

Wind energy development in Morocco: Evolution and impacts

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ABSTRACT

Over the past ten years, Morocco has been focusing on developing renewable energy, especially wind power. This new energy policy has enabled it to become, in 2017, the leading country in the Middle East and North Africa region and the second one in Africa in terms of installed wind power capacity. In 2019, Morocco moved for the first time from the status of electricity importer to that of electricity exporter, better yet green electricity. This paper provides a quantitative study of the demand, production and installed power capacity of electrical energy in Morocco over the past two decades. It mainly focuses on the evolution of installed wind power capacity and its share in the global energy mix during this period, as well as its future prospects by year 2030. This article presents a synthesis work based on an updated assessment of the carried-out wind projects and aims to assess the realization of Morocco's national energy strategy which sets out to achieve 42% of renewable energy by 2020, and more specifically 14% of the overall energy mix being wind energy. It also aims to show the impact of wind energy integration in terms of energy autonomy, industrial integration and CO2 emissions reduction.

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1. INTRODUCTION

Over the past ten years, wind energy has been significantly developing for it being clean and low-cost [1-5]. In 2018, the world's installed wind power increased to 591 GW [6] and is expected to represent about 10% of the world's electricity production [7]. The majority of North African countries, including Morocco, have adopted national energy strategies to develop wind energy.

Due to its over 90 percent fossil fuel dependence [8-11], but also fully aware of the increase in demand for electric power related to economic dynamics and living standards changes, Morocco has adopted in 2009 an energy transition policy that is mainly based on the deployment of renewable energy resources. Not being a hydrocarbon-producing country, Morocco is heavily dependent on imports. This considerably increases its energy bill which absorbs more than 25% of its total export revenues [8, 12]. Hence, the national energy strategy, launched in 2009, aimed to achieve 42% renewable energy in the overall installed electrical capacity by the end of 2020, of which 14% would be wind, and 52% by the year 2030, of which 20% would be wind [8-11, 13-23].

In the literature, numerous studies focus on renewable energies in Morocco. In [16], the authors present the evolution of the installed renewable energy capacities for the years 2010 and 2014 as well as the

forecasts for the year 2020. In [8], the authors reviewed the projects implemented between 2009 and 2014. Their work focuses on evaluation of the social benefits of the installation of renewable energy in the concerned regions, as well as on the CO₂ savings. In [13], the authors examine Morocco's capacity to produce green energy and its politics to guarantee its energetic needs. The authors of [10] describe the deployment of renewable energy between 2009 and 2014 focusing on obstacles to overcome and the potential to meet the country's goal. Finally, the authors of [9] provide the evolution by the end of 2016 of Morocco's different energies installed capacity. Their work explains the national energy strategy and presents an estimate of wind and solar energy capacity by 2030.

All the above-mentioned work is related to renewable energies as a whole (hydraulic, solar, wind, and biomass), covering the 2009-2016 period and mainly dealing with prospects. Given that Morocco has one of the largest deposits and potentials in both Africa and the Middle East, and given the efforts and investments made in this sector, we believe that wind energy and its evolution over the past two decades deserve a special focus and a detailed study. Thus, this article presents a synthesis work mainly focused on wind energy in Morocco since the first wind farm was installed in 2000 until the end of 2019. The objective is to provide an update and assess the extent to which Morocco implemented its 2009 set out energy strategy.

First and foremost, this paper provides a quantitative study and an analysis of the evolution of demand, production and total installed electrical energy capacity between 2000 and 2019. Secondly, it examines the wind energy state of the art, showing Morocco's assets in terms of wind energy deposits and potential. It lists the various wind farms built since 2000, as well as future wind projects. The installed wind power annual evolution, its share in Morocco's total installed capacity as well as the produced quantities compared to conventional energies are then presented. Thirdly, it reviews the adopted policy regarding the siting of wind sites. Then, on the one hand, it compares 2000 and 2019 Morocco's wind capacities, and on the other hand, it compares Morocco's installed capacity with that of African and MENA countries. The current effective implementation rate with the one targeted by the national energy strategy are compared. Also, the impact of wind farms in operation is evaluated in terms of energy autonomy gain, environmental protection, and industrial integration.

