African Journal of Advanced Pure and Applied Sciences (AJAPAS)
Online ISSN: 2957-644X
Volume 4, Issue 1, January - March 2025
Page No: 256-264
Website: https://aaasjournals.com/index.php/ajapas/index

ISI 2024: 0.877	SJIFactor 2024: 6.752	معامل التأثير العربي: 1.62

Impacts of Renewable Energy Sources and Artificial Intelligence on Grid Reliability and Cost: A Case Study of Libya

Suleiman Abdulagadir M. Edreis [1*], Mostafa Abubakar Mohmed Kaud [2], Abdussalam Mohamed Ali Altaher [3], Aimn Azoumi Mohammed [4], Massoud Ali Abdalhadi [5]
[1,2] Department of Computer Technologies, Higher Institute of Science and Technology Wadi Atba, Libya
[3,4,5] Department of Information Technology, Higher Institute of Science and Technology, Wadi Al-Ajal, Libya

تأثير مصادر الطاقة المتجددة والذكاء الاصطناعي على موثوقية الشبكة وتكلفتها: دراسة حالة ليبيا

سليمان عبد القادر إدريس[1*]، مصطفى أبو بكر محمد قايد[2]، عبد السلام محمد علي الطاهر[3]، أيمن عزومي محمد[4]،
مسعود علي عبد الهادي[5]
[1،2] قسم هندسة الحاسوب، المعهد العالي للعلوم والتقنية، وادي عتبة، ليبيا
[3،4،5] قسم تقنية المعلومات، المعهد العالي للعلوم والتقنية، وادي الآجال، ليبيا

[*]Corresponding author: sulemanedres@gmail.com

Received: November 17, 2024	Accepted: February 04, 2025	Published: February 13, 2025

Abstract
Libya with its abundant solar and wind resources, stands at the forefront of renewable energy potential in North Africa. However, integrating these intermittent energy sources into the grid poses significant challenges, particularly regarding reliability and cost. This manuscript explores the dual role of renewable energy and artificial intelligence (AI) in addressing these challenges, focusing on Libya's unique climatology. The study evaluates the technical, economic, and environmental impacts of renewable energy integration, supported by AI-driven solutions, and provides actionable recommendations for Libya's energy transition.

Keywords: Libya, solar and wind resources, North Africa, environmental impacts, energy integration.

الملخص
تحتل ليبيا بمواردها الوفيرة من الطاقة الشمسية وطاقة الرياح طليعة إمكانات الطاقة المتجددة في شمال إفريقيا. ومع ذلك، فإن دمج مصادر الطاقة المتقطعة هذه في الشبكة يفرض تحديات كبيرة، وخاصة من حيث الموثوقية والتكلفة. تستكشف هذه المخطوطة الدور المزدوج للطاقة المتجددة والذكاء الاصطناعي في معالجة هذه التحديات، مع التركيز على مناخ ليبيا الفريد. تقيم الدراسة التأثيرات الفنية والاقتصادية والبيئية لدمج الطاقة المتجددة، بدعم من الحلول التي تعتمد على الذكاء الاصطناعي، وتقدم توصيات قابلة للتنفيذ للتحول في مجال الطاقة في ليبيا.

الكلمات المفتاحية: ليبيا، موارد الطاقة الشمسية وطاقة الرياح، شمال إفريقيا، التأثيرات البيئية، تكامل الطاقة.

1. Introduction

Libya's heavy reliance on fossil fuels for electricity generation and its vulnerability to energy insecurity [1] . Libya's energy landscape is characterized by a heavy dependence on fossil fuels, particularly natural gas and oil, for electricity generation. This reliance poses significant challenges, including energy insecurity, environmental concerns, and economic volatility. Understanding these dynamics is essential for formulating strategies for a sustainable energy transition.
The country's vast renewable energy potential, particularly solar and wind, due to its geographic and climatic conditions. Libya possesses vast renewable energy potential, particularly in solar and wind resources, owing to its favorable geographic and climatic conditions [2]. This potential offers a unique opportunity for the country to transition towards a sustainable energy future, reduce reliance on fossil fuels, and enhance energy security.
The global trend of using AI to optimize renewable energy integration and grid management. As the world increasingly shifts towards renewable energy sources, the integration of these variable resources into existing energy systems presents significant challenges. Artificial Intelligence (AI) emerges as a transformative tool that

