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Promoting Sustainable Development in Libya through Renewable Energy : Opportunities and Challenges

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Abstract:

The pressing necessity to attain sustainable development in Libya and search for renewable energy sources that are environmentally friendly and pose no risks to human health has become a critical priority. This urgency is driven by the escalating energy demand and excessive dependence on non-renewable resources such as oil and gas, which may threaten the energy needs of future generations. To achieve the aims of this research, a descriptive-analytical methodology was utilized to evaluate the role of renewable energy in facilitating sustainable development in Libya, alongside the opportunities and obstacles it faces. Furthermore, this paper seeks to raise awareness about the necessity of rationalizing the consumption of conventional energy resources. Based on the conducted literature review, Libya, endowed with abundant natural resources, especially solar and wind potential, is well-positioned to transition from its dependence on fossil fuels to a renewable energy-driven economy. Yet, the contribution of renewable energy to Libya's energy mix remains insignificant. Moreover, Libya faces significant challenges, including political instability, insufficient infrastructure, limited investment, and a shortage of technical expertise. Addressing these issues requires effective policies, international collaboration, and capacity-building initiatives to facilitate the successful integration of renewable energy technologies. Transitioning to sustainable energy is a multifaceted approach that offers significant opportunities, such as reducing pollution, preserving natural resources, creating jobs, and ensuring that future generations have access to a sustainable energy environment and liveable ecosystem.

Keywords: Sustainable development, Renewable energy in Libya, Solar energy, Wind energy

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تعزيز التنمية المستدامة في ليبيا من خلال الطاقة المتجددة : الفرص والتحديات

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الملخص :

لقد أصبح تحقيق التنمية المستدامة في ليبيا والبحث عن مصادر متجددة للطاقة صديقة للبيئة ولا تشكل أي مخاطر على صحة الإنسان أولوية بالغة الأهمية. ويرجع هذا إلى الطلب المتزايد على الطاقة والاعتماد المفرط على الموارد غير المتجددة مثل النفط والغاز، مما قد يهدد احتياجات الطاقة للأجيال القادمة. ولتحقيق أهداف هذا البحث، تم استخدام منهجية الوصف التحليلي لتقييم دور الطاقة المتجددة في تسهيل التنمية المستدامة في ليبيا، إلى جانب الفرص والعقبات التي تواجهها. علاوة على ذلك، تسعى هذه الورقة إلى زيادة الوعي بضرورة ترشيد استهلاك موارد الطاقة التقليدية. واستناداً إلى مراجعة الدراسات السابقة التي أجريت، فإن ليبيا، التي تتمتع بموارد طبيعية وفيرة، وخاصة إمكانات الطاقة الشمسية وطاقة الرياح، في وضع جيد للانتقال من اعتمادها على الوقود الأحفوري إلى اقتصاد مدفوع بالطاقة المتجددة. مع ذلك فإن مساهمة الطاقة المتجددة في مزيج الطاقة في ليبيا لاتزال ضئيلة. علاوة على ذلك، تواجه ليبيا تحديات كبيرة، من ضمنها عدم الاستقرار السياسي، والبنية التحتية غير الملائمة، والاستثمار المحدود، ونقص الخبرات الفنية. إن معالجة هذه القضايا تتطلب سياسات قوية، وتعاوناً دولياً، ومبادرات لبناء القدرات لتسهيل التكامل الناجح لتقنيات الطاقة المتجددة. إن التحول إلى الطاقة المستدامة هو نهج متعدد الأوجه يوفر فرصاً كبيرة، مثل الحد من التلوث، والحفاظ على الموارد الطبيعية، وخلق فرص العمل، وضمان حصول الأجيال القادمة على بيئة طاقة مستدامة ونظام بيئي صالح للعيش.

1. Introduction :

Pursuing Sustainable Development (SD) has become a critical global priority, driven by the pressing need to mitigate the detrimental effects of conventional energy sources on human health, and the environment, and secure a prosperous future for subsequent generations. Moreover, fossil fuels are non-renewable resources that will ultimately be depleted, leading to energy shortages and escalating prices. In recognition of these challenges, the United Nations adopted the (17) Sustainable Development Goals (SDGs)

in 2015 to tackle a wide range of interconnected global challenges, [1]. Notably, (SDG7) emphasizes ensuring universal access to affordable, reliable, sustainable, and modern energy sources by 2030.

