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The Role of Natural Resources, Electricity Production, Economic Globalization, and R&D in CO_2 Neutrality: An Empirical Investigation for Kuwait

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ABSTRACT

At the 27th conference of parties in Egypt, Kuwait declared the environmental agenda of turning carbon neutrality by 2050, and many nations have started progressing towards carbon neutral agendas. Environmental research and development are essential factors in achieving these goals. This paper examines the relationship between natural resources, R&D, electricity production, economic globalization, and CO_2 emissions in Kuwait from 1975 to 2020. We employed unit-root tests to verify the integrative properties of the variables. Additionally, the FARDL method was used to analyze the relationship between the variables. The Fourier Toda-Yamamoto causality test is applied to explore the causal links between natural resources, economic globalization, electricity production, R&D, and CO_2 emissions. The empirical findings reveal that these variables are cointegrated and imply long-run relationships. Moreover, R&D expenditures reduce CO_2 emissions, while natural resources, electricity production, and economic globalization increase CO_2 emissions. Based on the empirical results, this study suggests attaining the targets of SDG-07 (clean and affordable energy), SDG-09 (R&D, innovations), and SDG-13 (climate change).

Keywords: Natural Resources, Electricity Production, CO_2 Emissions, Economic Globalization, FARDL, Kuwait
JEL Classifications: Q00, Q01 Q4, Q5

1. INTRODUCTION

Environmental degradation has garnered significant attention in both the academic and policy spheres for several years. climate change is among the foremost concerns, and global warming is recognized as our era's paramount ecological challenge. Besides the surge in extreme weather conditions, which amplifies storms and alters ocean currents, climate change disrupts rainfall patterns and elevates sea levels. These transformations have been noted to have adverse impacts on environments, human well-being, and biodiversity. Nevertheless, mitigating carbon emissions, promoting financial development, and ensuring global sustainability necessitate a comprehensive understanding of the interconnections among electricity production, economic globalization, natural resources, research and development, and environmental footprint.

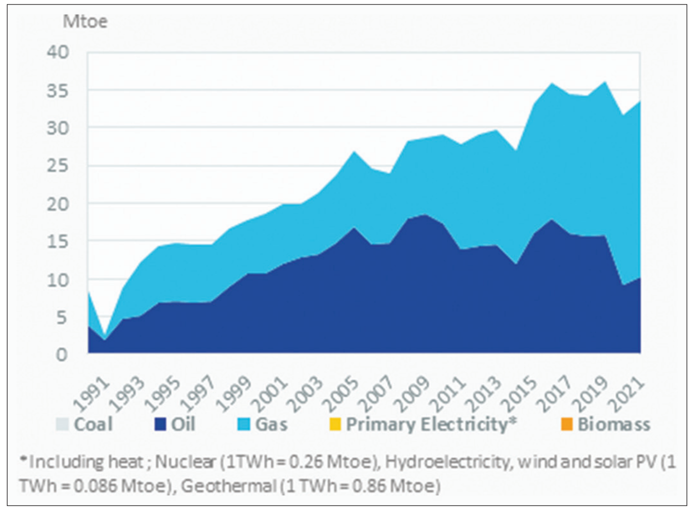
At the recent United Nations (UN) Climate Change Conference, also known as COP-27, held in Sharm El-Sheikh (Egypt), global leaders discussed several problems related to global warming and environmental pollution. A key focus of the conference was consolidating previous achievements and emphasizing the need to enhance all nations' green transformation capacities. In alignment with 7 and 13 of Sustainable Development Goals (SDGs), leaders explored ways to mitigate global heating through enhanced worldwide action plans (Uche et al., 2023). At the 2022 COP-27 Summit in Egypt, Kuwait pledged to realize net-zero greenhouse gas (GHG) emissions by 2050. This pledge is a component of the country's circular economy plan. As Kuwait 2035 strongly focuses on economic diversification, the banking industry is anticipated to play a substantial role in funding development projects that support clean technological innovation, renewable energy initiatives, and alternative energy. Acknowledging the need for a revised energy strategy, the government is improving energy efficiency in three ways: By putting national energy efficiency plans into action, raising public awareness of cleaner energy use, and cutting subsidies. Kuwait also intends to open a facility that encourages recycling and lowers carbon footprints. As part of its shift to sustainable energy, the nation is also looking into the generation of blue hydrogen from natural gas and petroleum. Kuwait enacted legislation in 2016 to raise the cost of water and electricity to promote prudent use. By using its plentiful solar and wind resources, Kuwait wants to raise the percentage of renewable sources in its electricity generation mix from 1% to 15% by 2030.

In the 2022 Egypt Agreements, global leaders recognized that technologies, innovations, and creating sustainable policies are a substantial challenge that requires careful consideration of financial and environmental factors (Saqib et al., 2023). In addition, West-Asian County is home to a couple of high-pollution developed nations, ranked fifteenth among the top CO_2-producing countries in the world (Review of World Population, 2023). Coal-related carbon pollutions still account for the largest resource of fossil fuel-related CO_2 emissions, and worldwide coal consumption is predicted to drive worldwide carbon pollution to 33.0 GTs carbon dioxide emissions in 2021 (Global Energy Review, 2021). As human society grows, GHG emissions impact food, lives, and other sectors, impeding socioeconomic activity and citizens' quality of life. Numerous research works have demonstrated that elevated CO_2 emissions have a major role in this issue (Pachiyappan et al., 2021; Abbasi et al., 2021; Dogan et al., 2020; Du et al., 2019). Natural resource extraction is unrelenting, and social inequality is growing due to environmental deregulation and resource exploitation (Nguyen-Van-Quoc et al., 2023).

As shown in Figure 1, Kuwait's energy consumption per capita has been very high in the last decades, fluctuating around 7.6 toes since 2020, placing the country among the world's top ten. Electricity consumption has also been significant, fluctuating around 15 MWh per capita since 2015, ranking in the world's top 10. Total energy use raised by 6% in 2021, following a 12% drop in 2020. Between 2014 and 2016, energy consumption increased sharply and then stabilized at around 36 Mtoe until 2019. Before that, from 2008 to 2013, it remained relatively stable at around 28 Mtoe.

Researchers have examined climate issues linked to the growing amount of pollution that is impacting the global economy in great detail since 1990 (Al-Mutairi et al., 2017). The key source of CO_2 emissions is the burning of fossil fuels. Kuwait's economy consumed an estimated 1.6 quadrillion British thermal units (quads) of primary energies in 2021, up from 1.5 quads in 2020, after the nation began to recover from the effects of the COVID-19 pandemic. We expect energy consumption to continue growing in 2022 as the economy strengthens and as higher oil production requires more energy consumption in the oil industry. Natural gas and oil accounted for virtually all of Kuwait's main energy use, and coal and renewable energy comprised a fraction of consumption. The shares of natural gas in Kuwait's consumption of energy usage increased from 32% in 2009 to 65% in 2021 because natural gas displaced some oil in the electric power and industrial sectors. Kuwait is regarded as one of the countries that emit the highest amount of CO_2 per capita worldwide (Al-Mullai and Foon Tang, 2013). The recent rise in energy consumption, particularly in the need for electricity, has resulted in substantial environmental issues, particularly concerning carbon dioxide emissions (Paraschiv et al., 2015; Lean and Smyth, 2010).

