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Charting Saudi Arabia's course to net zero emissions: The crucial role of energy efficiency

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Executive Summary

The evaluation of the role of energy efficiency in addressing climate change is paramount, given the concerns about the ongoing global warming. This study delves into the impact of energy efficiency on carbon intensity within Saudi Arabia' decarbonization and examines its potential contributions to the nation's ambitious net-zero emissions target. Analyzing a time series of data from 1971 to 2020 and employing a quantile regression model, our findings underscore the critical significance of energy efficiency in mitigating GHG emissions, emphasizing the necessity of harnessing this tool to expedite the decarbonization process. Notably, the model remains robust, even when accounting for variations in the proxy used to measure energy efficiency, affirming its effectiveness in combatting environmental degradation in Saudi Arabia. Furthermore, our findings reveal that energy efficiency exerts a more substantial influence on carbon intensity within the twenty-fifth to seventy-fifth quantiles, compared to the tenth and ninetieth quantiles. Recognizing these distinct effects across carbon intensity quantiles is imperative when shaping Saudi Arabia's decarbonization objectives. In an extension of our analysis, we project carbon intensity trends through 2060 under a scenario where energy efficiency experiences enhancement. The results indicate that energy efficiency improvements could contribute to up to one-fifth of Saudi Arabia's decarbonization efforts by 2060. The findings underscore the pivotal role of energy efficiency in fostering climate stability and crafting a more promising future.

Keywords: Energy Efficiency; Climate Change Mitigation; Carbon Intensity; Net-Zero Emissions; Saudi Arabia; Quantile Regression

1. Introduction

Considering the urgency of the global climate change, the need to save and optimize energy consumption has become exceedingly crucial, particulalry in oil-exporting countries. In fact, energy stands at the core of both developed and developing nations' economic growth and progress. Realizing a decarbonized future hinges on profound shifts in behavior and the adoption of technologies that promote considerate and efficient energy use (Belaïd et al., 2023).

The 2015 Paris Agreement, ratified by 193 countries, underscores the urgent necessity to enhance energy production processes and consumption efficiency. Its primary objective is to cap the global temperature increase below two degrees Celsius and strive to keep it below 1.5 degrees Celsius (UNFCCC 2023). The International Energy Agency (IEA) recently emphasized the need to expedite energy efficiency improvements. They suggest various measures such as enhancing insulation, accelerating the adoption of heat pumps, installing digital thermostats, assisting small businesses in boosting efficiency, and motivating individuals to reduce heating thermostat temperatures (Motherway et al. 2022). These international efforts underscore the growing significance of taking swift action on energy efficiency.

Consequently, the concept of energy efficiency is gaining momentum. Energy efficiency has evolved into a pivotal tool for curtailing greenhouse gas (GHG) emissions and attaining climate objectives (Filippini and Hunt 2015; Bakaloglou and Belaïd 2022; Belaïd 2023). Beyond environmental benefits, reducing energy consumption through efficiency measures enhances energy security, affordability, and relieves the burden on vulnerable populations (Belaïd, 2018; Belaïd 2022 a, b; Belaïd and Flambard, 2023). As nations prioritize energy efficiency, they can reduce the energy required to generate a given level of economic output, leading to lower carbon intensity, reduced energy costs, and enhanced well-being for their citizens (Belaïd et al., 2020, 2021).

Despite the potential advantages of energy efficiency, more research is essential to comprehend its impact on carbon intensity and its contribution to achieving climate targets in Saudi Arabia. This study aims to bridge this knowledge gap by providing empirical evidence.

Saudi Arabia, the largest nation in the Middle East both in terms of land area and economy, has witnessed significant urbanization and population growth. Since 1990, it has embarked on structural reforms to encourage privatization, promote economic diversification, and stimulate investment. In 2016, Saudi Arabia unveiled the Vision 2030 plan, which seeks to enhance resource sustainability for future generations while maximizing the current well-being of its citizens. This includes a commitment to reduce the country's carbon footprint, aligning it with the Paris Agreement and its long-term environmental protection goals. In 2021, Saudi Arabia went a step further by announcing its commitment to achieve carbon neutrality, or an economy with net-zero GHG emissions, by 2060 (Vision 2030, Belaïd et al., 2022).

