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The Impact of Renewable Energy Sources on the Agricultural Sector in Southern Libya

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Index Terms
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Abstract
The agricultural sector in southern Libya faces existential challenges from water scarcity, climate change, and unreliable energy infrastructure. This mini review examines the potential of renewable energy technologies sparticularly solar and wind power to transform agricultural production in the Fezzan region. Analysis of climatological data reveals that southern Libya receives exceptional solar irradiation exceeding 7 kWh/m²/day, creating optimal conditions for photovoltaic applications. Recent initiatives, including the Wafa Fezzan solar installation project and photovoltaic water pumping systems at the Sahara Research Center, demonstrate technical feasibility and economic viability. However, significant barriers persist: high upfront capital costs, limited technical capacity, institutional fragmentation, and data scarcity due to civil conflict in terms of security. The review synthesizes evidence from peer-reviewed studies and policy documents to evaluate both opportunities and challenges. It concludes that renewable energy integration offers a pathway to climate-resilient agriculture in southern Libya, provided that implementation strategies address land-use trade-offs, ensure smallholder accessibility, and align with sustainable water management practices.

أثر مصادر الطاقة المتجددة على القطاع الزراعي في جنوب ليبيا

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الكلمات المفتاحية
الطاقة المتجددة، الزراعة، الري الشمسي، القدرة على التكيف مع تغير المناخ، منطقة فزان، ليبيا.

الملخص
يواجه القطاع الزراعي في جنوب ليبيا تحديات وجودية ناجمة عن ندرة المياه، وتغير المناخ، وعدم استقرار البنية التحتية للطاقة. تتناول هذه الدراسة الموجزة إمكانات تقنيات الطاقة المتجددة، ولا سيما الطاقة الشمسية وطاقة الرياح، في إحداث نقلة نوعية في الإنتاج الزراعي بمنطقة فزان. يكشف تحليل البيانات المناخية أن جنوب ليبيا يتمتع بإشعاع شمسي استثنائي يتجاوز 7 كيلوواط/م²/يوم، مما يهيئ ظروفًا مثالية لتطبيقات الطاقة الكهروضوئية. وتُظهر المبادرات الحديثة، بما في ذلك مشروع تركيب الطاقة الشمسية في وفاء فزان وأنظمة ضخ المياه الكهروضوئية في مركز بحوث الصحراء، الجدوى التقنية والاقتصادية. ومع ذلك، لا تزال هناك عوائق كبيرة: ارتفاع التكاليف الرأسمالية الأولية، ومحدودية القدرات التقنية، والتشتت المؤسسي، وندرة البيانات نتيجة للصراع الأهلي الذي يحد من الأوضاع الأمنية في تلك الفترة. تُركّز هذه الدراسة على الأدلة المستقاة من الدراسات المحكمة والوثائق السياسية لتقييم الفرص والتحديات على حد سواء. يخلص التقرير إلى أن دمج الطاقة المتجددة يمثل سبيلاً نحو زراعة قادرة على التكيف مع تغير المناخ في جنوب ليبيا، شريطة أن تراعي استراتيجيات التنفيذ المفاضلات المتعلقة باستخدام الأراضي، وتضمن وصول صغار المزارعين إليها، وتتوافق مع ممارسات الإدارة المستدامة للمياه.

1. INTRODUCTION

Libya stands at a critical juncture in its development trajectory. Despite possessing Africa's largest proven oil reserves, the country faces chronic electricity shortages that disproportionately affect rural agricultural communities, particularly in the southern Fezzan region (Lagili et al., 2023). The paradox is stark: a nation built on fossil fuel wealth struggles to power its farms, while abundant renewable resources remain largely untapped.

Southern Libya's agricultural sector operates under extreme environmental conditions. The region receives less than 100 mm of annual precipitation, making irrigation not merely beneficial but essential for crop survival (House of Representatives, 2026). Agriculture here is entirely dependent on fossil groundwater extraction from the Nubian Sandstone Aquifer System, requiring energy-intensive pumping that strains both the electrical grid and farm economics. The Libyan electricity network, already compromised by years of conflict and underinvestment, provides unreliable service to rural areas, with frequent outages disrupting irrigation schedules and post-harvest processing.

Climate change compounds these challenges. Rising temperatures, increased evapotranspiration rates, and more frequent dust storms threaten crop yields and soil health. A February 2026 workshop in Sebha, organized by the House of Representatives' Foreign Affairs Committee, explicitly identified agriculture as "the most affected by climate change" in southern Libya and called for urgent adaptation measures, including expanded renewable energy deployment (House of Representatives, 2026).

Libya’s agricultural sector overall account for only around 2 percent of gross domestic product but is nevertheless critically important for rural livelihoods and national food security (Basha, 2026). It should be noted that Libya imports nearly three quarters of its food. Agriculture is the biggest water user in the country as it consumes 83 per cent of the total water used. The groundwater levels in the country are falling by 1 to 2 meters each year due to excessive water extraction. The trajectory of unsustainability will also result in climate change by 2050 which is expected to raise temperature by 2 to 3 degree Celsius. The 10 to 15 percent increase in evapotranspiration will add to water demand (The world Factbook, 2024).

