Original Paper

Future directions for solar energy in a global context with particular emphasis on Saudi Arabia, the Middle East, and North Africa

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Abstract. *Solar energy has emerged as a viable and sustainable replacement for conventional energy sources with significant environmental and financial advantages. Photovoltaic (PV) systems and concentrating solar power (CSP) technologies are used to harness the energy of sunlight and have been widely applied, leading to a sharp increase in solar installations across the globe. The use of solar energy has been propelled even further by decreasing solar panel prices, developments in energy storage, and encouraging regulations. This article analyzes future directions for solar energy in a global context, with a*

particular emphasis on the Kingdom of Saudi Arabia (KSA), and the Middle East and North Africa (MENA) region. It proposes a discussion of the challenges and opportunities relating to solar cell adoption in the KSA and MENA region, also in the light of the potential paradox of countries who are among the largest producers of fossil-fuels being in the forefront of the move to carbon-negative technologies.

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1. Introduction

The development of solar energy on a global scale has been driven by the world's rising energy demand and growing concerns about the environmental impacts of continuing use of fossil fuels and climate change. Leaving aside debates concerning the adequacy and efficacy of international agreements on the phasing out of fossil fuels, solar energy is now well-established as a renewable, abundant, and clean energy source capable of making an important contribution to attempts at resolving the global energy dilemma. The solar cell (SC) plays a crucial function in harvesting energy efficiently. The scope and benefits of solar PV technology for societies all over the world are abundant. This article aims to provide a broad discussion of the potential global impact of SCs, then focusing on the KSA and the MENA region, where SCs are particularly promising due to the growing population and abundance of sunlight, with associated challenges that must be overcome. The future of SCs in these regions is discussed, and how technology, supply chains, and economics can drive further adoption if appropriately balanced. The intention is to contribute to existing literature by addressing often-overlooked regions of the globe and examining their unique opportunities and potential when looking at SC development and adoption in a global context.

2. Progress, challenges, and future directions for the KSA and the MENA region in a global context.

Over a period of several decades, the KSA has greatly increased its use of clean energy sources like SCs (Gul, 2016). Solar energy usage started in 1960, and a systematic improvement initiative for the advancement of solar energy was launched by King Abdul-Aziz City for Science and Technology in 1977 (Said, El-Amin, & Al-Shehri, 2004). Due to a construction boom and an escalating

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population, the country's need for power is continuously growing. Power generation must be adequate and suitable given the current high loads and the hazards of conventional energy production using fossil fuels must be curbed and gradually eliminated.

The KSA is potentially among the largest generators of solar PV energy due to its advantageous location in a sunbelt area, vast expanses of desert land, and year-round clear skies. It is economically advantageous to try to produce renewable energy in the country using PV cells and direct sunlight because the average amount of energy from the sun falling on the country is 2200 thermal kWh/m2 (Alawaji, 2001). On the other hand, there are still many difficulties with solar energy worldwide, including overheating and potential cooling systems, cost issues and a lack of funding, low efficiency, and technical difficulties (Yousif, 2020). However, the lifespan of solar power modules, which is greatly affected by degradation brought on by heat and humidity, has been extended and problems limitations due to processes, such as light reflection off the cell's surface and the collision and recombination of light's created electrons and holes, which prevent them from contributing to the cell's output, have been increasingly successfully addressed. Figure 1 illustrates the technological advances in SCs.

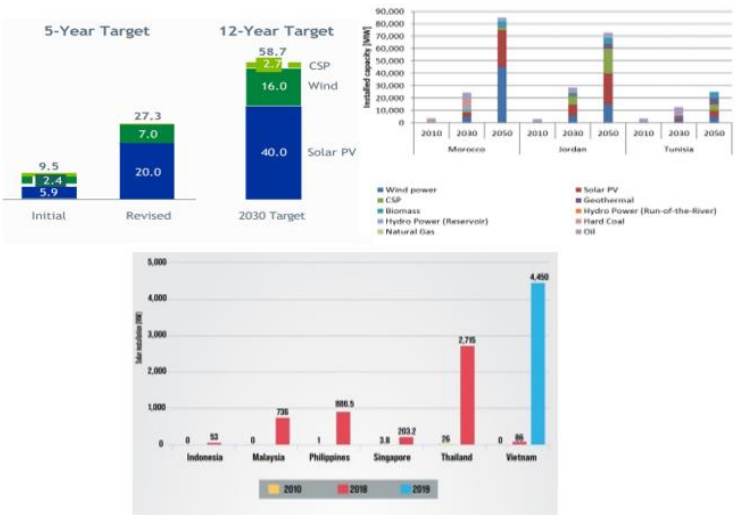

Figure 1. The progress of SC technology in KSA, MENA region, and Asia (Alshehri, 2019; ASEAN Centre for Energy, 2019; Zelt, Krüger, Blohm, Bohm, & Far, 2019).