2. RESEARCH METHOD

The methodology followed in this work consists of consulting, studying, analyzing, and comparing the various official and annual reports and statistical data published by the relevant national and transnational ministries, offices, and agencies such as the National Office of Electricity and Water from 2004 to 2018 [18], Ministry of Energy, Mines and the Environment from 2000 to 2019 [19], Moroccan Agency for Energy Efficiency National from 2016 to 2019 [20], Moroccan Agency for Sustainable Energy 2018-2019 [21], International Energy Agency 2014 and 2019 [12, 22], Global Wind Energy Council from 2014 to 2019 [6, 24-28], World Bank Group from 2009 to 2016 [15], Egyptian Electricity Holding Company from 2015 to 2018 [29], and Mauritanian Electricity Company from 2015 to 2018 [30].

As the reports for the current year are not yet available, the data cover 20 years, from 2000 to 2019. In the case of lack of information for some years, such as 2000 to 2004, data obtained from scientific articles or specialized information sites were cross-checked. This methodology allowed us to follow the historical evolution of the different quantities, subjects of our study, namely the demand for electric energy, the production of electric energy, the global installed power in electric energy, and the installed power in wind energy in Morocco. In the case of difference or contradiction between some figures obtained from different sources, the minimum values of the powers concerned were chosen.

3. STATE OF ELECTRICAL ENERGY IN MOROCCO

3.1. Evolution of electricity demand

The demand for electrical energy is growing steadily in Morocco. It increased from 13903 GWh in 2000 to 38852.7 GWh in 2019. This increase is mainly due to industrial development (realization and launch of major industrial projects), population growth, and improved living standards, not to mention the completion of the rural electrification project from which 99.64% of the country's rural areas have benefited [18, 19, 31].

3.2. Evolution of electricity generation

The electric power production went from 11540 GWh in 2000 to 40352 GWh in 2019, i.e. an average growth rate of around 6.89% per year. According to the statistics of the Directorate of Financial Studies and Forecasting, the production recorded at the end of 2019 an increase of 16.9%, which allowed Morocco to be self-sufficient in terms of electricity production. Better still, while Morocco was until 2018 an

importer of electricity for more than 2 billion dirhams, it is closing 2019 as a net exporter of electricity [32]. Morocco's surplus was exported to Spain [18-19].

3.3. Evolution of the installed capacity

Between 2000 and 2019, Morocco's installed electric power capacity has developed from 4389 MW to 10959 MW, an average increase of 5.15% per year. As shown in Figure 1, the share of renewable energy rose from 27.80% in 2000 to 33.60% in 2019 [18, 19]. Moreover, wind energy projects scheduled to come on stream by the end of 2020 will increase this percentage. It should also be noted that the share of hydropower will fall in favor of wind and solar energy. As shown in Figure 2, in 2000, hydropower represented 26.60% of the energy mix, while wind energy contributed barely 1.2% and solar energy did not yet exist. On the other hand, in 2019, with a 33.60% rate of installed capacity in renewable energies, the share of hydropower was 16.20%, i.e. a 60.54% drop in favor of wind and solar power.