This review examines the intersection of renewable energy and agriculture in southern Libya through five lenses: (1) the region's renewable energy climatology and resource potential, (2) documented applications and pilot projects, (3) positive impacts on agricultural productivity, (4) mathematical models, (5) negative consequences and implementation challenges, and (6) policy pathways for sustainable integration.

2. RENEWABLE ENERGY CLIMATOLOGY OF SOUTHERN LIBYA

2.1 Solar Resource Assessment

Southern Libya lies within the global "sun belt," receiving some of the highest solar irradiation levels on Earth. Analysis of satellite-derived datasets, including NASA's MERRA-2 and the European Centre's ERA5-Land products, indicates that the Fezzan region receives annual average global horizontal irradiation exceeding 2,200 kWh/m² (Lagili et al., 2023). Daily averages range from 6.5 kWh/m² in winter months to over 8.0 kWh/m² during summer, with clear-sky conditions prevailing for more than 350 days annually as demonstrated in Figure 1.

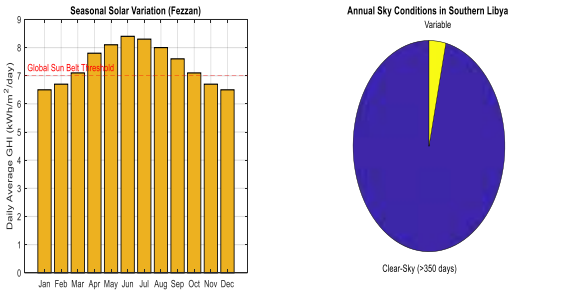


Figure 1. Seasonable Solar Variation, (b) Annual sky conditions in Southern Libya

The implications for agricultural applications are substantial. Photovoltaic systems in Sabha, Murzuq, and Ubari operate at capacity factors exceeding 25%, comparable to the best solar resources globally as illustrated in Figure 2. Unlike coastal regions where humidity and aerosol loading can reduce performance, the interior's dry atmosphere minimizes soiling losses and maximizes direct beam radiation particularly valuable for concentrating solar thermal applications in food processing (Mohamed & Masood, 2018).

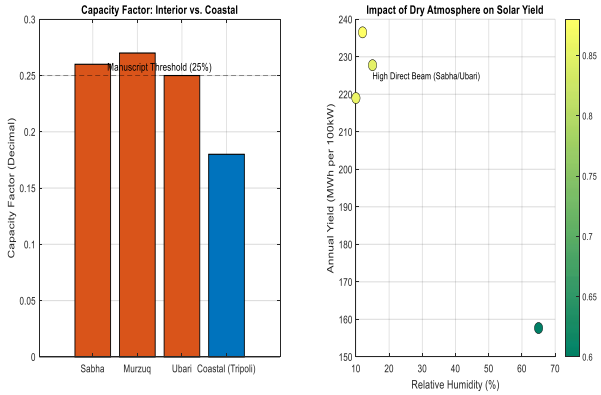


Figure 2. Capacity factor: interior vs coastal (b) impact of dry Atmosphere on solar yield.

2.2 Wind Resource Characteristics

While solar resources dominate discussions of Libyan renewable energy, wind power also presents opportunities for agricultural applications. The complex topography of southern Libya, including the Tibesti massif and regional depression systems, creates localized wind regimes that remain poorly characterized due to the absence of ground-based measurement stations as shown in Figure 3 (Kassem et al., 2020).

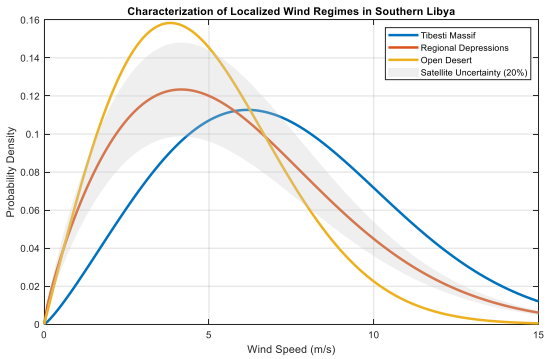


Figure 3. Characterization of Levelized Wind Regimes in Southern Libya (Hersbach et al., 2023)

Satellite-derived estimates suggest mean wind speeds of 4.5-6.0 m/s at 50-meter height across much of Fezzan, with the highest potentials in areas where topographic channeling occurs as shown in Figure 4 (Lagili et al., 2023). These speeds are sufficient for small-scale wind turbines serving individual farms or small agricultural clusters. Importantly, wind resources in southern Libya exhibit complementary patterns to solar irradiation: winter months with lower solar availability often experience stronger winds, suggesting potential for hybrid systems that smooth energy supply that presented in Figure 5.

