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Correlation between Economic Growth and Carbon Emissions in the Context of the Transition to a Zero-Carbon Economy

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Abstract. *The energy sector is increasingly popular today and plays a vital role in our everyday lives. That is why, in this paper I am trying to analyze the existing literature and find a correlation between economic growth and carbon emissions. I utilized various scenarios for this research. The first direction is based on a study seeks to scrutinize earlier literature encompassing economic growth, energy consumption, and carbon emissions, encompassing both individual country analyses and multi-country studies spanning until the year 2019. The second one on usage of both growth and environmental functions to illustrate the efficacy of renewable energy in fostering economic growth and mitigating carbon emissions in the context of the 15 primary renewable energy-consuming nations. Exploring the impact of disaggregated energy consumption, technological innovations, and capital on economic output and CO2 emissions in India from 1990 to 2018 is the third direction, while the fourth has at its base the influence of Information and Communication Technology (ICT) on renewable energy consumption using panel data from 90 countries spanning the period 2000-2014. The fifth scenario is about the effects of climate change and technological innovation on economic growth, energy consumption, and carbon emissions by analyzing annual observations of diverse variables across Asian and European countries from 1996 to 2021. The final perspective investigates the factors influencing Energy Mix Diversification (EMD) by utilizing a panel sample encompassing seven major emerging (E7) economies—Brazil, China, India, Indonesia, Mexico, Russia, and Turkey—observed from 1995 to 2018.*

Keywords: Literature review, Carbon emissions, Economic growth, Renewable energy, Energy mix, Climate change

Introduction

In the last decade, the energy industry has proved its dynamism and importance, thus solidifying its position as a pillar of resistance in the global economy. Energy markets are characterized by significant uncertainties and risks, in comparison with those from other sectors.

This paper's scientific context comes from the sector's dynamic evolution over the past decade, its recent rapid growth, and the evergreen interest from an expanding base of investors. Also, an additional reason is the strategy adopted by the European Commission in 2015 - *Clean energy for all Europeans package* - which is in line with the global aspiration for a cleaner and more sustainable future, an action that led to the acceleration of growth in the sector renewable energy.

The main question that this paper should answer is if it is worth analyzing together the economic growth, the carbon emissions and their many variables. The economic shift towards a zero-carbon emissions economy is highly significant both locally and globally. The aim to limit the global average temperature increase to 1.5 to 2°C is endorsed by members of the United Nations Framework Convention on Climate Change, comprising world leaders, policymakers, stakeholders from various sectors, and the general public. The United Nations Framework Convention identifies six fundamental sectors vital for attaining this objective, including renewable energy, energy efficiency, urban infrastructure, carbon, gas management and agricultural land management.

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International energy markets are undergoing dynamic and complex change on several dimensions: technological, climatic, geopolitical and economic. Romania must anticipate and align itself with international market trends, as well as geopolitical realignments that influence strategic partnerships.

Thus, in the following literature review, there are six sub-chapters that revolve around the same subject: the correlation between economic growth and carbon emissions. Through energy survey, analysis about the utilization of renewable energy, the impact of energy resources, the influence of information and communication technology, interconnection between energy consumption, carbon emissions, climate change, and technological innovation and through the energy mix in developing economies, we will estimate if our research question will come to fruition.

Literature review

Energy Survey

In order to understand better the correlation between economic growth and carbon emissions, first we will delve into a survey regarding this subject.

Prior research has concentrated on both single-country and multi-country data analyses, as prominently emphasized in the current literature review.

The study's initial segment delves into the relationship between economic growth and carbon emissions, analyzing diverse methodologies regarding their connection. However, some empirical findings from multiple authors, reached different conclusions. Authors such as Selden and Song (1994), Galeotti et al. (2009), Saboori et al. (2012), Fujii and Managi (2013), Wang and Liu (2017), and He et al. (2017) have provided empirical evidence supporting the validity of the Environmental Kuznets Curve (EKC) hypothesis. Conversely, Holtz-Eakin and Selden (1995), Azam (2016), and Antonakakis et al. (2017) observed a consistently increasing curve, while Friedl and Getzner (2003) identified an N-shaped curve. Additionally, Agras and Chapman (1999) and Richmond and Kaufmann (2006) concluded that there is no significant relationship between economic growth and environmental pollutants.