Nations worldwide, including Libya, strive to diversify their energy portfolios. The transition towards sustainable energy is essential for environmental, economic, and social reasons, as it reduces dependence on fossil fuels, mitigates the impacts of climate change, and promotes economic growth while ensuring long-term energy security and enhancing the well-being of Libyan citizens. Therefore, Renewable Energy (RE) technologies such as solar, wind, hydro, ocean, biomass, and geothermal have emerged as viable solutions to supplant conventional electricity generation methods and to overcome current environmental challenges.

Despite the promising prospects of (REs), their widespread adoption and implementation face several challenges. One of the primary obstacles is the relatively high cost associated with developing, deploying, and maintaining these technologies, particularly in the early stages of commercialization [2, 3]. Significant investments in research and development are required to enhance the efficiency, reliability, and cost-effectiveness of (REs). Additionally, implementing (REs) technologies presents policy, information, and human resource challenges.

This paper studies the influence of (RE) sources on achieving SDGs. It also highlights the opportunities and obstacles associated with (RE) implementation in Libya and suggests effective strategies to overcome them. Furthermore, this paper seeks to raise awareness about the necessity of rationalizing the consumption of conventional energy resources. This approach ensures that future generations have access to a sustainable energy environment and liveable ecosystem.

2. The concept of Sustainable Development (SD):

Sustainable development (SD) is a holistic approach to growth and progress that balances economic, social, and environmental goals. This concept emerged as a response to increasing concerns regarding environmental degradation, resource depletion, and social inequalities resulting from conventional economic development models. The most widely accepted definition of sustainable development was articulated in the Brundtland report (1987), officially titled “ Our Common Future ”, and published by the United

Nations which states that sustainable development is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [4, 5]. The sustainable development concept is often encapsulated in the three pillars of sustainability Fig 1, which are essential for creating a balanced and equitable approach to development, [6]. These pillars are:

1. Environmental Sustainability :
   - Environmental sustainability focuses on protecting and preserving natural resources and ecosystems to ensure they remain available for future generations, [7].
2. Social Sustainability :
   - This term pertains to maintaining and improving the well-being of individuals and society over the long-term, [8].
3. Economic Sustainability :
   - It refers to practices and strategies that ensure long-term economic growth and development without depleting natural, human, or social resources, [9]. It involves creating resilient and inclusive economic systems that support well-being, equity, and stability for present and future generations.

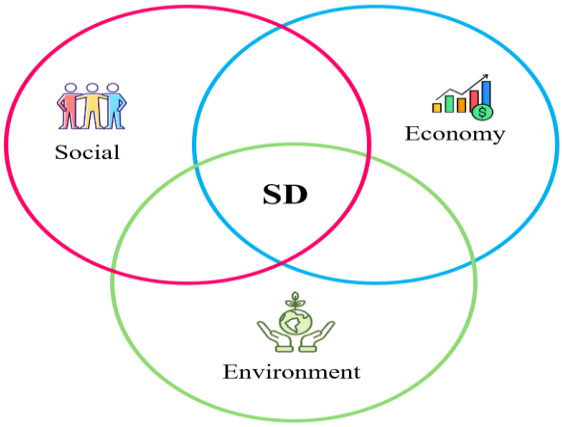

Figure (1) Sustainable development pillars, [10]

3. Renewable Energy Sources (RES) :

Renewable energy is derived from naturally replenishing resources or processes that can be sustainably harnessed without depleting the Earth's finite reserves, [11, 12].These sources are characterized by their ability to regenerate within a relatively short timeframe, hence offering a viable alternative to non-renewable fossil fuels, Fig 2:

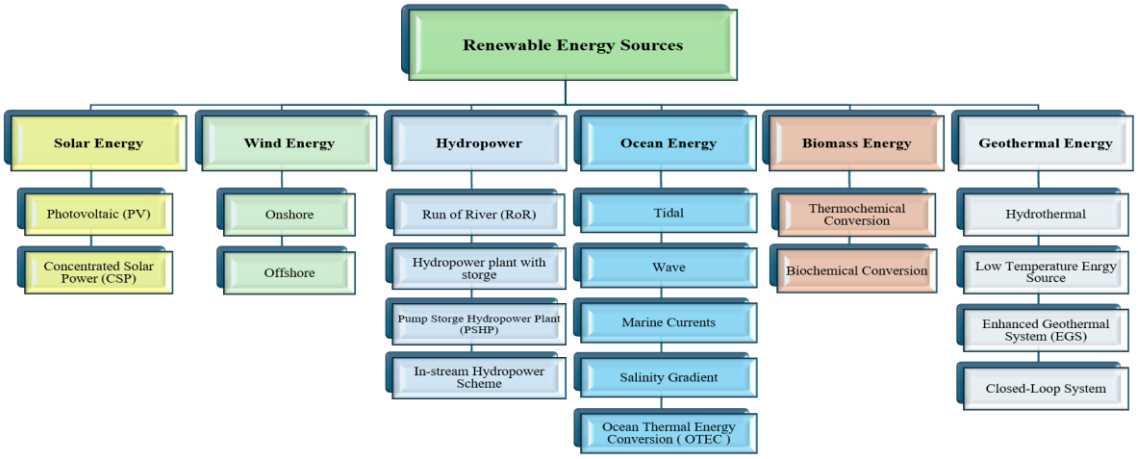

Figure (2) Renewable Energy Sources

- Solar energy:

Solar energy is generated by converting sunlight into electricity using Photovoltaic (PV) Cells or solar thermal systems.

- Wind energy:

Wind is used to produce electricity by converting the kinetic energy of air in motion into electricity.

- Hydropower:

Energy from moving water often harnessed through dams or rivers, drives turbines and produces electricity.

- Ocean energy:

It includes wave energy and tidal energy, harnessing the potential and kinetic energy of seawater.

- Biomass energy:

It is derived from organic materials such as wood, agricultural residues, or animal waste. It can be burned or converted into biofuels.

- Geothermal energy:

It refers to the thermal energy generated and stored beneath the Earth's surface. This energy arises from the temperature difference between the Earth's core and surface, resulting in a continuous conductive transfer of thermal energy towards the surface, known as the geothermal gradient,[13].

3.1 Contributions of Renewable Energy to Sustainable Development:

The incorporation of renewable energy sources is pivotal to achieving sustainable development objectives. (REs) offer a clean, sustainable, and efficient substitute for fossil

fuels, addressing economic, environmental, and social facets and paving the way for a more sustainable future. The contributions of renewable energies to (SD) can be summarized as follows, in Fig 3:

1. Environmental Benefits:
   - Reduction in greenhouse gas emissions: renewable energy sources like solar, wind, and hydropower generate electricity without emitting carbon dioxide, mitigating climate change.
   - Preservation of natural resources: unlike fossil fuels, renewables do not deplete finite resources, ensuring availability for future generations, [14].
   - Pollution reduction: (RE) technologies reduce air, water, and soil pollution, improving public health and ecosystems.
2. Economic Advantages:
   - Energy security: utilizing local renewable resources reduces reliance on imported fuels, enhancing energy independence, [15].
   - Job creation: the renewable energy sector generates jobs in manufacturing, installation, and maintenance.
   - Cost-effectiveness: as technology advances, the costs of renewables continue to decline, making them more affordable in the long run.
3. Social Impact:
   - Access to energy: (RE) systems, particularly decentralized ones like solar panels, bring electricity to remote and underdeveloped regions, improving living standards.
   - Health benefits: reducing air pollution from burning fossil fuels lowers health risks, decreases medical costs, and improves quality of life.
   - Equity and inclusion: community-driven renewable projects empower local populations and ensure equitable energy distribution.
4. Alignment with Sustainable Development Goals (SDGs):

   Renewable energy supports multiple SDGs, [16, 17] such as,:
   - (SDG7): Affordable and Clean Energy
   - (SDG13) : Climate Action
   - (SDG3): Good Health and Well-being
   - (SDG8): Decent Work and Economic Growth