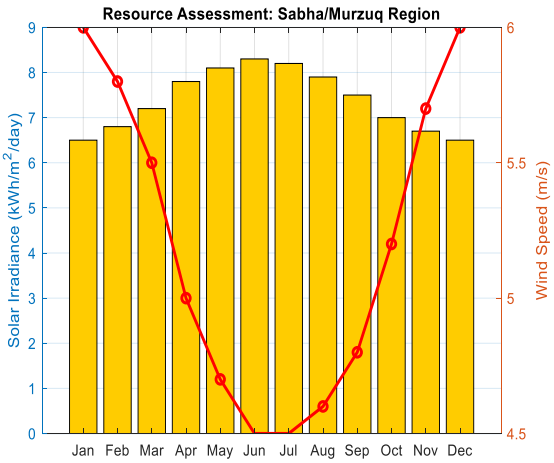


Figure 4. Resource Assessment: Sabha/Murzuk (Alsharif et al, 2025).

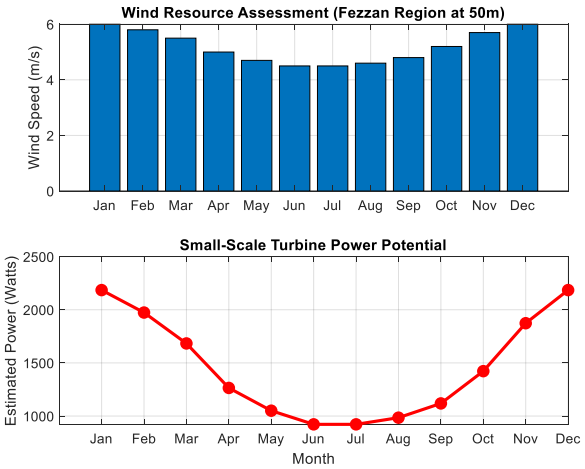


Figure 5. (a) Wind Resources Assessment (Fezzan Region) and (b) Small-scale Turbine Power Potential (Alsharif et al, 2025).

2.3 Data Limitations and Uncertainty

A significant constraint on renewable energy planning in southern Libya is the scarcity of ground-truth measurements. The civil conflict that began in 2011 destroyed monitoring infrastructure and halted maintenance of existing meteorological stations. Researchers have consequently relied on satellite reanalysis products, which show variable accuracy when compared against limited historical ground data (Lagili et al., 2023). Studies evaluating five major satellite products TerraClimate, ERA5, ERA5-Land, MERRA-2, and CFSR found that while all performed adequately for solar assessment, wind resource estimates showed greater divergence, with CFSR and ERA5-Land demonstrating the strongest correlation with available measurements.

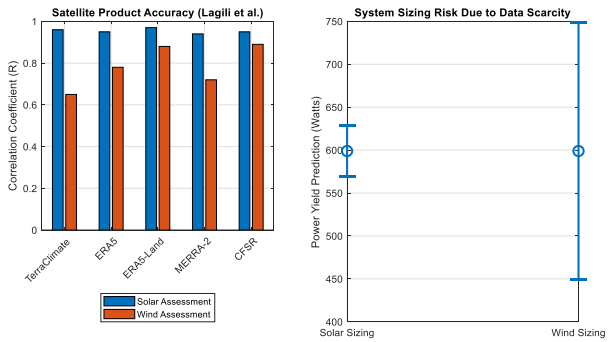


Figure 6. (a) Satellite Production Accuracy & (b) System Sizing Risk Due to Date Scarcity.

This data gap represents more than an academic concern in that presented in Figure 6. Without reliable wind speed distributions and solar variability patterns, system designers cannot optimize equipment sizing or accurately predict energy yields, increasing financial risk for farmers considering renewable investments.

3. Renewable Energy Applications in Southern Libyan Agriculture

3.1 Photovoltaic Water Pumping

The most mature renewable energy application in southern Libyan agriculture is photovoltaic water pumping (PVP). A pioneering installation at the Sahara Research Center in southern Libya demonstrated the technical viability of solar-powered irrigation during two years of operational testing in the early 2010s (Abolgasim et al., 2006). The system successfully supplied water for horticulture and livestock, confirming that PV pumps are "efficient and cost effective for those area where the water are not so deep" and that they "can be used to supply these applications with water". Based on various climatology actions that causes changes in producing energy from the renewables in the case study, monthly climatological profile for southern region of Libya as tabulated in Table I.

TABLE I. Southern Libya Climatological Profile (Nassar, et al, 2024)

Month	$Solar_G$ (kWh/m²/day)	$Wind_V$ (m/s)
Jan	6.5	6.0
Feb	6.8	5.8
Mar	7.2	5.5
Apr	7.8	5.0
May	8.1	4.7
Jun	8.3	4.5
Jul	8.2	4.5
Aug	7.9	4.6
Sep	7.5	4.8
Oct	7.0	5.2
Nov	6.7	5.7
Dec	6.5	6.0

While the system technical and Economic Parameters of the proposed system are presented in Table II.

TABLE II. System Technical & Economic Parameters

Parameter	Value
$PV_{Efficiency}$	0.18
$Panel_{Area_{m2}}$	25
$Well_{Depth_m}$	40
$Pump_{Efficiency}$	0.75
$System_{Cost_{USD}}$	20000
$Diesel_{Annual_{OpEx}}$	4000
$Farm_{Income_{USD}}$	5000

Besides the previously climatology data of the case study, System Technical & Economic Parameters, the policy priority analysis is presented in Table III.

