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Article

Analysis of electricity production and consumption in Morocco: Assessing the electricity deficit and key contributing factors

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Abstract: This paper examines the electricity sector of Morocco from 2011 to 2022. Based on the data from the U.S. Energy Information Administration, the World Bank, and ONEE, four major indicators were computed: electricity deficit (ED), electricity import dependency (EID), self-sufficiency ratio (SSR), and per capita electricity consumption (PCEC). The findings indicate that electricity production increased from 20.3 TWh in 2011 to 41.2 TWh in 2022, while consumption climbed from 26 TWh to 35 TWh for the same period. The self-sufficiency ratio remained above 100% after 2015 and reached a maximum of 121.2% in 2019, clearly indicating Morocco's transition from an importer to a net exporter of electricity. Although the renewable capacity has grown to make up 38% of the mix, coal stayed the main source (59.4% in 2022). The per capita consumption went up from 790 kWh to 934 kWh. These results unveil that Morocco has made remarkable strides in electricity self-sufficiency while still facing the challenge of fossil fuel lock-in. Accelerating the integration of renewables, making the grid more flexible, and formulating specific coal transition policies are the study's main recommendations for ensuring sustainability in the long run.

Keywords: Morocco; electricity sector; electricity deficit; electricity generation; electricity consumption

1. Introduction

Transitioning the global energy system to cleaner sources is a major challenge given the continuing reliance on fossil fuels and the need for rapid cuts in greenhouse gas emissions [1].

Although fossil fuel-based power generation still meets 75% of the world's electricity requirements, many parts of the world are committing to the Paris Agreement and are seeing solar, wind, and hydro as the main sources for future electricity generation. Recent studies have emphasized the need for integrated approaches to sustainable energy systems that simultaneously address carbon emission reductions, renewable energy deployment, and energy security constraints [2].

The pace of making changes based on the Paris Agreement varies considerably worldwide, and developing countries are at the stage of finding ways of implementing the environmental goals while keeping up their industries and providing energy to their people [3].

One of the examples of a country facing these types of issues is Morocco. Due to the scarcity of hydrocarbons, the nation imports nearly 90% of its primary energy needs (oil, coal, natural gas), making the Moroccan economy highly sensitive to global market fluctuations [4].

Morocco has an ambitious plan through the National Energy Strategy 2009–2030, focusing on 52% renewable electricity and 15% energy efficiency improvement by 2030 [5].

At the end of 2022, renewables represented roughly 38% of the electricity grid capacity, which firmly places Morocco as the first mover in clean energy at the regional level [6].

Nonetheless, the transition from oil and coal to clean and green energy sources is a complex issue and understanding it is made even more difficult by the fact that the economic and social aspects of the change are at least as important as the technical ones [7]. Despite growing literature on Morocco's renewable potential, desalination-energy nexus, and green hydrogen prospects, few studies have conducted longitudinal analyses of electricity balance indicators specifically deficit, import dependency, and self-sufficiency ratios over the strategy implementation period (2011–2022) [8]. This gap limits the empirical assessment of whether policy targets have translated into measurable outcomes [9].

We are going to fill these holes by looking at how Morocco's electricity generation and consumption have evolved during the period 2011 to 2022 [10]. The main purpose of the paper can be broken down into four objectives: (i) to measure how the electricity deficit and self-sufficiency ratio have changed over time; (ii) to find out whether import dependency has increased or decreased; (iii) to study electricity consumption per capita; and (iv) to place this work within Morocco's national energy plan and compare it with other countries.

Through the application of descriptive statistics and time-series analysis of data obtained from the U.S. Energy Information Administration, the World Bank, and ONEE, the study computes the following four standardized indicators: electricity deficit (ED), electricity import dependency (EID), self-sufficiency ratio (SSR), and per capita electricity consumption (PCEC). What's really new about this paper is its comprehensive, indicator-based review of Morocco's electricity change during a very important policy implementation period, providing actual evidence of the move to self-sufficiency while pointing out enduring structural problems [10].

The paper is divided into sections as follows. Data sources and methodology are discussed in Section 2 which focuses on presenting the results obtained from data analysis on electricity generation, consumption, and the derived indicators. Section 3 is meant to put these findings in the context of policy targets and international comparators. Finally, Section 4 gives a summary of the policy implications of the work, its limitations, and ideas for further research.

2. Materials and methods

2.1. Data collection

This paper employs a descriptive quantitative approach to investigate and analyze the electricity sector of Morocco in 2011–2022. We have collected the yearly data of the generation, consumption, net imports of electricity, and population from the three most trusted and internationally known sources, i.e., the U.S. Energy Information Administration (EIA), the World Bank Open Data portal, and the Moroccan National Office of Electricity and Drinking Water (ONEE) [11,12].

