energy has become a key solution to Libya's ongoing energy challenges. The national roadmap, *Renewable Energy Strategic 2013–2025*, outlines a goal of producing 7% of the country's electricity from renewable sources by 2050, with a focus on solar photovoltaics, wind power, and solar thermal technologies. Although political instability has slowed progress, both private investors and public institutions have continued to support the development of solar PV projects for power generation. Solar PV technology has been successfully implemented in Libya since 2003, particularly in remote areas where extending the national grid is costly and impractical. These systems have proven to be reliable alternatives, delivering consistent electricity without the need for conventional off-grid solutions such as diesel generators. Additionally, the General Electricity Company of Libya has installed numerous solar PV units in rural communities, demonstrating their effectiveness and cost-efficiency. Libya also holds significant potential for large-scale solar development. Studies show that the country has abundant solar resources that can be harnessed to generate substantial amounts of electricity. Joint initiatives with other countries—such as the Desert Technology Project—seek to export solar-generated electricity from Libya to Europe. This ambitious plan has the potential to

deliver substantial clean energy to European markets while significantly cutting carbon emissions. Overall, solar PV technology offers a sustainable and environmentally responsible solution to Libya's energy needs. By expanding investment in solar power systems, the country can reduce its dependence on fossil fuels, pollution, and lower greenhouse gas emissions. With ongoing improvements in solar technologies and increasing global commitment to renewable energy, Libya is well-positioned to capitalize on its abundant solar resources and move toward a more sustainable energy future. During the year of 2025, Libya has commissioned its first-ever 1 MW solar power plant in the city of Kufra, Shown in Fig. (4). Designed with a peak capacity of 1.14 MWp, the facility is expected to produce 2,182 MWh of electricity annually. See reference [10].

Figure (4): 1MWp Kufra solar power plant [10].

3.2. Benefits and Limitations

Assessing the advantages and disadvantages of gas turbine power plants and solar energy in Libya provides valuable insights into their suitability for meeting the country's energy needs. Gas turbine power plants offer several benefits, including high fuel-to-electricity conversion efficiency, which helps reduce operational costs. They can also quickly adjust output to match fluctuating demand, supporting grid stability. However, these plants depend on fossil fuels, making them susceptible to price volatility and supply disruptions. In addition, they contribute to greenhouse gas emissions, posing environmental challenges. Conversely, solar energy offers several significant benefits for Libya. Solar photovoltaic technology is renewable, environmentally friendly, and well-suited to the region's abundant sunlight. Once installed, it entails minimal operating costs and requires less maintenance compared to conventional power plants. Solar energy also reduces reliance on imported fuels, thereby enhancing energy security. However, its power generation is intermittent, influenced by factors such as clouds or nighttime, which necessitates storage solutions to ensure a continuous supply. In conclusion, both gas turbine power plants and solar energy present distinct advantages and limitations within the Libyan context. Policymakers must carefully consider these factors to make informed decisions regarding the country's future energy mix.

4. Overview of Renewable Wind Energy

4.1. Description of wind energy technology

Wind Energy Technology refers to the process of generating electricity by converting the kinetic energy of wind into electrical energy using wind turbines. Wind turbines consist of blades, a rotor, a shaft, and a generator [4]. When wind blows, it causes the blades to rotate, turning the rotor connected to the generator, which then produces electricity. Wind energy is renewable, clean, and sustainable, producing no direct greenhouse gas emissions during operation. It can be installed onshore or offshore, with offshore sites often providing stronger and more consistent winds. However, wind power is intermittent, depending on wind speed and availability, and requires suitable locations to maximize efficiency. Modern wind farms often include energy storage or hybrid systems to balance supply with demand, making wind a reliable contributor to an integrated renewable energy mix. Fig. (4) shows the wind turbine components. see reference Engr. Shahzada F., (2022) [4].