TABLE III. Policy Priority Analysis

Strategy	Impact	Feasibility	Priority (Impact × Feasibility)
Local Tech Training	0.70	0.85	0.595
Smallholder Subsidies	0.85	0.60	0.510
Groundwater Metering	0.95	0.40	0.380

The proposed system considering Photovoltaic Water Pumping is utilizing sun light into green energy to run water pump as demonstrated in Figure 7.



Figure 7. Photovoltaic Water Pumping

The economic logic of PVP in southern Libya is compelling. Diesel pumping entails fuel transport costs across vast distances, exposure to volatile global oil prices, and maintenance requirements for engines operating in harsh conditions. Solar pumps, by contrast, have minimal operating costs and can operate unattended for extended periods. For date palm cultivation a dominant agricultural activity in Fezzan oases solar pumping aligns well with irrigation requirements. While dates require less frequent watering than horticultural crops, the ability to pump on demand without fuel constraints enables more precise irrigation scheduling.

Figure 8 show the Economic Payback: Solar vs Diesel Pumping.

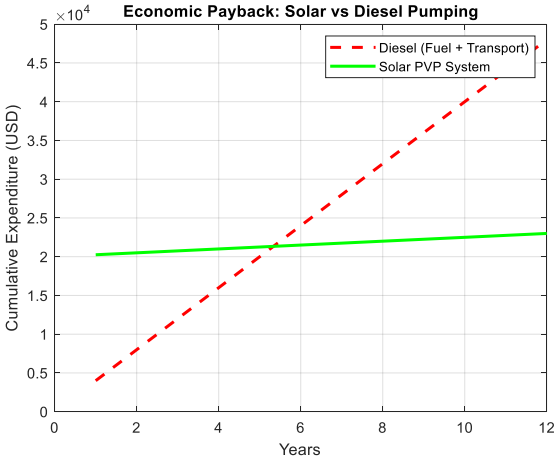


Figure 8. Economic Payback: Solar vs Diesel Pumping.

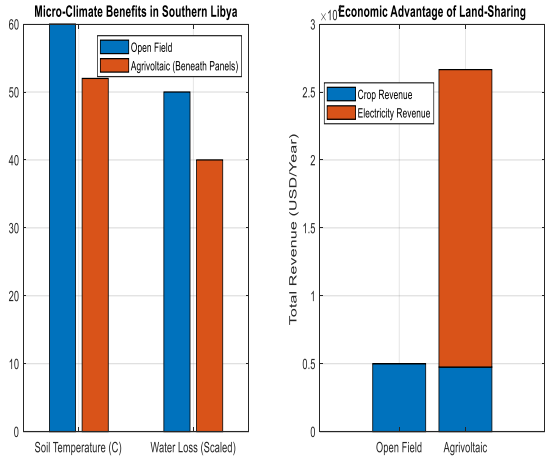
3.2 Recent Implementation Initiatives

The theoretical potential of agricultural solarization is now being translated into practice. In February 2026, the Wafa Fezzan Initiative announced the completion of its first-phase solar power installations on farms in the Al-Bawanees region, approximately one hour northeast of Sebha (Libya Herald, 2026). The project, supported by Libya's eastern-based government, provides farmers with complete solar power systems aimed at "providing a reliable energy source, improving agricultural efficiency, reducing operational costs, and promoting the use of clean and sustainable energy solutions".

This initiative represents a shift from isolated pilot projects to systematic deployment. The implementing organization explicitly frames the work as addressing "the South's most pressing challenge: food security," with solar energy systems designed to "ease farmers' burden from unstable electricity and soaring costs" (Libya Herald, 2026). The phased approach beginning in Al-Bawanees with plans for regional expansion acknowledges the logistical challenges of operating in conflict-affected areas while building momentum for broader adoption.

3.3 Agrivoltaics: An Emerging Frontier

Beyond simply powering agricultural operations, recent technological developments suggest opportunities for integrating energy production with farming activities. Agrivoltaic systems, which elevate solar panels to permit crop cultivation beneath them, have attracted growing research attention globally (Naman et al., 2025). In arid environments, the partial shading provided by solar arrays can reduce crop water stress and lower soil temperatures, potentially improving growing conditions for certain species. Figure 9 presents the Breakdown Results as shown in Figure 9 (a) that presents the Micro-Climate Benefits in Southern Libya, while Figure 9 (b) show the Economic Advantages of Land-Sharing.