enhances the efficiency and reliability of renewable energy integration and grid management [3]. This section explores the global trend of leveraging AI technologies in the energy sector [4].
The main objectives of this study are to address to assess the impacts of renewable energy sources on Libya's grid reliability and cost. To explore the role of AI in enhancing grid stability, reducing costs, and optimizing renewable energy integration. Additionally, it provides policy and technical recommendations tailored to Libya's climatology and energy infrastructure. The article is organized in order to contribute to knowledge. The remaining sections are classified as follows. Section 2 discusses Libya's Energy Landscape and Climatology. The Renewable Energy Integration: Challenges and Opportunities are presented in Section 3. Section 4 lists the Future work and recommendations. The Results and discussion are placed in Section 5. Finally, the summary of the conclusion and list of recent cited references are closing the article.

Libya's Energy Landscape and Climatology

Libya, located in North Africa, has a unique energy landscape shaped by its abundant fossil fuel resources and its arid, desert climate [5].

Current Energy Infrastructure

Electric cars, and smart houses connected to alternative energy sources produced by wind turbines and solar panels (Smart grid concept design, Flat isometric illustration isolated on a white background) [6], [7]. The general overview of Libya's grid (centralized fossil fuel-based power plants, ageing infrastructure, and limited grid flexibility) [8]. While the challenges (frequent blackouts, high transmission losses, and underinvestment in grid modernization) [9].

Figure 1 Renewable energy infrastructure.

Renewable Energy Potential

Renewable energy potential refers to the capacity of various renewable energy sources to meet global energy demands sustainably [10]. An overview of the major renewable energy sources and their potential is tabulated in Table 1. The renewable energy sources potential is demonstrated in Figure 2 based on a projection provided from the International Energy Agency (IEA) [13].

Table 1: Renewable Energy Potential [11], [12]**.**

Sources	Potential
Solar Energy	Libya has one of the highest solar irradiance levels globally, averaging 2,000–2,500 kWh/m²/year.
Wind Energy	Coastal regions, particularly in the east and west, experience consistent wind speeds of 7–9 m/s, ideal for wind farms.
Hydropower and Biomass	Limited potential due to arid climate and scarce water resources.

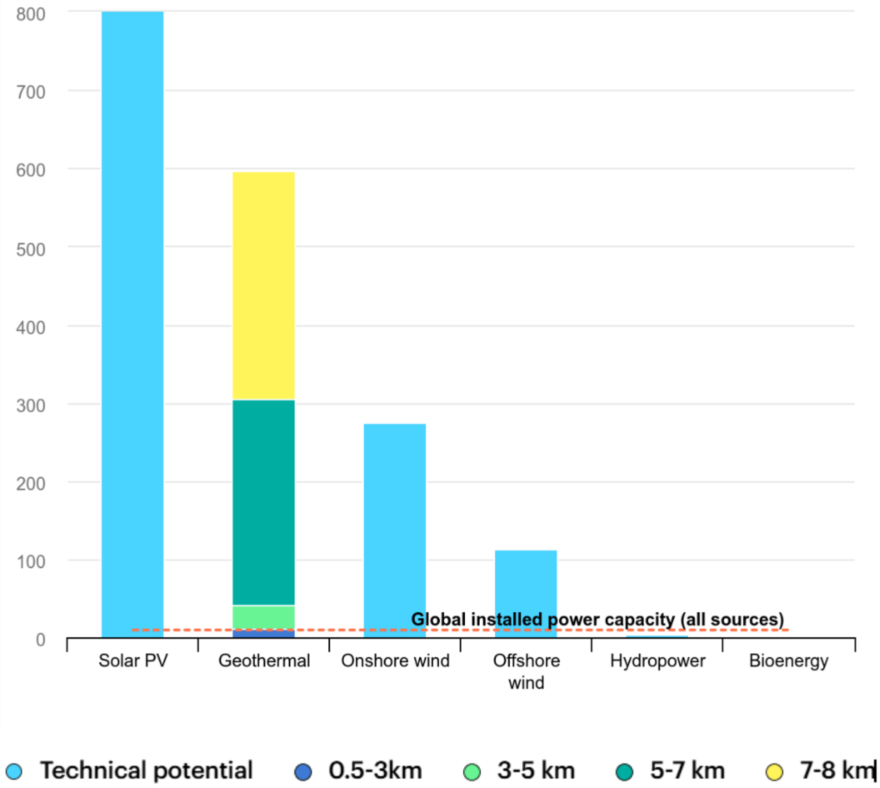

Figure 2 Technical potential of selected renewable energy technologies for electricity generation [13].

