

Renewable Energy Development in OAPEC Countries: History, Current Status, and Outlook

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Abstract

The renewable energy industry has grown its contribution to the global energy mix, particularly in terms of electricity generation. This study investigates the implications of an increasing renewable energy share on OAPEC countries and proposes a comprehensible policy strategy for the region. Four main topics are discussed: scientific and engineering principles of renewable energy utilization, current strategies for electricity generation in each OAPEC member country, economic and environmental implications of the energy transition under two future scenarios, as well as political interactions between oil-consuming and oil-producing countries. Based on this study, realistic and cost-effective strategies are proposed for OAPEC countries to better leverage their significant renewable energy resources while stabilizing fossil fuel supplies and strengthening their position in the global energy market. To mitigate the negative impacts of the energy transition, OAPEC countries are encouraged to take the following steps: 1) Developing renewable energy in conjunction with fossil fuel resources to reduce local demand for fossil fuel and increase the supply for exportation; 2) Reviewing economic policies, environmental regulations, and carbon taxes imposed by oil-consuming countries; 3) Increasing investment in renewable energy infrastructure; 4) Cooperating to achieve a balance between economic development and environmental protection.

Keywords

OAPEC, Renewable Energy, Global Energy Mix, Solar Energy, Wind Energy, Fossil Fuel

1. Introduction

The problems associated with fossil fuel use (coal, oil, and natural gas), such as depletion of a limited resource, pollution, and greenhouse gases, can be ad-

dressed in two ways: 1) Using renewable and clean energy sources to replace fossil fuel; 2) Implementing efficiency practices in all aspects of energy production, distribution, and consumption so that less fuel is used to obtain the same product. Increasing energy efficiency can reduce the use of fossil fuel, while renewable and clean energies can directly replace fossil fuel [1]. In light of the global trend to reduce fossil fuel consumption, oil-producing countries must carefully balance the economic and environmental impacts of their energy strategy. This study collects and reviews the scientific, political, and economic data on renewable energy investment for OAPEC countries and recommends specific strategies to meet environmental goals without degrading OAPEC's economic influence.

This study is structured as follows: Section 2 reviews technologies for producing and distributing renewable energy. Section 3 reports on the current status of renewable energy policy and infrastructure investment in each OAPEC country. Section 4 summarizes the key predictions of a prior OAPEC study on the evolution of energy generation and demand between 2017 and 2040 [2]. Section 5 exposes some of the conflicts of interest between oil-consuming countries and OAPEC countries. Finally, section 6 puts forth detailed recommendations for OAPEC countries moving forward, and section 7 concludes.

1.1. Organization of Arab Petroleum Exporting Countries (OAPEC)

OAPEC was founded in January 1968 to promote international economic cooperation within the petroleum industry. Its countries are Algeria, Bahrain, Egypt, Iraq, Kuwait, Libya, Qatar, Saudi Arabia, Syria, Tunisia, and the United Arab Emirates (UAE). OAPEC's headquarters are in the State of Kuwait [3].

OAPEC seeks to achieve the following goals for its member countries: embrace close national ties, preserve common interests, unify efforts to maintain the flow of petroleum to markets on profitable terms, establish a suitable climate for industry, develop oil-economic policies and legal mechanisms, and promote the exchange of technology and information [3].

OAPEC countries have a total area of 8.19 million km² and a total population of 276.16 million. These figures represent 5.4% of the habitable area in the world and 3.6% of the world's population. The economic output of OAPEC is 2110.92 billion dollars per year, or approximately 2.5% of the global economy. The most recent reported value of all exported goods was 492.13 billion dollars per year [4].

1.2. Environmental Impacts and the Kyoto Protocol

Energy consumption from fossil fuel has led to environmental pollution problems, which include air, water, and soil pollution. Energy and environmental problems are closely related to each other because it is almost impossible to produce, transfer, or consume energy without significant environmental impacts. The environmental impacts associated with energy production and con-

sumption include air and water pollution, global warming, and solid waste disposal issues [5].

Human activity since the industrial revolution has led to an increase in the release of greenhouse gases into the atmosphere, especially carbon dioxide and methane. In addition, industrial activity has added ozone to the troposphere and released significant quantities of chlorofluorocarbons and nitrogen dioxide. About 75% of the increase in carbon dioxide over the past 20 years is due to burning fossil fuel. Carbon dioxide emissions are the primary driver of global climate change [6].

Carbon dioxide is the most important type of emission in terms of quantity; for example, it accounted for 82% of the total greenhouse gas emissions worldwide in 2000 [7].

The burning of fossil fuel releases not just carbon dioxide but also other greenhouse gases. Carbon emissions raise global temperatures by trapping solar energy in the atmosphere, which can cause storms, fires, droughts, and heat waves. Carbon emissions directly affect human health as well, causing more respiratory diseases due to increased smog and air pollution.

The Kyoto Protocol is an international agreement with binding targets for reducing greenhouse gas emissions. The Protocol requires a 5% reduction in emissions from developed countries relative to 1990 levels over the period 2008-2012. The protocol includes two sets of specific commitments in fulfillment of the general principles established by the United Nations Framework Convention on Climate Change (UNFCCC) [8]. The first group includes the obligations assumed by all committing parties, while the second group is concerned with the responsibilities carried by developed countries towards developing countries [8].

1.3. Environmental Impacts and the Kyoto Protocol

This section reviews current efforts and future strategies for electricity generation using solar power and other renewable sources in OAPEC countries. It also describes the development of technologies used in the generation of electric power and compares the performance of these technologies and other sources in terms of efficiency, meeting electric energy demand, reducing fossil fuel consumption, and reducing emissions from thermal power plants.

This section also reviews government strategies in the area of electric power generation from renewable sources over the next ten years, considering the climatic and geographic nature of each member country. The individual objectives of each member country, concerning improving the efficiency of renewable energy plants and the total capacity of generating projects, are also discussed.

