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## Article

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## Electricity Development and Opportunities to Reduce Carbon Dioxide Emissions in Morocco

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### ABSTRACT

Morocco, as many other countries in North Africa, is becoming vulnerable to climate change consequences. Its sulfur dioxide (SO<sub>2</sub>) and carbon dioxide (CO<sub>2</sub>) emissions are relatively high due to the electricity production, this sector is still heavily relying on coal. Morocco is also an emerging country, aiming to raise its economic development indicators and pursue a sustainable energy approach, facing additional challenges with industrial development and many coal infrastructures already in place. For the country, renewable energy is considered the most efficient pathway to decarbonize the electricity sector and reduce CO<sub>2</sub> emissions. The main goal is to meet the growing need for electricity while preserving the environment. This study investigates the electricity sector in Morocco and its production sources, it highlights the limitations of the current model and gives an opportunity analysis to meet the carbon neutrality target. This study also provides some development axes and recommendations to accelerate and support the new energy vision.

**Keywords:** Electricity production, Carbon Dioxide emissions, Energy transition, Coal, Renewable energy, Morocco

**JEL Classifications:** Q540, Q5, Q28, Q42

### 1. INTRODUCTION

Due to global warming issues, several protocols such as the Montreal Protocol, Kyoto Protocol and Paris protocol have been signed by many countries around the world. The Montreal Protocol came first in 1987 (Velders et al., 2007) after ozone depletion has been demonstrated. The Kyoto Protocol came in 1997 (Oberthur and Ott, 1999) after proving that greenhouse gases effects are causing global warming. The Paris protocol came last in 2015 (Streck et al, 2016), it counted 190 country signing to engage effort and policies to limit climate change consequences. These protocols aim to reduce environmental pollution and call on the most polluting countries to initiate drastic action plans.

Morocco is particularly vulnerable to climate change, it is reflecting in periods of droughts, floods and heat waves with an average warming estimated at 1°C and rainfall variability reaching

30% (Chentouf and Allouch, 2018). In 2018, a worldwide study (Green Peace Nasa, 2019) was conducted based on data delivered by NASA's IMO satellite, which monitors the air quality on the planet's surface. The study classified Morocco as the 2<sup>nd</sup> most polluting country for SO<sub>2</sub> emissions in Africa, after South Africa. As for CO<sub>2</sub> emissions, it has been proved that carbon dioxide is the largest contributor to climate change (York and McGee, 2017), presenting serious climate treats. Morocco's CO<sub>2</sub> emissions come mainly from the electricity sector, still heavily relying on coal.

Therefore, Morocco is reviewing its electricity production policy, being the main source of CO<sub>2</sub> and SO<sub>2</sub> emissions according to the energy High commission Report (HCP, 2018). Several challenges arise such as the forecast increase in electricity consumption, also several opportunities must be seized, with the important renewable energy potential especially in solar and wind resources, other alternatives such as natural gas can also be considered. This study

analyzes the Moroccan electricity sector in the light of the new sustainable goals set to conduct energy transition. The Moroccan electricity sector is strategic in energy transition and presents as many challenges as opportunities.

## 2. THE CURRENT CONTEXT OF THE MOROCCAN ELECTRICITY SECTOR

### 2.1. Electricity Consumption and Gas Emission

Carbon Dioxide and sulfur dioxide are considered among the most important indicators reflecting harmful impact on environment, especially CO<sub>2</sub> which is proved to be the major greenhouse gas mainly blamed for global warming (Letcher, 2019). According to many works on this subject (Jackson et al., 2017), despite the decline in coal use, many industrial trends are accentuating CO<sub>2</sub> emissions, especially the growing use of fossil resources correlated to the growing demand. According to the same study (Jackson et al., 2017) electricity and energy consumption from fossil fuels are accounting for 90% of dioxide emissions. In Morocco, the energy mix is dominated by hydrocarbons. According to the latest statistics of the International Energy Agency (IEA) on electricity generation in Morocco (Electricity Generation in Gwh by Source, Morocco 1990-2019), Hydrocarbons represented 52% in 2019 intended mainly for transport, coal on the other hand represented 33% in 2019 intended for electricity production. The Joint Research Centre (JRC) technical Report (JRC, 2019) confirmed that Morocco has little fossil energy reserves, energy dependence is therefore almost total. The 2018 annual report of the Moroccan exchange office stated that energy imports exceeded 90%, as a result, the economic trade balance suffers from a huge deficit, which during the mentioned year amounted to 20 billion dollars (Foreign Exchange office, 2018), half of which is completely attributed to energy imports.

