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Review

Overview of the Role of Energy Resources in Algeria's Energy Transition

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Abstract: Algeria is a wealthy country with natural resources, namely, nuclear, renewable, and non-renewable sources. The non-renewable energy sources are considered the lion's share for energy production (98%). Algeria's efforts to ensure and strengthen its energy security will take an important step in the coming decades by commissioning new energy infrastructure based on intensive use of water, coal, nuclear, non-renewable, and renewable sources. The implementation of new power infrastructure is expected to be operational from 2030. The renewable power realization in Algeria is relatively less compared to other African countries, i.e., Morocco, Egypt, South Africa, etc. The total renewable power installed capacity in Algeria reached 686 MW in 2020, as part of its national energy portfolio, although the Algerian government has spent tremendous efforts on introducing new sustainable technologies to enable the transition towards a cleaner and sustainable energy system. Indeed, the country announced its plan to install around 22 GW of renewable energy capacity by 2030. It will include 1 GW bio-power from the waste, 13.5 GW from solar PV, 2 GW from CSP, 15 MW from geothermal, 400 MW cogeneration, and, finally, 5 GW from wind. The scope of the present research provides general information about the usage of energy resources such as fossil, nuclear, and renewable sources in Algeria and also covers the energy supply outlook. The present effort is the first of its kind which discusses the application of the coal and nuclear as clean energy sources as part of renewable energy transition. Additionally, it also includes the description of the existing Algerian energy sector and information about water and water desalination and their usage in other sectors.

Keywords: nuclear; renewable energy; solar; water; wind energy

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1. Introduction

Ever-growing global population, power demands, and the environmental awareness have led the people from all walks of life to develop and use clean and renewable energy sources (RES). Furthermore, the renewable sources will not run out, do not emit greenhouse gases (GHG), and are available everywhere and to everyone, irrespective of political and geographical boundaries. Renewables give birth to new industry, boost national economy, create new jobs, provide economical energy, and, at the same time, minimize the adverse effects of conventional energy sources. The utilization of RES is being encouraged in a wide range of applications, such as quality power supply to isolated and small applications through hybrid power systems [1–5], offgrid and grid-connected wind and solar

PV farms [6–13], power generation using the solar chimney concept [14], and solar air conditioning and desalination [15–17]. With technological advancement and commercial acceptance of RES and new energy industries, the demand for energy storage systems is increasing. Super-capacitors [18] and lithium-ion batteries [19] have become the preferred energy storage media for hybrid power systems, smart grids, and other applications due to their high energy density, fast charging and discharging speeds, and long life [20]. It is evident from Figure 1 that cumulative renewable power utilization is increasing at a steady pace [21].

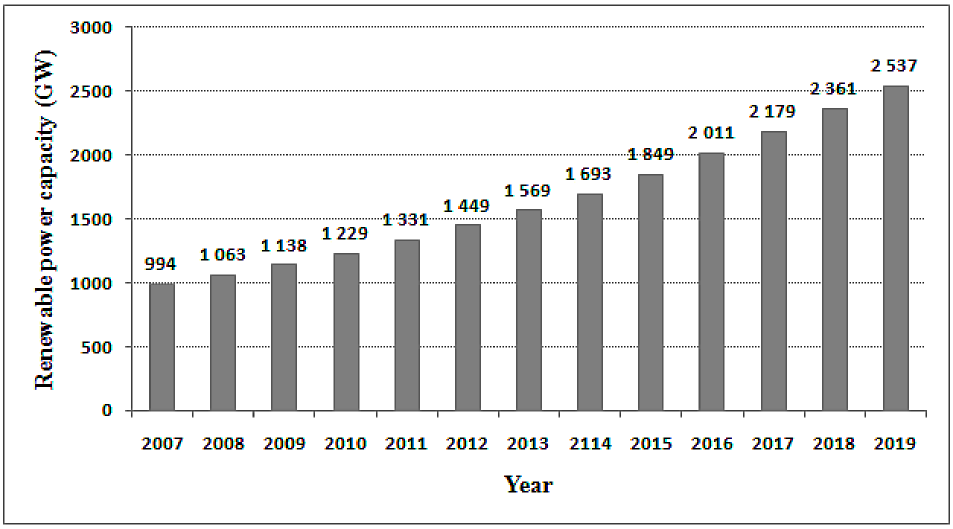

Figure 1. Global cumulative renewable power installed capacity growth (GW) [21].

The global renewable capacity increased from 2179 GW to 2361 GW, corresponding to years 2017 to 2018, with a growth of 8.4%. Similarly, the renewable power growth increased by 7.5% in 2019 (an addition of 176 GW) compared to 2018. On average, the global renewable power capacity has been increasing by 8.1% from 2007 to 2019.

In 2017, the solar photovoltaic (PV) and wind power capacities grew by impressive volumes of 32% and 10%, respectively. This growth can be attributed to continuously decreasing costs of both of these technologies and technology maturity. The levelized cost of energy (LCOE) from PV decreased by 73% between 2010 and 2017, whereas that of onshore wind energy by almost 25% [22]. The present cost of RES has become almost compatible with traditional fossil fuel technologies and in some cases and regions, it has even become economic, especially when including externalities such as health impacts. Keeping in view the growing spectrum of renewables worldwide, Algeria is also moving forward, implementing renewable energy (RE)-based applications in the country to accomplish the GHG targets.

Algeria is located in North Africa between 35° and 38° north latitude and 8° and 12° east longitude and shares borders with seven countries (Mauritania, Morocco, and Western Sahara in the west, Tunisia and Libya in the east, Mali in the southwest, and Niger in the southeast), as shown in Figure 2. It is the largest country in Africa and the 10th largest in the world, with a total area of 2,381,741 km^2. The entire territory is divided into three geographical zones, viz., the north (Tellien Region), the high plateaus, and the Sahara Desert. About 87% of the area is occupied by the Sahara Desert, which explains why 90% of the population is concentrated in the north of the country [23]. Algeria is a country which is rich in natural resources and is geographically located at a strategic position in Africa. It can play a crucial role in providing the energy security to Europe and to its neighboring countries. All of these important assets make Algeria a key player in various regional integration projects and partnerships. Indeed, Algeria is among the five strategic partners, besides Canada, Norway, the US, and Turkey, with whom the Commission has established such a cooperation framework [24].

Figure 2. Geographical map of Algeria.

The energy production in Algeria depends on fossil fuel sources. According to the Ministère de l'Energie, the structure of installed power by origin is dominated by the gas turbines (11,530 MW), followed by the combined cycle (6080 MW), steam turbines (2306 MW), and diesel (362 MW) for the year 2018. The rest (686 MW) is shared among RES such as hydro, photovoltaic, and wind, as illustrated in the graph below (Figure 3).

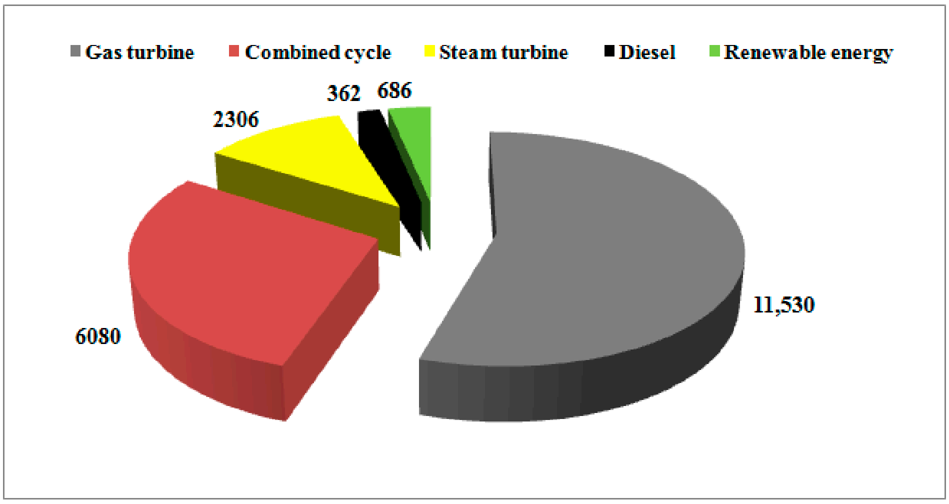

Figure 3. The total installed capacity breakdown of Algeria until 2018.

The renewable power in Algeria shows a steady growth (see Figure 4). Between years 2007 and 2014, the cumulative capacity remained almost stagnant but in 2016 and 2017, respective increases of 54.5%and 37.6% are observed compared to 2015 [21]. A total of 170 MW and 181 MW of renewable power capacities were added in 2016 and 2017, respectively. However, from 2017 to 2019, the cumulative capacity again remained unaltered. Algeria has promoted the utilization of RE through a series of renewable energy conducive policies, laws, and awareness programs [25].

