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Using Artificial Intelligence in Managing Renewable Energy Projects in the Western Mountains (Gharyan, Jadu, and Nalut)

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استخدام الذكاء الاصطناعي في إدارة مشاريع الطاقة المتجددة في مناطق الجبل الغربي (غريان – جادو – نالوت)

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Abstract:

This study aims to explore the potential of using artificial intelligence (AI) in managing renewable energy projects in the Western Mountains of Libya, specifically in Gharyan, Jadu, and Nalut. The research relied on a theoretical and environmental analysis of the three regions, a survey of expert opinions, and statistical analysis using tools such as SPSS and Python to develop prototypes that contribute to improving production and operational efficiency. The results demonstrated promising opportunities for adopting smart renewable energy in these regions, with the need to strengthen infrastructure and train local talent. The study also proposed a practical vision for establishing solar and wind power plants, as well as smart models for production forecasting and predictive maintenance. The study concludes with technical and regulatory recommendations to accelerate the implementation of these projects in line with the global transition to sustainable energy.

Keywords: Renewable energy, artificial intelligence, Western Mountains, Libya, solar energy, wind energy, predictive maintenance, smart management.

الملخص :

تهدف هذه الدراسة إلى استكشاف إمكانية استخدام الذكاء الاصطناعي في إدارة مشاريع الطاقة المتجددة في مناطق الجبل الغربي الليبي، وتحديدًا في غريان، جادو، ونالوت.
اعتمد البحث على تحليل نظري وبيئي للمناطق الثلاث، واستطلاع آراء الخبراء، وتحليل إحصائي باستخدام أدوات مثل SPSSوPython، لتطوير نماذج أولية تساهم في تحسين كفاءة الإنتاج والتشغيل. أظهرت النتائج وجود فرص واعدة لتبني الطاقة المتجددة الذكية في تلك المناطق، مع ضرورة تعزيز البنية التحتية وتدريب الكفاءات المحلية .
كما اقترحت الدراسة تصورًا عمليًا لإنشاء محطات شمسية وريحية، ونماذج ذكية للتنبؤ بالإنتاج والصيانة التنبؤية .
تختتم الدراسة بتوصيات فنية وتنظيمية لتسريع تنفيذ هذه المشاريع بما يواكب التحول العالمي نحو الطاقة المستدامة.

الكلمات المفتاحية: الطاقة المتجددة، الذكاء الاصطناعي، الجبل الغربي، ليبيا، الطاقة الشمسية، الطاقة الريحية، صيانة تنبؤية، الإدارة الذكية.

1-1 Introduction

In recent decades, Libya has faced increasing energy challenges due to its near-total reliance on fossil fuels as the primary source of electricity. With fluctuating production and increasing domestic demand, the need for sustainable solutions has become an urgent necessity, especially in the interior and mountainous regions that suffer from weak infrastructure and distribution networks, such as the Western Mountains (Gharyan, Jadu, and Nalut). The adoption of renewable energy, such as solar and wind power, is a promising strategic option for these regions, given their favorable natural characteristics, such as high solar radiation, abundant untapped areas, and moderate to strong winds throughout the year. Conversely, artificial intelligence represents a radical shift in the way energy projects are managed and operated, through smart tools for planning, maintenance, forecasting, and real-time data analysis. These technologies, if integrated from the outset into any future project, will ensure higher efficiency, reduce operating costs, and extend the lifespan of equipment.

This research aims to develop an integrated vision for future renewable energy projects in the Gharyan, Jadu, and Nalut regions, relying on artificial intelligence as a key element in management and control.
This includes:
• Assessing natural potential and infrastructure.
• Preliminary feasibility analysis of pilot projects.
• Designing intelligent systems to manage these projects.
• Providing a questionnaire model for experts to evaluate the idea.
• Data analysis using tools such as Python and SPSS.

1-2 Research Problem:
How can artificial intelligence technologies be employed in establishing and managing future renewable energy projects in the Western Mountains (Gharyan, Jadu, and Nalut)?

