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Wind energy integration in Africa: development, impacts and barriers

Touria Haidi[1,2], Bouchra Cheddadi[1]
[1]Department of Electrical Engineering, Laboratory of Energy and Electrical Systems, Ecole Nationale Supérieure d'Electricité et de Mécanique, University Hassan II of Casablanca, Casablanca, Morocco
[2]Department of Electrical Engineering, Laboratory of Systems Engineering, Ecole Hassania Des Travaux Publics, Casablanca, Morocco

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ABSTRACT

The African renewable energy initiative (AREI), adopted in 2015 by nearly half of the African countries, planned to install 10 GW of renewable energy by the end of 2020 and 300 GW by 2030, of which 100 GW would be wind. These countries have each adopted their own national energy strategy defining their rate of renewable electricity capacity, particularly wind, in the overall energy mix by 2020 and/or 2030. This article aims to assess the implementation of these strategies by evaluating the up-to-date achievements in regards to wind energy and thus infer the AREI realization rate by the end of 2020. It focuses on the wind energy investments of the major African countries while comparing their effective realization rates with those targeted by their national strategies. This article also covers the impact of wind energy integration and the barriers to its development in Africa. Taking into account the recent study published in 2020 by the Global Wind Energy Council which assessed the wind energy potential in Africa at 59 TW, the obtained results show that the huge wind power potential in Africa is still far from being exploited and that only Morocco, Egypt and South Africa are on the right track.

Corresponding Author:

Touria Haidi
Department of Electrical Engineering, Laboratory of Energy and Electrical Systems, École Nationale Supérieure d'Electricité et de Mécanique
El Jadida Road, Km 7, Casablanca, Morocco
Email: touriahaidi60@gmail.com

1. INTRODUCTION

Wind energy has been developed a lot in the last decade due to its cleanliness and relatively low cost [1]–[9]. In 2020, the global wind capacity reached 743 GW [10], [11] representing about 10% of the global electricity capacity [10]. Africa's wind capacity is only 6491 MW, although it has a huge wind power potential which has been estimated at 59 TW by the new study published in 2020 by the World Bank's International Finance Corporation, in collaboration with the Global Wind Energy Council (GWEC) [12]. The exploitation of this potential could largely cover the electrical demand of the whole continent.

Africa relies mostly on fossil fuels, but at the COP21 in 2015, it was encouraged to integrate renewable energy into its overall electricity mix. Nearly half of African countries endorsed this policy and have defined their national energy strategies for the deployment of renewable energy, especially wind energy. Under the framework of the African renewable energy initiative (AREI), they are committed to the installation of 10 GW by 2020 and 300 GW of renewable energies by 2030, of which 100 GW would be wind power [13]–[15].

There are many studies in the literature on the state of electrical energy in Africa and the evolution of renewable energy. Kazimierczuk [16] looks at national and international measures to sustain and incentivize the development of sustainable energy and focuses on the case study of Kenya in terms of electricity transition and the role of wind energy development in this transition. Mandelli *et al.* [17] provides an assessment of the overall energy situation in Africa and its renewable resource potential, as well as a review of policies and programs adopted this area on the continent in this continent. Mas'ud *et al.* [18] examines the situation of renewable energy and focuses on the cases of Cameroon and Nigeria. Other authors reviewed the wind energy capacities of Ghana, Mali, Egypt and Morocco [1], [19]–[24]. Aliyu *et al.* [25] studied mainly the renewable resources capacities, energy efficiency means and national energy policies adopted by South Africa, Egypt and Nigeria. Ameen and Lalk [5] analyzed the obstacles to wind energy deployment and reviewed the potential and projects for wind energy in Sub-Saharan region based on pre-2017 data. However, the majority of these papers have focused on renewable energy as a whole. The articles that have focused on the evolution of wind power have only dealt with the cases of a number of regions or countries in Africa or have been based on data ending in 2017 at best or have not taken into account the African wind power potential (59 TW), revealed in 2020 and which largely exceeds the previous estimates.