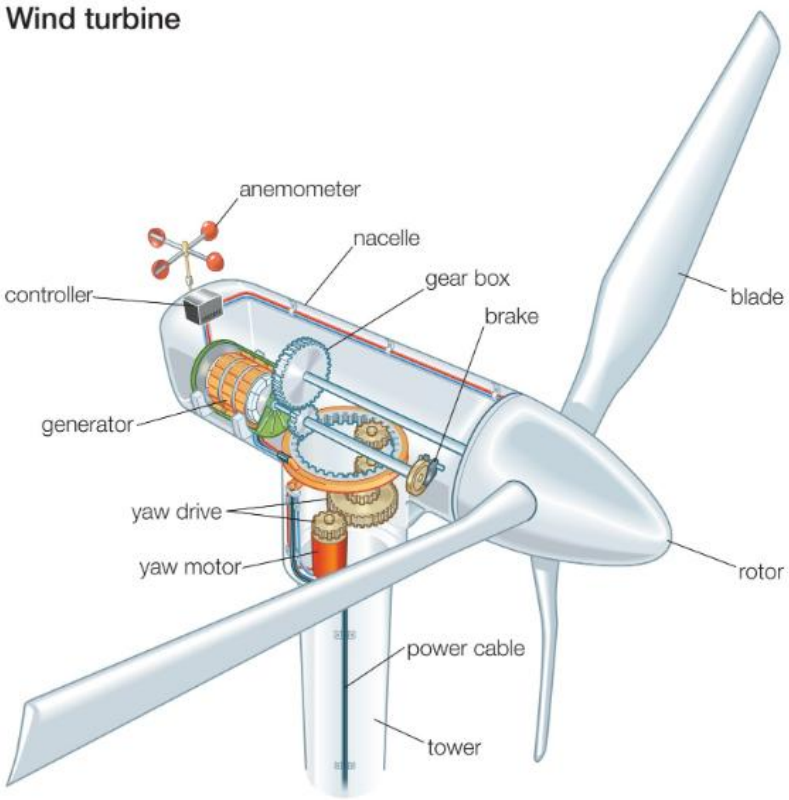

Figure (5): Wind Turbine Components [4]

4.2. Benefits and Limitations

Wind energy technology offers a renewable and environmentally friendly source of electricity, producing no direct greenhouse gas emissions and contributing to reduced reliance on fossil fuels. Once installed, wind turbines have relatively low operating and maintenance costs, and they can be scaled from small community projects to large utility-scale farms, providing flexibility and promoting local job creation. However, wind energy also has limitations. Its output is intermittent and depends on wind availability, requiring storage solutions or backup systems to ensure a stable supply. Suitable sites are limited to areas with consistent wind speeds, and the high initial costs of turbines and infrastructure can be a barrier. Additionally, wind farms may raise aesthetic, noise, and wildlife concerns, and integrating large-scale wind power into existing grids can pose technical challenges.

5. Gas Turbine Power Plant Comparison with Solar and Wind Turbine Power Technology in Libya

5.1. Installation costs

Evaluating the economic feasibility of energy systems in Libya requires a comparison of the installation costs associated with gas turbine power plants and renewable energy. Gas turbines involve high initial capital costs due to their complex equipment and the need for fuel supply infrastructure, whereas advancements in photovoltaic and wind power technologies have significantly lowered the cost of solar and wind installations. Installation expenses for both options are influenced by factors such as fuel availability and regulatory frameworks. Solar energy, supported by Libya's abundant sunlight, reduces dependence on imported fuels. To make informed and sustainable energy investment decisions, stakeholders must weigh upfront capital costs against long-term economic benefits and environmental considerations in line with Libya's energy requirements. See references: (Almaktar et al., 2021) [1], (Beitelmal et al., 2022) [7], (Maka et al., 2021) [8].

5.2. Operations and maintenance costs

The economic viability of energy systems in Libya can be assessed by comparing gas turbine power plants with renewable energy technologies. Gas turbines involve high operational costs due to continuous fuel consumption and regular maintenance requirements. In contrast, solar and wind energy systems—particularly solar photovoltaic installations—require minimal maintenance and incur lower operating costs. Libya's limited water resources further complicate the operation of gas turbines, as they depend on water-intensive cooling systems, whereas solar and wind energy systems are better suited to arid environments since they do not require water for operation. Additionally, the availability and cost of spare parts significantly influence the overall operation and maintenance expenses of both systems, with Libya's limited infrastructure affecting reliability and affordability. While gas turbines demand high initial capital investment and ongoing maintenance due to their technical complexity, solar and wind energy systems provide a more cost-effective alternative with reduced maintenance needs. A thorough

understanding of these cost factors is essential for making informed and sustainable energy investment decisions in Libya.