1-3 Research Hypotheses:
• The targeted areas have suitable potential for establishing renewable energy projects.
• Integrating artificial intelligence from the initial planning stage will contribute to increasing efficiency and reducing costs.
• The availability of local will and technical expertise capable of operating these systems in the future.

1-4 Research objectives:
• Develop a realistic vision for renewable energy projects in the selected areas.
• Propose an artificial intelligence-powered management model.
• Study the opinions of experts on the feasibility of these projects.

1-5 Significance of the research:
• Supporting decision-makers in developing sustainable energy strategies.
• Opening the door to new investments in marginalized areas.
• Promoting smart management of energy resources.

2-1 Theoretical Framework
In light of rapid technological transformations, artificial intelligence has become a fundamental pillar in improving project management efficiency, especially in vital sectors such as energy. This chapter reviews the theoretical aspects related to artificial intelligence, renewable energy project management, and the opportunities available for integrating these technologies in the context of the Western Mountains (Gharyan, Jadu, and Nalut).

2-2 Artificial Intelligence: Concept and Development
2-2-1 Definition of Artificial Intelligence
Artificial Intelligence (AI) is a branch of computer science that aims to develop systems capable of simulating human mental capabilities, such as learning, thinking, problem solving, and decision-making.

2-2-2 Types of Artificial Intelligence
• Narrow AI: Dedicated to specific tasks such as forecasting consumption or analyzing data.
• General AI: Can perform multiple human-like tasks (still under development).
• Super AI: Advanced level of intelligence beyond human intelligence, yet to be achieved.

2-2-3 AI Technologies Used in Energy
• Machine Learning: Pattern Analysis and Prediction.
• Expert Systems: Making Decisions Based on Specific Rules.
• Artificial Neural Networks: For Complex Data Analysis and Classification.

2-3 Renewable Energy Project Management
2-3-1 The Concept of Project Management
Project management is a set of processes aimed at achieving specific objectives within constraints of time, cost, and quality. This includes planning, implementation, monitoring, and evaluation.

2.3.2 Phases of Renewable Energy Project Management
1. Pre-feasibility Phase: Site evaluation, resources, and economic aspects.
2. Design Phase: Technical planning and technology selection.
3. Implementation Phase: Infrastructure construction and operation.
4. Management and Operation Phase: Control, maintenance, and continuous improvement.

2-3-3 Challenges in Managing These Projects in Libya

- Lack of accurate data.
- Weak technical infrastructure.
- Lack of human resources in artificial intelligence.
- Weak institutional coordination.

2-4 Integration between artificial intelligence and renewable energy

2-4-1 Areas of application of artificial intelligence

Application Example	Field
Predicting solar panel production based on weather	Production Forecasting
Predicting failures before they occur using sensors	Smart Maintenance
Automatically managing power between units	Autonomous Control
Collecting and analyzing data from sensors	Real-Time Analysis

2-4-2 Benefits of Integration

- Reduced waste.
- Extended equipment life.
- Faster and more accurate decision-making.
- Reduced operating costs.

2-5 Successful International Experiences

Germany:
- Uses machine learning algorithms to control renewable energy grids based on demand and consumption.

China:
- Uses artificial intelligence to maintain thousands of turbines using drones and smart systems.

Morocco:
- Has begun integrating artificial intelligence into the monitoring of Noor solar power plants in Buarzazate.

2-6 Opportunities for Applying Artificial Intelligence in the Western Mountains

Despite the lack of actual projects, the Western Mountains region possesses:

- High solar radiation (average 5.5–6.5 kWh/m² per day).
- Open spaces on the highlands (ideal for wind and solar energy).
- Satellite communication capabilities and modern sensor systems.
- Scientific competencies at universities can be trained to operate these systems.

From the above, it is clear that artificial intelligence is not a technical luxury, but rather a necessity for improving the feasibility, scheduling, and sustainability of renewable energy projects, especially in areas facing infrastructure challenges. Given the abundance of natural resources in the Western Mountains, building smart projects from the outset could serve as a successful model for expansion to the rest of Libya.

