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The Future of Solar Investments in MOROCCO

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ABSTRACT: The future of solar investments in Morocco looks bright, thanks to the country's significant solar capacity and favorable geographic conditions. This study offers a thorough examination of the potential for solar energy investment in Morocco, with a focus on the country's current state, political landscape, technological advancements, and the socioeconomic and environmental effects. It also explores the future trends in the country including artificial intelligence (AI) for renewable energy prediction and green hydrogen production. The study also delves into the updated solar policy framework in the country, highlighting its goals of achieving 80% renewable energy by 2050 and installing 6000MW of solar capacity by 2030. It also examines the regulatory structures, incentive programs, and strategies aimed at reducing dependence on fossil fuels and attracting more investments in solar energy projects. The study analyzes the practicality of these policies, taking into account economic sustainability, technological progress, environmental effects, and infrastructure improvements. The findings propose an effective system for improving solar investments and attaining sustainable energy goals in Morocco.

KEYWORDS: Solar Energy, Solar Investment, Sustainable Energy Goals, Technological Advancement, Political landscape, Solar Policy Framework

I. INTRODUCTION

Morocco has become a major player in the worldwide shift towards renewable energy, placing a strong emphasis on solar power. With its plentiful sunlight, the North African nation is perfectly situated for harnessing solar energy. The Moroccan government has been actively working to harness this potential, implementing large-scale solar projects to meet the increasing energy needs of the country and decrease dependence on fossil fuels.

Morocco benefits from its favorable geographical location, which results in abundant solar irradiance. This makes the country an ideal region for the production of solar energy. The country benefits from approximately 3,000 hours of sunlight annually, with vast stretches of desert and open land providing abundant opportunities for solar installations. The vast availability of solar energy has led to the creation of ambitious projects aimed at harnessing this clean and sustainable power source.

Morocco's dedication to solar energy is clear with its National Energy Strategy, which incorporates the National Solar Plan (NSP). The NSP has a goal of substantially boosting the proportion of solar power in the nation's energy blend. One of the impressive projects in this plan is the Noor Solar Complex, a network of interconnected solar power plants situated near the city of Ouarzazate.

The Noor Ouarzazate Solar Complex plays a vital role in Morocco's commitment to renewable energy. The facility in the Draa-Tafilat area is the largest concentrated solar power (CSP) complex globally, boasting an impressive capacity of 580 MW. This project alone has significantly boosted Morocco's capacity for renewable energy. The Noor Solar Complex is divided into multiple phases, including Noor I, Noor II, Noor III, and Noor IV. These phases generate substantial amounts of renewable energy, helping to decrease Morocco's reliance on fossil fuels.

The Moroccan government is committed to increasing the country's renewable energy capacity to 52% of the total installed capacity by 2030, demonstrating their strong dedication to sustainable energy. The government has established a goal of achieving a 20% energy savings by 2030, showcasing its dedication to a more ambitious energy efficiency program.

Green hydrogen production plays a vital role in Morocco's renewable energy strategy. The country's interest in hydrogen stems from its ability to be produced at cost-effective rates. According to current projections, it is expected that Morocco's levelized cost of hydrogen (LCOH) will decrease to €1 per kilogram by 2030, assuming ideal conditions. This can be accomplished by significantly decreasing capital expenditures (CAPEX) and electricity expenses. For instance, the capital expenditure (CAPEX) for electrolyzers is expected to decrease significantly, while the cost of renewable electricity is projected to decline as well.

In addition, Morocco has strategic ambitions to export green hydrogen and synthetic fuels. By 2050, the government has ambitious plans to export a significant amount of synthetic

fuels and green hydrogen, capitalizing on its abundant renewable energy resources. These exports are projected to reach impressive levels, with the aim of harnessing a renewable energy potential of 55 GW. These exports are expected to have a crucial impact in meeting global demand for clean energy and supporting international efforts to combat climate change.

Morocco's renewable energy programs are supported by robust policy frameworks and global collaborations. The country has attracted significant investments from global financial institutions and energy companies, enabling the development of large-scale renewable energy projects. These partnerships are crucial for the exchange of technology and expertise, necessary for the successful implementation of advanced renewable energy systems.

In summary, Morocco has made substantial investments in solar energy, set ambitious capacity goals, and placed a strong focus on the generation of green hydrogen. With Morocco's initiatives, there is no doubt that the country is poised to become a global leader in the transition to sustainable energy systems, making a significant impact on renewable energy markets worldwide.

II. METHODOLOGY

This study utilizes a mixed-methods approach, incorporating both quantitative data analysis and qualitative policy review. The study gathered the numerical data on solar capacity and geographic distribution of solar insolation from various national and international energy reports. Geographic information systems tools were utilized to create maps of areas with abundant solar radiance. The study also examined government policy documents, technological research papers, and economic impact assessments to assess the present and future state of solar energy in Morocco. The research analyzed important parameters such as solar panel efficiency, energy storage capacity, concentrated solar power and grid integration to gain insights into technological advancements. Case studies and statistical analyses were used to evaluate the socio-economic and environmental impacts.