The aim of this article is to assess and update the achievements in this field and to measure the extent to which African countries that have opted for a national energy strategy defined after Conference of Parties (COP 21), have been able to succeed and implement it. It first presents a new assessment and review of the development of consumption, generation, and total electrical capacity in Africa from 2000 to 2019 and then describes the development of installed wind power and its part of the overall installed capacity between 2000 and 2020 while making an updated inventory and synthesis of the huge wind energy deposits and potentials of the countries of the continent. It identifies the main African wind farms operational between 2000 and 2020, as well as those under construction and establishes an assessment of the main African governments that have invested in wind power while comparing their actual realization rate in 2020 with that targeted by their national energy strategies. Finally, the impact of operational wind parks is assessed and the barriers to wind energy development in Africa are explained.

2. METHOD

The approach used in this article is to collect statistical data and analyze official documents, published between 2000 and 2020, by various international organizations operating in the domains of electrical, renewable and wind energies, such as, the international energy agency (IEA), the Africa energy portal (AEP), the global wind energy council (GWEC), and the international renewable energy agency (IRENA). We also used data published by the various ministries, offices, and national agencies of African countries, operating in the field of energy, electricity, and economy. In case of missing data, scientific articles, specialized information sites and/or statistical data providers such as statista, wind power, our world in data, enerdata, and world wind energy association were used. The study and analysis of these data allowed us to determine the evolution, between 2000 and 2019, of the state of electrical energy in Africa: installed capacity, renewable capacity, electricity demand, electricity generation as well as the evolution between 2000 and 2020 of its installed capacity in wind energy.

2.1. State of electrical energy in Africa

2.1.1. Installed electrical capacity in Africa

As shown in Table 1, installed electricity power in Africa grew from 102.02 GW in 2000 to 140.71 GW in 2010, and 235.72 GW in 2019. Its average annual growth rate (AAGR) is 3.27% between 2000 and 2010, and 5.9% between 2010 and 2019, i.e. an AAGR of 4.5% between 2000 and 2019 [26]. This rate appears to be higher than the global AAGR of 3.1% for the latter period, but Africa's installed electricity capacity remains low and is only 3.25% of that of the world. Its distribution is not uniform as the regions of South Africa and North Africa alone account for over 79% of the continent's overall power capacity, with 49.84% for North Africa and 29.88% for South Africa [26].

As shown in Figure 1, the 235.72 GW of installed electricity capacity in 2019 is made up of 48 GW of renewable energy with a clear predominance of hydro and, as shown in Table 2, the 187.715 GW of non-renewable installed capacity is predominantly fossil. As shown in Table 2, hydropower accounts for 13.81%, solar for 3.07%, wind for 2.44%, bioenergy for 0.69%, geothermal for 0.35% while 77.45% of the electricity capacity is fossil fuels. Renewable energies represent barely 20% of the total installed electrical capacity, which is below the global rate of 34.7% [27].

Table 1. Evolution of installed capacity in Africa and in the world [26], [27]

Year	2000	2005	2010	2015	2019
Installed capacity in Africa in GW	102	117	141	177	236
Installed capacity in world in GW	3545	4207	5220	6444	7078

