

Integrating Desalination and Solar Energy into the WEFE Nexus: A Sustainable Pathway for Addressing Water Scarcity and Achieving Food Security in Algeria

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Abstract:

This study explores the use of solar-energy desalination within Algeria's Water-Energy-Food-Environment (WEFE) Nexus as a strategy to combat water scarcity and food insecurity, offering a comparison with gas-based systems. The research incorporates a literature review, analysis of international data, and scenario modeling.

Results highlight Algeria's significant solar energy potential, ranging from 2,000 to 3,000 kWh per square meter annually, which can help lower energy costs and reduce carbon emissions. The adoption of desalinated water is shown to bolster irrigation practices and enhance agricultural resilience against drought conditions.

Keywords: WEFE Nexus; Desalination; Solar Energy; Water Scarcity; Food Security; Algeria; Sustainability; Renewable Energy.

Jel Classification Codes: Q01; Q18; Q48; Q54; Q56; O13; O33; O55

1. INTRODUCTION

Algeria is facing growing water scarcity due to ongoing droughts, decreasing groundwater reserves, rapid population growth, and increasing demand from the agricultural sector. With renewable water availability per person dropping below 500 cubic meters annually, the country is categorized as experiencing "absolute water scarcity." This situation puts significant strain on both domestic water use and agricultural output. The challenges are further exacerbated by climate change, which is anticipated to reduce rainfall and raise temperatures throughout the Mediterranean and North African regions.

Algeria is simultaneously confronted with the pressing challenge of transforming its energy system. The nation's economy is still predominantly reliant on natural gas, accounting for over 98% of its electricity generation. This heavy reliance hinders energy diversification and poses significant challenges to the sustainability of crucial sectors such as water and agriculture. Meanwhile, food security is growing more precarious as local production falls short of meeting demand, resulting in increasing food imports and heightened exposure to global market instabilities.

Tackling these interconnected challenges demands an integrated and multi-faceted approach. The Water–Energy–Food–Ecosystems (WEFE) Nexus offers a comprehensive framework by highlighting the interconnections between resources and the importance of coordinated planning. Within this framework, solar-powered desalination stands out as a viable solution. It boosts water supply while leveraging solar energy to minimize the carbon footprint and lower the energy expenses typically linked to water production. This combination creates a powerful synergy, improving resource efficiency, advancing sustainability, and bolstering resilience against climate change.

Although Algeria has made recent investments in desalination, its existing systems largely depend on fossil fuels, resulting in an energy-water trade-off that hampers sustainable long-term solutions. Limited research has been conducted on the integration of solar-powered desalination within the WEFE Nexus to simultaneously address water security, agricultural growth, and ecosystem conservation. This lack of study restricts policymakers from gaining a comprehensive understanding of the role renewable-based desalination could play in a cohesive national strategy.

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This paper aims to evaluate how combining desalination and solar energy within the WEF (Water-Energy-Food-Environment) Nexus can provide a sustainable solution for addressing water scarcity and enhancing food security in Algeria. The study seeks to explore the following research questions:

- In what ways can solar-powered desalination improve water availability while lowering dependency on conventional energy sources?
- What effects might this integration have on agricultural productivity and food security?
- How can the WEF Nexus framework contribute to better governance and the sustainable management of resources in Algeria?

To investigate these issues, the study employs a mixed-methods approach, focusing on the integration of solar-powered desalination into Algeria's resource systems through the WEF Nexus lens. The research concentrates on coastal and semi-arid areas, including Algiers, Oran, Annaba, and specific zones within the Sahara known for their solar energy potential. Data were gathered from sources such as FAO, IEA, NASA, local agencies, and reports on existing desalination plants. The analytical framework interconnects key elements such as water supply, energy consumption, agricultural yields, environmental impacts, and governance mechanisms. Water assessments are used to estimate current deficits and potential gains from desalination efforts. Meanwhile, energy analyses compare the costs and emissions associated with fossil fuel-based systems versus solar-powered alternatives. This comprehensive approach aims to provide actionable insights for sustainable development in Algeria.

This research advances the existing body of literature by offering a context-specific examination of the integration of solar-powered desalination systems within the Water-Energy-Food-Environment (WEF) Nexus framework in Algeria. Unlike prior studies that have predominantly focused on either desalination technologies or Nexus interactions in isolation, this study adopts a comprehensive approach by incorporating scenario-based projections, governance dynamics, and resource interdependencies to evaluate their collective impact on water security and agricultural sustainability in the Algerian context. By interrelating solar

energy potential, the expansion of desalination capacity, and the dynamics of agricultural water demand within a unified analytical framework, this study establishes a strategic paradigm for long-term resource management and planning.