Climatology and Its Impact on Renewable Energy

Due to the seasonal impact through out of the year in the country of the conducted study, based on a projection provided from International Energy Agency (IEA) it divides into four seasons as demonstrated in the Figure 3 [14]. High solar irradiance and clear skies make solar energy highly viable [15] . Seasonal wind patterns along the Mediterranean coast provide consistent wind energy potential. Challenges (sandstorms, high temperatures, and dust accumulation on solar panels, which reduce efficiency).

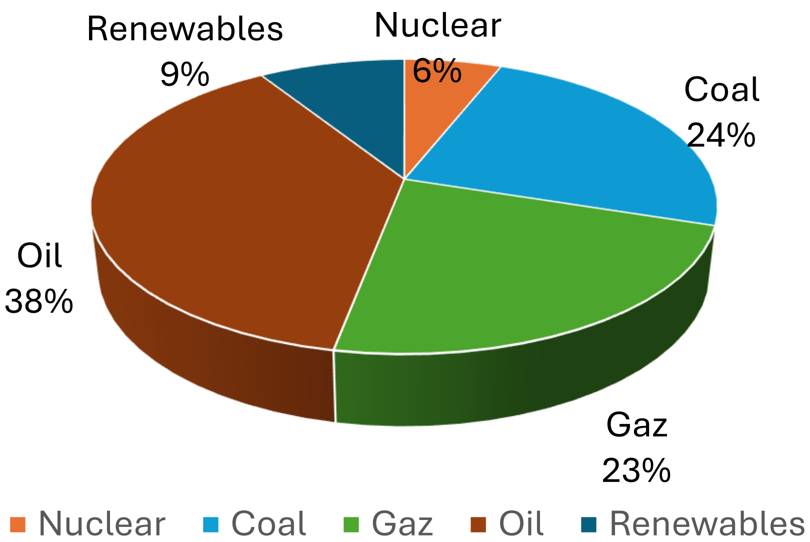

Figure 3: Global energy consumption by fuel type.

Renewable Energy Integration: Challenges and Opportunities

The challenges and opportunities of renewable energy integration can be listed as presented in Table 2 [16], [17]. While the Role of Artificial Intelligence in Renewable Energy Integration presented in Table 3 [6], [18], [19], [20], [21].

Table 2: Challenges and opportunities of renewable sources integration.

Challenges and opportunities	Features
Intermittency and Variability	- Solar and wind energy are inherently intermittent, leading to fluctuations in power supply. - The need for accurate forecasting and real-time adjustments to maintain grid stability.
Grid Reliability	- The impact of renewable energy on grid frequency and voltage stability. - The reduction of inertia in the grid due to the displacement of conventional power plants. - Solutions: grid-forming inverters, synthetic inertia, and advanced control systems.
Energy Storage and Flexibility	- The critical role of energy storage systems (e.g., batteries, pumped hydro) in balancing supply and demand. - The potential for demand-side management and flexible loads to enhance grid flexibility. - Emerging technologies: hydrogen storage and supercapacitors
Grid Infrastructure Upgrades	- The need for modernizing Libya's grid to accommodate distributed energy resources (DERs). - Challenges: high upfront costs, lack of technical expertise, and political instability. - Smart grid technologies: advanced metering infrastructure (AMI), distribution automation, and real-time monitoring.

Table 3: Role of Artificial Intelligence in Renewable Energy Integration.

Roles	Observation
AI for Renewable Energy Forecasting	- Machine learning algorithms to predict solar irradiance and wind speeds with high accuracy. - Case studies: AI-driven forecasting tools used in countries with similar climates (e.g., Morocco, Saudi Arabia).
AI for Grid Management	- AI-based energy management systems (EMS) optimize power flow and reduce grid congestion. - Predictive maintenance using AI to identify and address grid faults before they cause outages. - AI-driven load forecasting to balance supply and demand in real-time.
AI for Cost Optimization	- AI algorithms to minimize the levelized cost of energy (LCOE) for renewable energy projects. - Optimization of energy storage systems to reduce operational costs. - AI-enabled peer-to-peer energy trading to lower electricity prices for consumers.
AI for Enhancing Reliability	- AI-based fault detection and isolation to improve grid resilience. - Autonomous grid restoration using AI to minimize downtime during outages. - AI-driven cybersecurity measures to protect the grid from cyber threats.

