Toward Sustainable Development: Unfolding the Nexus among Exports, Foreign Direct Investment, Capital Formation, Natural Resource Rent, Unemployment, and Low-Carbon Transition in Morocco

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Abstract

Morocco faces the challenge of balancing industrial growth with environmental sustainability, as increasing economic activities have led to rising CO_2 emissions. Understanding how key economic factors contribute to mitigating this challenge is essential for achieving sustainable development. Therefore, this study aims to explore the nexus between exports of goods and services, foreign direct investment (FDI), gross capital formation, total natural resource rent, unemployment, and low-carbon transition in Morocco, with a focus on their role in sustainable development. We developed a comprehensive framework to investigate the impact of these variables on low-carbon development via novel mathematical models such as grey relational analysis (GRA) and the grey technique for order of preference by similarity to ideal solution (TOPSIS). The analysis draws on data covering the period from 2000-2022. The results reveal that exports of goods and services play a pivotal role, contributing significantly to CO_2 emissions and serving as a key indicator of industrial growth, followed by foreign direct investments, which have a weight of 0.580. This study offers actionable insights for decision-makers, businesses, governments, and policymakers, encouraging a shift toward green production in manufacturing exports to reduce CO_2 emissions and promote sustainable development in Morocco.

Keywords: Sustainable development; Industrial growth; low-carbon transition; Renewable energy; Morocco; CO_2 emissions

1. Introduction

In the 21st century, many developing countries face the challenge of balancing economic growth with sustainable development. As global markets become increasingly interconnected and competitive, these countries are under pressure to diversify their economies, enhance industrial productivity, and integrate into global value chains. This shift toward industrialization offers the promise of economic advancement, increased job creation, and improved standards of living (Jian Wang et al., 2024). However, complex trade-offs, including environmental degradation, social inequalities, and the overexploitation of natural resources, often occur. The global transition toward sustainable industrial practices has highlighted an urgent need to

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address how developing economies can achieve industrial growth without compromising their social and environmental well-being.

The complexity of this issue is further magnified by international agreements such as the Paris Agreement, which have set ambitious climate targets for all nations. While developed countries often possess the resources and technologies required for cleaner growth, developing countries face the dual burden of catching up economically while adhering to global environmental standards (Magazzino et al., 2022). This situation often results in a development paradox, where the pursuit of industrial growth can sometimes conflict with the imperatives of climate action. However, the potential to create more inclusive, sustainable, and resilient economies is also significant if countries can successfully integrate sustainability into their development strategies (Maure et al., 2024).

The transition to low-carbon has become a crucial framework for aligning economic development with environmental sustainability. In light of increasing climate change, resource depletion, and demographic shifts, policymakers and stakeholders are compelled to develop strategies that promote economic prosperity while safeguarding the natural ecosystem. The low-carbon transition focusses on the shift towards low-carbon technologies, sustainable resource management, and the incorporation of environmental goals into fundamental economic planning (Tariq et al., 2024). This comprehensive perspective regards low-carbon development not only as an environmental issue but also as a crucial catalyst for innovation, competitiveness, and socio-economic resilience (Cao et al., 2022). Prioritizing low-carbon development enables developing countries to enhance industrialization and generate employment while maintaining ecological integrity.

The implementing low-carbon strategies involves significant complexity and trade-offs. Developing economies face the challenge of balancing foreign investment attraction, industrial capacity expansion, and the fulfilment of rapidly increasing domestic demand, all while addressing ecological degradation and adhering to global climate agreements (Opoku et al., 2022). The integration of green technologies necessitates significant initial investments, specialized expertise, and the establishment of institutional frameworks, which can be difficult to implement. Despite these challenges, the prospective long-term advantages are considerable. Effective low-carbon strategies can enhance economic diversification, mitigate vulnerability to external shocks such as fluctuating fossil fuel markets, and facilitate sustainable socioeconomic transformations that are consistent with national development goals and international environmental obligations (Qamruzzaman and Karim, 2024).

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In this context, the integration of policy, technology, and finance is essential for achieving the full potential of low-carbon strategies. Governments should implement regulations and incentives that promote clean production methods while also investing in research and development (R&D) to foster innovation in renewable technologies and resource-efficient manufacturing (Shan et al., 2021). Simultaneously, engagement from the private sector is essential, as businesses are crucial in advancing technology and expanding green solutions. Collaborative partnerships among government bodies, industry, and civil society enable developing economies to establish resilient pathways that integrate environmental stewardship into industrial and economic activities. This integrated approach is fundamental for enhancing sustainability, promoting inclusive growth that satisfies current needs while ensuring future generations can thrive (Adomako and Tran, 2022)

The simultaneous focus on industrialization and renewable energy has reshaped the economic landscape of developing countries, leading to rapid sectoral growth and diversification. Traditionally, numerous developing economies such as Morocco has relied heavily on agricultural exports and its abundant natural resources. However, the strategic decision to attract technologically advanced industries, supported by competitive tax incentives, affordable labor, and geographic proximity to major markets, has transformed the country into an attractive destination for international investment (Frascari et al., 2018). This transformation has been reflected in the growth of the industrial sector, which now contributes to economic development (Frascari et al., 2018). The rise of new manufacturing and technology sectors in developing economies have bolstered export capabilities, making the country a key player in the global supply chain (Gallab et al., 2021).

This study aims to examine the nexus between key economic factors including exports of goods and services FDI, gross capital formation, natural resource rent, unemployment, and the low-carbon transition of Morocco toward sustainable development. A critical focus is placed on evaluating the integration of Morocco's industrial acceleration strategies and renewable energy initiatives within its broader sustainability framework. By addressing these interconnected dimensions, this research develops a robust analytical framework to assess the influence of economic, industrial, and energy policies on fostering low-carbon transition. This study employed advanced Grey Relational Analysis (GRA) models, a novel approach recognized for its robustness in delivering consistent and unbiased results. The methodology is particularly advantageous for its ability to generate optimal outcomes, even with limited data samples, and effectively identify the most influential factors driving low-carbon development

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in Morocco. A key strength of the GRA model lies in its superior accuracy and reliability compared to conventional statistical techniques (Ikram et al., 2020). Moreover, the study's findings are generalizable to economies with similar socio-economic contexts, broadening its applicability and relevance to policy and decision-making frameworks. The study’s findings are intended to provide actionable, evidence-based recommendations for policymakers and stakeholders, facilitating the alignment of industrial development with environmental sustainability. This study answers threefold questions:

Q1: How do export of goods and services, FDI, capital formation, natural resource rent, and unemployment influence Morocco's progress toward low-carbon development?

Q2: How do these factors interact with each other to influence environmental outcomes?

Q3: What policy recommendations of the study can be drawn from the analysis to promote sustainable industrial development in Morocco?

To integrate industrialization with sustainable practices, offer valuable lessons, there remains a critical research gap in understanding the interplay between these strategies. Existing studies have often focused on either industrial policies or its renewable energy transitions in isolation. However, analyses of how these strategies intersect and contribute to achieving sustainable economic growth are limited. This study seeks to address this gap by providing a comprehensive analysis of and renewable energy initiatives, exploring how the developing economies have balanced industrial growth with environmental objectives.

The findings of this research aim to provide valuable insights to help policymakers to analyze the interplay between goods and services FDI, gross capital formation, natural resource rent, and unemployment, in fostering low-carbon transition within the framework of sustainable development. By analyzing Morocco’s achievements and challenges, this study develops a comprehensive framework that can guide developing countries in addressing similar complexities. This analysis holds particular relevance for nations in Africa and the Middle East, which are striving for economic diversification while contending with the demands of global climate commitments. Morocco’s experience offers a potential strategic roadmap for achieving economic transformation that harmonizes industrial growth with environmental sustainability and social resilience.

This study is structured as follows: Section 2 detailing the Morocco theoritical framework and Morocco’s low-carbon transition. Section 3 provides the literature review. Section 4

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elaborates on the grey relational analysis and grey TOPSIS methods. Section 5 discusses the findings and analysis, followed by Section 6, which outlines the discussion and implications. The final section concludes the study.

2. Theoretical Framework and Low-Carbon Transition in Morocco

The Resource-Based View (RBV) offers a robust theoretical framework for understanding how Morocco's unique natural resources serve as a vital catalyst for its low-carbon transition. Morocco's extensive renewable energy potential, encompassing solar, wind, and hydropower resources, has positioned the country as a leader in the MENA region's sustainability initiatives (Leonard et al., 2024). These resources, combined with strategic investments and government incentives, have attracted significant FDI into the renewable energy sector, enabling the nation to leverage its resource endowments for economic and environmental gains (Uddin et al., 2024). By emphasizing the strategic importance of these resources, the RBV aligns with our study's aim of investigating how resource advantages, coupled with capital formation and natural resource rents, contribute to Morocco's SDGs. This perspective highlights that Morocco's ability to achieve low-carbon development is intricately tied to its effective utilization and management of these natural assets, providing insights into how resource-based strategies can be optimized for long-term sustainability.

Morocco's industrial achievements continue to grow, driven by a sustained influx of FDI across various sectors of its economy. As one of the most attractive destinations for foreign investors in North Africa, Morocco has consistently capitalized on its strategic location, political stability, and investment-friendly policies to encourage global interest (Bakour et al., 2022). The increasing FDI inflows into diverse industries have played a crucial role in propelling economic growth. However, this new wave of industrialization has inevitably brought challenges, particularly concerning environmental sustainability (Qamruzzaman et al., 2023). Prior studies have suggested that as economies expand, they tend to exert pressure on their ecological systems, often resulting in increased pollution and resource depletion (Ahmed et al., 2021; Leonard et al., 2024). Therefore, Morocco's commitment to sustainable practices, particularly renewable energy, becomes critical as the country balances growth with its environmental objectives.