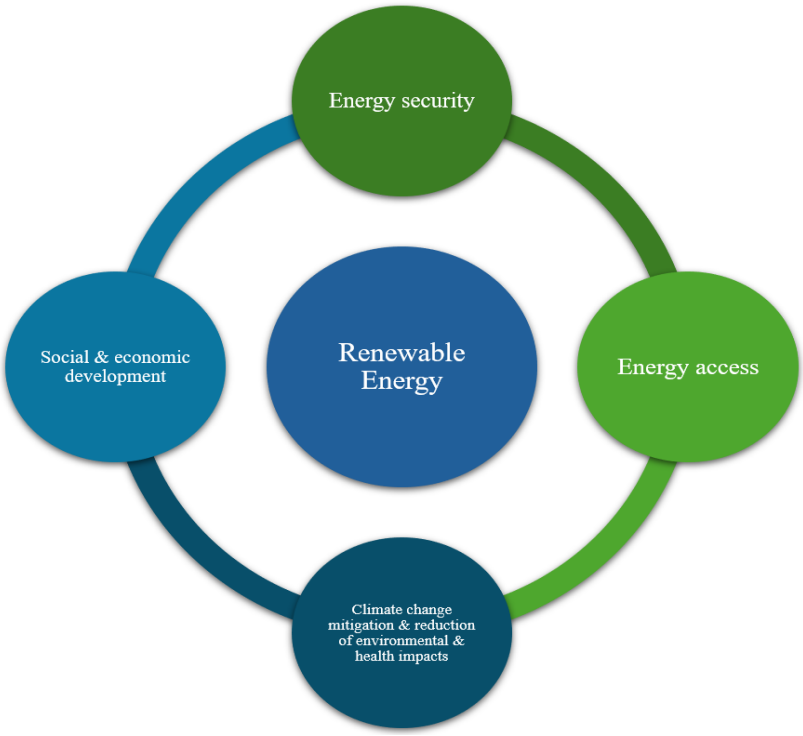

Figure 3: Contributions of Renewable Energy to Sustainable Development

4. The energy situation in Libya :

Over the past five decades, Libya's economy has demonstrated a significant dependence on revenue from the oil and gas sectors. These industries have funded most of the nation's development initiatives and administrative expenditures, characterizing Libya's economic model as a rentier or unilateral economy. Furthermore, the oil sector supplies the necessary fuel for generating electrical power, a fundamental resource that underpins various financial activities, serving consumers and producers across diverse sectors. The General Electricity Company of Libya (GECoL) is Libya's state-owned electricity company, that manages the country's electricity generation, transmission, distribution, and network operations) faces significant challenges in consistently providing customers with the required quantity and quality of electricity due to over-reliance on fossil fuels.

Libya has recently faced challenging circumstances that have hampered the production and distribution of electricity from conventional sources, leading to shortages and disruptions in the power supply. Consequently, there is a pressing need to enhance

energy efficiency and integrate renewable energy technologies into the energy mix. This necessitates the development of a comprehensive strategy that encompasses scientific, technical, economic, and social dimensions, while also considering legislative and institutional factors. Particular emphasis must be placed on strengthening environmental protection measures and ensuring the nation's energy security.

Libya's production of electricity predominantly depends on non-renewable fossil fuel resources, according to data from the International Energy Agency (IEA). In 2022, the country produced (35,106) gigawatt-hours (GWh) of electricity from non-renewable sources, constituting nearly (100 %) of its total electricity production, [18] Fig 4. (RE) sources, specifically solar power, contributed a negligible amount, generating only (8GWh), representing approximately (0.02 %) of Libya's overall electricity mix, Fig 5.

Libya is experiencing a significant surge in electricity demand due to population growth, necessitating substantial infrastructure development such as constructing additional power lines and generation facilities. Furthermore, industrial expansion requires consistent power plant operations and heightened fuel consumption. These factors underscore the imperative for the Libyan government to explore, evaluate, and assess the viability of implementing renewable energy technologies.