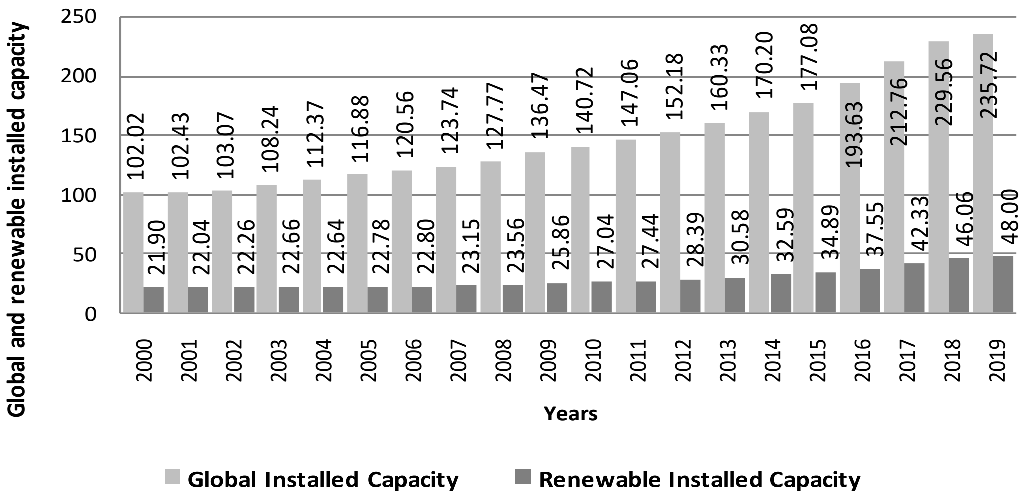


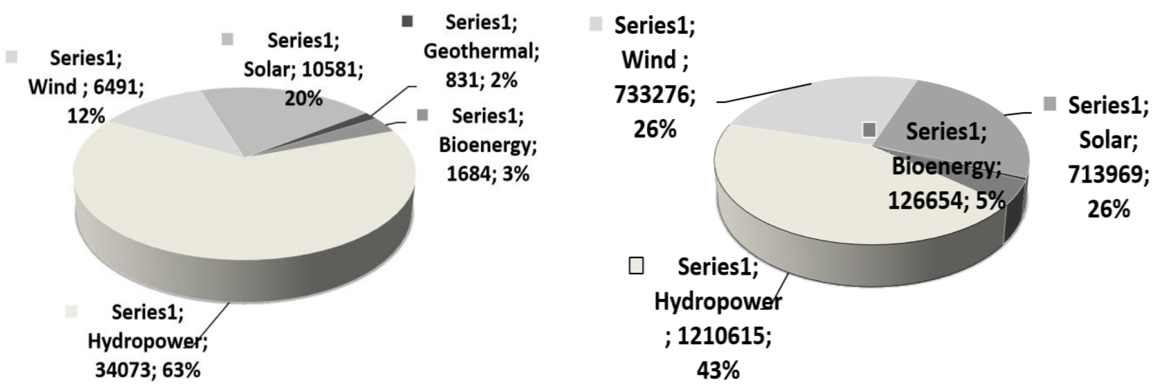
Figure 1. Evolution of global and renewable installed capacity in Africa from 2000 to 2019 in GW [26], [27]

Table 2. Installed capacity and share of installed capacity by source in Africa in 2019 [26], [27]

Type of energy source	Fossil	Hydro	Solar	Wind	Bioenergy	Geothermal	Other	Nuclear
Installed capacity in MW	182551	32558	7236	5753	1626	830	3224	1940
Installed capacity in %	77.45	13.81	3.07	2.44	0.69	0.35	1.36	0.82

2.1.2. Evolution of renewable capacity in Africa

As illustrated in Figure 1, installed renewable energy in Africa grew by about 22 GW in 2000 to 27 GW in 2010, to 53.6 GW in 2020. It represents only 1.9% of global renewable energy capacity. The AAGR between 2010 and 2019 is 6.6% while the global AAGR is 8.7%, which shows a low growth relative to other continents [10]. In 2015, after the COP21, the AREI had a target to increase its installed renewable energy capacity by 10 GW by the end of 2020. Looking at Figure 1, we see that between 2015 and 2020, Africa has been able to add more than 13 GW. It has therefore been able to achieve this target by more than 100%, however, the strategy was aimed at developing solar and wind energy, whereas it was hydro that dominated. Indeed, more than 63% of the renewable capacity in Africa is hydro, compared to 43% worldwide. Figure 2 shows the distribution of renewable energy in 2020 in Africa in Figure 2(a) and in the world in Figure 2(b).



(a) (b)

Figure 2. Distribution of renewable energy in 2020 in (a) Africa and (b) the world [27]

2.1.3. Evolution of electricity demand and generation in Africa

Figure 3 shows that the electric consumption increased from 379 TWh in 2000, to 554 TWh in 2010, to reach 692 TWh in 2019 [28]. The compound annual growth rate (CAGR) went from 3.87% between 2000 and 2010 to 2.5% between 2010 and 2019, or 3.22% between 2000 and 2019 [28]. South Africa and North Africa consume for over 60% of this demand.