(a) (b)

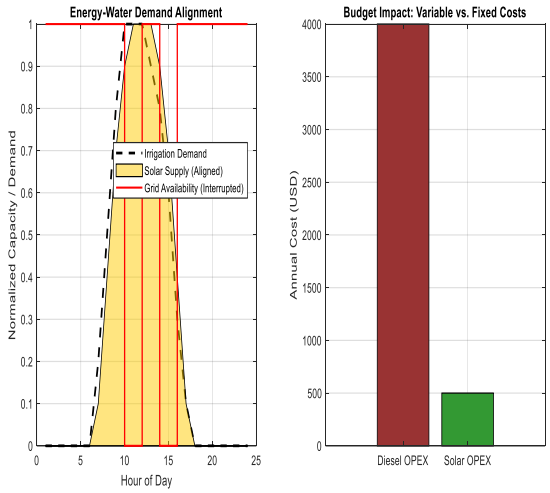
Figure 9. Breakdown Results. (a) Micro-Climate Benefits in Southern Libya, (b) Economic Advantages of Land-Sharing

While no documented agrivoltaic installations exist in southern Libya, the region's high solar radiation and water constraints make it a candidate for such approaches. Research from similar Saharan environments indicates that shade-tolerant crops grown under PV arrays can achieve comparable yields to open-field cultivation while generating significant electricity revenue (Trommsdorff et al., 2024). However, implementation would require careful variety selection and system design optimized for local conditions.

4. POSITIVE IMPACTS ON AGRICULTURAL DEVELOPMENT

4.1 Energy Access and Operational Reliability

The most immediate benefit of renewable energy adoption is improved energy access. Southern Libyan farms connected to the national grid experience frequent power interruptions that can last hours or days, disrupting irrigation schedules with potentially catastrophic consequences for crops during critical growth stages (Lagili et al., 2023). Solar-powered systems, by contrast, provide generation during daylight hours when irrigation demand peaks, creating natural alignment between energy supply and water demand. The Energy-Water Demand Alignment is presented in Figure 10 (a) and Figure 10 (b) show the Budget Impact Variable vs. Fixed Costs.



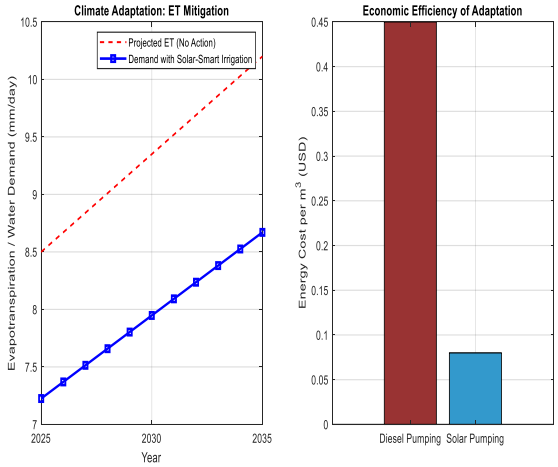
(a) (b)

Figure 10. (a) Energy-Water Demand Alignment and (b) Budget Impact Variable vs. Fixed Costs.

For farms beyond grid reach a substantial portion of Fezzan's agricultural area diesel generation has been the only option, with fuel costs consuming up to 40% of operating budgets. Solar systems eliminate fuel purchase and transport, converting a variable operating expense into a fixed capital cost. The economic benefit extends beyond direct savings: reliable power enables farmers to adopt precision irrigation technologies, run post-harvest processing equipment, and maintain cold chains for perishable products.

4.2 Climate Resilience and Adaptation

Climate models project increasing temperatures and evapotranspiration rates across North Africa, intensifying pressure on already scarce water resources (House of Representatives, 2026). Renewable energy can support adaptation through several mechanisms as presented in Figure 11. First, solar-powered irrigation enables more efficient water application, reducing the energy cost of each cubic meter pumped and encouraging conservation. Second, renewable-powered desalination though currently expensive could eventually unlock brackish groundwater resources unsuitable for direct agricultural use. Third, energy access supports climate information systems: weather stations, soil moisture sensors, and communication networks all require reliable power.



(a) (b)

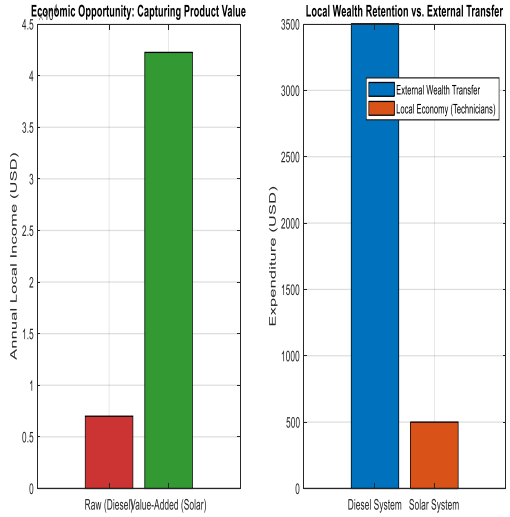
Figure 11. Adaptation breakdown. (a) Climate Adaptation: ET Mitigations. (b) Economic Efficiency of Adaptation.

The February 2026 Sebha workshop explicitly linked renewable energy to climate adaptation, recommending "expanding renewable energy use" alongside "adopting drought and sandstorm-resistant agricultural methods" (House of Representatives, 2026). This policy framing recognizes that energy and water are inseparable in arid-zone agriculture; sustainable adaptation requires addressing both simultaneously.

4.3 Rural Economic Development

Renewable energy deployment creates economic opportunities beyond the farm gate. Installation, maintenance, and system design require skilled technicians, potentially creating employment for young people in southern communities where job options are limited (Naman et al., 2025). The distributed nature of solar generation keeps energy expenditures within local economies rather than transferring wealth to fuel suppliers.