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Recognizing the environmental implications of economic growth, Morocco has taken deliberate steps to reduce its carbon footprint by investing heavily in renewable energy sources such as solar, wind, and hydropower (El Hathat et al., 2023). This strategic focus not only supports the nation's ambition to reduce CO2 emissions but also aligns with global sustainability goals. The shift toward greener energy solutions has positioned Morocco as a leader in the MENA region's renewable energy landscape, contributing positively to its overall environmental quality (Ourya et al., 2023). As these investments gain momentum, they create significant changes in the nation's carbon emissions profile, influencing the country's overall environmental outcomes. Understanding the relationship between FDI in renewables and Morocco's low-carbon transition is vital for assessing how these factors interact and contribute to the broader goal of sustainable development (Bouyghrissi et al., 2022). This literature review explores these dynamics, moving from a global perspective to a concentrated focus on the Moroccan context, thus offering a comprehensive analysis of the variables that drive sustainable growth.

Morocco exemplifies this broader global challenge. As a country with a strategic geographic location, abundant natural resources, and a young and growing population, Morocco holds significant potential to become an industrial leader in the region. However, like many developing economies, it faces the challenge of aligning its industrial ambitions with sustainable practices. In the early 2000s, Morocco stood at a critical crossroads, facing a transformative decision that would shape its future trajectory. The country had to choose between continuing as a consumption-driven economy, heavily dependent on imports, or embarking on a more ambitious path of industrialization aimed at economic diversification and resilience (Belcaid, 2022). This decision became a defining moment in Morocco's development, reflecting a broader dilemma faced by many nations in the Global South.

The strategic importance of Morocco lies not only in its geographic position but also in its role as a bridge between Africa and Europe. This unique position allows Morocco to leverage trade agreements with the European Union (EU) and other regions, offering a gateway for African products to enter European markets (Casano & Panizza, 2024). This positioning has made the stakes higher for Morocco to pursue a model of development that aligns with the standards and expectations of both regional and international partners, especially in sectors such as renewable energy and sustainable industrialization (Bouyghrissi et al., 2022).

Recognizing the potential for industrialization, Morocco launched its first industrial strategy in the early 2000s. This strategy aimed to shift the country's economic focus from raw

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materials, such as agricultural products and phosphates, to value-added industries (Ministry of Industry and Trade, 2014). However, initial efforts faced numerous challenges, including infrastructure bottlenecks, limited access to financing, and a workforce that required upskilling to meet the demands of new industries. Despite these setbacks, Morocco's commitment to industrialization remained steadfast and underscored the long-term vision of economic transformation (Gallab et al., 2021).

Figure 1 illustrates the distribution of energy consumption in Morocco across various sources from 2000--2023, quantified in terawatt-hours (TWh). In 2023, oil constituted 58.42% of the total energy supply, whereas coal accounted for 29.86%. Renewable energy sources, such as wind (6.27%), solar (2.02%), hydropower (0.16%), and other renewables (0%), have experienced growth; however, their contribution remains minimal in comparison with that of fossil fuels. Gas accounts for 3.27%, whereas nuclear and other renewable sources have a negligible effect on the energy mix. The graph illustrates a gradual shift toward renewable energy, with oil and coal continuing to dominate the energy sector. Morocco, despite its ambitious renewable energy objectives, remains significantly dependent on fossil fuels, with oil and coal constituting the core of its energy infrastructure. The objective of Morocco is to achieve 52% of its electricity generation from renewable sources by 2030 (Boulakhbar et al., 2020); however, the existing trajectory indicates that significant investments and policy adjustments will be necessary to attain this goal.

The Industrial Acceleration Plan (IAP) represents a more structured and ambitious approach to industrial growth. Its objectives included increasing the industrial sector's contribution to GDP from 14% to 23%, creating 500,000 new industrial jobs, and fostering the development of interconnected industrial ecosystems (Ministry of Industry and Trade, 2014). The plan focused on attracting foreign direct investment (FDI), promoting investments in high-value sectors, and improving the integration into global supply chains. Providing fiscal incentives, building advanced technological infrastructure, and leveraging free trade agreements (FTAs), are key players in regional and global markets (Němečková, 2021).

While pursuing its industrial ambitions, it positioned itself as a leader in the shift toward a green economy. Hosting the United Nations COP7 in 2001 and COP22 in 2016, Morocco demonstrated a commitment to global climate goals and sustainable development. The country's renewable energy investments, particularly in solar and wind power, have been central to its efforts to balance industrial growth with environmental responsibility (Slighoua et al., 2022). Projects such as the Noor Ouarzazate Solar Complex, one of the world's largest

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concentrated solar power plants, illustrate Morocco's strategic focus on reducing its carbon footprint while improving energy security (Smouh et al., 2022).

Moreover, these efforts have significantly diversified the energy mix, allowing the developing countries to reduce their reliance on imported fossil fuels. The shift toward renewable energy has also positioned Morocco as a regional leader in clean energy production, with wind power alone increasing its share of total electricity generation from 6% in 2000 to

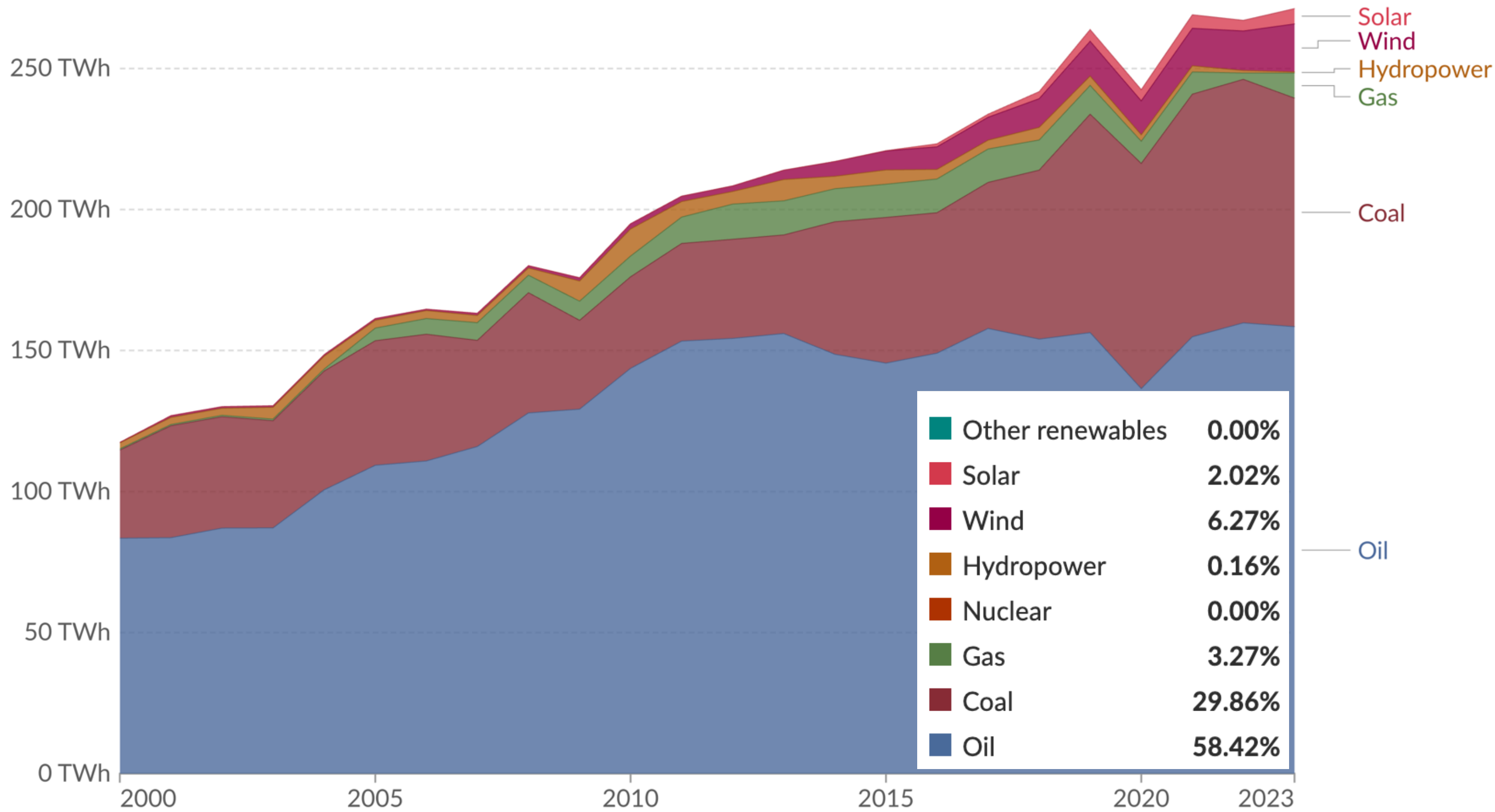

Figure 1: Morocco energy consumption from 2000-2023. Source:(Our World In Data, 2024)

The annual CO_2 emissions of Morocco from 2000-2022, which represent a 106.07% increase in emissions, are presented in Figure 2. The graph shows a constant increase in CO_2 emissions, which is consistent with Morocco's increasing energy consumption, industrialization, and economic progress. Despite efforts to integrate renewable energy, such as the development of solar and wind power projects, the country continues to rely largely on fossil fuels, resulting in an increase in emissions. This increase highlights Morocco's dilemma in lowering its carbon footprint while fulfilling the expanding energy demands of its population and economy.