The second area of research investigates the relationship between energy consumption and economic growth. Examples include works by Richmond and Kaufmann (2006), Soytas et al. (2007), Apergis and Payne (2010), Ozturk and Acaravci (2010), Arouri et al. (2012), Wang et al. (2011), Shahbaz et al. (2011), Saidi and Mbarek (2016), Adewuyi and Awodumi (2017), Shahbaz et al. (2017), Sarwar et al. (2017), Tiba and Omri (2017), and Sarwar et al. (2018).

The third segment scrutinizes the correlation between energy consumption and carbon emissions. Energy consumption is identified as a significant contributor to carbon emissions, whether through direct or indirect pathways. Numerous researchers have empirically explored the relationship between energy consumption and carbon emissions in both single and multiple countries. Some of these studies include works by Ang (2008), Jalil and Mahmud (2009), Zhang and Cheng (2009), Soytas and Sari (2009), Alkhathlan and Javid (2015), Ahmad et al. (2016), Saidi and Mbarek (2016), Tiba and Omri (2017), Adewuyi and Awodumi (2017).

On the one hand, it is recommended that authors categorize the literature into underdeveloped, developing, and developed countries, facilitating a more targeted discussion of the interplay of variables within these classifications. On the other hand, future studies should use suitable analytical methods that clearly will streamline the decision-making process. While previous research has utilized a multitude of indicators such as energy efficiency, energy intensity,

and renewable energy, this study focuses on a select few factors directly impacting economic growth and carbon emissions (Waheed, et al. 2019).

Analyzing how the utilization of renewable energy affects both carbon emissions and economic growth

Achieving sustainable development goals (SDGs) involves closing the gap between carbon emissions and economic development, presenting a key solution in this endeavor. This aspect of the research can be divided into three distinct categories of literature.

The first strand of literature concentrates on the impact of renewable energy on economic growth. For instance, within the context of the United States, Sari et al. (2008) illustrated that renewable energy plays a crucial role in boosting economic growth. However, a study by Menegaki (2011) focused on a panel of 27 European countries spanning from 1997 to 2007. Menegaki's research findings do not suggest a positive correlation between economic growth and renewable energy consumption. Instead, they offer evidence in favor of the neutrality hypothesis. This outcome is partially ascribed to the unequal and inadequate utilization of renewable energy sources in these nations.

The second research category centers on the effect of renewable energy on environmental quality, particularly its influence on CO2 emissions. Studies analyzing the connection between renewable energy consumption (REC) and CO2 emissions have generated mixed results. For example, Sadorsky (2009) presents two empirical models for a panel of emerging economies, revealing a positive and statistically significant relationship between per capita GDP growth and per capita REC. Over the long term, a 1% rise in GDP per capita correlates with approximately a 3.5% increase in per capita renewable energy consumption in these economies. Conversely, within European and Eurasian nations, Tiwari (2011) illustrates that non-renewable energy exerts a detrimental effect on GDP growth, resulting in heightened CO2 emissions. On the contrary, renewable energy has a positive impact on GDP growth rates.

The third section of literature provides a comprehensive overview of studies examining the relationship between renewable energy consumption (REC), economic growth, and environmental quality. For instance, Menyah and Wolde-Rufael (2010) investigated the relationship among CO2 emissions, nuclear and renewable energy consumption, and real GDP in the United States. Their Granger causality test results suggested a unidirectional link from nuclear energy to CO2 emissions, with no identified relationship between REC and CO2 emissions. In a study focusing on G7 countries, Aydin (2013) analyzed the relationship between CO2 emissions, REC, real GDP, and population density.