These sources were primarily chosen due to their methodological consistency, public accessibility, and common appearance in peer-reviewed energy research. Data were cross-checked among different sources in order to guarantee the credibility of the data. The smallest differences in the units or definitions were dealt with by giving preference to the sources (for national electricity data, we prioritized ONEE; for scenarios requiring international comparability, we opted for EIA and World Bank).

2.2. Calculation of key metrics

Four metrics were computed to evaluate Morocco's electricity enterprise performance. All the formulas listed below are the standard definitions that the International Energy Agency (IEA) and the World Bank have established [13,14].

Electricity deficit (ED) indicates the amount by which electricity consumption exceeds electricity production in Equation (1). The domestic production capacity of a country determines its ability to satisfy national electricity requirements [15].

$$ED = EC - EG \tag{1}$$

The formula shows that electricity consumption (EC) and electricity generation (EG) determine the electricity deficit (ED) value. A positive value indicates a deficit requiring imports; a negative value indicates a surplus available for export or storage.

Electricity import dependency (EID) measures the share of electricity demand satisfied through imports in Equation (2) and serves as a primary measurement tool for assessing electricity system vulnerability [16].

$$EID = \frac{EI}{EC} \times 100 \tag{2}$$

The calculation for EID uses this formula which requires EI to represent electricity imports. where *EI* stands for net electric imports. Positive figures signify net import dependence, while negatives signify net export capacity.

This indicator complies with the IEA convention for assessing trade dependency. The indicator demonstrates how much of national energy system operations face risks from external supply interruptions and international price fluctuations [17].

The self-sufficiency ratio (SSR) measures how much of the domestic generation can satisfy local electricity needs in Equation (3):

$$SSR = \frac{EG}{EC} \times 100 \tag{3}$$

More than 100% means domestic production is more than sufficient; less than 100% means the country is structurally reliant on imported electricity [18,19].

Per capita electricity consumption (PCEC) is a general indicator of how much electricity each individual consumes on average in Equation (4). The equation PCEC = EC/POP (EC refers to electricity consumption and POP represents total population) defines the approach to determine per capita electricity consumption.

$$PCEC = \frac{EC}{POP} \tag{4}$$

The indicator typically presents its results in kilowatt-hours (kWh) per capita which establishes a uniform standard for assessing energy consumption across different time periods.

2.3. Strengths and limitations

2.3.1. Strengths

The research sources data from official, public datasets that cover the period of 12 years which supports transparency and routability for the study. Besides, the implementation of recognized indicators helps to make international benchmark comparisons.

2.3.2. Limitations

The paper only presents a descriptive study and does not use econometric modelling or methods of treatment of causality. The aggregation on a yearly basis may hide seasonal or monthly variations. Besides, the research is limited to power generation and does not consider primary energy consumption (e.g., direct use of fossil fuels for transport and heating) which is still largely import-based.

2.4. Synthesis and interpretation

The analysis results were combined to form a single comprehensive and integrated view of the changes that the electricity sector in Morocco has undergone.

The focus of the interpretation is mainly on identifying the main features that make up the Moroccan energy system along with pointing out strengths, weaknesses, and new trends.

Recommendations have been provided based on the results that are the most effective and efficient in terms of promoting energy conservation, increasing local electricity production, and reducing dependence on imports.

The adopted methodological framework helps researchers to stay focused analytically and internally consistent over the course of their work, and, at the same time, generate public policy-relevant outcomes. The framework enables the quantification of the extent to which Morocco is moving toward the goals of sustainability and energy independence as a result of its implementation.

3. Results and discussions

3.1. Electricity generation

The electricity generation in Morocco has experienced continuous development since the year 2011 until the present time which extends to the year 2022. The country experiences this phenomenon because its economy develops and its population increases while people demand more energy. The total electricity generation has shot up from a little over 20.3 billion kWh in 2011 to almost 41.2 billion kWh in 2022, more than doubling in just a little over ten years. The positive trend demonstrates how energy requirements have increased for industrial, residential and service sectors. **Figure 1** shows the process of ongoing structural conversion which continues to develop.

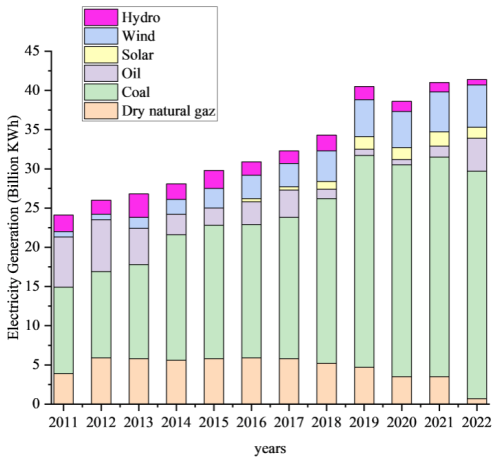

Figure 1. Evolution of Morocco's Electricity Generation Mix.