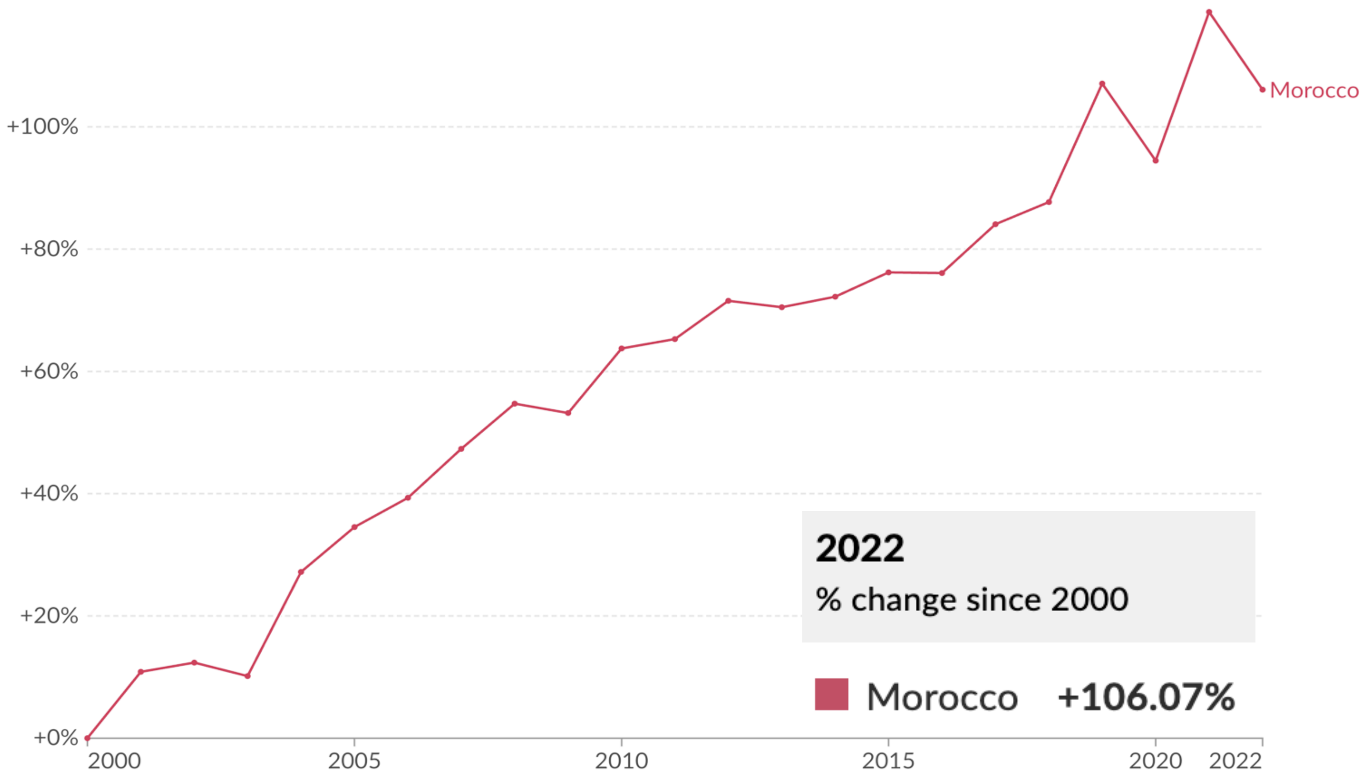

Figure 2: Annual CO2 emissions in Morocco from 2000-2022 (Our World in Data, 2023)

Moreover, Morocco's industrial strategy emphasizes the creation of value chains within the automotive, aerospace, and textile industries, which have become significant contributors to its economic output. The presence of global companies such as Renault, PSA Peugeot, and Boeing in Morocco's industrial zones is a test of the country's success in attracting investment (El-Khodary et al., 2024). These industrial ecosystems have generated substantial employment opportunities, thereby addressing some of the social challenges associated with economic transformation (El Aynaoui et al., 2022).

3. Literature review

Achieving sustainable development involves a balance between economic growth and environmental stewardship (Ramzan et al., 2023). This study highlights the interplay between exports of goods and services, FDI, capital formation, and natural resource rents in shaping economic growth and social well-being, while also addressing concerns regarding environmental effects and unemployment. This study analyzes these interdependencies to identify strategies that promote economic progress while ensuring a transition to a low-carbon

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future. Moreover, this study highlights the significance of cohesive, proactive policies that align economic goals with environmental sustainability.

Dong et al. (2018) analyzed the relationships among CO_2 emissions, natural gas, and renewable energy, emphasizing their impacts on economic growth. Their research, set within the Chinese context, offers insights into how these variables interact in a heavily industrialized economy. China, which contributes to high pollution levels and significant investments in renewable energy, presents a valuable case study for understanding the complexities of balancing industrial growth with environmental sustainability. Despite extensive efforts to invest in renewable energy sources, this study reveals that the impact on reducing CO_2 emissions remains limited. This finding underscores the challenges that nations face when attempting to align rapid economic growth with environmental objectives. Moreover, it highlights the importance of selecting appropriate indicators to assess the effectiveness of low-carbon strategies, as different economic environments may yield varied results (D. Wang et al., 2022). Moreover, Hasan et al. (2023) utilized the Environmental Kuznets Curve (EKC) model to examine the correlation between industrial expansion and CO2 emissions in BRICS countries. The study indicates that fossil fuel consumption adversely affects the environment, whereas renewable energy, financial progress, and enhanced trade openness positively contribute to environmental sustainability.

Furthermore, Ansari, (2022) proposed the environmental Kuznets curve (EKC) as a framework for analyzing the dynamic relationship between economic growth and environmental quality, particularly in terms of CO_2 emissions. The EKC hypothesis suggests that environmental degradation initially increases with economic growth but eventually decreases as societies reach higher income levels and adopt more sustainable practices. Using advanced econometric techniques such as the autoregressive distributed lag (ARDL) approach, a positive relationship between economic expansion and CO_2 emissions in the short term was identified (Chang et al., 2022). However, as income levels rise, the relationship weakens, indicating the potential for long-term environmental improvement. This research provides valuable insights into how economic policies can shape environmental outcomes over time, contributing to a deeper understanding of sustainable growth pathways.

Yang et al. (2023) utilized the Method of the Moments Quantile Regression (MMQR) to examine the impact of natural resources, green finance, green energy, and economic growth on the ecological footprint in Nordic countries between 1990 and 2018. The results indicate that natural resources and economic growth significantly contribute to environmental degradation,

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whereas green energy and green finance play a mitigating role, highlighting their potential as sustainable solutions across all quantiles.

Moreover, Rosita et al. (2021) focused on the Indonesian manufacturing sector and assessed the impact of industrial activities on CO_2 emissions via the logarithmic mean Divisia index (LMDI) from 2010-2014. This study explores the relationship between industrial growth and environmental performance, revealing significant variations in the impact of economic activities on emissions. The analysis shows that while some industries contribute substantially to CO_2 emissions, others have a minimal impact, indicating the need for industry-specific policies to manage environmental outcomes (Mentel et al., 2022). The findings emphasize the importance of tailored approaches to reduce the carbon footprint of industrial growth, suggesting that similar analyses could provide useful insights for countries such as Morocco, where industry-specific strategies could play a critical role in achieving low-carbon transition.

Evaluating Morocco's trajectory toward low-carbon development is crucial, as the nation has made substantial progress in both economic and environmental domains. With significant investments in renewable energy projects, Morocco has positioned itself as a regional leader in sustainability (Houssini & Geng, 2022). The Moroccan government has initiated several large-scale renewable energy projects, including the Noor Solar Power Plant, to diversify its energy mix and reduce its dependence on fossil fuels. These investments are designed to align with the nation's strategic objective of deriving 52% of its energy needs from renewable sources by 2030 (Aqachmar et al., 2019). These initiatives have not only attracted foreign investment but also demonstrated Morocco's commitment to integrating sustainability into its economic development model. The evaluation of low carbon in Morocco thus requires a thorough assessment of how these investments impact CO_2 emissions and overall economic performance.

Ikram and Sadki, (2024) developed a green technology assessment framework for Morocco's low-carbon trend from 2016-2023, using a multicriteria decision-making model that measures the country's progress toward sustainability. The study highlights Morocco's upward trajectory in terms of low-carbon-transition, reflecting the positive impact of its renewable energy investments. Data analysis reveals that Morocco's efforts to enhance its energy infrastructure and adopt sustainable practices have contributed significantly to reducing the country's carbon intensity. This research offers a localized perspective on the challenges and opportunities associated with implementing low-carbon strategies in a developing economy, providing a basis for policymakers to design more effective sustainable policies.

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In a comparative study, Mikayilov et al. (2018) examined the relationship between economic growth and environmental sustainability in Azerbaijan via traditional variables and cointegration analysis. This research highlights how energy efficiency improvements can influence the elasticity of CO_2 emissions, offering insights into the potential for achieving sustainable growth. By focusing on a dataset spanning from 1992-2013, this study provides a long-term perspective on the effects of energy practices on environmental outcomes. The findings suggest that while economic growth can drive increases in emissions, strategic investments in energy efficiency can mitigate these effects, similar to the potential outcomes of Morocco's renewable energy strategy (Šimelytė, 2019). Furthermore, Hasan et al. (2022) employed the Auto-Regressive Distributed Lag (ARDL) model to investigate the impacts of renewable and nonrenewable energy consumption on the growth environment nexus in Bangladesh from 1980 to 2018. The results demonstrate that renewable energy promotes economic development and enhances environmental quality, whereas nonrenewable energy impedes growth and leads to environmental deterioration. Furthermore, the investigation did not uncover any evidence that supports the environmental Kuznets curve hypothesis in the context of Bangladesh.