Production increased from 445 TWh in 2000 to 675 TWh in 2010 and will reach 858 TWh in 2019 [26], i.e. a CAGR of 4.25% for the period 2000-2010 and 2.7% for the period 2010-2019, i.e. 3.5% between 2000 and 2019. The discrepancies between consumption and production are explained by excessive losses in the transmission lines, which can reach 20% of the power produced and which are caused by the lack of maintenance and the age of the infrastructure [11]. In 2019, with world consumption and production at 23105 TWh and 26914 TWh respectively, Africa consumes and produces only about 3% of world production and consumption [28].

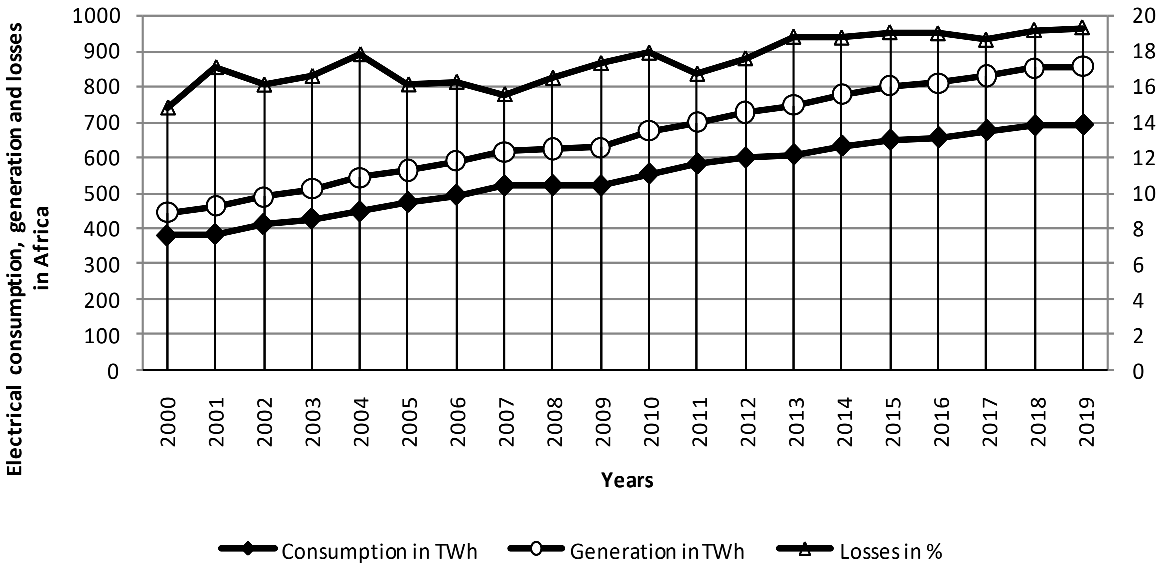


Figure 3. Electrical demand in TWh, electrical production in TWh and losses in percent in Africa [28], [29]

2.2. Wind energy in Africa

2.2.1. Wind energy potential

In 2015, the African wind power potential was estimated at about 109 GW [13], [15], but the new study published in 2020 by the World Bank's International Finance Corporation in collaboration with GWEC evaluated it at over 59 TW [12] which is way more than half of the global wind power potential, estimated in 2015 to be around 95 TW [30]. As seen in Figure 4, the best wind areas in Africa are in the north, the far east and far west and the south [12]. In two thirds of the areas concerned, the wind speed is above 7.5 m/s, while the remaining third have wind speeds above 8.5 m/s showing the abundance, richness, and quality of wind potential in Africa. The countries with the best wind resources are grouped in Table 3 [12].

2.2.2. History

Egypt built the first pilot wind farm in North Africa in 1988, with a capacity of 400 kW. In 1993, Kenya commissioned the first unit of the 350K W Ngong Hills plant, which was the first wind farm in East Africa [31]. The first park in South Africa, named Klipheuwel (3.16 MW) was commissioned in 2002 [32]. In Central Africa, Amdjarras (1.1 MW) is the only existing park, built by Chad in 2016. In West Africa, it was only in 2020 that Senegal commissioned the first phase of the first wind farm named Tayba Nday (50 MW).