2. Foundations of Renewable Energy Generation and Storage

Energy is described as clean if it is derived from renewable energy sources that are free of emissions, or if it adopts energy efficiency practices so that less fuel is

used, and it has fewer environmental impacts. Renewable energy is defined as energy created, renewed, and sustained without depletion or significant damage to the environment. Fossil fuel such as coal, oil, and natural gas are not renewable, as they are depleted through use. Fossil fuel also emits harmful pollutants and greenhouse gases.

Major renewable energy sources include solar and wind energies [1], hydrogen [9] [10], as well as Electric Vehicle (EV) technologies, which can serve as a storage medium for the electrical energy generated by renewable sources [11].

This section summarizes the technological foundations of renewable energy sources that are mainly in OAPEC countries: solar, wind, and hydroelectric energies.

2.1. Solar Energy

Solar energy is one of the most important renewable energy sources. Although solar energy is theoretically sufficient to meet all the world's energy needs, it is not currently used on a large scale due to its relatively high cost of exploitation and the need for large areas of solar cells.

Solar energy has the most potential among renewable energy sources because it is free, non-polluting, and inexhaustible. The basic principle of solar energy applications is to convert solar energy into other types of energy that can be used.

There are two main technologies for generating electricity from solar energy: solar energy concentrators, and photovoltaic cell systems. In energy concentrators, solar energy is collected and converted into heat, then the heat is converted into electricity by an engine. In photovoltaic cells, solar energy is converted directly into electricity.

A photovoltaic system consists of solar panels, which are made up of smaller units called photovoltaic cells. A photovoltaic cell is made of a semiconducting material such as silicon. It converts solar radiation into electricity in three stages: 1) Silicon atoms absorb photons and release electrons; 2) The flow of electrons generates an electric current; 3) The cell collects the current and transfers it to wires.

It is common for silicon to be used in solar cells, but silicon solar cells have low efficiency (between 15% and 20%). Other promising materials can reach up to 40% efficiency, such as cadmium telluride, cadmium sulfide, copper-indium diselenide, and gallium arsenide, but at a much higher production cost.

A single solar cell produces from 1 to 2 watts of power and its lifespan is about 20 to 35 years. The cost of solar panels has been declining over time. It is currently valued at \$2.50 per watt and is expected to drop to \$1.20 per watt by 2023 [1].

Solar energy concentrators work by focusing solar radiation into a small area to produce heat. The system consists of a receiver, which absorbs the solar radiation and converts it into energy, and an optical system which directs solar radiation.

tion to the receiver. Concentrators of solar energy are used to heat and cool places and also to produce hot water for buildings [12].

2.2. Wind Energy

Wind energy has been harnessed since ancient times to carry out activities such as sailing boats, grinding grain, pumping water, and generating electricity. But the widespread development of modern wind turbine technology did not occur until recently, in response to the energy crisis of the early seventies.

Wind turbines convert the kinetic energy of the wind into another type of energy that can be used. Wind energy is one of the fastest-growing energy sources in the world. Recently constructed modern facilities brought the world's total wind energy capacity to 539 GW (gigawatts) in 2017. China is the world leader in this area, with a wind power capacity of 188 GW. The United States comes in second with a capacity of 89 GW, followed by Germany, India, and Spain with capacities of 56, 33, and 23 GW respectively. The global capacity for wind power increased by 16.6%, 17.2%, 11.8%, and 10.8% in the years 2014, 2015, 2016, and 2017. The current total capacity of wind energy can cover more than 5% of global electricity demand [13].

The cost of wind energy has fallen from \$0.50 per kWh in the early 1980s to \$0.05 per kWh in the mid-1990s. The current cost of wind energy, including capital and operating costs, is \$0.082 per kWh. This is well below the cost of modern coal and nuclear power plants whose average value is \$0.11 per kWh. In contrast, modern natural gas plants produce electricity at a much higher cost of \$0.63 per kWh [14].

Areas with average wind speeds of 14 mph or more are considered economically feasible locations to use wind energy. Most commercial wind turbines generate up to 3.2 MW of electrical power. Recently installed wind turbines can generate more than 8 MW of electricity. The rotational speed of a rotating wind turbine is usually less than 40 rpm (less than 20 rpm for large turbines). The diameter of a single wind turbine blade can reach 97.5 meters.

Several types of wind turbines exist. They can be classified according to the direction of the axis of rotation (vertical or horizontal), and by the torque mechanism of the rotating shaft (lifting or pulling). So far, vertical axis turbine designs of the pulling type have not achieved a high enough efficiency to succeed and spread, reaching a maximum efficiency of 15%. The efficiency of horizontal axis turbines of the lift type, on the other hand, has reached 59%. For this reason, the vast majority of wind turbines built around the world are of the horizontal axis lift type [15].

When a wind energy project is implemented, a group of turbines is usually installed, and the site is called a wind farm. A wind farm has several advantages, the most important of which are low development costs, simplicity of transmission lines, and easy access for operations and maintenance. A single turbine is often installed to supply homes far from the electrical grid in remote areas.

The number of wind turbines in a given location is determined by spacing considerations. If the turbines are too close to each other, the airflow through one turbine affects the airflow through the next, and this reduces the performance. On the other hand, if the turbines are far apart, this means poor use of the site as there is no possibility to install additional turbines. The ideal spacing between turbines is estimated to be from 3 to 5 blade diameters between turbines in the same row, and from 5 to 9 blade diameters between rows [16].

High-altitude wind farms are often built because wind speed increases with height, to reduce the impact of wind turbulence, and to give more flexibility in the distribution of the turbines.

There are also many geophysical factors to consider when planning a wind farm project, such as vegetation cover, topography, surface roughness rate, soil porosity, and pressure capacity [17]. Another important factor is to ensure that the project site is far from urban development plans that may impede wind access.

2.3. Hydropower (Hydroelectric Power)

Hydroelectric power generation relies on collecting river water in dams at high elevations and then directing the water through a hydraulic turbine where the potential energy is converted into electricity. Hydropower represents the largest source of electricity production from renewable energies and even meets most of the electricity needs in some countries.