Green transformation remains a pivotal indicator of sustainable growth in rural areas, particularly in developing countries. Barbier and Burgess, (2020) discusses the role of the agrarian sector and its interaction with poverty rates in fostering low-carbon development. Investments in renewable energy and low-carbon technologies are identified as essential to transforming rural economies. This study's insights are relevant for Morocco, where rural areas represent a significant part of the national economy, and investment in green infrastructure could facilitate more balanced and sustainable growth (Perry, 2020).

Furthermore, developed economies face challenges in their transition to low-carbon. Schreiner and Madlener (2021) conducted an input–output analysis in Germany, exploring the effects of green investments on the economy's macroeconomic performance. The study reveals that while low-carbon transition can stimulate certain sectors, it may also require substantial economic adjustments. These findings underscore that the path to sustainability is complex and multifaceted, even for countries with advanced infrastructure. Similar challenges are likely in Morocco, as it continues to develop its renewable energy sector and adapt its economic model to meet sustainability goals (Meir et al., 2022). Shen et al. (2021) explored urban development in China, focusing on the need for industrial structure adjustments to support sustainable growth in less developed urban areas. Their research highlights the importance of targeted investment

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in green infrastructure, drawing parallels to Morocco's urbanization strategy, where renewable energy investments are key to promoting sustainable development (Amini Alaoui et al., 2024).

In Morocco, recent investments in renewable energy have not only attracted foreign capital but also contributed to the country's ability to meet its ambitious energy goals. Government policies, such as tax incentives and support for private sector involvement in green projects, have been instrumental in driving this progress (Houssini & Geng, 2022). Using advanced econometric tools such as the ARDL bounds test and bootstrapping techniques, researchers have analyzed the causal relationships between economic growth, $CO2$ emissions, and renewable energy investments, offering a detailed understanding of the interconnected dynamics. Salahuddin et al. (2018) analyzed the effects of electricity consumption, economic growth, and financial development on CO_2 emissions. By using World Bank data from 1980--2013, the ARDL approach provides insights into the long-term impacts of FDI and other economic factors on environmental outcomes. This approach is valuable for understanding how Morocco's FDI inflows in renewable energy can shape its future environment.

In this study, we employed multiple models, GRA, conservative maxmin and grey TOPSIS, to analyze Morocco's low-carbon development. The TOPSIS model is known for its precision in ranking alternatives and is widely used for decision-making in complex scenarios. Previous studies have applied this method to evaluate the economic and environmental benefits of Morocco's shift toward renewable energy. Aouragh and Essahlaoui, (2018) offer a detailed analysis of Morocco's investment climate, highlighting how FDI inflows have evolved since the early 2000s and the role of renewable energy projects in attracting global interest.

This study fills the literature gap by employing a comprehensive analytical approach that integrates various relevant economic and environmental elements into multidimensional framework. The research transcends evaluations by analyzing the linkages among exports, foreign direct investment, capital formation, natural resource rents, unemployment, and low-carbon transition in Morocco. By utilizing novel decision making GRA and grey TOSPSIS models, this study provides a detailed, context-dependent analysis of how these variables jointly impact Morocco's advancement towards its SDGs. This study offers policymakers and stakeholders evidence-based options that reconcile economic growth with long-term environmental sustainability, thus addressing a significant gap in the current literature.

4. Data & Methodology

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This research aims to explore the nexus between exports of goods and services, FDI, gross capital formation, total natural resource rent, unemployment, and low-carbon development within the Moroccan context. Morocco plays a leading role in both industrialization and sustainability within Africa, making it a valuable and novel case study. The analysis draws on data sourced from the World Development Indicators (WDI), covering the period from 2000-2022, with detailed information on all variables outlined in Table 1. This study employs advanced analytical methods, including grey relational analysis (GRA) and grey TOPSIS, to assess the influence of industrial growth on various low-carbon development variables. This study employed advanced mathematical GRA models, a state-of-the-art technique recognized for its dependability and accuracy in delivering impartial outcomes. This method proves to be exceptionally efficient in extracting valuable insights from limited datasets and identifying the key elements that drive low-carbon development in Morocco. The GRA model stands out for its remarkable accuracy and reliability, especially when compared with conventional statistical approaches (Lu et al., 2023). Furthermore, a maximin model was developed to rank the variables on the basis of their impact, whereas grey TOPSIS served as a tool for prioritizing factors with a stronger influence on low-carbon development outcomes. MATLAB was used to facilitate the application of these methods, ensuring precise and robust analysis.

Table 1: Descriptions of the variables and data sources

Variables	Description of variables	Unit of measurement	Data source
CO2 Emissions	Carbon dioxide emitted by the country is contributed by all industries and consumers.	Kt (1000 metric tons)	Our World in data
Renewable Electricity Output	Total percentage of renewable energy contribution into energy-producing from all energy sources.	% Of total electricity output	Our World in data
Exports of goods and services and primary income	The sum of all exports coming from services and goods as well as receipts from income.	USD ($)	World Bank
Foreign Direct Investments, net inflows	Inward direct investments are made by nonresidents.	USD ($)	World Bank
Gross capital Formation	The total value of sectorial fixed capital formation.	USD ($)	World Bank
Inflation	A general increase in prices of goods and services within an economy.	%	World Bank
Total natural resources rents	The difference between the price of a commodity and the cost of producing it within an economy.	% of GDP	World Bank
Unemployment	Percentage of the population not being in paid employment, within an age range of the legal capacity.	% of total labor force	HCP

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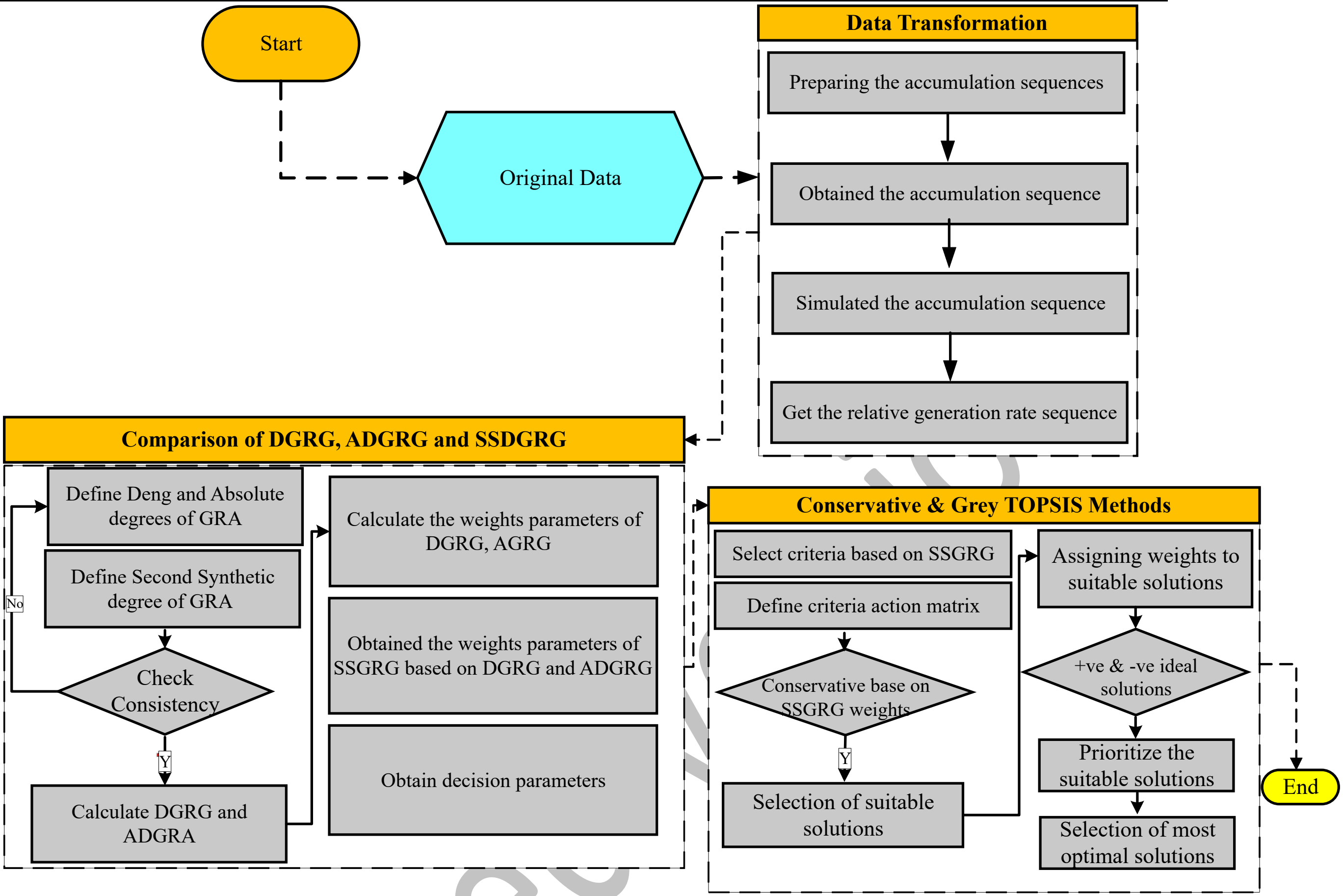

Figure 3: Methodology framework of the research

Grey System Theory (GST)

Deng introduced grey system theory (GST) in 1982, marking its first phase of development. The grey method, known for its ability to function with incomplete and limited input, has since become widely used across the globe to address complex and uncertain situations (Ju-Long, 1982). The concept of grey systems has found applications in a range of fields, including health research, sociology, natural sciences, and engineering. One of the key strengths of grey models is their ability to produce reliable results even with small datasets, offering a distinct advantage over similar approaches. The degree of data completeness is a crucial aspect of the grey system (Y. Liu et al., 2019). Grey systems can be categorized on the basis of the completeness of their data: "white" data refer to systems with fully known information, whereas "black" data pertain to systems where information is largely unknown (S. Liu & Yang, 2017). In this study, we employed the grey TOPSIS method, built upon parameters from the grey relational analysis (GRA) model, to examine the impact of industrial growth drivers on low-carbon transition in Morocco.