2. Scenario Modeling Methodology

The scenario analysis employed in this study relies on a streamlined analytical framework integrating secondary data sources and widely recognized technical parameters in the field of desalination research. Projections of water production were derived from both existing and anticipated capacities of desalination plants in Algeria. The energy requirements for desalination processes were calculated based on average energy consumption for reverse osmosis, which typically falls within the range of 3 to 4 kWh per cubic meter of water produced. Carbon emissions were quantified using emission factors linked to electricity generation primarily driven by natural gas.

The Levelized Cost of Water (LCOW) was estimated based on cost data for desalination facilities and renewable energy systems provided in existing literature. These estimations encompass capital expenditures, operational costs, and energy consumption. The applied modeling framework facilitates a comparative analysis across three distinct policy scenarios: conventional desalination reliant on fossil fuels, hybrid systems integrating solar and natural gas, and desalination operations powered entirely by solar energy.

3. Literature Review

3.1 Global WEF E Nexus Studies

The WEF E Nexus has gained significant attention as a framework for integrated resource management. Introduced by (Hoff, 2011), the Nexus approach emerged as a response to increasing global sustainability challenges. Subsequently, (Bazilian, 2011) and (Howells, 2013) expanded on this concept by developing system-wide models that illustrate the interconnections between water, energy, and food systems. In the Mediterranean region, Allan, Keulertz, and Woertz (Allan, 2015) focused on addressing governance-related issues, whereas Endo And al. (Endo, 2017) emphasized the importance of cross-sectoral data integration and policy coordination. More recently, Daher and Mohtar (Daher, 2020)

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contributed by creating quantitative Nexus tools designed to support strategic national planning, particularly in arid zones.

3.2 Solar-Powered Desalination Systems

Solar desalination has garnered considerable academic focus as a sustainable, low-carbon solution. Ghaffour, Missimer, and Amy (Ghaffour, 2013) analyzed advancements in renewable-powered desalination technologies, highlighting photovoltaic-driven reverse osmosis (PV–RO) as the most energy-efficient approach. Kalogirou (Kalogirou, 2020) explored solar thermal desalination systems, along with advancements in their performance. Al-Karaghoul and Kazmerski (Al-Karaghoul, 2013) evaluated the techno-economic viability of desalination in the Middle East and North Africa, identifying significant cost benefits for PV–RO in regions with high solar irradiation. More recently, Shahzad and al. (Shahzad, 2019) investigated hybrid solar-thermal and waste-heat desalination systems, emphasizing their minimal environmental impact.

Recent research conducted between 2022 and 2024 underscores the decreasing costs associated with photovoltaic technologies and the growing economic viability of renewable energy-powered desalination systems. These advancements significantly enhance the feasibility of implementing large-scale solar desalination projects, particularly in regions characterized by abundant solar irradiation, such as North Africa and the Middle East.

3.3 Climate Change, Drought, and Water Stress in North Africa

North Africa is widely regarded as a region highly vulnerable to climate change. Research conducted by Chebana, Ouarda, and Duong (Chebana, 2014) revealed increasingly severe drought patterns in Algeria. Similarly, Giorgi and Lionello (Giorgi, 2008) classified the Mediterranean as a climate-change hotspot, characterized by rising temperatures and decreasing rainfall. Further studies by Tramblay and al. (Tramblay, 2018) And Driouech and al. (Driouech, 2021) pointed to a growing occurrence of recurrent droughts and extreme heat events, which are contributing to accelerated groundwater depletion and diminished agricultural productivity. These findings underscore the pressing need to adopt non-conventional water resources.

3.4 Energy Transition in Algeria

Algeria's energy transition literature highlights significant advances alongside enduring structural obstacles. Aissaoui (Aissaoui, 2016) and Belmihoub, Dadda, and Bouhoun (Belmihoub, 2017) pointed out the country's strong dependence on natural gas and underscored the pressing need for diversification. Mahrane and al. (Mahrane, 2019) examined plans for renewable energy development and identified institutional hurdles that impede implementation progress. On the other hand, Hadeef and Boudghene Stambouli (Hadeef, 2020) emphasized Algeria's extraordinary solar potential—ranked among the highest globally—arguing that large-scale solar energy integration is both technically feasible and economically advantageous, particularly for applications such as desalination and rural electrification.