Besides to the aforementioned impacts of renewable energy sources, there are different types of impacts such as economic and environmental as tabulated in Table 4 that can cause effects on the system components.

Table 4: Economic and environmental Impacts [22], [23].

Impacts types	Classifications	Features
Economic	Cost of Renewable Energy Integration	- The declining cost of solar PV and wind turbines globally and their potential cost-effectiveness in Libya. - The cost of grid upgrades, energy storage, and AI-driven solutions. - The long-term economic benefits of reducing reliance on fossil fuels.
	Investment and Financing	- The role of government policies, subsidies, and incentives in attracting investment.

		- The potential for private sector participation and public-private partnerships (PPPs). - The need for international financing and support from organizations such as the World Bank and African Development Bank.
	Job Creation and Economic Growth	- The potential for job creation in the renewable energy and AI sectors. - The impact on local economies, particularly in rural areas with abundant renewable resources. - The need for workforce training and education to support the transition
Environmental	Reduction in Greenhouse Gas Emissions	- The significant contribution of renewable energy to reducing Libya's carbon footprint. - The potential for renewables to help Libya meet its climate targets under the Paris Agreement.
	Water Use and Conservation	- The lower water footprint of renewable energy compared to fossil fuels. - The potential for renewable energy to support water desalination and irrigation
	Land Use and Ecological Considerations	- The impact of large-scale renewable energy projects on land use and ecosystems. - The need for careful site selection to minimize environmental impacts.

Table 5: Policy and Regulatory Framework.

Policy	Remarks	Ref
Government Policies and Targets	- Libya's National Renewable Energy Strategy (2013) and its alignment with global climate goals. - The role of the Renewable Energy Authority of Libya (REAoL) in promoting renewable energy projects .	[24], [25]
Grid Codes and Standards	- The need for updated grid codes to accommodate renewable energy integration and AI-driven solutions. - The importance of grid resilience and cybersecurity in the context of renewable energy.	[26]
Market Design and Pricing	- The impact of renewable energy on electricity markets and pricing mechanisms. - The need for market reforms to support the integration of renewables and AI technologies.	[27]

Table 6: Case Studies and Real-World Examples [28], [29].

Project names	Features
Morocco's Noor Solar Plant	- The role of AI in optimizing the performance of concentrated solar power (CSP) plants. - Lessons for Libya in terms of technology adoption and policy implementation.
South Africa's Renewable Energy Program	- The use of AI for grid management and cost optimization in South Africa's Renewable Energy Independent Power Producer Procurement Program (REIPPPP). - Lessons for Libya in terms of private sector involvement and financing.
Saudi Arabia's Smart Grid Initiatives	- The integration of AI and renewable energy in Saudi Arabia's Vision 2030. - Lessons for Libya in terms of grid modernization and workforce development.

Future work and recommendations

Libya with its abundant solar and wind resources, has significant potential for renewable energy integration. However, the country faces challenges in grid reliability and cost efficiency due to its reliance on fossil fuels, outdated infrastructure, and lack of advanced energy management systems. Below presented in Table 7 a framework for FUTIRE (Future Utility Technologies for Integration of Renewable Energy) work and recommendations for Libya.

Table 7: Future Outlook and Recommendations [28]

Future works and recommendation	Explanations
Technological Innovations	- The potential for breakthroughs in AI and renewable energy technologies. -The role of digitalization, blockchain, and IoT in enhancing grid reliability and reducing costs.
Capacity Building and Knowledge Sharing	- The importance of international cooperation and knowledge sharing. - The need for training programs to build local expertise in renewable energy and AI.
Policy Recommendations	- Develop a long-term renewable energy strategy with clear targets and incentives. - Establish a regulatory framework to support AI-driven grid management and renewable energy integration. - Promote public-private partnerships to attract investment and accelerate the energy transition.

Results and discussion

Based on the data utilized for the parameters presented in Table 8, the results have been acquired as will be discussed on next figures.

Table 8: Parameters utilized in the study.