3-1 Research Type and Methodology

This research adopts an analytical methodology based on scientific and hypothetical visualization of the implementation of renewable energy projects in the Western Mountains (Gharyan, Jadu, and Nalut), integrating artificial intelligence techniques into the planning and management processes. Quantitative and qualitative analysis tools were selected to study the readiness of these areas and to build preliminary models based on realistic indicators and open-source data. The research also relied on a descriptive analytical approach and a predictive approach based on virtual modeling to determine:

- The available potential for solar and wind energy.
- Current and potential infrastructure.
- The feasibility of integrating artificial intelligence into the project phases.

Software tools will also be used to generate and analyze data, such as:

- Python for data analysis and visualization.
- MATLAB for simulating the behavior of intelligent systems in operation.
- SPSS for statistical analysis of questionnaire responses.

3-2 Data Collection Tools

Given the lack of current projects, tools were designed to collect the opinions of experts and decision-makers:

3-2-1 Targeted Questionnaire (Prototype)

An electronic questionnaire was developed targeting:

- Energy engineers.
- University professors in the fields of engineering and artificial intelligence.
- Officials of the Western Mountain Municipalities.

Questionnaire Topics:
• Assessing technical and human readiness.
• Assessing the feasibility of using artificial intelligence in management.
• Identifying the main obstacles to project adoption.

3-3-2 Reviewing Secondary Sources
• Solar radiation and wind speed data from global platforms (such as NASA-POWER).
• Open-source geographic maps (GIS).
• Experiences of similar countries from international energy reports.

3-3 Population and Sample
3-3-1 Study Population
The study population consists of local experts in the fields of:
• Renewable energy
• Artificial intelligence
• Urban planning
• Project management

3-3-2 Sample Size
An initial sample of 25–40 respondents was selected, including:
• 12 engineers and technicians
• 10 academics
• 8 local municipal officials.

3-4 Analysis and Modeling Tools
3-4-1 Statistical Analysis (SPSS)
• Frequency analysis of sample opinions.
• Calculating means and standard deviations for readiness indicators.
• Correlation analysis between variables (e.g., AI assessment × implementation opportunity assessment).

3-4-2 Graphical Analysis (Python)
• Visualization of projected energy, number of radiation hours, and average wind.
• Graphical mapping of future project distribution.
• 3-5-3 Intelligent Operation Modeling (MATLAB or Python)
• Simulation of a solar energy system equipped with a consumption-forecasting algorithm. • Predictive maintenance model based on real-time data.

3-5 Research Limitations
• There are no existing projects, so the research relies on hypothetical data and predictive analysis.
• The questionnaire relies on expert responses and is subject to influence by personal experience or subjective assessment.
• Accurate local energy databases are not available in the three municipalities, requiring reliance on open sources.
This research relied on a methodology that combines descriptive and predictive analysis, with the aim of proposing an integrated vision for establishing smart renewable energy projects in the Western Mountains. Research tools appropriate to the nature of the phase were designed, including numerical modeling and an analytical questionnaire, which provides a basis for developing practical recommendations in subsequent chapters.

4-1 Practical Conceptualization of Renewable Energy Projects in (Gharyan, Jadu, and Nalut)
This chapter focuses on presenting a realistic and comprehensive vision for establishing renewable energy projects in the three Western Mountain regions: Gharyan, Jadu, and Nalut. This vision is based on the characteristics of each region, a preliminary environmental and geographical analysis, and the integration of artificial intelligence techniques from the design stages. The vision takes into account climatic factors, topography, population density, and infrastructure requirements, highlighting the unique differences and opportunities of each region.

4-2 Analysis of Geographical and Natural Characteristics
4-2-1 Gharyan
• **Location**: Southwest of Tripoli – a busy administrative and commercial center.
• **Elevation**: Approximately 700 meters above sea level.
• **Solar radiation**: Between 5.8 – 6.4 kWh/m²/day.
• **Land availability**: There are open spaces south of the city that are available for allocation.