5.3. Fuel consumption

In Libya, gas turbines constitute a major component of the national energy infrastructure, as most electricity is produced by fossil fuel–based power plants. Available data indicate that conventional gas turbines account for approximately 39.3% of electricity generation, while combined cycle gas turbines (CCGT) contribute about 37% of the total output. This significant share highlights Libya's strong dependence on fossil fuels to satisfy the growing demand for electricity. The widespread use of gas turbines is driven not only by their operational efficiency but also by logistical challenges related to fuel transportation, particularly in southern regions of Libya where water scarcity presents additional constraints. Moreover, the high annual costs of fuel consumption and transportation have prompted increasing interest in solar energy as a viable alternative for reducing fuel use and associated expenses. The favorable conditions for renewable energy power plants in areas near the Sahara Desert present a strong opportunity to reduce dependence on fossil fuels by integrating solar and wind energy into existing power grids. Improving plant efficiency and decreasing the fuel mass flow rate through preheating the air supplied to combustion chambers can further reduce fossil fuel consumption, supporting a transition toward cleaner and more sustainable energy sources. Although gas turbines currently play a major role in Libya's energy sector, there is considerable potential to reduce dependence on fossil fuels by adopting renewable energy sources such as solar power. By utilizing the region's abundant solar resources, Libya can move toward developing a more sustainable and environmentally friendly energy system. Table (2) will present the cost of fuel quantities (Million $) consumed by General Electric Company of Libya for power generation. See reference [6].

Table 2: The cost of the fuel quantities (M$) consumed by GECOL for power generation (source: reference (official GECOL letter dated 06/11/2023) [6].

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

5.4. Available land area

Land requirements are a critical factor in assessing the feasibility and impact of gas turbine power plants and solar energy systems. Gas turbine power plants generally require extensive land areas to accommodate their large-scale infrastructure, including turbines, generators, cooling systems, fuel storage facilities, and auxiliary equipment, as well as access roads for operation and maintenance. In contrast, solar energy systems have more flexible spatial requirements. Solar panels can be installed on rooftops or deployed across open areas such as deserts and unused land.

In Libya, the vast desert regions receive high levels of solar irradiation throughout the year, creating a strong opportunity to exploit solar energy without placing pressure on valuable land resources. Studies indicate that each square kilometer of desert in the Middle East and North Africa region receives solar energy equivalent to approximately 1.5 million barrels of crude oil annually, highlighting the immense potential for solar power generation. Small-scale solar photovoltaic systems deployed in local communities can further alleviate stress on critical grid infrastructure while occupying minimal land area. Compared to gas turbine power plants, which demand significant land for installation and operation, solar energy systems provide a more efficient and environmentally responsible use of available space by utilizing open and underused areas. Harnessing Libya's abundant solar potential can sustainably meet local electricity needs and contribute to broader energy demands. Overall, the contrasting spatial requirements of these two energy systems illustrate different approaches to power generation: gas turbine plants involve large land footprints, whereas solar energy systems offer a cleaner, more resource-efficient alternative with minimal land impact. See references: (Almaktar et al., 2021) [**1**], (Khalil et al., 2017) [9].

5.5. Pollution levels

Gas turbine power plants have a significant environmental impact, particularly due to their high CO_2 emissions. These plants depend primarily on fossil fuels, leading to substantial releases of greenhouse gases into the atmosphere. Compared with renewable energy options such as solar and wind power, gas turbine plants exert a considerably greater negative effect on the environment. Studies indicate that the amount of CO_2 emitted per unit of electricity generated by gas turbines is significantly higher than that produced by renewable energy sources. This is a serious concern, as CO_2 emissions are a major driver of climate change and global warming. The continued operation of gas turbine power plants in Libya further contributes to rising pollution levels. Numerous studies highlight the urgent need to transition toward cleaner and more sustainable energy sources. By reducing dependence on gas turbine power plants and expanding the use of renewable alternatives such as solar and wind

power energy, Libya can substantially lower pollution and mitigate its environmental footprint. Solar energy systems are widely acknowledged for their environmental benefits and their role in supporting sustainable development. In Libya, solar photovoltaic (PV) systems are frequently deployed in remote and off-grid areas where connection to the national electricity network is costly, offering a practical alternative to conventional energy sources such as diesel generators. The integration of energy storage within these PV systems enables them to reliably meet local energy demands, ensuring continuous power supply during grid outages or shortages. In Libya, solar PV technology has been applied across a wide range of sectors, including powering mobile communication stations, solar-driven water desalination, PV-based LED lighting systems, photovoltaic water pumping, cathodic protection of oil pipelines, and standalone household electrification systems. These applications highlight the adaptability of solar energy in addressing diverse energy needs. A feasibility study of a standalone solar-powered LED lighting system in Libya demonstrated notable benefits, such as reduced pollution, fuel savings, and overall cost efficiency. The system achieved a 75% reduction in electricity consumption and eliminated approximately 75% of CO_2 emissions compared to conventional high-pressure sodium lighting systems. Moreover, solar and wind energy technology offers economic advantages through emissions reduction and stable long-term energy costs. Overall, solar and wind energy systems play a crucial role in lowering pollution and carbon emissions while providing a reliable electricity supply for various applications in Libya. Their adoption not only promotes sustainable development but also delivers economic benefits and environmental protection. See references: (Almaktar et al., 2021) [**1**], (Beitelmal et al., 2022)[**7**], (Khalil et al., 2017)[9].

