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Current Status, Scenario, and Prospective of Renewable Energy in Algeria: A Review

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Abstract: Energy demand has been overgrowing in developing countries. Moreover, the fluctuation of fuel prices is a primary concern faced by many countries that highly rely on conventional power generation to meet the load demand. Hence, the need to use alternative resources such as renewable energy is crucial to mitigate fossil fuel dependency alongside the reduction of Carbon Dioxide emission. Algeria's being the largest county in Africa has rapid growth in energy demand since the past decade due to the significant increase of residential, commercial, and industry sectors. Currently, the hydrocarbon-rich nation highly dependent on fossil fuels for electricity generation, where renewable energy only has a small contribution to the country's energy mix. However, the country has massive potential for renewable energy generations such as solar, wind, biomass, geothermal, and hydropower. Therefore, the government aims to diversify away from fossil fuel and promoting renewable energy generations through policies and renewable energy-related programs. The country's Renewable Energy and Energy Efficiency Development Plan focuses on large scale solar, wind generation as well as geothermal and biomass technologies. This paper provides an update on the current energy position and renewable energy status in Algeria. Moreover, this paper discusses RE policies and programs that aim to increase the country's renewable energy generation and its implementation status.

Keywords: Algeria; Africa; Renewable Energy; Solar; PENREE.

Highlights:

- Algeria has potential for solar, wind, hydro, geothermal and bio-power resources.
- Algeria target 27% of renewable energy generation into their energy mix by 2030
- The country has slow renewable energy development progress as in 2020.
- Algeria focused on increasing solar generation by 2030.

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Nomenclature:

DZD	Algerian Dinar
SPE	Algerian Electricity Production Company
SGTE	Algerian Electricity Transport Network Management Company
AEC	Algerian Energy Company
AIAER	Algerian Institute for Renewable Energies and Energy Efficiency
MEM	Algerian Ministry of Energy and Mining
CO2	carbon dioxide
CSP	Concentrating Solar Power
CREG	Electricity and Gas Regulation Commission
EPI	Environmental Performance Index
FIT	Feed-in Tariff
GW	Gigawatt
GDP	Gross Domestic Product
HDI	Human Development Index
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
IEA	International Energy Agency
IHA	International Hydropower Association Limited
MW	Megawatt
NFREC	National Fund for Renewable Energies and Cogeneration
NFREC	National Fund for Renewable Energy
ONM	National Meteorological Office
NEAL	New Energy Algeria
PPA	power purchase agreement
CDER	RE Development Centre
RE	Renewable Energy
PENREE	Renewable Energy Development and Energy Efficiency Program
REN21	Renewable Energy Policy Network for the 21st Century
SKB	Shariket Kahraba Berrouaghia
SKH	Shariket Kahraba Hadjret Ennouss
SKD	Shariket Kahraba Koudiet Eddraouche
SKS	Shariket Kahraba Skikda
SKT	Shariket Kahraba Terga
SKTM	Shariket Kahraba wa Taket Moutadjadida
UDES	Solar Development Unit
PV	Solar Photovoltaic
APRUE	The National Agency for Promotion and Rationalization of Energy
FNER	The National Energy Efficiency Fund
FNME	The National Fund for Energy Management
OPEC	The Organization of the Petroleum Exporting Countries
Tcf	Trillion Cubic Feet

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1. Introduction

The consumption of electrical power has always been increasing due to the rapid growth of population and economy. The total global energy consumption increased by 2.9 % in 2018 reached 26,700 TWh in 2018, where the energy worldwide rose 30 % from 2016 to 2018 [1,2]. The United Nations Human Development Index (HDI) proposes that growth in energy consumption up to around 100 Gigajoules (GJ) per person is linked with the substantial promotion in human development and comfort. Fossil fuels contribute almost 75 % of global electricity requirements in 2018, leading to higher Carbon Dioxide (CO2) emission. On the other hand, the Intergovernmental Panel on Climate Change (IPCC) reported the global average of temperature in the earth's surface has increased from 0.2 °C to 0.6 °C, resulting in the disappearance of ice sheets, massive changes in vegetation, regional extinctions and sea-level rise of about 120 meters [3]. Hence, it is crucial to reduce CO2 emission through the introduction of Renewable Energy (RE) generations to replace fossil fuel generations. Since a decade ago, many countries have implemented the green energy economy with goals and policies to increase their RE generations and reduce fossil fuel generations [4]. In 2018, there are 169 countries with RE goals, and 150 countries have funds for RE research and development with supportive policies [1].

Algeria located in the Sunbelt, which has a high potential for solar energy. In 2011, the Algerian Ministry of Energy and Mining (MEM) had introduced the law N°11-11 to fund and support the RE projects and laid the groundwork for the future RE program and sustainable development in the country. This law is considered a new incentive to commence initiatives to minimize the excessive consumption of conventional energy that is subjected to higher CO2 emissions and fluctuation of oil and gas prices [5].

There have been several researchers that provide updates on RE status in Algeria. For example, A. Boudghene Stambouli provides a review on the energy development in Algeria in 2012 [6,7]. The author discusses the country's energy scenario alongside exploring the potential of solar and wind in reducing dependency on fossil fuel. Other works related to Algerian energy status focus on the relationship between renewable and non-RE that contributes to high CO2 emission, such as in [8]. Recently, there has been a study on Algeria RE status and policy as in [9,10]. However, these studies do not provide the in-depth status of Algeria's current RE capacity and generation but focus on RE future targets and policies.

Moreover, they also heavily rely on old reports and literature from the past decades. There also discrepancies between the energy data provided by these sources. Therefore, this article's goal is to collect, compile, summarize, and analyses the data from sources such as reports, scientific articles, and online news articles related to the subject of RE in Algeria.

To the best of author knowledge, there has been no comprehensive review on the status and prospective of RE in Algeria since 2012. Hence, this paper will provide recent updates on current RE installation, potential, and policies. This paper is structured as follows: Section 2 provides information on the data collection sources. Section 3 provides information on the current global energy status. The introduction to Algeria's geography and demographic and status update on energy in the country discussed in Section 4. Section 5 reviews the RE potential such as solar, wind, hydropower, geothermal, and biomass in the country. Meanwhile, section 6 summarizes the energy stakeholders in the country. Section 7 focuses on policies and programs for RE. Section 8 shows the status of the country's RE development and installation. Additionally, social, economic, and environmental status from RE development in the country presented in section 9. Finally, Section 10 summarizes the findings and provides insights into the strategies implemented to increase RE generation in the country.

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2. Data Collection

This work mainly explores the status of RE in Algeria and the implementation of its laws, regulations, and programs. Additionally, this study includes the potential for RE installations in the country. The information gathered in this study is collected and summarized from official published reports. The main reports used as a reference in this study are listed below:

a) World Energy Outlook 2019 by International Energy Agency (IEA) [2]

b) International Energy Outlook 2019 by U.S Energy Information Administration.[11]

c) BP Statistical Review of World Energy 2019 [12]

d) Renewables Global Status Reports (2015-2020) by Renewable Energy Policy Network for the 21st Century (REN 21) [1,13–17]

e) World Energy Issues Monitor Reports (2015-2020) by World Energy Council [4,18–22]

f) Algeria Special Report 2020 by Africa Energy Series [23]

g) Hydropower Status Reports (2015-2020) by International Hydropower Association Limited (IHA) [24–29]

h) National Energy Report and Renewable Energy and Energy Efficiency Program report by Ministry of Energy and Mining (MEM), Algeria.[30,31]

i) National Renewable Energy Program 2015-2030 report by Shariket Kahraba wa Taket Moutadjadida, (SKTM), which is Sonelgaz holding's electricity generation subsidiary.[32]

Other resources related to the latest RE news in the country were obtained from online reports and scientific articles.

3. Global Energy Status

The global energy demand has been growing from 2011 to 2018 by approximately 30 % and expected to be doubled by 2022 [1]. Hence, many countries are moving toward RE to reduce dependency on fossil fuel and to mitigate CO2 emissions. There have been many countries that showed interest in RE sources to meet their energy demand. Huge investment alongside new policies and RE programs were introduced in developing countries for generation diversification and shifting to higher RE penetration. Nowadays, the cost of RE technologies is all-time low compared to past decades [33]. Moreover, having an abundance of renewable resources such as solar irradiation, wind speed, geothermal, and biomass leading to interest by their government to reconsider the usage of renewable energies instead of conventional fossil fuel [33].

Figure 1 shows the global energy mix in 2019 [1]. Fossil fuel contributes 72.7 % of the total global generation, with RE contributes 27.3 %. The global fossil fuel mix reduced by 2.8 %, complemented by the RE sources for the past three years. The RE contribution to global energy is increasing in each year compared to the previous year. Hydropower contributed 58 % from total global RE generation in 2019, followed by wind (21.6 %), Solar Photovoltaic (PV) (10.3 %), bio-power (8 %) and other generations such as geothermal, concentrated solar thermal power (CSP) and ocean power contribute 1.5 %. The year 2019 recorded the most significant increase in RE capacity due to reducing project expenses, significant investments, and the development of technology in the field. Global funding of also RE has been increasing throughout the years, leading to higher RE generation [1][34]. More than 200 GW of RE been added in this year, contributing towards a total of 2,588 GW of RE installed capacity. The distribution of the global RE technology mix is shown in Figure 2.

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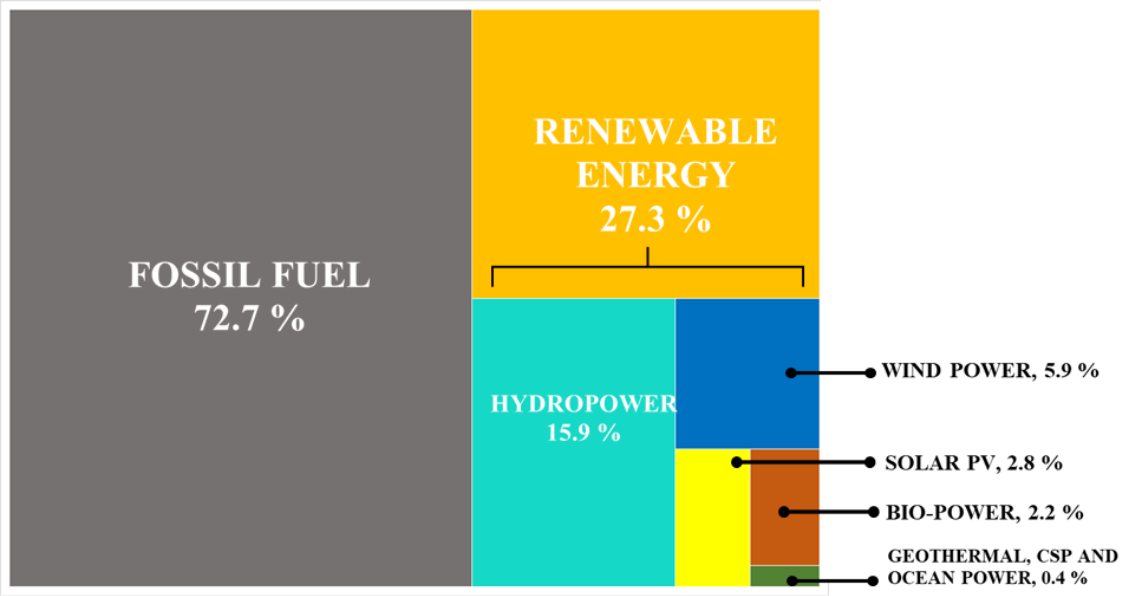

Figure 1. Global Energy Mix, 2019.