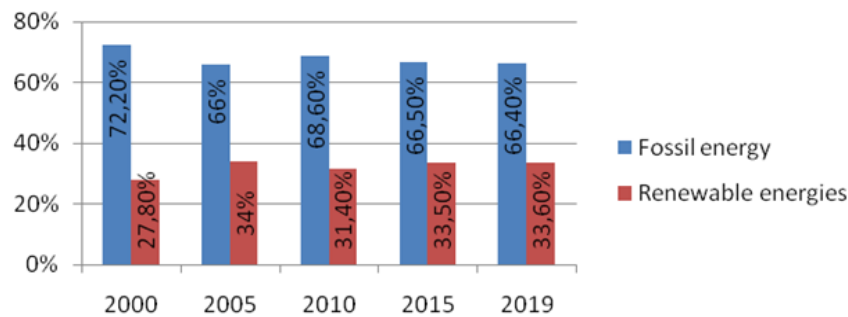


Figure 1. Energy mix in Morocco from 2000 to 2019 [18, 19]

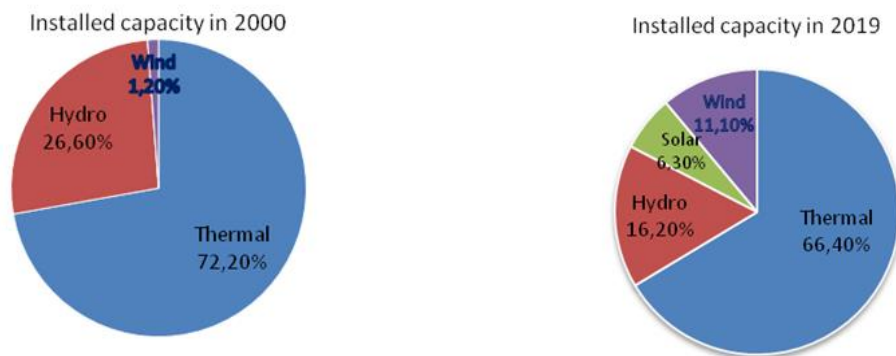


Figure 2. Distribution of installed capacity in Morocco in 2000 and 2019 [18, 19]

4. WIND ENERGY IN MOROCCO

Morocco has one of the most important deposits in the world with 3500 km of shoreline and winds reaching 11.5 m/s at 80 m [33, 34]. These resources are capable to produce about 25,000 MW onshore [10, 14, 33-39]. The studies and works carried out by the Moroccan Agency for Energy Efficiency have identified four suitable areas for the construction of large wind farms.

As shown in Figure 3, the first zone is located in the southern Atlantic coasts in places like Tarfaya, Laayoune, and Dakhla. The average annual wind speed in this area varies from 7.5 m/s to 9.5 m/s at 40 m. The second zone is in the north of the kingdom and has a yearly mean wind speed varies from 9.5 m/s to 11 m/s at 40 m [38]. The third zone is the region of Essaouira with a regular average speed of 9 m/s. The fourth zone is in the Taza couloir between the Atlas and Rif mountains and has a speed of 7.8 m/s to 40 m [33-37]. Aware of this potential, and to reduce its dependence on fossil fuels, Morocco launched in 2010, an integrated program for renewable energies, and in particular, an integrated program for wind energy, aiming to increase wind energy to 14% of the energy mix by 2020 and 20% by 2030 [10, 11, 13, 21].