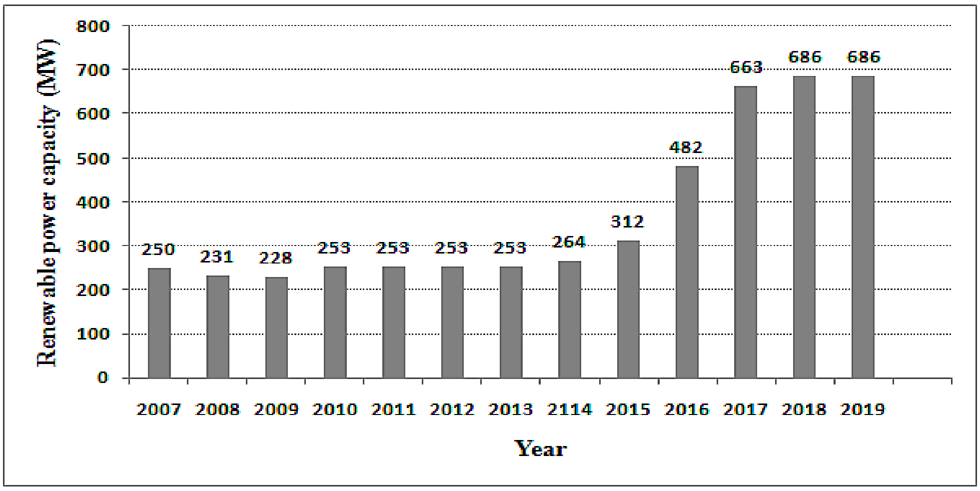

Figure 4. Algerian cumulative renewable power installed capacity growth (MW).

Algeria has set a target to achieve a 27% RES penetration into its existing national energy mix by 2030. The national RE targets are set to be achieved using solar PV, concentrated solar thermal, cogeneration, biomass, geothermal, and wind. The proposed renewable energy capacities are expected to be accomplished in two phases. The first phase program (2015–2020) will focus on the development of 4525 MW capacity buildup based on the contributions of different RE sources. The second phase (2021–2030) will be directed towards the development of electrical interconnection between the north and Sahara (Adrar).

Some previous studies have focused on the status of energy in Algeria. Among them, the studies [26,27] were related to non-renewable sources and [28] referred to the nuclear energy program in the country. Some others have assessed implementation of RE in Algeria and analyzed its utilization. In this context, readers are referred to published studies [21,29,30]. Based on the existing literature, the present work highlights the usage of both non-renewable and renewable energy in Algeria. It further discusses the implications of nuclear energy, the role of coal in power generation, and their existing national potentials. As a complete guide, this study gives professionals and political leaders detailed, updated information of energy resources and their usage in Algeria.

2. Research Methodology

The materials employed in this work include the research papers published in well-known journals such as the Energies Journal, Journal of Cleaner Production, Energy Reports, Sustainability, Renewable and Sustainable Energy Reviews, Energy Conversion and Management, Water Resources Management, etc. Besides these, other sources are also considered from the following:

- IEEE and other conferences.
- Government publications related to the Algeria Ministry of Energy, Ministry of Water Resources of Algeria, National Sanitation Office, National Waste Management Agency, etc.
- Energy Information Administration EIA, British Petroleum (BP), International Energy Agency (IEA), United Nations, World Water Assessment Programme (WWAP), International Renewable Energy Agency (IRENA).
- Newspaper and legislation (the Algerian Official Journal).
- Miscellaneous (dissertations, books, websites, magazines).

This state of the art review research work provides general information about the usage of energy resources (fossil, nuclear, and renewable) in Algeria and presents the supply energy outlook. This review is expected to be the first of its kind that discusses the applications of coal and nuclear in renewable energy transition and the possibility of their usage as clean sources of energy.

3. Survey of Energy Sector in Algeria

The economy of Algeria is heavily dependent on the export of fossil fuels such as natural gas and petroleum. Sahara Desert oil fields produce one of the highest quality crude oils in the world, with the American Petroleum Institute gravity of 44°–45°, and it contains an extremely low amount of sulfur of about 0.05% [31]. On the other hand, natural gas is characterized by an appreciable specific gross calorific value (high heating) of about 39,565 kJ/m^3 [31]. The natural gas reserves in Algeria are mostly located in the eastern, southwestern, and central Sahara.

3.1. Natural and Shale Gas Energy

Algeria is among the top 10 natural gas producers in the world, as the eighth largest natural gas (NG) exporter, and the third in terms of recoverable shale gas resources [32]. Indeed, according to the BP Statistical Energy Review 2021, Algeria has proven NG reserves of 2.3 × 10^{18} m^3 with NG production of 81.5 × 10^{12} m^3 and consumption of 43.1 × 10^{12} m^3 in the year 2020. With the start of the LNG plant at Arzew in 1964, Algeria became the world's leading producer of LNG.

Algeria exported approximately 41.1 × 10^{12} m^3 of NG in 2016, of which approximately 26.1 × 10^{12} m^3 was transported via pipelines and 15 × 10^{12} m^3 by LNG tankers. It produces 2.1% of the world's gas with R/P (reserve to production ratio) of 28 years [33]. It is interpreted as the lifetime of gas reserves at a constant rate of production and no new discoveries. The Algerian Sahara has the following seven shale gas basins (Figure 5):

- Eastern basins: Ghadames (Berkine) and Illizi.
- Central basins: Timimoun, Ahnet and Mouydir.
- Southwestern basins: Reggane and Tindouf.

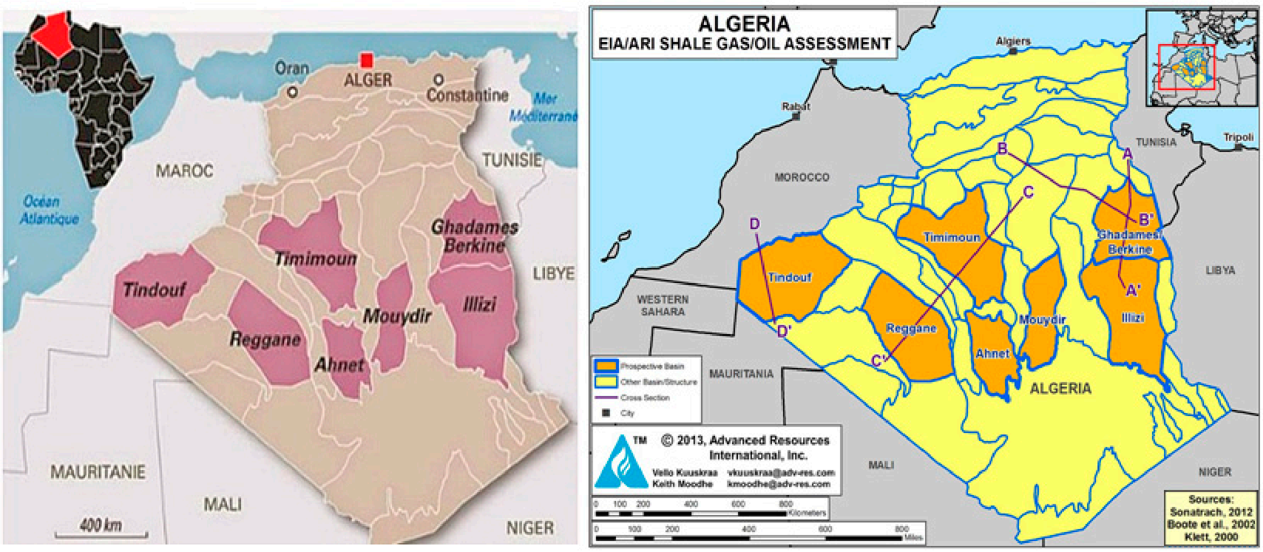

Figure 5. Shale gas basins of Algeria [34].

Algeria, with 20 × 10^{18} m^3 equivalent NG reserves, is the third largest technically recoverable shale gas resource in the world [35]. The widespread availability of shale gas is developing gas to liquids (GTL) technology as the favorable option [36]. However, it is still in its infancy-stage development and the Algerian state is actively trying to develop these resources. In 2014, the country produced 83 × 10^{12} m^3 of NG. IEA predicts that the country's NG production will increase to 116 × 10^{12} m^3 by 2040 under their new policy provision [37].