3.1. Hydropower

Hydropower is energy derived from falling or moving water [28]. Hydropower stations vary in terms of type, storage, size, and the height of the water. Generally, hydropower is classified based on their generation capacity where small hydro is a scheme below 10 MW, mini-hydro (scheme below 2 MW), micro-hydro (scheme below 500 kW), and pico-hydro (scheme below 10 kW) [35–37]. Hydropower plays an essential part in RE and in global energy production, where it contributes 15.9% of the global power in 2019 with a total capacity of 1,150 GW [28,38]. The hydropower generation roses by 1.4 % in 2019 from 1,134 GW to 1,150 GW [1,28]. The investment in large hydropower plants shared an obvious increase in world energy consumption, through an increase in the demand over the last ten years.

3.2. Wind

Wind energy is contemplated as one of the most efficient technologies in RE generation. The system uses kinetic energy from the wind to turn turbines for power generation [39]. The amount of wind energy available varies daily and seasonally. The total amount of wind energy able to be harnessed significantly depends on the characteristics, performance, and size of the wind turbines [33][39]. The total global wind generation in 2019 is 651 GW, with an increase of 10.2 % from 2018 [40,41].

3.3. Solar

Solar PV uses PV modules to convert energy from the sun into electricity [1]. Solar PV contributes 2.8% of the total global energy. The PV generation increased by 115 GW (22.5%) in 2019 from 512 GW to 627 GW, as shown in Figure 2 [42]. Hence, it has become the world's fastest-growing RE energy technology, the most expanded and competitive in the power generation market, through the facilities such as adequate frameworks and policies offered by the governments of most countries [39,43].

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3.4. Bio-Power

Bio-power includes solid biomass, liquid biofuels, biogas, and landfill gas [1]. This technology uses materials such as biomass to generate electricity or heat through methods such as direct firing, cofiring, anaerobic digestion, pyrolysis, and gasification [1]. Bio-power is a spatially spread resource. The bio-power also shows to have high greenhouse gasses emission but less than its fuel fossil counterpart [1]. Bio-power contributed 2.2% of the total global power generation in 2019. Bio-power generation capacity is at 136 GW in 2019, roses 4.6 % from 130 GW in 2018 to 136 GW in 2019 [1].

3.5. Geothermal

Geothermal is a technology that harnesses heat from the earth's sub-surface [44]. Geothermal energy has high efficiency with an average capacity factor of around 74.5%, and with the implementation of new technology, it can attain 90 % in the ideal site. The estimated geothermal reserve could supply the global world around 217 million years [45]. The geothermal has various applications, including penetration and heating system. In 2019, global geothermal power generation capacity reached 14 GW, which is a 5.3 % increase from the year 2018.

3.6. Concentrating Solar Power (CSP)

The CSP generates electrical power with mirrors to reflect a large amount of sunlight to a receiver that will be heated to drive a steam turbine connected to a generator [46]. The CSP capacity was at 6.45 GW in 2019, with an 18 % increased from 2018 that shows its most significant increment since 2014. Since the cost to build new CSP plants dropped significantly between 2016 and 2019. Numerous CSP stations are constructed in parallel with solar PV plants [1].

3.7. Ocean Power

Ocean power belongs to technologies that generate energy from the ocean through tidal streams, tidal range, ocean waves salinity gradient, and temperature gradient [47]. In this paper, ocean power does not include marine biomass and offshore wind power. This technology represents the smallest RE contribution with small scale projects. In 2019, ocean power generation capacity was 532 MW and had been stagnant for the past three years [1]. Although ocean power resource is vast, but mostly untapped due to immature technologies available.

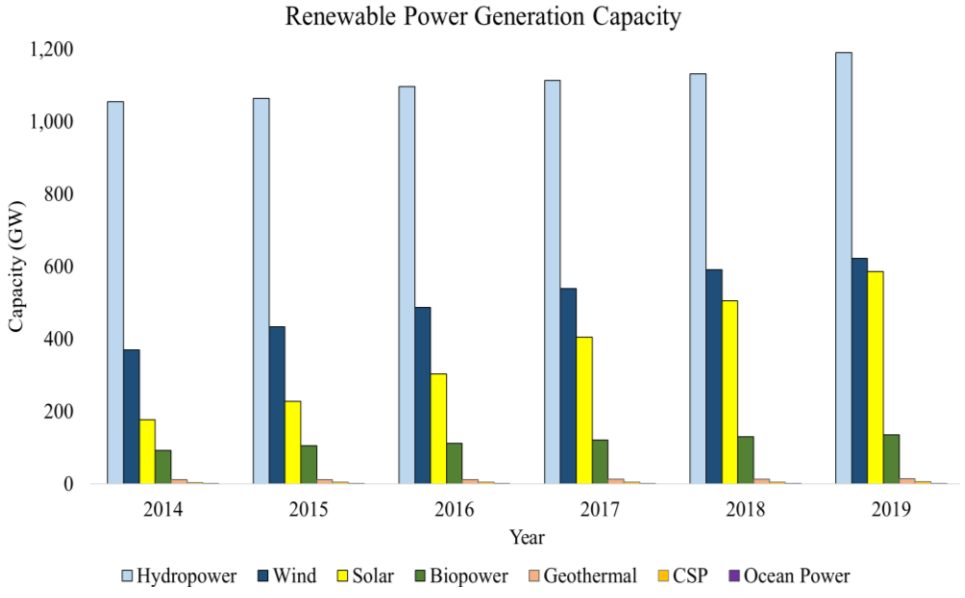

Figure 2. Global RE generation capacity.

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4. Energy Status in Algeria

Algeria is the largest county in Africa and the 10th largest in the world. It has an area of 2,381,741 km² and an estimated population of 42.2 million peoples with an average of 17.71 inhabitants/ km² [48]. It is located in the North of Africa with 1,644 km coastline, as shown in Figure 3 [49]. The Southern part of the country consists of a significant portion of the Sahara Desert. This region has a hot year around. However, the coastal area of the country is mountainous and hilly, with an average rainfall of 400 to 670 mm with temperature ranges from 25°C to 11°C.

Figure 3. Algeria location in Africa.

Algeria has 4th most influential economy in Africa, with $178.3 billion Gross Domestic Product (GDP) per capita [50]. The country's economy is mainly based on the production and export of gas and oil. Sonatrach is a national company responsible for the hydrocarbon sector. Algeria is among the countries that have an abundance of fossil and fuel and a member of The Organization of the Petroleum Exporting Countries (OPEC) [51][52]. Gas and oil basins in the country located in seven areas: the Ghedames and Illizi basins in the east; the Timimoun, Ahnet and Mouydir basins in central; and the Reggane and Tindouf basins in the southwest as illustrated in Figure 4 [50]. The country has the 3rd most extensive reserves of gas and the 7th most significant oil reserves in the world. In 2018, Algeria produced 12.2 billion barrels and 159 trillion cubic feet (Tcf) of oil and natural gas reserves, respectively [34].

Figure 5 shows the current energy mix of Algeria. The country relies heavily on fossil fuel generation for electricity, such as natural gas and oil, that contribute 64.84 % and 34.63 %, respectively. Algeria showed substantial growth in the production of gas, and oil from the year 2000 to 2018 contributed from a 33.3 % increase in the population [40][51]. Although 28 % of the Algeria population is located in a rural area, 100% of households in the country have access to electricity [48].

The government launched hydrocarbon law in July 2011 to increase competitiveness by easing taxes and encouraging import and export to attract foreign investment. Moreover, Algeria will have many oil refineries and gas treatment center projects kicked-off under the supervision of the national oil company Sonatrach [50]. Currently, the Algerian government is seeking to minimize the energy reliance on hydrocarbons, which represents 99.47 % of the country's power generation under the petroleum crisis.

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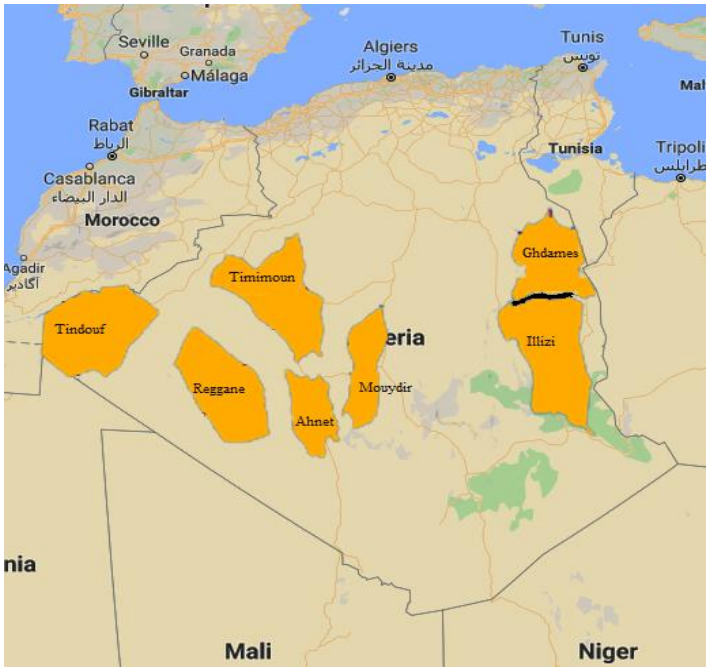

Figure 4. The location of gas and oil basins in Algeria.

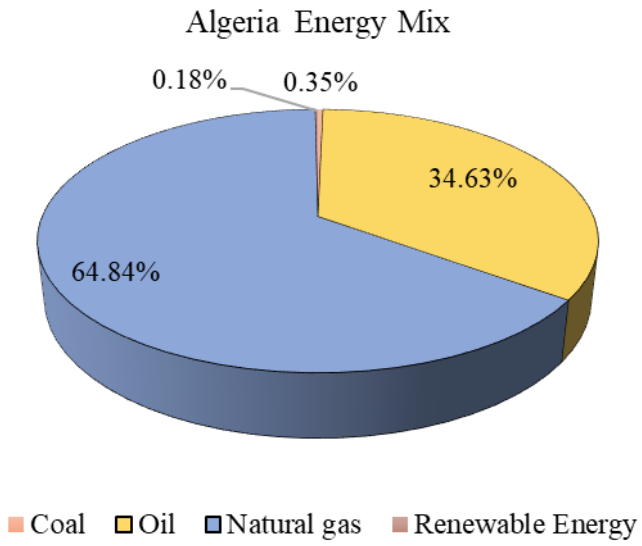

Figure 5. Algeria fossil fuel generation mix in 2019.