The KSA is by now regarded as the highest producer of solar energy per unit of electrical capacity (0.003 GW) compared to other nations (AlOtaibi et. al., 2020). The country's Vision 2030 plan aims to lessen the nation's reliance on oil while increasing private sector involvement in the economy and creating the opportunity for future solar energy deployment to be accelerated. Figure 2 shows the current trends of PV supply chain.

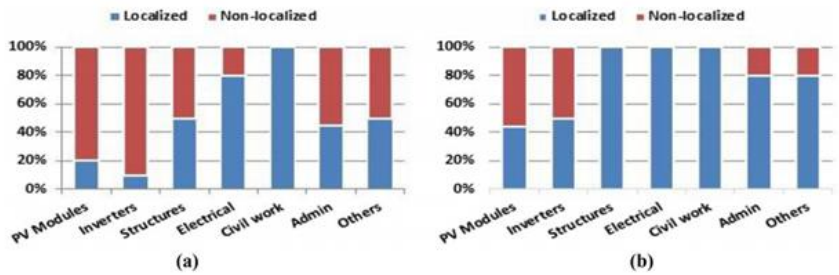

Figure 2. (a) PV chain supplied locally and globally in 2018 (b) the expected values of PV for 2023 (AlOtaibi et al., 2020).

Many other MENA governments are focusing their attention on diversifying solar energy through large-scale projects. In the Middle East, in Abu Dhabi plans are underway to develop several solar energy projects by 2025. In the United Arab Emirates, the Mohammed Bin Rashid Solar Park plans to finish a 5 GW plant by 2030. By 2030, Morocco aims to produce 52% of its energy from renewable sources. In the years up to the end of 2022, growth rates in the use of solar energy in Egypt and Tunisia have been 30% and 20%, respectively and in the same period Oman planned for 1.5 GW of solar power facilities to be online. Jordan is boosting its expenditures on clean energy, and helping people use renewable energy sources to become more self-sufficient and save money by generating their own electricity. Despite political unrest and administrative difficulties, Iraq has included solar energy in its future energy mix plans (News, 2020). Figure 3 illustrate the trends of solar power in MENA region.

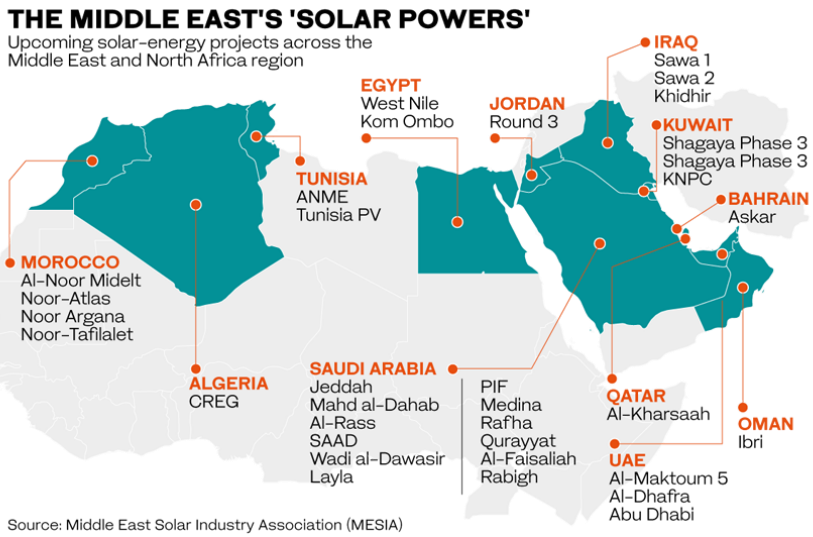

Figure 3. Solar power utilization in MENA (News, 2020).