3.2. Petroleum/Oil

According to the above survey, Algeria had proven oil reserves of 12.2 thousand million barrels at the end of 2016 and produced on average 1579 thousand barrels of crude oil per day. Of this, Algeria consumed domestically, on average, 412 thousand barrels a day in 2016 [38]. According to the national oil and natural gas company, SONATRACH, approximately 2/3 of the Algerian territory is unexplored or underexplored as of now [39]. According to the Oil &Gas Journal, Algeria has currently five refineries, with a total refining capacity of 523 kb/day. The Skikda refinery is the largest in Africa (Figure 6), with a capacity of 355 kb/day(Table 1). The refining capacity is planned to be expanded soon. Under the same scenario, the nation's oil production is projected to drop from 1.6×10^6 b/day in 2015 to 1.4×10^6 b/day in 2030, before rising to 1.5×10^6 b/day in 2040 [40]. Of this, most of the production will be in the form of NGLs and condensates.

Figure 6. SONATRACH Skikda refinery project.

Table 1. Algeria oil refineries [39].

Refinery	Capacity (kb/d)	Type
Skikda	355	Crude oil/condensate
Hassi Messaoud	22	Crude oil
Algiers (El Harrach)	58	Crude oil
Arzew	75	Crude oil
Adrar	13	Crude oil
Total	523	-

3.3. Uranium/Nuclear

In the 1960s, France conducted 17 nuclear weapons tests (4 atmospheric and 13 underground) in the Algerian Sahara at two locations, viz., Reggane and InEkker [41–43]. Algeria is also looking towards developing a civilian nuclear program for power generation. It possesses two research reactors. The 1 MW_t pool-type light-water-moderated Nur reactor uses uranium fuel enriched up to 20% U-235 and it started operation in 1989 at Draria. It is devoted to training and research purposes for reactor engineering [44,45]. The other one, a 15 MW_t heavy-water-moderated Es-Salam reactor, is fueled with 3% enriched LEU. It was started in 1992 at Ain Oussera (Djelfa). It is used for materials testing, radio isotopes production, and training of reactor operators [46]. In addition to these, there is a nuclear fuel fabrication pilot plant which was commissioned in 1999 and is used to develop the rod and plate type of nuclear fuel elements.

Algeria has not utilized nuclear energy yet. However, in 2013, the government, in cooperation with Russia, planned to build its first nuclear power plant by 2025 with a total capacity of 1 × 10^3 MW. Both countries agreed to increase uranium exploration in the Hoggar region (southern Tamanrasset), which has estimated uranium reserves of around 29,000 tones [47]. At present, there is an adequate infrastructure to support nuclear power development in the country. Indeed, nine potential regions were identified for nuclear power plant (NPP) installation (Figure 7) [48]:

- Coastal region: Nedroma, Dahra, Azeffoun-Bejaia, Cap Bougaroun, Cap de fer, El Taref (1000–1200 MW/unit).
- High plateaus region: Tlemcen Nord and Sud, Oum El Bouaghi (300–600 MW/unit).
- Southern region: Djemaa-M'Rara (≤300 MW/unit).

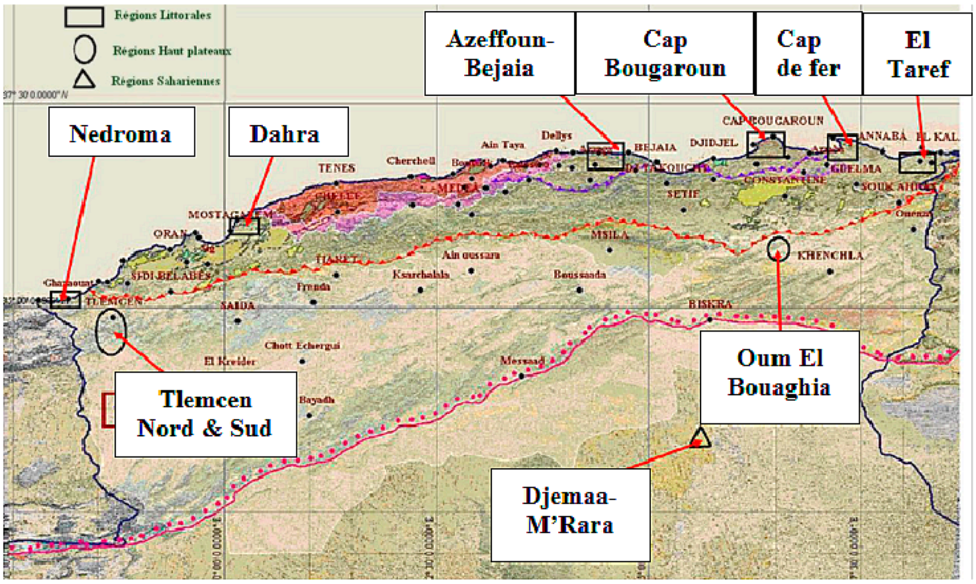

Figure 7. Distribution of the projected future nuclear power plant, NPP, in Algeria.

Nuclear energy can play a vital part in renewable energy transition. For Algeria, it would be better to install small modular reactors (SMRs), using light-water technology, which are relatively safer and not complex in the design. These kind of reactors have negative void coefficient of reactivity due to the light water applied as a coolant and as a neutron moderator [49]. Furthermore, nuclear energy can be used to avoid seasonal fluctuations in output from renewable sources. Finally, it can be coupled with renewable energy sources as a hybrid energy generation system. The advantage of this system is that it enables the use of heat in an industrial process instead of reducing the production of the reactor or releasing energy through cooling and can generate new source of income [50]. Furthermore, this energy mix can be controlled by using smaller nuclear supply combined with a larger share of RE or fossil fuel to substitute nuclear energy in the future. Reaching the green energy transition with reduction of nuclear energy is possible.

3.4. Coal

Algeria has considerable potential of coal reserves. The important hard coal basin exists in the Béchar region which has large coal deposits subdivided into three sub-basins, namely, Mezarif, Kenadsa, and Abadla. The Béchar region has a reserve of 208 million tons of coal which is not yet exploitable. Kenadsa is the largest coal mine in this region (Figure 8). In April 2007, the Algerian Minister of Energy and Mines, Chakib Khelil, stopped the international bidding for the Tinhert integrated GTL project with a capacity of about 30,000 barrels per day of ultra-clean fuel for export. Gas production was expected to be an average of 3.0 billion m^3 per year from this project.

Figure 8. Coal mine in Kenadza (Béchar).

This was probably due to the difficulties that SONATRACH, the Algerian national oil and gas company, had in managing a large integrated project with two large LNG initiatives (Skikda and GassiTouil projects) going on in parallel [51]. It was stated by the ex-Minister of Energy and Mines in September 2013 that "Algeria contemplates the possibility of exploiting its resources (such as coal and uranium) in order to generate electricity" [52]. In 2015, only 20 thousand tons of cooking coal was imported. Nevertheless, the domestic consumption of coking coal in the steel industry and iron reached around 0.1 million TOE in 2016 [37,40].

The exploitation and maturity of clean coal Techs are essential to promote sustainable development in Algeria in the future. This source of energy could be transformed to clean energy using integrated gasification combined cycle (IGCC) or carbon capture and storage (CCS) technology which are presently too costly to be relevant, even in developed countries. However, Algeria is among the countries which have the largest CO_2 capture and storage facilities in the world since 2004 [53]. It has installed a CCS facility on a site in Salah (Saharan area) that now removes and emplaces deep underground 800,000 tons of CO_2 each year.

The combined effect of CO_2 removal and underground storage facilitate sustainable use of biomass, a fuel to create a net negative impact on emissions. Using synthetic fuels and renewable electricity in sectors such as industry, transport, or agriculture is a feasible pathway to decarbonize the energy system.

4. Energy Consumption and Production

The primary energy sources in Algeria include natural gas, oil, hydro-electricity, and non-negligible renewables. The other energy sources, such as coal or nuclear power, are not used as of now for power generation. As seen in Table 2, the primary energy production rose by +7.3% to 166.2 MTOE in 2016 compared with 2015.This growth was driven by natural gas, followed by crude oil, which offset the decline in condensate and LPG productions. The primary electricity production (including hydro-electricity) increased significantly by +51.1% in 2015, compared to 2016, to reach 336 GWh as a result of installation of 13 new PV projects with a total capacity of 180 MW (part of the national Renewable Energy Program). However, the primary energy production in 2016 was still dominated by the natural gas (54%), followed by crude oil (33.8%), condensate (6.3%), LPG (5.9%), and finally other products (primary electricity and solid fuels: wood) (only 0.1%) (Table 2). The total primary energy consumption during 2006–2016 is summarized in Table 3. It is evident from the data in Table 3 that the total primary energy consumption in Algeria increased from 33.8 MTOE in 2006 to 55.1 MTOE in 2015. However, between 2015 and 2016, it remained unchanged at 55.1 MTOE due to the stability in fuel consumption (Table 4).

Table 2. Primary energy production in Algeria [54].