The electricity production rose to 76.4 TWh in 2018 from 76.0 TWh in 2017, proportional to the population growth of almost 1 million people [12]. The load demand has increased by 7.4 % from 2007 to 2017. The country's population and energy consumption profile are shown in Figure 6. By 2030, the generation expected to rise to approximately 150 TWh considering an additional 5.2% increment each year. The promulgation of the new -law N° 02/01 February 2002 corresponding to the distribution of electricity grid and the gas put the steppingstone for reorganizing the sector and opening the electricity market. The outcome of this law includes significant grid expansion for electricity transmission from the year 2002 to 2015. Moreover, Algeria able to export more than 880 GWh of electricity in 2017 to the neighboring countries such as Tunisia and Morocco [53][54]:.

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Due to the increase of energy demand in each year, Sonalgaz company estimated that 34,441 km of transmission lines are planned from 2017 to 2027. Currently, 9,930 km transmission lines are under development, with another 24,511 km planned, which includes national and international interconnection [55].

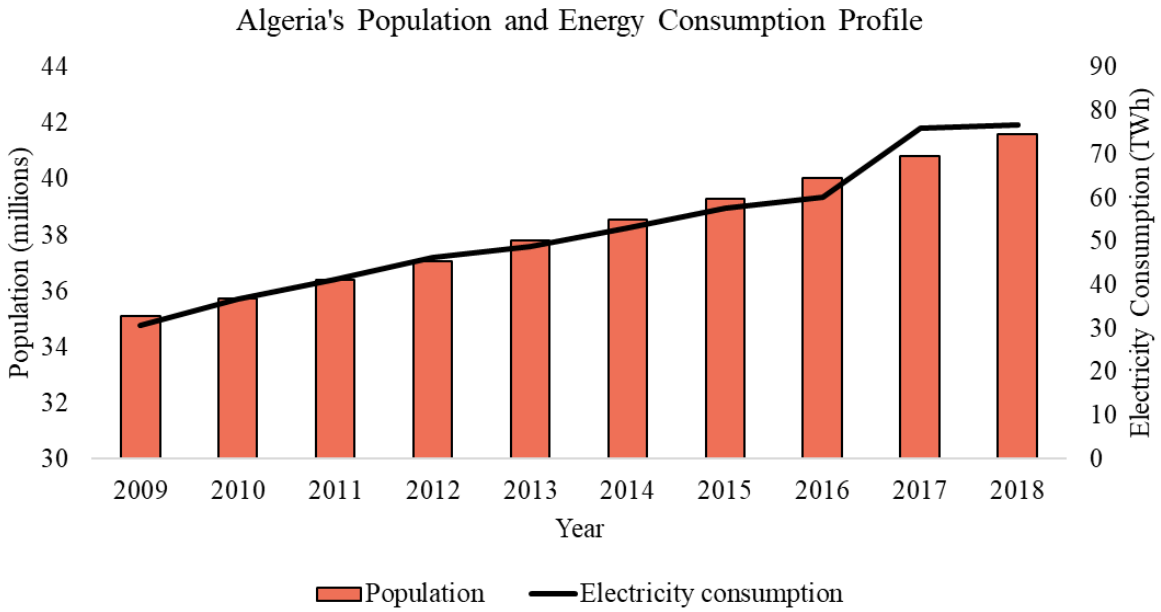

Figure 6. The evolution of population and electricity consumption in Algeria.

5. RE Potential in Algeria

The government has launched the policies and funds for RE development in the country since 1998. Algeria has promising RE sources such as hydropower, wind, geothermal, biomass, and solar due to its geographical location [33][56].

5.1. Solar

The country receives direct irradiation estimated at 169,440 kW/m²/year with potential generation of 3,000 kWh /year [57] [53]. Table 1 shows the potential solar generation in Algeria. The desert in the country is considered among high average solar irradiation and temperature globally. The duration of insolation is around 2,000 to 3,900 hours annually with horizontal surface radiation around 3 to 5 kWh/m². There is a network of 78 meteorological measurement stations by the National Meteorological Office (ONM) distributed throughout the country. Figure 7 and Figure 8 show the country's irradiation and temperature distribution [55].

Table 1. Solar potential in Algeria [58].

Location	Coastal area	Inner area	Desert area
Surface (%)	4	10	86
Average of the sunrise (hour/ year)	2,650	3,000	3,500
Average energy received (kWh/m²/year)	1,700	1,900	2,650

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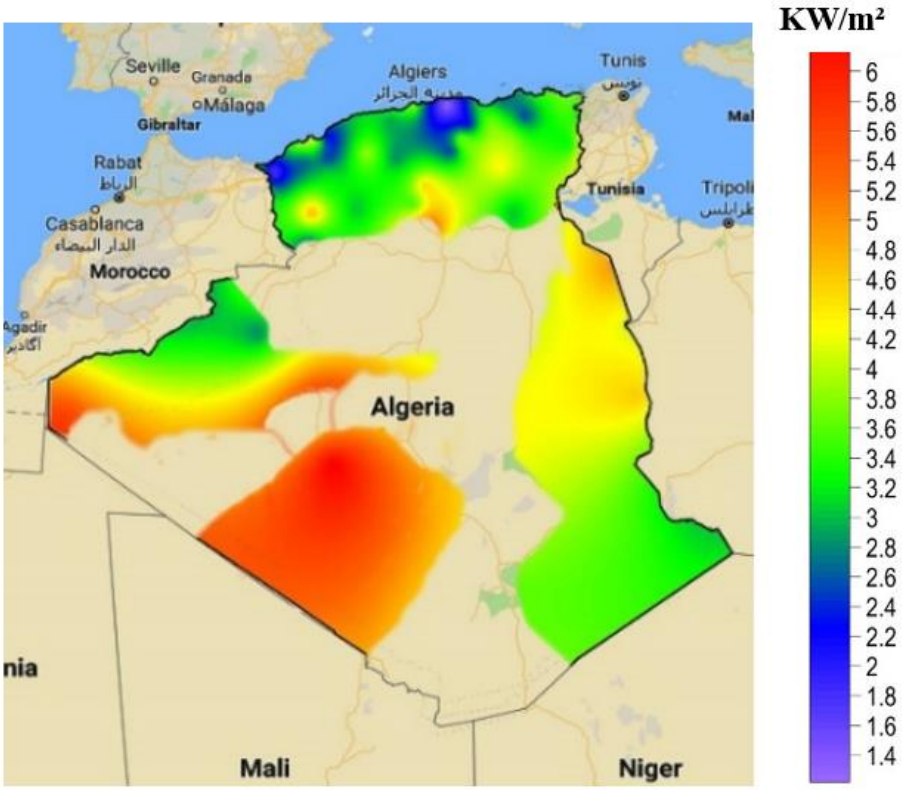

Figure 7. The solar irradiation in Algeria kW/m².

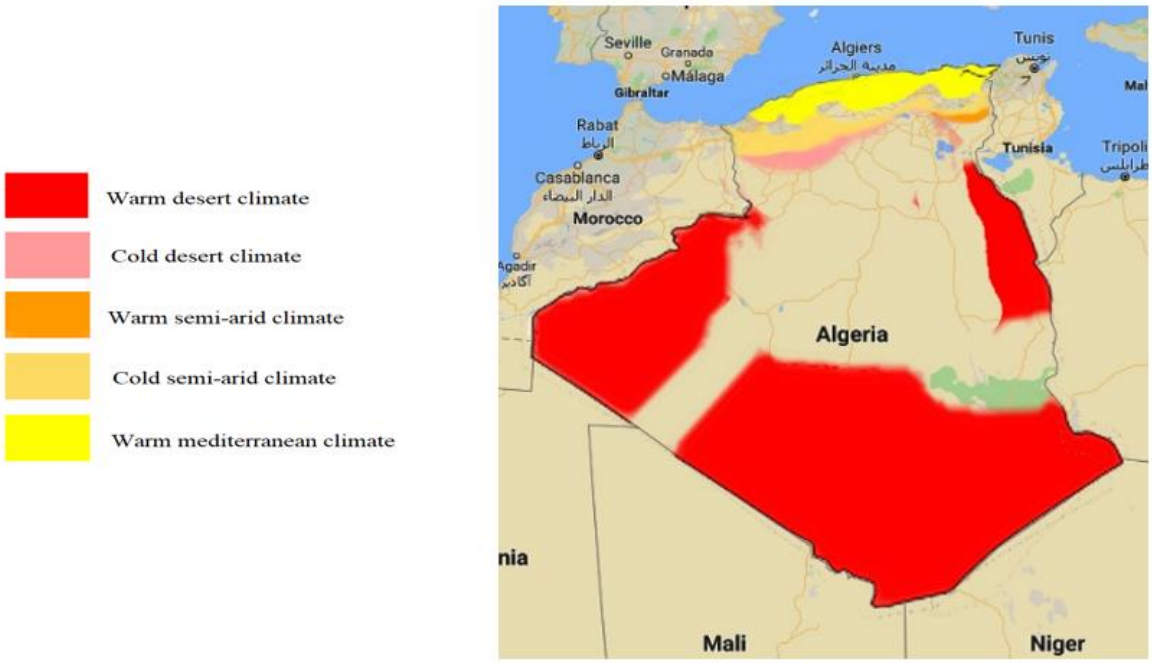

Figure 8. The temperature distribution in Algeria

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The solar generation potential in the desert area of the country is illustrated in Figure 9. The desert area on the country covers 2,048.297 km2 of land [33]. This area has potential for 168 x 1012 kWh/year considering 50% space factor and 10% efficiency.