From a policy standpoint, energy policy should be crafted with a dual focus on economic development and environmental sustainability, considering the utilization of energy sources domestically. Future research endeavors could enhance this study by delving into policy thresholds and critical masses. This would involve investigating the points at which the integration of renewable energy could lead to increased economic growth without adversely affecting environmental quality (Saidi & Mbarek, 2016).

The impact of energy resources on both economic growth and carbon emissions

Limiting global warming to 1.5°C is crucial. The International Energy Agency (IEA) emphasizes the urgency of achieving carbon neutrality in the 21st century and has outlined a roadmap to achieve carbon neutrality (net zero emissions) by 2050. Aligned with the Paris Agreement on

climate change, the objective is to slash global carbon emissions by roughly 45% by 2030. The challenge varies among nations due to differences in the levels of emissions production.

However, there is a noticeable lack of research examining this relationship within the context of India. Parikh et al. (2009) delved into the pattern of CO2 emissions in India, specifically scrutinizing the influence of the country's economic development on its carbon emissions. Using Employing Social Accounting Matrix (SAM) analysis, their findings revealed that almost 57% of CO2 emissions in India stem from coal combustion.

Apergis et al. investigated in 2010, the connections between renewable resources, nuclear power sources, carbon emissions, and economic development across 19 nations. They utilized various panel econometric techniques, including LLC, IPS, Fisher-ADF, and Fisher-PP, alongside panel cointegration and VECM. Their empirical analysis indicated that heightened utilization of nuclear power is associated with a reduction in carbon emissions. Simultaneously, CO2 emissions were found to positively influence renewable energy consumption.

Alam et al. (2011) conducted an empirical study examining the correlation between power resource utilization, carbon emissions, and economic development in India from 1971 to 2006. Employing the innovation accounting method, they identified a bidirectional relationship between power usage and carbon emissions. In 2017, Wen-Cheng Lu utilized various panel econometric techniques, including cross-sectional dependence, Westerlund panel cointegration, and causality tests. Magazzino (2017a, 2017b) emphasized that economic growth does not have a significant impact on carbon emissions for a panel of 19 APEC nations over the period from 1960 to 2013.

Presently, the world is shifting towards embracing renewable energy resources for its energy needs. The technological differences between developed and developing countries have led to the implementation of distinct climate change agreements that apply universally, including to India.

The research findings verified the existence of a long-term correlation among energy consumption, technological innovations, economic growth, CO2 emissions, and capital. Regarding long-run elasticities, it was observed that both renewable power usage and technology positively influence the development of India's economy. In opposite way, non-renewable power consumption and capital were found to have a negative impact on the economy. (Hu et al., 2021).

Assessing the influence of information and communication technology on the consumption of renewable energy.

Numerous studies have scrutinized diverse factors affecting renewable energy consumption, yet the influence of information and communication technologies (ICT) on such consumption has been largely neglected. The objective of this study is to examine the effect of ICT on renewable energy consumption, analyzing panel data from 90 countries between 2000 and 2014.

ICT has the capacity to enhance enterprise performance, improve investment efficiency, and reduce costs (Manochehri, et al. 2012). Moreover, considering the spatial characteristics of technology and investment, it is probable that renewable energy consumption exhibits spatial dependency.

However, the existing literature has somewhat overlooked the role of ICT in renewable energy. ICT plays a crucial role in allowing economies to integrate renewable resources into their energy mix by eliminating technological, informational, and social barriers (Mirza, et al. 2009). The potential interaction channels between ICT and renewable energy consumption can be established in two ways.

Firstly, ICT may influence renewable energy consumption by impacting the economy. In a thriving economy, investment in renewable energy is likely to increase spontaneously. Presently, a substantial portion of global economic activities, trade, and foreign direct investment relies on information and communication technology (Salahuddin and Alam, 2016).