The electricity generation process has brought about changes to the energy mix even though traditional energy sources continue to hold a dominant position in the worldwide energy distribution.

3.2. Energy mix composition

Figure 2 shows the electricity generation mix in Morocco, which displays the percentage contributions of primary energy sources including coal, natural gas, wind, hydropower, solar power, and oil.

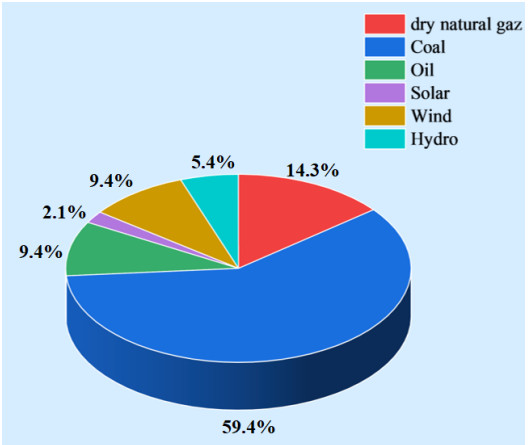

Figure 2. Electricity Generation Mix in Morocco.

3.2.1. Coal

In Morocco coal remains the primary source of electricity generation producing approximately 59.4% of total electricity in the country during 2022. The main reasons for its sustained dominant position in the market include its established capacity, its more stable supply networks, and its ability to supply constant power needs. The environmental problems arise from the excessive reliance on coal because it generates high levels of greenhouse gas emissions and produces carbon emissions through its combustion. The continued dominance of coal (59.4% in 2022) reflects infrastructural lock-in mechanisms, including sunk capital costs in existing thermal plants, long-term fuel supply contracts, and baseload reliability requirements that intermittent renewable sources cannot yet fully guarantee.

3.2.2. Natural gas

Dry natural gas ranks as the third most important electricity generation source after coal and oil and produced 14.3% of total electricity generation in 2022. The increasing importance of natural gas results from its superior efficiency and lower carbon emissions when compared to coal and oil. Natural gas currently serves as an essential dependable energy source that renewable energy sources need because of their unpredictable power generation patterns. Natural gas expansion serves as a strategic element because it decreases power generation environmental impact while maintaining operational flexibility.

3.2.3. Wind energy

Wind energy has experienced significant development since 2016 which marks a crucial point in Morocco's journey towards renewable energy. The electricity generation capacity of the system reached 9.4% by 2022. The country experiences this growth because of its strong wind resources which especially exist in its coastal regions and the establishment of major projects such as the Tarfaya Wind Farm. The quick development of wind energy demonstrates Morocco's commitment to expand its energy resources while decreasing its fossil fuel consumption.

3.2.4. Hydropower

Hydropower has maintained its position as an essential energy source in the national energy mix which produced 9.4% of total energy output in 2022. The main reason for its constancy is the presence of geographic locations suitable for the generation of hydropower, with the mountain regions being the primary ones. Hydropower provides essential support to electricity systems because it operates as a reliable and effective method of generating renewable energy. Its combination with intermittent energy sources such as wind and solar power makes it especially valuable.

3.2.5. Solar energy

The country generates 5.4% of its electricity through solar energy which has increased over the entire period since that time. The Noor Ouarzazate Solar Complex achieved this result through its solar energy facilities which received extensive investment from multiple major financial backers. This facility which serves as the largest CSP plant in the world demonstrates Morocco's commitment to solar

energy development for future generations. Solar energy development is expected to become a major driving force behind the energy mix development. Despite this growth, renewable integration faces challenges including grid congestion in southern transmission corridors, the need for flexible backup capacity to manage intermittency, and financing risks for large-scale storage projects.

3.2.6. Oil

The role of oil in electricity generation has seen a drop to a very low level, with the figure being as low as 2.1% in 2022. The current situation supports the new policy framework which requires the use of cheaper and more sustainable energy solutions. The decreasing dependence on oil resources demonstrates Morocco's energy plan which aims to remove all high-emission and low-economic electricity generation methods from its power generation mix.

3.3. Temporal evolution of the energy mix

The energy mix of Morocco from 2011 until 2022 shows three distinct phases that developed different national priorities and strategic approaches and operated with various levels of technological advancement.