Moreover, reliable electricity enables agricultural diversification. Farmers with dependable power can invest in value-added activities drying, processing, packaging that capture more of the final product value. Cold storage powered by solar panels allows coordination with distant markets, reducing post-harvest losses that currently plague perishable crop production. The cumulative effect is strengthened rural livelihoods and reduced pressure for out-migration from vulnerable communities. Figure 12 (a) presents the Economic Opportunity for Capturing Product Value, while Figure 12 (b) presents the Local Wealth Retention vs. External Transfer.



(a) (b)

Figure 12. (a) Economic Opportunity: Capturing Product Value, (b) Local Wealth Retention vs. External Transfer.

The following mathematical models govern the photovoltaic water pumping (PVP) system within the context of Southern Libya's unique climate and geological constraints, as described in your provided manuscript.

5. MATHEMATICAL MODELS OF THE UTILIZED PARAMETERS

1. Solar Resource and Cell Temperature Model

In the Fezzan region, ambient temperatures (T_a) frequently reach 45°C. The actual cell temperature (T_c) is higher due to intense irradiation (G), which reduces efficiency.

$$T_c = T_a + \left(\frac{NOCT - 20}{800}\right) \cdot G$$

The temperature-adjusted open-circuit voltage (V_{oc}) is modeled as:

$$V_{oc(adj)} = V_{oc(stc)} + K_v \cdot (T_c - T_{stc})$$

2. Photovoltaic Power Output Model

Southern Libya receives exceptional solar irradiation exceeding $7kWh/m^2/day$. The instantaneous power output (P_{pv}) is calculated as:

$$P_{pv} = \eta_{pv} \cdot A \cdot G \cdot [1 - \beta_p(T_c - T_{stc})]$$

- η_{pv}: Efficiency of the panel (approx. 18% in the region).
- A: Total surface area of the PV array.
- β_p: Temperature coefficient of power.

3. Hydraulic Pumping Model

Since agriculture in Fezzan is entirely dependent on fossil groundwater extraction from the Nubian Sandstone Aquifer, the energy required is a function of the total dynamic head.

$$P_{required} = \frac{\rho \cdot g \cdot H \cdot Q}{\eta_{pump}}$$

- ρ: $Density\ of\ water\ (1000kg/m^3)$.
- g : Acceleration due to gravity $(9.81\backslash textm/s^2)$.
- H: Vertical lift or head (typically 20–50m for Libyan wells).
- Q: Flow rate (m^3/s).
- η_{pump}: Combined efficiency of the motor and pump.

4. Water-Energy Nexus Paradox (Depletion Model)

The manuscript highlights a critical risk: lower pumping costs from solar energy $(C_{solar} < C_{diesel}$) may incentivize increased water abstraction (Q_{total}), accelerating the drawdown of the non-renewable aquifer.

$$\Delta L_{aquifer} = \int \frac{Q_{out}(t) - Q_{in}(t)}{S \cdot A_{aquifer}} dt$$

- $Q_{in} \approx 0$: Southern Libyan groundwater has minimal to no recharge.
- S: Storativity of the aquifer.
- ΔL: The drop in the water table level.

$$S \cdot Aaquifer \cdot \frac{dL}{dt} = Qin - Qout$$

5. Economic Feasibility Model

The economic transition is modeled as a shift from high variable operational costs (C_{op}) to high upfront capital costs (C_{cap}).

$$NPC = C_{cap} + \sum_{t=1}^{n} \frac{C_{maint}}{(1+r)^t}$$

- NPC: Net Present Cost.
- r: Discount rate.
- n: Lifespan of the system (typically 20–25 years for PV).
- Diesel systems in the south are heavily impacted by fuel transport costs over vast distances, often consuming up to 40% of operating budgets.

6. NEGATIVE CONSEQUENCES AND IMPLEMENTATION CHALLENGES

6.1 Land-Use Competition

Renewable energy development, if poorly planned, could compete with agricultural land rather than supporting it. Utility-scale solar installations require substantial land areas; a 10 MW photovoltaic plant occupies approximately 20 hectares. In the Fezzan context, where arable land is concentrated in limited oasis areas, siting large renewable projects on productive soil would be counterproductive (European Commission, 2025).

This concern extends beyond direct land occupation. Agricultural land near renewable installations may experience price inflation as energy developers compete with farmers for access, potentially displacing agricultural activities. The phenomenon, documented in European contexts, could replicate in Libya if regulatory frameworks fail to distinguish between energy development on marginal versus prime agricultural land (Kapp, 2016, cited in Trommsdorff et al., 2024).