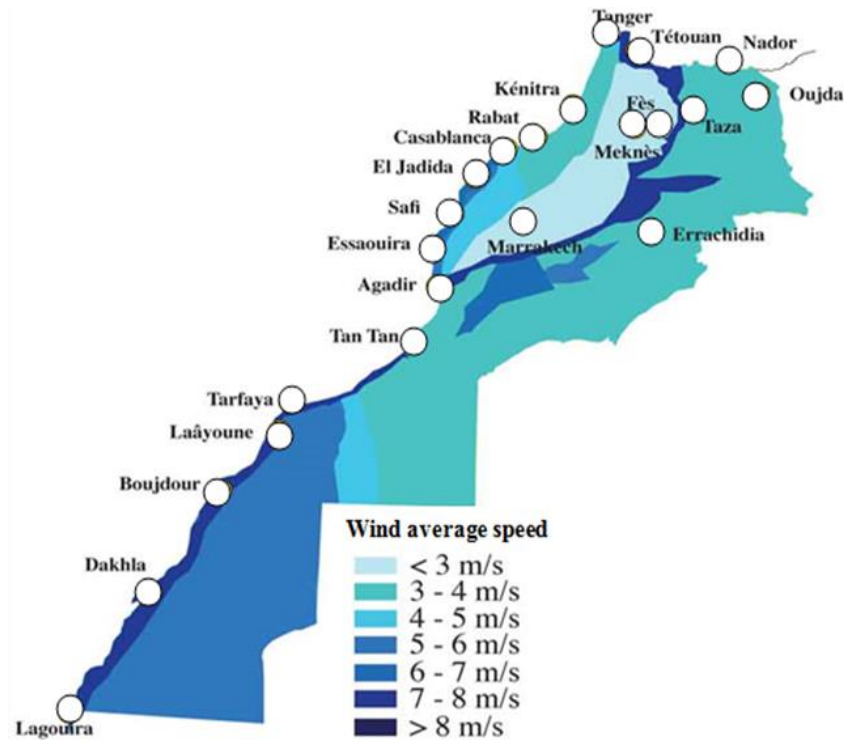


Figure 1. Wind map of Morocco [33, 34]

4.1. Operational wind farms

The first wind farm in Morocco and Africa, Koudia Baida (or Abdelkhalek Torres, 54 MW), was commissioned in 2000, in Tetouan [37, 40, 41]. Its construction has allowed the technological appropriation of this type of park. Other more powerful parks have been created, including one of the most important wind farms in Africa, namely Tarfaya park, with a power of 303 MW which was commissioned in 2014 [18, 19, 21, 41]. Then, other parks were created along the Moroccan coasts in the north and south, which are among the windiest regions in the world, such as those of Tangier, Essaouira, Boujdour, Laayoune [9, 10, 18, 19, 21, 33, 41]. Table 1 provides the list of the constructed parks averaging an annual production of 4669 GWh per year and about 3.42 million tCO₂ of saved emissions per year.

4.2. Wind farms under construction or development

The integrated Wind Energy program adopted in 2010 included the construction of six wind farms located in both the north and south with a total capacity of approximately 1000 MW [9, 10, 18, 19, 42], but in 2015, Morocco has revised upwards its ambitions [22], and added the projects of the Safi park (200 MW), Oualidia (36 MW) and the repowering of the Koudia El Beida Park (300 MW). Figure 4 displays the locations of operational, and under construction or development wind farms [9, 13, 33]. Table 2 lists the wind farms under construction or under development [9, 10, 18, 19, 21, 33].

The Midelt (180 MW), Oualidia (36 MW), Safi (200 MW) and Taza (150 MW) parks are still under construction. The commissioning of the first and second is scheduled for the end of 2020, that of the Safi Park, as well as the first phase of the Taza Park (87 MW) is scheduled for the end of 2021. The Boujdour Park (300 MW) is fully financed, while the others are under development.

4.3. Choosing the location of wind sites

Morocco's policy in this area consists of:

- Developing new wind energy projects in new sites.
- Building additional wind farms on the same site, as in the case of the Akhfenir1 (100 MW) and Akhfenir2 (100 MW).
- Dismantle of the old wind turbines already installed and their replacement with more powerful wind turbines (repowering), as in the case of the Koudia El Baida Park, where the current 90 turbines will be dismantled and replaced. Morocco is the African and MENA precursor when it comes to this model.