Figure 1: Kuwait's total primary energy consumption



Source: US Energy Information Administration

Against this backdrop, this study investigates the impacts of natural resources, economic globalization, electricity production, and Research & Development (R&D) expenditure on CO_2-related environmental pollution in Kuwait, using a quarterly dataset from 1975q1 to 2020q4. While earlier research attempted to evaluate the effects of these factors on Kuwait's CO_2 emissions, this study seeks to address specific gaps in the literature review. Most prior studies relied on a single indicator to represent environmental quality, such as CO_2 emissions or environmental footprints. This study attempts to investigate a more comprehensive analysis by considering multiple influencing factors simultaneously. However, this paper examines the impacts of electricity production, economic globalization, natural resources, and R&D on the ecological footprint, aiming for carbon neutrality by reducing emissions to zero. The roles of natural resources and environmentally related R&D are crucial and cannot be overlooked. Thus, to analyze their influence on Kuwait's attainment of carbon neutrality from 1975 to 2020, the research includes these two as controlled variables. Moreover, the Fourier Auto-Regressive Distributed Lags (FARDL) approach is utilized to precisely capture these variables' impacts. The findings of this study will provide valuable insights for policymakers in Kuwait.

The rest of the paper is organized as follows: Section 2 presents the relevant empirical literature. Section 3 discusses the data and econometric methods. Section 4 shows empirical findings. Finally, Section 5 concludes by offering policy recommendations.

2. LITERATURE REVIEW

The rapid increase in carbon emissions worldwide has garnered significant attention from researchers and policymakers, prompting urgent actions to attain an environment of carbon neutrality. Extensive literature has explored various factors and their effect on attaining an economy without emissions. Nevertheless, this research specifically focuses on the role of R&D related to natural resources and the environment and its impact on carbon neutrality. Most research studies rely on a single metric to gauge environmental quality. While environmental footprint can arise from various warming, this research specifically centers on carbon emissions related to environmental footprint. Consequently, the literature review has been organized into two sub-sections, which systematically outline conclusions presented in prior studies.

2.1. Natural Resources and Ecological Quality

Natural resources play an important role in national development; nevertheless, they can also contribute to ecological damage. The relationship between natural resources and pollution has crucial ecological implications. Although this area has not been extensively examined, the existing literature presents notable findings. Agboola et al. (2021) suggested that over-reliance on natural resources impacts ecological degradation in Saudi Arabia. Liu et al. (2022) employed the Bootstrap Causality method and found that the effect of natural resources on environmental degradation varies in the short- and long-run.

Moreover, many researchers have investigated various environmental quality determinants. For example, using CO_2 as a proxy for ecological degradation, Danish et al. (2019) scrutinized the influence of abundant natural resources on the environmental footprint in Brazil, Russia, India, China, and South Africa (BRICS) countries. The results reveal that the abundant natural resources mitigate the environmental footprint in Russia but increase it in India. Furthermore, Luo et al. (2023) explored the effect of natural resources on the environmental quality of higher-income, middle-income, and lower-income nations. Applying the Mean Group (MG) regression method, the findings evidence the cointegration between the variables and the validity of the Environmental Kuznets Curve (EKC) hypothesis. Additionally, natural resource rents are helping to mitigate CO_2 emissions in oil-exporting countries. Similarly, Lei et al. (2022) assessed the association between natural resources and environmental footprint in G-20 nations. Using the Cross-Section ARDL (CS-ARDL) method, the study suggests that natural resources raise the environmental footprint. Ahmad et al. (2020) inspected the influence of natural resources on the ecological footprint in the US. The results recommended that natural resource abundance decreases the country's environmental footprint. Besides, the unidirectional causality runs from natural resources to environmental footprint. Alvarado et al. (2021) studied the effect of natural resources on environmental footprint in Latin America. The findings recommend that natural resources have a significantly positive impact on the environmental footprint, indicating that excessive reliance on natural resources deteriorates the environmental quality.

In contrast to these findings, Pu et al. (2024) analyzed the determinants of environmental degradation in BRICS nations. The study revealed that natural resource rent negatively impacts the environmental footprint. Additionally, the study confirmed an inverted U-shaped linkage between natural resources and environmental footprint, supporting the EKC hypotheses.

2.2. Research and Development and Environmental Quality

Recently, many researchers attempted to explore the relationship between R&D along with the other macroeconomic variables on environmental pollution (Pata et al., 2023; Ahmad et al., 2023; Shabbir Alam et al., 2023; Wang et al., 2021; Umar et al., 2021; Ganda, 2019). These studies highlighted the positive influence of R&D on the achievement of carbon neutrality by referring to different channels, such as economics and technology. Khan et al. (2019) discussed the detrimental influence of R&D in achieving the carbon neutrality target.

Moreover, Zhu et al. (2024) observed the link between R&D and CO_2 emissions in BRICS nations. The study used an extension of the Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) methodology and the CS-ARDL technique. Alam and Hossain (2024) investigated the influence of R&D and green energies on carbon emissions in China, finding a significant connection between R&D and environmental pollution both in the short- and long-run.

In addition, Bai et al. (2020) and Feng et al. (2009) demonstrated a significantly negative link between green technology and ecological pollution, concluding that technological innovations bring energy-efficient technologies that contribute less to ecological pollution. Weber and Neuhoff (2010) examined the relationship among technological development, sources of renewable energies, and environmental degradation, showing that renewable energy sources and technological advancements significantly reduce ecological pollution, ultimately enhancing environmental quality. Many researchers have suggested the positive influence of technological R&D advancement in lowering CO_2 emissions or enhancing ecological quality (Song et al., 2019; Miao et al., 2017; Lee and Min, 2015; Zhao et al., 2015). For instance, Nikzad and Sedigh (2017) examined the influence of R&D in technological innovation on environmental security, highlighting that R&D in green innovation is efficient for ecological quality. Further research by Vona and Patriarca (2011) and Herring and Roy (2007) studied a threshold effect of income level on the influence of green innovations on environmental pollution. The carbon abatement effect of green innovations significantly differs below and above the threshold values. Ulussever et al. (2024) determined that in high-emission nations like the Gulf Cooperation Council (GCC) members, India, and China, technological innovation improves the environment.

2.3. Economic Globalization, Electricity Production, and Environmental Quality

Several studies showed a positive significant impact of economic globalization and electricity consumption on the ecological footprint (Nepal et al., 2021; Odhiambo, 2021; Usman et al., 2020; Destek& Sarkodie, (2019); Kurniawan and Managi, 2018; Al-Mulali and Sheau-Ting, 2014). Ashraf et al. (2023) investigated the spatial effects of energy transition and economic globalization on environmental pollution in 75 Belt and Road initiative nations. The results suggest that natural gas consumption and economic globalization positively affect CO_2 emissions. Langnel and Amegavi (2020) explored the long- and short-run dynamics of electricity production, economic globalization, and CO_2 emissions in Ghana by applying the ARDL model. The outcomes suggest that electricity consumption significantly decreases environmental pollution, while economic globalization increases CO_2 emissions. Tillaguango et al. (2024) examined the causal link among oil prices, financial globalization, and carbon dioxide emissions in Latin American oil-producing nations. The outcomes revealed a bidirectional causal relationship between carbon emissions and oil consumption, as well as a unidirectional causality between CO_2 emissions and economic globalization. Moreover, Asongu et al. (2020) studied the nexus among electricity production, economic globalization, and carbon emissions in African economies. The results showed that electricity production has negative effects on carbon emissions, while economic globalization exerts a positive effect. Saint Akadiri et al. (2020) examined the nexus between globalization, electricity consumption, and carbon emissions in Turkey, noting that both electricity consumption and globalization affect environmental pollution in the long-run.