2.4. Renewable Energy Prospects and Challenges

The contribution of electricity from renewable sources is expected to increase in coming years, but the entry of wind and solar energy into the electric grid involves a degree of risk due to the continuous changes in supply. Wind and solar conditions can vary rapidly, for example, solar power input ceases at night and decreases dramatically when clouds or dust are present.

Exploiting renewable energy sources fully, therefore, requires building an electrical network that is more flexible than the traditional system, capable of accommodating an irregular supply of electricity without waste. A new approach to electricity distribution, called the smart grid, is an important area of research and development for electrical engineers. It requires the development of new technologies for energy storage.

The need for smart storage systems is expected to grow exponentially. Storage of solar energy for night use is one option, but this increases the cost of solar power and may not be effective in many applications. However, using the latest technologies, engineers are continuing to work on making solar energy systems more efficient and cost-effective. This is driven by the fact that solar energy has the greatest potential of all energy sources and there is no limit to the amount that can be used to meet our energy needs. It should also be noted that the cost of solar energy systems has been decreasing steadily over time.

A significant increase in solar installations is expected in the coming years. The main reasons for this trend are: 1) The decreasing cost and the increasing efficiency of solar panels; 2) Increased interest in and awareness of renewable energies, especially solar energy; 3) The growth and improvement of complementary technologies for solar energy such as storage and smart grid.

Wind turbine technology has also greatly improved over the years. There is room for further improvements that will help make this sustainable method of power generation more widespread. Some of the challenges are scaling up turbines, tailoring turbines to a specific site, developing new structural dynamic concepts for turbines, developing custom generators and power electronics, improving manufacturing technology, and improving control and storage technologies.

Although wind energy is free and renewable, modern wind turbines are very expensive and have a distinct disadvantage: since they only produce power when the wind blows, the power output of the turbines is inherently irregular. Moreover, the best locations for wind parks are often far from traditional power grids, so in stalling wind power may require the construction of new power lines. Nevertheless, wind turbines are expected to play an increasing role in the global energy supply in the near future.

3. Renewable Electricity Generation in OAPEC Countries

3.1. History, Current Status, and Outlook

The OAPEC region lies within a geographic area with the highest solar radiation worldwide. The average solar radiation flux is about 6 kWh/m²/day, or the equivalent of 2000 kWh/m²/year. The intensity of solar radiation varies with the season and from one region to another within the same country (Figure 1).

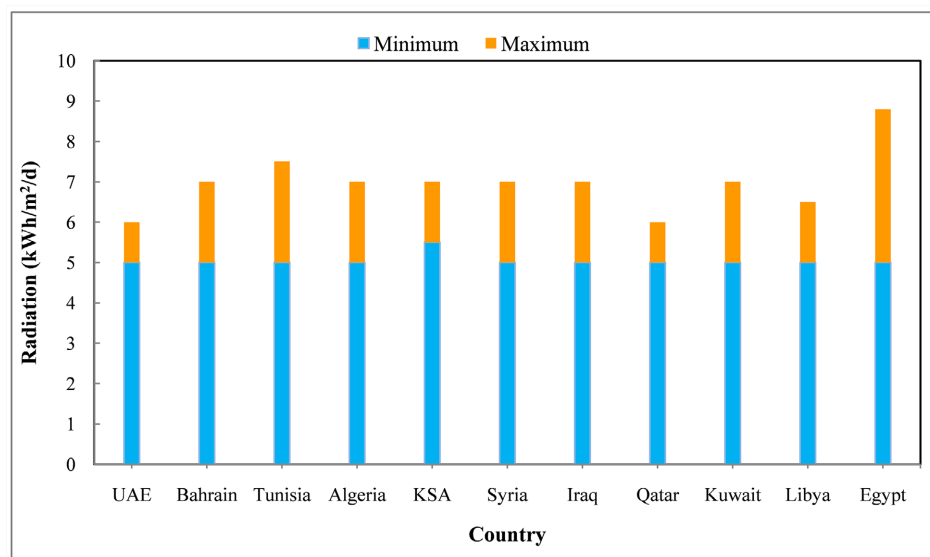


Figure 1. Average daily solar radiation in OAPEC countries. Source: Joint Arab Economic Report 2018 [18].

Considering only electricity from renewable energy sources, 90% of the generation capacity among OAPEC countries is concentrated in three countries: Syria, Iraq, and Egypt. Hydroelectric energy is the largest contributor, accounting for 85.7% of all renewable electricity produced by all OAPEC countries.

It is worth noting that renewable energies in the OAPEC region are underutilized compared to their theoretical capacity. The total amount of electricity generated from renewable sources for the year 2014 amounted to only 8.4 GW.

In recent years, interest in diversifying energy sources has grown among countries, and some countries have announced their future strategies for the contribution of renewable energy to the energy mix. For example, Saudi Arabia, the UAE, and Egypt recently announced their desire to operate nuclear reactors for peaceful purposes, to meet the growing electricity demand, and to release more oil and gas for export. In accordance with the global trends of reducing oil and gas consumption and the environmental burden, most countries have plans to increase their reliance on renewable energies in the field of electric generation.

Over the past decade, several OAPEC countries have achieved tangible progress in developing the electricity generation sector using renewable energy generation plants. Algeria, Egypt, and the UAE have developed photovoltaic power plants with capacities of 324, 100, and 213 MW, respectively. In addition, there is a new project to generate electricity using concentrated solar energy in Abu Dhabi with a capacity of 100 MW. Algeria and Egypt have also established hybrid solar power plants. The total capacity of the Algerian station is 150 MW, with a 20 MW solar generating capacity. The total capacity of the Egyptian station is 140 MW with 40 MW solar generating capacity.