This study delves into how energy efficiency can contribute to Saudi Arabia's aspirations of carbon neutrality. We employ carbon intensity, a widely used macro-level energy efficiency indicator, as a proxy for environmental degradation (Filippini and Hunt 2015). Carbon intensity effectively balances a nation's economic growth and environmental sustainability by considering carbon emissions in relation to economic development. Our study involves two main stages: first, an empirical investigation into the impact of energy efficiency on carbon dioxide emissions, followed by a simulation estimating how energy efficiency can contribute to Saudi Arabia's net-zero targets by 2060. Specifically, we assess the effects of a 30% reduction in energy intensity by 2060, with a 15% reduction by 2030, on carbon intensity.

This study offers two significant contributions to the carbon and energy intensity relationship literature. First, from an empirical perspective, we draw from an extensive dataset spanning almost five decades, from 1971 to 2020. Our focus on Saudi Arabia, a rapidly growing economy committed to energy transition and the world's largest OPEC oil producer, provides unique insights. Second, from a methodological standpoint, we introduce an innovative quantile regression (QR) approach coupled with a simulation model to forecast the interplay of carbon and energy intensities. This method allows us to align our research with Saudi Arabia's objectives for improving energy efficiency.

To the best of our knowledge, this study is pioneering in measuring energy efficiency's role in achieving net-zero GHG emissions in Saudi Arabia. Saudi Arabia's proactive stance on energy efficiency improvements provides a valuable context for our empirical analysis. It highlights the pivotal role that energy efficiency may play in realizing net-zero emissions by 2060.

The subsequent sections of this article unfold as follows: Section 2 presents the data and methodology, Section 3 presents and discusses the key findings, and finally, Section 4 concludes and provides policy implications.

2. Data and Methodology

This study employs a rigorous and comprehensive methodology that combines empirical analysis and simulation techniques. This approach is designed to evaluate the influence of energy efficiency on carbon intensity and to provide forecasts regarding its potential contributions to Saudi Arabia's ambitious net-zero emissions objectives.

2.1. Data

To lay a robust foundation for the analysis, the study leverages an extensive longitudinal dataset that spans a significant period from 1971 to 2020. Covering nearly five decades of Saudi Arabia's energy landscape, this dataset enables a comprehensive and in-depth examination of the role of energy efficiency in the nation's journey toward decarbonization. **Table 1** lists detailed definitions of the variables and their sources.

Table 1. Definitions of the variables and their data sources.

Variable	Definition	Source
Carbon intensity	Measures the amount of carbon dioxide emitted per dollar of GDP. Calculated as the ratio between annual carbon dioxide emissions in megatonnes and annual GDP in 2015 US dollars.	Annual carbon dioxide emissions: WDI GDP: Enerdata
Energy intensity	Measures the amount of energy used to produce one unit of GDP. Calculated as the ratio between annual energy consumption (i.e., coal, gas, oil, electricity, heat, and biomass) in koe and annual GDP in 2015 US dollars.	Enerdata
Electricity intensity	Measures the amount of electricity used to produce one unit of GDP. Calculated as the ratio between annual electricity consumption by the residential, tertiary, and agricultural sectors in kilowatt hours and annual GDP in 2015 US dollars.	Electricity consumption: IEA GDP: Enerdata

Note: WDI stands for World Bank Development Indicator. Data collected in July 2022.

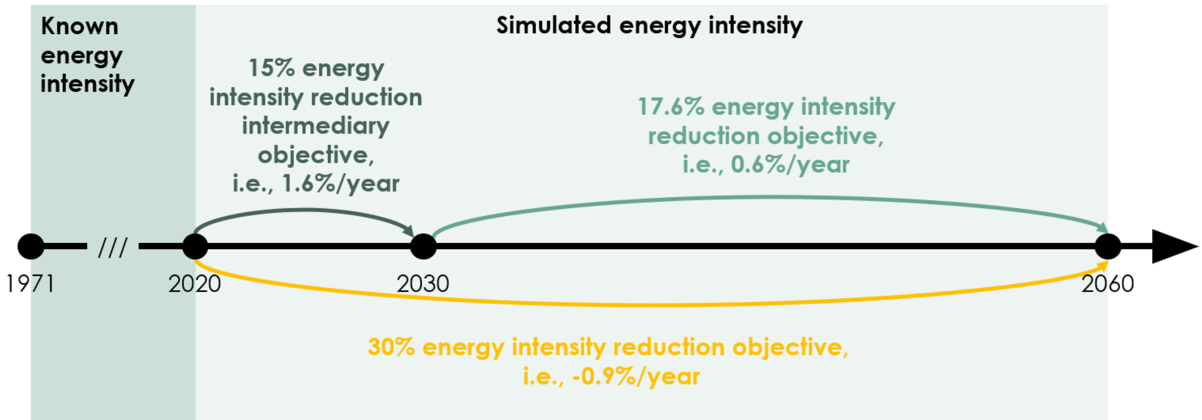
2.2. Quantile Regression

The empirical analysis is based on a Quantile Regression (QR). This approach goes beyond conventional regression techniques by dissecting the effects of energy efficiency across the entire spectrum of carbon intensity. Doing so provides a nuanced understanding of how energy efficiency impacts different segments of the carbon intensity scale.