Electricity can be produced by various sources such as coal, fossil fuels or renewable sources, the Figure 1 shows the evolution of the electricity generation in Morocco between 1990 and 2019 by source.

According to the statistics above, in 2019, coal was accounted for 65% of electricity production, its consumption increased by 57% between 2015 and 2019. This increase is justified by

the replacement of fuel in some power plants, reason why coal consumption fell by 60% between 2015 and 2019.

Power plants that burned coal, natural gas, and petroleum fuels are therefore the source of about 77% of total Morocco's electricity generation.

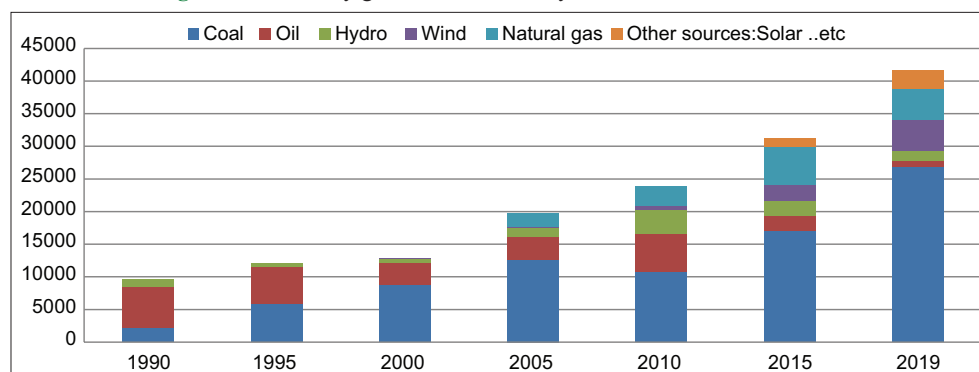
In addition to national production which was around 41 TWh in 2019, Morocco is taking advantage of its positioning as a regional platform for electricity exchanges between Europe and north Africa. In fact, according to the United Nations COMTRADE database, Morocco contribution is around 76% of Spain's electricity imports. Currently, the transit of this electrical energy is provided by an interconnection made of 15 submarine cables of about 29 km in length (Red Electrica, 2016). Electricity goes through a network made of 23.330 km of very high voltage (T.H.T) and high voltage (H.T.) lines. The distribution network is made up of 80,662 medium voltage lines (M.T.) and 191,380 km of low voltage lines (B.T.) (Red Electrica, 2016).

In 2018, Morocco emitted 216 kilotons of SO<sub>2</sub> (Green Peace Nasa, 2019), ranking 25 in the list of most SO<sub>2</sub> polluting countries in the world, and 2<sup>nd</sup> in Africa. Three thermal power plants appear in the GreenPeace Nasa report: First, Jorf Lasfar plant, a Moroccan coal plant ranked 74th in the world, with emissions of 113 kilotons of SO<sub>2</sub> per year, followed by the Mohammedia plant, also a coal plant, with 73 kilotons and that of Safi, commissioned and produced 30 kilotons of SO<sub>2</sub> for just a few days of operation. This last plant, which intends to meet 25% of the national electricity demand, will produce a significant amount of SO<sub>2</sub>.

The consumption of net electrical energy has grown steadily since 2000, recording an average annual growth rate around 7% (IEA, Morocco electricity consumption database). According to the IEA statistics of CO<sub>2</sub> emissions by source in Morocco, 63% of CO<sub>2</sub> emissions, combining both electricity and industrial sectors, come from oil followed by coal with 34% and only 3% from natural gas. The Figure 2 presents of electricity generation and CO<sub>2</sub> emissions from IEA database.

According to the statistics, the annual emissions of carbon dioxide have increased by 20% between 2000 and 2015, but only by 7% between 2015 and 2019. In fact, the energy

**Figure 1:** Electricity generation in Gwh by source, Morocco 1990-2019



Source: IEA Data Base – Morocco

consumption is driven by population growth, industrialization, and economic development, this also can be attributed to the implementation of the national program for global rural electrification (European union report on Morocco, 2012). This program is aiming to generalize access to electricity for isolated populations in rural areas. Given the rising demand, electricity is an efficient energy carrier to energy transition, by providing clean source of production to lower or even suppress CO<sub>2</sub> and SO<sub>2</sub> emissions.