Parameters	Value	Unit
Time	24	Hours
Number of scenarios	100	
RESs capacity	50	MW
Grid capacity	100	MW
RESs variability	0.2	%
Cost RESs	0.05	$/Kw
Cost grid	0.10	$/kW
AI Efficiency	10	%

Figure 4 appears to contain two probability distribution graphs which is illustrates the impacts of renewable energy sources and artificial intelligence on grid reliability and cost, as discussed in the MATLAB code. The grid reliability graph indicates a high probability of achieving nearly 99.4% reliability, while the total cost graph shows a concentration of costs around $160, reflecting potential cost savings and efficiency improvements.

Furthermore, the Grid Reliability that measured in (%) as shown in x-axis that represents grid reliability percentages ranging from 98.6% to 100% and in the y-axis represents the probability, with values ranging from 0 to 0.6. while the total Cost that measured in ($) represented in x-axis the total costs ranging from 154to154*to*168. While the y-axis represents probability, with values ranging from 0 to 0.4. Based on the results obtained the average of grid reliability and cost are tabulated in Table 9.

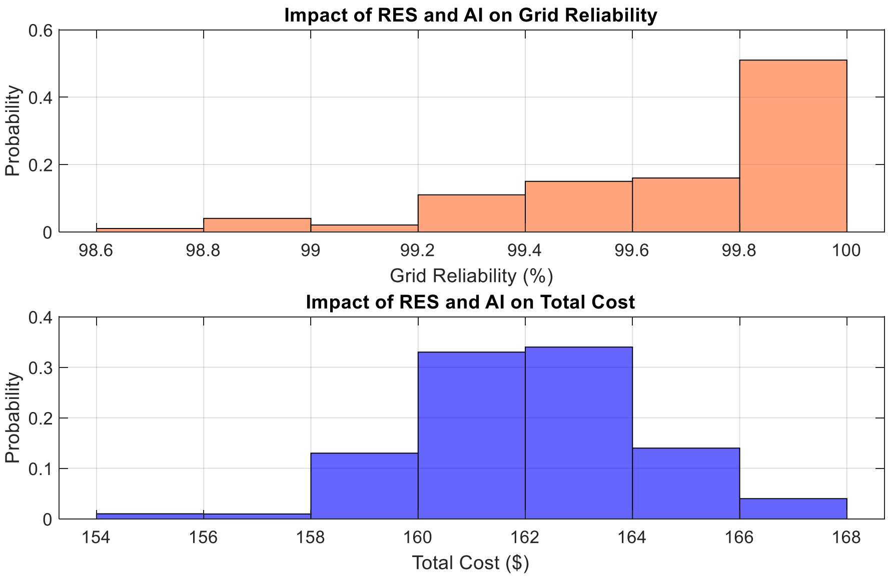

Figure 4 Acquired reliability and total cost.

Table 9: Average of the results

Averages	Value
Average Grid Reliability	99.71%
Average Total Cost:	162.13$

The acquired simulation analyzing result in Figure 6 shows the grid performance (grid usage). The peak usage can be defined as the grid usage peaks at certain hours, possibly during the morning or evening when demand is highest. On the contrary, low usage can be detected in periods of lower usage, likely during nighttime or off-peak hours.