3.3.1. 2011–2015

The primary characteristic of this initial period involved the dependence on fossil fuels which included coal, natural gas, and oil, while renewable sources provided only a minimal share. The period served to establish the legal and physical framework through which renewable energy would expand after the first investments and policy development activities.

3.3.2. 2016–2018

This period marked the beginning of transformation which brought about an increase in renewable energy deployment, especially for wind and solar power technologies. The installation of multiple major wind and solar power facilities led to renewables achieving a greater share of the energy market. The current shift demonstrates that the national energy plans have been successfully implemented to achieve both sustainable development and effective resource diversification.

3.3.3. 2019–2022

The period showed renewable energy as the major power source which registered significant growth through wind and solar advancements. The electricity production for this period relied on coal as the primary power source while the system used both traditional power sources and renewable energy for electricity generation. The current situation demonstrates how Morocco's energy system remains in its transitional phase.

3.4. Electricity consumption

3.4.1. National consumption path (2011–2022)

The analysis of electricity consumption in Morocco for the past ten years shows two patterns of consumption growth. The first pattern shows continuous growth while the second pattern shows growth that follows different economic development and

urban expansion and increased energy use across various industries. This development is reflected in the changes in the economy and demography of Morocco (**Figure 3**) and shows the increasing difficulties of combining economic growth and energy use. According to the data, electricity use in Morocco was 26 terawatt-hours (TWh) in 2011.

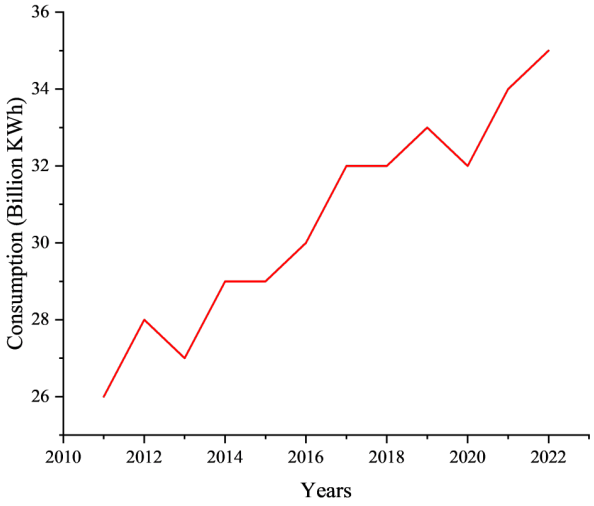

Figure 3. Trends in Electricity Consumption in Morocco.

This figure is on the rise, with consumption reaching 28 TWh the next year, which indicates early and clear signs of growing energy needs. The drivers behind this are the industrialization process, the geographical expansion of cities, and a growing middle class with consumption habits. It is worth mentioning here that these few years correspond with the implementation of Morocco's sectoral strategies that aim at making it a regional industrial platform, especially in the sectors of manufacturing and automotive.

The year 2013 was a year of crisis, during which a decline in electricity consumption was recorded to 27 TWh. Although the change is very small, it is worth a detailed study. The main reason could be the following. There was a temporary economic slowdown, which could be linked to bad weather conditions, affecting the agricultural sector. On the other hand, it could also be the initial effects of the implementation of energy efficiency and demand-side management measures that became more perceptible. The idea of improved energy efficiency is very much in line with the public policies of those days that were, in fact, gradually incorporating the concerns of energy sobriety. Surprisingly, this small drop did not affect the general upward trend, and consumption quickly bounced back to 29 TWh by 2014, a level which was held throughout 2015. The survival of this momentum at that time shows the ongoing development of the national transport and distribution infrastructure, the remarkable increase of household electricity access in the rural and peri-urban areas, as well as the implementation of new industrial projects especially in export processing zones.

Electricity consumption increased from 30 TWh in 2016 to 33 TWh in 2019, with a steady increase during the period 2016–2019, that is, a 10% growth cumulatively over these four years. During this period, Morocco saw significant modernization of its energy infrastructure and also investments in renewables like photovoltaic and

concentrated solar thermal power and wind energy under the 2009–2030 National Energy Strategy. Besides, the expansion of the industrial base, growth in the tertiary sector, and the increasing electrification of households have contributed to this consumption rise. Also, during this period, the operational activities of the first solar units of the Noor-Ouarzazate complex started; however, their production seems more aligned with the export logic and replacement of fossil fuel imports rather than with the direct meeting of growing domestic demand.