Furthermore, Shehzad et al. (2022) examined the link among electricity consumption, economic globalization, and environmental footprint in China from 1995: Q4 to 2017: Q4. The ARDL bound technique evidenced that while economic globalization significantly impacts carbon footprints, it has an insignificant effect on the overall environmental footprint (Li & Haneklaus; 2022b). Tariq et al. (2023) found that carbon emissions in India are caused by electricity usage, with a statistically significant increase in carbon emissions due to economic globalization. Lv and Xu (2018) discovered a negative association between economic globalization and ecological pollution in fifteen developing countries. González-Lorente et al. (2024) performed a time series analysis to gauge the impacts of electricity generation and economic globalization on ecological pollution in 45 European nations. The findings concluded that despite recent improvements in electricity generation and climate change, economic globalization continues to push environmental pollution. Khan and Ozturk (2021) investigated economic globalization's direct and indirect impacts within the EKC framework. The outcomes confirm the validity of the EKC and the presence of a U-shaped link between economic globalization and ecological pollution both in the short- and long-run.

No research focuses on natural resources, electricity production, economic globalization, and R&D in Kuwait. Given the vital role of economic globalization in Kuwait and the country's relevance as an oil exporter, the importance of the selected case study is clear. Hence, the study's findings can generate the necessary knowledge to provide policy recommendations for the Kuwaiti government.

3. DATA AND METHODOLOGY

3.1. Data

To examine the drivers of the environmental footprint in Kuwait, data from 1975 to 2020 is derived. The quadratic match-sum technique is applied, following Wang et al. (2022), to convert the yearly series into a quarterly format. This method, superior to other interpolation approaches, considers seasonality by minimizing dataset changes through the transitions from low to high occurrence. To prevent misspecification errors, the log transformation has been applied to all variables. Table 1 provides a detailed description of the variables used in this research, including their sources, measurement units, and additional information. In addition, Figure 2 presents the flowchart of the empirical strategy. The dependent variable, EF, denotes the composite index of carbon dioxide emissions related to environmental degradation, constructed using data on Kuwait's ecological footprint and biocapacity levels. Ecological footprint stands for the assessment of humanity's impact on the planet and its sustainability by comparing human consumption patterns with the Earth's capacity to regenerate resources and absorb waste. The environmental footprint encompasses several aspects of human activity, including energy consumption, food production, transportation, and waste generation, providing a comprehensive understanding of environmental impact. Biocapacity refers to the productivity of environmental assets, such as forest land, cropland, grazing land, fishing grounds, and built-up land. If left unharvested, these areas can also absorb garbage produced, particularly carbon emissions from burning fossil fuels.

The following describes the independent variables in the models: Kuwait's involvement in international trade, income payments, international debts, FDI, and other globalization-related activities is measured by the economic globalization (ECOG) index. Economic globalization is generally divided into trade and financial globalization. According to Gygli et al. (2019), this index gives high values to superior economic globalization and lower values to lower levels.

ELEP stands for the process of generating electricity power from several sources, such as fossil fuels (oil, coal, natural gas), nuclear energies, renewable sources (solar, wind, hydroelectric, geothermal), and other alternative technologies. Electricity production is a crucial component of modern society, powering homes, businesses, industries, transportation systems, and more. The diverse sources used for electricity production have different environmental impacts, costs, and levels of sustainability, making energy policy and infrastructure decisions significant for both economic and environmental reasons.

R&D involves scientific investigation and technological innovation aimed at mitigating, understanding, and adapting to the impacts of global climate change. R&D efforts on climate change seek to address urgent environmental challenges while fostering sustainable development and promoting the transition to a low-carbon economy. These endeavors play an important role in informing policy decisions, driving technological advancements,

Figure 2: Flowchart of the empirical methodology

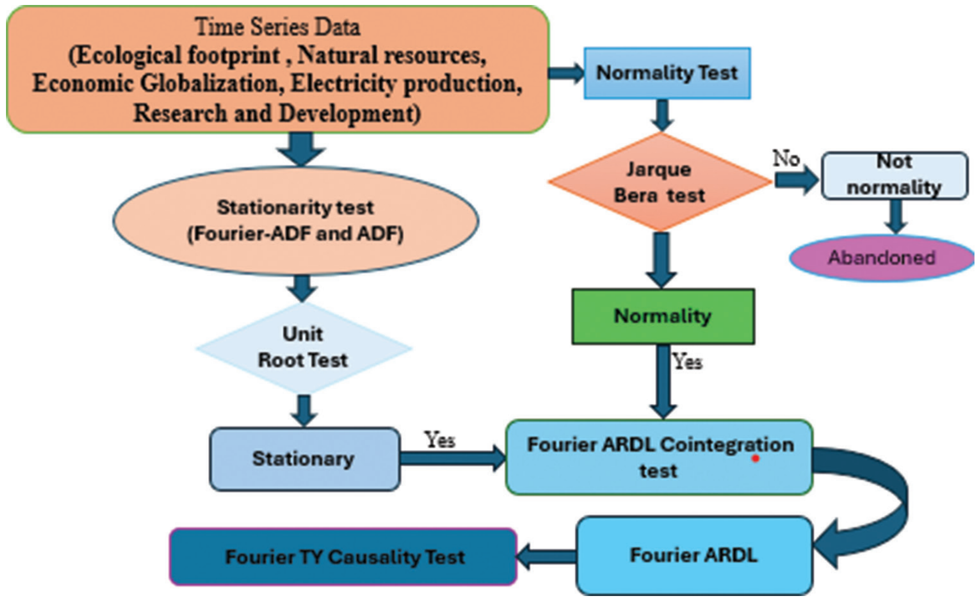


Table 1: Variables' description

Variable	Unit of measurement	Source
CO_2-related index of environmental footprint quality	Total global hectare	Global Footprint Network (2022), https://www.footprintnetwork.org/licenses/public-data-package-free/
Ecological footprint	Global hectares of land	GNF (2024), https://data.footprintnetwork.org
Economic Globalization	Economic globalization index (0-100)	Gygli et al. (2019)
Electricity production	% of total electricity production	WDI (2024), https://databank.worldbank.org/source/world-development-indicators
Research and development	Technicians in R&D (per million people)	
Natural resources	Natural resource rents (% of GDP)	

Source: Authors calculation

and facilitating international cooperation to address one of the most pressing issues of our era.

NR stands for natural resources and includes air, forests, wildlife, water, soil, minerals, and energy from renewable sources such as wind and sunlight. They provide raw materials for food, energy, and industry, as well as crucial ecosystem services like air and water purification, pollination, and climate regulation. However, the sustainable management of natural resources is crucial as overexploitation, pollution, and habitat destruction can lead to ecological degradation, loss of biodiversity, and adverse impacts on human well-being. Therefore, preserving and conserving natural resources is essential to ensure their availability for future generations and to maintain the health and balance of the earth's ecosystems.

The log model used in the study is:

$$lEF = \beta_0 + \beta_1 lECOG + \beta_2 lELEP + \beta_3 lR\&D + \beta_4 lNR + \varepsilon \quad (1)$$

Due to structural changes, traditional estimation methods can produce misleading results (Perron and Ng, 1996). To address this issue, this study applies the FADF and ADF tests to estimate the order of integration of the relevant variables.