It is Morocco who has commissioned, in 2000, the first wind farm in Africa of relatively large power compared to other existing parks at the time, named Abdelkhalek Torrés (50 MW) [33]. Afterwards, other more interesting wind farms were built, especially after the COP21 in Paris, where African countries became aware of the need to integrate renewable energies into their energy mix, especially wind and solar.

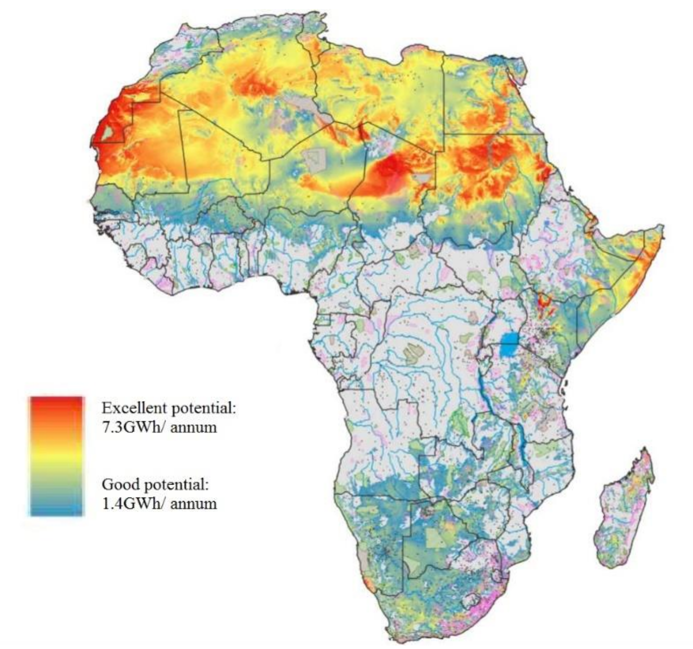


Figure 4. Total technical potential of wind energy in Africa [12]

Table 3. Potential wind capacity (PWC) in GW and average capacity factor (ACF) in % in African countries with great wind resources [12]

Region in Africa	Potential Wind Capacity/Average Capacity Factor	Countries						
North		Algeria	Egypt	Libya	Tunisia	Morocco	-	-
	(PWC)	7717.1	3389.2	5855.4	512.3	719.3	-	-
	(ACF)	36.9	36.5	37.4	35.6	32.9	-	-
West		Burkina	Mali	Mauritania	Niger	Nigeria	Senegal	-
	(PWC)	638.4	4047.9	4229.4	3846.7	1261.1	492.1	-
	(ACF)	27.7	35.0	39.2	35.3	28.6	29.4	-
East		Ethiopia	Kenya	Madagascar	Somalia	Sudan	Tanzania	-
	(PWC)	1171.1	1073.5	704.4	1625.7	6508.4	620.4	-
	(ACF)	31.2	31	31.1	35.5	36.7	28.8	-
Central		Chad	Cameroon	-	-	-	-	-
	(PWC)	3607.4	114.1	-	-	-	-	-
	(ACF)	37.8	27.7	-	-	-	-	-
South		Angola	Botswana	Mozambique	Namibia	South Africa	Zambia	Zimbabwe
	(PWC)	651.2	1298.8	681.1	1842.3	2712.4	930	468.7
	(ACF)	24.2	27.4	26.3	27.2	29.3	24.8	26.1

3. RESULTS AND DISCUSSION

In 2020, the wind capacity in Africa reached 6491 MW. It was only 134 MW in 2000, rising to 862 MW in 2010, then to 3322 MW in 2015. Figure 5 shows the evolution of this capacity between 2000 and 2020. It was therefore multiplied by 48.44 between 2000 and 2020; however, it still represents only 2% of the global electrical capacity in Africa and less than 1% of the global wind capacity. South Africa, Morocco and Egypt are the countries that have invested the most in wind power, with respectively 2636 MW, 1405 MW and 1375 MW of installed capacity, other countries are following suit such as Kenya, Ethiopia, Tunisia, and Senegal. Table 4 shows the main operational wind farms with significant capacities up to the end of 2020 and Table 5 lists the main wind farms under construction in 2021.