Contrary to the other years, 2020 was a year with an extraordinary drop in consumption to 32 TWh. Although it is a decline of only 3% compared to 2019, it resulted from the direct impact of the COVID-19 pandemic on health and the economy. Lockdown and border closure, as well as restrictions on the resumption of economic activities, have caused different value chains to be disrupted, numerous industrial activities to be temporarily suspended, and sectors that depend on energy to be contracted markedly to a great extent, tourism, hospitality, and transport. While the 2020 decline coincides with COVID-19 lockdowns, we acknowledge this as a temporal correlation observed in descriptive data rather than a causally tested relationship. The rapid recovery to 34 TWh in 2021 suggests that the underlying structural demand remained robust.

The maximum level of 35 TWh that was reached in 2022 clearly shows the persistence and strength of the structural growth in energy demand which, besides the industrialization and economic diversification processes, is underpinned by urbanization and metropolization intensification as well as general and differentiated improvement of living conditions within the population. This upward curve that has changed very little and hardly ever gone down over the decade studied is significant evidence of Morocco's energy landscape deep structural change. This change, however, is also evidenced by the fact that, notwithstanding this growth, public authorities are continually making the necessary commitment to meet the rising electricity needs that are a result of population growth and the economy's industrial emergence phase. What is more, this raises a very important issue about the sustainability of such a model of growing energy demand and the need to step up the energy transition toward decarbonized sources as well as drastic energy efficiency improvements in all sectors.

3.4.2. Trends in energy consumption per individual

Per capita energy consumption data analysis shows a very notable and statistically significant rise during the time span of the research from 790.18 to 934.38 kWh per capita between 2011 and 2022 as shown in **Figure 4**.

Besides this marked increase in the individual use of energy, the rise in this figure is also associated with the concurrent demographic increase that has been happening during the same period, as well as economic development as measured by gross domestic product per capita. The time series data shows continuous growth which demonstrates economic development through stable growth patterns that mark the upward trend in living standards and the extended electricity access to Moroccan citizens, as well as the rising usage of household appliances and information and communication technology in homes.

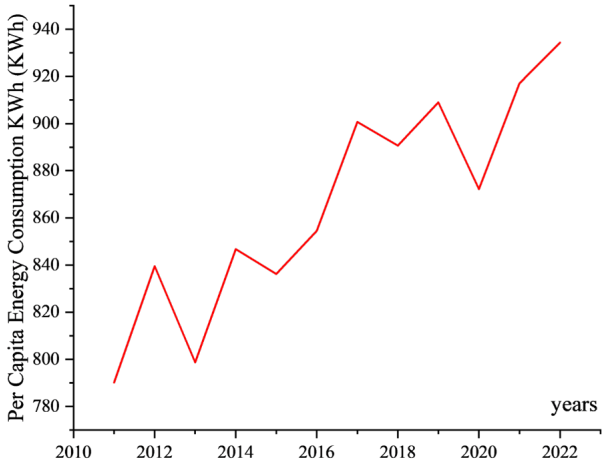

Figure 4. Trends in Per Capita Energy Consumption in Morocco.

The growth of per capita consumption is a rounded indicator that is very much in line with the economic development and social transformation processes. Not only does it reflect quantitative growth in electricity availability as Morocco is at electrification rate saturation in rural and urban areas, but it also captures the qualitative intensification of consumption that shows changing lifestyles, urbanization of consumption patterns, and growing aspirations toward comfort and energy services in line with those of advanced economies. Regionally and internationally, when compared with average and other countries of similar income, Morocco appears to be at the midstage of its energy transition, with individual electricity demand still in positive growth while industrialized and mature economies show stagnation or decline in electricity demand.

3.5. Analysis of Morocco's electricity deficit and consumption metrics

3.5.1. Electricity deficit

Electricity deficit, defined as the difference between domestic electricity generation and consumption, turned from negative to positive numbers in the period 2011 to 2015 (**Figure 5**).

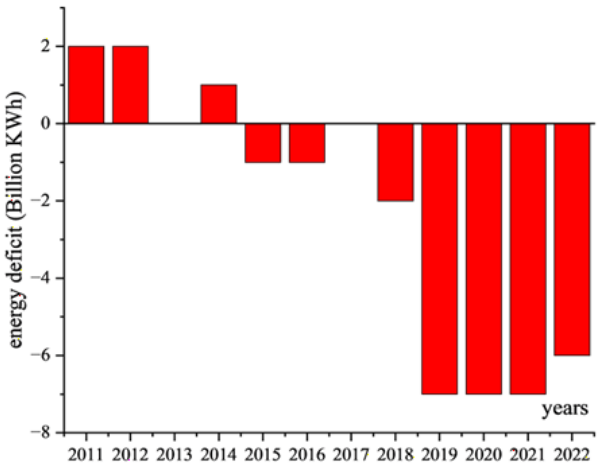

Figure 5. Annual Electricity deficit in Morocco (2011–2022).