## 2.2. Electricity Generation Sources: Fossil Versus Renewables

In many countries, fossil fuels still dominate the electricity generation mix. In Morocco, fossil fuels such as coal, oil and natural gas are the main energy source of power generation, they will probably continue to generate power due to the existing infrastructure and affordability. The amount of CO<sub>2</sub> produced per kWh varies according to the resource type.

According to IEA statistics on Morocco's coal imports, coal use in power generation is increasing since 2010 in order to meet the growing electricity demand. The following Figure 3 shows the coal imports evolution in Morocco from 1990 to 2018.

Coal use has slowed markedly in 2010, but its actual trajectory remains increasing due to the lack of economically viable alternatives. The average change in coal imports between 2010 and 2018 is 24%. The main disadvantage of fossil fuels is their environmental impact, especially their CO<sub>2</sub> emissions, although, natural gas is considered by many authors, such as Leug (Leug, 2015) the cleanest fossil energy source.

To reduce greenhouse gas emissions, Morocco is reorienting its energy strategy towards renewable resources, the statistics shown in Figure 4 confirms the progression trend of renewable energies as a growing source of electricity production.

The statistics are showing that Morocco timidly began the introduction of renewable energies in 1990 with hydroelectric power generation, with no more than 915 GWh between 1990 and 1995. In 2000, the first wind generated electricity appeared with 64 GWh. Wind energy developed very rapidly to become the first renewable energy source in the electricity mix in 2019, with 4966 Gwh generated, representing 59% of the renewable energy mix. Solar is the last renewable source joining the energy mix, but its growth between 2015 and 2019 is dazzling, solar is already representing 20% of the renewables source in 2019.

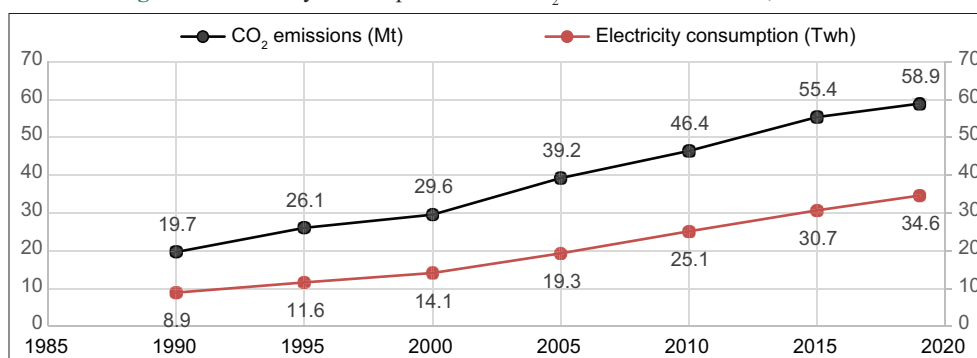
Significant progress has been achieved by implementing renewable projects since 2010. Morocco is turning massively towards renewable energies, increasing the share of green electricity would definitely help reduce fuel use in the future.

## 3. THE MOROCCAN ENERGY TRANSITION STRATEGY

### 3.1. Achieving Carbon Neutrality

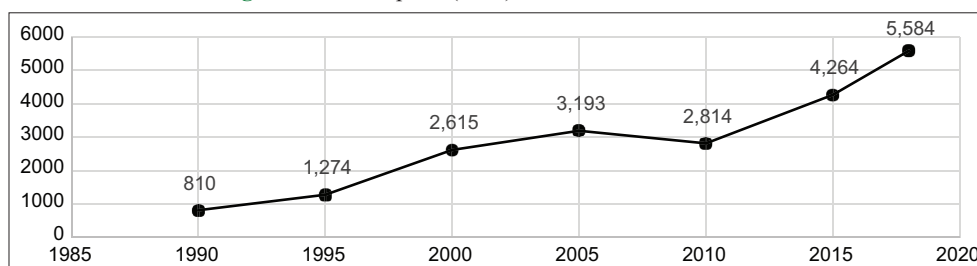
The European Union is committed to reach at least 32% of renewables in the energy mix by 2030 and reduce the greenhouse gas emissions by 40% in 2030 and by 80-90% in 2050 (Solé et al., 2020). The world demonstrated awareness and responsibility by signing the Paris Agreement (Cui et al., 2019), a worldwide commitment to reduce greenhouse gas emissions to limit global

Figure 2: Electricity consumption versus CO<sub>2</sub> emission in Morocco, 1990-2018



Source: IEA Data Base – Morocco

Figure 3: Coal imports (Ktoe) , EIA, Morocco 1990-2018



Source: IEA Data Base – Morocco

temperature change. Morocco has shown its strong commitment to this dynamic, the kingdom has positioned itself for several years as a forerunner in renewable policy.