We run the Fourier ADF test with breaks and the ADF test in equations (2)-(3), respectively, by reformulating these models into an error correction form and incorporating the augmentation component as described by Yaya et al. (2021):

$$\Delta Y_t = \mu + \beta t + \gamma_1 \sin\left(\frac{2\pi kt}{N}\right) + \gamma_2 \cos\left(\frac{2\pi kt}{N}\right) + (\rho - 1)Y_{t-1} + \sum_{i=1}^{p} ci\Delta Y_{t-1} + \varepsilon_t \quad (2)$$

$$\Delta Y_t = \mu + \beta t + \alpha DU_t + \varphi D(T_B)_t + (\rho - 1)Y_{t-1} + \sum_{i=1}^{p} ci\Delta Y_{t-1} + \varepsilon_t \quad (3)$$

where ρ is the lag-lengths for augmentation through the information criterion, and c indicates the slope of the augmented components. Becker et al. (2004) noted that choosing high frequencies can lead to random variations in parameters, whereas selecting lower frequencies might affect the validity of tests.

Following Furuoka (2017), a goodness of fit test using the F-statistics is performed. In the absence of structural breaks, the regression of the ADF model is constrained. However, The Fourier ADF model considers structural breaks. The spectral density function shifts to zero frequency during breaks or structural changes.

Banerjee et al. (2017) initially applied the FADL cointegration model. This approach accounts for unknown structure and structural break(s) when estimating cointegration. The outcomes from this approach are considered more effective than those from the Vector Error Correction Model (VECM). For long-run analysis, cumulative positive and negative shocks in the variables must be identified before detecting hidden cointegration. Fourier functions can detect structural changes, and no additional tests for structural changes are necessary with the Fourier-based ARDL method. The Fourier function can indicate structural changes in the model, as shown in eq. (4), which supports the argument of Kirikkaleli et al. (2023) that conventional ARDL approaches are not as resilient as Fourier-based ARDL approaches:

$$d(t)=\sum_{k=1}^{n} ak\sin\left(\frac{2\pi kt}{N}\right)+\sum_{k=1}^{n} bk\cos\left(\frac{2\pi kt}{N}\right) \quad (4)$$

where the Fourier ARDL method is assessed utilizing k-values ($5\geq k\geq 0$); $d(t)$ is deterministic terms; t stands for the trend, and T is the sample size; n is the number of frequencies. A selective value of single-frequency is utilized (Becker et al., 2006) as in eq. (5):

$$d(t)=\gamma_1\sin\left(\frac{2\pi kt}{N}\right)+\gamma_2\cos\left(\frac{2\pi kt}{N}\right) \quad (5)$$

Equation (6) depicts the Fourier ARDL approach applied in this study:

$$\begin{aligned}\Delta lEF_t &= \beta_0+\gamma_1\sin\left(\frac{2\pi kt}{N}\right)+\gamma_2\cos\left(\frac{2\pi kt}{N}\right)+\beta_1 lEF_{t-1}\\ &+\beta_2 lECOG_{t-1}+\beta_3 lELEP_{t-1}+\beta_4 lR\&D_{t-1}+\beta_5 lNR_{t-1}\\ &+\sum_{i=1}^{p-1}\phi i\Delta lEF_{t-1}+\sum_{i=1}^{p-1}\alpha i\Delta lECOG_{t-1}\\ &+\sum_{i=1}^{p-1}\varphi i\Delta lELEP_{t-1}+\sum_{i=1}^{p-1}\vartheta i\Delta lR\&D_{t-1}\\ &+\sum_{i=1}^{p-1}\theta i\Delta lNR_{t-1}+e_t\end{aligned} \quad (6)$$

Yilanci et al. (2019) used a sampling rate that minimized the sum of squared residuals and applied bootstrapping simulations. They also employed the Fourier Toda-Yamamoto test to analyze causal associations in time series data. These estimators use the Wald-modified (M-WALD) method to conduct causality assessments. In fact, the Granger causality method has issues with non-stationarity or different integration order across variables, which the M-WALD estimator overlooks (Wolde-Rufael, 2005). Alternatively, both smooth and gradual structural transitions may be considered in a causality analysis employing the Fourier Toda-Yamamoto approach, also known as the gradual shift causation test. When several structural breaks occur, the Fourier Toda-Yamamoto causality analysis is considered more trustworthy than the conventional Toda-Yamamoto tests.

According to Perron (1994), ADF tests tend to bias towards a false null. Before determining the integration order of the variables, the Brock-Dechert-Scheinkman (BDS) model by Broock et al. (1996) is applied to identify stochastic potential differences. It is used to consider various embedding dimensions, which range from two to six. The BDS test has several advantages over other methods (Gozbasi et al., 2014), like its ability to prevent model misspecification and reduce subjective judgment errors. It is a powerful tool for examining the stochastic characteristics of time series data. The baseline equation for the BDS test is as follows:

$$BDS_{mt}(\varepsilon)=T^{\frac{1}{2}}+\left[C_{mT}(\varepsilon)+C_{mT}(\varepsilon)^{m}\right]/\delta_{mT}(\varepsilon) \quad (7)$$

where T is the sample size, ε denotes the proximity co-efficient selected at random, and $\delta_{mT}(\varepsilon)$ is the standard deviation of the numerator of the statistics (Kocenda, 2001).

4. RESULTS AND DISCUSSION

The results of descriptive statistical analysis are shown in Table 2. The mean value of IEF, IECOG, IELEP, IR&D, and INR, are 20.58, 4.197, 3.058, 3.5895, and 3.743 respectively. All the factors of this study indicate an impressive level of standard deviation as 0.632, 0.069, 0.280, 0.308, and 0.311, for IEF, IECOG, IELEP, IR&D, and INR respectively. Moreover, The Jarque-Bera (JB) normality test indicates that all variables except R&D follow a Gaussian distribution. The descriptive characteristics of the factors allow us to move towards the FARDL and causality estimators of Fourier Toda-Yamamoto to study relationship between energy use, foreign direct investment, trade service, natural resources and environmental footprint in Kuwait.

The outcomes of the BDS non-linearity model, reported in Table 3, confirm that the time series dataset utilized in this investigation has non-linear patterns. Subsequently, the order of integration of the variables is confirmed by applying the ADF and PP tests.

Table 4 depicts the findings of these two tests. The results demonstrate that EF, ECOG, ELEP, and NR contain a unit root, and the series become stationarity at the first order difference, I(1). We provide the F-ADL cointegration results in Table 5 because the unit root test results allow us to investigate the possibility of cointegration among the variables. The t-test statistics for the model are higher than the critical levels, as indicated by the co-integration findings. This examination suggests cointegration using the Fourier method and indicates a long-run link between the variables. In the next phase, this study employs the Fourier ARDL

Table 2: Descriptive statistics

Variable	EF	ECOG	ELEP	R&D	NR
Mean	20.58	4.197	3.058	3.589	3.743
Median	20.56	9.067	3.060	3.645	3.738
Maximum	21.60	9.372	4.012	4.127	4.265
Minimum	19.42	7.606	2.365	2.981	2.598
Standard deviation	0.632	0.069	0.280	0.308	0.311
Skewness	−0.062	−2.155	−0.674	0.947	−1.032
Kurtosis	1.752	2.764	1.984	5.813	5.325
Jarque-Bera	12.007	18.516	8.191	2.664	18.544
P-value	0.0366**	0.002**	0.016**	0.263	0.000***

***and **signify the 1%, and 5%, significance level, respectively estimator to assess the impact of natural resources, electricity production, economic globalization, and research and development on the environmental footprint in Kuwait.

The long-run results of the FARDL model are indicated in Table 6. Regarding Table 6, the outcomes indicate a positive significant impact of natural resources on environmental footprint and emphasize that a long-run 1% rise in natural resources raises environmental footprint by 0.1857%. This result suggests that the rent-seeking effect of natural resources poses a long-run threat to the Kuwaiti environment, as indicated by the carbon-related effects. This is plausible because the revenues generated from natural resources can incentivize continued exploration and consumption, often disregarding ecological consequences. These findings regarding the positive contribution of natural resources to the ecological footprint are in line with Hassan et al. (2018), who disclose that natural resources drive environmental degradation in Pakistan. Nevertheless, this finding contradicts the outcomes of Zafar et al. (2019) for the US, Balsalobre-Lorente et al. (2018) for some EU nations, Ibrahim and Ajide (2021) for some BRICS economics, and Chen et al. (2024) for seven emerging countries.