The geographical study aimed to locate and evaluate places in Morocco that have a high potential for solar radiation. A comprehensive map of horizontal sun irradiance throughout Morocco reveals that the southern and south-central portions of the nation have the highest levels of irradiance, exceeding 2250 kWh/m2 and ranging between 2100 and 2250 kWh/m2, respectively. This research enabled the selection of the most favorable areas for solar investments.

The study from the technical side assessed the present condition and future capacity of solar technology in Morocco through the Policy assessment is the examination of existing and prospective government policies and incentives that have an influence on solar investments. The socio-economic impact study specifically examined the wider consequences of solar investments in Morocco, including the development of employment opportunities, stimulation of economic growth, and the realization of environmental advantages.

Data analysis involved the utilization of statistical and computational tools to effectively process and interpret the data that has been collected. Using Geographic Information Systems, solar radiance and climatic zones were mapped to determine the best areas for solar investments. Analyzed trends in technological efficiency, cost reductions, and socio-economic impacts using statistical methods. An analysis was conducted to compare the effectiveness of various policies and incentives.

III. FINDINGS

This study provides a comprehensive analysis of solar energy development in Morocco, including an examination of the country's potential, current policies, technological advancements, and socio-economic impacts.

1- Solar capacity in Morocco

Morocco is a significant contributor to worldwide solar energy potential, with an estimated sun irradiation of over 5 kWh/m2/day. The evaluation of solar capacity in Morocco reveals significant prospects for both photovoltaic (PV) and concentrated solar power (CSP) technologies

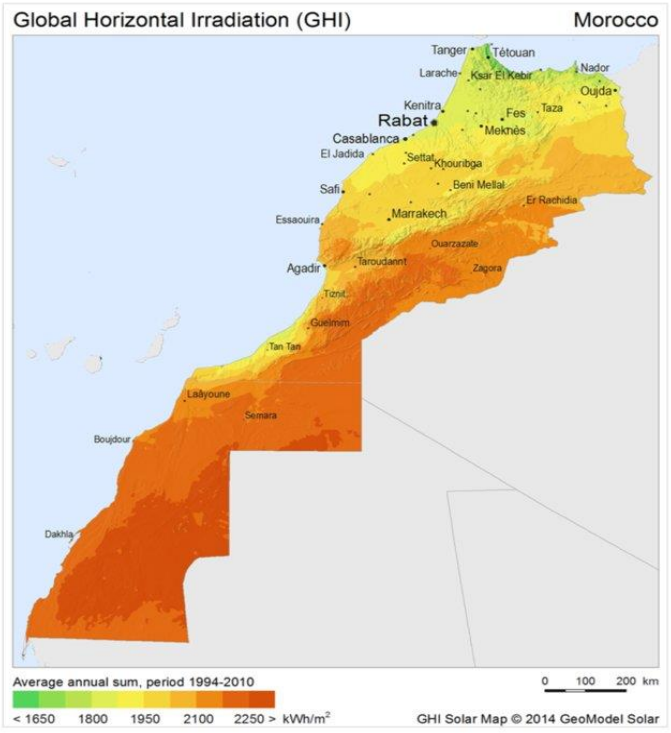

Figure 1: map of global horizontal solar irradiation in Morocco

Region	GHI (kwh/ m²)	Characteristics
Southern Morocco	>2250	Maximum irradiance, perfect for large scale solar projects
South-central Morocco	2100-2250	Maximum irradiance, supports existing and future projects

Westen Morocco 1950-2100 High solar potential, appropriate for medium large projects
North-western Morocco 1800-1950 moderate irradiation, appropriate for smaller-scale projects
Northern Morocco 1650-1800 Lower irradiance, viable with additional optimization

Table 1: characteristics and classifications of Moroccan regions according to GHI map

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Northern Morocco	1650-1800	Lower irradiance, viable with additional optimization

1- The future of solar politics

Morocco set a more ambitious goal to increase the share of renewable energy in its electricity mix to 52% by the year 2030 and In December 2021.The country achieved 14% (2000 MW) of its production capacity from CSP and PV technologies in 2020, with further plans to escalate this to 20% (4560 MW) by 2030.

Fossil fuels percentage in the energy mix is steadily declining, it fell from 66% in 2015 to 58% in 2020 and by 2030, it is expected to decline to 48%.

The study demonstrated a proactive strategy to improving grid integration for future solar policy in Morocco by identifying affordable grid reinforcements and creating a base case grid model for 2030.

2- Technological advancement and innovations

The progress in technology has played a crucial role in improving investments in solar energy.

the expense of producing renewable energy has significantly decreased in the last ten years due to the continual enhancement of technology, the benefits of producing on a larger scale, competitive distribution networks, and enhanced expertise of developers. From 2010 to 2021, the price of electricity generated by utility-scale solar photovoltaics (PV) decreased by 88%.