For Morocco, the targets communicated through the ministry of environment (Economic, Social and Environmental Council, 2020) articulate ambition for lowering CO<sub>2</sub> emissions by conducting energy transition toward renewables, but do not explicit detailed plans to move away from coal. In fact, the switch from fossil fuels to renewables represents a challenge in terms of necessary investments and technical barriers. Morocco is still highly dependent on imported fossil fuels for its energy needs (JRC, 2019), the kingdom has announced (Ministry of Energy and Mines, Draft Law N° 94-17, 2016) planning to introduce natural gas into the energy mix through the construction of the first importation and storage platform for Liquid Natural Gas (LNG) by 2030, intended to replace coal in electricity production, but also intended for industrialists. In fact, the global energy context presents significant development opportunities in the LNG market where supply exceeds demand due to increasing volumes of shale gas as well as the discovery of several gas fields in Africa (El Ghazi et al., 2019). This imbalance between supply and demand benefits the importing countries; LNG therefore becomes accessible and presents a long-term development opportunity for Morocco. The target to meet by 2030 in electricity sources was announced by the national water and electricity office is represented in Figure 5:

To reduce its energy dependence and reduce its greenhouse gas emissions, Morocco wants to reach 52% of the installed electrical capacity with renewable energies by 2030. Achieving these goals will not be possible without a huge reduction in coal consumption. In the future, renewable energy can supply two-thirds of the total global energy demand and contribute to decrease the greenhouse gas emissions.

### 3.2. Observations and Limitations of the Current Electricity Sector

The current electricity production scheme presents several challenges, the main actor in this sector is undoubtedly the National Electricity Office (ONEE), since it covers a wide field of intervention. it is itself the producer and distribution operator, this monopoly presents a factor that deters new operators from entering this market. On the other hand, the projected increase in electricity demand presents many opportunities. Many studies such as (Bhatia and Angelou, 2016) and (Chakravorty et al., 2014) have demonstrated a close relationship between human

development indicators and the degree of connectivity to the power grid as well as the level of consumption of electrical energy. The various programs undertaken to generalize access to the national electricity grid have made it possible to increase the connectivity rate during the last decade.

Emissions from electricity generation vary by type of energy source and by efficiency of electric power plants. The following Table 1 represents the evolution of the electricity power plants production by source.

The Table 1 is showing that fossil resources continue to occupy a dominant position. In terms of ranking, coal comes first while petroleum products come second. Despite the growth in volume, the share of electrical energy produced from coal is increasingly diluted in the overall mass of electrical energy produced. Indeed, the energy mix is now more diversified and made up of more environmentally friendly resources like hydroelectric, wind and solar. Morocco is concentrating its effort to accelerate coal retirements plan by pursuing parallel initiatives to deploy low-carbon energy such as natural gas and energy efficiency programs.

Despite recent positive progress, Morocco will have to face many challenges. for hydroelectric power, it is highly dependent on rainfall. The releases of the dams allowing the turbines to operate are conditioned by the required level of water reserves. Wind and solar generation remain subject to the intermittent supply. As a result, their contribution to overall electricity production is around 19% in 2019, while the objective is to reach 52% by 2030.

To overcome those challenges, it is necessary to prepare the adequate legislative context to allow new investors, especially in the private sector, to invest in electricity production from renewable sources.

## 4. OPPORTUNITIES AND RECOMMENDATIONS

### 4.1. Morocco's Energy Potential and New Renewable Projects

While the carbon intensity of electricity generation can be decreased by investing in low carbon energy resources such as natural gas, other drastic orientation can be taken such as relying completely on renewable resources. EIA considers electricity generation from renewable sources such as biomass, hydro,

**Table 1: Electricity power plants production (GWh) in Morocco 2014-2019**

Electricity plants	Electricity power plants production GWh					
	2014	2015	2016	2017	2018	2019
Coal	15,955	17,113	16,985	17,545	21,261	26,900
Oil	2570	2211	2882	3494	1289	816
Natural gas	5600	5784	5909	5836	5198	4698
Hydro	2033	2281	1662	1565	1998	1654
Solar		5	401	415	950	1581
Wind	1924	2519	3000	3035	3841	4699
Other sources	1302	1302	1302	1302	1302	1302
Total production	29,384	31,215	32,141	33,192	35,838	41,650