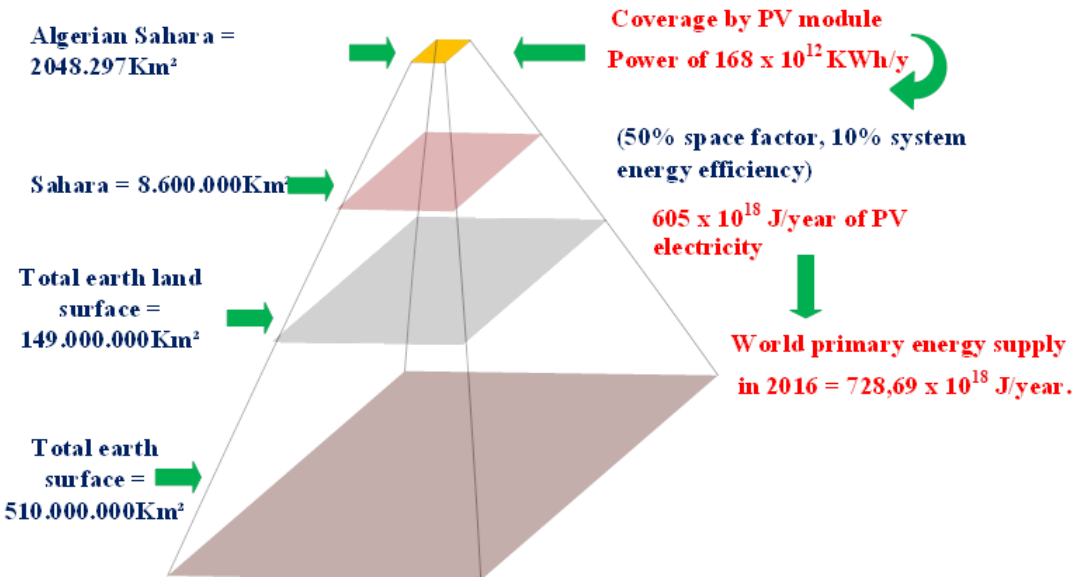

Figure 9. Potential solar for the Sahara Desert

5.2. Hydropower

Algeria has promising potential for hydropower generation due to the availability of dam sites and high average rainfall. Currently, there is a minimal study found that investigates the potential of hydropower in the country.

The average rainfall that flows over Algerian territory is estimated at 65 billion cubic meters per annum, with a potential of 103 dam sites [59]. Figure 10 shows potential sites for dams and rivers that are in the northern region of the country.

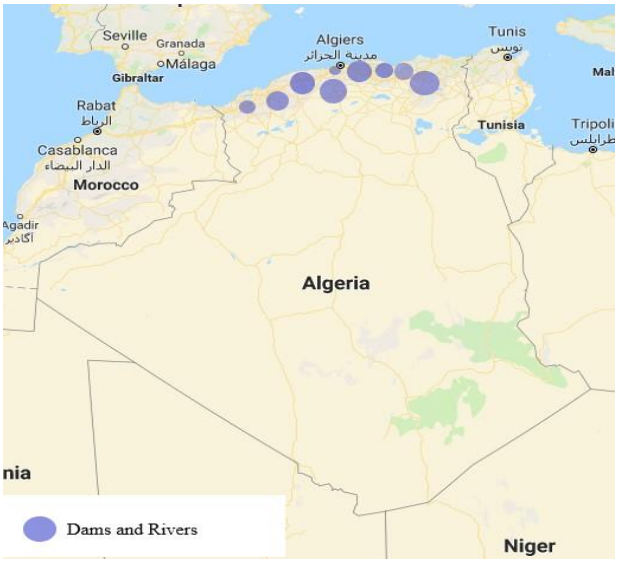

Figure 10. Potential dams and rivers locations in Algeria for hydropower generation.

5.3. Wind

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The wind resource in Algeria varies from one location to another based on topography and climate. The country is divided into two distinct geographical areas. The northern region of the country has a coastline of more than 1,600 km2 with mountainous topography. Whereas, the desert is in the southern region of the country. There were several studies been conducted to analyze the wind power generation potential in the country. Recently, Y. Himri et al. conducted a study to determine the feasibility of wind generation in the South West region of the country [60].

Moreover, Djamila Abdeslame studied the wind data measured over ten years from four locations in the country [61]. Additionally, H. Daaou Nedjari et al. from CDER conducted a study to determine the optimal locations for wind generation in the country [62]. The study in [62] by CDER provides a comprehensive study for wind potential in the country from 74 meteorological stations in the country.

Based on these studies, Algeria has the potential for wind generations in several regions, such as M'Sila, Bou Chekif, Djelfa, and Mecheria. These locations have wind presents throughout the year, with speed ranges from 6 to 7 m/s. Although, there are other locations with high wind speed, such as in Salah and Adrar. These locations are not suitable for wind generation installation due to geographical conditions and the unavailability of the electrical transmission network. On the other hand, extreme temperatures up to 50^{0}C limiting the installation for south desert locations in the country. Figure 11 illustrates the available wind speed across regions in the country [63][22].

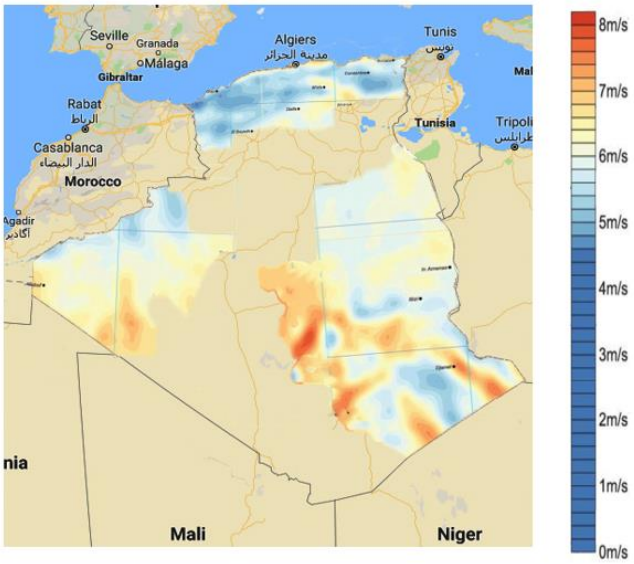

Figure 11. The wind speed potential in Algeria

5.4. Geothermal

Geothermal power is a promising solution to increase RE integration in the country due to the availability of a large number of hot springs [31]. Only limited works were found that investigates the potential geothermal resources in Algeria. For example, Fatima Zohra Kedaid from CDER develops a database of low-temperature geothermal locations in Algeria that includes information such as thematic maps, thermal springs, and hot water resources [64]. Additionally, Hakim Saibi summarizes the geothermal data and settings of Algeria from geothermal exploration data available from CDER [65]. Recently, Abdelkader Ait Ouali et al. conducted studies to evaluate the potential of geothermal in North Central Algeria in locations 31 thermal springs in locations such as Ouarsenis, Biban, and Kabylie [66].

Based on the studies in [64] and [65], there are more than 240 hot springs available and distributed from east to west and located at a moderate altitude in the mountainous regions in the country. The highest recorded temperature was 98^{0}C for the eastern area,

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68ºC for the western area, and 80ºC for the central area. Meanwhile, the southern area has an average temperature of 50ºC. Figure 11 shows the available locations for geothermal generation in the country. Meanwhile, Figure 13 shows the geothermic chart of 41 hot spring samples in the country.

The formation of the intercalary continental constitutes a vast number of the hot water reservoir in the southern region of the country. This reservoir, known as the "Albian aquifer," is exploited through boreholes and has an average temperature of 57 °C and 4 m3/s flow and can have potential generation up to 700 MW [65]. Table 2 shows the locations of hot springs in the country. The Arabic term 'Hammam' means hot springs.

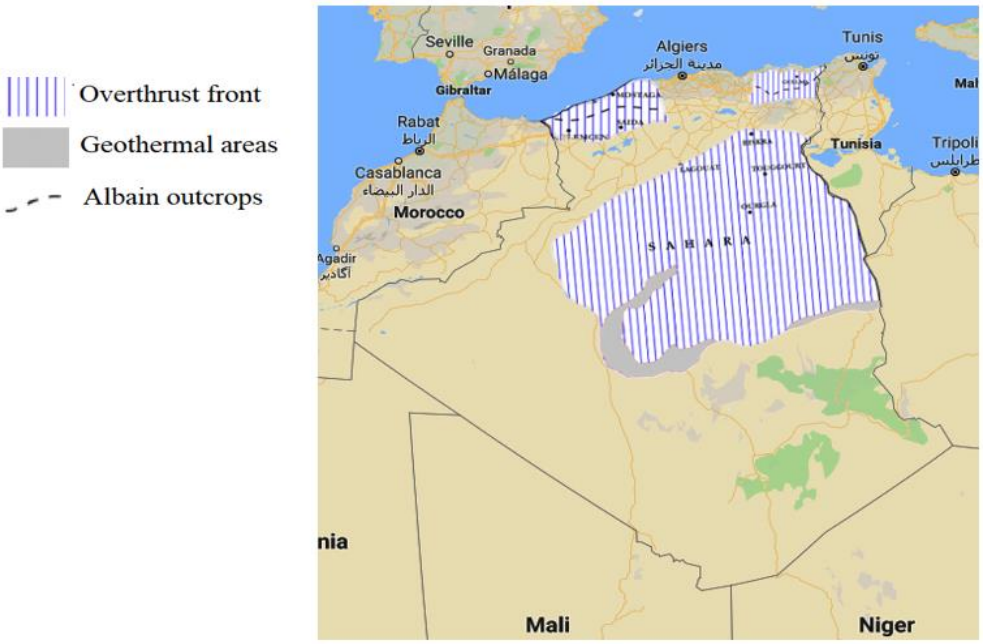

Figure 12. Geothermal potential locations in Algeria

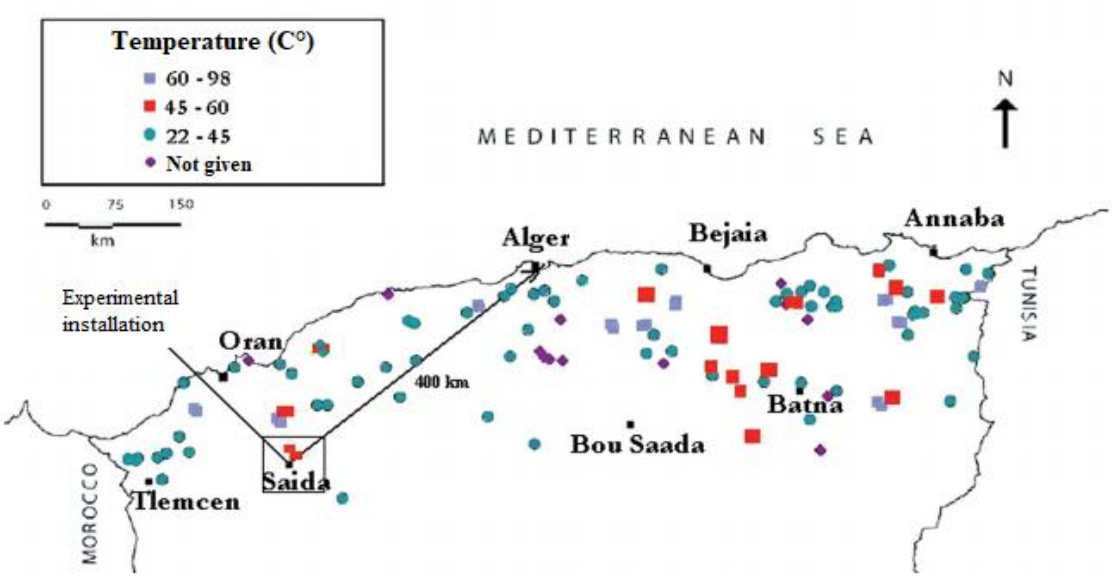

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Figure 13. The geothermic chart in Algeria

Table 2. Thermal source locations in Algeria

Thermal Source	Location	Temperature (c°)
Hammam Rabbi	Saïda	49
Hammam Bouhadjar	Aïn Témouchent	66.5
Hammam Ain Mentila	Relizane	31
Hammam Righa	Aïn Defla	67
Hammam Melouane	Blida	38.5
Hammam El Mesrane	Djelfa	42

5.5. Bio-power

Algeria has vast and diversified bio-power resources. The assessment of bio-power resources such as biomass is critical for the development of the bioenergy sector in the country. There were only limited works been conducted for bio-power potential assessment in the country. Amine Akbi from CDER provided an overview of the potential bioenergy in the country that focuses on domestically available biomass resources form energy generation [67]. Meanwhile, Boukelia Taqiy Eddine and Mecibah Med Salah investigates the potential of solid waste for biomass energy generation in Algeria [68]. The bio-power potential in the country based on the work conducted in [67] is summarized in Table 3.