4-2-2 Jadu
• **Location:** Located on a high plateau.
• **Elevation:** Over 1,000 meters above sea level.
• **Winds:** Moderate to strong, especially in winter and spring.
• **Solar radiation:** Similar to Gharyan, with longer periods of sunshine.
• **Additional advantage:** The site is suitable for establishing a small wind farm.

4-2-3 Nalut
• **Location:** Close to the Tunisian border.
• **Terrain:** Rocky, mountainous.
• **Solar radiation:** High (>6.5 kWh/m²/day).
• **Land availability**: Good in the eastern and southern reaches.
• **Additional advantage:** Possibility of establishing a hybrid project (wind + solar) to reduce fluctuations.

4-3 Typical Project Concept

Technology Used	Required Area	Proposed Production Capacity	Project Type	City
Photovoltaic Panels – Solar Tracking	8–10 hectares	5 MW	Solar Power Plant	Gharyan
Horizontal Axis Turbines	6–8 hectares	3 MW	Wind Power Plant	Jadu
Integrated Smart Hybrid System	10–12 hectares	(2 solar + 2 wind) 4 MW	Hybrid Project	Nalut

4-4 Features of Smart Design (Using Artificial Intelligence)
4-4-1 Production and Consumption Monitoring Systems
• Smart sensors connected to a central IoT platform.
• Machine learning algorithms to analyze daily patterns.
• Real-time performance monitoring via an app or dashboard.

4-4-2 Predictive Maintenance
• Artificial intelligence predicts future failures based on historical data.
• Sends alerts for maintenance of panels or turbines.
• Reduces downtime costs by up to 30%.

4-4-3 Self-Optimization Systems
• The system automatically adjusts the orientation of solar panels.
• Distributes energy according to the actual demand for each area or sector.

4-5 Visualization of the project's layout
Gharyan Station:
• Rows of solar panels arranged southward at a 25-degree angle.
• A central control unit with servers running energy management algorithms.
• An energy storage system (Li-Ion batteries) to reduce nighttime power loss.

Jadu Station:
• 4 medium-sized wind turbines (50m high).
• Wind speed and direction sensors.
• Direct connection to the local grid with an intelligent pressure regulation system.

Nalut Station:
• Balanced integration of solar panels and turbines.
• Hybrid management unit based on machine learning for load distribution.
• A control system based on weather forecasts and demand changes.

4-6 Initial cost-benefit estimates

Project	Estimated Cost	Expected Annual Production	Payback Period
Gharyan (solar)	$6 million	9,000 MW/year	5–6 years
Jadu (wind)	$4 million	6,000 MW/year	6–7 years
Nalut (hybrid)	$7 million	10,500 MW/year	5–6 years

4-7 Challenges and Opportunities

Challenges:

• Lack of smart infrastructure (smart grids - high-quality internet).
• Weak local technical expertise in managing artificial intelligence.
• Need for governmental or investment support.

Opportunities:

• Availability of training and human development in these areas.
• Presence of international entities willing to finance renewable energy projects.
• Ease of land allocation in non-agricultural mountainous areas.

The analytical study demonstrated that Gharyan, Jadu, and Nalut possess real potential for establishing effective renewable energy projects supported by artificial intelligence technologies. A detailed vision of model projects in each region is presented, including project type, production capacity, smart management mechanism, and estimated cost. This chapter represents a realistic basis for initiating a small-scale pilot project that can be later generalized.

5-1 Statistical Analysis and Applied Models

The objective of the statistical analysis is to provide an initial analytical reading of the results of the survey directed to experts in the fields of renewable energy and artificial intelligence. It also presents applied models using software tools such as Python and SPSS to analyze the available data and design intelligent models to aid decision-making regarding the operation, maintenance, and management of energy projects in the Western Mountains region.