Until 2015, Morocco was recording deficits, i.e., generation was not enough to cover demand. However, from 2015 the situation reversed, and surpluses became

regular features, with the largest one being in 2019.

The aforementioned change is due to the ramp-up of the renewable generation capacities in line with the 2009–2030 National Energy Strategy. The 2019 surplus is the result of: (a) the availability of the solar and wind power plants; (b) the reduced demand due to the macroeconomic conditions; and (c) the lag between the electrical infrastructure provision and consumption.

Having a physical surplus alongside the varying import dependency means that electricity balance and primary electricity imports are only partly related to each other.

3.5.2. Electricity import dependency

Import dependency (expressed as net electricity imports divided by total electricity consumption) is a measure of how much of external supply a country depends on (**Figure 6**). At 7.69%, dependency was at a certain level in 2011. By 2013, the ratio climbed to 0%, which means that the amount generated indigenously was enough to cover the country's overall needs. After 2014, dependency fluctuated several times reaching −21.21% in 2019.

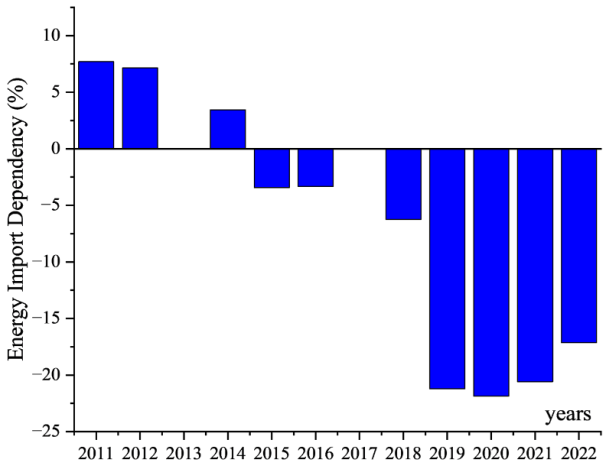

Figure 6. Electricity Import Dependency in Morocco (2011–2022).

Negative numbers indicate that production has exceeded consumption, which is the case of export or storage. The position at zero dependency, no imports in 2013, was mainly due to the combination of the deployment of renewables, demand moderation, and generation efficiency mechanisms. The dismantling of this position after 2013 is largely a reflection of a dynamic system, as infrastructure cycles, demand fluctuations, and maintenance schedules cause ongoing equilibrium disturbances. The 2019 number of −21.21% is quite a significant change from being a net importer of electricity at the top to a net exporter; this has a lot of effects not only on trade balances but also on the regional electricity market.

3.5.3. Self-sufficiency ratio

The self-sufficiency ratio of local production to consumption (**Figure 7**) reached its highest level at 103.45% in 2015, though it experienced gradual decreases throughout the following years while maintaining a level above 100%.

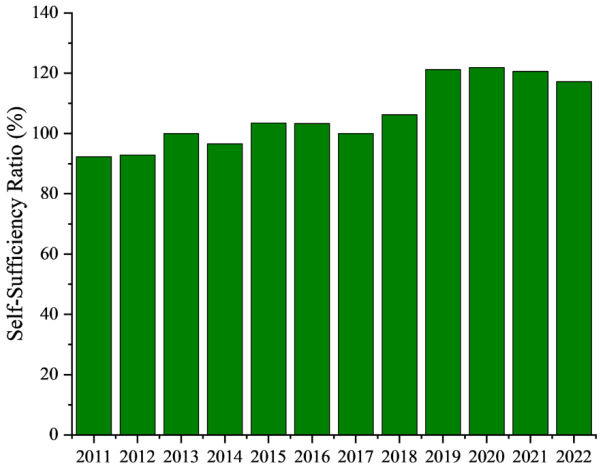

Figure 7. Self-Sufficiency Ratio in Morocco (2011–2022).

Numbers greater than 100% are indicators of production surplus. 2015 being the year when a zenith was attained is largely because of the deployment of Noor-Ouarzazate Phase I and Tarfaya wind farm. Maintaining the ratios above one for the whole period viewed clearly points to the fact that renewable capacity build-up is on par with demand increase. Apart from safeguarding against fossil fuel price fluctuations, this mode of operation ensures supply security even in the wake of unexpected disruptions.

Between 2011 and 2022, Morocco transformed its trade status in the electricity sector from net importer to a net exporter. However, this change is related only to electricity balance and must not be mistaken for Morocco becoming a primary energy independent country: it still depends largely on the imports of fossil fuels (oil, coal, natural gas) to cover its total energy consumption. The level of self-sufficiency referred to here is based on the fact that the year-round electricity generation capacity is greater than electricity demand, which does not equate to total energy independence.