Higher efficiency=more electricity production from the same area of solar panels

Morocco has been actively investing in energy storage systems related to solar energy to enhance the reliability and efficiency of its renewable energy infrastructure. Morocco has been increasingly deploying battery storage systems, such as lithium-ion batteries, in conjunction with solar photovoltaic (PV) installations.Progress in battery technology, including the enhanced energy density, accelerated charging capabilities, and extended cycle life of lithium-ion batteries, may provide more effective storage of surplus solar energy for future use.

Morocco's Noor Solar Complex, located near Ouarzazate, includes CSP plants with thermal energy storage capabilities. These plants use molten salt as a storage medium to store excess heat generated during the day.

It's worth noting that the Noor 1 power plant is outfitted with a thermal storage system lasting 3 hours. In contrast, the thermal storage capacity for the Noor 2 and Noor 3 plants extends to 8 hours. This ensures uninterrupted energy distribution, including during evening hours when demand peaks.

These technological improvements guarantee a more dependable and uniform supply of solar energy, thereby tackling a major obstacle faced by renewable energy sources.

3- Socio economic and environmental impact

The investments in solar energy in Morocco have resulted in significant socio-economic advantages, such as the creation of jobs and the stimulation of economic growth.

Renewable energy development in Morocco is anticipated to increase GDP by 0.51 by 2025, leading to increased economic growth, and According to a study by the International Renewable Energy Agency (IRENA), the deployment of renewable energy, including solar, could contribute to a 1% increase in Morocco's GDP by 2030.the study projects that by 2030, the renewable energy sector could draw investments totaling approximately $40 billion, stimulating economic growth, and opening new business prospects.

A study conducted by Fehri et al. (2020) projected that by 2030, the sector has the capacity to create approximately 163,000 new jobs, particularly in solar and wind energy sectors.

The increased deployment of solar power plants in Morocco will contribute to a significant reduction in greenhouse gas emissions, helping to combat climate change.

A study conducted by Ben Sassi et al. (2021) revealed that achieving Morocco's renewable energy targets could potentially reduce the country's greenhouse gas emissions by 42 million tons annually by the year 2030, and according to MASEN it is expected from Noor Ouarzazate solar complex project to reduce CO2 emissions by760 000 tons per year by 2030, this limit represents Morocco's target to reduce CO2 emission by 45.5%. It means that the modeling of the energy system will consider this emissions limit to not exceed it from 2030 onwards.

4- Future trends

There are several emerging trends in Morocco that are set to enhance the growth and sustainability of the solar energy sector in the future:

• Artificial intelligence AI for Renewable Energy Prediction

The application of AI in renewable energy systems, exemplified by the Moroccan case study, showcases the potential for AI to drive innovation and sustainability in the global energy transition. A study conducted in Casablanca city, especially in Ben Msik faculty at Hassan 2 university, they proposed a model based on MLP mode to predict the output power in PV panels which is installed in the roof of the university. The model demonstrated a good performance and showed promising results in predicting PV power output in Casablanca, So, Morocco is demonstrating AI's ability to maximize the use of renewable energy sources in Morocco in the region.

• Green hydrogen production

Morocco's goals for the growth of its green hydrogen economy are high. The country intends to dramatically increase exports and production over the next three decades to position itself as a major worldwide supplier by 2050.

The National Green Hydrogen Commission's strategy outlines Morocco's ambitious goal of increasing its renewable energy capacity to 55 GW by 2050. The increasing domestic and export-oriented production of green hydrogen will be facilitated by this improved infrastructure for renewable energy.

Morocco has equally bold objectives for exports. The country wants to export 33 TWh of synthetic fuels and 81 TWh of green hydrogen by 2050.

Morocco will be positioned as a major strategic player in the global switch to sustainable energy sources as a result.

• Hybrid energy system

An exemplary instance is the Moroccan hybrid energy system, which boasts a remarkable renewable rate of 44.57%. This suggests a significant reliance on renewable energy sources to generate electricity, hence lowering the nation's carbon footprint.

Furthermore, studies have shown that the hybrid storage model—which has a Cost of Energy (COE) of 0.577 $/kWh—is the best option. This suggests that the most affordable solution for Moroccan homes is the hybrid storage system, which combines the benefits of battery and hydrogen storage technologies.

These trends indicate a shift toward sustainable and locally driven energy solutions in Morocco's request to increase renewable energy contributions by 2030.

IV. CONCLUSION

With its strategic investments in solar energy, Morocco has emerged as a frontrunner in the field of renewable energy. The country's favorable geographic conditions and strong policy frameworks have played a crucial role in its success. The nation's commitment to sustainable energy is evident in the significant potential of PV and CSP technologies, as well as advancements in energy storage and smart grid integration. The socio-economic benefits, such as job creation and environmental improvements, provide strong evidence for the viability of large-scale solar investments. Future trends, such as AI for energy prediction and green hydrogen production, showcase the innovative approaches that will propel Morocco's solar energy sector into the future. This study's findings offer a detailed plan to boost solar investments and help Morocco reach its renewable energy objectives.

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