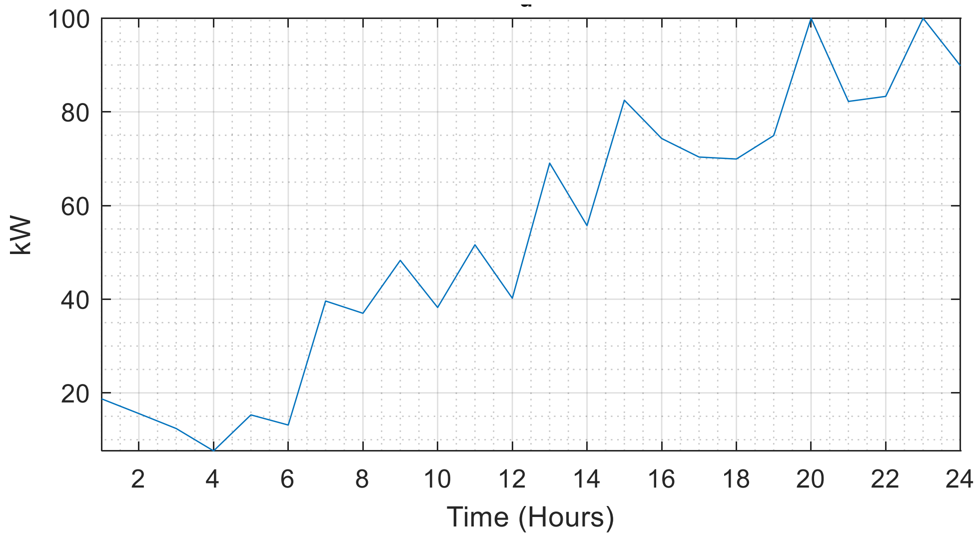

Figure 6 Gris usage.

The unmet demand is demonstrated in Figure 7 for the two-dimensional plot. The X-Axis represents time in hours, ranging from 2 to 24 hours. While the Y-Axis Represents the kW load that ranges from 0 to 3.5.

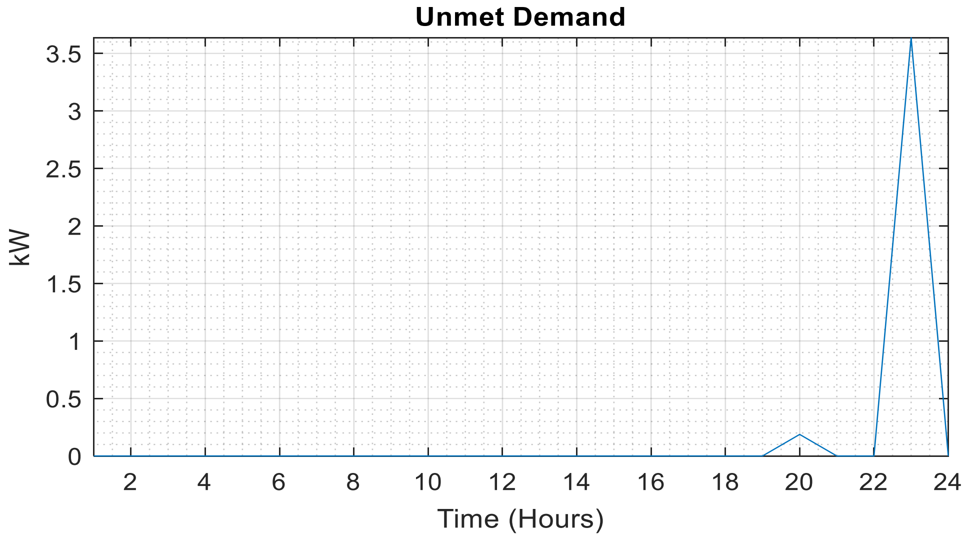

Figure 7 Unmet demand.

Conclusion

The integration of renewable energy sources and AI technologies offers a transformative opportunity for Libya to enhance grid reliability, reduce costs, and achieve sustainable development. By leveraging its abundant solar and wind resources and adopting AI-driven solutions, Libya can overcome the challenges of intermittency and grid instability. With the right policies, investments, and international cooperation, Libya can position itself as a leader in renewable energy and AI integration in North Africa.

References

[1] A. O. M. Maka, S. Salem, and M. Mehmood, "Solar photovoltaic (PV) applications in Libya: Challenges, potential, opportunities and future perspectives," *Clean. Eng. Technol.*, vol. 5, p. 100267, 2021, doi: 10.1016/j.clet.2021.100267.

[2] A. Alsharif, C. W. Tan, R. Ayop, K. Y. Lau, and A. M. Dobi, "A rule-based power management strategy for Vehicle-to-Grid system using antlion sizing optimization," *J. Energy Storage*, vol. 41, no. April, p. 102913, Sep. 2021, doi: 10.1016/j.est.2021.102913.

[3] M. Khaleel, A. A. Ahmed, and A. Alsharif, "Artificial Intelligence in Engineering," *Brill. Res. Artif. Intell.*, vol. 3, no. 1, pp. 32–42, Mar. 2023, doi: 10.47709/brilliance.v3i1.2170.

[4] M. A. Ahmad, A. Teredesai, and C. Eckert, "Interpretable Machine Learning in Healthcare," in *2018 IEEE International Conference on Healthcare Informatics (ICHI)*, IEEE, Jun. 2018, pp. 447–447. doi: 10.1109/ICHI.2018.00095.