Some of the main impacts of the increase in wind energy in Africa include: i) increase in the installed electrical capacity using clean energy, at competitive costs and therefore improving energy security and especially access to electricity for the population; ii) reduction of carbon emissions, though according to the IEA, Africa generates only about 2% of global greenhouse gas emissions; iii) transfer of wind technology and increase of the rate of industrial integration in this field; iv) creation of tens of thousands of jobs during the construction of each wind farm; and v) possibility for several countries with high wind potential to become exporters of clean electricity.

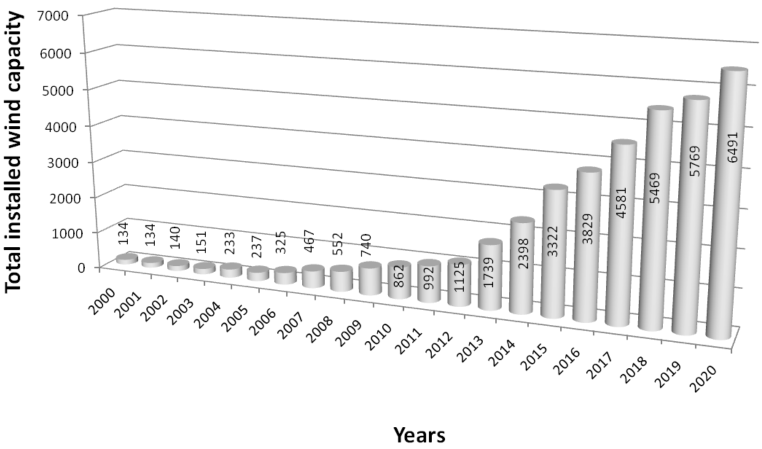


Figure 5. Total installed wind capacity in Africa from 2000 to 2020 in MW [10], [26]

Table 4. List of the principal operational wind farms in Africa in 2020 [16], [25], [31], [34]

Country	Park name	Year of commissioning	Installed power (MW)	Number of turbines	Unit power of turbines	Estimated annual production (GWh/year)	Saved CO_2 emissions ($KtCO_2$/year)	Investment in Millions of Dollars
South Africa	Nxuba	2020	140	47	3	460	460	244
	Perdeclaar	2020	110	48	2.30	368.8	410	-
	Kangnas	2020	140	61	2.30	513.2	550	260
	Loeriesfontein 2	2017	140	61	2.30	563	550	260
	Khobab	2018	140	61	2.30	563	550	260
	Aar1 and 2	2015-2017	244.5	136	1.50	644	620	350
	Cookhouse	2014	138.6	66	2.10	341	384	190
	Dorper	2014	100	40	2.50	-	290	181
	Gouda	2015	138	46	3	423	406	210
	Amkhala	2016	134.4	56	2.40	450	445	310
	Gibson Bay	2017	111	37	3	420	383	-
	Jeffreys bay	2014	138	60	2.30	460	420	-
	Sere	2015	100	46	2.30	298	300	188
Morocco	Midelt	2020	210	50	3-4.20	560	360	250
	Aftissat	2018	201.6	56	3.60	1000	700	400
	Khalladi	2017	120.5	40	3	378	336	170
	Akhfenir2	2016	102	61	1.67	378	270	180
	Tarfaya	2014	301.5	131	2.30	1084	790	560
	Akhfenir1	2013	101	61	1.67	378	270	140
	Dahr Saadane	2010	140	165	1.85	510	380	275
Egypt	Za'farana	2001-2010	545	700	0.85-0.60-0.66	1400	834	1100
	Gabal-Zeit *	2018	580	290	2	-	-	672
	Ras Ghareb	2019	262.5	125	2.10	-	730	400
Ethiopia	Ashegoda	2011-2013	120	84	1-1.67	400	300	290
	Adama 2	2016	153	102	1.50	479	-	345
Kenya	Turkana	2019	310	365	0.85	1250	737	680
Tunisia	Bizerte	2012-2015	190	143	1.32	600	300	360
Senegal	Tayba N'diaye**	2020-2021	158	46	3.45	450	300	377