3.5 Agricultural Vulnerability and Food Imports

Several authors examine Algeria's dependence on imported food commodities. Bessaoud, Pellissier, and Rolland (Bessaoud, 2019) emphasized structural limits in agricultural productivity, particularly inefficient irrigation and land pressures. Cherchali and Kalla (Cherchali, 2015) documented the growing gap between domestic cereal production and national consumption needs. According to Benouniche and Kuper (Benouniche, 2014), poor irrigation efficiency undermines water productivity, increasing vulnerability to climate variability. These studies collectively show how water scarcity translates directly into food insecurity.

3.6 Previous Attempts at Integrated Resource Management

Attempts to implement integrated resource planning in the MENA region have yielded mixed outcomes. Hussein, Menga, and Greco (Hussein, 2018) highlighted the political and institutional challenges of adopting Nexus-based governance in countries with scarce water resources. Scott, Meza, and Varady (Scott, 2016) explored integrated water–energy strategies in arid areas, stressing the importance of robust regulatory coordination. In North Africa, El-Sadek (El-Sadek, 2010) and Bouchaour and Boufadel (Bouchaour, 2020) recognized desalination's potential but cautioned that reliance on energy undermines long-term sustainability without incorporating renewable sources. Nonetheless, there is limited research that explicitly connects desalination, solar energy, and agriculture within the Water-Energy-Food-Ecosystem (WEFE) Nexus for Algeria.

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3.7 Gap in the Literature

While research on the WEFE Nexus, solar desalination, and climate vulnerability in North Africa has advanced, three significant gaps persist:

- A lack of integrated Nexus modeling tailored to Algeria, encompassing desalination, solar energy supply, irrigation demands, and ecosystem limitations.
- Limited empirical studies evaluating both the economic and environmental impacts of solar-powered desalination in agricultural contexts.
- Inadequate governance-focused research addressing coordination challenges among Algeria's water, agriculture, and energy sectors.

These gaps highlight the pressing need for a comprehensive, system-level analysis to strategically integrate solar-powered desalination into Algeria's WEFE Nexus, aiming to sustainably enhance water security and agricultural productivity.

4. Theoretical Framework

4.1 Concept of the WEFE Nexus

The Water–Energy–Food–Ecosystems (WEFE) Nexus provides a framework designed to emphasize the interconnected and interdependent nature of vital resources. Departing from traditional sectoral approaches, it focuses on integrating water, energy, food systems, and ecosystems to enhance resource efficiency, minimize conflicts, and foster sustainability. This approach acknowledges that actions in one area, such as withdrawing water for agricultural purposes, significantly affect energy consumption, food availability, and ecosystem resilience. It underscores the importance of harmonized planning and management to address these multifaceted challenges effectively.

4.2 Systems Thinking Theories

Systems thinking serves as the methodological backbone for Nexus analysis. By examining elements as integral parts of a dynamic and interconnected system, this approach uncovers feedback loops, emergent behaviors, and long-term implications (Meadows, 2008). Applied to Algeria, it proves essential in grasping the interplay among water scarcity, energy

generation, and agricultural needs in the face of climate variability. Moreover, it supports scenario modeling to evaluate the ripple effects of solutions like solar-powered desalination across various sectors.

4.3 Sustainability Principles

The theoretical foundation of this framework is rooted in sustainability principles, which strive to harmonize economic, social, and environmental goals. Central tenets encompass resource efficiency, intergenerational equity, and climate resilience, as outlined by seminal works such as (WCED, 1987) and (Sachs, 2015). In the context of the Water-Energy-Food-Ecosystem (WEFE) Nexus, sustainability encompasses not only the fulfillment of present-day demands for water, energy, and food but also the preservation of ecosystem health, the mitigation of greenhouse gas emissions, and the reduction of vulnerability to disruptions including droughts and energy supply challenges.

4.4 Nexus Policy Coherence and Governance

Successfully implementing the Nexus approach demands policy alignment and cohesive governance structures. This entails fostering collaboration across ministries, agencies, and sectors to streamline objectives and minimize inefficiencies, as highlighted by Endo And al. (Endo, 2017). In the context of Algeria, this requires synchronizing policies related to water management, renewable energy initiatives, and agricultural development strategies. Research underscores the necessity of institutional integration, inclusive decision-making processes, and planning informed by data to break down sectoral barriers and promote effective Nexus-driven solutions.