Source: Energy International Agency. Electricity Power Plants Production GWh Morocco 2014-2019



**Table 2: Current and upcoming solar projects in Morocco (MASEN, 2018)**

Completed solar projects	Capacity in MW	Year	Futur solar projects	Capacity in MW	Year
Noor	160	2016	Noor PV	120	2021
Ouarzazate I			Tafilalt		
Noor CSP	210	2018	Noor PV	200	2021
Ouarzazate II			Atlas		
Noor	150	2018	Noor	800	2022
Ouarzazate III			Midelt I		
Noor PV	70	2018	Noor PV II	400	2023
Ouarzazate IV					
Noor	80	2018	Koudia	200	2023
Laâyoune			Baida		
Noor	20	2018	Private	300	2023
Boujdour					

**Table 3: Current and upcoming wind projects in Morocco (ONEE, official website)**

Completed wind projects	Capacity in MW	Year	Futur wind projects	Capacity in MW	Year
A. Torres	50	2000	TISKRAD	300	2021
Tétouan			Laâyoune		
Amogdoul	60	2007	JBEL	200	2022
Essaouira			LAHDID		
TANGER I	140	2011	MIDELT	180	2021
TARFAYA	300	2014	BOUJDOUR	100	2021
AKHFENNIR	100	2014	TANGER II	70	2021
FOUM EL OUED	50	2014	KOUDIAT	200	2021
			BAIDA I & II		
HAOUMA	50	2014	SAFI	200	2021
DAFTISSAT	200	2019	AFTISSAT	200	2022
			II		
JBEL	120	2019	OUALIDIA	36	2020
KHALLADI			I & II		
TAZA	150	2019			

solar, and wind to be carbon neutral (U.S. Energy Information Administration).

To do this, Morocco is currently developing two large-scale projects based on solar and wind projects, they fall within the framework of the national renewable energy plan. A summary presentation of the main projects either recently entered service or still in progress are presented in Table 2 for the solar projects and Table 3 for wind projects.

For solar energy, the target capacity is 2000 MW, aiming to ensure an annual production of 4500 GWh. The Noor solar power plant in Ouarzazate was completed in 2018 with 590 MW capacity. Phases Noor in Tafilalt, Atlas and Midelt, for which the contracts have already been singled out, are planned to be completed by 2023. Ultimately, the installed capacity of the Noor future solar projects will add 1500 MW capacity.

The second program relates to wind energy, the targeted installed capacity of is also 2000 MW and aims to produce 6600 GWh annually. Currently, more than 1000 MW has either already entered service or is under development. This trend will likely continue with

the growing number of renewable projects, it will be fastened by the implementation of climate policies and rapid cost reductions in low-carbon technologies. The work of Gielen (Gielen et al., 2019) illustrates low carbon energy technology trends and highlights the role of renewable energy in the global energy transformation.

Current projects are not yet sufficient to achieve carbon neutrality in Morocco where electricity consumption is only increasing because of industrial development. Even if energy transition is found to be technically possible given Morocco's potential, it will require adequate policies and fundamental political changes. Whatever advances or innovations made, their impact will remain limited if they are not accompanied by the adequate business model and legislation.

## 4.2. Legislative Context of the New Energy Transition Ambition

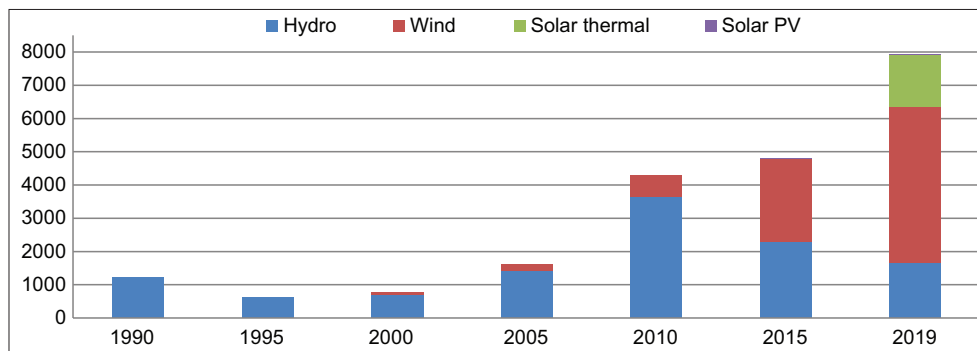
Since Morocco is a developing Country, and since it has been shown that most of developing countries face more challenges to ensure energy transition (Al Irsyad et al., 2017) because of the many critical issues dealt with at same time. In fact, the 2018 World Bank report noted that Morocco is facing many challenges in the educational, social, and economic sectors. The electricity sector initiated the liberalization of its production through public-private partnerships with international and national players. The reform made by Morocco to gradually withdraw subsidies from fossil fuels was a very big step towards the energy transition ambitions