Energy Product (MTOE)	2015	2016	Evolution (%)	Share of Total Primary Energy Production (%)
Natural gas	79.931	89.731	+12.3	54.0
Crude oil	54.250	56.193	+3.6	33.8
Condensate	10.885	10.449	−4.0	6.3
LPG	9.753	9.726	−0.3	5.8
Primary electricity	0.053	0.080	+51.1	0.1
Solids fuels: wood	0.006	0.006	−3.1	
Total	154.878	166.185	+7.3	100

Table 3. Primary energy consumption in the period 2006–2016 [54].

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Total of primary energy consumption MTOE	33.8	35.6	37.7	39.9	38.9	41.3	45.1	47.8	51.6	55.1	55.1

Table 4. Primary energy consumption by fuel between 2015 and 2016 [54].

	Oil	Natural Gas	Coal	Nuclear Energy	Hydro-Electricity	Renewables	Total
2015 (MTOE)	19.5	35.5	0.1	-	Less than 0.05	Less than 0.05	55.1
2016 (MTOE)	18.9	36.0	0.1	-	Less than 0.05	0.1	55.1

5. Desalination and Water

Water covers 67% of the Earth's surface and is essential for human life. Only about 2.5% of the world's water is fresh water. Of that, less than 1.0% is accessible through aquifers and surface sources. The rest is enclosed in ice caps and glaciers, or is underground [55].

5.1. Water in Algeria

Algeria is considered among the driest MENA countries in the world and fell below the physical water poverty line of 1000 m^3/capita/year in 2014 (<500 m^3/capita/year) [56]. The Government's investments in the water purification sub-sector, over the last 30 years, amounted to USD 15 billion [57]. Table 5 gives the details of some dams developed in the country. It is noticeable from Table 5 [56,58] that 38% of the dams are old and were built during the 1930s and 1960s, since the average lifetime of a dam is 50 years. It is also clear that only 25% of this list of dams is intended for power generation which represent fairly few numbers. However, the north center and the northeast of Algeria are the most favored regions in terms of rain and precipitation in the form of snow at the mountain peaks. This subject will be discussed in detail in Section 6.

Algeria's population stood at 41.3 million in 2017 and is expected to reach 57.4 million by 2050 [59]. Therefore, the country faces a decrease in water resources and a growing demand due to population growth and materialistic lifestyles. This implies that other means of potable water resources and technologies have to be explored and implemented. These options may include, but are not limited to, seawater desalination and wastewater reclamation.

5.2. Desalination

In 2012, the total water resources withdrawal was estimated at 8425 million m^3. Of this total, 4800 million m^3 was obtained as surface water and 3000 million m^3 from underground. It is well above the annual renewable water volume of 615 million m^3 desalinated water and 10 million m^3 of directly used treated wastewater [58]. At a national level, water withdrawal was estimated for three main sectors, namely, agricultural (4990 million m^3), municipal (415 million m^3), and industrial (3020 million m^3) [60]. Government has invested heavily in seawater desalination. A list of some of the desalination plants installed during the 2000s is presented in Table 6. There are more than ten seawater desalination plants which have been commissioned with a total sweet water production capacity of 2,310,000 m^3/day, including that at Mactaa (500,000 m^3/day), which is among the largest in the world (See Figure 9) [61].

Table 5. Details of dams implanted in Algeria.

Location	Year of Construction	River	Dam Height (m)	Capacity (10^6 m^3)	Reservoir Area (km^2)	Purpose	Age Dam till 2020 (Years)
AinDefla	1938	Chelif	105	280	11.985	Power Generation (PG)	82
Batna	2003	Rbôa	-	65	-	Irrigation/Water Supply(I/W.S)	17
Bechar	1968	Guir	38	350	57.15	I/W.S	52
Biskra	1950	El Abiod	73	47	3.256	PG	70
Biskra	2000	El Hai	42	55	-	I/W.S	20
Mila	2003	Kebir	120	1000	-	I/W.S	17
Chlef	1932	Fodda	101	228	7	PG	88
Bouira	2006	Isser	120	640	-	I/W.S	14
Boumerdes	1985	Boudouaou	108	145.6	5.2	I/W.S	35
Chlef	1983	Sly	87	280	8.85	I/W.S	37
El Bayadh	2001	Mouilah	-	122.5	-	I/W.S	19
Bejaia	1954	Agrioum	76	160	-	PG	66
El Tarf	1965	B. Namoussa	50	171	9.87	I/W.S	55
Guelma	1987	BouHamdane	93	220	11	I/W.S	33
Khenchela	1985	Babar	-	41	-	I/W.S	35
Mascara	1948	El Hammam	99	73	5.369	PG	72
Mascara	1985	Sahouat	60	100	7	I/W.S	35
Medea	1934	NaharOuasel	14	55	24	I/W.S	86
Jijel	1963	DjenDjen	82	200	-	PG	57
Mila	2003	Kebir	120	1000	-	I/W.S	17
M'sila	1939	Ksob	46	29.5	-	I/W.S	81
Relizane	1988	OuedRhiou	70	450	21	I/W.S	32
S. Ahras	1995	Cherf	-	157	-	I/W.S	25
Mostaganem	2011	Kerrada	-	50	-	I/W.S	9
Skikda	1984	Fessa	60	125	10	I/W.S	36
Tiaret	1935	Mina	60	56	4.575	PG	85
Tipaza	1992	El Hachem	-	97	-	I/W.S	28
Tissemsilet	2004	OuedFodda	-	75	-	I/W.S	16
TiziOuzou	2001	OuedAissi	-	175	-	I/W.S	19
Tlemcen	1946	Tafna	55	63	3.412	PG	74
Tlemcen	1999	Tafna	-	177	-	I/W.S	21

Table 6. Details of the large desalination plants installed during the 2000s.

Location	Capacity (10^3 m^3/Day)	Amount (10^6 USD)	Disposal Cost USD/m^3	Elevation (m)	Energy Consumed kWh/m^3
Skikda	100	136	0.7398	8	3.56
Kahrama	90	400	0.8500		Electric Generation 343 MWh
Cap Djenet	100	138	0.7257	−2	3.7
Souk Tlata	200	251	0.7725		-
El Tarf	100	-	0.89		-
Honaine	200	291	0.8299	23	4.42
Mostaganem	200	227	0.7257	8	≤3.40
Ténès	200	231	0.5885	0	-
Fouka	120	180	0.7505	6	≤4
Maqtaa	500	492	0.5577	4	3.2
Hamma	200	258	0.8521	0	4
BeniSaf	200	240	0.6994	10	≤4.15
Oued Sebt	100	115	0.6794	-	-
Jijel	100 (Planning)	-	-	-	-
Bejaia	100 (Planning)	-	-	-	-

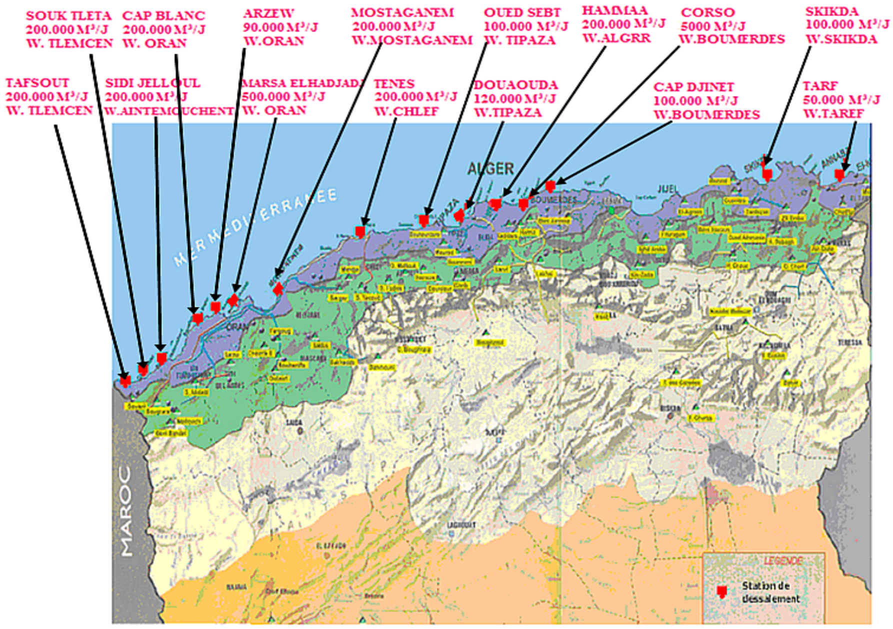

Figure 9. Geographical locations of 13 seawater desalination plants in Algeria.