OAPEC countries differ in their access to renewable energy sources and the extent to which exploiting those sources is appropriate given the country's climate and geographic nature. The ability to benefit from solar energy also varies among countries, because the efficiency of photovoltaic cells decreases by half a percent for each degree of temperature exceeding 25°C. Efficiency also decreases when dust collects on solar panels. Taken together, these factors mean that electricity generation using solar energy is appropriate in the Egyptian and Tunisian regions, which have more moderate temperatures and fewer dust storms than the Arab Gulf countries (Saudi Arabia, Kuwait, Qatar, UAE, and Bahrain). It is worth noting that Egypt and Iraq import most of their fuel needs, so they have the incentive to establish renewable energy power plants.

3.2. Egypt

The electrical generation capacity in Egypt increased significantly over the period 2011-2017, in the form of thermal and steam generating stations and combined cycle generating stations. Its total capacity in 2017 was equivalent to 20 GW. Its capacity is expected to have increased during the period 2018-2022 due to wind and solar photovoltaic projects launched by the New and Renewable Energy Authority (NREA), and due to the private sector implementing solar photovoltaic and wind power plants. The total capacity of these projects is 2400

MW (**Table 1**). It is expected that renewable energy sources will reach 31.2% of Egypt's total generation capacity by 2030.

3.3. Syria

The total installed generation capacity from dam generating stations in Syria was approximately 15% of the total generation capacity in 2010, and the generated energy from dams was about 9% of the total energy produced for that year.

In 2020 the Syrian government embarked on a search for alternatives for electricity generation, by preparing a plan for both solar and wind energies, funded by the European Union. However, the internal political situation in the country has prevented the implementation of new projects for electricity production.

3.4. Iraq

The total generation capacity of dams in Iraq is 26.1 GW. At the end of 2017, with the increase in total energy demand during that year, there was a generation deficit equivalent to 31.9 TWh (Terawatt-hour). This deficit led to many interruptions in the grid and the overall suffering of the Iraqi network. To increase generation capacity, the Iraqi government has contracted private investors to implement thirteen electric generation projects using solar energy.

3.5. Libya

The internal political situation in Libya halted efforts started in 2011 to establish generating stations operating on renewable energies. The Libyan plan aimed to establish renewable energy stations with a capacity of 1200 MW using concentrated solar energy.

3.6. Tunisia

At the end of 2016, the Tunisian government established an action plan for renewable energies aimed at generating at least 30% of the country's electricity from renewable energy sources by 2030. More precisely, it is expected that the generation rates for hydroelectric, solar, and wind energy would rise to 37% of the total generation capacity on the grid by 2030.

Table 1. Current and future generation capacities for Egypt. Source: The Arab forum for electricity regulators, report on the Egyptian experience in developing renewable energies [19].

Expected grid capacity (2030)	(2024-2030)	(2021-2023)	(2018-2020)	Capacity (MW)	Generation Type
55,472	-	-	13,890	41,582	Thermal
2832	-	-	32	2800	Hydropower
8000	4620	1500	1740	140	Solar
14,300	9541		1042	747	Wind
80,604	14,161	1500	16,704	45,269	Total

3.7. Algeria

By the end of 2017, Algeria managed to achieve the equivalent of 19.5 GW in total capacity. This figure includes natural gas-fired power plants (there are large reserves of natural gas in Algeria) as well as thermal, hydroelectric, solar, and wind units. The installed capacity met the entire demand for electricity in 2017. The Algerian government has set plans in motion to increase reliance on renewable energies so that by 2030 renewables will account for 15.3% of the total generation on the grid.

3.8. Kingdom of Saudi Arabia

Saudi Arabia established King Abdulla City for atomic and renewable energies to increase its ability to generate energy using wind, solar, thermal, and nuclear energies, as well as to increase total electricity production from clean sources and reduce its dependence on fossil fuel. However, the amount of energy generated by solar plants is not expected to exceed 2.4% of the total energy generated in the year 2017. By 2030, it is expected that the installed capacities of solar power plants will reach 7.7% of the total generation capacity in the Kingdom.

3.9. State of Kuwait

Kuwait has managed to establish 26 small electric generation projects using solar energy, with a total capacity of 15 MW, including solar panels covering parking areas and building roofs. The capacity of the recently opened “Al-Shaqaa” solar plant is 50 MW. In addition, the construction of a wind power plant with a capacity of 15 MW is currently underway. The government has also contracted the construction of a 1500 MW solar power plant “Al-Dibdaba”, as part of a plan for renewable energy to reach 15% of its generation capacity by the year 2030.

3.10. Kingdom of Bahrain

Bahrain relies mainly on natural gas for its thermal generation units, such as the government stations “Sitrah”, “Riffa” and “Hidd”, in addition to two stations belonging to the private sector “Al-Dur” and “Al-Azl”. Its natural gas consumption has increased during the last few years. The Bahraini government intends to establish solar and wind power plants in the future to offset the increase in natural gas consumption.

The “Al-Oula” plant is considered Bahrain’s first solar generation project, with a capacity of 5.0 MW. The plant is comprised of photovoltaic panels installed on the roofs of parking lots. Another renewable electricity project called “Al Budoor” with a capacity of 5.0 MW is underway. It includes a photovoltaic power plant and a wind power plant. The government intends to provide 15% of the country’s electricity needs from renewable sources by 2035 [20].

3.11. State of Qatar

Qatar currently uses natural gas to fuel its power plants, which are considered

the most efficient generation systems in the Arab world. The capacities of the sestations account for 80% of the total generation capacity on the grid. The Qatari government has announced a goal to reach 20% of the energy generated by wind and solar plants by 2030 [20]. 15 MW has already been implemented from the solar station in the “Al-Raheel” area.

3.12. United Arab Emirates (UAE)

Demand for electricity in the UAE is expected to increase at an annual rate of 4.3% over the period 2018-2025. Therefore, the UAE government has intensified its efforts to diversify sources of electricity generation.