Table 3: BDS test results

Dimension	BDS statistic	Standard error	z-statistic
EF			
2	0.1842***	0.0082	20.3265
3	0.3002***	0.0131	20.4376
4	0.3731***	0.0158	21.1515
5	0.4176***	0.0166	22.0051
6	0.4427***	0.0162	23.6885
ECOG			
2	0.1097***	0.0091	18.5788
3	0.1812***	0.0147	18.5277
4	0.2437***	0.0178	18.2320
5	0.2725***	0.0189	18.6766
6	0.2750***	0.0186	19.2855
ELEP			
2	0.0237***	0.0115	18.0627
3	0.0610***	0.0186	18.2797
4	0.0941***	0.0225	19.1742
5	0.1097***	0.0239	19.5877
6	0.1164***	0.0234	19.8586
R&D			
2	0.0798***	0.0106	16.4735
3	0.1160***	0.0171	20.7662
4	0.1192***	0.0206	22.7631
5	0.0992***	0.0218	22.9449
6	0.0654***	0.0213	23.0698
NR			
2	0.0689***	0.0093	17.3419
3	0.1267***	0.0151	18.0372
4	0.1476***	0.0184	18.1797
5	0.1446***	0.0195	20.5403
6	0.1341***	0.0191	22.9278

***signify the 1%, significance level, respectively

Similarly, the electricity production and economic globalization have a positive relationship with environmental footprint in long-run. A 1% increase in electricity production and economic globalization upsurge the level of environmental footprint with a coefficient's values of 0.1044% and 0.3941%, respectively, at a 1% level of significance, respectively. The results further support the hypothesis that raised renewable resources use in the energies sector, specifically in generation of electricity, a significantly reduction in environmental footprint is still far from reality. The economic globalization results in a significant increase in environmental footprint. A large volume of international trade, which can result from the expansion of production capacity, significantly increases the negative externality in the import sector and leads to a significant rise in the environmental footprint. This result corroborates the findings of Alvarez-Herranez (2017), who found the same relationship in the case of the USA, (Chandra Voumik and Ridwan, 2023) for the Argentina, (Voumik et al., 2023) for the Australia and (Zaman et al., 2021) for BRIC countries.

According to the findings, the coefficient of research and development is a negative impact on environmental footprint. a 1% upsurge in R&D decreases the environmental footprint by −0.0653 over long-term. The outcomes show that conflicts between the economic globalization and the environment can be mitigated through the adoption of research and development. In the Kuwait, implementing measures to prevent environmental degradation, promoting electric vehicles, transitioning to decarbonized transportation, and deploying a variety of

Table 4: Unit root test results

ADF unit root test				
Variable	Levels	Probability value	First differences	Probability value
EF	−2.3465	0.9945	−3.4581**	0.006
ECOG	−3.7435	0.4362	−4.7517***	0.001
ELEP	−2.3041	0.453	−4.4539***	0.012
R&D	−3.0092	0.1727	−4.9228*	0.01
NR	−2.3465	0.5331	−4.2203**	0.003

PP unit root test				
Variable	Levels		First differences	
	Test statistic	P-value	Test statistic	P-value
EF	−11.1381	0.3291	−19.101	0.001***
ECOG	−12.808	0.2593	−25.593	0.0113*
ELEP	−16.017	0.0839	−24.245	0.001***
R&D	−18.002	0.0747	−23.798	0.018*
NR	−12.413	0.358	−21.723	0.001***

***and **signify the 1%, and 5%, significance level, respectively renewable energy technologies are crucial steps. Accelerating patent approvals for environmental technologies can support the country's green strategy, addressing longstanding concerns regarding industrial transformation. Moreover, patents for innovative solutions play a crucial role in mitigating ecological footprint, thus contributing to the US' achievement of its Sustainable Development Goals (SDGs). By fostering technological advancements and promoting sustainable practices, these patents help address environmental challenges and support long-term sustainability objectives. Our study findings are similar with (Bergougui, 2024; Saqib and Dincă, 2024; Uche et al., 2024; Li and Haneklaus, 2022a; Ahmed et al., 2020; Awan et al., 2022; Danish et al., 2020; Kurniawan and Managi, 2018; Pata, 2018; Voumik et al., 2023). Further analysis can explore the causal relationships between these factors.

Finally, according to the outcomes of Fourier Toda-Yamamoto causality technique results in Table 7, NR, ELEP, ECOG, and R&D seem to have uni-directional causality effects on environmental footprint (EF). The outcomes also reveal the importance of the NR, ELEP, ECOG, and R&D variables for predicting EF in Kuwait. The results show that the consumption of natural resources electricity production, and economic globalization causes an increase in EF. These results are consistent with past research works of (Shabbir Alam et al., 2023). Furthermore, the negative relationship between research and development suggests that by increasing investments in technological innovation, the government of Kuwaiti may hence produce better records on economic growth. Given Kuwait's longer history of higher environmental pollutions, this one step will also make it apparent to other economies that they must take a lesson from them. According to the International Energy Agency, Kuwait's commitment to investing's in decarbonization of the electricity sector through substantial investments in hydro-electric, nuclear, and renewable source technologies is a key factor in its progress toward a green economy. The government aims to generate all of its power from resources of renewable's energy by 2050. This initiative underscores Kuwait's dedication to sustainable energy development and reducing its carbon footprint. Figure 3 reflects the long-run pictorial findings from FARDL.

Figure 3: Empirical analysis of long-run estimation results

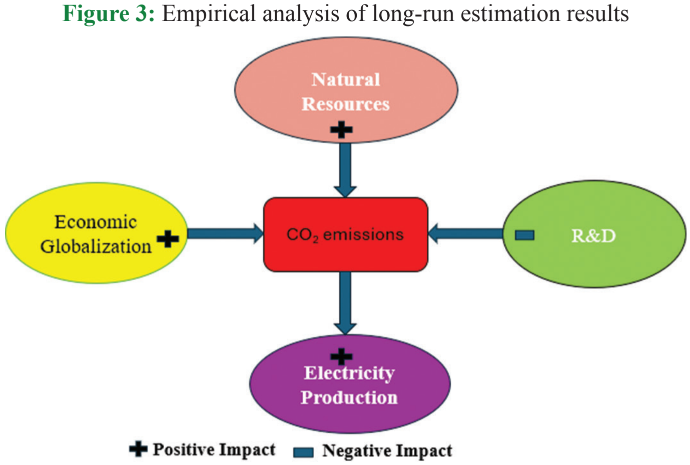


Table 5: Results of fourier ADL cointegration analysis

Model	Test statistic	Frequency	Min AIC
EF=*f* (NR, ELEP, ECOG, R&D)	−5.3117**	2	−2.0314

**signify the 5%, significance level, respectively

Table 6: Fourier ARDL results

Variable	Coefficient	Standard error	t-statistic	Probability value
NR	0.1857	0.1597	1.1627	0.0058**
ELEP	0.1044	0.0250	3.0596	0.0471*
EOCG	0.3941	0.0195	4.3247	0.6721
R&D	−0.0653	0.0307	−0.0725	0.0041**
CointEq(−1)	−0.1137	0.0932	−0.5116	0.5769