However, there is a widespread consensus that economic growth fundamentally hinges on productivity. As Cardona et al. have asserted, the substantial growth in productivity over the last two decades is largely attributed to information and communication technology. Nearly all industries experience increased productivity through the intensive utilization of ICT devices. ICT is regarded as a specific form of technological innovation, capable of enhancing productivity by facilitating technology transfer and serving as a means to further innovate production technology (Cardona, et al. 2013).

Secondly, this connection can be established through the political channel. Since the internet serves as the primary source of political news, the diversity and openness of information have significantly increased (Gimmler, 2001). In contemporary times, due to the abundance of real-time updated political information on social platforms, people are more likely to be exposed to various political events. Consequently, individuals have more opportunities to express political demands and opinions (Kushin, Yamamoto, 2010).

Currently, numerous academic articles demonstrate that ICT has played a significantly positive role in anti-corruption efforts (Hunady, 2019). Since a supportive political and institutional environment is vital for the deployment of renewable energy, ICT can aid in creating an economic and political climate conducive to renewable energy development.

The variations in results could be attributed to differences in the selection of indicators, research samples, and estimation methods. Importantly, the failure to consider spatial characteristics could also be a contributing factor (Liu, et al. 2018).

With the challenges posed by dwindling energy resources and environmental degradation, the judicious utilization of renewable energy is becoming increasingly imperative. Empirical findings suggest a positive and significant spatial spillover effect between countries in renewable energy consumption. The development of ICT has a precisely positive impact on renewable energy consumption. In other words, not only do local information and communication technologies influence renewable energy consumption, but the changes in renewable energy consumption in adjacent areas also positively contribute.

In essence, the consumption of renewable energy is influenced by three main factors: the direct impact of local determinants, the indirect influence of neighborhood determinants, and the feedback effect of variables dependent on the neighborhood. Drawing from the above findings, several notable recommendations can be offered for policymakers. Given the strong spatial dependence observed in renewable energy consumption, countries should enhance cooperation in the deployment of renewable energy to foster its development. Therefore, policymakers should prioritize and emphasize the development of ICT (Lv, et al. 2022).

The interconnection between energy consumption, carbon emissions, climate change, and technological innovation

The increasing dependence of industries on fossil fuels intensifies the frequency of extreme weather events, subsequently posing a risk to sustainable economic growth (Zhao, Gerety, Kuminoff, 2018). This, in turn, leads to economic losses manifested as decreased investment, labor productivity, and output (Magazzino, et al. 2021).

Although there has been a recent increase in the proportion of renewable energy, fossil energy remains the predominant global energy source. The extensive exploitation and utilization of fossil energy contribute to elevated carbon emissions, and the misalignment of resources further exacerbates carbon dioxide emissions (Xie, et al. 2023).

Thus, extreme climate conditions reciprocally affect energy consumption and carbon emissions. In particular, extremely hot summers and cold winters lead to increased demand for electricity and heating, consequently escalating energy consumption and resulting in higher carbon emissions (Shang, et al. 2022).

According to Solow's exogenous growth theory, external technological innovation can enhance productivity, fostering increased saving and investment, thereby leading to higher economic growth. However, the assumption that technological innovation is entirely exogenous does not align with reality. The theory of endogenous economic growth has challenged this assumption, asserting that technological innovation is endogenous and a result of knowledge and ideas (Solow, 1956) and (Romer, 1990).

Nevertheless, a significant portion of the existing literature lacks sample comparisons, often focusing solely on studying the relationship between technological innovation and economic growth either from the perspective of individual countries or the global scale. Consensus within existing literature suggests that advanced technology has the capacity to enhance energy efficiency, enabling the production of a certain output while consuming less energy (Ratner, et al. 2021).

Saudi et al.'s (2019) analysis indicates that Indonesia has the potential to decrease energy inefficiency by investing significantly in research and development (R&D), exporting technology, and employing various other strategies. Sun et al., discovered that technological innovation has a notably positive effect on enhancing energy efficiency across all categories of countries (Sun, et al. 2019). Simultaneously, stringent pollution control targets can contribute to the improvement of innovation capacity (Aqib, Zaman, 2023).