In 2014, the Abu Dhabi water and electricity authority established a solar power plant “One” with a capacity of 100 MW, operating on a concentrated solar energy system. In 2017, the UAE Ministry of Energy & Infrastructure contracted a private investor to build a photovoltaic solar power plant in the “Sweihan” area with a capacity of 1177 MW. In addition, the UAE has undertaken the construction of several solar generating stations in the Mohammed bin Rashid Al Maktoum solar energy complex (Table 2). It is expected that by 2030, the generation capacity of the UAE from renewable energy will reach 6500 MW, or 14.4% of the total generation capacity.

3.13. Results and Discussion

The efforts of OAPEC countries are achieving tangible progress in electricity generation from renewable energy sources. This section has reviewed their strategies and future prospects.

Qatar ranks first among the Arab Gulf countries, having the most efficient electrical generation system and a target to reach 20% of the energy generated from renewable energies by 2030. It is followed by the UAE with 14.3%, then Bahrain and Saudi Arabia with 10%, and finally Kuwait.

4. Growth of Renewable Energy Supply and Demand

This section aims to study the growth of global demand for renewable energy sources and its implications on the demand for fossil fuel, especially oil, during

Table 2. Implementation phases of the Al Maktoum solar energy complex. Source: Arab Petroleum Investment Corporation [21].

Electricity price (Cent/kWh)	Tech type	First year in service	Capacity (MW)	Part	Phase
unknown	photovoltaic	2013	13	-	1
5.84	photovoltaic	2017	200	-	2
2.99	photovoltaic	2018 2019 2020	200 300 300	1, 2, 3	3
7.3	concentrator	2020	700	747	4
-	unknown	2010-2030	3287	747	future phases
			5000		Total

the period 2017-2040. To achieve this goal, this study summarizes predictions from a prior OAPEC study related to global demand for major energy sources and the consequent changes in the global energy mix [2].

4.1. Prediction Scenarios

Renewable energy predictions of energy supply and demand are based on two distinct scenarios: the “New Policies Scenario” (NPS) and the “Sustainable Development Scenario” (SDS) [2]. The NPS and SDS scenarios are described in detail in the second and fourth parts of that study, respectively.

NPS incorporates all policies and measures affecting the energy markets that were adopted in years up to and including 2015, and also assumes that governments will act on any relevant intentions announced during the period, even if their precise implementation was not yet defined. For example, the latter category includes energy-related components of the Intended Nationally Determined Contributions (INDCs), submitted as pledges by governments in 2015 to the United Nations Framework Convention on Climate Change Conference of the Parties (COP21). These policies support investment in renewable energy and improved energy efficiency for conventional energy sources. It also promotes clean energy sources, carbon tax, and reform of energy subsidies. However, opponents of NPS claim that it reflects highly inadequate and relaxed climate policies that will cause a global temperature increase of 2.7°C to 3.3°C. Unlike SDS, NPS also requires significant investment in oil and gas to meet the increasing global energy demand [22] [23].

SDS is based on the more optimistic outcome of achieving all targets set by the Kyoto protocol and the Paris agreement. SDS assumes a significant rise in the number of enacted clean energy policies and investment strategies, sufficient to put the global energy system on track for attaining Sustainable Development Goals (SDGs) [24]. In addition, SDS assumes that all current net zero emissions pledges are achieved in full by 2070 for all countries. This scenario is consistent with limiting the global temperature rise to 1.65°C (below 2°C) [22] [23].

This study also examines the potential repercussions of renewable energy growth on the future of global oil supplies and investments.

4.2. Predicted Total Demand on Primary Energy Sources

According to international conventions [25], one ton of “oil equivalent” energy describes the quantity of energy contained in one ton of crude oil. This unit is used to express and compare the energies of different sources. For example, one ton of oil equivalent is equal to 1616 kg of coal, 1069 cubic meters of natural gas, or 954 kg of gasoline. For electricity, one ton of oil equivalent is equal to 11.6 MWh (megawatt hour). Demand for fossil fuel is expected to rise from 10.9 to 12.5 billion tons of oil equivalent by 2040, according to NPS. On the other hand, according to SDS, demand for fossil fuel is expected to decrease to 7.8 billion tons of oil equivalent (**Figure 2**).

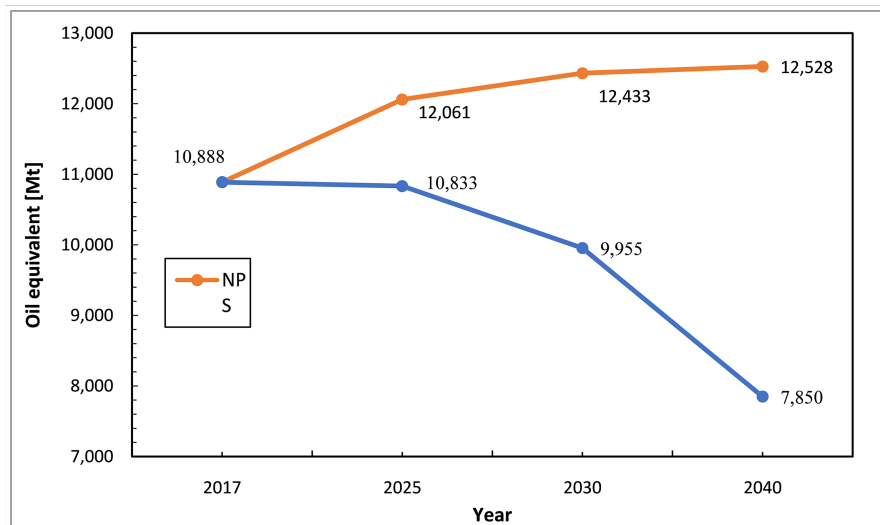


Figure 2. Expected global demand for fossil fuel (2017-2040). Source: OIAPEC 2019 [2].

The global demand for crude oil is expected to rise from 4.0 to 4.3 billion tons according to NPS. It is expected to decrease to 2.8 billion tons, according to SDS (**Figure 3**).

