Electricity Production and Greenhouse Gas Emissions: What Role Does The Energy Mix Play? A Comparative Analysis of Morocco and France

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Abstract. As Global greenhouse gas emissions are largely driven by electricity production, decarbonising this sector is key to achieving sustainable development goals. The carbon profile of national grids is largely determined by the composition of their energy mixes. This paper compares Morocco's and France's carbon intensity rates between 1990 and 2023, highlighting the implications of their divergent national electricity strategies for decarbonisation. France's sustained reliance in nuclear power has enabled it to maintain a low baseline level of emissions, further reinforced by the strong integration of renewable technologies. In contrast, Morocco remains heavily anchored in fossil fuels, with coal and natural gas dominating its energy mix, even though the gradual development of solar and wind resources is slowly reshaping its profile. The analysis shows that France continues to record one of the lowest carbon intensity rates in the world, while Morocco remains constrained by its ongoing dependence on fossil fuels, making it difficult to achieve deeper reductions in greenhouse gas emissions. The comparison between the two countries reinforces the urgency of acceleration renewable deployment, improving energy storage capacities, and implementing long-term harmonized policy frameworks to guide both nations particularly Morocco toward low-carbon and resilient electricity infrastructures.

Keywords: Electricity generation, Carbon intensity, Energy mix, Decarbonization strategies, Renewable and nuclear energy

1 Introduction

Electricity production is a crucial pillar of modern economies, as it powers industrial activity, drives technological innovation, and enhances living standards. However, its remains one of the main sources of greenhouse gas emissions. Approximately 41% of global energy related CO_2 emissions come from this sector alone [1]. Decarbonising electricity therefore central to international climate strategies, notably the Paris agreement and the United Nations Sustainable Development [2,3]. The carbon intensity of national systems depends largely in the structure of electricity mix, which defines both sustainability and resilience system and its level of long and medium-term sustainability.

France offers a remarkable example of a low-carbon electricity system. Since the 1970s, the French government has pursued a nuclear-based strategy that has profoundly shaped the country's trajectory. In 2021, nuclear power still accounted for around 69% of

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total electricity production, supplemented by hydropower , wind and solar energy, while fossil fuels made up less than 7% of the energy mix [1]. The increased use of nuclear energy has resulted in a carbon intensity of approximately 56.9 gCO_2/kWh, one of the lowest in Europe and nearly seven times lower than the continental average [1]. Furthermore, the continued growth of renewable energies, particularly wind and solar power since the mid-2010s has helped to strengthen the robustness and sustainability of the French electricity[4].The strategy adopted by France illustrates how technological decision, supported by a coherent long-term policy, can lead to significant structural benefits in terms deducing carbon emissions.

This context stands in stark contrast to Morocco's electricity sector, which remains heavily reliant on fossil fuels particularly coal and natural gas for its operation. By the end of 2022, coal alone accounted for 28% of the electricity generated, while oil and gas together made up just under 20% [5]. This import-driven model increases both the carbon intensity of the system and its vulnerability to external price shocks two unfavorable dynamics in an increasingly volatile energy landscape.

In contrast, Morocco has positioned itself as a continental frontrunner in the deployment of renewable energy [6]. Since the early 2010s, the country has launched large-scale programs such as the Moroccan solar Plan and the National Energy Strategy 2030, aimed respectively at reducing the share of fossil fuels and natural gas, and at diversifying the electricity mix. By 2023, renewables accounted for 21,7% of total electricity production, with wind contributing 15,4% and solar 5,1%. The government has set ambitious targets of 52% by 2030 [6]. These initiatives underscore Morocco's strategic commitment to renewable energy, although structural dependence on fossil fuels still constrains its decarbonisation trajectory.

The comparison between the energy trajectories of France and Morocco is enlightening, as it illustrates how national choices, rooted in divergent socio-political and economic contexts, shape the sustainability of electricity systems. France, with its century-old nuclear power plants and one of the lowest carbon intensities, is already operating in the post-carbon era; Morocco, on the other hand, is striving to reclaim the future by diversifying a mix that still dependent on coal, which has been a catalyst for high carbon intensity until now. The question that arise from these opposing paths concern the weight of technical choices, the structure of governance bodies and the planning horizon that drives national energy transitions.

The objective of this paper is to compare carbon intensity of electricity production in Morocco and France, with a particular focus on how differences in their energy mixes shape emission outcomes.

2 Materials And Methods

2.1 Data Sources and Case selection

The data used in this paper were collected from World Bank Data [7] and World Energy Balances [8] to ensure consistency and comparability between their two countries.

The Choice of Morocco and France is by their constricting energy trajectories. France has a long relied on nuclear energy, achieving very low carbon intensity levels, whereas Morocco has historically been dependent on fossil fuels but is now pursing on one of the most ambitious renewable energy programs in Africa. This contrast provides an excellent basis for understanding how differences in policy orientation, natural resource endowment and investment in energy infrastructure on carbon emissions and the pace of energy transition.