2.3. Simulation Modeling

Based on the econometric analysis, the paper utilizes a simulation model to project future scenarios. This model considers the potential effects of a 30% reduction in energy intensity by 2060, with an interim target of achieving a 15% reduction by 2030. Through this modeling, the paper offers insights into how energy efficiency measures may shape Saudi Arabia's progress toward its net-zero emissions commitment. This forward-looking approach is instrumental in understanding the long-term implications of energy efficiency improvements in the context of Saudi Arabia's sustainability goals. The key hypotheses of the simulation are illustrated in Figure 1.

Figure 1: Simulation model assumptions



Note: ***Simulation of an energy efficiency improvement scenario:*** 30%-reduction of energy intensity attained in 2060, with an intermediary 15%-reduction objective in 2030. Source: Authors' elaboration

3. Empirical results and discussion

The OLS estimation of Model (1) reveals a robust and statistically significant relationship between energy intensity and carbon intensity. Specifically, a 1% decrease in energy intensity, signifying a more energy-efficient economy, results in a substantial reduction of 0.42% in carbon intensity. This finding aligns with prior research in countries like Brazil, India, China, South Africa, Turkey, and Iran, which also demonstrated the positive impact of improved energy efficiency on reducing ecological footprints and carbon emissions.

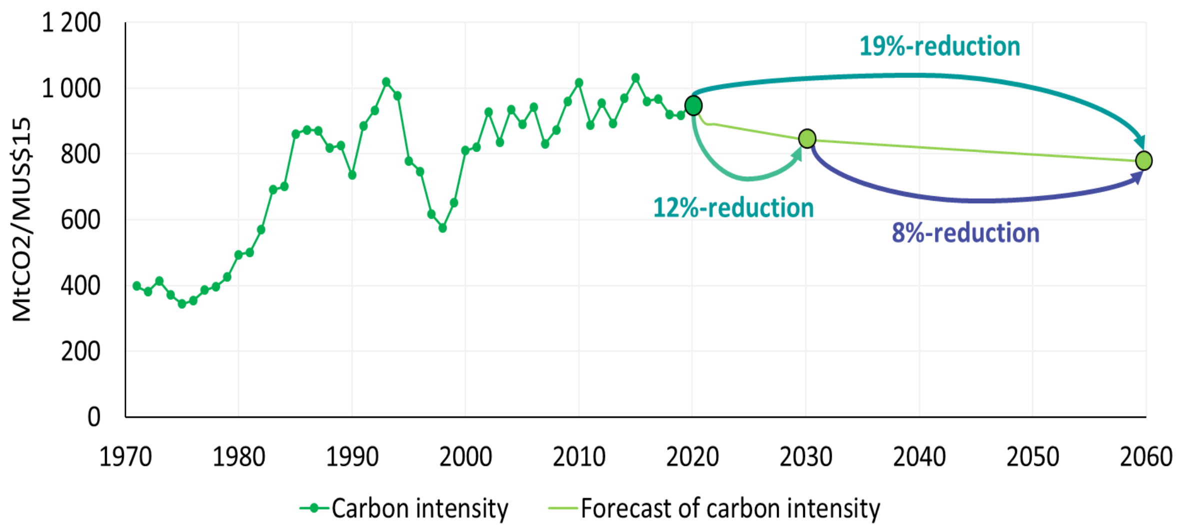
The QR approach provides a more nuanced understanding of the relationship between energy intensity and carbon intensity. It reveals that this impact is highly significant but varies across different quantiles. In lower quantiles of carbon emissions, where the environmental impact is minor, reducing energy intensity has a relatively smaller effect on carbon dioxide emissions. However, as carbon intensity increases, the reduction in energy intensity's impact becomes more pronounced, peaking at the twenty-fifth quantile, where a 1% decrease in energy intensity leads to a 0.45% reduction in carbon intensity. Beyond this point, the efficacy of energy efficiency in reducing carbon emissions diminishes. These findings emphasize that additional measures are required to achieve substantial reductions as carbon emissions increase.