4.1 Grey Relational Analysis (GRA) Models

The grey relational analysis (GRA) model, also known as grey incidence analysis (GIA), represents an advanced framework refined by (Javed & Liu, 2019). It is considered a foundational phase in the development of modern grey systems theory (Ahmadi et al., 2022). The roots of grey system theory trace back to the work of Professor Julong Deng, a Chinese researcher who completed his pioneering work in 1982. Initially, Deng's theory was applied across various academic disciplines to address issues of sensitivity, particularly in situations characterized by incomplete, ambiguous, and fragmented data. One of the key advantages of using grey systems methods is their suitability for analysis even with limited datasets (Karimi et al., 2024).

Deng further enhanced the GRA model in 1985 by introducing the concept of the grey relational grade (GRG), a critical tool for measuring relationships between variables. Junjie Wang et al. (2017) noted that the sensitivity of the grey incidence model is greater than that of traditional system analysis methods, allowing for more precise evaluations. The grey incidence model excels in addressing complex problems where traditional methods struggle due to the lack of clear data and intricate processes (Abid et al., 2021). The core principle of GRA models is to assess relationships by measuring the degree of similarity between data patterns, using mathematical curves to analyze proximity in extended relational databases (Singh & Pandey, 2024). While Deng's original GRA model focuses on analyzing partial connections, later iterations, such as the fourth GRA, explore deeper relationships between datasets. Moreover, the second synthetic GRA aims to capture a more comprehensive clustering of data relationships (Javed, Liu, et al., 2019).

4.2 Deng's Degree of GRA Model

Various researchers have developed numerous GRA techniques; however, Deng's (1985) model is particularly prominent and effective, playing a pivotal role in the foundation of grey system theory. Deng's GRA model, owing to its fundamental principles, has been widely applied in practical applications across various domains, encompassing both theoretical and empirical research (Zuo et al., 2016). According to Ikram et al. (2020), Deng's method for estimating grey incidence between two datasets, X_0 and X_1, is presented as follows:

The initial image of X0 and Xi, where i=1, 2, …, m, is first computed.

$$X'i = Xi/xi(1) = (x'i(1), x'i(2), \dots, x'i(n)); i = 0,1,2,3 \dots, m. \quad (1)$$

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Second, the difference in the sequences of X'_0 and X'_i i=1, 2,3, …, m is calculated as:

$$\Delta i(l) = || x'0(l) - x'i(l) ||, \Delta = (\Delta i(1), \Delta i(2), \dots, \Delta i(n)), i = 1,2,3, \dots, m. \quad (2)$$

Third, the maximum and minimum are established as:

$$M = \max_i \max_l \Delta_i(L),\ m = \min_i \min_l \Delta_i(L). \quad (3)$$

The fourth step involves calculating the grey relation coefficients, also known as grey incidence coefficients, via the following formula:

$$\gamma_{0i}(l) = \frac{m+\xi M}{\Delta i(l)+\xi M};\ \xi \in (0,1);\ l = 1,2,\ \dots,\ n;\ i = 1,2,\dots,\ m, \quad (4)$$

With a representation of ξ, the distinctive coefficient is assumed to be ξ=0.5.

The last phase involves the calculation of the grey incident degree, commonly known as Deng's grey coincidence degree, as outlined below:

$$\gamma_{0i} = \frac{1}{n}\sum_{l=1}^{n}\left(\gamma_{0i}(L)\right); i = 1,2,\dots,m. \quad (5)$$

Adjusting the fraction of 1/n assigned weights wl results in the following:

$$\gamma 0i = \sum L = 1n(\gamma 0i(L) \times wl); i = 1,2,3 \dots, m. \quad (6)$$

If the influence of each component on the system is not the same, the total number of weight vectors will be equal to one, i.e., $\sum wl = 1$. This suggests *1/n* that the graded variables are spread uniformly, whereas w_k is a grading technique for maldistribution used in real-world situations (T. K. Wang et al., 2017) because the initial segment of Deng's relational model can be effectively linked because of the equal weighting of each free component among the low-carbon-transition indicators.

4.3 Absolute degree of the GRA model:

Zhicai and Li, (2018) differentiate between deng's GRA and the absolute GRA (ADGRA) model. While Deng's GRA focuses on analyzing the influence of GRA elements on the basis of the patterns within grey data, the ADGRA model assesses the magnitude of these elements, offering insights into the relationships between them. Both the Deng model and the ADGRA approach are valuable in research, as they enable precise measurement of mathematical proximity through the use of recurrence arcs. The methodology for establishing the absolute grey connection between two intervals, denoted X_0 and X_1, is outlined as follows:

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First, X_0^0 and X_1^0 are the null starting points computed from the interval sequence in X0 and X1. Computing $|s_0|, |s_1|$ and $|s_1 - s_0|$ is the second step.

Then, DGI (the absolute degree of grey incidence) (ε01) is comprehensively evaluated among the gap series of X0 and X1; hence, the method shown below is utilized:

$$\varepsilon_{01} = \frac{1+|s_0|+|s_1|}{1+ |s_0|+|s_1|+|s_1-s_0|}. \tag{7}$$

More information on the GRA frameworks, including Deng's occurrence and the outright relationships between entities, as well as their characteristics, is available(S. Liu & Yang, 2017). The GRA model acquainted with Deng has produced the GRG (Degree if Grey Incidence), also referred to as Deng’s grey relation analysis model, and it is presented as:

$$\gamma_{0i} = \sum_{l=1}^{n} \left(\gamma_{0i}(L) \times w_l \right); i = 1,2,3,\ldots,m, \tag{8}$$

Or

$$\gamma_{0i} = \frac{1}{n} \sum_{l=1}^{n} \left(\gamma_{0i}(L) \right); i = 1,2,3,\ldots,m, \tag{9}$$

The GRG ratio, which is further supported by the grey incidence ratio, is denoted by γ0i (L). The first representation of formula (1) of the GRA model represents the weighted version, whereas (2) represents a nonweighting formula.

The ADGRA model establishes the notion of the ADGRA of grey connections. It reads as follows:

$$\varepsilon_{01} = (1 + |s_0| + |s_1|) / (1 + |s_0| + |s_1| + |s_0 - s_1|) \tag{10}$$

Let the development insight into the extent model be represented by $X_i = (x_i(1), x_i(2), \ldots.., x_i(n))$ and C denote the fulfilling order operator, and $X_i(L)c = (x_i(L)c - x_i(1); L = 1,2,3, .. n$; then, C is the sequence operator beginning at nil, and X_iC is known as Xi's zero-scale sequence point. *X_iC* is frequently abbreviated as $X_iC = X_1^0 = (x_i^0(1), x_i^0(2), \ldots .. x_i^0(n))$.

Under the assumption that X_i and X_j are the same lengthwise, meaning that for variables with a single chronological sequence, the zero-starting point images are X_i and X_j:

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$$X_i^0 = \left(x_i^0(1),\ x_i^0(2), x_i^0(3)\ \ldots,\ x_i^0(n)\right), \tag{11}$$

$$X_j^0 = \left(x_j^0(1),\ x_j^0(2), x_j^0(3)\ \ldots,\ x_j^0(n)\right). \tag{12}$$

Then,

$$|s_i| = \left|\sum_{l=2}^{n-1} x_i^0(L) + \frac{1}{2} x_i^0(n)\right| \tag{13}$$

and

$$|s_j| = \left|\sum_{l=2}^{n-1} x_j^0(L) + \frac{1}{2} x_j^0(n)\right| \tag{14}$$

The absolute difference between $s_i - s_j$ is calculated as:

$$|s_i - s_j| = \left|\sum_{l=2}^{n-1}\left(x_i^0(L) - x_j^0(L)\right) + \frac{1}{2}\left(x_i^0(n) - x_j^0(n)\right)\right| \tag{15}$$

Javed et al. (2019) proposed the second synthetic degree of grey relation analysis (SSGRA) theory as follows:

$$\varrho_{ij} = \theta\varepsilon_{ij} + (1-\theta)\gamma_{ij};\ \theta \in [0,1], \tag{16}$$

where ij represents the second synthetic degree of grey incidence/grey relation (SSGRG). The symbol γij denotes Deng's degree of grey incidence (GRG), whereas εij signifies the absolute degree of grey relation (absolute GRG). Deng's grey incidence model is founded on the coefficient of grey relation or occurrence at specific locations. The absolute relational paradigm is founded on a comprehensive perspective. SSDGRA is tasked with assessing the overall connectivity among tandem repeat stages and evaluating the significance of their functions. Liu et al. presented the initial synthetic grey model technique (SDGRA), which integrates both relative and absolute grey occurrence methodologies.

The systematic ideas that underpinned the SDGRA model were used to build the SSDGRA model. It adopts a value of θ=0.5, aiming to achieve a balanced perspective that equally integrates the two elements, γ and ε, without bias toward either. This parameter can be adjusted as needed; for example, if a preference for γ is desired, the θ value can be reduced accordingly. Conversely, if a greater emphasis on ε is needed, the θ value can be increased temporarily (Mahmoudi et al., 2019).