2.2 Methodological approach

The methodological approach adopted in this study is based on a positivist epistemological position, emphasizing a comparative descriptive approach. This approach particularly suited for examining differences and similarities between countries by relying on objective, quantifiable data rather than subjective interpretations [9]. In this context of the study, we focus on Morocco and France, two countries with contrasting electricity system and energy transition strategies, over the period 1990-2023. The analysis relies on two main indicators.

The first is the share of each energy source in total electricity generation, expressed as a percentage (%) in order to capture the structural composition and evolution of the electricity mix. The second is study the carbon intensity of electricity, expressed by million tonne of CO_2 per Gigawatt-hour ($MtCO_2$/Gwh) [10]. This metric provides a standardize measure of the environmental impact associate with electricity production between Morocco and France.

3 Result and discussion

3.1 Share in Energy Source in Electricity Production

Analyzing the energy mix in electricity production provides insight into the structural difference between Morocco and France. Figure 1 and 2 present the share of each energy source such as, fossil fuels, nuclear energy and renewable energies in total electricity generation for the period 1990-2023.
The share electricity production by source is calculated as shown in Eq. (1):

$$Share_{it} = \frac{E_{it}}{\sum_{j=1}^{n} E_{j,t}} * 100 \qquad (1)$$

With:
$\boldsymbol{Share_{it}}$: Share of energy source in total electricity production at time t (%)
$\boldsymbol{E_{it}}$: Electricity production by source i at time t (Gwh)
$\sum_{j=1}^{n} \boldsymbol{E_{j,t}}$: Total electricity production by all sources at time t (Gwh)

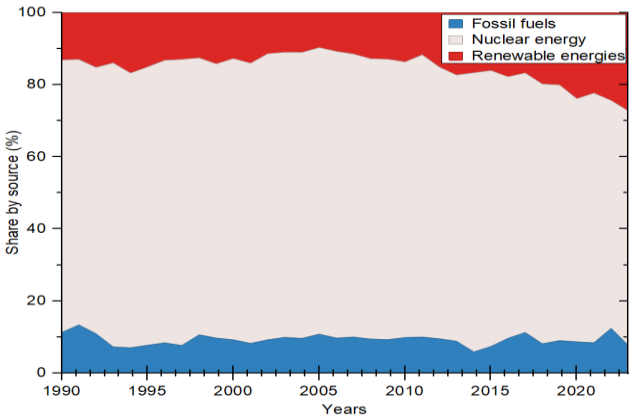

Fig. 1. Share of electricity production by source in France between 1990 and 2023

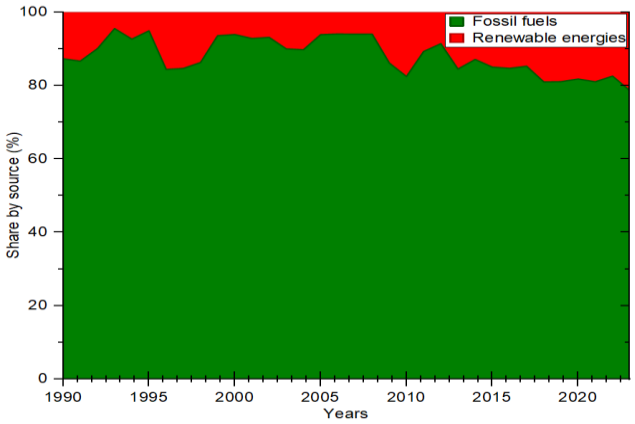

Fig. 2. Share of electricity production by source in Morocco between 1990 and 2023

Firstly, as shown in Figure 1, electricity production in France has been largely dominated by nuclear energy. This accounted for an average of between 75% and 90% of the energy mix, with relative stability until the early 2010s, when it decreased to around 70% in 2023. Meanwhile, the contribution of renewable energies remained relatively low for a long time, fluctuating between 8% and 12%. However, starting in 2015, a sustained growth trend emerged, driven by the considerable development of wind and solar power, as well as the modernisation of hydroelectric infrastructure. This evolution enabled renewables to account nearly 25% of electricity mix in 2023, marking a significant turning point in the diversification of electricity production.

During the same period, the proportion of electricity generated from fossil fuels remained generally low, ranging between 5% and 10%, with occasional variations depending on the short-term needs of the power system. Coal and natural gas, the main sources used, are employed as backup solutions during winter consumption peaks, temporary outages of nuclear power stations or drops in renewable energy production due to adverse weather conditions. Although their contribution to the electricity mix has declined due to policies aimed at reducing greenhouse gases, and the gradual closure of the most polluting plants, they still play a strategic role in ensuring the flexibility and security of supply of the French power grid.

In the case of Morocco (Figure 2), electricity production between 1990 and 2023 has largely been dominated by fossil fuels, which have accounted for the majority of the energy mix, often making up 80% of it. Despite some fluctuations, this situation highlights the country's structural dependence on coal, oil and natural gas in order to meet its electricity demand. Although energy transition policies have been adopted and renewable energy development is progressing, the share of fossil fuels remains high. This reflects the slow pace of shifting towards a more decarbonised energy mix, as well as the need for alternative infrastructure to ensure supply security.