4.5 Technology–Society Interaction

The Nexus framework incorporates the interplay between technology and society, acknowledging that technological innovations—such as solar-powered desalination—are inherently embedded within broader societal, economic, and institutional frameworks (Geels, 2005). The successful adoption of such technologies hinges on factors including financial feasibility, regulatory backing, social acceptance, and their alignment with national development objectives. In the context of Algeria, solar-driven desalination embodies a dual dimension: a promising technological advancement and a complex socio-economic undertaking. Realizing its

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sustainable implementation necessitates the formulation of supportive policies, the establishment of investment structures, and active public participation.

4.6 Conceptual Integration

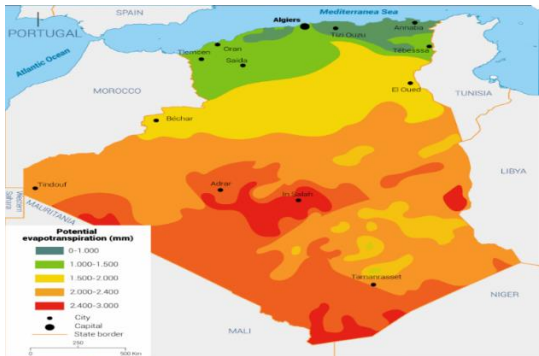
Integrating the Water-Energy-Food-Environment (WEFE) Nexus, systems thinking, sustainability principles, policy coherence, and the interplay between technology and societal dynamics, the proposed theoretical framework offers a robust perspective for examining the contribution of solar-powered desalination in Algeria. This framework facilitates the evaluation of technical viability, resource optimization, environmental implications, and governance mechanisms, ensuring that proposed interventions are evaluated in terms of technical feasibility, economic viability, environmental sustainability, and governance coordination.

5. Results

5.1 Water Shortage Indicators in Algeria

Algeria is categorized as a nation experiencing absolute water scarcity, with per capita renewable water availability falling below 500 m³ annually (FAO, 2020). Surface water resources are unevenly distributed across the country, with only 12% located in the southern regions.

Fig.3. Algeria showing water scarcity hotspots by region



Source : report FAO, 2024.

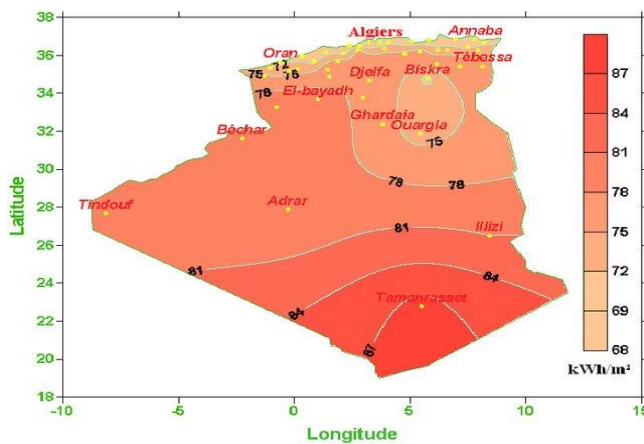
Meanwhile, the overexploitation of groundwater has contributed to

declining aquifer levels. Agricultural activities account for approximately 80% of the total water consumption, while urban areas frequently encounter supply shortages during dry periods. Prolonged droughts, especially during the 2020–2024 period, have further intensified water stress in major cities like Algiers, Oran, and Annaba.

5.2 Solar Energy Potential

Algeria possesses some of the highest levels of solar irradiation worldwide, with values ranging from 2,000 to 3,000 kWh/m² annually, particularly in its Sahara and southern regions (Hadeif, 2020).

Fig.1. Solar irradiation potential across Algeria



Source : Salah Larbi : *Hydrogen production system analysis using photolysis process in the northern region of Algeria*,2013.

This remarkable solar energy potential presents a significant opportunity to sustainably power energy-intensive desalination facilities, thereby decreasing dependence on fossil fuels and ensuring a more stable energy supply for water production and agricultural irrigation.