Table 1. List of operational wind farms [9, 10, 18, 19, 21, 33, 40, 41]

Park name	Location	Year of commissioning	Installed power (MW)	Number of turbines	Unit power of turbines	Estimated Annual production (GWh/year)	Saved CO2 emissions (KtCO2/year)	Investment in millions of dollars
Aftissat	Boujdour	2018	203	67	3	1000	700	400
KHalladi	Tanger	2017	120.5	40	3	378	336	170
Akhfenir2	Laayoune	2016	102	61	1.67	378	270	180
Tarfaya	Tarfaya	2014	301.5	131	2.3	1084	790	560
Akhfenir1	Laayoune	2013	101	61	1.67	378	270	140
Foum El Oued	Laayoune	2013	50.6	22	2.3	200	140	80
Haouma	Tanger	2013	50.6	22	2.3	200	140	80
Cimar	Laayoune	2012	5	5	1	16	11.8	10
DahrSaadane	Tanger	2010	140	165	1.85	510	380	275
Lafarge+	Tetouan	2009	22	11	2	77	58	40
Amougdoul	Essaouira	2007	60	71	0.85	210	156	80
Lafarge	Tetouan	2005	10	12	0.85	38	30	10
Koudia Baida	Tetouan	2000	54	90	0.6	200	140	52
Total			1220.2			4669	3421.8	2077

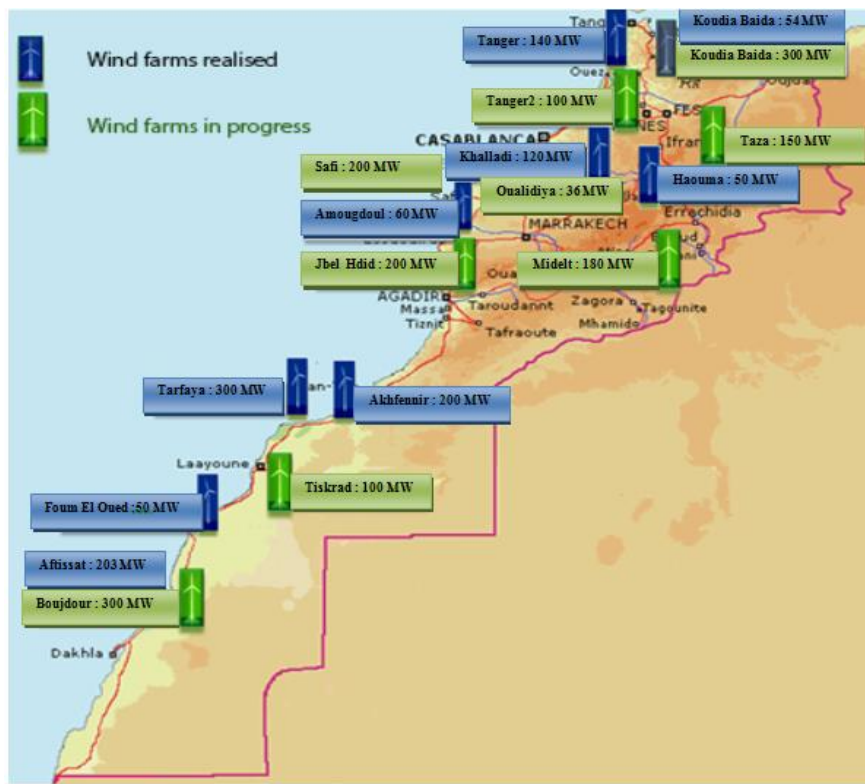


Figure 4. Location of wind farms completed and under construction in Morocco [9, 13, 33]

Table 2. List of wind farms under construction or development [9, 10, 18, 19, 21, 33]

Park name	Location	Planned commissioning date	Installed power (MW)	Estimated Annual Production (GWh/year)	Avoided Co2 (Tco2/year)	Investment in millions of dollars
Midelt	Midelt	2020	180	560	280 000	230
Boujdour	Boujdour	2022	300	1000	710 000	414
Taza	Taza	2021-2022	150	540	300 000	250
Tanger2	Tanger	2020-2021	100	362	280 000	137
Jbel Lahdid	Essaouira	2022	200	600	460 000	360
Koudia Baida	Tetouan	2020-2025	300	-	-	330
Safi	Safi	2021	200	798	650 000	350
Oualidiya	Oualidia	2020	36	110	67 200	45
Tiskrad	Tarfaya	2022	100	325	230 750	180
Total			1566			2296

5. RESULTS AND DISCUSSION

As shown in Figure 5, the demand for electrical energy increased from 13903 GWh in 2000 to 26531 GWh in 2010, hence approximately doubling, to reach 38852.7 GWh in 2019 [18, 19]. Over the last two decades, it has increased at an average rate of 5.50% per year. The reasons for this increase are explained in the subsection 3.1.