*460 MW operational, ** 50 MW operational

Table 6 lists the national wind strategies of African countries that have installed wind farms. These strategies have set a target to be reached, in terms of wind capacity or/and percentage of its capacity in their overall installed electrical power, for a given target year (2020 or 2025 or 2030). By analyzing the results obtained in Table 6, we see that in the end of 2020: i) with wind power accounting for 11.8% of the overall installed electrical capacity in 2020, Morocco has achieved 84.29% of its target of reaching 14% of wind power in its overall electrical capacity and 70.25% of its target to reach 2000 MW in 2020. With these results, we can say that it is the first country in Africa that has been able to adapt its means to its goals; ii) South Africa is at the top of the rankings in the installed wind capacity, but this capacity represents, in 2020, only about 4.84% of its energy mix and less than 19% of its target to reach 14400 MW in 2030; iii) Egypt ranks third with 1375 MW. It has achieved about 19% of its target of having 7200 MW of wind power by the end of 2020, while it has only achieved about 17% of its target of having 12% of its overall capacity in wind power by the end of 2020; iv) some countries such as Kenya, Ethiopia, Tunisia have ambitious targets for 2030 which they are still far from achieving them, but they have a political will to move forward in their wind projects; v) some countries, such as Chad, Cape Verde, Seychelles, Tunisia, Somalia, Mauritania, and Senegal have a high share of wind capacity in their global renewable capacity, while their investments in wind power are low. This is because the renewable capacity in these countries is also low. For example, Cabo Verde has only 35 MW of renewable energy, of which 28 MW is wind, which explains the 80% rate that should not mislead us; and vi) according to the GWEC, only 0.01% of the African wind potential is exploited and although the African countries with significant wind potential are numerous, they have not all invested in wind energy. These include Algeria, Niger, Chad, Sudan, Zambia, Madagascar, Tanzania, Angola, Mali, Nigeria, Botswana, Namibia, and Libya.

Table 5. List of the principal wind farms under construction in Africa [16], [25], [31], [34]

Park name	Location	Estimated Year of commissioning	Installed capacity (MW)	Number of turbines	Unit power of turbines	Estimated Annual generation (GWh/year)	Estimated reduced CO_2 emissions ($KtCO_2$/year)	Investment in Millions of Dollars
Golden Valley	South Africa	2021	120	48	2.5	477	482	223
Garob	South Africa	2021	140	46	3.15	573	600	237
Karusa	South Africa	2021	140	35	4.2	585	611	223
Soetwater	South Africa	2021	140	35	4.2	585	611	223
Copperton	South Africa	2021	102	34	3.15	360	-	170
Roggeveld	South Africa	2021	140	47	3-3.15	555	503	304
Oyster Bay	South Africa	2021	140	41	3.6	568	590	180
West Baker	Egypt	2021	250	96	2.625	1000	550	325
Kipeto	Kenya	2021	102	60	1.7	-	-	335
Taza	Morocco	2022	150	50	3	540	430	250
Boujdour	Morocco	2021	300	87	3.4	1000	710	414
Jbel Lahdid	Morocco	2023	270	-	-	810	620	314
West Bakr	Egypt	2021	252	70	3.6	1000	560	325
Aicha 1	Ethiopia	2021	120	80	1.5	-	-	257
Assela	Ethiopia	2023	100	29	3.45	300	260	170.5
Boulenouar	Mauritania	2022	100	39	2.6	591	-	167

Table 6. Wind capacity National Strategy targets and completion rates in 2020 for the African countries which invested in wind capacity [18], [21], [34], [35]