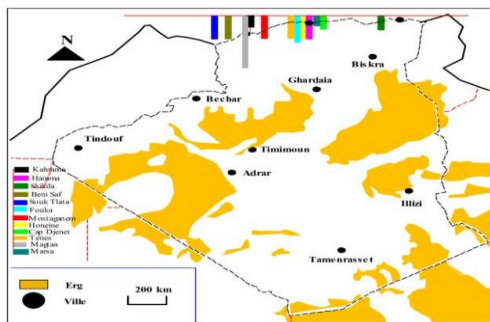
5.3 Desalination Capacity Trends

The development of desalination infrastructure in Algeria has exhibited consistent growth over the past two decades, particularly within its coastal urban centers. The country's installed desalination capacity currently surpasses 450,000 m³/day, supported by several significant facilities located in Algiers, Hamma, and Ténès. Despite this advancement, the predominant reliance on natural gas as an energy source for these plants

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leads to elevated operational expenditures and significant emissions of carbon dioxide. To address these challenges, Algeria's national water strategy includes ambitious plans to expand desalination capacity to a range between 1 and 1.5 million m³/day by the year 2030.

Fig.2. Existing and planned desalination plants locations in Algeria.



Source: B. Remini ; M. Amitouche : *is sustainable desalination the safe way for achieve water security?* , Larhyss Journal, 2023, pp:239-267.

Additionally, there is growing emphasis on incorporating renewable energy sources within these systems to enhance both operational efficiency and overall environmental sustainability.

5.4 Impact Analysis of Integrating Desalination into Agriculture

Scenario analysis demonstrates that the provision of desalinated water for specific irrigation initiatives can enhance cereal yields by 15–20% and boost vegetable production by 25–30% in semi-arid regions. The implementation of advanced irrigation techniques, including drip and sprinkler systems, optimizes water efficiency and reduces water consumption per hectare by 15–25% relative to traditional methods. Furthermore, the integration of desalinated water mitigates crop susceptibility to drought, contributing to more consistent agricultural output and diminishing reliance on food imports.

The anticipated rise in agricultural productivity is largely attributed to enhanced irrigation reliability and the implementation of efficient technologies like drip and sprinkler systems. In semi-arid regions, maintaining a steady water supply greatly minimizes crop stress during

crucial growth stages, ultimately boosting yields. Research conducted in comparable climatic areas has shown that better irrigation management can lead to a 15–30% increase in productivity, especially for cereal grains and horticultural crops.

5.5 Nexus Interactions: Water → Energy → Food → Ecosystems

Integrating desalination into the WEF E Nexus underscores the interconnected nature of these sectors:

- Water-Energy: Utilizing solar-powered desalination reduces reliance on electricity and cuts down fossil fuel consumption.
- Water-Food: Enhanced water availability boosts irrigation efficiency, leading to more reliable crop production.
- Energy-Food: Optimized energy usage lowers costs associated with irrigation and agricultural processes.
- Ecosystems: Incorporating renewable energy minimizes CO₂ emissions, while effective brine management is crucial for safeguarding marine environments.

This holistic approach emphasizes how actions in one domain can ripple through and impact multiple aspects of resource management.

5.6 Scenario Projections (2030–2050)

By 2050, it is anticipated that the complete implementation of solar-powered desalination could potentially fulfill 30–35% of the agricultural water requirements. This advancement is expected to significantly lower greenhouse gas emissions and enhance resilience to water stress driven by climate change (IPCC, 2021).

Table 1. Scenario Projections (2030–2050)

Scenario	Water Supply (billion m ³ /year)	Energy Consumption (TWh/year)	CO ₂ Emissions (tonnes/year)	LCOW (USD/m ³)
Baseline (fossil fuel)	0.8	6.0	1,200,000	0.85
Hybrid (50% solar)	1.1	4.2	300,000	0.65
Full Solar Integration	1.5	0.5	<50,000	0.55

Source : *The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report. 2021.*

The findings underscore the practicality and strategic significance of

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integrating renewable energy with desalination processes to advance Algeria's objectives in achieving water, food, and energy security.

Key parameters were evaluated through a qualitative sensitivity analysis to test the robustness of the scenario projections. The analysis focused on variations in photovoltaic costs, investment expenditures, and agricultural water demand. Results show that decreasing solar technology costs greatly enhance the economic viability of solar-powered desalination by lowering the Levelized Cost of Water. On the other hand, rising investment costs or a sharp increase in irrigation demand could hinder the widespread adoption of such systems. These findings underscore the critical role of technological advancements and supportive policy measures in shaping the long-term success of solar desalination in Algeria.