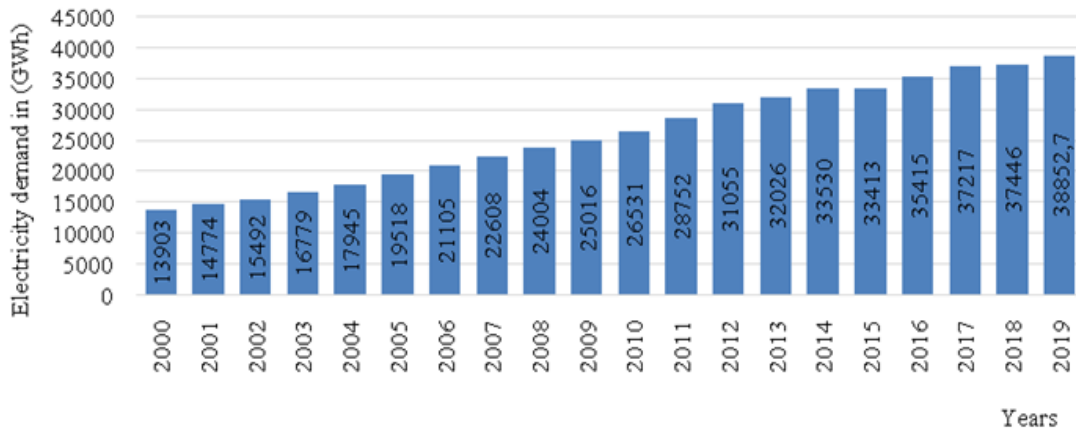


Figure 5. Evolution of electricity demand in Morocco from 2000 to 2019 (GWh)

As shown in Figure 6, electricity production in Morocco increased from 11540 GWh in 2000 to 40352 GWh in 2019, i.e. an average increase of around 6.89% per year. Before 2000, the electrical production was mainly coal and oil-based relying on thermal power plants, but as renewable energies were integrated, their share of total production increased from 6.66% in 2000 to 18.9% in 2010, with hydropower dominating (16%), to reach 19.56% in 2019, with wind power dominating (11.7%) [18, 19]. Morocco's installed electric power capacity is shown in Figure 7. Between 2000 and 2019, it has evolved from 4389 MW to 10959 MW, an average increase of 5.15% per year [19-21].

As shown in Figure 8, between 2000 and 2019, Morocco increased its overall installed wind power capacity from 54 MW to 1220 MW. Despite a relatively low volume of new installations compared to leading countries in wind energy production such as China, between 2000 and 2019, the proportion of wind energy in overall installed electrical energy has evolved from 1.20% to 11.10% [9, 10, 18, 19, 21, 33, 40, 41]. It should be noted that the share of wind energy in renewable energies (wind+solar+hydraulic) reached 33% in 2019 against only 4.30% in 2000.