Table 3. Potential bio-power in Algeria

Bio-power resources	Annual biogas potential (million m^3)	Potential energy (GWh)
Agribusiness and industry wastes		
Amurca available from the olive oil industry	10.5	17.74
Pomace available from the olive oil industry	-	215.5
Whey available from the dairy industry	2.35	3.97
Urban wastes		
The organic fraction of household wastes	974	1,646

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Sewage from wastewater treatment plants	22.91	38.72
TOTAL	1,009.76	1,706.43

6. Algeria Energy Stakeholders

There are several authorities and companies in Algeria that are responsible for the energy landscape in the country. The Ministry of Energy and Mines (MEM) is responsible for the energy policy and addresses issues of energy generation, transmission, distribution, and consumption in the country. Meanwhile, the Electricity and Gas Regulation Commission (CREG) serves as the regulatory body. At the same time, other energy stakeholders comprise of the utility and service companies, and other institutions that provide funding, service and research and development works. The government-owned companies such as SONATRACH and SONELGAZ are the key player in Algeria energy sector. The country energy stakeholders are summarized in Table 4:

Table 4. Algerian primary energy stakeholders [10,69].

No	Authority/Company	Role
	Government Bodies and Authorities	
1	Ministry of Energy and Mines (MEM)	Responsible for the development of policies and strategies for the exploitation, production, and usage of energy and mineral resources in the country.
2	The National Energy Efficiency Fund (FNER)	Providing funds for the development of RE in Algeria
3	The National Fund for Energy Management (FNME)	Providing funds for the development of RE in Algeria
4	The National Agency for Promotion and Rationalization of Energy (APRUE)	Promotes and control the national energy efficiency program and increase the awareness- and allocation of information on energy utilization
5	New Energy Algeria (NEAL)	Responsible for the country's RE production and development. Moreover, it also responsible for partnership, consultation for RE, and energy efficiency projects.
6	Electricity and Gas Regulation Commission (CREG)	Responsible for the regulation of electricity and gas for consumers and operators.

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7	Algerian Institute for Renewable Energies and Energy Efficiency (IAER)	Institute that facilitates RE and energy efficiency scientific research and knowledge exchange.
8	RE Development Centre (CDER)	Carry scientific activities for RE development in the country.
	Utilities	
1	SONATRACH	A national company responsible for the hydrocarbon reserves and the oil industry.
2	SONELGAZ	A national company responsible for the production, transport, and distribution of electricity.
3	Algerian Energy Company (AEC)	An association between SONELGAZ and SONATRACH with primary responsibility for production, commercialization, transportation, and distribution of electricity in Algeria.
4	Algerian Electricity Production Company (SPE)	SONELGAZ subsidiary company responsible for producing electricity.
5	Algerian Electricity Transport Network Management Company (SGTE)	SONELGAZ subsidiary company that is responsible for electricity transmission.
6	Electricity distribution companies	SONELGAZ subsidiary company that is responsible for the distribution of electricity that comprises of the western distribution company (SDO), the eastern company (SDE), the Algiers distribution company (SDA) and the central distribution company (SDC),
7	Independent power producers	The independent power producers in the country comprise of companies such as Shariket Kahraba Skikda (SKS), Shariket Kahraba Berrouaghia (SKB), Shariket Kahraba Terga (SKT), Shariket Kahraba Koudiet Eddraouche (SKD) and, Shariket Kahraba Hadjret Ennouss (SKH).

7. RE Program and Regulations

7.1. RE Programs

Algeria relies heavily on its primary energy generation, which is natural gas, to meet its electricity demand. The country is committed to diversifying its energy mixes due to the declining oil and gas prices alongside environmental issues. In February 2011, the country launched the Renewable Energy Development and Energy Efficiency Program

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(PENREE) to introduce RE into the nation's energy mix. Initially, the program plant provides 12 GW of national RE installation and 10 GW of RE export between 2011 to 2030. The goal of this program is to have 40% of the energy mix from RE by 2030. The national RE program installation was planned in three stages. The first stage was the establishment of pilot projects from 2011 to 2013. Next, the development of additional projects to be commenced from 2014 to 2015. Finally, large scale development of RE projects will be completed from 2016 to 2020. Meanwhile, the 10 GW RE energy export planned to be installed between 2021to 2030.

In February 2015, MEM announced the updated RE program. The primary goal of the updated program related to RE is to have 22 GW of RE installation by 2030 that contributes 27 % to the energy mix [70]. The program comprises of two stages of targets which are 4,395 MW installation between the year 2015 to 2020 and a total 17,605 MW from 2021 to 2030. Figure 14 shows the target installations of RE based on technologies. However, in 2019, the government has announced to relaunch PENREE to accelerate RE development in the country [71]. Hence, Algeria will be focusing more on solar energy development through the call for tenders in 2020.

7.2. RE Regulations

The primary law and orders related to the promotions and production of RE in Algeria are shown in Figure 15. The law No. 04-09 allows Algeria to clearly defines the RE goals for the country [10,72]. Law No. 09-09 of 2009 was launched to achieve these goals with a practical set of measures such as the establishment of National Fund for Renewable Energy (NFRE) and allocation of 0.5% of oil royalties for the RE fund. Additionally, Law No. 11-11 in 2011 established the National Fund for Renewable Energies and Cogeneration (NFREC), where NFRE extended to include cogeneration activities alongside the increment of 1% of oil royalties for RE fund [10,72]. Later, the incentives to carried out to increase RE generation were identified in Executive Decree No. 13-218 of 2013. Thus, the government pledge to grant bonuses for diversification of electricity from RE generations alongside buying RE electricity produced by both public and private entities. Lastly, Executive Decree No. 17-98 and Executive Decree No. 17-204 were introduced in 2017, where RE generation projects need to be distributed through tenders and auctions [10,72].

7.3. Financial Aids

The development of new RE generations contributed by the Algerian government through the NFREC. The fund primarily contributed by the 1% tax imposed for oil revenue alongside energy consumption taxes. The fund goal is not limited to financing feed-in tariff under the power purchase agreement (PPA) but also to finance the development of new RE projects. Algeria is the first African country to introduce the Feed-in Tariff (FiT) scheme through Executive Decree No. No.04-92 of 2004 to boost RE development and diversity in their energy mix [73]. The RE technologies included in the FiT scheme are CSP, bio-power, solar PV, hydropower, and wind. Meanwhile, the Executive Decree No. 13-218 of 2013 provides administration of the FiT implementation alongside bonuses in the percentage of the price per kWh. Based on the executive decree, the bonuses for RE generation from solar PV and wind is 300%, CSP and bio-power is 200 %, and hydropower is 100% [73]. Moreover, there is also financial aid bonus for a hybrid CSP and gas system that is based on the CSP contribution. The system with CSP capacity of 25%, 20 to 25%, 15 to 20%, 10 to 15 % and 5 to 10% are granted bonuses of 200%, 180%, 160%, 140% and 100%, respectively. Additionally, the country launches a new tariff in 2014 that is valid for 20 years for solar PV and wind [74]. The FiT is for RE in Algeria is summarized in Table 5.

Table 5. FiT for RE in Algeria [10,73,75]

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Source	Contribution	FiT (DZD/ kWh)	
		First 5 years	5 to 15 years
PV	<5 MW	15.94	11.80-20.08
	> 5MW	12.75	9.44-16.06
Wind	<5 MW	13.10	9.55-16.66
	> 5MW	10.48	7.64-13.33

7.4. RE Program Effectiveness Status

Table 6 shows the target and achievement of Algeria RE installation up to early 2020. The installed RE capacity as in early 2020 is significantly lower than the target [76]. The progress of PV and wind are far from target capacity with 13.33% and 5%, respectively. Meanwhile, there is no development for other RE generations, such as bio-power and geothermal.

Table 6. National RE program target installation and achievements

Source	Target in 2020 (MW)	Installed by 2020 (MW)	Achievement (%)
PV	3,000	400	13.33
Wind	1,010	50	5
Bio-power	360	0	0
Geothermal	5	0	0
CSP	-	25	-
TOTAL	4,375	475	10.7

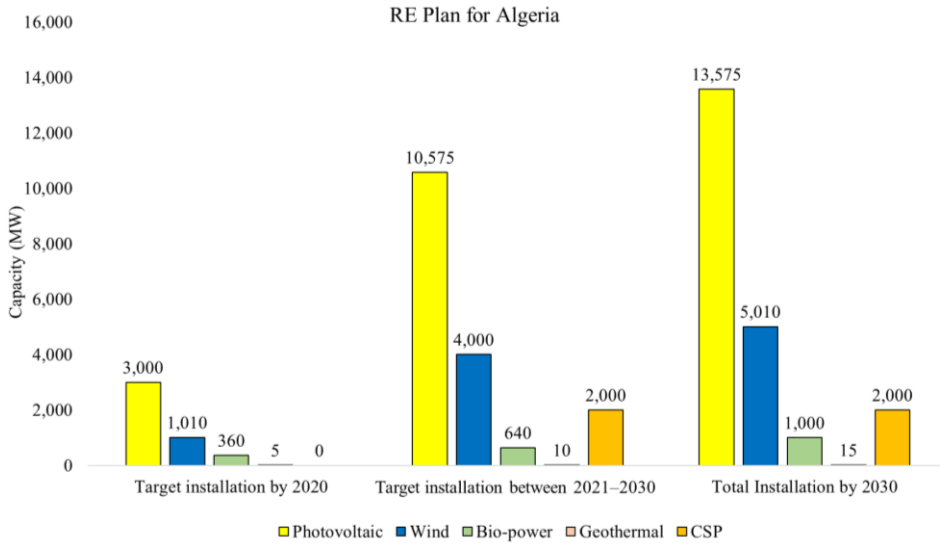

Figure 14. Algeria RE current and future generation plan.