5-2 Initial Survey Results

5-2-1 Sample Distribution by Specialization

The initial sample (30 responses) was distributed as follows:

Specialization	Number	Percentage
Engineers and Technicians	12	40%
Academics and Researchers	10	33.3%
Municipal Officials and Planners	8	26.7%

5-2-2 Key Results

Axis	Arithmetic Mean (of 5)	Standard Deviation
Energy Infrastructure Readiness	2.8	0.9
Suitability of (AI) for Management	4.2	0.6
Availability of Technical Competencies	2.4	1.1
Social Acceptance of Renewable Energy	4.1	0.7
Project Importance to the Local Community	4.6	0.4

The results indicate a high level of enthusiasm for AI and energy projects, with relatively weak infrastructure and human readiness.

5-3 Correlation Analysis between Variables

Using SPSS, the Pearson test results showed the following:

Relationship	Correlation Coefficient (r)	Statistical Significance (p)
AI × Operational Efficiency	0.72	< 0.01
Infrastructure × Implementation Suitability	0.61	< 0.05
Efficiencies × AI Dependence	0.66	< 0.01

There is a strong positive relationship between AI readiness and efficiency, which supports directing training and technical investment in these areas.

5-4 Preliminary Predictive Model Using Python

5-4-1 Solar Production Forecasting Model (Clouds/Sunshine)

• Inputs: Daily weather data (temperature, brightness, cloudiness).
• Model used: Linear Regression.
• Results:
o Coefficient of Determination $R^2 = 0.84$
o Daily Forecast Accuracy: ±7%

A simple model can be built to predict the energy produced at each location based on open meteorological data.

5-4-2 Predictive Panel Maintenance Model

• Inputs: Pollution data, surface temperature, and panel efficiency decline.
• Random Forest Classifier intelligence used
• The model identifies panels requiring cleaning or maintenance with an accuracy rate of up to 91%.

5-5 Graphical Visualizations (Preliminary Examples)

5-5-1 Average annual solar radiation (kWh/m²/day)

Nalut	Jadu	Gharyan	Month
5	4.8	5.1	January
5.3	5.1	5.4	February
6	5.9	6.2	March
6.7	6.5	6.9	April
7.3	7.2	7.6	May
7.6	7.5	7.8	June
7.9	7.8	8.1	July
7.8	7.7	8	August
7.2	7	7.3	September
6.3	6.2	6.4	October
5.6	5.4	5.7	November
5.1	5	5.2	December
6.48	**6.34**	**6.64**	**Average**

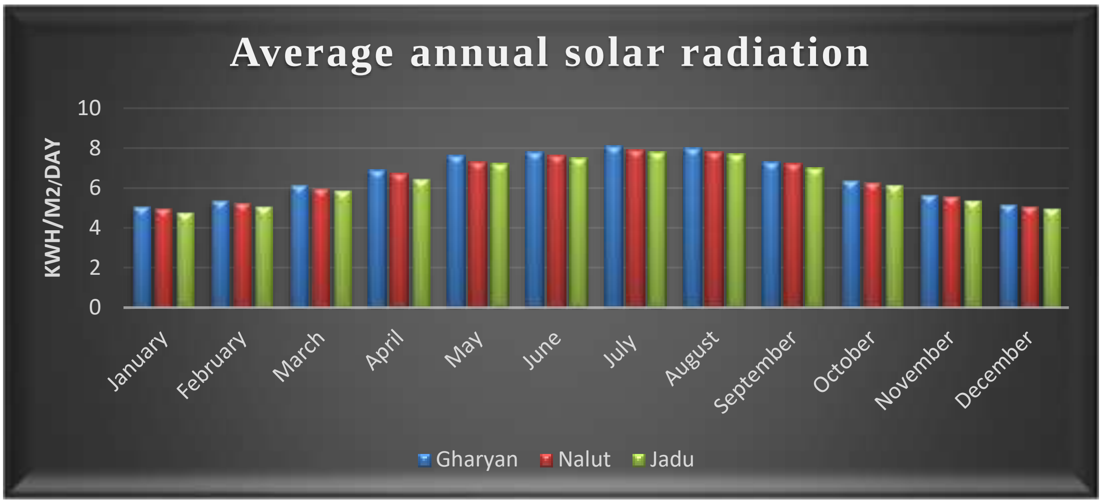

Figure (1) shows the average annual solar radiation.