***, **, and *signify the 1%, 5%, and 10% significance level, respectively

Table 7: Results of fourier frequency toda-yamamoto causality test

Null hypothesis	Test statistic	P-value
NR does not cause EF	1.700*	0.036
ELEP does not cause EF	2.058*	0.047
ECOG does not cause EF	1.740**	0.002
R&D does not cause EF	3.110**	0.009

***, **, and *signify the 1%, 5%, and 10% significance level, respectively

Table 8: Results of diagnostic tests

Test	F-statistic	P-value
BGP	8.3859**	0.00378
DW	1.0129***	0.000
White	1.320	0.105
ARCH	1.743	0.429
JB	4.2116	0.1217

***, and **signify the 1%, and 5% significance level, respectively

Figure 4: CUSUM and CUSUMSQ test

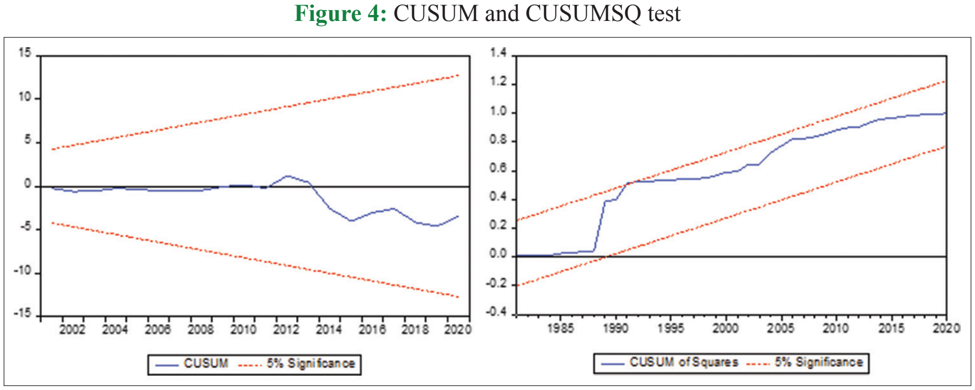


Figure 4 represents the reliability and stability of coefficients assessed with FARDL test. These results from FARDL approach don't have issue, such as auto-correlation, non-normality, heteroskedasticity, and unstable coefficients as Table 8 illustrates. The results of Breusch-Godfrey and Durbin Watson test demonstrate that residuals terms don't have auto-correlation problem, the White, and ARCH tests show that there are no heteroscedasticity problems, and the Jarque-Bera test reveals that the residuals are normally distributed. The model's structural stability estimation verifies its reliability, the CUSUM and CUSUM-square visual analysis are seen in Figure 4. Plots that stay within a 5% critical boundaries range suggest that the model's dimensions are reasonably stable. The following graphic demonstrated that, at a 5% level, CUSUM and CUSUM-square are within the line.

5. CONCLUSIONS AND POLICY RECOMMENDATIONS

Kuwait starts progressing towards carbon neutrality by 2050 and significantly reducing carbon intensity demonstrates its commitment to improving environmental quality. However, the country's continued reliance on fossil fuels, unclean economic globalization practices, and the extensive use of unsustainable methods to increase economic and fossil fuel output may hinder the achievements of these environment goals. In light of these challenges, this study aims to investigate the factor's prompting CO_2-related environmental quality indicators, such as carbon footprint and biocapacity, in Kuwait. Unlike previous studies, this research estimates innovatively an index of environmental quality to quantify the CO_2-related pollutions experienced by living people in Kuwait.

Environmental degradation has become a bone of contention between ecological specialists and policy makers universally. Notably, environmental issues have been a problem for both developed and developing countries. The Kuwait economy's powerful economic situation and significant resource consumption in the global economy support the focus on the Kuwait economy. Kuwait can have a big impact on sustainability problems because of its substantial growth, natural resources, population density, and environmental pollutions. It will also need more energies in the future than it does now. The largest makers of greenhouse emissions and environmental harm are those nations with high energy production. The best nations in the world are focusing on clean, renewable energy as a result, with Kuwait at the forefront of renewable energy for both users and producers. Kuwait needs to drastically alter its environmental policies in order to advance this phenomenon. The purpose of this study is to investigate empirically the relationship between natural resources (InNR), electricity production (InELEP), economic globalization (InECOG), research and development (InR&D) and environmental footprint (InEF) in Kuwait from 1975 to 2020. Instead of the more traditional ARDL and Granger causality tests, we employ a new econometric method called the Fourier ARDL and Fourier Toda Yamamoto causality approach to achieve the objectives of the research.

The ARDL long-run outcomes and causation analysis results show that natural resources, electricity production, and economic globalization, along with effectively ecological policies, play a crucial role in increase environmental footprint in Kuwait. Kuwait needs to use less unexpected energy wastage. Kuwait must prioritize efforts to rationalize energy consumption, as its heavily subsidized electricity program encourages excessive and widespread use. By addressing this issue, the country can reduce the social and environmental costs associated with government subsidies. Kuwait's poor performance in collecting power bills results in significant resource wastage, raising the question of whether the country can sustain such a flexible approach to energy consumption. Re-evaluating these subsidies could lead to more efficient energy use and a reduction in unnecessary expenses. In Kuwait, the transport industry has grown at an incredible rate over the past 20 years as a result of both, population increase and fast urbanization. There is a contention that a substantial number of emissions are also attributable to the transport sector, an eventuality that cannot be completely ruled out for a nation such as Kuwait. As a result, decreasing emissions from this sector has to receive adequate attention as well. More importantly, we found that the most crucial factors in advancing the depth of Kuwait energy transition are natural resources, renewable energy innovations, and environmental research and development policies.

In this context, the Kuwaiti government can achieve the growth of a sustainable economy by strengthening ecological rules that encourage the effective resources use. Policymakers should implement a range of ecologically friendly measures to facilitate transition to renewable energies. This approach will make it easier for both businesses and individuals to access renewable energy sources. Besides, it will encourage companies to participate in renewables sources plans, helping to meet nation's ecological goals. By fostering a supportive regulatory environment and investing in renewable energy infrastructure, Kuwait can align its economic development with sustainability objectives. Moreover, policy-makers can encourage ecological growth by leveraging the process of energy transition and adapting available resources and environmentally friendly innovations to support sustainable energy use. Companies and businesses that demonstrate good environmental practices can be encouraged to adopt green energy through tax exemptions on the sale, acquisition, and equipment implementations that reduce environmental footprints. The government can also provide incentives to well-functioning environmental organizations to invest in suitable green energies projects, acknowledging high initial costs associated with such investments. Since Kuwait contributes 20.86 metric tons of carbon emissions globally, environmental actions should attention on addressing the damaging environmental externalities caused by manufacturing companies. Encouraging these companies to implement green technologies will help protect the atmosphere, promote ecological sustainability, and support sustainable development. By implementing these strategies, Kuwait can advance its environmental development goals and facilitate the transitions to a more sustainable and environmentally friendly economy. Furthermore, complete execution criteria are still insufficient in the early stages of the green finance program and assessment structure. To increase the efficacy of green finance, policymakers must plan an ecological revelation backdrop and enhance the guidance given to the Kuwait government.

Finally, this study has some limitations that should be addressed in future research. Firstly, the study is aimed at a specific region, and future researchers might select to corroborate its outcomes utilizing panel data or time series in other regions. Secondly, while this study examines the factor's influencing development of sustainable economic through the consumption of natural resources, environmentally friendly innovations, and environmental policies, other sustainable development pointers—such as energy efficiency, green energy consumption, carbon emissions, and contribution in global value chain's—may provide different perspective. Consequently, additional research should validate the results of this study by investigating diverse geographic regions and utilizing diverse statistical methods to comprehend the ways in which sustainable development reacts to external influences.