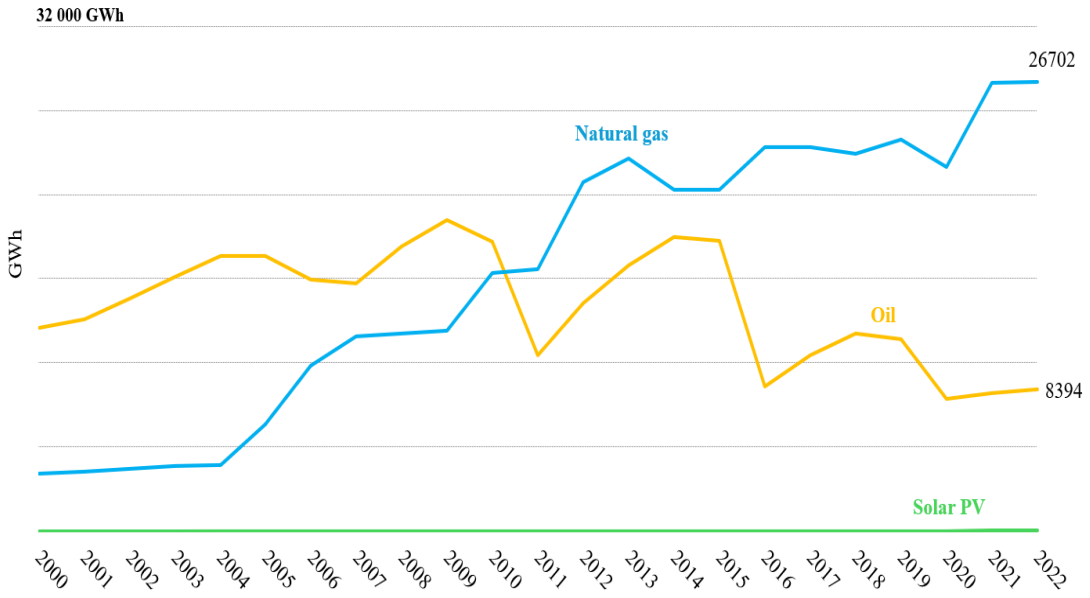

Figure 4: Evolution of electricity generation sources in Libya since 2000, [18]

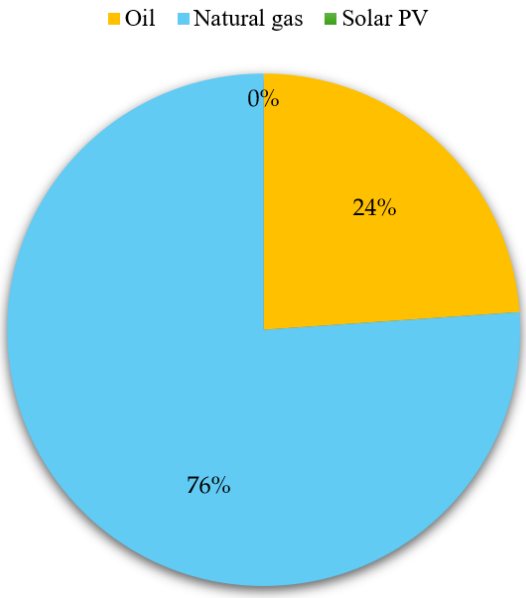

Figure 5: Electricity generation sources, Libya, 2022, [18]

4.1 The state of Renewable Energy in Libya :

Libya has significant potential in renewable energy resources, particularly solar and wind energy ref. The country benefits from abundant year-round sunshine and consistent coastal winds. Up to now, the share of (RE) technologies in Libya's energy mix holds only a tiny contribution to meeting the basic energy needs, mainly utilizing solar technology, [18]. It has been utilized primarily for supplying remote rural regions, powering microwave repeater stations, facilitating small-scale water heating and pumping applications, and enabling cathodic protection systems. However, the full realization of Libya's renewable energy potential has been hampered by political instability, security issues, and entrenched dependence on fossil fuels. Nevertheless, there have been noteworthy endeavours to harness renewable energy sources in Libya.

Libya's geographical location within the Desert region endows it with an extensive solar energy potential. The European Commission's Joint Research Center (JRC) estimates Libya's contribution to the Mediterranean region's total solar energy potential at (20 %) of (332) TWh/year. The International Renewable Energy Agency (IRENA) calculates North Africa's solar potential at (2600) TWh/year, with Libya accounting for (1050) TWh/year, [19].