All of these plants use reverse osmosis (RO) desalination technology, except the Kahrama plant which uses the MSF process, since reverse osmosis is the most efficient technique and requires little amount of electrical energy per cubic meter, which is one of the main reasons why RO is used in Algeria. Obviously, from Table 6, the cost of water varies from place to place with the elevation (low-lying land) and according to the size of the desalination plant. Additionally, the cost also depends on the quality of water source such as its temperature, salinity, and alkalinity, as can be seen in Table 7. Furthermore, other mono-block SWRO plants, with an aggregate capacity of 57,000 m^3/day, have been developed in the same period and are listed in Table 8 [62–64].

Table 7. The physicochemical parameters of seawater for different places.

SWRO	pH	T (°C)	NO_3^- mg/L	HCO_3^- mg/L	Ca^{+2} mg/L	Mg^{+2} mg/L	Cl^- mg/L	K^+ mg/L	SO_4^{-2} mg/L	B mg/L	Fe^{+2} mg/L	TDS g/L
Cap Djinet	8.22	15.7	6.33	130	381	724.0	6472.2	142.15	1023.4	3.81	0.085	35.7
Hamma	7.8	17.8	5.9	135	200	780.9	6816.0	148.8	1260.0	3.72	0.078	35.2
Fouka	7.7	15.6	5.8	134	220	807.0	6532.0	145.7	1100.0	3.46	0.09	36.1
Mostaganem	7.6	18.1	5.1	131	237	776.9	6453.6	144.9	1180.1	3.51	0.082	36.6

Table 8. Mono-block SWRO plants installed along the coastal areas of Algeria.

Location	Capacity (10^3 m^3/Day)	Population to Serve
Zéralda	5	33,330
Staoueli	2.5	16,660
AinBenian	5	33,330
Ghazaouet	5	33,330
Bou Ismail	5	33,330
L.BenMhidi	7	33,330
Tigzirt	2.5	47,000
Bousfer	5	16,660
Ain Turk	2 × 2.5	33,330
BouZdjer	5	33,330
BouZdjer	5	33,330
Corso	5	33,330

In technological terms, the existing desalination plants use a mix of thermal and RO processes [65]. Water pricing is regulated according to the Decree 05-13 of 9 January 2005 on tariff policy, and any additional cost of production is covered by government as subsidy. This decree defines the tariff rules and prices for water and sanitation services. It defines five tariff zones: Hydrographic, Algiers, Chlef, Constantine, Oran, and Ouargla, which cover the entire country, as shown in Table 9 [66,67].

Table 9. Tariff water pricing for the five zones.

Zone	Cities Covered	Tariff Water Pricing (DA/m^3)
Algiers	Algiers-Boumerdès-Tipaza-Blida-Medea-TiziOuzou-M'Sila-BordjBouArréridj-Bouira-Setif-Bejaia.	6.30
Oran	Oran-Mascara-Mostaganem-Tlemcen-Ain Témouchent-Saida-Sidi Bel Abbès-El Bayadh-Naama.	
Constantine	Constantine-Khenchela-Batna-Mila-Jijel-Annaba -Biskra-Souk Ahras-Guelma-El Tarf-Skikda-Oum El Bouaghi-Tebessa.	
Chlef	Chlef-Tiaret-Relizane-Ain Defla-Djelfa-Tissemsilt.	6.10
Ouargla	Ouargla-Adrar-Laghouat-Illizi-El Oued-Tindouf-Béchar-Tamanarest-Ghardaia.	5.8

Regarding the water produced by desalination, the tariffs for [62,65]:

- Seawater reverse osmosis (SWRO) is DA 50–60 (USD 1 = DA 75).
- Multi-stage flash distillation (MSF) is DA 60–70.

Mobilization by non-conventional water through desalination in 2025 will reach 800×10^6 m^3/year, and in 2040 it is expected to increase to 1000×10^6 m^3/year [68].

5.3. Wastewater

Water reuse enhances freshwater availability for meeting human and environmental needs and is being used in several places. It can be used for multiple purposes, ranging from irrigation and landscaping to industrial. It can also be used as a source of potable drinking water with additional treatment. During the year 2013, the volume of wastewater collected in Algeria was 1570.4 million m^3/year. Of this, 275.2 million m^3/year was safely treated and only 19.3 million m^3/year was used for irrigation and groundwater recharge [69]. At present, there are 177 wastewater treatment plants in operation with a total installed capacity of 805 million m^3/year (sufficient for 13,791,687 people). The Algerian wastewater treatment plant is expected to reach more than 270 units with a total installed capacity of around 1300 million m^3/year by 2020 [69].

6. Hydro-Electric Energy

Algeria's climatic regions can be divided into three zones, viz., north, semiarid, and arid, as shown in Figure 10 [70]. The north of the country is situated in a sub-humid bioclimatic zone. Rainfall is generally higher in the mountains than in plains. The average rainfall in this zone varies from 700 to 900 mm. The high plateau region belongs to the lower semiarid bioclimatic stage with cold to very cold temperatures in winter and hot in summer. The annual rainfall in this zone is observed to be between 300 and 600 mm. The Sahara is a sparsely populated desert region belonging to arid bioclimatic stage.

Here, the evaporation reaches considerable proportions (between 3000 and 5000 mm/year), whereas the annual rainfall remains very low (<200 mm). The country is divided into five hydrographic basins which can be grouped into 19 watersheds. In 2008, the total installed capacity of 59 dams in these watersheds is approximately 6 milliards m^3 [71]. In 2015, about 72 large dams were operational [72] and most of them were being used for irrigation and drinking purposes. The hydro-electricity production was very limited. However, by 2014, the share of hydraulic electricity production reached 254 GWh [73].

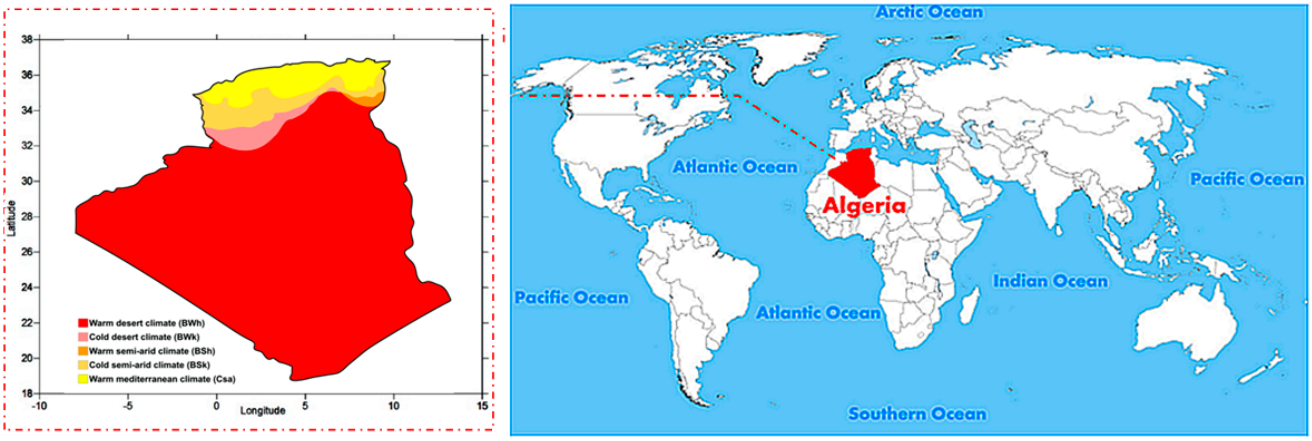

Figure 10. Algeria climatic map.

Hydro-energy sources can play a crucial role in the whole national energy mix due to the existence of favored regions in the north of Algeria, northeast, and north center in terms of precipitation. In fact, a hydro-electric development program must be drawn up by the government. This may include new hydro-electric plants such as conventional (dams) and run of the rivers. Besides this, the government may construct multipurpose dams for power generation, water supply, and irrigation. As a matter of fact, the government plans to increase the total number of dams to 140 by 2030 and thereby achieve a storage capacity of nearly 12 billion m^3 across the country [74]. Hydro power can be used to store the water in upper reservoirs during access energy from the wind and the solar and then can be used to generate hydro power during peak load demands.

7. Electricity Generation and Grid

The national electricity generation reached 67.7 TWh in year 2015 and the installed capacity attained 17,089 MW. This generation capacity comprises 56% of open cycle gas turbines, 25.8% combined cycle gas turbines, 14% conventional steam turbines, 2% diesel, 1% hybrid cycle, 1% hydro, and 0.2% renewables [75]. The thermal centers consume around 17 billion m^3 of gas. In 2014, the net national electricity consumption was 45 billion kWh and the respective per-capita generation was 1356 kWh, which is about 40% of the worldwide average per-capita consumption of 3100 kWh [39].