On the other hand, renewable energies have maintained a limited share in electricity production, ranging between 10% and 20%. However, significant progress has been made since the 2010s thanks to large-scale wind and solar projects being deployed, and existing hydroelectric resources being enhanced. This reflects efforts to diversify the energy mix and reduce dependence on fossil fuels as part of national energy transition strategy. Despite these advances, however, renewables have not yet reached a sufficient level to rival the dominance of fossil fuels. This underscores the urgency of accelerating investments to improve grid integration and develop storage capacities, in order to maximize their contribution to energy security and decarbonisation of Morocco's electricity sector.

3.2 Carbon intensity of electricity production in Morocco and France

The carbon intensity of electricity generation is a key indicator for assessing the environmental performance of national energy system [11] its reflects the amount of CO2 emitted per unit of electricity produced and allows for a direct comparison between Morocco and France (Figure 3). It is calculated using the following formula of Eq. (2):

$$CI_{it} = \frac{CO_{2\ t}}{E_t} \qquad (2)$$

With:
$\boldsymbol{CI_t}$: Carbon intensity at time t (MtCO2/Gwh)
$\boldsymbol{CO_{2\ t}}$: Total of carbon dioxide emissions from electricity generation at time t (MtCO2)
$\boldsymbol{E_t}$: Total electricity generation by source at time t (Gwh)

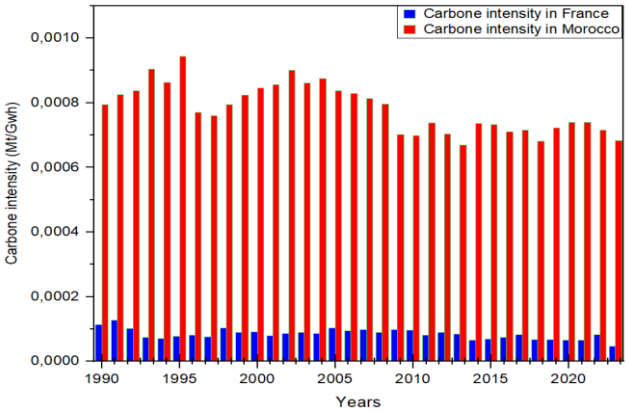

Fig. 3. Carbon intensity of electricity Production in Morocco and France between 1990 and 2023

The Carbon intensity in the electricity production of Morocco and France since 1990 shows sharply divergent trajectories (Figure 3).

In Morocco, the intensity fluctuates from 0.0008 to 0.0010 Mt/GWh, reflecting a persistent dependence on thermal sources, particularly coal. A clear peak in emissions occurred during the 1990s and early 2000s [12] and the data from 2010 onwards reveal a modest decline, which is attributed to the gradual increase in wind and solar capacity. Nevertheless, these renewables remain too small a proportion of the national energy mix to trigger significant decoupling from carbon derived from fossil fuels.

By contrast, France has a very low carbon intensity, with values between 0.00005 and 0.00012 Mt/GWh. This stable baseline is primarily due to a well-established nuclear fleet, which is now being supplemented by an increase in wind and solar capacity. Variability is confined to narrow margins and is largely driven by the planned maintenance cycles of nuclear reactors or the temporary dispatch of thermal units during peak demand hours, when low-carbon sources are insufficient.

3.3 Discussion

The analysis reveals two contrasting trajectories. In France, the nuclear strategy initiated in the 1970s has enabled the production of low-carbon electricity at a level of between 0.00005 and 0.00012 MtCO2/GWh. The increasing incorporation of renewable energy sources, such us hydropower, wind power, solar power, since the 2010s has reinforced this

position, establishing France as one of the countries with the lowest emissions in the world [1,4].

Conversely, Morocco's energy sector is still heavily reliant on fossil fuels, particularly coal, which results in high emissions of 0.0008-0.0010 MtCO2/GWh. Although solar and wind projects launched since the 2010s have reduced this dependence slightly, their combined share of around 22% in 2023 remains insufficient to trigger deep decarbonisation [7].

These results highlight the importance of strategic choices. A coherent, long-term energy policy, such as that in France, promotes a sustainable reduction in emissions. For Morocco, the major challenge is to rapidly reduce coal's share and accelerate the integration of renewable energy in order to ensure a viable energy transition [2,3].

4 Conclusion

This paper highlights the contrasting trajectories of electricity production and carbon intensity in Morocco and France between 1990 and 2023. It shows how different energy strategies can directly influence environmental outcomes.

France's historical dependence on nuclear power and gradual integration of renewable energies has enabled it to maintain one of the lowest carbon intensities in the world [13].
In contrast, Morocco remains heavily dependent on fossil fuels, particularly coal, which generates significant emissions despite making progress in developing wind and solar power.

This comparative analysis emphasizes the importance of strategic decisions, technological investments and a consistent policy framework for achieving successful and sustainable decarbonisation. Morocco's urgent challenge is to accelerate the integration of renewable energies, reduce the share of coal strengthen and network infrastructure to ensure a resilient, low-carbon electricity future.

Ultimately, both countries' experiences demonstrate that the energy mix is more than just a technical issue; it is a vital strategic tool for achieving climate goals and ensuring long-term energy security.

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