Wind energy presents a promising opportunity, particularly in Libya's coastal regions, which benefit from favourable wind conditions. The eastern coastal areas experience wind speeds reaching up to (8.21) m/s [20], making them well-suited for efficient electricity generation. This renewable energy source holds the potential to significantly diversify Libya's energy portfolio, considering the nation's ongoing reliance on fossil fuels.

The Libyan Government's Strategic Plan for Renewable Energy (2013-2025) outlines ambitious goals for integrating renewable energy sources into the nation's power generation portfolio. Notably, the plan mandates that (10 %) of Libya's energy mix must originate from renewable sources by 2025, escalating to a (30 %) renewable contribution by 2030. This strategic initiative signifies a transformative shift for Libya, as the country has historically depended on oil and natural gas to meet its energy requirements. Pursuing renewable solutions will diversify Libya's energy production capabilities while mitigating environmental impacts.

The Renewable Energy Authority of Libya (REAoL) reports that wind energy projects currently under development have a combined capacity of (240) megawatts:

1. Derna wind project, the first phase (60 MW).
2. Derna wind project, the second phase (60 MW).
3. Al-Maqroun Wind Project (120 MW).

Private sector initiatives have also emerged, with companies like Solar Energy Solutions (SES) planning (50) MW solar power plant in Sabha, and the LEC aiming for a colossal (500) MW solar power plant in Sebha. These projects are poised to significantly augment Libya's electricity mix while reducing its fossil fuel dependency, [21].

Overall, the adoption of wind and PV solar systems not only offers a feasible means of meeting energy needs for family farms but also addresses critical issues of electricity scarcity, water crises, and environmental sustainability, promoting a pathway towards sustainable development in the country.

4.2 Summary of recent literature on solar and wind energies in Libya:

Numerous scientific studies have explored the potential for (RES), such as wind and solar power, across various locations within Libya. These investigations can be summarized as follows:

- A research study analyzed the feasibility of implementing Concentrating Solar Power (CSP) plants in Libya. The findings demonstrated that Libya possesses suitable conditions and can be economically competitive in deploying (CSP) technology, [22].
- In a study conducted by [23], the wind density in Zawara City was assessed utilizing the Weibull distribution and wind speed data measured in Zwara at 10, 30, and 50 m heights in the year 2007. The findings revealed that the average annual wind power densities were 113.71 W/m^2, 204.19 W/m^2, and 243.48 W/m^2, respectively.
- The economic viability of solar energy in the Al Jofra region was evaluated in [24] using System Advisor Model (SAM) software. The study concluded that (PV) and (CSP) systems are the most promising technologies for generating electricity in this area.
- To assess the potential of (RE) including, solar, wind, wave, biomass, and geothermal utilizing the NASA dataset, [25] concluded that Al Kufrah presents the most favourable option for the construction of a large-scale solar power plant to generate electricity from solar energy resources when compared to other regions within the country. The average potential of solar (PV) and onshore wind over the Libyan territories amounts to (1.9) /kW/year and (400 W/m^2), respectively.
- In a study [26], the solar and wind energy potential was evaluated across five agricultural coastal regions: Aljmail, Azzawiyah, Castelverde, Msallatah, and Sabratah. The analysis, employing measured data and multiple datasets, demonstrated that these selected areas exhibit significantly higher potential for solar energy generation compared to wind energy generation. Moreover, the findings validated the feasibility of establishing solar power plants of varying capacities within these regions.
- [27] evaluated six potential locations within Libya (Kufra, Benghazi, Tripoli, Tobruk, Sabha, and Misrata) based on twelve established criteria to determine the optimal site for establishing a solar farm. Utilizing a hybrid multi-criteria approach that integrated the GRAY-TOPSIS method, the findings revealed that Misrata emerged as the highest-ranking city with a weightage of (0.53), while Benghazi, situated in the western region of the country, secured the second position with a value of (0.47).
- [28] investigated the impediments obstructing the proliferation of renewable energy sources in Libya. The research methodology entailed a hybrid Multiple-Criteria Decision-Making (MCDM) approach, integrating the Analytic Hierarchy Process

(AHP) and Combined Compromise Solution (CoCoSo) techniques to evaluate these hindrances. The study identified eight distinct obstacles and proposed seven strategic recommendations to overcome them.