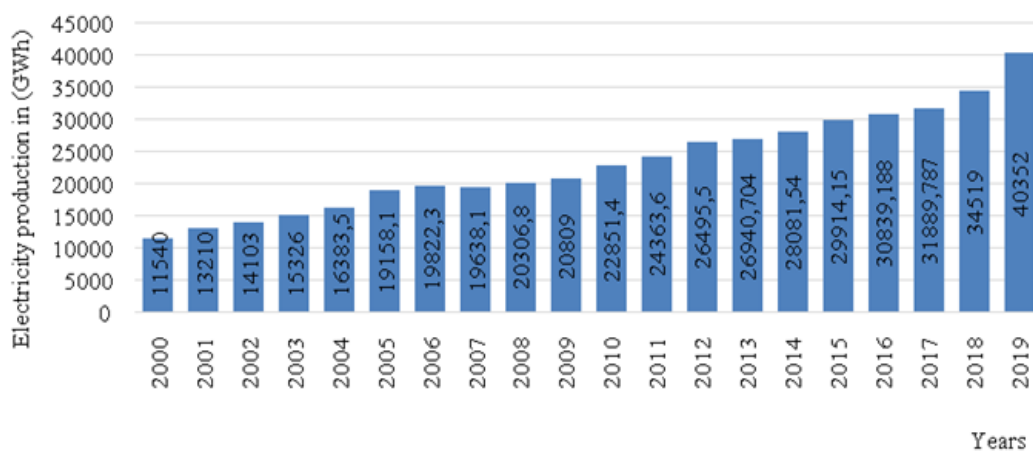


Figure 6. Evolution of electricity production in Morocco from 2000 to 2019 (GWh)

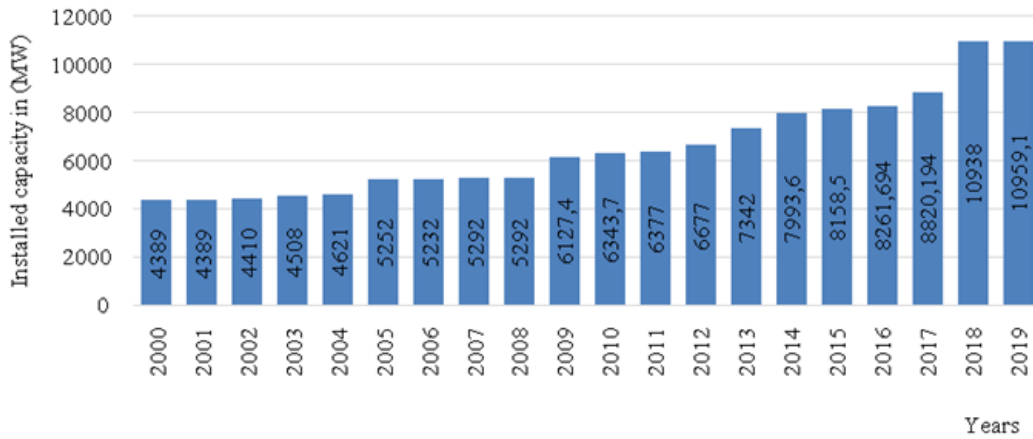


Figure 7. Evolution of installed capacity in Morocco from 2000 to 2019 (MW)

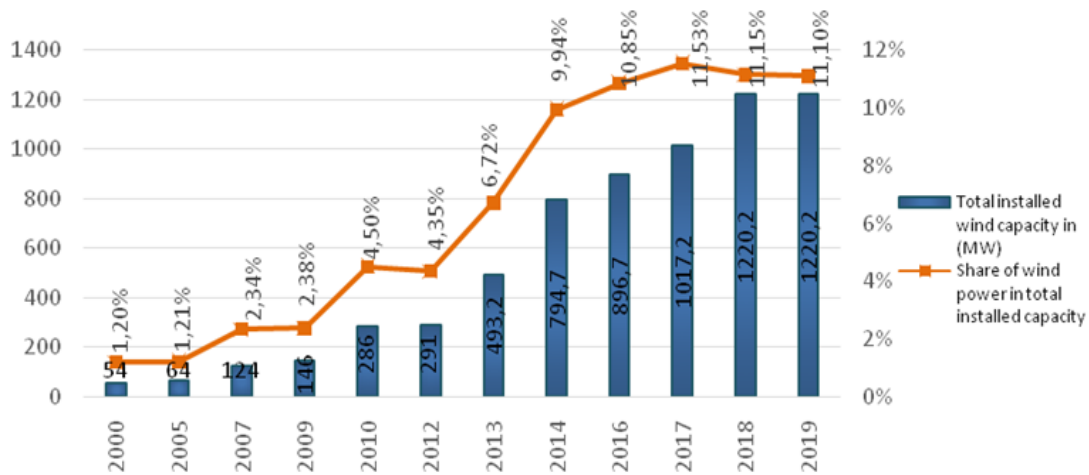


Figure 8. Installed wind capacity and share of wind power in total installed capacity, from 2000 to 2019