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REFERENCES

Abbasi, K.R., Shahbaz, M., Jiao, Z., Tufail, M. (2021), How energy consumption, industrial growth, urbanization, and CO_2 emissions affect economic growth in Pakistan? A novel dynamic ARDL simulations approach. Energy, 221, 119793.

Agboola, M.O., Bekun, F.V., Joshua, U. (2021), Pathway to environmental sustainability: Nexus between economic growth, energy consumption, CO_2 emission, oil rent and total natural resources rent in Saudi Arabia. Resources Policy, 74, 102380.

Ahmad, M., Jiang, P., Majeed, A., Umar, M., Khan, Z., Muhammad, S. (2020), The dynamic impact of natural resources, technological innovations and economic growth on ecological footprint: An advanced panel data estimation. Resources Policy, 69, 101817.

Ahmed, Z., Asghar, M.M., Malik, M.N., Nawaz, K. (2020), Moving towards a sustainable environment: The dynamic linkage between natural resources, human capital, urbanization, economic growth, and ecological footprint in China. Resources Policy, 67, 101677.

Alam, M.B., Hossain, M.S. (2024), Investigating the connections between China's economic growth, use of renewable energy, and research and development concerning CO_2 emissions: An ARDL bound test approach. Technological Forecasting and Social Change, 201, 123220.

Al-mulali, U., Foon Tang, C. (2013), Investigating the validity of pollution haven hypothesis in the gulf cooperation council (GCC) countries. Energy Policy, 60, 813-819.

Al-Mulali, U., Sheau-Ting, L. (2014), Econometric analysis of trade, exports, imports, energy consumption and CO_2 emission in six regions. Renewable and Sustainable Energy Reviews, 33, 484-498.

Al-Mutairi, A., Smallbone, A., Al-Salem, S.M., Roskilly, A.P. (2017), The first carbon atlas of the state of Kuwait. Energy, 133, 317-326.

Alvarado, R., Tillaguango, B., Dagar, V., Ahmad, M., Işık, C., Méndez, P., Toledo, E. (2021), Ecological footprint, economic complexity and natural resources rents in Latin America: Empirical evidence using quantile regressions. Journal of Cleaner Production, 318, 128585.

Ashraf, J., Ashraf, Z., Javed, A. (2023), The spatial spillover effects of energy transition and trade openness on CO_2 emissions. Energy and Buildings, 292, 113167.

Asongu, S.A., Agboola, M.O., Alola, A.A., Bekun, F.V. (2020), The criticality of growth, urbanization, electricity and fossil fuel consumption to environment sustainability in Africa. Science of the Total Environment, 712, 136376.

Awan, A., Sadiq, M., Hassan, S.T., Khan, I., Khan, N.H. (2022), Combined nonlinear effects of urbanization and economic growth on CO_2 emissions in Malaysia. An application of QARDL and KRLS. Urban Climate, 46, 101342.

Bai, C., Feng, C., Yan, H., Yi, X., Chen, Z., Wei, W. (2020), Will income inequality influence the abatement effect of renewable energy technological innovation on carbon dioxide emissions? Journal of Environmental Management, 264, 110482.

Bergougui, B. (2024), Investigating the relationships among green technologies, financial development and ecological footprint levels in Algeria: Evidence from a novel Fourier ARDL approach. Sustainable Cities and Society, 112, 105621.

Chandra Voumik, L., Ridwan, M. (2023), Impact of FDI, industrialization, and education on the environment in Argentina: ARDL approach. Heliyon, 9(1), e12872.

Chen, K., Qammar, R., Quddus, A., Lyu, N., Alnafrah, I. (2024), Interlinking dynamics of natural resources, financial development, industrialization, and energy intensity: Implications for natural resources policy in emerging seven countries. Resources Policy, 90, 104809.

Danish, Hassan, S.T., Baloch, M.A., Mahmood, N., Zhang, J.W. (2019), Linking economic growth and ecological footprint through human capital and biocapacity. Sustainable Cities and Society, 47, 101516.

Danish, Ulucak, R., Khan, S.U.D. (2020), Determinants of the ecological footprint: Role of renewable energy, natural resources, and urbanization. Sustainable Cities and Society, 54, 101996.

Destek, M.A., Sarkodie, S.A. (2019), Investigation of environmental Kuznets curve for ecological footprint: The role of energy and financial development. Science of the Total Environment, 650, 2483-2489.

Dogan, E., Ulucak, R., Kocak, E., Isik, C. (2020), The use of ecological footprint in estimating the environmental Kuznets curve hypothesis for BRICST by considering cross-section dependence and heterogeneity. Science of the Total Environment, 723, 138063.

Du, K., Li, P., Yan, Z. (2019), Do green technology innovations contribute to carbon dioxide emission reduction? Empirical evidence from patent data. Technological Forecasting and Social Change, 146, 297-303.

European Commission Joint Research Centre (JRC). (2023), GHG Emissions of All World Countries Report 2023. Available from: https://edgar.jrc.ec.europa.eu/report_2023

Feng, K., Hubacek, K., Guan, D. (2009), Lifestyles, technology and CO_2 emissions in China: A regional comparative analysis. Ecological Economics, 69(1), 145-154.

Ganda, F. (2019), The impact of innovation and technology investments on carbon emissions in selected organisation for economic Co-operation and development countries. Journal of Cleaner Production, 217, 469-483.

González-Lorente, Á., Hernández-López, M., Martín-Álvarez, F.J., Nieto-González, I.L. (2024), Classification of European countries according to indicators related to electricity generation. Energy Strategy Reviews, 51, 101268.

Herring, H., Roy, R. (2007), Technological innovation, energy efficient design and the rebound effect. Technovation, 27(4), 194-203.

Ibrahim, R.L., Ajide, K.B. (2021), The dynamic heterogeneous impacts of nonrenewable energy, trade openness, total natural resource rents, financial development and regulatory quality on environmental quality: Evidence from BRICS economies. Resources Policy, 74, 102251.

International Energy Agency. (2021), Global Energy Review: CO2 Emissions in 2021. Available from: https://iea.blob.core.windows.net/assets/c3086240-732b-4f6a-89d7-db01be018f5e/GlobalEnergyReviewCO2Emissionsin2021.pdf

Khan, M., Ozturk, I. (2021), Examining the direct and indirect effects of financial development on CO_2 emissions for 88 developing countries. Journal of Environmental Management, 293, 112812.

Kirikkaleli, D., Sofuoğlu, E., Ojekemi, O. (2023), Does patents on environmental technologies matter for the ecological footprint in the USA? Evidence from the novel Fourier ARDL approach. Geoscience Frontiers, 14(4), 101564.

Kurniawan, R., Managi, S. (2018), Coal consumption, urbanization, and trade openness linkage in Indonesia. Energy Policy, 121, 576-583.

Langnel, Z., Amegavi, G.B. (2020), Globalization, electricity consumption and ecological footprint: An autoregressive distributive lag (ARDL) approach. Sustainable Cities and Society, 63, 102482.

Lean, H.H., Smyth, R. (2010), CO_2 emissions, electricity consumption and output in ASEAN. Applied Energy, 87(6), 1858-1864.

Lee, K.H., Min, B. (2015), Green R&D for eco-innovation and its impact on carbon emissions and firm performance. Journal of Cleaner Production, 108, 534-542.