Global demand for natural gas is expected to rise from its 2017 value of 3.1 billion tons of oil equivalent to 4.4 or 3.4 according to NPS or SDS, respectively (**Figure 4**).

Global demand for renewable energy sources combined (solar, wind, etc.) is expected to rise from 2.0 billion tons of oil equivalent in 2017 to 3.6 or 4.2 according to NPS or SDS, respectively (**Figure 5**).

Finally, the predictions of the two scenarios indicate that the global energy mix will change. For example, the percentage of fossil fuel is expected to decrease from 80.2% to 73.3% according to NPS, and to 59% according to SDS. However, note that fossil fuel is expected to remain dominant according to both scenarios (**Figure 6**).

4.3. Predicted Demand on Energy Sources for Electricity Generation

The total electrical energy generated in 2017 using all fuel sources was 25,642 TWh (terawatt-hour). Fossil fuel accounted for the largest share in this sector at 64.9%, equivalent to 16,654 TWh.

According to NPS, the quantity of fossil fuel consumed for electricity generation is expected to increase at an annual rate of 0.8%, reaching 19,934 TWh or 49.3% of total electrical energy in 2040. According to SDS, the electric energy generated using fossil fuel will decrease at an annual rate of 3.4% to reach 7536 TWh, or 20.3% of total energy (**Figure 7**).

Both scenarios expect that the share of electricity generated from oil will decrease, from 940 to 527 TWh according to NPS, or from 840 to 196 TWh according to SDS (**Figure 8**).

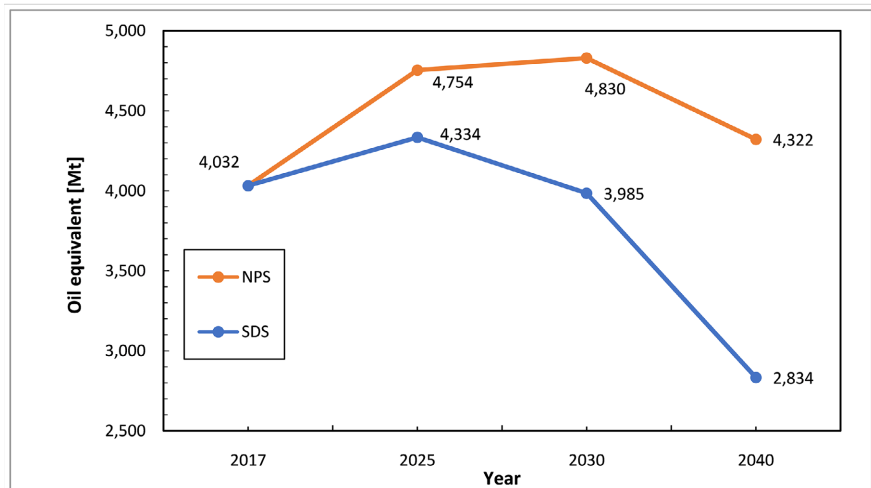


Figure 3. Expected global demand for oil (2017-2040). Source: OAPEC 2019 [2].

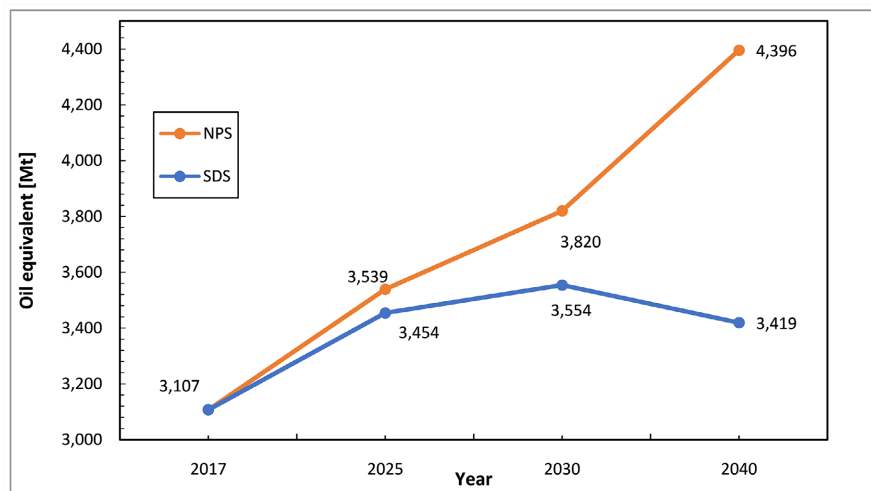


Figure 4. Expected global demand for natural gas (2017-2040). Source: OAPEC 2019 [2].

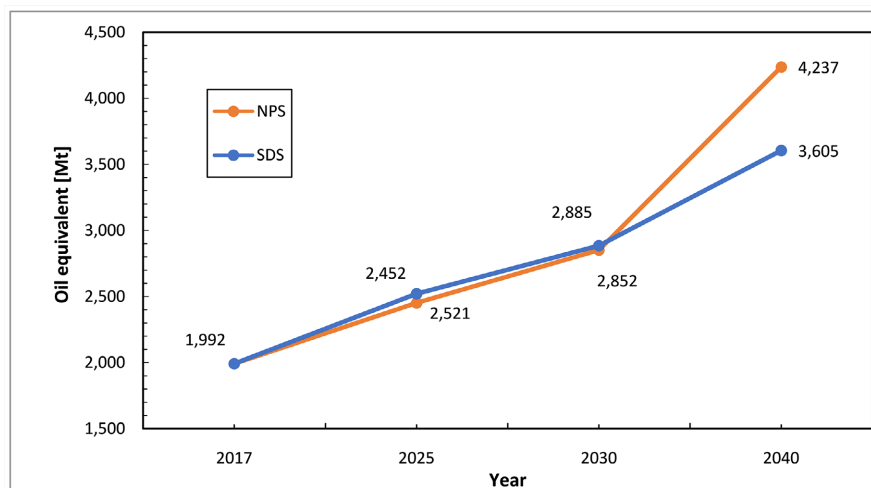


Figure 5. Expected global demand for renewable energy sources (2017-2040). Source: OAPEC 2019 [2].