6. Discussion and Analysis

6.1 Water Scarcity and the Role of Desalination

Algeria is confirmed to be experiencing absolute water scarcity, with agricultural activities accounting for the majority of resource consumption. Traditional water sources are inadequate to satisfy present and future demands, particularly in semi-arid and coastal areas. Incorporating desalination into the water supply system serves as an effective solution by offering a dependable, unconventional source of water. This insight is consistent with research conducted in North Africa and the Middle East, where desalination has been recognized as a crucial approach to ensuring freshwater availability for both agricultural purposes and urban needs.

6.2 Solar-Powered Desalination: Energy and Environmental Implications

The integration of solar energy plays a critical role in reducing dependency on conventional energy sources and minimizing carbon emissions. Transitioning to desalination processes powered entirely by solar energy can lower annual CO₂ emissions to under 50,000 tonnes, a stark contrast to the 1.2 million tonnes produced annually under fossil-fuel-based

systems. Additionally, it contributes to significant reductions in operational costs. These findings underscore the strategic potential of renewable energy in decoupling freshwater production from fossil fuel reliance, addressing water scarcity in arid regions (Al-Karaghoul, 2013). By harnessing Algeria's substantial solar irradiance, desalination systems can achieve greater sustainability and economic feasibility, thereby advancing the nation's broader energy transition objectives.

From an economic standpoint, solar-powered desalination systems require a higher upfront investment compared to traditional desalination plants. Despite this, their operational costs are noticeably lower since they rely less on fossil fuels. Initial assessments indicate that the payback period for large-scale solar desalination projects could fall within a range of 10 to 15 years, contingent upon factors such as plant size, solar technology expenses, and financing terms. In the long run, the decreasing cost of photovoltaic technology is anticipated to further improve the economic viability of solar-powered desalination systems.

6.3 Impacts on Agriculture and Food Security

The research highlights that utilizing solar-powered desalination systems has the potential to stabilize and enhance agricultural productivity, with a notable impact on cereal production and high-value crops. Through scenario modeling, it is projected that yields in irrigated regions could improve by 15 to 30%, thereby decreasing reliance on food imports and strengthening food security. These results align with prior studies within the Nexus framework, which underscore the critical role of water availability in shaping agricultural output, particularly in arid and semi-arid environments (Benouniche, 2014).

6.4 Nexus Interactions and Systemic Benefits

The integration of desalination technologies within the framework of the Water-Energy-Food-Ecosystem (WEFE) Nexus underscores significant interdependencies across its interconnected components:

- **Water–Energy Nexus:** The incorporation of solar-powered desalination systems diminishes reliance on fossil fuels while

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contributing to more stable electricity consumption patterns.

- Water–Food Nexus: Ensuring a consistent and reliable water supply through desalination directly supports agricultural productivity and minimizes risks associated with drought conditions.
- Energy–Food Nexus: Advances in energy efficiency lead to reduced irrigation costs, thereby indirectly enhancing agricultural profitability and sustainability.
- Water–Ecosystem Nexus: Effective brine management strategies and the integration of renewable energy sources contribute to mitigating the environmental consequences of desalination processes.

These intricate interactions demonstrate the potential of employing a strategic planning approach within the WEF Nexus framework to optimize synergies while minimizing trade-offs. Consequently, this reinforces the necessity of adopting robust cross-sector governance mechanisms to address these interdependencies effectively (Daher, 2020).

6.5 Scenario Comparisons and Policy Insights

The scenario analysis highlights that incorporating partial solar integration in desalination systems within a hybrid scenario provides notable water and energy advantages. However, transitioning to fully solar-powered desalination offers the most profound gains in terms of sustainability, affordability, and carbon emissions reduction. Policymakers are encouraged to prioritize renewable energy-driven desalination methods in areas where water scarcity aligns with abundant solar resources, particularly in coastal and agricultural regions. Effective strategic planning should incorporate:

- Advanced irrigation systems aimed at maximizing water efficiency
- Brine management solutions coupled with circular economy principles to safeguard environmental ecosystems
- Coordinated governance across the ministries responsible for water, energy, and agriculture to promote unified and coherent

policymaking

6.6 Comparison with International Experiences

The findings align with global patterns observed in the MENA region, where nations like Saudi Arabia, the UAE, and Morocco have effectively incorporated solar or hybrid desalination systems into their strategies for water and food management (Kalogirou, 2020); (Scott, 2016). Algeria has the opportunity to draw insights from these examples while customizing approaches to fit its unique local conditions, regulatory environment, and socio-economic context.