4.4 Grey TOPSIS Method

In 1981, Yaoon and Hwang presented the TOPSIS concept, which assesses n alternatives on the basis of m criteria. The TOPSIS method provides the advantage of offering both positive and negative ideal solutions for decision-making. The positive ideal solution represents aspects

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such as revenue growth, whereas the negative ideal solution addresses efforts to minimize expenses (Yoon & Hwang, 1981). The best alternatives are determined on the basis of their closeness to the ideal solution and their maximum divergence from negative influences. The grey linguistic variables based on grey numbers used to prioritize the industrial growth indicators are presented in Table 2.

Table 2: Linguistic variables on the basis of grey numbers

Highly Unimportant	Unimportant	Moderate	Important	Highly Important
HU	U	M	I	HI
[0.0,0.2]	[0.2,0.4]	[0.4,0.6]	[0.6,0.8]	[0.8,1.0]

The grey system plays a crucial role in ensuring accuracy when evaluating uncertain system data. The following steps are associated with the grey TOPSIS approach.

Level 1: As shown in Table 4, grey variables are utilized to determine the weight of each criterion on the basis of an evidence-based assessment. When the number of selected nodes increases to *e*, Eq. (24) calculates the criterion *g* weights for the alternatives.

$$\otimes w_g = \frac{1}{e}\left[\otimes w_g^1 + \otimes w_g^2 + \cdots + \otimes w_g^e\right] \tag{17}$$

Level 2: Grey expressions should be employed to assess the condition of each research alternative against the specified criteria. The value of option h in criterion g is calculated using Equation (17) when e selection criteria are present.

$$\otimes G_{hg} = \frac{1}{e}\left[\otimes G_{hg}^1 + \otimes G_{hg}^2 + \cdots + \otimes G_{hg}^e\right] \tag{18}$$

Level 3: The grey decision matrix is presented in Equation (19).

$$E = \begin{bmatrix} \otimes G_{11} & \otimes G_{12} & \dots & \otimes G_{1n} \\ \otimes G_{21} & \otimes G_{22} & \dots & \otimes G_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \otimes G_{m1} & \otimes G_{m2} & \dots & \otimes G_{mn} \end{bmatrix} \tag{19}$$

The essential function of alternative h in criterion g in Equation (18) is denoted by $\otimes G_{hg}$.

Level 4: a representation in (12) normalizes the grey decision matrix

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$$E^* = \begin{bmatrix} \otimes G_{11}{}^* & \otimes G_{12}{}^* & \dots & \otimes G_{1n}{}^* \\ \otimes G_{21}{}^* & \otimes G_{22}{}^* & \dots & \otimes G_{2n}{}^* \\ \vdots & \vdots & \vdots & \vdots \\ \otimes G_{m1}{}^* & \otimes G_{m2}{}^* & \dots & \otimes G_{mn}{}^* \end{bmatrix} \quad (20)$$

Equation (21) is a normalization method once the criteria are of the benefit attribute.

$$G^*{}_{hg} = \left[\frac{\underline{G}_{hg}}{G_g^{max}}, \frac{\overline{G}_{hg}}{G_g^{max}}\right] \; Where \; G_g^{max} = max_{1 \le g \le m}\left\{ \overline{G}_{hg} \right\} \quad (21)$$

Equation (22) is used for normalization if the criterion is a cost attribute.

$$G^*{}_{hg} = \left[\frac{G_g^{min}}{\overline{G}_{hg}}, \frac{G_g^{min}}{\underline{G}_{hg}}\right] \; Where \; G_g^{min} = min_{1 \le g \le m}\left\{ \underline{G}_{hg} \right\} \quad (22)$$

When the normalization process is performed, the values of the grey matrix range between [0, 1].

Level 5: A weighted normalized grey decision matrix is then established, as presented in Equation (23).

$$X = \begin{bmatrix} \otimes X_{11} & \otimes X_{12} & \dots & \otimes X_{1n} \\ \otimes X_{21} & \otimes X_{22} & \dots & \otimes X_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \otimes X_{m1} & \otimes X_{m2} & \dots & \otimes X_{mn} \end{bmatrix} Where \; \otimes X_{hg} = \otimes G_{hg}^* \times \otimes w_g \quad (23)$$

Level 6: the computation of the ideal's solution's values is negative and positive, computed via equations (24) and (25).

$$S^{max} = \left\{\left[max_{1 \le g \le m} \underline{X}_{\,h1}, max_{1 \le g \le m} \overline{X}_{\,h1}\right], \left[max_{1 \le g \le m} \underline{X}_{\,h2}, max_{1 \le g \le m} \overline{X}_{\,h2}\right], \dots, \left[max_{1 \le g \le m} \underline{X}_{\,hn}, max_{1 \le g \le m} \overline{X}_{\,hn}\right]\right\} \quad (24)$$

$$S^{min} = \left\{\left[min_{1 \le g \le m} X_{\,h1}, min_{1 \le g \le m} \overline{X}_{\,h1}\right], \left[min_{1 \le g \le m} X_{\,h2}, min_{1 \le g \le m} \overline{X}_{\,h2}\right], \dots, \left[min_{1 \le g \le m} \underline{X}_{\,hn}, min_{1 \le g \le m} \overline{X}_{\,hn} \quad (25)$$

Level 7: Equation (26) shows the computation of the multitude of greyness between the perfect options and approaches.

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$$A\{S_h \leq S^{max}\} = \frac{1}{n}\sum_{g=1}^{n} A\{\otimes X_{hg} \leq \otimes G_g^{max}\} \tag{26}$$

Level 8: On the basis of the optimal values obtained in Step 7, an ascending ranking of alternatives is established, prioritizing those with the lowest degree of greyness.

5. Results and discussion

This study examines the relationships between unemployment, inflation, gross capital formation, exports of goods and services, total natural resources, and foreign direct investments, particularly in relation to renewable electricity output and CO_2 emissions. These relationships are evaluated on a scale from 0 to 1, where 0 indicates the weakest connections, as seen with the absolute GRG and SSGRG, and 1 represents the strongest correlations among the variables. The conventional range for Deng's GRG lies between 0.5 and 1, whereas both the absolute GRG and synthetic GRG fall within the 0-1 range.

Through the use of an analytical framework for evaluating the influence of goods and services exports on low-carbon development, many grey analysis metrics, including the absolute grey relational grade (GRG), Deng's GRG, and the second synthetic relational grade (SSRG), are employed. Table 3 shows that the correlation between exports of products and services and low-carbon development has a grey relational grade of 0.9540, whereas its correlation with renewable electricity output is 0.9648. This research suggests that industrial growth is more closely linked to renewable electricity output than to low-carbon development. Morocco's export strategy is increasingly aligned with low-carbon development, as it promotes renewable energy technologies and sustainable farming practices. The consumption of renewable energy is crucial for boosting economic growth and advancing sustainable development efforts. Conversely, dependence on nonrenewable energy continues to be a significant factor in CO2 emissions, posing challenges to achieving climate goals (Radmehr et al., 2021). Morocco intends to generate economic growth while decreasing emissions by utilizing its solar and wind potential, establishing itself as a regional leader in green technologies (Hakimi & Hamdi, 2016).

Conversely, a high weight value of 0.9851 was observed in the association between renewable electricity output and low-carbon development. Moreover, a lower weight value of 0.9779 was identified in the relationship between industrial growth and CO_2 emissions. When gross capital formation was analyzed with respect to other variables, the findings revealed a

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strong association with renewable electricity output, reaching a high value of approximately 0.9912. Investing in green infrastructure is crucial for driving both economic growth and environmental sustainability. This finding is consistent with research indicating that increased capital investment in renewable technology can accelerate the transition to a low-carbon economy, emphasizing the importance of smart capital allocation in promoting sustainable development (Topcu et al., 2020). In contrast, its association with CO_2 emissions was significantly lower, at 0.9342, highlighting a weaker relationship. However, increased capital formation, especially in the industrial and infrastructure sectors, may result in elevated CO_2 emissions due to the proliferation of energy-intensive operations. Redirecting these investments toward green technologies might alleviate this impact, fostering economic growth and reducing emissions (Shahbaz et al., 2019). Moreover, the relationship between CO_2 emissions and capital formation is significant, underscoring the necessity of adopting policies that promote the integration of cleaner technologies and sustainable practices to mitigate adverse environmental effects (Etokakpan et al., 2020).

Inflation is considered one of the more indirect effects of industrialization in the model. A high value of 0.9099 for the GRG, which is consistent across other indicators, demonstrates a strong association between inflation and CO_2 emissions. This finding aligns with insights from the literature review, which highlighted CO_2 emissions as a direct outcome of industrialization, further validated by the results of this analysis. Inflation contributes to lower emissions by reducing industrial output and energy usage. However, the magnitude of this impact is frequently moderate, as increased inflation can reduce economic activity but may not result in significant emission reductions without more severe inflationary pressures. In contrast, focused policy actions addressing energy efficiency and green investment are anticipated to be more effective in achieving significant CO2 reductions than depend solely on inflationary effects (Grolleau & Weber, 2024).

Natural resource rent is a crucial factor that is closely tied to industrial growth and significantly influences results. The AGRG and SSGRG had the highest weight values of 0.9819 and 0.7841, respectively, and their impact is evident across various indicators, particularly in relation to CO_2 emissions and renewable electricity output. Among these, CO_2 emissions demonstrate the strongest association with natural resource rent, whereas renewable electricity output follows closely as the second most associated variable. Natural resources have various effects on carbon emissions. In some circumstances, their abundance reduces pollution due to the availability of enormous reserves, yet in others, unsustainable natural resource

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exploitation contributes to environmental degradation. Furthermore, renewable energy sources greatly help reduce CO2 emissions, supporting a cleaner and more sustainable energy transition (Danish et al., 2019). The growth of industry has a considerable effect on how efficiently natural resources are used, particularly in sectors dominated by heavy industries, which frequently face challenges related to resource inefficiency, even with ongoing efforts to enhance and modernize their frameworks (Xu and Tan, 2020).