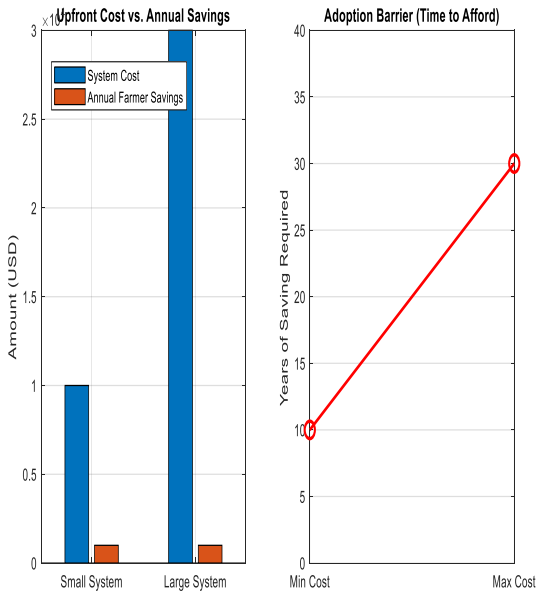
6.2 Water-Energy Nexus Complexities

While solar irrigation reduces fossil fuel dependence, it does not address and may exacerbate groundwater depletion. The Nubian Sandstone Aquifer System, which supplies most southern Libyan agriculture, is fossil water with minimal recharge. Lower pumping costs could incentivize increased abstraction, accelerating aquifer drawdown and advancing the eventual exhaustion of this non-renewable resource.

This tension between energy sustainability and water sustainability requires careful policy attention. Solar-powered irrigation without extraction limits is environmentally problematic; it simply substitutes one resource depletion problem (fossil fuels) for another (fossil water). Effective integration requires coupling renewable energy deployment with groundwater governance, including metering, extraction limits, and transitions to higher-value, lower-water crops.

6.3 Financial and Capacity Barriers

The upfront cost of renewable energy systems remains prohibitive for many smallholder farmers. A complete solar pumping system with sufficient capacity for significant irrigation may cost $10,000-30,000 far beyond the reach of farmers operating at subsistence levels (European Commission, 2025). Credit access in southern Libya is limited, and the absence of agricultural banks or microfinance institutions specializing in renewable energy financing creates an adoption barrier as in shown Figure 13 demonstrate the Upfront Cost vs. Annual Savings in Figure 13 (a) while in figure 13 (b) presented the Adaptation Barrier (Time to Afford).



(a) (b)

Figure 13. (a) Upfront Cost vs. Annual Savings (b) Adaptation Barrier (Time to Afford).

Even when systems are installed, operational capacity may be lacking. Solar pumps, while simpler than diesel engines, still require maintenance and occasional troubleshooting. The concentration of technical expertise in Tripoli and Benghazi leaves southern communities underserved. The Wafa Fezzan Initiative's approach providing complete systems with apparently integrated support represents one model, but scaling this approach across the region would require substantial investment in local technical capacity.

6.4 Institutional Fragmentation and Policy Gaps

Libya's divided governance structures complicate renewable energy planning. The country operates with competing governments in Tripoli (internationally recognized) and Benghazi (eastern-based), each with different priorities and limited coordination. The Wafa Fezzan Initiative operates with eastern government support, but its ability to coordinate with Tripoli-based institutions is unclear. Meanwhile, international partners face diplomatic challenges engaging with either administration without alienating the other.

This fragmentation extends to data sharing, regulatory approval, and grid connection all essential for renewable energy scaling. The lack of unified technical standards for solar installations creates quality risks, as farmers may purchase substandard equipment without recourse. Grid connection protocols, where farms seek to sell excess power, are undefined in most of the country.

7. DISCUSSION AND POLICY IMPLICATIONS

7.1 Balancing Opportunities and Risks

The evidence reviewed here suggests that renewable energy offers genuine potential to transform southern Libyan agriculture, but that realizing this potential

requires navigating complex trade-offs. The technical resource base is exceptional, pilot projects demonstrate feasibility, and policy recognition is growing. Yet the risks of maladaptation accelerating groundwater depletion, displacing agriculture from productive land, concentrating benefits among wealthier farmers are equally real.

The critical question is not whether renewable energy should be deployed, but how. Deployment models matter enormously. Small-scale, distributed systems serving individual farms or small cooperatives spread economic benefits and avoid land-use conflicts. Community-owned installations, managed by farmer cooperatives, build local capacity and keep revenues within agricultural communities. Hybrid systems combining solar with minimal backup generation maintain reliability without over-investment.

7.2 Priority Actions for Sustainable Integration

Groundwater governance integration: No renewable energy project in southern Libyan agriculture should proceed without clear groundwater extraction provisions. This may involve metering, tiered pricing, or extraction caps tied to aquifer sustainability. Solar pumping without consumption controls is environmentally incomplete.

Targeted financing mechanisms: Smallholder access requires subsidized credit, grants, or leasing arrangements that match agricultural cash flows. The European Commission's analysis emphasizes that "high upfront costs of clean energy technologies limit smallholder farmers" and recommends "subsidies, training, and financial support" (European Commission, 2025). Libya's sovereign wealth could be partially redirected to support agricultural renewable energy.

Capacity building networks: Technical training programs in Sebha, Murzuq, and Ubari could create a corps of locally based solar technicians, reducing dependence on distant experts. Partnerships with technical colleges in neighboring countries (Tunisia, Algeria) could accelerate skill development while Libyan institutions rebuild.

Data infrastructure investment: The data gaps identified by Lagili et al. (2023) constrain planning and investment. A network of automated weather stations across Fezzan, solar-powered and satellite-connected, would provide the ground-truth measurements needed for accurate resource assessment and system design.