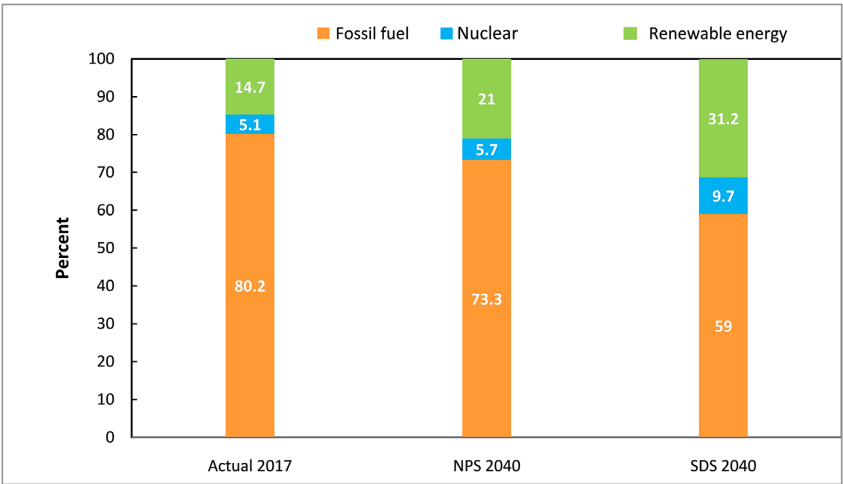


Figure 6. Expected global energy consumption mix in 2040. Source: OAPEC 2019 [2].

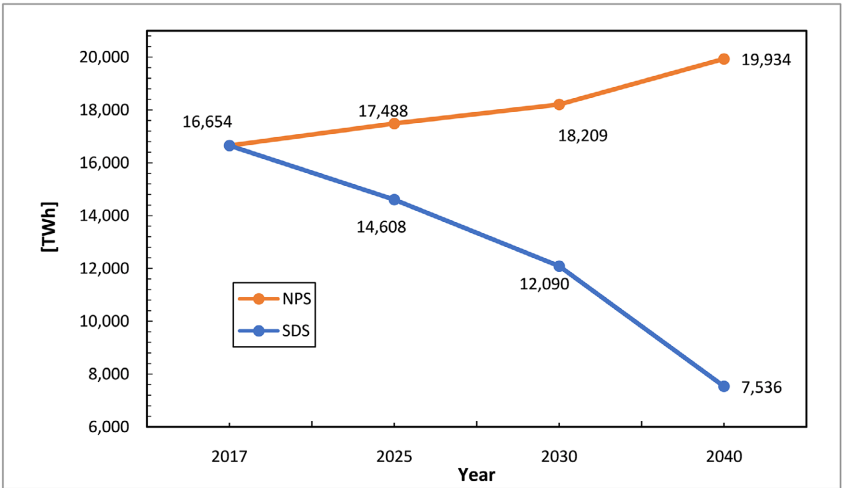


Figure 7. Expected demand for fossil fuel in electricity generation (2017-2040). Source: OAPEC 2019 [2].

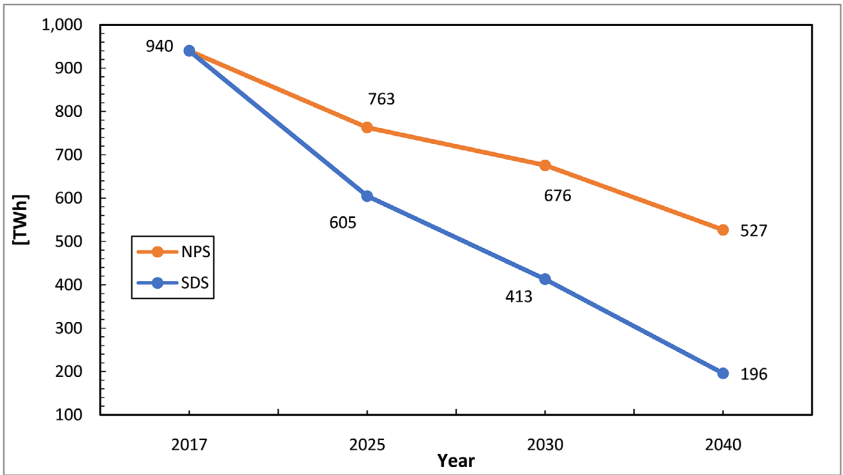


Figure 8. Expected oil demand for electricity generation (2017-2040). Source: OAPEC 2019 [2].

The share of electricity generated from renewable energy will increase from 6351 to 16,752 TWh according to NPS, and from 6351 to 24,585 TWh according to SDS (Figure 9).

In terms of percentages, electricity generation from fossil fuel will decrease from 64.9% to 49.3% or 20.3% according to NPS and SDS, respectively. Electricity generation from renewable energy will rise from 24.8% to 41.5% or 66.3% according to NPS or SDS, respectively (Figure 10).