The opening of the private production market was made possible thanks to Law 13-09 (Law 13-09, 2010), it offers the possibility for any private operator, to produce and inject electricity from any renewable source into the national grid, subject de certain conditions, only the high voltage network is concerned by this legislation. Still the Moroccan electricity sector is heavily relying on ONEE. It could be argued that the current state of the supply of electrical energy does not present the characteristics of a dynamic market govern by the law of supply and demand. Until 2010, all production is either produced by ONEE or transit through the latter. The advent of Law 13-09 constitutes a loophole to promote the production of electric energy from renewable sources. Indeed, this law liberalizes the production of clean energy under very specific conditions, while the production of electrical energy from fossil sources is excluded from this scheme. More recently, Law 58-15 adopted on 2015, modifies and supplements Law 13-15, binding the ONEE to buy the surplus produced from renewable sources.

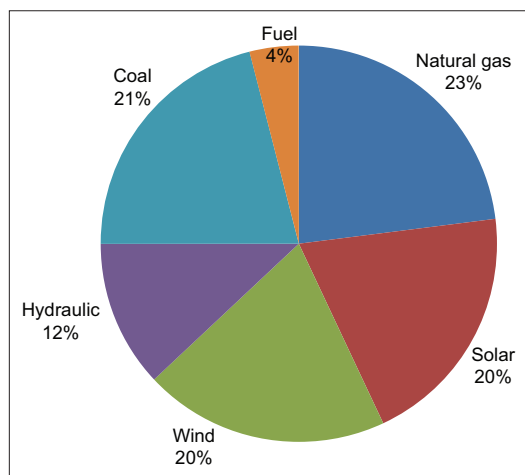
Meeting the ambitious targets set by Morocco will require heavy investments, a fundamental condition is to have legal framework encouraging private actors to invest. A study has been conducted by the world bank group in 2019 (Peszko et al., 2019) to explore potential options for implementing an environmental fiscal reform, such as implementing Carbon or environmental taxes on CO<sub>2</sub> emissions.

## 5. DISCUSSION AND RECOMMENDATIONS

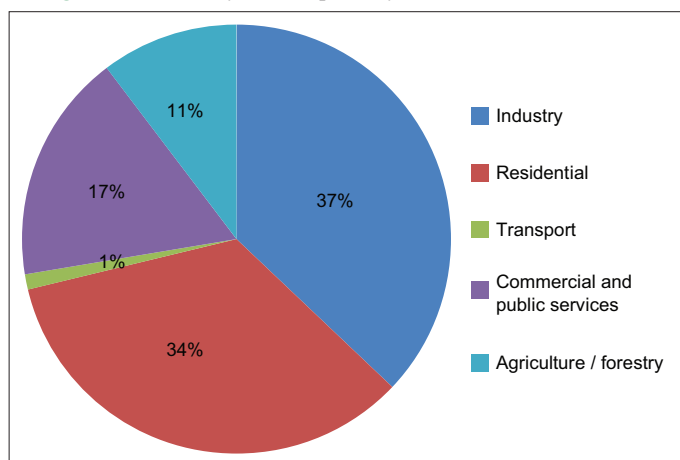
To accelerate the energy transition, it is important to understand the distribution market in order to target the most consuming sectors.

**Figure 4:** Renewable electricity (Gwh) generation by non-combustible source, Morocco 1990-2019

Source: IEA Data Base – Morocco

**Figure 5:** National electric package by 2030

Source: ONEE report in COP 22 conference, 2016

**Figure 6:** Electricity consumption by sector in Morocco in 2018

Source: IEA Data Base - Morocco

The Figure 6 classifies sectors by electricity consumption based on EIA, 2018 statistics.