6.7 Implications for Sustainable Development

Integrating solar-powered desalination into the WEF Nexus offers Algeria an opportunity to tackle water scarcity, advance its energy transition, and strengthen food security all at once. This solution directly supports Sustainable Development Goals 2 (Zero Hunger), 6 (Clean Water and Sanitation), and 7 (Affordable and Clean Energy), fostering climate resilience and safeguarding ecosystems. The research highlights the importance of cohesive planning, cutting-edge technology, and inclusive governance involving multiple stakeholders to achieve long-term sustainable results.

7. Conclusion

This study highlights how incorporating solar-powered desalination into Algeria's WEF Nexus provides a sustainable solution to mitigate water shortages and enhance food security.

7.1 Key findings include:

- Algeria is grappling with severe water scarcity as traditional water resources struggle to keep up with the increasing demands of agriculture and urban development.
- Solar-powered desalination has the potential to generate 1.2–1.5 billion cubic meters of freshwater annually, cut reliance on fossil fuels, and considerably decrease CO₂ emissions.

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- Agricultural productivity has the potential to increase by 15–30% when desalinated water is utilized alongside efficient irrigation methods. This approach not only mitigates vulnerability to droughts but also helps reduce dependency on food imports.
- Nexus analysis underscores the intricate interconnections among water, energy, food, and ecosystems, illustrating that well-designed strategic interventions can generate benefits across multiple sectors.
- Scenario modeling shows that fully integrating solar energy offers the greatest benefits in terms of sustainability, cost-efficiency, and environmental preservation when compared to baseline or hybrid methods.

The study highlights the critical role of embracing a systems-based, Nexus-focused strategy for resource management in water-scarce nations such as Algeria. Integrating renewable energy, water production, and agriculture offers the potential to strengthen resilience, promote sustainability, and bolster food security.

7.2 Recommendations

From the findings, the recommended policy measures are as follows:

- Encourage the adoption of renewable-powered desalination by focusing on the development of solar-driven desalination facilities in coastal areas and regions with high sunlight exposure. Strategically align these systems with agricultural irrigation networks to enhance sustainability and resource efficiency.
- Enhance irrigation practices by adopting advanced methods such as drip irrigation, sprinkler systems, and smart irrigation technologies. These techniques optimize water usage and significantly minimize waste.
- Develop integrated governance structures by enhancing coordination among the ministries of water, energy, and agriculture. This will promote policy alignment and support effective Nexus-based planning.
- Effective environmental management of brine necessitates the adoption of circular economy principles, emphasizing sustainable practices for brine disposal and the recovery of salts. Such strategies are vital to mitigating adverse environmental impacts, safeguarding marine

ecosystems, and fostering resource efficiency in brine management processes.

- Prioritize Investment in Research and Innovation: Facilitate the advancement of applied research focusing on hybrid renewable-desalination systems, the development of climate-resilient crop varieties, and the implementation of data-driven Nexus modeling. These efforts are essential to inform policymaking processes and drive evidence-based decisions.
- Public-Private Partnerships (PPPs): Foster cooperation among government entities, the private sector, and international organizations to support the funding and execution of extensive solar desalination initiatives.

7.3 Future Research Directions

Future studies should focus on:

- Detailed spatial and temporal modeling of water, energy, and food interactions at both regional and farm scales.
- An analysis of the socio-economic implications associated with the adoption of desalination technologies and the evaluation of public acceptance within both rural and urban communities.
- Monitoring the long-term environmental effects of brine disposal and its impact on ecosystems.
- Incorporation of climate change scenarios for assessing resilience under projected future conditions (2030–2050).

Focusing on these key areas allows Algeria to develop strong, sustainable, and scalable approaches to water, energy, and food security. This ensures that the WEF Nexus plays a crucial role in supporting national development and achieving climate adaptation objectives.

8. Bibliography List :

8.1. Books :

1. Geels, F. W. (2005). *Technological transitions and system innovations: A co-evolutionary and socio-technical analysis*. Edward Elgar Publishing.
2. Kalogirou, S. A. (2005). *Seawater desalination using renewable energy sources*. *Progress in Energy and Combustion Science*, 31(3), 242–281.
3. Kalogirou, S. A. (2020). *Solar thermal desalination: Recent developments and future perspectives*. *Desalination*, 491, 114540.