The power sector is regulated by CREG (Algerian Regulatory Commission of Electricity and Gas), which is responsible for fixing the electricity tariff. Electricity prices are subsidized at DA 04/kWh (Algerian dinars per kWh) [76]. The electric power network operates at very high, high, and medium voltages of 10, 30, 60, 90, 220, and 400 kV. In 2015, it consisted of over 27,284 ckm of transmission and 303,462 ckm of the distribution lines [75]. The structure of the Algerian electric grid is divided into the following three systems, as shown in Figure 11 [61,77]:

- Interconnected Network of the North (RIN): It extends in the north of the country and covers Ghardaia, HassiR'Mel, Hassi Messaoud, and Béchar. It has high-voltage transmission lines (220–400 kV) that carry power from distant sources to demand centers.
- The Pole of InSalah-Adrar-Timimoun (P.I.A.T): This pole constitutes an interconnected network in the south from InSalah to Adrar and Timimoun and is supplied by gas-turbine-based power plants. By 2020, the P.I.A.T will be connected to the national grid (RIN) through a 400 kV line including the localities of El Golea and Beni Abbes.
- The isolated networks of the south (RIS): There are 26 sites in the far south, provided power through diesel generators and gas turbines via local networks.

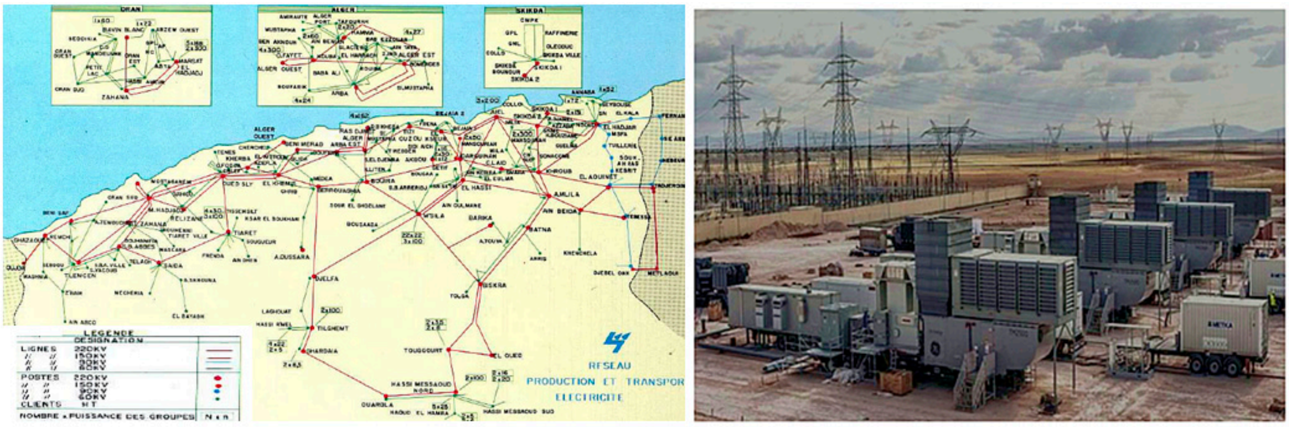

Figure 11. National energy grid of Algeria.

8. Renewable Energy

Algeria is blessed with substantial renewable resources of all forms, notably solar and wind. As part of its commitment to reducing GHG, Algeria is one of the 192 countries that have signed the Kyoto Protocol and is one of 114 nations that have ratified the Copenhagen Accord. Algeria has signed bilateral cooperation agreements with USA, France, Germany, Spain, etc., in the north, Brazil in the south, and China in the east. These partnerships offer prospects for the investment growth, promotion of technology transfer, reinforcement of interconnections, and creation of the Maghreb electricity market [78]. In 2015, total installed renewable power generation capacity in Algeria reached 533 MW (solar 295 MW, hydro 228 MW, and wind 10 MW) [79]. In the same year, the country announced its plan to install around 22 GW of renewable energy capacity by 2030. It will include 1 GW bio-power from the waste, 13.5 GW from solar PV, 2 GW from CSP, 15 MW from geothermal, 400 MW cogeneration, and 5 GW from the wind, as given in Table 10.

Table 10. Renewable energy targets in Algeria [77].

Renewable Sources	First Stage 2015–2020	Second Stage 2021–2030	Total (MW)
Photovoltaic	3000	10,575	13,575
Wind energy	1010	4000	5010
CSP	-	2000	2000
Cogeneration	150	250	400
Biomass	360	640	1000
Geothermal	05	10	15
Total (MW)	4525	17,475	22,000

The renewable energy projects will be completed in two stages [80,81]. The first-stage program (2015–2020) will focus on the development of 4525 MW RE capacity as per the contributions of different sources given in Table 10 above. Figure 12 shows the PV park among other projects which have been completed by SONELGAZ. The second-stage program (2021–2030) will be directed towards the development of electrical interconnection between the north and Sahara (Adrar). This will facilitate the deployment of renewable power plants in InSalah, Adrar, Timimoun, and Béchar regions. Overall, the renewable energy deployment program in the country foresees the realization of 60 solar PV and thermal, windfarms, and hybrid power systems by 2020 (Figure 12) [82]. According to the official statement from the Ministry of Energy, the RE development plan will be announced during the Global Energy Club's meeting with an investment of USD 120 billion.

Figure 12. Solar projects in the Algerian Sahara.

Most of the renewable energy projects are expected to be installed in the Sahara regions. Indeed, these regions are becoming a pioneer in Algeria for the exploitation of electricity from renewable sources. Table 11 illustrates the detail of 14 installed PV parks and one wind farm directed and handled by Shariket Kahraba wa Taket (SKTM) Moutadjadida (subsidiary of SONELGAZ) in Sahara.

Table 11. Energy output and installed capacity of completed projects in Sahara [83].

Site	Region	Area Project (km^2)	Installed Capacity (MW)	Energy Output at June 2017 (GWh)	Commissioning Date
El Hadjira	Ouargla	0.6	30	9.738	2017
Oued Nechou PV	Ghardaia	0.05	1.1	4.593	2014
Tindouf	Tindouf	0.18	09	6.376	2015
Djanet	Illizi	0.06	03	10.729	2015
Tamanrasset	Tamanrasset	0.26	13	36.410	2015
Aoulef		0.1	05	12.557	2016
Zaouiate Kounta		0.12	06	15.213	2016
Reggane		0.1	05	12.221	2016
Timimoune	Adrar	018	09	23.8222	2016
In Salah		0.1	05	12.328	2016
Kaberten (PV)		0.06	03	9.584	2015
Adrar		0.4	20	59.585	2015
Kaberten (wind farm)		0.33	10.2	51.579	2014

Algeria could be a potential country for an energy transition. It could also be an exporter of renewable energy in the world in the near future, being the largest country in Africa. The following sections focus on the renewable analysis in Algeria, notably Adrar region, and bring an in-depth investigation of the solar and wind resources over time. It further discusses how the seasonal patterns of these resources relate to the seasonal fluctuations in electricity demand. In this context, we are going to mention two demonstration projects (wind farm and PV park) located in Kaberten and Adrar, respectively.

8.1. Solar Energy

Algeria is among the Arab countries which are part of the Sunbelt, and it benefits from high solar insolation intensities. Algeria has one of the highest solar potentials in the world, estimated at 13.9 TWh/year [84]. The average annual sunshine is evaluated at 2650 h/year in the coastal region, 3000 h/year in the high plateau, and 3500 h/year in Sahara. The corresponding average annual direct normal irradiance (DNI) in the above three regions is estimated to be 1700, 1900, and 2650 kWh/m^2/year, respectively (see Table 12). This could favor the development of concentrated solar power (CSP). In addition, Algeria's global horizontal irradiance (GHI) ranges between 2100 kWh/m^2/year in the north and 2400 kWh/m^2/year in the south. Figure 13 provides an illustration of the geographic locations best suited for CSP and PV according to the values of DNI and GHI.

Table 12. Solar potential in Algeria [54].