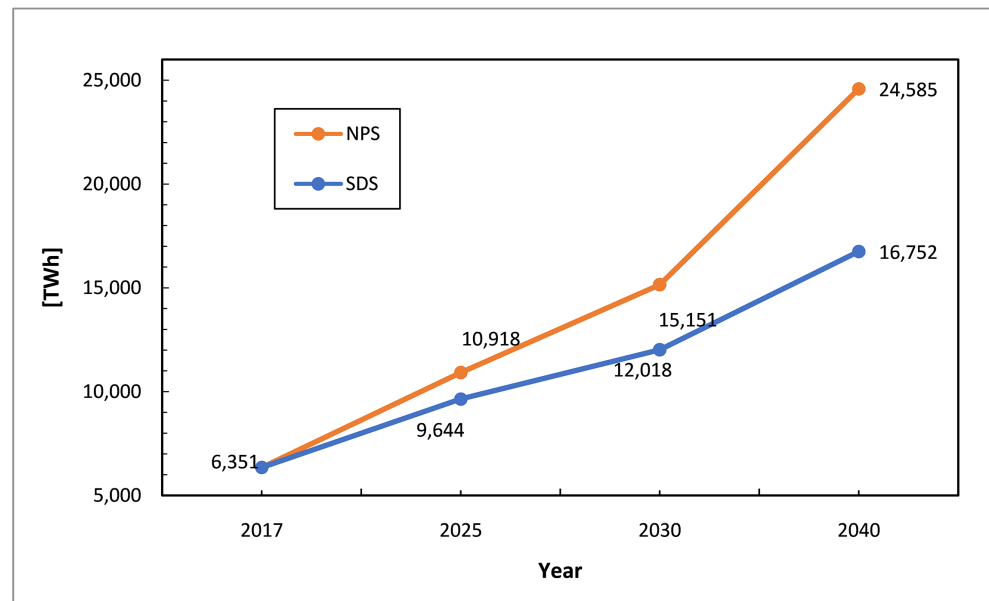


Figure 9. Expected demand for renewable energy in electricity generation (2017-2040). Source: OAPC 2019 [2].

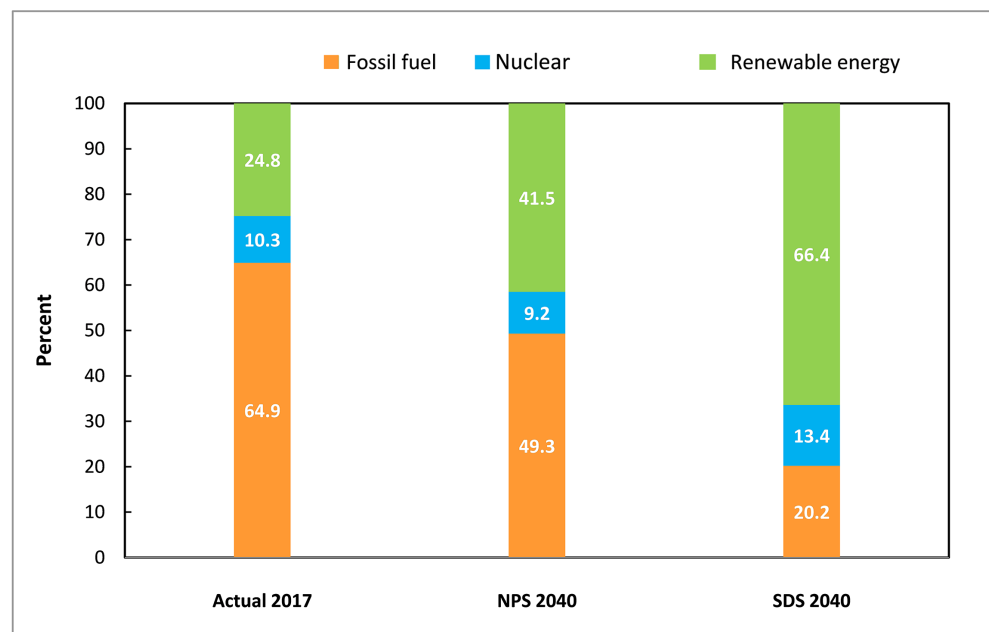


Figure 10. Expected mix of sources for electricity generation in 2040. Source: OAPC 2019 [2].

5. Conclusions

This study investigated the issues around renewable energy from several viewpoints: scientific principles and engineering foundations, strategies and prospects for electricity generation among OAPEC countries, future expectations of energy supply and demand, and possible repercussions of moving away from conventional fossil fuel resources.

In recent years, renewable energies have witnessed rapid growth across the world, especially solar and wind energy. The pace of growth is expected to increase in coming years as industrialized countries move towards low-emission energy sources and provide increasing government support and tax incentives to renewables. OAPEC countries are included in this trend and have responded to rising domestic energy consumption, by taking steps to benefit from their abundant renewable sources, especially solar energy. However, there is also a perception amount OAPEC countries that renewable energies compete with oil exploitation, or that the global energy transition will necessarily have a negative impact on their economies.

In fact, several OAPEC countries have announced strategic goals to increase the diversity of the energy mix and launched projects to increase their electricity generation capacity with renewables. But this diversity must be achieved sustainably and supported by traditional market mechanisms. The goal is to introduce more renewable energy into the mix without negative impacts.

A key challenge is to avoid market instability, for example, if the funding to increase oil supplies is reduced (or if oil-consuming countries perceive this as a risk). More precisely, there is a contradiction between consuming countries' desire to obtain secure oil supplies from OAPEC countries, and their desire to exit oil dependency. These taxes are justified as a means to weaken the oil demand and reduce its share in the energy mix over the long run, but they also reduce the share of profits received by oil-producing countries. Therefore, OAPEC countries see carbon taxes imposed on petroleum products as discriminatory and preventing free competition in the market. The policies of oil-consuming countries related to the search for alternatives to fossil fuel also raise concerns in oil-producing countries over reduced demand and a weaker regional economy. Overall, this situation has cultivated a reluctance among OAPEC countries to increase investment in the oil sector. There are other concerns related to the weakening global demand for fossil fuel, and OAPEC countries need to invest in protecting their economic position not just in the short term, but over the long term.

This study argues that OAPEC countries can successfully navigate the reduced demand for fossil fuel by embracing renewable energy as a strategic and complementary resource and increasing their investment in renewable capacity and infrastructure to reduce domestic demand for fossil fuel. With careful planning, the energy demand supplied by fossil fuel can be shifted from domestic to external consumers, while simultaneously stabilizing the supply available to oil-consuming

countries and reducing the environmental impact of industrial activities. Several specific actions are proposed that can be adopted by OAPEC countries to achieve these goals.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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