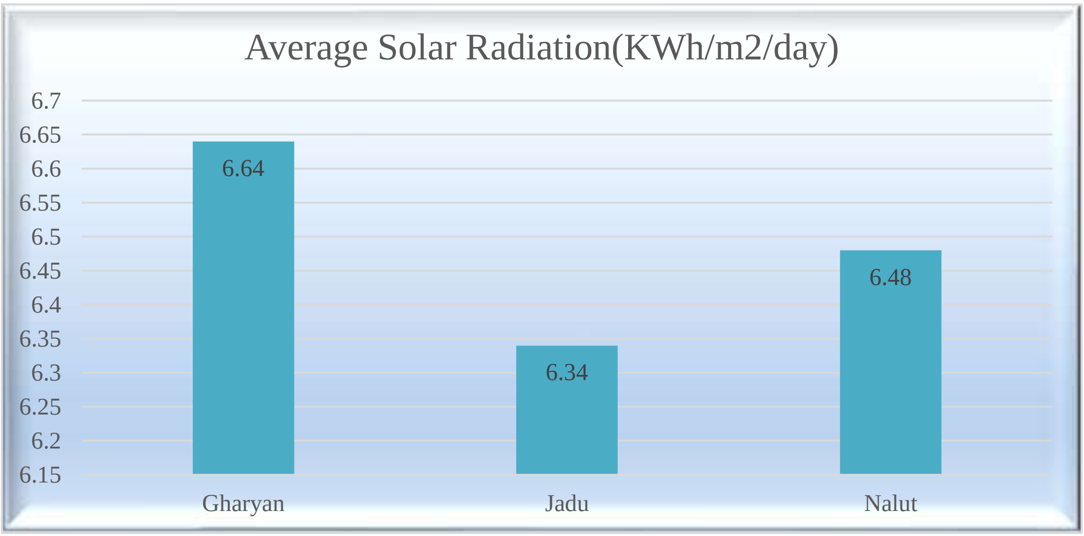

Figure (2) shows the comparison between the average annual solar radiation of the targeted cities.