[5] A. Alsharif, C. W. Tan, R. Ayop, A. Ali Ahmed, M. Mohamed Khaleel, and A. K. Abobaker, "Power Management and Sizing Optimization for Hybrid Grid-Dependent System Considering Photovoltaic Wind Battery Electric Vehicle," *2022 IEEE 2nd Int. Maghreb Meet. Conf. Sci. Tech. Autom. Control Comput. Eng. MI-STA 2022 - Proceeding*, pp. 645–649, 2022, doi: 10.1109/MI-STA54861.2022.9837749.

[6] K. Taghizad-Tavana, A. Alizadeh, M. Ghanbari-Ghalehjoughi, and S. Nojavan, "A Comprehensive Review of Electric Vehicles in Energy Systems: Integration with Renewable Energy Sources, Charging Levels, Different Types, and Standards," *Energies*, vol. 16, no. 2, p. 630, Jan. 2023, doi: 10.3390/en16020630.

[7] A. Alsharif, A. Salem, D. Alarga, and A. A. Ahmed, "Stochastic Method and Sensitivity Analysis Assessments for Vehicle-to-Home Integration based on Renewable Energy Sources".

[8] A. Alsharif, C. W. Tan, R. Ayop, K. Y. Lau, and C. L. Toh, "Sizing of Photovoltaic Wind Battery system integrated with Vehicle-To-Grid using Cuckoo Search Algorithm," *5th IEEE Conf. Energy Conversion, CENCON 2021*, pp. 22–27, 2021, doi: 10.1109/CENCON51869.2021.9627291.

[9] M. A. Hannan, S. Y. Tan, A. Q. Al-Shetwi, K. P. Jern, and R. A. Begum, "Optimized controller for renewable energy sources integration into microgrid: Functions, constraints and suggestions," *J. Clean. Prod.*, vol. 256, p. 120419, 2020, doi: 10.1016/j.jclepro.2020.120419.

[10] Y. Sawle, S. C. C. Gupta, A. Kumar Bohre, and A. K. Bohre, "PV-wind hybrid system: A review with case study," *Cogent Eng.*, vol. 3, no. 1, pp. 1–31, Dec. 2016, doi: 10.1080/23311916.2016.1189305.

[11] A. B. de empresas de pesquisa ABEP *et al.*, "What is the difference between On-grid and off-grid solar power?," *J. Chem. Inf. Model.*, vol. 53, no. February, p. 2021, 2021, [Online]. Available: https://doi.org/10.1080/09638288.2019.1595750%0Ahttps://doi.org/10.1080/17518423.2017.1368728%0Ahttp://dx.doi.org/10.1080/17518423.2017.1368728%0Ahttps://doi.org/10.1016/j.ridd.2020.103766%0Ahttps://doi.org/10.1080/02640414.2019.1689076%0Ahttps://doi.org/

[12] M. P. Bakht, Z. Salam, A. R. Bhatti, W. Anjum, S. A. Khalid, and N. Khan, "Stateflow-Based Energy Management Strategy for Hybrid Energy System to Mitigate Load Shedding," *Appl. Sci.*, vol. 11, no. 10, p. 4601, May 2021, doi: 10.3390/app11104601.

[13] International Energy Agency (IEA), "Technical potential of selected renewable energy technologies for electricity generation," IEA, Paris. Accessed: Feb. 05, 202AD. [Online]. Available: https://www.iea.org/data-and-statistics/charts/technical-potential-of-selected-renewable-energy-technologies-for-electricity-generation

[14] Ahmed Moh A Al Smin, Alkbir Munir Faraj Almabrouk, Sairul Izwan Safie, Mohd Al Fatihhi Mohd Szali Januddi, Mohd Fahmi Hussin, and Abdulgader Alsharif, "Enhancing solar hybrid system efficiency in Libya through PSO & flower pollination optimization," *Prog. Energy Environ.*, vol. 27, no. 1, pp. 23–31, 2024, doi: 10.37934/progee.27.1.2331.

[15] A. Alsharif, I. Imbayah, A. Abdulraheem, A. M. A. Massoud, and O. N. Elazoomie, "Applicability of Solar Energy in Libyan Southern Cities: Challenges and Difficulties," *Int. Sci. Technol. J.*, vol. 36, no. 1, pp. 1–14, Jan. 2025, doi: 10.62341/aimo1756.