Further analysis through quantile slope equality and symmetric quantile tests confirms the heterogeneous distribution of estimated quantile parameters. These tests indicate that the effect of energy intensity on carbon intensity varies significantly across quantiles, highlighting the suitability of quantile modeling in addressing the research question.

Building upon the QR estimations from Model (1), we utilize the parameter estimates obtained from the OLS estimation to simulate carbon intensity predictions based on energy intensity. These simulations consider the energy efficiency improvements and economic growth associated with Saudi Arabia's Vision 2030 program, which aims for a 30% reduction in carbon emissions by 2060, with an interim target of a 15% reduction by 2030.

Simulations paint an optimistic picture. If the target energy efficiency improvements are realized, it is forecasted that Saudi Arabia could achieve an 18.95% reduction in carbon intensity between 2021 and 2060. Furthermore, a 15% reduction in energy intensity by 2030 could lead to a 12.15% decrease in carbon emissions (Figure 2). These results are promising because they solely focus on energy efficiency improvements, proxied by energy intensity reductions. Therefore, a concerted effort to enhance energy efficiency can contribute significantly, accounting for nearly one-fifth of the government's carbon neutrality goal by 2060, when compared to 2020 emissions levels. The remaining four-fifths can be achieved by activating other measures, including developing hydrogen, diversifying energy production and consumption, and embracing greener energy sources.

Figure 2: Forecasted carbon intensity, 2021-2060.



Source: Authors' elaboration (Belaïd and Massié,2023)

These results underscore the substantial role of energy efficiency in the decarbonization process and highlight the importance of a multi-pronged approach to achieve Saudi Arabia's carbon neutrality objectives.

4.Conclusions

In Saudi Arabia, the journey towards a low-carbon energy transition is driven by two compelling forces: decarbonization policies and the development of low-carbon technologies. Since ratifying the 2015 Paris Agreement, Saudi Arabia has made significant strides in implementing policies to reduce its environmental impact. This transition towards a low-carbon economy is intrinsically linked to technological advancements facilitated by research and development. Drawing from the insights provided by the QR model and simulation approaches, we can discern several dimensions of energy efficiency policy, which hold the key to mitigating carbon emissions and achieving climate sustainability.

This study delves into the pivotal role of energy efficiency in Saudi Arabia's pursuit of carbon neutrality, a critical aspect of the nation's broader sustainability objectives that mandate a significant reduction in greenhouse gas emissions. Leveraging an innovative time-series QR approach, our analysis highlights the profound influence of energy efficiency in shaping the kingdom's future greenhouse gas emissions.

The findings put forth robust estimates that affirm the compelling argument that improvements in energy efficiency can yield significant reductions in carbon emissions, contributing substantially to climate change mitigation. Specifically, a 1% enhancement in energy efficiency correlates with a 0.45% reduction in carbon emissions within the lowest carbon emissions quartile. However, the QR model sheds light on the varied impacts of energy efficiency enhancements across different carbon emissions quartiles.

In forecasting future carbon intensity while considering Saudi Arabia's energy efficiency improvement goals, we find promising indications that the nation's ongoing efforts can set it on a trajectory toward carbon neutrality. Nevertheless, we must recognize the need to engage additional mechanisms, including adopting carbon capture and storage, and integrating green energy technologies to expedite the decarbonization process.

To sum up, our research underscores the pivotal role of energy efficiency as the linchpin of any comprehensive national climate mitigation strategy. It encourages policymakers to tailor strategies according to the specific challenges posed by varying emissions levels. Continuous monitoring, evaluation, and further research are imperative to steer Saudi Arabia towards its net-zero emissions aspirations.

Yet, this study only marks the beginning of a larger research journey. Future endeavors may include incorporating additional explanatory variables into empirical models, such as the shares of renewable, nuclear, and hydrogen energy. These factors represent potential determinants of carbon intensity and carbon dioxide emissions. Furthermore, by estimating the contributions of each aspect of Saudi Arabia's energy policy, future studies can simulate diverse scenarios beyond energy efficiency improvements, offering policymakers a detailed roadmap to achieve their objectives.

In conclusion, the quality of the findings remains intrinsically linked to data quality, the robustness of the model, and the study's assumptions. It is essential to recognize that these findings do not consider the potential impacts of unforeseen technological disruptions or other developments that may significantly augment energy efficiency. Hence, ongoing monitoring, evaluation, and policy adjustments remain pivotal to ensure that energy efficiency policies effectively achieve Saudi Arabia's ambitious net-zero emissions objectives.

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