Country	Wind capacity target	Installed wind capacity in 2020 in MW	Completion rate in %	Wind capacity share in overall capacity target	Wind capacity share in overall capacity in %	Completion rate in %	Wind capacity share in the total renewable capacity in %
South Africa	14400 MW by 2030	2636	18.30	-	3.79	-	27.35
Morocco	2000 MW by 2020	1405	70.25	14% by 2020 20% by 2030	11.8	84.28 59	40.76
Egypte	7200 MW by 2020	1375	19.10	12% by 2022 14% by 2035	2.12	17.67 15.14	23.07
Kenya	2036 MW by 2030	336	16.50	-	11.47	-	15.36
Ethiopia	1224MW by 2020 7000 MW by 2030	324	26.47 4.63	-	7.11	-	6.87
Tunisia	835 MW by 2020 1755 MW by 2030	244	29.22 13.90	-	3.98	-	60.86
Senegal	-	50	-	-	4.65	-	21.74
Mauritania	-	34	-	-	5.85	-	28.21
Cabo Verde	76 MW by 2020	28	36.84	-	15.90	-	78.57
Mauritius	-	11	-	6% by 2020 8% by 2025	1.28	21.34 16	4.21
Algeria	1700 MW by 2030	10	0.59	-	0.04	-	1.45
Nigeria	20 MW by 2015 40 MW by/2025	3	15 7.50	-	0.02	-	0.14

4. CONCLUSION

This paper presents an updated synthesis and assessment of African wind power development during the period 2000-2020 and aims to evaluate the progress made in this field to achieve the national energy strategies for 2020 and/or 2030 that have been adopted by the African countries that adhered to the AREI. With the installation of more than 13 GW of renewable energy capacity between 2015 and 2020, Africa has been able to achieve its strategy of adding 10 GW of renewable energy by the end of 2020, however 63% of it was hydro while the objective was to develop mainly wind and solar. Africa's installed wind capacity constitutes only about 2% of its overall electricity capacity and less than 1% of the global wind capacity. Only 0.01% of Africa's wind power potential is exploited. Given that IRENA has estimated that among the 300GW of renewable energy targeted by the AREI by 2030, 100 GW would be wind, and knowing that the total wind capacity reached by the end of 2020 is 6491 MW, we deduce that only 6.49% of this target has been achieved. Regarding national energy strategies, only Morocco has been able to achieve 84.29% of its national energy strategy for 2020, the other African countries are still at less than 20%. Many barriers have contributed to this low achievement rate: i) existence of abundant fossil and hydraulic natural resources that some countries prefer to exploit first and consider that investment in other energy sectors is not a priority, or even that they are against their interests, especially since Africa is responsible for only about 2% of CO_2 emissions; ii) for some countries technical problems were caused by the difficulty of connecting the wind farms to the national grids because of their limited capacity or the obsolescence; iii) insufficient financial means despite financial incentives and support from international organizations; and iv) lack of clear and serious government policies in this area. Despite all these problems, Morocco, South Africa, and Egypt are well on their way and other countries such as Ethiopia, Kenya, and Senegal are starting to invest more and more in this field.

The targets have not yet been met, but the renewable projects under construction or development, as well as the maintenance and extension of national electricity grids, not forget the $100 billion a year in donations and loans that rich countries have promised Africa, can help meet or approach the expected targets. It should be noted that a major limitation to our work was the lack of technical data from some countries and/or wind farms. The future orientations of this work would be to measure, in figures, the environmental, economic, and social impact in terms of reduction of CO_2 emissions, employment opportunities, access to electricity, energy autonomy and to carry out a reflection on the perspectives of development of the electrical wind power in Africa for the horizon 2030-2050.

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BIOGRAPHIES OF AUTHORS

Touria Haidi is a professor at EHTP, Morocco. She has a degree in electrotechnical engineering, a certificate of Advanced Studies in Information Processing, and a Specialised Master's in Information Systems. Her research is focused on renewable energies and electrical networks. She can be contacted at email: touriahaidi60@gmail.com.

Bouchra Cheddadi is a Professor in EST, UH2C, Casablanca, Morocco. She had a doctorate in Applied Mathematics from EMI, Rabat, Morocco, and she had an Engineer degree from ENSEM, Casablanca in 1992. Her research works was about Heat and Mass Transfer Phenomena which include: The development of a simulation and synthesis tool specific to the study of the double diffusive convection and Thermosolutal convection in annular cylindrical spaces. Currently, her research works are more focused on power systems (Power flow, state estimation, Smart Grid). She can be contacted at email: Bcheddadi@hotmail.com.