Table 3: Emissions from the tow energy systems. (source: reference (Beitelmal et al.,2022) [7])

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

6. Conclusion

In conclusion, the comparison between gas turbine power plants and renewable solar and wind energies in Libya offers important insights for the country's energy sector. Although gas turbine systems provide operational flexibility and dependable power generation, they are constrained by high operational costs and environmental impacts. In contrast, solar photovoltaic (PV) and wind turbine technologies offers significant benefits, including sustainability and lower operating expenses, despite challenges such as intermittency and high initial capital investment. A comprehensive evaluation of installation, operation, and maintenance costs indicates that solar and wind turbine energy has the potential to be more economically viable over the long term than gas turbine power generation. Moreover, considering environmental factors such as carbon dioxide emissions and air pollution, solar and wind energy stand out as a cleaner alternative that supports global sustainability goals. Solar and wind energy systems also generally require more land area compared to gas turbine power plants. Based on these findings, it is crucial for Libyan policymakers to prioritize the expansion of renewable energy through supportive policies and regulatory frameworks. By enhancing regulations that promote renewable energy development and attract investment in sustainable technologies, Libya can move toward a cleaner and more economically sustainable energy system. Overall, this comparative analysis highlights the importance of transitioning to renewable energy sources, particularly solar and wind power, to ensure a sustainable future for Libya's energy sector.

References:

1. Almaktar, M., Elbreki, A. M., & Shaaban, M. (2021). Revitalizing operational reliability of the electrical energy system in Libya: Feasibility analysis of solar generation in local communities. *Cleaner Engineering and Technology*, *4*, 100144. https://doi.org/10.1016/j.clet.2021.100144
2. Al-Hashmi, S. A., Sharif, M., Elhaj, M., & Almrabet, M. (2017). The future of renewable energy in Libya. *Zawian University Bulletin*, *19*(3).
3. Maddileti, T., & Cherukur, L. (2019). Review on types of solar power systems. *International Journal of Research*, 499–500.
4. Fahad, S. (2022). *Wind energy, wind power plant, wind turbine working*. Electronic Clinic. https://www.electroniclinic.com/wind-energy-wind-power-plant-wind-turbine-working/
5. Hamza, A. S., Mohamed, M. A., & Ali, A. A. (2022). *A comparison between Photovoltaic Cells and Concentrated Solar-Power: A review paper for Bani-Walid city, Libya*.
6. General Electric Company of Libya (GECOL). (2023, November 6). *Prices (M$) of different fuel types consumed by GECOL power plants for power generation* [Official letter].

7. [7] Beitelmal, W. H., Okonkwo, P. C., Al Housni, F., Grami, S., Emori, W., Uzoma, P. C., & Das, B. K. (2022). Renewable energy as a source of electricity for Murzuq health clinic during COVID-19. *Energy Reports*, *8*, 1241–1249. https://doi.org/10.1016/j.egyr.2021.12.038
8. [8] Maka, A. O. M., Salem, S., & Mehmood, M. (2021). Solar photovoltaic (PV) applications in Libya: Challenges, potential, opportunities and future perspectives. *Sustainability Analytics and Modeling*, *1*, 100014. https://doi.org/10.1016/j.samod.2021.100014
9. [9] Khalil, A., Rajab, Z., Amhammed, M., & Asheibi, A. (2017). The benefits of the transition from fossil fuel to solar energy in Libya: A street lighting system case study. *Applied Solar Energy*, *53*, 168–176. https://doi.org/10.3103/S0003701X17020086
10. [10] Energy Capital & Power. (n.d.). *Libya commissions 1 MW solar power plant in Kufra*. https://energycapitalpower.com/libya-commissions-1-mw-solar-power-plant-in-kufra/
11. Abdussalam Ali Ahmed. (2025). Hybrid Tidal-Wave Systems with Advanced Materials for Efficient and Durable Renewable Ocean Energy. Libyan Open University Journal of Applied Sciences (LOUJAS), 1(1), 29-43