Based on the above findings, the following were discovered. The influence of technological innovation on economic growth exhibits notable regional variations. While technological innovation has markedly stimulated sustainable economic growth in European countries, the same impact is not observed to the same extent in Asian countries. Specifically, frequent extreme weather events, whether extreme cold or extreme heat, have spurred technological innovation in both Asian and European countries, with a more pronounced impact observed in European nations.

Conversely, the technological transfer of traditional industries from European countries has contributed to increased energy consumption and abnormal climate changes in Asian countries to some extent. Thirdly, a correlation exists between carbon emissions and temperature fluctuations, wherein rising temperatures during summer and declining temperatures during winter lead to increased energy consumption in both Asian and European countries. However, technological innovation has demonstrated a significant capacity to substantially reduce carbon emissions (Tao, et al. 2023).

Diversifying the energy mix in developing economies

Diversifying the energy mix (EMD) is acknowledged as a viable strategy for emerging economies to attain energy security objectives and fulfill net-zero carbon emissions targets by 2050. Therefore, the research from Nibedita and Irfan, investigates the factors influencing Energy Mix Diversification (EMD) by utilizing a panel sample from seven prominent emerging economies (E7), which include Brazil, China, India, Indonesia, Mexico, Russia, and Turkey. The observation period spans from 1995 to 2018.

Long-term forecasts indicate that energy efficiency and carbon emissions are key drivers of EMD, while technological progress, financial development, and globalization have negligible impacts. Nevertheless, in the short run, all variables, with the exception of economic growth, are identified as impediments to Energy Mix Diversification (EMD) (Nibedita & Irfan, 2024).

To achieve sustainability goals, the E7 economies are emphasizing cohesive policy frameworks that highlight the intersection of economic security and energy security. Moreover, they have implemented various initiatives aimed at sustaining a consistent trajectory of economic growth (Gyamfi, et al. 2021).

The E7 economies also wield significant influence on global carbon emissions, accounting for an estimated share of 47.9% in 2020 and 48.5% in 2021. Analyzing the statistics for these years suggests that the E7 economies face vulnerability to climate change concerns, attributable to the rapid escalation of energy consumption and carbon emissions.

The challenges faced by policymakers and governments include the imperative for E7 economies to institute structural reforms ensuring economic stability, encourage diversification of the energy mix, enhance the effectiveness of political institutions, steer clear of protectionist measures, foster the development of clean technologies, ensure the equitable distribution of globalization benefits across society, and formulate effective strategies to mitigate global carbon emissions (Nibedita & Irfan, 2021).

The findings of this research are groundbreaking, revealing a cointegrating relationship among crucial variables such as GDP, GDP squared, energy diversification, energy efficiency, technological progress, financial development, globalization, and carbon emissions. These results underscore a synergy between the two dimensions of energy security. Moreover, the inverse relationship between technological progress and energy diversification suggests a rebound effect of technological progress in E7 economies. Carbon emissions facilitate the progression of energy diversification, whereas financial development and globalization impede energy diversification in these economies. Specifically, energy efficiency and carbon emissions are identified as catalysts for energy mix diversification in E7 economies (Nibedita & Irfan, 2024).

Conclusions

In this study, my objective was to investigate and analyze the correlation between economic growth and carbon emissions within the framework of transitioning towards a zero-carbon economy. I used six references from the specialized literature that are tackling the same subject but from different perspectives.

The conclusion is that there is a positive correlation between the said elements because historically, as economies grow, there has been an associated increase in carbon emissions. This underscores the challenge of achieving economic prosperity while simultaneously addressing environmental concerns. Also, this includes promoting clean energy sources, implementing energy efficiency measures, and embracing environmentally friendly technologies.

The implementation of regulations, incentives for green technologies, and international cooperation to curb carbon emissions while supporting economic growth together with investments in green technologies and innovation are critical for achieving a more sustainable pattern of economic growth. Although it is extensive and constantly evolving, the specific literature is still far from reaching a conclusion on the subject studied.

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