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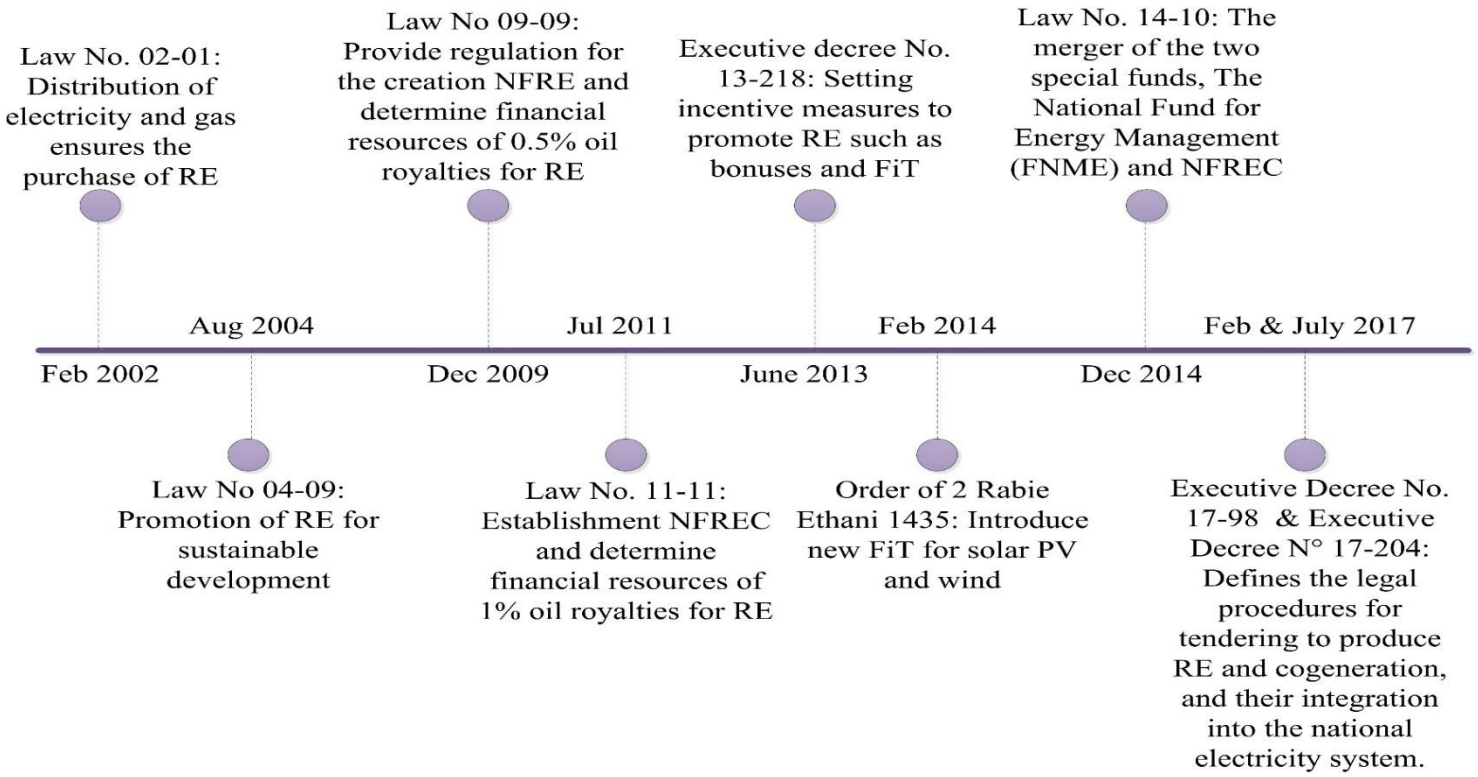

Figure 15. Major laws and regulations related to RE in Algeria.

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8. Renewable Energy Status

8.1. Solar

The RE master plan in Algeria focuses on the development of solar energy, with a total of 13,500 MW solar PV generation planned for 2030. The RE installed in Algeria based on technology is shown in Figure 16. Most of the installed PV in the country is aimed to provide electricity for rural areas with difficulties in grid extension. Figure 18 shows the locations of all PV stations in the country, and the list of installed PV farms is listed in Table 8.

Figure 19 shows the two PV power stations installed in Algeria.

The country's first solar plant installed in 2011, and there are 22 plants available with a total capacity of 423 MW at the end of 2019, which is seven times lower than the target of 3,000 MW by 2020 [23]. According to the initial target, a total of 60 PV generation plant projects were planned for the period 2011 to 2020.

In the past years, the country relies on imported solar modules from countries such as France, Spain, and China, leading to high-cost solar projects. Therefore, the country promotes domestic solar module manufacturing facilities. The government also supports the solar module manufacturing company through the requirement of local PV modules and systems in the tender for large solar projects. Hence, there have been several solar module factories developed in Algeria by companies such as Condor, ALPV, Aures Solaire, and ENIE to serve for national solar projects. Table 7 lists the PV factory location in Algeria and its annual capacity. Condor established the country's first solar factory in Bordj Bou Arreridj, Northern Algeria, in late 2013. The company also have a 51% stake in the French-Algerian company, Aures Solaire that has 50 MW manufacturing facility in Sidi Bel Abbes, Western Algeria, and 30 MW facility in Batna, Eastern Algeria. Algeria state-owned electronics company, ENIE, has a solar manufacturing facility with an annual capacity of 25 MW in Sidi Bel Abbes, Western Algeria. Additionally, the Algerian PV Company (ALPV) owned a PV production facility with an annual capacity of 12 MW at Batna, Eastern Algeria. Moreover, Miltech, which is the country's telecom and the renewable company, is currently building a solar module manufacturing facility with 100 MW annual capacity in Chelghoum El Aid, Northeast Algeria by 2020 [77].

In 2018, the CREG launched the first solar tender for 150 MW PV capacity for deployment at five locations in the country. This tender has limited success with only eight proposals for a total combined capacity of 90 MW, with only 50 MW procured [23]. The 50 MW winning project awarded to Power Generation, owned by Algerian company Condor. The successful project awarded a 20-year PPA, where they will build and operate the plant. In early 2020, the country has relaunched PENREE by opening another 150 MW tender and seeking proposals from both foreign and local companies. These are part of the country's plant to achieve 2,000 MW target by the end of 2020 [78].

Table 7. PV factory locations in Algeria

Company	Capacity (MW)	Location	In operation since
Condor	130	Bordj Bou Arreridj, Northern Algeria	2013
ALPV	12	Batna, Eastern Algeria	2010
Aures solaire	50	Sidi Bel Abbes, Western Algeria	2016
Aures solaire	30	Batna, Eastern Algeria	2017
ENIE	25	Sidi Bel Abbes, Western Algeria	2016
Milltech	100	Chelghoum El Aid, Northeast Algeria	2020 (under development)

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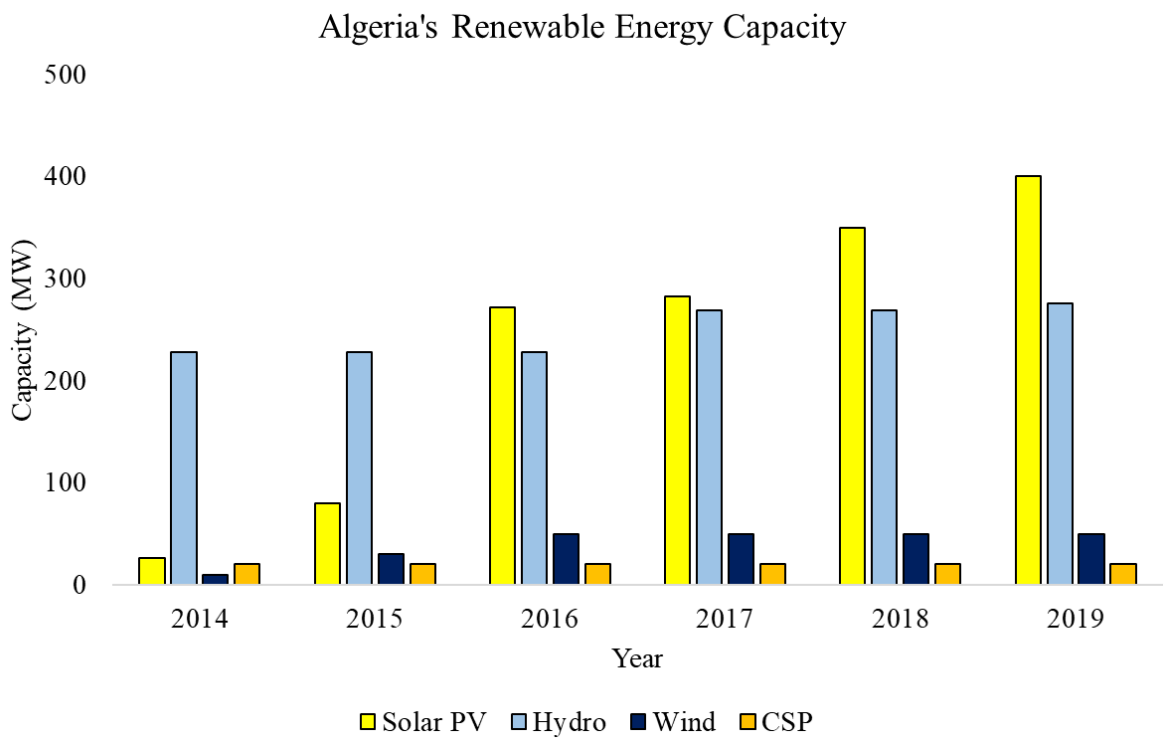