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8.2. Journal article :

1. Endo, A., Kakinuma, K., & Matsumoto, K. (2017). *Water–Energy–Food Nexus modelling for sustainable development*. Sustainability Science, 12(1), 123–134.
2. Ghaffour, N., Missimer, T. M., & Amy, G. L. (2013). *Technical review and evaluation of the economics of solar-powered desalination systems*. Desalination, 308, 1–11.
3. Giorgi, F., & Lionello, P. (2008). *Climate change projections for the Mediterranean region*. Global and Planetary Change, 63(2–3), 90–104.
4. Howells, M., Hermann, S., Welsch, M., Bazilian, M., Segerström, R., Alfstad, T., ... & Gielen, D. (2013). *Integrated analysis of climate, land, energy, and water strategies*. Energy Policy, 39(12), 7896–7906.
5. Aissaoui, R. (2016). *Energy transition challenges in Algeria: Policy and institutional perspectives*. Renewable Energy Journal, 92, 123–135.
6. Al-Karaghoul, A., & Kazmerski, L. L. (2013). *Optimization of solar-powered desalination systems in the MENA region*. Renewable and Sustainable Energy Reviews, 24, 343–356.
7. Allan, J. A., Keulertz, M., & Woertz, E. (2015). *The Water–Energy–Food Nexus: Governance challenges in the Mediterranean*. Global Policy, 6(4), 495–503.
8. Bazilian, M., Rogner, H., Howells, M., Hermann, S., Arent, D., Gielen, D., ... & Yumkella, K. K. (2011). *Considering the energy, water and food nexus: Towards an integrated modelling approach*. Energy Policy, 39(12), 7896–7906.
9. Benouniche, M., & Kuper, M. (2014). *Irrigation efficiency and water productivity in Algerian agriculture*. Agricultural Water Management, 137, 85–94.
10. Bessaoud, O., Pellissier, V., & Rolland, B. (2019). *Food security and agricultural productivity in Algeria*. Food Security, 11(3), 565–579.
11. Belmihoub, F., Dadda, H., & Bouhoun, A. (2017). *Renewable energy potential and policy in Algeria*. Energy Strategy Reviews, 17, 55–64.
12. Chebana, F., Ouarda, T. B. M. J., & Duong, V. T. (2014). *Drought risk assessment in Algeria: Trends and variability*. Journal of Hydrology, 519, 2581–2594.
13. Cherchali, A., & Kalla, M. (2015). *Food imports and agricultural vulnerability in Algeria*. Mediterranean Journal of Social Sciences, 6(6), 180–192.

14. Daher, B., & Mohtar, R. H. (2020). *A quantitative Nexus approach for water, energy, and food security*. Environmental Science & Policy, 112, 130–140.
15. Driouech, F., Nkaizirwa, J., & El Hage, A. (2021). *Hydro-climatic variability and water stress in North Africa under climate change*. Climate Dynamics, 57, 1231–1248.
16. El-Sadek, A. (2010). *Integrated water resources management in the MENA region: Lessons from Algeria*. Water International, 35(2), 180–196.
17. Shahzad, K., Qasim, M., & Ali, F. (2019). *Hybrid solar desalination systems: Energy efficiency and environmental benefits*. Renewable Energy, 139, 1–15.

8.3. Seminar article:

18. Bouchaour, T., & Boufadel, M. (2020). *Desalination challenges in North Africa: Energy, environment, and policy*. Desalination, 490, 114550.
19. Hoff, H. (2011). *Understanding the Nexus: Background paper for the Bonn 2011 Conference: The Water, Energy and Food Security Nexus*. Stockholm Environment Institute.
20. Hadeif, R., & Boudghene Stambouli, A. (2020). *Potential of solar energy for sustainable water and energy systems in Algeria*. Renewable Energy, 146, 1403–1417.
21. Mahrane, A., Boulahia, T., & Benammar, S. (2019). *Barriers to renewable energy deployment in Algeria*. Renewable and Sustainable Energy Reviews, 103, 43–55.
22. Scott, C. A., Meza, F., & Varady, R. G. (2016). *Integrated water–energy strategies for arid regions*. Journal of Environmental Management, 172, 20–28.

8.4. Internet websites:

23. UNDP. (2020). Human development report: Water, energy, and food security in North Africa. United Nations Development Programme. Retrieved from <https://www.undp.org>
24. World Bank. (2019). Algeria: Water and irrigation sector assessment. Washington, DC: World Bank Group.
25. FAO. (2020). Aquastat: Algeria country profile. Food and Agriculture Organization of the United Nations. Retrieved from <http://www.fao.org/aquastat/en>
26. IEA. (2021). Renewable energy market report: Algeria. International Energy Agency. Retrieved from <https://www.iea.org>