Lei, X., Yang, Y., Alharthi, M., Rasul, F., Faraz Raza, S.M. (2022), Immense reliance on natural resources and environmental challenges in G-20 economies through the lens of COP-26 targets. Resources Policy, 79, 103101.

Li, B., Haneklaus, N. (2022a), Reducing CO_2 emissions in G7 countries: The role of clean energy consumption, trade openness and urbanization. Energy Reports, 8, 704-713.

Li, B., Haneklaus, N. (2022b), The potential of India's net-zero carbon emissions: Analyzing the effect of clean energy, coal, urbanization, and trade openness. Energy Reports, 8, 724-733.

Liu, H., Alharthi, M., Atil, A., Zafar, M.W., Khan, I. (2022), A non-linear analysis of the impacts of natural resources and education on environmental quality: Green energy and its role in the future. Resources Policy, 79, 102940.

Luo, J., Ali, S.A., Aziz, B., Aljarba, A., Akeel, H., Hanif, I. (2023), Impact of natural resource rents and economic growth on environmental degradation in the context of COP-26: Evidence from low-income, middle-income, and high-income Asian countries. Resources Policy, 80, 103269.

Lv, Z., Xu, T. (2018), Is economic globalization good or bad for the environmental quality? New evidence from dynamic heterogeneous panel models. Technological Forecasting and Social Change, 137, 340-343.

Miao, C., Fang, D., Sun, L., Luo, Q. (2017), Natural resources utilization efficiency under the influence of green technological innovation. Resources Conservation and Recycling, 126, 153-161.

Nepal, R., Paija, N., Tyagi, B., Harvie, C. (2021), Energy security, economic growth and environmental sustainability in India: Does FDI and trade openness play a role? Journal of Environmental Management, 281, 111886.

Nikzad, R., Sedigh, G. (2017), Greenhouse gas emissions and green technologies in Canada. Environmental Development, 24, 99-108.

Odhiambo, N.M. (2021), Trade openness and energy consumption in sub-Saharan African countries: A multivariate panel Granger causality test. Energy Reports, 7, 7082-7089.

Pachiyappan, D., Ansari, Y., Alam, S., Thoudam, P., Alagirisamy, K., Manigandan, P. (2021), Short and long-run causal effects of CO_2 emissions, energy use, GDP and population growth: Evidence from India using the ARDL and VECM approaches. Energies, 14(24), 8333.

Paraschiv, F., Fleten, S.E., Schürle, M. (2015), A spot-forward model for electricity prices with regime shifts. Energy Economics, 47, 142-153.

Pata, U.K. (2018), Renewable energy consumption, urbanization, financial development, income and CO_2 emissions in Turkey: Testing EKC hypothesis with structural breaks. Journal of Cleaner Production, 187, 770-779.

Pata, U.K., Kartal, M.T., Adebayo, T.S., Ullah, S. (2023), Enhancing environmental quality in the United States by linking biomass energy consumption and load capacity factor. Geoscience Frontiers, 14(3), 101531.

Saint Akadiri, S., Adewale Alola, A., Olasehinde-Williams, G., Udom Etokakpan, M. (2020), The role of electricity consumption, globalization and economic growth in carbon dioxide emissions and its implications for environmental sustainability targets. Science of the Total Environment, 708, 134653.

Saqib, N., Dincă, G. (2024), Exploring the asymmetric impact of economic complexity, FDI, and green technology on carbon emissions: Policy stringency for clean-energy investing countries. Geoscience Frontiers, 15(4), 101671.

Saqib, N., Ozturk, I., Usman, M. (2023), Investigating the implications of technological innovations, financial inclusion, and renewable energy in diminishing ecological footprints levels in emerging economies. Geoscience Frontiers, 14(6), 101667.

Shabbir Alam, M., Duraisamy, P., Bakkar Siddik, A., Murshed, M., Mahmood, H., Palanisamy, M., Kirikkaleli, D. (2023), The impacts of globalization, renewable energy, and agriculture on CO_2 emissions in India: Contextual evidence using a novel composite carbon emission-related atmospheric quality index. Gondwana Research, 119, 384-401.

Shehzad, K., Zaman, U., Zaman, B.U., Liu, X., Jafri, R.A. (2022), Lithium production, electricity consumption, and greenhouse gas emissions: An imperious role of economic globalization. Journal of Cleaner Production, 372, 133689.

Song, X., Zhou, Y., Jia, W. (2019), How do economic openness and R&D investment affect green economic growth?-evidence from China. Resources Conservation and Recycling, 146, 405-415.

Tariq, G., Sun, H., Fernandez-Gamiz, U., Mansoor, S., Pasha, A.A., Ali, S., Khan, M.S. (2023), Effects of globalization, foreign direct investment and economic growth on renewable electricity consumption. Heliyon, 9(3), e14635.

Tillaguango, B., Hossain, M.R., Cuesta, L., Ahmad, M., Alvarado, R., Murshed, M., Rehman, A., Işık, C. (2024), Impact of oil price, economic globalization, and inflation on economic output: Evidence from Latin American oil-producing countries using the quantile-on-quantile approach. Energy, 302, 131786.

Uche, E., Das, N., Ngepah, N. (2024), Green environments reimagined through the lens of green finance, green innovations, green taxation, and green energies. Wavelet quantile correlation and rolling window-based quantile causality perspective. Renewable Energy, 228, 120650.

Uche, E., Ngepah, N., Cifuentes-Faura, J. (2023), Upholding the green agenda of COP27 through publicly funded R&D on energy efficiencies, renewables, nuclear and power storage technologies. Technology in Society, 75, 102380.

Ulussever, T., Kartal, M.T., Pata, U.K. (2024), Environmental role of technology, income, globalization, and political stability: Testing the LCC hypothesis for the GCC countries. Journal of Cleaner Production, 451, 142056.

Usman, O., Alola, A.A., Sarkodie, S.A. (2020), Assessment of the role of renewable energy consumption and trade policy on environmental degradation using innovation accounting: Evidence from the US.

Renewable Energy, 150, 266-277.

Vona, F., Patriarca, F. (2011), Income inequality and the development of environmental technologies. Ecological Economics, 70(11), 2201-2213.

Voumik, L.C., Rahman, M.H., Rahman, M.M., Ridwan, M., Akter, S., Raihan, A. (2023), Toward a sustainable future: Examining the interconnectedness among Foreign direct investment (FDI), urbanization, trade openness, economic growth, and energy usage in Australia. Regional Sustainability, 4(4), 405-415.

Wang, K.H., Su, C.W., Lobonţ, O.R., Umar, M. (2021), Whether crude oil dependence and CO_2 emissions influence military expenditure in net oil importing countries? Energy Policy, 153, 112281.

Weber, T.A., Neuhoff, K. (2010), Carbon markets and technological innovation. Journal of Environmental Economics and Management, 60(2), 115-132.

Yilanci, V. (2019), A Residual-Based Cointegration Test with a Fourier Approximation. MPRA Paper No. 95395.

Zaman, M., Pinglu, C., Hussain, S.I., Ullah, A., Qian, N. (2021), Does regional integration matter for sustainable economic growth? Fostering the role of FDI, trade openness, IT exports, and capital formation in BRI countries. Heliyon, 7(12), e08559.

Zhao, X., Yin, H., Zhao, Y. (2015), Impact of environmental regulations on the efficiency and CO_2 emissions of power plants in China. Applied Energy, 149, 238-247.

Zhu, R., Xu, Q., Xiqiang, X., Sibt-e-Ali, M., Waqas, M., Ullah, I., Anwar, A. (2024), Role of resources rent, research and development, and information and communication technologies on CO_2 emissions in BRICS economies. Resources Policy, 93, 105072.