Figure 16. RE installed capacity in Algeria from 2014 to 2019

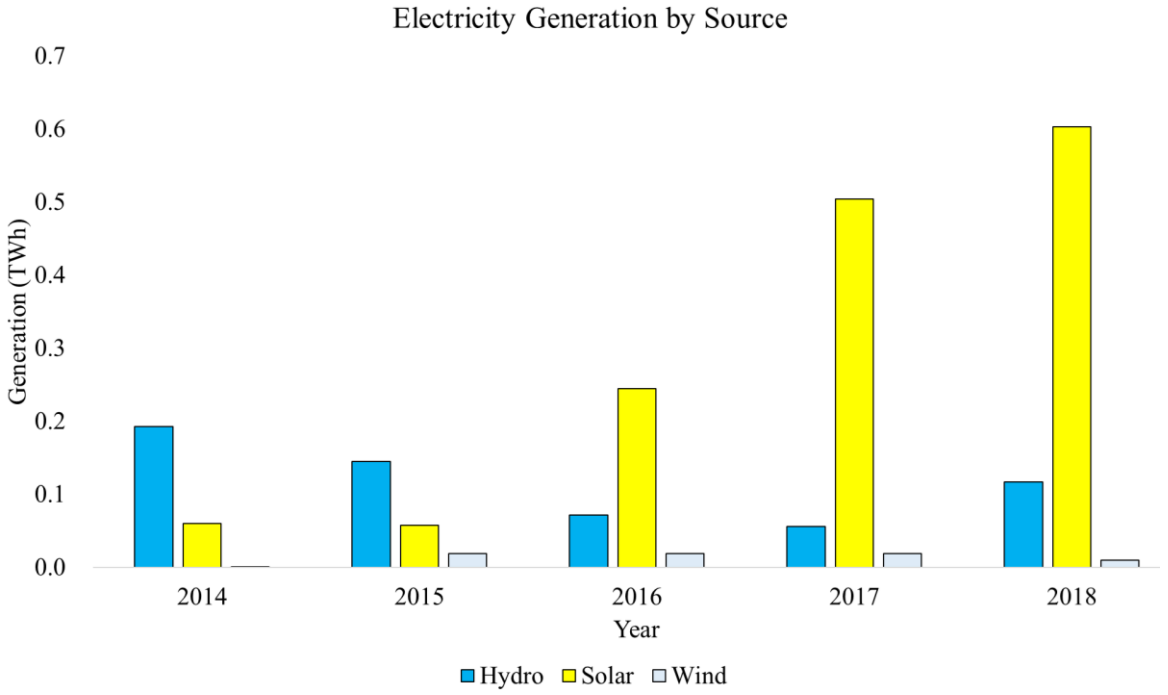

Figure 17. Algeria electricity generation by RE from 2014 to 2018

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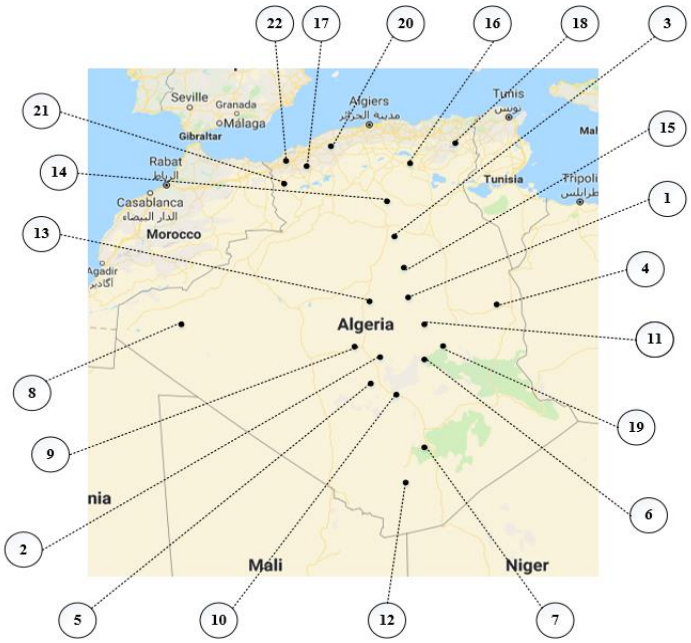

Figure 18. Locations of PV stations in Algeria

Table 8. Installed solar generations [33].

	Station	Location	Capacity (MW)
1	SPP1	Hassi R'mel	25
2	SPE	Adrar	10
3	Ghardaïa	Ghardaïa	11
4	Djanet	Illizi	3
5	Adrar	Adrar	20
6	Kabertene	Adrar	13
7	Tamanrasset	Tamanrasset	13
8	Tindouf	Tindouf	9
9	Z.Kounta	Adrar	6
10	Timimoun	Adrar	9
11	Reggane	Adrar	5
12	In-salah	Tamanrasset	5
13	Aoulef	Adrar	5
14	Ain EL-Lbel	Djelfa	20
15	Khang	Lghouat	20
16	Oued EL-Kebrit	Souk Ahras	15

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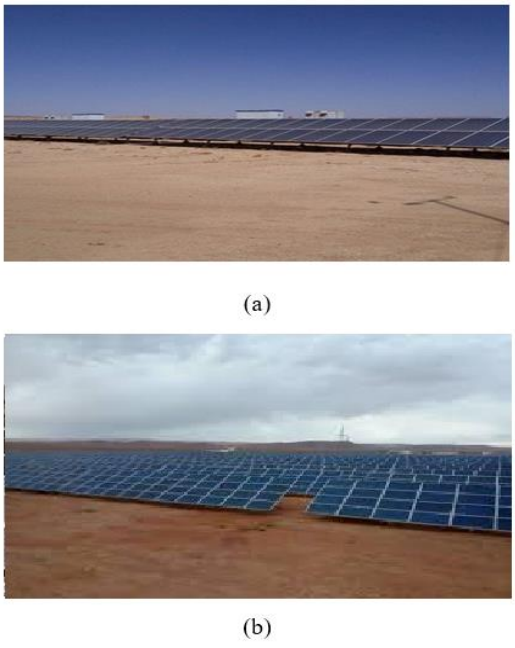
17	Sedrate Leghzal	Naama	20
18	Ain EL-Melh	M'sila	20
19	EL-Hadjira	Touggourt	10
20	Ain Shouna	Saida	30
21	E.B.S Chikh	El Bayadh	24
22	Telga	Telemcene	12



(a)

(b)

Figure 19 (a) PV farm in Tamanrasset. (b) PV farm in Djelfa

Algeria also focused on the development of solar thermal energy, such as CSP, as a major source of RE to cover 5% of the national energy mix by 2030. Initially, six solar thermal plants planned for the country by 2020. Algeria has one integrated solar combined cycle plant in Hassi R'mel with a capacity of 25 MW solar CSP and 130 MW combined cycle gas plant, as shown in Figure 20.

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Figure 20. CSP Hassi R'mel station [Source: edited from Google Maps]

8.2. Hydropower

There are 13 hydropower plants in Algeria with an annual generation of 389.4 GWh, which was the third-largest energy mix in the country after natural gas and oil. The country's small hydropower system (below 10 MW system) contributes 42 MW of the total generation [79].

Most of the hydropower plants were in the northern regions of the country. Figure 21 shows the locations of hydropower plants in Algeria. Meanwhile, Table 9 shows the list of hydropower installed plants based on the MEM report. The hydropower capacity based on the MEM report back in 2007 was 269 MW from a total of 13 hydropower stations [58]. Meanwhile, the hydropower reported to be 228 MW from 2014 to 2016 and increased to 269 MW from 2017 till 2019 based on Hydropower Status Reports by International Hydropower Association (IHA) [24–29].

Although the country has up to 269 MW of hydropower capacity, the country started to cease the operation of all hydropower generations in phases starting from 2014 and devoting the dams for water and irrigation purposes due to water shortages [80,81]. Hence, the hydropower generation of the country has dropped by 13% from 2007 to 2017, as shown in Figure 17.

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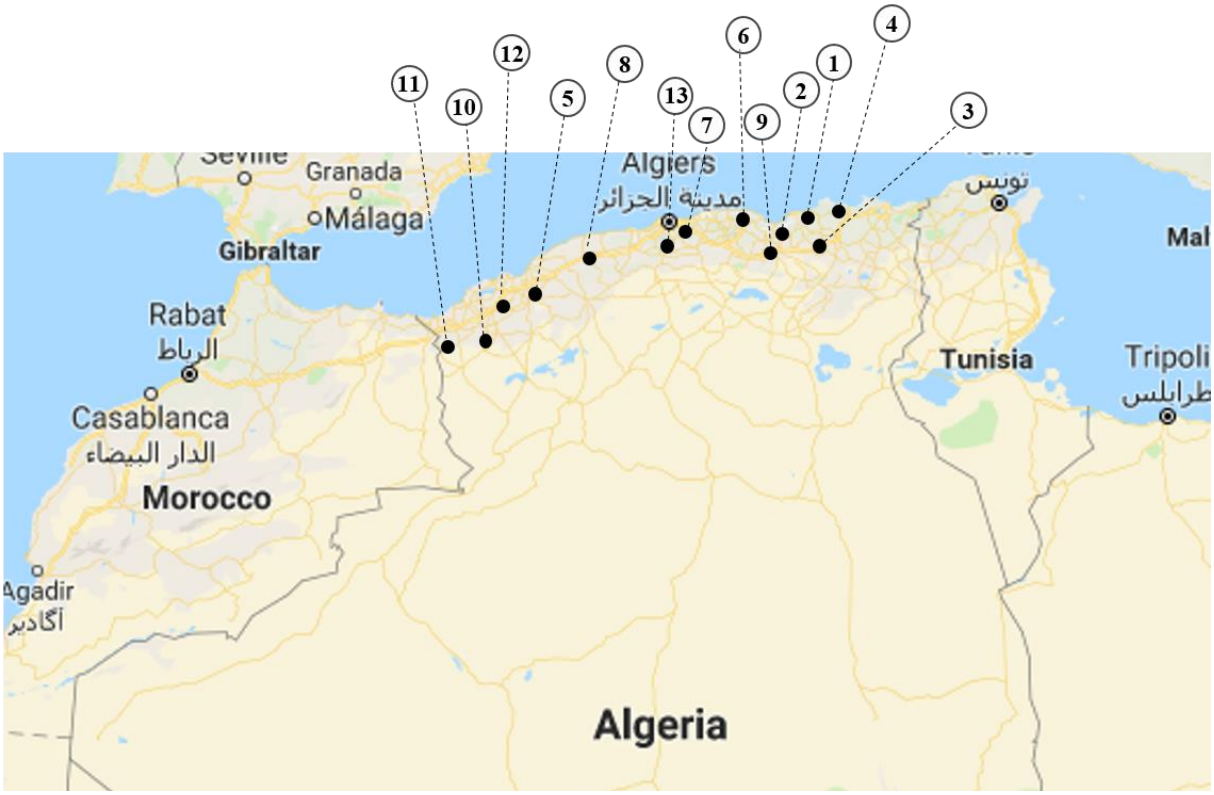

Figure 21. Locations of hydropower plants in Algeria.