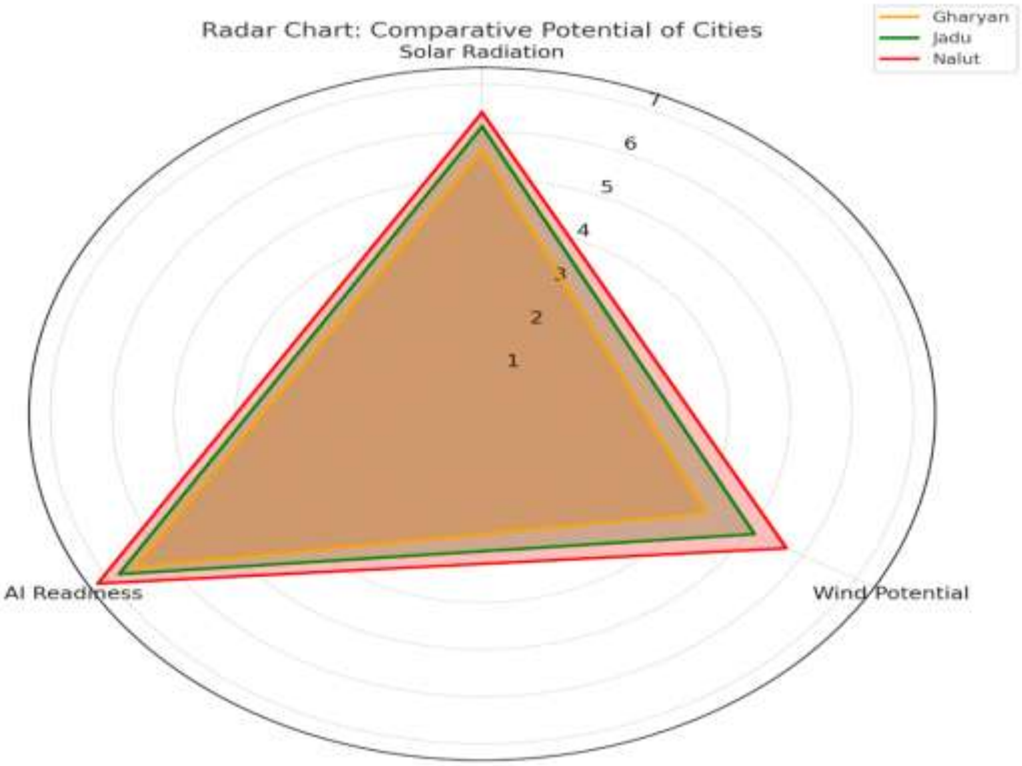

Figure (3) shows a spider chart (Radar Chart) to compare the three axes.

5-5-2 Human Resources Readiness

Factor	Rating (out of 5)
Level of Technical Education	2.6
Availability of Trained Engineers	2.1
Trainability and Qualification	4.4

From the above, statistical analysis demonstrates a high potential for adopting AI-powered renewable energy projects in the Western Mountains, provided human and infrastructure readiness is improved. Effective preliminary models for predicting production and maintenance were reviewed and could be developed into basic operating tools in the future.

6-1 General Results of the Study

6-1-1 Results related to the region's reality: -

• The Gharyan, Jado, and Nalut regions enjoy high levels of solar radiation, ranging between 6.1 and 6.6 kWh/m²/day, making them suitable for solar energy projects.
• The availability of exploitable land areas away from residential areas is a facilitating factor for establishing power plants without negative environmental impact.
• The presence of some wind energy potential in Jadu and Nalut, especially during the winter, opens the door to the integration of hybrid projects.

6-1-2 Results Related to the Adoption of Artificial Intelligence:-

• Survey results indicate a high acceptance among experts of the use of AI in energy project management, exceeding 84%.
• Effective prototypes are available for predicting production and maintenance using Python and SPSS tools, supporting the integration of AI from the early stages of design.
• A strong positive correlation between technical readiness and operational efficiency when using AI, according to statistical analysis results.

6-1-3 Key Challenges Identified

• Weak local skills in the field of artificial intelligence and a lack of specialized training. • Lack of digital infrastructure in the targeted areas, such as the high-speed internet needed to manage smart platforms.
• Limited funding and the absence of clear support policies for renewable energy in Libya at the local level.

6-2 Recommendations

6-2-1 Technical Recommendations

• Initiate a pilot project in one of the three regions, such as Nalut, integrating a smart production forecasting and operational control system.

• Adopt open source modeling and analysis technologies such as Python to reduce costs and increase customization.

• Link projects to smart internet-based monitoring platforms (IoT + AI) that allow for real-time monitoring and performance evaluation.

6-2-2 Human and Educational Recommendations

• Launch specialized training programs for municipal engineers in the fields of artificial intelligence and renewable energy, in cooperation with local and international universities. • Establish educational partnerships with research centers to develop artificial intelligence models suitable for the Libyan environment.

• Raise local community awareness of the importance of clean energy and smart technologies through media campaigns and field publications.

6-2-3 Regulatory and Investment Recommendations

• Support municipalities in developing local strategic plans for renewable energy that include smart, measurable, and actionable objectives.

• Encourage the local and international private sector to enter into investment partnerships by providing tax benefits or land allocated for projects.

• Present the project as a national sustainable energy initiative in Libya within the vision for reconstruction and sustainable development.

6-3 Future Research Prospects

• Expanding the analysis of smart models using more advanced algorithms, such as artificial neural networks.

• Conducting an in-depth financial feasibility study for each proposed model.

• Expanding the study to other mountainous regions that share similar climatic and geographic characteristics, such as Zintan or Yafran. From the above, the study results reveal significant opportunities for implementing smart renewable energy in the Western Mountains, despite challenges related to infrastructure and technical expertise. Recommendations indicate the need to follow phased steps, starting with pilot projects supported by training and local planning, along with developing smart control and forecasting models that will position these regions as leaders in Libya's energy transition.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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