Regions	North Country		Sahara	Unit
	Coast	High Plateaus		
Area	4	10	86	%
Average sun duration	2650	3000	3500	hours/year
Average annual energy received	1700	1900	2650	kWh/m^2
Average GHI	2100	2100	2400	kWh/m^2/year

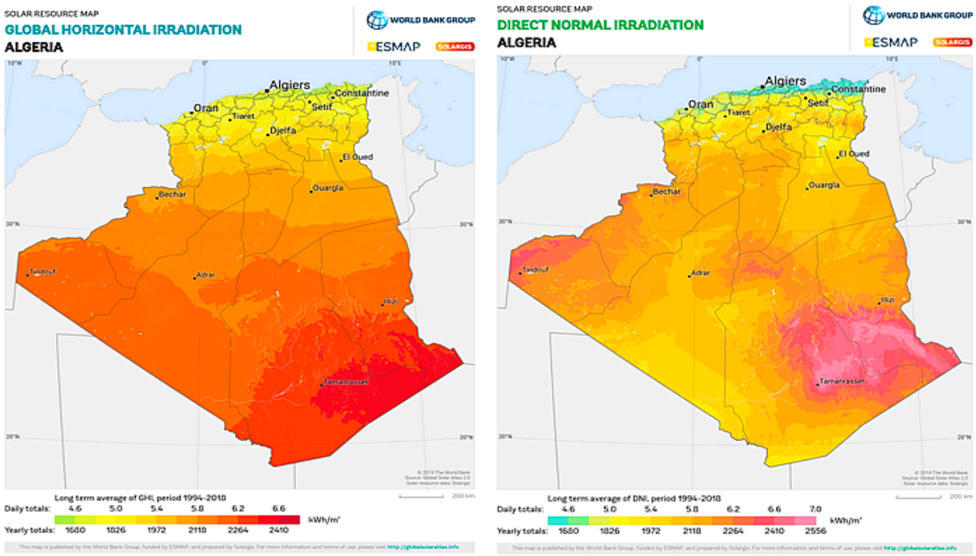

Figure 13. Global resource potential for CSP and PV.

At present, the solar power generation in the country is insignificant but the deployment of CSP plants is due to start in the 2020s in the south, high plateau and coastal regions. These power projects include the following:

- 150 MW parabolic trough CSP plant with gas solar combined cycle installed in 2011 in HassiR'mel.
- A platform with 1.1 MW PV capacity with multi-technology installed in Ghardaïa and in operation since 2014 [85].

Furthermore, about 20 solar PV power plants with capacity of around 225 MW were commissioned in 2016 in the south and high plateau regions [77]. Referring to the national renewable energy development program 2015–2030, SKTM has recently signed an agreement with a Chinese company for the construction of a 9 PV plant with an installed capacity of 50 MW for the benefit of the regions of the great south, namely, Guezzem (6 MW), Tinzaouatine (3 MW), Djanet (4 MW) and Bordj Omar Dris (3 MW), Bordj Badji Mokhtar (10 MW), Timiaouine (2 MW), Talmine (8 MW), Tabelbala (3 MW), and Tindouf (11 MW). Completion of these projects will allow SKTM to annually save 20,600 tons of gasoline and generate a revenue of USD 14 million annually [86].

The PV park is situated at the exit of Adrar, as shown in Figure 14. It is composed of twenty subfields of 1 MW power capacity; each consists of 186 strings (4092 modules YL245P-29P PV). A total of 81,840 polycrystalline silicon PV occupies an area of 0.4 km^2 and is oriented to the south at an inclination angle of 27°. This park was commissioned in October 2015 and connected to electrical grid through 4 × SG500MX inverters (500 kW) and then to 2 × 0.315/30 kV step-up power transformers (1.25 MVA). The characteristics of the PV modules, inverter, and transformer are summarized in Tables 13–15. The energy output of the PV system, performance ratio, and capacity factor depend on weather parameters, particularly solar radiation, temperature, and wind speed, as shown in Table 16.

Figure 14. Photovoltaic park of Adrar (Algeria).

Table 13. Principal characteristics of polycrystalline silicon panel YL245P-29b [87].

Item	Details
Type	Polycrystalline
P_m	245 W
Amperage	
I_{mp}	8.28 A
I_{sc}	8.83 A
Voltage	
V_{mp}	29.6 V
V_{oc}	37.5 V

Table 14. Technical sheet data of SG500MX inverter [88].

Input DC	
V_{max}	1000 V
$V_{Start\text{-}up}$	500 V
V_{MPPT}	460~850 V
V_{min}	460 V
P_{max}	560 kW
I_{max}	1220 A
Output AC	
$P_{nominal}$	500 kW
P_{max}	550 kW
I_{max}	1008 A
$V_{nominal}$	315 V
cosφ	0.9 (Inductive/Capacitive)

Table 15. Technical data of SCLB10 transformer [89].

Rated power	1250 kVA
Vector group Short circuit impedance	Dy11y11 6.28%
Primary side	
Rated voltage Rated current	2 × 315 V 2 × 1146 A
Secondary side	
Rated voltage Rated current	30 kV 24.1 A

Table 16. Weather data and energy data measured and collected from the PV station during one year (January–December 2018).

Month	Temperature (°C)	Solar Radiation (kWh/m^2)	Wind Speed (m/s)	Energy Output (MWh)	Performance Ratio (%)	Capacity Factor (%)
January	15.3	172.3	4.6	2813.2	82.4	20.3
February	16	180.5	4.3	2813.2	78.9	21
March	21.6	232.4	4.4	3450.6	74.7	23.2
April	26.2	224.2	5.1	3252.8	73.1	22.7
May	29.5	251.4	4.1	3230.8	64.8	21.8
June	35	243.1	4.8	2945.1	61	20.4
July	40.8	246.4	4.3	2725.3	55.8	18.4
August	33.9	225	4.7	2967	66.2	19.9
September	32.7	194.5	4.6	2813.2	72.5	19.6
October	25.7	181.3	3.6	2736.3	75.8	20.3
November	19.2	185.4	3.7	2945.1	79.7	20.4
December	14	202.8	4.7	3274.7	80.8	22

From this table, it is observed that as the monthly temperature and solar radiation vary from 14.0–40.8 °C and 172.3–251.4 kWh/m^2, the monthly energy output varies from 2725.3–3450.6 MWh, respectively. This indicates that as the temperature rises, the energy output declines up to some extent, even though there is a high quantity of solar radiation (case of July). The monthly capacity factor for this station ranges between 18.4% (July) and 23.2% (March). However, the monthly performance ratio varies between 55.8% in July and 82.4% in January. The variations in the performance ratio are due to the local weather conditions and inverter inefficiency. This leads to a reduction in the energy yield of the PV system.

8.2. Wind Energy

In Algeria, the first wind speed measurement campaign was carried out in the 1910s. However, wind measurements were taken as an average of three readings at 7 a.m., 1 p.m., and 6 p.m. each day. These three hourly values were utilized to obtain the daily average wind speed values [84,90]. The wind atlas was developed based on wind speed measurements made at 37 locations in the country using the WAsP [91]. Kasbadji Merzouk [92] collected average wind data from 64 stations made at 10 m to assess the wind energy potential of Algeria. The study showed that the windy regions are in the southwest part of Algeria, Sahara [92]. Kasbadji Merzouk and Merzouk [93] carried out wind power potential assessment for water pumping in the west of high plateau of the country (El Bayadh, Djelfa, and Tiaret) using wind machines of 100, 600, and 850 kW rated power. They concluded that the two wind machines of capacities 600 and 800 kW were found to provide useful power density for small applications [93].

Wind power might be useful in areas where the annual mean wind speed is more or less around 5–6 m/s [94]. The local studies indicated that high average wind speed distribution is concentrated in the southwest of the country. The best wind potential is observed in the southwestern region [53,94–100], where the annual mean wind speed is higher than 5 m/s (Figure 15).

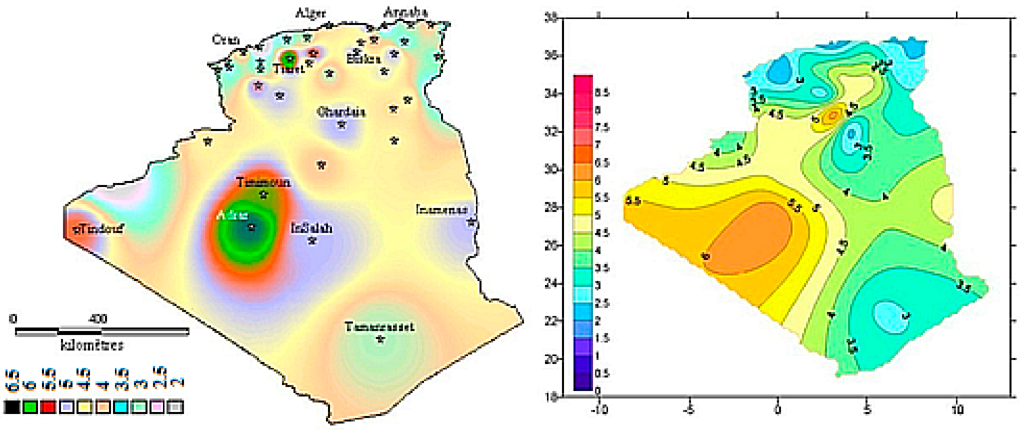

Figure 15. Map showing wind speed measurement 10 m AGL in Algeria [92].