Providing renewable for the industrial sector, which is consuming the major part the electricity production, can be very interesting, especially, since recent years, many firms have been showing their environmental commitment. This can be attested by new electricity sales transactions in the form of Power purchase Agreements (PPA)

(Luther-Jones, 2019). Especially as Morocco is positioning itself as a strong and a reliable industrial destination for multinational companies such as mechanical and metallurgical industries, attested by the industrial acceleration plan by the ministry of industry (Moroccan Ministry of Industry, Trade, Investment and Digital Economy: Industrial Acceleration Plan 2014-2020).

The residential sector comes second with a significant consumption share of 34%, this sector can be subject to considerable optimization. Several studies have focused on the residential electric model, its profitability and efficiency, such as the work of Idiano D'Adamo (D'adamo, 2018) on the profitability of the residential photovoltaic system or Arthur Rinaldi (Rinaldi et al., 2021) on decarbonizing heat with optimal photovoltaic and storage investments. The success of such models is generally based on subsidies being proportional to the importance of energy produced. Many research are also conducted to provide new technological solutions for more eco-friendly residential energy consumption (D'Adamo, 2018).

Carbon capture and storage technologies can also be considered to reduce CO<sub>2</sub> released from the use of fossil fuels by 90%, this technology has been successfully used by several countries such as the US and Canada (Mohd et al., 2020). Some other research are made to develop techniques to constrain CO<sub>2</sub> emissions from coal power plants (Fei et al., 2020). This can be a very useful alternative for existing coal infrastructure, the ideal is to reduce new investment in coal to cut CO<sub>2</sub> from source. It is also possible to consider changing course for coal plants to be used by another energy source, such as natural gas, the cost effectiveness will be the main issue if such orientation is considered. This alternative would be economically better than shutting down existing coal facilities, especially in a context of growing energy demand. Since the current worldwide trend is the use of natural gas rather than coal in electricity production (Jacobson, 2020).

Other technological alternatives can be considered such as the production of electricity via biomass or wood, but since this alternative involves forest exploitation, this kind of alternative, which generally does not justify a significant reduction in CO<sub>2</sub> emissions, can only worsen the climate impact as demonstrated by Sterman (Sterman et al., 2018).

Other tracks can be considered such as implementing urban and territorial planning on the principles of energy efficiency and sustainable development. As for legislative facilities, special focus must be given to the evolution of the legislative context and its ability to support the energy transition, the government can consider encouraging private investment and allowing connection also to medium-voltage (MV) and low-voltage networks (LV).

It is important to underline that one cannot think of complete migration towards renewable energy, given the inconvenience and the instability that this could generate (Kasperowicz et al., 2017). Many fluctuation problems can appear if the energy system is generated 100% from renewables.

## 6. CONCLUSION

Morocco is facing many challenges in term of energy demand and supply due to rising electricity demand, and like many other countries, Morocco is still using and operating coal power plants for electricity generation. The kingdom has set very ambitious goals toward energy transition in the electricity sector. Since renewable sources such as hydro, wind, solar, biomass and geothermal power are zero carbon electricity generators, it is important to consume more renewable than fossil resources, particularly coal and fuel to achieve the CO<sub>2</sub> reduction target and meet near and long-term climate goals.

The global goal can also be summarized on three key targets: ensure affordable, reliable, and clean electricity with respect of the environment.

Energy transition is very challenging and faces vulnerabilities due to new necessary investments and resource limitations, however, Morocco is making very significant progress in terms of renewable energy, yet the main challenge remains to specify roadmap alternative trajectory for coal use. Despite the legislative progress, serious political and law reforms are still needed to accelerate energy transition. Environmental fiscal reforms can strongly contribute to achieving the setting goals. The use of renewable energy in conventional energy systems is not always associated with the reconstruction of the entire system. It is possible to power the system for a part of fluctuating sources without major modification of the system, the problems appear only if one wants to create a system powered by nearly 100% by renewable energy, where the greater part of the energy comes from fluctuating sources.

Finally, technological development is a key element for a successful energy transition to renewable energy, rapid innovation in this sector must take place to endorse the ongoing transition. The optimization efforts are concentrated in the supply sector, but it would be potentially interesting to develop mechanisms to regulate demand by supporting the institution of energy efficiency. By operating the combination of the supply and demand level, Morocco will maximize its chances of achieving the target and rather succeed in its energy transition.

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