Table 9. Hydropower plants in Algeria

No	Station	Capacity (MW)
1	Draguina (Bejaia)	71.5
2	Ighil emda (Bejaia)	24
3	Mansoria (Bejaia)	100
4	Erraguene (Jijel)	16
5	Souk el djemaa (Relizane)	8.085
6	Tizi meden (Tizi ouzou)	4.458
7	Ighzenchebel (Algiers)	2.712
8	Ghrib (Ain defla)	7
9	Gouriet (Bejaia)	6.425
10	Bouhanifia (Mascar)	5.700

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11	Oued fodda (Chlef)	15.6
12	Beni behdel (Tlemcen)	3.5
13	Tessala (Algiers)	4.228
	TOTAL	269.208

8.3. Wind

The first and only wind turbine farm in Algeria was installed in 2014 at Kabertene Adrar in the southern region of the country with a generation capacity of 10 MW [10,60]. The onshore wind farm owned and operated by Sonelgaz comprises 12 units of 850 kW turbines. Figure 22 shows the wind farm located in Adrar. Initially, there were seven wind generation plants planned for completion by 2020. However, there only one plant that has been developed and operational. As illustrated in Figure 17, the wind energy generation dropped by 47.4% from 19 GWh in 2017 to 10 GWh in 2018. Although the targeted wind generation in the country is 3,000 MW by 2030, there is no news or information made available by the government or RE companies regarding the wind power projects in the near future. The slower progress of wind generation compared to solar may be due to the moderate wind speed, less profit, and high maintenance cost. [82]. Moreover, the country also has less experience in wind generation with less precise wind maps available [82].

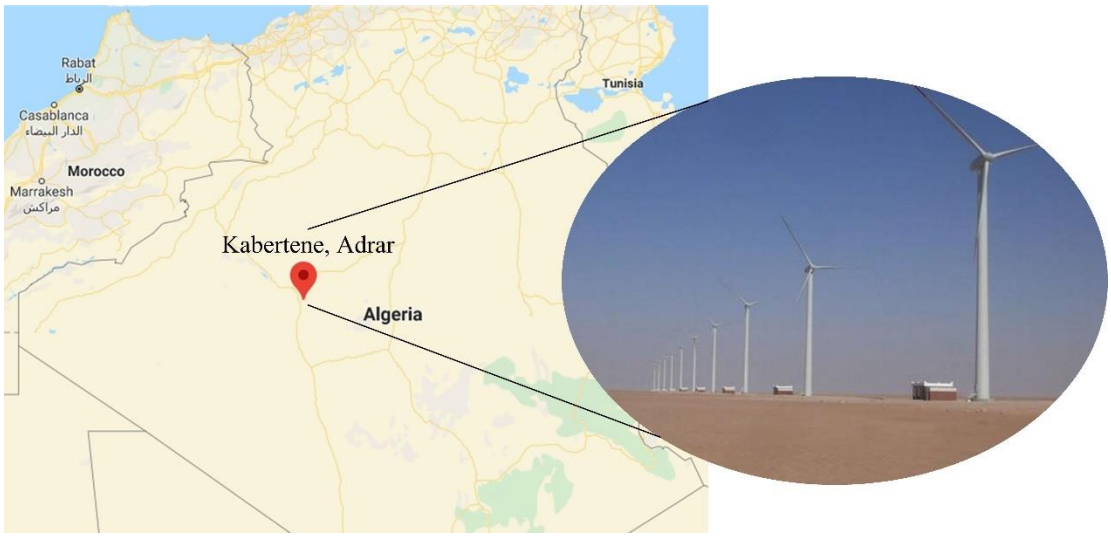

Figure 22. 10 MW wind power farm in Kabertene, Adrar.

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8.4. Geothermal

The CDER has established a geothermal center located in Saida (Sidi Aissa) for research and development of geothermal generation. The country has a geothermal generation target of only 15 MW by 2030. Currently, there are no planned projects in the pipeline for geothermal generation in the country.

8.5. Bio-power

CDER has established a bio-power research and development facility in Ouled fayet landfill. The target for Bio-power generation in the country is 1 GW by 2030. Currently, there is no bio-power generation in the country. In 2020, the government stated that the country would join the German Deserted project for RE supply that includes solar, wind, hydro, and biomass in Europe and the North African region [83].

9. Social, Economic and Environmental

The RE projects were aimed to improve the country's social, economic, and environmental development. The RE has immense potential for contribution to the creation of new jobs, education, agricultural improvement, municipal water supplies, and low carbon development.

The PENREE initial goal was not only limited to RE development and energy security. The plan also aims to create new jobs in the country. The plan includes 100,000 jobs creation for national RE production and 100,000 for export [84]. In 2020, the planned large solar power projects with up to 4 GW generation capacity is expected to create job opportunities for 56,000 people during the construction phase and 2,000 more jobs during operations [85]. According to [86], 20 years project of solar PV and wind considering construction, installation, and manufacturing alongside operation and maintenance jobs creates an average of 9.57 jobs/ MW and 0.93 jobs/ MW. Hence, there is an estimated of only 3,800 jobs currently available in the Algerian RE sector compared to 58,000 jobs planned to be made available by 2020.

In 2011, Algeria introduced a solar water heating program called ALSOL administered by APRUE. The ALSOL program was modeled based on the Tunisian solar water heating program called PROSOL that has been successfully implemented since 2005. The pilot phase consisted of a 45% subsidy for 400 residential systems with 200-liter storage tanks. The installation license for the 400 systems was distributed to 15 local companies. The systems were imported from Tunisia and France due to no local manufacturers available in the country. In mid-2011, APRUE announced the continuation of ALSOL for 2,000 residential homes with a similar subsidy. There is no new update available related to this program as in 2020, and there is no new program related to solar water heating announced by the government since then.

As for the education sector, the government has recently announced the development of an executive decree on the establishment of an educational institution to train RE and sustainable development professionals [87]. The graduated professionals from this program will support the job needs for the 22 GW RE plan by 2030. Moreover, Telemcen University in Algeria collaborated with the CDER for the development of RE short courses and training [88]. Solar Development Unit (UDES) and Silicium Technology Development Unit (UDTS) also have several collaborative programs with higher education institutions in the country [89].

The CO2 emissions in the country are highly influenced by the power generations from both oil and gas. Algeria ranked 83 at the Environmental Performance Index (EPI) out of 180 countries in 2018 [1]. Algeria committed to the Intended Nationally Determined Contribution (INDC) and agreed to reduce their greenhouse gasses by 7% by 2030. This target supported by the nation RE program that aims to have 27% of the energy mix from solar and wind sources by 2030 [90]. Figure 23 illustrates the CO2 emission trend in the country. The CO2 emitted in the country was 135.5 million tonnes in 2018, which is 6% higher than in 2017 [40]. The CO2 trend is increasing since the past decade, with an

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average growth of 4.1% due to the increasing load demand leading to higher power generation from fossil fuel resources [12].

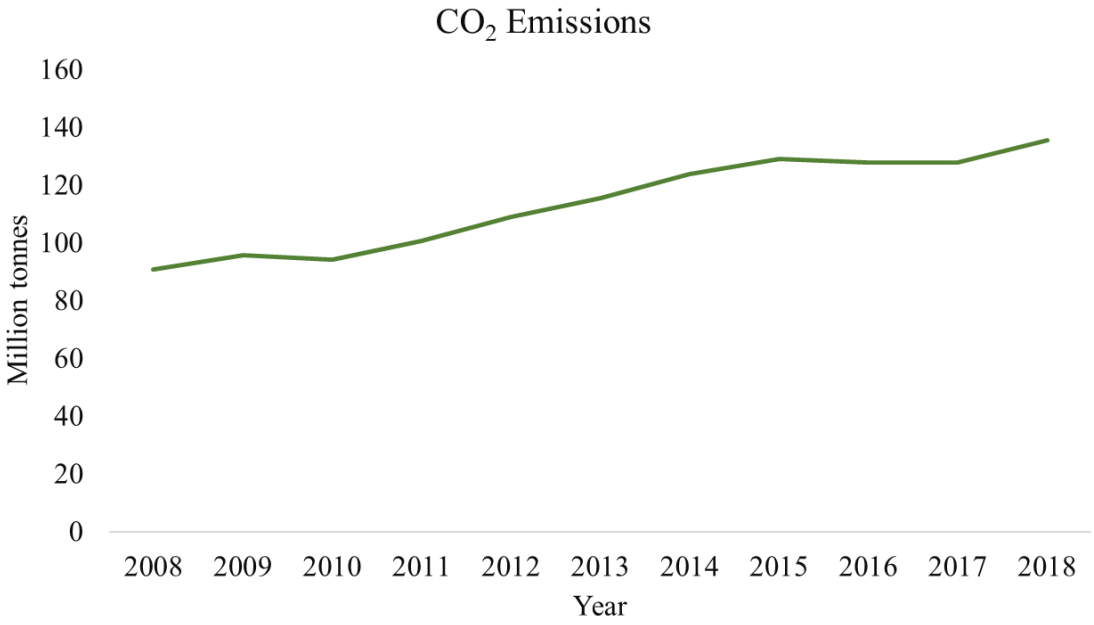

Figure 23. Algeria CO2 emission trend from 2008 to 2018.

10. Conclusions

This paper provides a critical review of the current energy situation in Algeria alongside RE resources availability and development status. RE proved to be a feasible solution to the current energy crisis in the country due to the fluctuation of fuel prices in the international market. Currently, the country relied heavily on its hydrocarbon sector, such as oil and gas, that contributed 99.47 % of its energy mix. Moreover, the country load demand has a 7 % growth since the past decade leading to higher energy consumption and high carbon emission. There were several vital laws, regulations, and programs introduced to increase the RE generation in the country. The goal of the national RE program, PENREE that was introduced in 2011, is to have 22 GW of RE generation that contributes 27% to the country energy mix by 2030. The RE program was updated in 2015 and 2019 that primarily targets to increase solar energy generation in the country. The plan is to have 13,575 MW of solar energy, 2,000 MW CSP, 5,010 MW of wind energy, 1,00 MW biopower, and 15 MW geothermal generation by 2030. Currently, there are only 22 PV plants available in the country with a total generation of 400 MW, one turbine plant with a total generation of 10 MW, and one CSP plant with a total capacity of 25 MW. There are 11 hydropower plants in the country with an annual generation of 389.4 GWh. However, the government decided to devote the hydropower dams for water and irrigation purposes since 2014, leading to lower power generations. There is no geothermal and bio-power generation currently available in the country. To significantly increase the RE development, the government has released tender for 150 MW large solar plant project in 2020.

Moreover, a new PV manufacturing factory by Miltech will be developed by 2020 with 100 MW annual capacity to add to the current five solar factories with a total capacity of 247 MW. The RE development was anticipated to contribute to the country's social, economic, and environment. Currently, the RE projects have only created 3,800 new jobs with a target of 58,00 jobs by 2020. The CO2 emission is increasing with 4.1 % growth since

the last decade due to an increase in energy demand with no significant emission reductions from RE generations. Additionally, the country also has a solar water heating program called ANSOL, which was introduced in 2011 to subsidize 45% of the installation cost for 400 residential houses. The country also aims to have educational institutions to support the needs of RE professionals. CDER, alongside other RE entities in the country, has collaborated with local universities for short courses and training.

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