Unemployment emerged as a recent policy factor, showing a notable influence on renewable electricity output, with an AGRG of 0.7241 and an SSGRG of 0.6165, as presented in Table 3. However, the trend shifted slightly when DGRG was used, where the association with CO_2 emissions increased to 0.5242, surpassing the 0.5088 association with renewable electricity output. Renewable energy offers chances to reduce CO_2 emissions while creating new jobs. Furthermore, renewable energy production enhances overall output by lowering unemployment. This shows that investing in renewable energy can benefit both the environment and the economy (Saboori et al., 2022).

Table 3: Association between Industrial Growth and Low-carbon Transition

Industrial growth	**Green growth**	**Absolute GRG**	**Deng GRG**	**SSGRG**
Exports of goods and services	CO_2 emission	0.954	0.6782	0.8161
	Renewable Electricity Output	0.9648	0.6691	0.817
Foreign direct investment	CO_2 emission	0.9851	0.6152	0.8002
	Renewable Electricity Output	0.9779	0.6358	0.8069
Gross capital formation	CO_2 emission	0.9342	0.6871	0.8107
	Renewable Electricity Output	0.9912	0.6777	0.8344
Natural resource rents	CO_2 emission	0.7987	0.6084	0.7031
	Renewable Electricity Output	0.9819	0.5863	0.7841
Unemployment	CO_2 emission	0.7053	0.5242	0.6148
	Renewable Electricity Output	0.7241	0.5088	0.6165

where $i = 12$, $j = 6$, and outcome = v (S_i, D_j), whereas $i = 1,\ldots12$ and $j = 1, 2, 3, 4, 5,6$. Let S_1, S_2, S_3, and S_4 to S_{12} represent the relationships of exports of goods and services, foreign direct investments, gross capital formation, inflation, total natural resource rent, and

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unemployment with CO_2 emissions and renewable electricity output, respectively, as presented in Table 4. SSDGRA reports both the selection parameters and the selection processes. Furthermore, we developed a proposed model to perform a systematic review to quantify the influence of industrial growth characteristics on low-carbon development, as shown in Table 5.

Table 4: Goals, criteria, and parameters

Goal	Decision Parameters description
Association/Influence	Measuring Grey Relation (Association and Influence) between exports of goods and services, foreign direct investment, gross capital formation, inflation consumer prices, total natural resources rents, unemployment, and CO_2 emission, renewable electricity output within Morocco
Criteria/state of nature (D_j); j = 1, 2…,k	Exports of goods and services (D_1) Foreign Direct Investment (D_2) Gross capital Formation (D_3) Inflation of consumer prices (D_4) Total natural resources rents (D_5) Unemployment (D_6)
Alternative action parameters (S_i); i=1, 2,…,m	The grey relation observed stronger between the exports of goods and services and CO_2 emissions (S_1) The grey relation observed stronger between exports of goods and services and renewable electricity output (S_2) The grey relation observed stronger between foreign direct investment, and CO_2 emission (S_3) The grey relation observed stronger between foreign direct investment, and renewable electricity output (S_4) The grey relation observed stronger between gross capital formation and CO_2 emissions (S_5) The grey relation observed stronger between both gross capital formation and renewable electricity output (S_6) The grey relation observed stronger between inflation consumer prices and CO_2 emissions (S_7) The grey relation observed stronger between inflation consumer prices and renewable electricity output (S_8)

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	The grey relation was greater between total natural resources rents and CO_2 emission (S_9)
	The grey relation observed stronger between total natural resources rents and renewable electricity output (S_{10})
	The grey relation observed stronger between unemployment and CO_2 emissions (S_{11})
	The grey relation observed between unemployment and renewable electricity output (S_{12})

Table 5: Criteria action

Second Synthetic GRG	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}
D_1..D6	0.816	0.82	0.8	0.807	0.811	0.834	0.796	0.649	0.703	0.784	0.615	0.617

We utilized the approach described below, which has been utilized effectively in several investigations (Ikram et al., 2022; Sun et al., 2020). We optimize the function for CO_2 emissions and renewable electricity output, a criterion of maximin.

$$max\ S_i\left\{\min S_k\ v(S_p,D_k)\right\} = max\ S_p \begin{bmatrix} 0.8161 \\ 0.8002 \\ 0.8107 \\ 0.7963 \\ 0.7031 \\ 0.6148 \\ 0.8170 \\ 0.8069 \\ 0.8344 \\ 0.6485 \\ 0.7841 \\ 0.6165 \end{bmatrix} = (0.6148, \text{Unemployment on } CO_2 \text{ Emissions}), (0.8344, \text{Gross Capital Formation on Renewable Electricity Output})$$

The results demonstrate that the greatest impact detected was unemployment on CO_2 emissions and gross capital formation on renewable electricity output, which is gross capital formation, also known as gross domestic investment.

According to Saccone et al. (2022), expenditures encompass investments in the country's economic capital assets; adjustments to net domestic inventory levels; land improvements; and the acquisition of facilities, equipment, and technology. The fixed assets

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include the construction of roads, railways, and other infrastructure, such as schools, offices, hospitals, private residences, and commercial and industrial facilities. Inventory refers to items that businesses hold to address temporary or unexpected changes in production or sales, as well as ongoing work. Over the past 20 years, significant growth has been achieved with the development of various infrastructures. Concurrently, these projects have been closely linked with major renewable electricity production initiatives, particularly in the last 15 years, during which more than 10 billion dollars have been invested in the renewable energy sector.

5.1 Grey TOPSIS Results

In this study, grey TOPSIS is used to compute all the influencing factors influencing CO_2 emissions and renewable power generation in Morocco. Conservative (maximin) was used to determine which industrial growth factor contributed the most to CO_2 emissions and renewable power output. Among all industrial factors, gross capital formation has been shown to have the greatest impact on CO_2 emissions. In doing so, a crucial debate emerges about the specific variable that contributes the most to CO_2 emissions and increasing environmental pollution, as well as which variable affects Morocco's low-carbon transition process. Energy intensity is the extent to which industrial growth relies on energy consumption, quantified by the energy used per unit of output. This link is affected by other factors, such as labor productivity, technological progress, and energy costs. These components are crucial in assessing the efficiency of energy utilization in industrial production and can profoundly influence total emissions (Abbasi et al., 2021). Moreover, social, economic, and industrial factors significantly influence CO_2 emissions in any economy. It is imperative to understand the interactions among socioeconomic activities that contribute to human-caused CO_2 emissions to develop effective emission control strategies. The identification of this relationship can assist in the clarification of the influence that socioeconomic factors have on the production of carbon emissions (Alkasasbeh et al., 2023).

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In this part, we used grey TOPSIS to assess any level of concentration regarding the six indicators of industrial growth, such as goods and services exports, capital formation, inflation, unemployment, and total natural resource rent. I determined the weights of each variable via absolute GRG, Deng GRG, and SSGRG. Using linguistic characteristics, grey relational analysis converts a grey evaluation matrix into a grey number. The grey positive and negative ideal solutions are shown in the table below. The following table shows the computed and rated degrees of greyness between EOGS, TNRR, GCF, ICE and UNE emissions. The following ranking of the alternatives is based on the values produced by the possible level of greyness:

$$EOGS(D_1 \leq S^{max}) = 0{,}502 \tag{27}$$

$$FDI(D_2 \leq S^{max}) = 0.580 \tag{28}$$

$$GCF(D_3 \leq S^{max}) = 0.516 \tag{29}$$

$$ICP(D_4 \leq S^{max}) = 0.671 \tag{30}$$

$$TNRR(D_5 \leq S^{max}) = 0.610 \tag{31}$$

$$UNE(D_6 \leq S^{max}) = 0.675 \tag{32}$$

$$EOGS > GCF > FDI > TNRR > ICP > UNE \tag{33}$$

Table 6 shows the grey group TOPSIS positive and negative solution findings based on the methodology utilized in this investigation. The results of the grey group TOPSIS, according to the approach used in this investigation, are shown in Table 7. According to the results, foreign direct investment ranks second with a weight of 0.580, but exports of goods and services have emerged as the most important indicator of industrial growth, contributing the most to CO_2 emissions. The degree of greyness of all the industrial growth indicators is shown in Figure 4. When faced with uncertainty, grey group TOPSIS improves the precision of decision-making. For that reason, politicians, corporations, and governments can all benefit from the study's methodology, which aims to shift industrial exports toward more environmentally friendly production methods, thereby lowering CO_2 emissions.