In global terms, it is projected that solar PV capacity will provide 25% of the world's power needs by 2050, reflecting a tenfold rise in PV's proportion of the generation mix from 2016. By 2050, it is anticipated that solar PV's installed capacity (8519 GW) will need to be expanded substantially more than wind's installed capacity (6044 GW)[2]. Solar PV will also facilitate the transformation of the world's electrical industry. By 2050, as shown in Figure 4, the total installed capacity of solar PV will reach 8,519 GW (IRENA, 2019).

Since many countries such as the KSA and others in the MENA sunbelt have a vast potential for solar energy, they can make an important contribution to the shift whereby renewable energy sources and electrification substitute fossil fuels as these become uncompetitive and unsustainable in a world increasingly moving to carbon-constrained economies and carbon-negative technologies. Such a result can be achieved both in terms of domestic consumption and also of transmitting renewable electricity across continents.

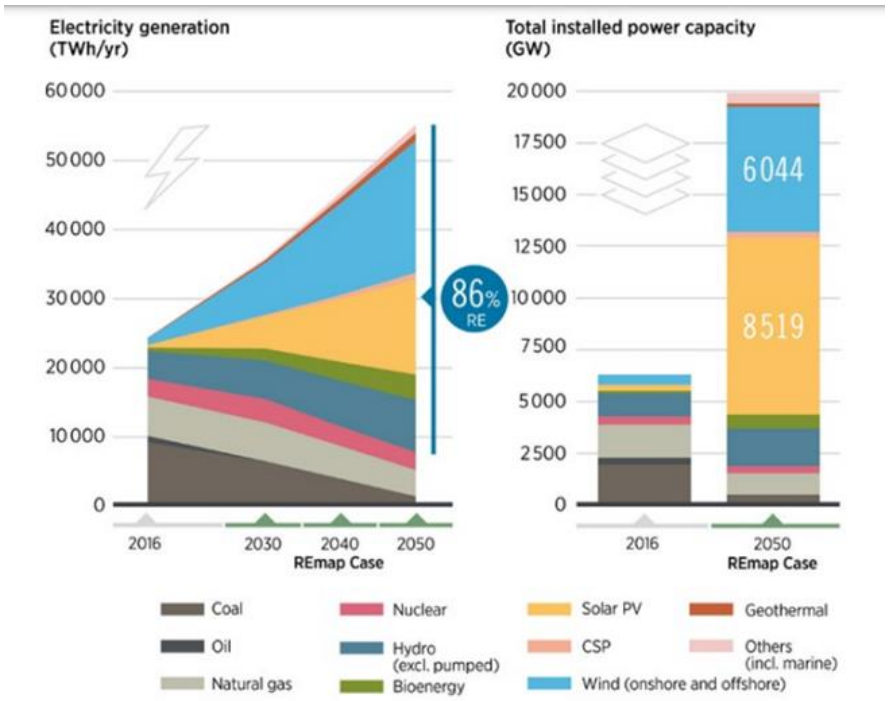

Figure 4. Photovoltaic solar energy expansion by 2050 (IRENA, 2019).

Initiatives well underway advance the sustainable development objectives of the countries in the region and establish them as pioneers in the renewable energy transition. Solar power and photovoltaics have revolutionized the world's energy scenario, but key challenges and opportunities remain. For example, theoretical limits have not been met practically for many SC materials, and further nanomaterials research could discover better SCs (Markvart 2021). The advent of SCs capable of flexibly being added conformally to different materials should also open new avenues for on-the-go charging. Similarly, SCs capable of capturing a wider range of the electromagnetic spectrum should lead to gains in power generation, even if theoretical efficiencies are not met. Novel developments in biological SCs may take decades to eventuate but research already indicates promising outcomes in the future (Wang 2020). With their solar energy potential and financial resources available due to fossil-fuel production,

the KSA and other MENA countries can play an important role in such developments.

3. Conclusions

The goal of ongoing research and development in the field of solar energy and photovoltaics is to increase SCs' efficiency and longevity while examining novel performance-improving materials and creating cost-effective manufacturing methods, which has particular importance for the economics of SCs. Areas with abundant sunlight, such as the KSA and the broader MENA region, provide ideal locations for producing, distributing, and researching, thereby making a highly significant contribution to the future of solar energy. Many countries in these areas are already investing heavily in solar power projects and moving towards a scenario in which fossil fuel-producing countries can become protagonists in the transition to sustainable energy sources (Najm, 2019). By embracing solar power, they have the chance to play an important role in lessening local and global environmental impacts of fossil fuels, attaining energy security, and creating more resilient societies for future generations.

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