3.6. International comparison and benchmarking

Electricity transition trajectories differ dramatically between Morocco and its regional peers; the latter are characterized by structural factors and strategic decisions. Despite having the largest natural gas reserves in Africa, exporting a net amount of energy and being a hydrocarbon-based economy, Algeria has hardly deployed renewable power (only about 2% of the electricity mix in 2022). It is through hydrocarbon rents that the country guarantees its energy security instead of diversifying, so the resilience model is quite a different one: while Algeria is confronted with carbon transition risks and demand pressures, Morocco is the one to suffer from supply vulnerabilities due to imports.

Egypt represents a middle case; accordingly, it has recently been rolling out renewable investments, chiefly via solar and wind, but the bulk of its electricity sector is still powered by domestic natural gas (over 80% of generation) [20]. As a result, Egypt's self-sufficiency hinges on indigenous fossil resources rather than a paradigmatic change of the generation system, which shields it from the international electricity markets model but at the same time exposes it to local fuel depletion and

subsidy/fiscal burden issues.

On the other hand, Spain is a fragmented European reference with which Morocco shares Mediterranean solar and wind potential. Spain had a renewable electricity share of around 47% in 2022, supported by decades of grid modernization, cross-border interconnection capacity (more than 12% of peak demand), and mature electricity market mechanisms. Morocco, although it has nearly reached the same level of renewable shares in installed capacity, does not have equal grid flexibility, demand-response infrastructure, or storage deployment. The fact that Morocco does not have a fully liberalized electricity market and that there is very little pumped-hydro or battery storage capacity (only at the pilot stage) means that system operators in Morocco have bigger problems with managing intermittency and frequency stability.

Türkiye on the other hand, is perhaps the best option for you to learn from. With a renewable electricity share of approximately 42% in 2022, Türkiye has shown that emerging economies can also achieve high renewable penetration. However, Türkiye's security foundation is based on significant domestic coal and large-scale hydropower assets that can provide dispatchable baseload capacity [21]. Morocco on the other hand, has no major domestic coal reserves and neither is it able to produce comparable hydropower (its hydro capacity is limited by hydrological variability and availability of suitable sites). So, while headline renewable figures may be comparable, the two systems are fundamentally different: Türkiye's renewable rollout is supported by dispatchable domestic resources, whereas Morocco's energy independence depends on variable renewable sources (solar and wind) supplemented by imported coal and natural gas.

This comparison highlights the uniqueness of Morocco's progress (**Table 1**). Negative electricity import dependency in a country without domestic fossil fuel reserves is a first in the MENA region [22]. It indicates that there has been a switch from supply insecurity (import dependency for electricity) to integration insecurity (dealing with large shares of variable renewables in a constrained grid).

Table 1. Comparative Electricity and Energy Indicators of Morocco and Selected Countries.

Country	Renewable share (%)	Self-sufficiency (%)	Net import dependency (%)	Primary energy profile
Morocco	38 (2022)	103–121 (2015–2022)	−21.2 (2019)	No fossil fuel reserves; import-dependent primary energy [10].
Egypt	~12 (2022)	~95	+5	Dominated by domestic natural gas [23].
Algeria	~2 (2022)	~98	+2	Hydrocarbon exporter; minimal renewables [24].
Spain	~47 (2022)	~105	−5	Diversified mix; advanced grid infrastructure [25].
Türkiye	~42 (2022)	~98	+2	Mixed hydro, coal, and renewables [16].

Unlike Algeria or Egypt, Morocco does not have indigenous hydrocarbons to fall back on during supply shortages. Unlike Spain, it cannot count on mature storage markets and extensive interconnections to balance the variability. And unlike Türkiye, Morocco does not have dispatchable renewables (such as large hydropower) or coal at its disposal to underpin its system. As a result, Morocco's path hints that for resource-poor developing countries, electricity self-sufficiency is possible through

renewable industrial policy, but at the same time, it opens up new vulnerabilities, such as grid inertia, curtailment risks, and storage financing gaps, that call for policy differentiations with those of resource-rich or industrially advanced peers.