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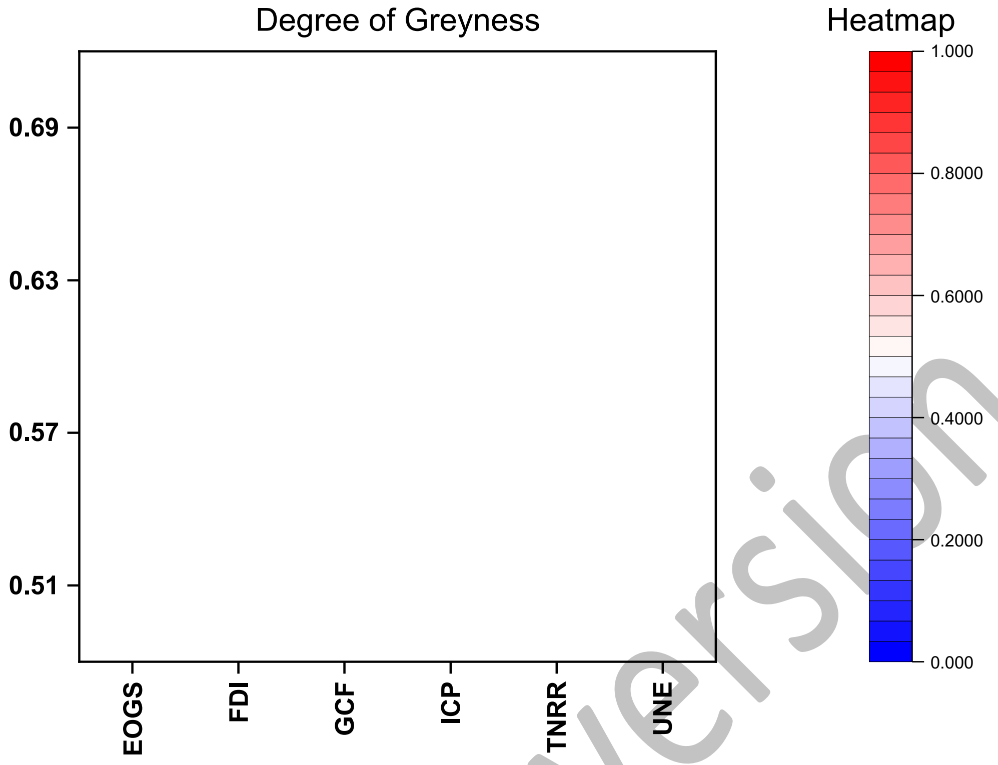

Figure 4: Degree of greyness heatmap of industrial growth variables

Table 6: Positive and negative ideal solutions

	$\boldsymbol{D_1}$	$\boldsymbol{D_2}$	$\boldsymbol{D_3}$	$\boldsymbol{D_4}$	$\boldsymbol{D_5}$	$\boldsymbol{D_6}$
S^{max}	[0.35,0.56]	[0.63,0.40]	[0.75,0.31]	[0.24,0.78]	[0.28,0.54]	[0.52,0.35]
S^{min}	[0.18,0.65]	[0.21 0.66]	[0.43,0.65]	[0.30,0.61]	[0.33,0.34]	[0.38,0.73]

Table 7: Grey TOPSIS-based ranking of industrial indicators influencing low-carbon transition

Codes	Variables	possibility degree of greyness	Ranking
EOGS	**Exports of goods and services**	0.502	1st
FDI	**Foreign Direct Investment**	0.580	3rd
GCF	**Gross capital Formation**	0.516	2nd
ICP	**Inflation consumer prices**	0.671	5th
TNRR	**Total natural resources rents**	0.610	4th
UNE	**Unemployment**	0.675	6th

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5.2. Sensitivity Analysis

This study employed a sensitivity analysis to evaluate the robustness and reliability of the results. The purpose of this analysis was to assess how changes in the weights of criteria impact the ranking of industrial indicators related to low-carbon transition. The final rankings of alternatives were assessed by developing five different scenarios in uncertain environments. The modified grey TOPSIS solutions for each case are displayed in Table 8. The prioritized rankings of alternatives of EOGS, FDI, GCF, ICP, TNRR, and UNE, resulting from the sensitivity analysis, are presented in Table 9. The analysis reveals that the hierarchy of possibilities is stable across all five situations, underscoring the stability of the study's conclusions.

Table 8: Results of grey TOPSIS solutions based on 5 scenarios

Codes	Original Case	Case 1	Case 2	Case 3	Case 4	Case 5
EOGS	[0.27,0.61]	[0.28,0.61]	[0.27,0.61]	[0.28,0.60]	[0.30,0.61]	[0.26,0.61]
FDI	[0.42,0.53]	[0.42,0.53]	[0.40,0.53]	[0.41,0.53]	[0.41,0.53]	[0.40,0.51]
GCF	[0.59,0.48]	[0.57,0.45]	[0.58,0.48]	[0.59,0.48]	[0.59,0.48]	[0.60,0.48]
ICP	[0.27,0.70]	[0.27,0.70]	[0.27,0.70]	[0.27,0.70]	[0.27,0.70]	[0.27,0.70]
TNRR	[0.31,0.44]	[0.32,0.41]	[0.32,0.44]	[0.31,0.41]	[0.31,0.44]	[0.31,0.44]
UNE	[0.45,0.54]	[0.44,0.50]	[0.45,0.54]	[0.45,0.54]	[0.45,0.54]	[0.46,0.55]

Table 9: Results of the sensitivity analysis

Codes	Current Case	Case 1	Case 2	Case 3	Case 4	Case 5
EOGS	**1**	1	1	1	1	1
FDI	**3**	3	3	3	3	3
GCF	**2**	2	2	2	2	2
ICP	**5**	5	5	5	5	5
TNRR	**4**	4	4	4	4	4
UNE	**6**	6	6	6	6	6

6. Conclusion and Policy Implications

The study addresses the research questions by utilizing GRA and Grey TOPSIS method to assess the determinants of industrial growth and their impact on low-carbon development in Morocco. The findings underscore the essential contributions of exports, gross capital formation, and foreign direct investment in fostering industrial advancement, while also noting the environmental repercussions, including heightened CO_2 emissions from manufacturing industries. The interrelatedness of these elements wherein exports, and capital formation propel

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economic expansion while exacerbating environmental issues, contrasts with FDI, which notably fosters renewable energy initiatives. The report advocates for enhancing investments in clean energy, implementing sustainable technology in industrial operations, and directing foreign direct investment into eco-friendly infrastructure to attain equitable and sustainable industrial growth.

The integration of the grey relational analysis (GRA) method with the grey TOPSIS methodology to rank the variables influencing industrial growth provides a clear understanding of the impact of each variable on low-carbon development. This approach offers a comprehensive overview of the analytical framework. The analysis identifies exports of goods and services as the most influential factor in industrial growth that impacts low-carbon development. This finding aligns with Morocco's substantial investment in infrastructure, which has attracted foreign companies, positioning the country as a key manufacturing and distribution hub. As a result, the surge in exports has led to increased CO_2 emissions, overshadowing the positive impacts of renewable electricity generation. Manufacturing firms, particularly those in heavy industries, are substantial energy consumers, often relying on coal, diesel, or gas power, which significantly contributes to CO_2 emissions.

Gross capital formation ranks second among the industrial variables influencing low-carbon transition in Morocco. GFCF, while not a complete measure of total investment, focuses on net additions to fixed assets, excluding financial assets and inventories. Within Morocco's economic structure, investments in fixed assets are crucial components of annual capital spending. Public investments in infrastructure play a pivotal role, although they are still outpaced by investments in the heavy manufacturing sector. The close proximity in influence between exports (0.502) and GCF (0.516) underscores the substantial impact of public investment on national development, even as it complements other forms of investment.

FDI emerges as the third most significant variable affecting low-carbon development, showing a strong correlation with other growth indicators. Unlike initial expectations that FDI would drive primarily exports, the analysis reveals that a considerable portion of foreign investment has been directed toward green sectors, such as renewable energy projects. This distinction highlights Morocco's strategic appeal for investments aimed at reducing CO_2 emissions, underscoring the unique context of low-carbon development in the country. The increasing threat of resource depletion and global warming has amplified concerns regarding the use of fossil fuels and energy resources. As economies and industrial activities expand, the corresponding rise in energy consumption has led to increased emissions of CO_2 and other

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greenhouse gases (GHGs), which are key drivers of climate change. The depletion of energy resources or environmental degradation could have severe consequences for Morocco's ecosystem and quality of life, emphasizing the need for sustainable energy practices.

This study offers significant insights for managers, governments, and policymakers. By assessing the impact of industrial growth variables on low carbon, the findings provide a nuanced understanding of Morocco's development trajectory since the launch of its industrial plans. The results indicate that investments in export-oriented manufacturing companies have substantially driven low-carbon development, supported by continuous investments in infrastructure that bolster the country's heavy industries, as evidenced by the gross capital foundation.

If current trends persist, with continued investment in nongreen industries and CO_2-emitting manufacturing, the long-term impacts could be detrimental to growth rates. To counter this, the Moroccan government should devise an action plan to attract more FDI, possibly through tax incentives and regulatory adjustments. Existing tax frameworks could be adapted to support carbon taxation and encourage green practices within manufacturing. Public capital investments have the potential to increase productivity by improving both the resource availability and the efficiency of existing resources. For example, investments in transportation infrastructure such as roads can reduce the overall cost of production for private companies, increasing their energy efficiency. However, the quality and maintenance of infrastructure are as critical as their existence. A large body of evidence suggests that extensive infrastructure development has at times reduced capital productivity, influencing the exports of goods and services. This calls for a government focus on sustainable infrastructure development that minimizes CO_2 emissions.

From the perspective of businesses, companies should embrace green production practices. As global trends shift toward taxing CO_2-emitting products, particularly in regions such as the European Union, the return on investment (ROI) for transitioning to greener production methods is likely to become more favorable in the long run. Government support will be essential in facilitating this transition, helping companies meet new market standards and regulations.

This study has several limitations. The study reflects industrial growth via six indicators supported by the literature that have been shown to accurately capture industrial growth. However, given the wide range of potential factors impacting industrial expansion, other

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indicators not included in this analysis may play a role, although on a smaller scale, they may be related to low-carbon development factors. On the other hand, the literature has a limited representation of low-carbon development indicators, focusing mostly on CO_2 emissions and energy production from renewable sources. This reveals a research gap, implying that future studies should look at a larger range of indicators to better understand the dynamics of low-carbon development. Future studies may consider the more advanced integrated methodologies to adequately analyze the constantly changing relationships among variables adequately, considering the complexity inherent in sustainable development processes.

Competing Interests: The authors declare that they have no conflicts of interest.

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