Agrivoltaic research: Given southern Libya's extreme conditions, investigating agrivoltaic approaches that pair energy production with crop cultivation should be a research priority. International partnerships with institutions in similar environments (e.g., Algeria's Sahara research stations) could accelerate learning.

7.3 Limitations and Research Needs

This review is constrained by the limited peer-reviewed literature specifically addressing renewable energy in southern Libyan agriculture. The conflict has disrupted academic research, and much available information comes from policy documents and news reports rather than systematic studies. Priorities for future research include: (1) detailed groundwater-energy modeling for representative Fezzan aquifers; (2) socioeconomic studies of farmer willingness to adopt solar technologies; (3) agronomic trials of crops under agrivoltaic conditions; (4) policy analysis of governance options for renewable energy in divided political contexts; and (5) life-cycle assessment of solar equipment under Saharan operating conditions.

8. CONCLUSION

Southern Libya stands at the intersection of formidable challenges and exceptional opportunities. The region's agriculture faces water scarcity, climate volatility, and energy insecurity, yet it sits atop some of the world's best solar resources and possesses groundwater reserves that if managed sustainably could support productive agriculture for generations. Renewable energy technologies, particularly solar photovoltaic systems, offer a pathway to address energy constraints while reducing fossil fuel dependence and building climate resilience.

The evidence reviewed here supports cautious optimism. Pilot projects demonstrate technical feasibility, recent initiatives show policy traction, and global experience provides lessons for effective implementation. Yet the path forward requires navigating genuine trade-offs. Solar pumps that accelerate groundwater depletion are not solutions; they are substitutions of one depletion problem for another. Agrivoltaic systems that displace food production are not synergies; they are competitions for scarce land. Financing mechanisms that exclude smallholders are not development; they are concentration of opportunity.

The February 2026 Sebha workshop recommendations expanding renewable energy, rationalizing water consumption, enhancing local research provide a policy framework that recognizes these complexities. The challenge now is implementation: building institutions capable of coordinated action, creating financing accessible to smallholders, investing in the data and skills that enable good decisions. If these foundations can be laid, renewable energy can fulfill its promise as a catalyst for sustainable agricultural development in one of the world's most challenging environments.

REFERENCES

Alsharif, A., Imbayah, I., Abdulraheem, A., Massoud, A. M. A., & Elazoomie, O. N. (2025). Applicability of solar energy in libyan southern cities: challenges and difficulties. *Int. Sci. Technol. J*, *36*(1), 1-14.

Basha, N. A. I. (2026). Climate Change and Its Impact on Groundwater Resources in Semi-Arid Regions: A Case Study of Libya. *Al-imad Journal of Humanities and Applied Sciences*. Retrieved from https://al-imadjournal.ly/index.php/ajhas/en/article/view/40.

Hersbach, H., Bell, B., Berrisford, P., Biavati, G., Horányi, A., Muñoz Sabater, J., Thépaut, J.-N. (2023). *ERA5 hourly data on single levels from 1940 to present* [Data set]. Copernicus Climate Change Service (C3S). https://doi.org/10.24381/cds.adbb2d47

Ibrahim, I. M., & Abolgasim, A. (2006). First results of photovoltaic water pimp in the south region of Libya.
European Commission. (2025). Energy transition effects on food security amidst climate change and progress toward sustainable development goals. Knowledge for Policy .
House of Representatives. (2026, February 9). House of Representatives calls for the adoption of agricultural methods resistant to drought and dust storms. Libya Update .
Kassem, Y., Çamur, H., & Aateg, R. A. F. (2020). Exploring solar and wind energy as a power generation source for solving the electricity crisis in Libya. Energies, 13(14), 3708 .
Lagili, H. S. A., Kiraz, A., Kassem, Y., & Gökçekuş, H. (2023). Wind and solar energy for sustainable energy production for family farms in coastal agricultural regions of Libya using measured and multiple satellite datasets. Energies, 16(18), 6725.
Libya Herald. (2026, February 3). Wafa Fezzan Initiative launches its first phase through installation of solar power systems on farms in Bawanees region .
Mohamed, O., & Masood, S. (2018). A brief overview of solar and wind energy in Libya: Current trends and the future development. Renewable and Sustainable Energy Reviews, 82, 165-175 .
Naman, Y., Kaundal, M., & Yashabh. (2025). Renewable energy integration in agriculture, food security and allied sectors. Journal of Scientific Research and Reports, 31(7), 1083-1098 .
Nassar, Y. F., El-Khozondar, H. J., Alatrash, A. A., et al. (2024). Assessing the Viability of Solar and Wind Energy Technologies in Semi-Arid and Arid Regions: A Case Study of Libya's Climatic Conditions. *Applied Solar Energy*, (1), 149-170.
The World Factbook. (2024). *Libya*. Central Intelligence Agency. Retrieved from https://www.cia.gov/the-world-factbook/countries/libya/Trommsdorff, M., et al. (2024). Farming the sun: The political economy of agrivoltaics in the European Union. Sustainability Science, 20, 1519-1534.