5. Key Opportunities of (RE) in Libya :

In addition to its oil and gas reserves, Libya boasts several other valuable natural resources. The nation's vast desert landscapes and high levels of solar irradiation present significant potential for the development of renewable energy sources, particularly in the areas of solar and wind power generation. Libya's renewable energy opportunities are not limited to these avenues, but they represent promising avenues for exploration and investment.

- Solar Energy Opportunities:

- Libya enjoys high solar irradiance levels, with an average of (3,200) sunshine hours per year and solar radiation of approximately (6 kWh/m²/day), [29], placing it among the highest rankings globally. Notably, each square kilometer of desert in the country receives solar energy equivalent to (1.5) million barrels of crude oil annually,[30] underscoring the immense potential for harnessing this renewable energy source. Investing in solar power could alleviate domestic electricity shortages and position Libya as a regional leader in clean energy production.

- Wind Energy Opportunities:

- Wind Resources: certain regions in Libya, such as the Green Mountain range, have substantial wind energy potential. Developing wind farms in these areas could diversify the energy mix and contribute to the renewable energy targets, [31]. A 2014 study conducted by the European Union's Joint Research Centre (JRC) assessed the wind energy potential in the Mediterranean region, encompassing Libya. The comprehensive analysis estimated the total wind energy potential for the entire Mediterranean area to be a substantial (766) GW. Notably, Libya's contribution to this regional potential was projected at a significant (35) GW. Furthermore, Libya itself possesses an estimated wind energy potential of approximately (10) GW, a capacity equivalent to the nation's current electricity demand, as reported by the Renewable Energy and Energy Efficiency Authority (REEEA) within Libya, [21].

- Strategic Initiatives:
- Renewable Energy Strategic Plan 2013-2025: Libya's government has outlined a plan to integrate renewable energy into the national grid, aiming for a (10 %) contribution by 2025. This includes investments in wind, concentrated solar power, photovoltaic systems, and solar water heating.
- International Cooperation: Collaborations with international organizations, such as the United Nations Development Programme (UNDP), are underway to support Libya's energy transition and climate resilience efforts.
- Economic and Employment Benefits:
- Job Creation: investing in renewable energy infrastructure can generate employment opportunities across various sectors, addressing unemployment challenges, especially among the youth.
- Reforms that encourage private sector participation in renewable energy projects can attract financing, drive innovation, and enhance efficiency within the energy sector. Stakeholders, especially local communities, are pivotal in promoting renewable energy initiatives in Libya. For example, involving local leaders and community members during the planning phase can help address concerns regarding land use, environmental impacts, and economic benefits. Stakeholders can facilitate training and educational programs for local communities, enhancing their understanding of renewable energy technologies. Local communities can advocate for renewable energy initiatives, promoting the advantages of such projects to other community members and local authorities. Their support can be instrumental in overcoming resistance to change and fostering a positive environment for developing renewable energy sources.
- Their involvement can enhance project acceptance, ensure sustainability, and contribute to the overall success of renewable energy initiatives
- In summary, Libya's abundant natural resources and strategic initiatives present substantial opportunities for renewable energy development, which can lead to economic diversification, job creation, and enhanced energy security.

6. Challenges in transitioning to renewable energy in Libya :

Libya, a nation blessed with abundant sunshine and vast arid regions, confronts multifaceted obstacles in harnessing renewable energy sources. Notwithstanding its advantageous geographic conditions, Libya encounters significant impediments to adopting renewable energy. Overcoming these challenges will be pivotal for Libya to successfully transition to renewable energy and capitalize on its bountiful solar and wind endowments. Table 1 outlines some of these challenges:

Table 1: Challenges to renewable energy in Libya

Challenge	Description
Lack of infrastructure:	The country's outdated electricity grid and insufficient infrastructure pose significant challenges for the growth of renewable energy sources, [25, 28].
Energy storage:	The intermittent nature of renewable energy sources such as solar and wind presents a significant obstacle to their widespread adoption and integration into existing power grids, [32, 33]. The incorporation of energy storage systems with renewable energy sources can significantly enhance energy security. Deploying storage technologies such as batteries (electrochemical energy storage), fuel cell systems, and pumped (mechanical energy storage) storage hydroelectric facilities can contribute to maintaining grid frequency stability and ensuring a reliable, continuous supply of electricity. Optimizing energy storage systems through enhanced efficiency, cost reductions, and seamless integration with renewable energy sources is paramount to facilitating the global shift towards a sustainable energy paradigm, [32].
Dependence on fossil fuel exports :	Libya heavily relies on oil and gas for both energy production and revenue, making the transition to renewable sources complex, [28].

Regulatory Framework:	Uncertain regulatory frameworks make it difficult for investors to commit to renewable energy projects, [34].
Political instability and security concerns :	Ongoing political instability and conflicts hinder investment and infrastructure development [34-36].
Reliability of renewable sources	The intermittent nature of renewable energy sources, such as solar and wind, can lead to supply discontinuities. This variability necessitates robust energy storage solutions and grid management strategies, which may not yet be fully developed in Libya. Additionally, limited research and Insufficient data on renewable energy resources hinder effective planning and investment.
Technical Expertise:	There is a shortage of skilled labour and technical expertise in the renewable energy sector within Libya.
Public Awareness:	There is limited public awareness and education about the potential benefits of renewable energy and the need for a sustainable energy transition.
Varying environmental and climatic conditions:	Libya's diverse environmental and climatic conditions across the country necessitate renewable energy solutions, increasing the complexity of implementation. For example, wind patterns differ geographically. Coastal areas or open plains may experience high wind speeds conducive to wind farms, while inland or mountainous regions may not. [21].
Financial Barriers:	The current electric energy tariff system and subsidy structure favour fossil fuels, making renewable energy less competitive [37].

7. Overcoming the Challenges of Renewable Energy:

To overcome the obstacles to renewable energy development in Libya, several strategies can be implemented. These strategies address the key challenges identified in literature, including political instability, lack of infrastructure, and insufficient public awareness. Table 3 shows the main strategies:

Table 2: Strategies to overcome the obstacles of RE development

	Strategy
1	Encouraging private sector participation by creating a stable regulatory and policy framework to attract investment and financing for renewable energy projects [28].
2	Establishing a feed-in tariff scheme or other incentives to promote investment in renewable energy, [38].
3	Strengthening the institutional capacity of relevant government agencies and regulatory bodies to support renewable energy deployment.
4	Developing a skilled workforce through training and education programs to support the growth of the renewable energy sector.
5	Promoting public awareness and education to increase understanding of the potential benefits of renewable energy and the need to transition to a more sustainable energy mix
6	Collaborating with international organizations and other countries to access technical expertise, financing, and best practices for renewable energy deployment.
7	Developing and implementing policies and measures to improve the stability and security of the country could help to attract investment and financing for renewable energy projects.
8	Comprehensive feasibility studies should be conducted to assess the potential for various renewable energy sources in different regions of Libya. This data can guide investment decisions and project planning, [39].

8. Conclusion:

Renewable energy holds immense potential for driving sustainable development in Libya, a country blessed with abundant solar and wind resources. By harnessing these clean energy sources, Libya can address critical challenges such as economic diversification, energy security, and environmental sustainability. The transition to renewables offers a pathway to reduce reliance on fossil fuels, which currently dominate the economy while mitigating greenhouse gas emissions and combating climate change. Additionally, renewable energy infrastructure can create jobs, stimulate technological

innovation, and provide reliable electricity to underserved communities, promoting social equity and economic growth.

For Libya, renewable energy is an environmental necessity and a strategic opportunity to build a resilient and diversified economy. By integrating solar, wind, and other renewable technologies, the country can ensure a sustainable energy future, reduce its carbon footprint, and preserve its natural resources for future generations. However, achieving this vision requires strong political commitment, effective policies, international collaboration, and investments in capacity-building and infrastructure. If successfully implemented, renewable energy can serve as a cornerstone for Libya's sustainable development, fostering economic stability, environmental protection, and improved quality of life for its citizens.

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