[16] M. G. M. Almihat and M. T. Kahn, "Wind Turbines Control Trends and Challenges: An Overview," *Int. J. Innov. Res. Sci. Stud.*, vol. 5, no. 4, pp. 378–390, Nov. 2022, doi: 10.53894/ijirss.v5i4.910.

[17] S. Deilami and S. M. Muyeen, "An Insight into Practical Solutions for Electric Vehicle Charging in Smart Grid," *Energies*, vol. 13, no. 7, p. 1545, Mar. 2020, doi: 10.3390/en13071545.

[18] Y. P. Wimalaratna, H. N. Afrouzi, K. Mehranzamir, M. B. M. Siddique, S. C. Liew, and J. Ahmed, "Analysing wind power penetration in hybrid energy systems based on techno-economic assessments," *Sustain. Energy Technol. Assessments*, vol. 53, no. PB, p. 102538, 2022, doi: 10.1016/j.seta.2022.102538.

[19] M. Rabiul Islam, W. Xu, Y. Guo, and K. Ma, "Solar Photovoltaic Power Plants," *Int. J. Photoenergy*, vol. 2017, pp. 1–2, 2017, doi: 10.1155/2017/1041375.

[20] S. Singh, P. Chauhan, and N. Jap Singh, "Feasibility of Grid-connected Solar-wind Hybrid System with

Electric Vehicle Charging Station," *J. Mod. Power Syst. Clean Energy*, vol. 9, no. 2, pp. 295–306, Mar. 2021, doi: 10.35833/MPCE.2019.000081.
[21] T. Elgallai, "Modeling and Power Quality Enhancement of PV Interfaced with Power Grid System," *Brill. Res. Artif. Intell.*, vol. 3, no. 2, pp. 423–433, Jan. 2024, doi: 10.47709/brilliance.v3i2.3417.
[22] H. Karunathilake, K. Hewage, J. Brinkerhoff, and R. Sadiq, "Optimal renewable energy supply choices for net-zero ready buildings: A life cycle thinking approach under uncertainty," *Energy Build.*, vol. 201, pp. 70–89, Oct. 2019, doi: 10.1016/j.enbuild.2019.07.030.
[23] C. Wang, J. Gu, O. Sanjuán Martínez, and R. González Crespo, "Economic and environmental impacts of energy efficiency over smart cities and regulatory measures using a smart technological solution," *Sustain. Energy Technol. Assessments*, vol. 47, p. 101422, Oct. 2021, doi: 10.1016/j.seta.2021.101422.
[24] REAoL, "National Renewable Energy Strategy," Renewable Energy Authority of Libya (REAoL).
[25] L. Henry *et al.*, "Key factors around ocean-based power in the Caribbean region, via Trinidad and Tobago," *Renew. Sustain. Energy Rev.*, vol. 50, pp. 160–175, 2015, doi: 10.1016/j.rser.2015.04.115.
[26] H. Abubakr, J. C. Vasquez, K. Mahmoud, M. M. F. Darwish, and J. M. Guerrero, "Comprehensive Review on Renewable Energy Sources in Egypt-Current Status, Grid Codes and Future Vision," *IEEE Access*, vol. 10, pp. 4081–4101, 2022, doi: 10.1109/ACCESS.2022.3140385.
[27] J. Warner, *Lithium-Ion Battery Packs for EVs*. Elsevier, 2014. doi: 10.1016/B978-0-444-59513-3.00007-8.
[28] Ahmed Moh A Al Smin, Alkbir Munir Faraj Almabrouk, Sairul Izwan Safie, Mohd Al Fatihhi Mohd Szali Januddi, Mohd Fahmi Hussin, and Abdulgader Alsharif, "Enhancing solar hybrid system efficiency in Libya through PSO & flower pollination optimization," *Prog. Energy Environ.*, vol. 27, no. 1, pp. 23–31, Jan. 2024, doi: 10.37934/progee.27.1.2331.
[29] B. Belgasim, Y. Aldali, M. J. R. Abdunnabi, G. Hashem, and K. Hossin, "The potential of concentrating solar power (CSP) for electricity generation in Libya," *Renew. Sustain. Energy Rev.*, vol. 90, no. March, pp. 1–15, Jul. 2018, doi: 10.1016/j.rser.2018.03.045.