Table 3 shows the progression of wind power generation from 64 GWh in 2000 to 4634 GWh in 2019 [18, 19], an increase from 0.6% of the total national power generation in 2000, to 11.70% in 2019. Compared to thermal power generation, wind power generation remains modest but is expected to grow with the commissioning of the projects under construction. However, the optimization of energy production from existing and future wind farms requires research studies to be carried out to select the best methods for controlling turbine setting parameters, the best procedures for selecting wind turbines, and their optimal location, according to the nature of each site, while taking into account the various constraints [43-48].

Compared to the Maghreb countries (Algeria, Tunisia, Libya, and Mauritania), Morocco has always been ranked first. Furthermore, as shown in Table 4, the wind energy projects developed have led to major increase in terms of installed wind power capacity and have enabled Morocco, in 2017 and 2018, to be ranked first in the MENA region, and second in Africa [28-30]. Moreover, the ambitious national energy strategy and investments in solar energy, allowed Morocco to be classified as one of the top actors in Africa and the MENA region, in terms of attractiveness for green energy, according to the British accounting firm Ernst & Young (EY) in its publication of the renewable energy country attractiveness index (RECAI) [49].

Furthermore, the integrated wind projects were at the origin of the Moroccan wind industry, through the installation in Tangier of a factory for the production of blades and towers, with an annual capacity of nearly 600 units, the only manufacturing plant for wind turbine blades in Africa and the Middle East. Thanks to this plant, the local industrial integration rate should reach 70% [50]. Finally, the growth of the share of renewable energies allowed Morocco to reduce its dependence on fossil fuels by more than 34% and prevented 5.6 million Tco2 per year [18, 33] of carbon dioxide CO2 emissions.

Table 3. Conventional and wind power generation in Morocco from 2000 to 2019 (GWh) [18, 19]

Year	Thermal production in GWh	Wind production in GWh
2019	32178.90	4634.10
2015	25047	2519
2010	18409.92	658.81
2005	17539.90	206.30
2000	10817	64

Table 4. Wind power installed capacity in leading African and MENA countries (MW) [25-30]

Year	South Africa	Morocco	Egypt	Tunisia	Mauritania	Libya	Algeria
2018	2085	1220	1190	245	34.4	27	10
2017	2085	1017	810	245	34.4	27	10
2016	1471	787	810	245	34.4	27	10
2015	1053	787	810	245	34.4	0	10

6. CONCLUSION

Despite a relatively low volume of new installations compared to the wind energy leaders, the share of wind energy in Morocco is steadily growing. Morocco has become one of the leading countries in this field, in Africa and the MENA region. Moreover, installed wind energy is a major element of Morocco's transition from the status of electricity importer to that of electricity exporter in 2019. Morocco has achieved 80% of the first step of its integrated program for wind energy aimed to have wind energy account for 14% and renewable energies represent 42% of its energy mix. These rates will improve by the end of 2020 with the commissioning of the parks under construction. Thanks to the local manufacture of wind turbine components such as towers and blades, and the involvement of local companies in the design, supply and construction of electrical and civil engineering works, Morocco has been able to achieve an integration rate of 70%. All things considered, the results of the Moroccan strategy are very satisfying, although it is to be hoped that the Coronavirus and its effects on Morocco's economy, as well as an unprecedented drop in the price of oil, won't alter the path of Morocco's evolution in this domain.

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