4. Conclusion

This research presents a longitudinal evaluation of Morocco's electricity sector performance during the major policy implementation period of 2011, 2022. The study uses four standardized indicators, electricity deficit (ED), electricity import dependency (EID), self-sufficiency ratio (SSR), and per capita electricity consumption (PCEC), that are tracked by descriptive time-series analysis to provide an evidence-based assessment of Morocco's achievement of the 2009 and 2030 National Energy Strategy goals. The main results are as follows:

Generation of electricity has more than doubled from 20.3 TWh in 2011 to 41.2 TWh in 2022, which is a compound trend that aligns with the expansion of industries and rural electrification programs. Consumption of electricity was up from 26 TWh to 35 TWh during the same time, with an only briefly lower figure of 32 TWh in 2020 during COVID-19 lockdowns and then quickly going up to 34 TWh in 2021. Morocco exceeded the 100% self-sufficiency level in 2015 and stayed above that level through 2022, reaching 121.2% in 2019, which indicates a structural shift from net importer to net exporter status of electricity trade. Import dependency on electricity hit a negative point since 2015 and reached a low of −21.2% in 2019, which is a strong indication that domestic production has been far over the requirements of the whole country during this time. Coal dominated the energy mix with 59.4% in 2022, which shows that the increase in renewable energy sources (to 38% of installed capacity) has only been a supplement rather than a replacement for fossil fuel baseload. Per capita electricity consumption went up from 790.2 kWh in 2011 to 934.4 kWh in 2022 and this is a portrayal of more people having access, urbanization, and higher household appliance intensity.

These results provide three points of understanding about the energy transitions in resource-limited developing countries. Firstly, the case of Morocco clearly illustrates that electricity independence is on the cards even for countries without domestic fossil fuel reserves if renewable industrial policy is supported by public investment in generation infrastructure. The change in the electricity trade balance rather changing from 2011 to 2022, is a structural break and thus goes against the general belief that import dependence is irreversible for hydrocarbon-poor nations. Secondly, the fact that a country both maintains a high level of self-sufficiency and also is a coal lock-in indicates a decoupling of security and sustainability objectives. Thirdly, the continuous growth in per capita consumption with self-sufficiency gains demonstrates that Morocco has been able to increase access without raising electricity import vulnerability, a pattern that deviates from many peer economies where demand growth outpaces domestic supply.

In terms of policy ramifications, these findings move beyond generic policy prescriptions by identifying specific structural barriers to transition. The continuous dominance of coal as a generation source that has been supported by sunk capital costs and requirements for baseload reliability means that coal phase-out will need

more than renewable targets; it will include active demand-side management, storage procurement contracts, and transitional financing mechanisms for stranded assets. Besides that, the differentiation between electricity self-sufficiency and primary energy independence must be reflected in national accounts. Although Morocco is currently electrically self-sufficient, it is still import-dependent for more than 90% of its primary energy needs. Policy communication that confuses one with the other is likely to raise misplaced energy security optimism, and thus under-invest in primary energy diversification.

This research contributes to the literature in three ways. Conceptually, it separates electricity balance indicators from primary energy metrics, which a lot has remained unaddressed in the existing analyses of the Moroccan energy sector. By concentrating on the electricity aspect, the study discloses that self-sufficiency and decarbonization are different and at times opposing transition goals. Methodologically, it develops an indicator-based framework for transition progress tracking that is replicable especially in data-poor environments. The combination of ED, EID, SSR, and PCEC presents an elegant but also exhaustive diagnostic set of tools that can also be applied by comparable emerging economies. Empirically, it highlights the exact moment and scale of Morocco's move from electricity deficit to surplus during 2014 and 2015, which can be a reference point for future policy evaluative work.

There are a few factors limiting the scope of this paper and also pointing the way for future research. The analysis is descriptive and therefore, modeling with econometrics is not used at all; hence, the relationships between renewable development and import dependency patterns revealed cannot be considered as a reason. Yearly totals may obscure seasonal variations in hydroelectric production and demand for peak that are important for planning the grid. Besides, the focus of this study is solely on overall national balances without consumption disaggregation by sector, nor does it consider transmission and distribution losses. Econometric analyses such as vector autoregression models may be used to test the causal effect of renewable capacity additions on trade balances. Sectoral decomposition of electricity demand would indicate which economic factors exert the greatest pressure on the generation-consumption balance. Techno-economic modeling of storage and grid flexibility options is required to evaluate the possibility of coal displacement under high renewable penetration scenarios. Finally, life-cycle assessments of Morocco's concentrated solar and wind farms would provide the net carbon and water footprint of the transition that go beyond generation-share metrics to true environmental sustainability evaluation.

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Abbreviations

EG	Electricity Generation
EC	Electricity Consumption
EI	Electricity Imports (net)
ED	Electricity Deficit
EID	Electricity Import Dependency
SSR	Self-Sufficiency Ratio
PCEC	Per Capita Electricity Consumption
POP	Total Population
ENR	Renewable Energy
MASEN	Moroccan Agency for Sustainable Energy
ONEE	National Office of Electricity and Drinking Water
CSP	Concentrated Solar Power

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