Algeria has promising wind potential of around 35.0 TWh/year and is considered to be the second most important source of renewable energy in the country [101]. A pilot wind farm project of total installed capacity of 10.2 MW is already operational in the area of Kabertene (Figure 16). This project was developed using 12 wind turbines from GAMESA (G52-Model) with rated power of 0.85 MW each at a total cost of EUR 22.6 million. The cost of wind energy generation from this wind form is found to be EUR 0.073/kWh. This site is located about 73 km north of Adrar at an altitude 250 m, near the SONELGAZ substation with geographical coordinates at (28°27′ N 0°02′ W). The selected wind turbine from Gamesa G52-850 has three blades, cut-in speed of 4 m/s, cut-off speed of 25 m/s, rotor diameter of 52 m, and hub height of 55 m (Table 17). These machines are based on double-fed induction generators operating at variable speed with pitch regulator and coupled with gearbox. In this pilot plant, the wind turbines are distanced 200 m (almost four rotor diameters) from each other and are aligned in a single row according to the northeast prevailing direction, as seen in Figure 17.

Figure 16. Pilot wind farm of 10.2 MW in Kabertene.

Table 17. Technical data of Gamesa G52-850 [102].

Item	Value	Unit
Rated power	850	kW
Wind turbine rotor	52	m
Hub height	55	m
Number of blades	3	
Cut-in speed	4	m/s
Rated speed	16	m/s
Cut-off speed	25	m/s
Gearbox ratio	3 stages; 1:61.74	
Generator voltage	Double-fed induction 690	V
Power factor *cosφ*	0.95 Ind/Cap	
Control system	Pitch-regulated	
Operational temperature limits:	−30 to +50	°C

Figure 17. Typical configuration of twelve wind turbines (12 × 0.85 MW) at Kaberten wind farm.

As mentioned before, there are 12 wind turbines numbered from WT01 to WT12 in this pilot plant. The annual energy output and capacity factor of each wind turbine is summarized in Table 18, while the corresponding values of the meteorological parameters measured at this site are given in Table 19 over a period of one year from 1 January 2015–31 December 2015.

Table 18. Data collected from Kaberten windfarm from 1 January 2015–31 December 2015.

Wind Farm	N° Wind Turbine	Production (kWh)	Capacity Factor "CF" (%)
Kabereten (Adrar)	WT01	2,250,284	30.22
	WT02	1,697,193	22.79
	WT03	697,817	9.37
	WT04	1,906,719	25.61
	WT05	1,944,630	26.12
	WT06	2,387,932	32.07
	WT07	1,875,750	25.19
	WT08	2,200,120	29.55
	WT09	1,952,431	26.22
	WT10	1,162,480	15.61
	WT11	1,894,519	25.44
	WT12	1,542,196	20.71
	Total	21,512,071	24.08

Table 19. Meteorological parameter for Kaberten from 1 January 2015–31 December 2015.

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Max Temperature (°C) *	19.2	22.1	25.9	36.2	39.9	42.3	44	45.1	39.3	33.9	26.5	21.9	33.1
Min Temperature (°C) *	4.7	7.4	9.5	18.9	22.7	25.5	28.2	30.4	26.4	21.4	13	7.5	18
Max Wind Speed (m/s) **	5.9	6.5	7.3	6.5	6.6	7.7	7.3	6.7	6.1	5.8	6.8	6.5	6.7
Wind Speed (m/s) **	4.1	4.1	4.8	4	4.4	5.3	5.3	4.4	3.9	3.6	5.1	5.1	4.5
Min Wind Speed (m/s) **	2.4	2.1	2.8	1.9	2.3	3.4	3.5	2.4	1.8	1.9	3.4	3.5	2.6
Relative Humidity RH (%) *	33.7	31.1	22.6	12.1	11	11.4	12.2	14.7	22.8	30.6	35	39.4	23
Surface Pressure PS (kPa) *	99.1	98.3	98.4	98.2	97.9	97.9	97.8	97.8	98	98.2	98.8	99.4	98.3

*: 2 m, **: 10 m.

The maximum annual energy output of 2,387,932 kWh was produced by WT06, while minimum of 697,817 kWh by WT03. The average maximum and minimum capacity factors were 32.07% and 9.37%, corresponding to wind turbines WT06 and WT03, respectively. In addition, an average energy output of 1,792,673 kWh was produced by each turbine with an average capacity factor of 24%. Overall, an annual energy yield of 21,512,071 kWh was obtained from the piolet wind farm at capacity factor of 24.08%. The WTs 03 and 10 produced relatively lower quantities of energy at lower capacity factors due to several reasons, as listed below:

- Extreme weather condition: the recorded temperature inside the nacelle was higher than operational ambient temperature limit of these wind turbines.
- Non-availability due to more frequent maintenance and repair.
- Malfunction of the SCADA system.
- Mechanical failures of bearings and gearbox (might be due to storms and dust).
- Design failure and manufacturing defects, such as inadequate electrical insulation (air temperature in Adrar sometimes attained or exceeded 46 °C).

A report on estimating the renewable energy potential in Africa, entitled A GIS-based approach, published in 2014 by International Renewable Energy Agency (IRENA), indicated that Algeria is among the countries having the highest wind energy potential. The above wind power potential was made using GIS data with wind speed measurements conducted at 80 m height. GIS maps, so generated, represent the areas associated with different wind turbine factor capacities (Table 20) [103].

Table 20. Areas associated with different wind turbine CF.

Wind Potential (TWh/Year)		
All areas with wind turbine CF greater than 20%	All areas with wind turbine CF greater than 30%	All areas with wind turbine CF greater than 40%
30,155	2535.9	153.4

8.3. Biomass

Biomass technologies were made in the country in the 1950s when École nationale supérieure agronomique-Algiers developed the biomass plant for the production of biogas via organic waste [104]. In this country, forest areas cover about 4.2 million hectares of the land, which is around 1.8% of the total land area of the country (238,174,100 ha). Theoretically, the total capacity of biomass which could be recovered is estimated at 3.7 mtep. According to l'Agence Nationale des Déchets (the National Waste Agency), the nation produces approximately 10.3 million tons of MSW each year, or in other words, 28,219 tons per day. This accounts to 0.6 kg/inhabitant/d for rural and 0.9 kg/inhabitant/d for the urban zones. The theoretical capacity of energy which could be produced from urban and agricultural wastes is estimated to be about 1.33 mtep/year [78,84].

Algeria plans to conduct feasibility studies in order to explore the potential of waste to energy and bioenergy resources. The SONELGAZ biomass energy project is in the feasibility phase at the Oued Smar site. The expected installed capacity of the plant is 2.0 MW, which is expected to reach a peak of 6.0 MW at the completion of this project (waste and sewage) [105]. As stated by DLR Deutsches Zentrumfür Luft-und Raumfahrt (German Aerospace Agency), the economic electricity supply side potential of biomass could be 12.1 TWh/a with full load hours (FLH) of 3500 [106]. The biomass energy can be used to meet energy needs, i.e., electric power, supplying heat for industrial facilities, and heating the homes.

9. Conclusions

Algeria can play a crucial role in providing the energy security to Europe and its neighboring countries. It is rich in natural resources such as fossil, nuclear, and renewables. The development of these energy resources is a priority for national energy policy. Nuclear is a wise choice that can play an increasing role during the energy transition. The use of coal, as a clean energy, is also proposed, but requires sophisticated, high-tech infrastructure which is expensive. However, Algeria has sufficient financial means and technical or scientific capacities to invest in such projects. Algeria is seriously engaged in the efforts of reducing the GHG emissions.

The following recommendations are made to increase the usage of clean energy resources for greener environment and sustainable development:

- The Algerian government should construct dams with multipurpose, namely, power generation, water supply, and irrigation.
- Hydro power can be used to store the water in upper reservoirs during excess and low-cost energy from wind and solar and can be used to generate hydro power during peak load demands.
- Although nuclear energy is a risky choice where security and safety is concerned, it would be better to couple it with other renewable energy options in order to compensate the fluctuating nature of renewables. This can be achieved by using a smaller nuclear supply combined with a larger share of RE or fossil fuel.
- In order to create clean coal energy, Algeria should invest in sophisticated and high-tech infrastructure such as IGCC or CCS technologies which are able to transform coal to clean coal energy. Indeed, the IGCC and CCS are essential to promote sustainable development in Algeria in the coming future.Hence, CCS can be combined with the sustainable use of biomass as a fuel to create a net negative impact on emissions. Using synthetic fuels and renewable electricity in industrial, transportation, and agriculture sectors is expected to be a feasible pathway to decarbonize the energy system.
- Shale gas is still in its infancy stage in Algeria but has an abundant potential reserve. The Algerian state is actively seeking to develop these sources.

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