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Deciphering the Dynamics of Economic Development and Green Energy: An In-depth Analysis of OECD Nations

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ABSTRACT

Worldwide, fossil fuel is employing to achieve the sustainability in the long term which is considered the main source of climate change and environmental degradation. Therefore, renewable energy is encouraging to develop and adopt alternative methods of power generation. This study aims to investigate the impact of economic development, trade openness, and technological progress on the adoption of green energy in OECD countries. For this objective a panel dataset of OECD is organized spanning from 1979-2022. Further, Fully Modified OLS and Dynamic OLS are employed to spotlight the fluctuating relationship among the parameters. The findings indicate that these factors have a dynamic and fluctuating relationship, with economic development fostering long-term adoption of green energy but impeding it in the short term. The study underscores the significance of international trade and technological advancement in advancing renewable energy use, with technological progress playing a crucial role in OECD countries. Ultimately, the research concludes that there is a substantive connection between economic growth, free trade, technological advancement, and green energy use in these countries. This study suggested that implementing policies that encourage trade openness, technological innovation, and sustainable economic development is essential to achieving ambitious renewable energy objectives and reducing carbon emissions.

1 Introduction

The modern era has witnessed extensive discourse on the adoption of renewable energy sources, which encompasses an array of topics such as economic progress, technical advancement, and international trade (Bhattacharya et al., 2020). The association among energy management, economic development, energy intake, and trade openness is an expose of significant interest (Destek & Sinha, 2020). Conversely, the connection amongst technical advancement and renewable resources utilization has received less attention (P. Zhang et al., 2023). Although (Moslehpour et al., 2023) have explored the impact of technical advancement on sustainable energy use using time series data, they have primarily focused on causal and bidirectional linkages. Moreover, (Liu et al., 2022) have explored the association between economic development and energy consumption in different contexts.

There is a substantial essence of empirical research that explores the relationship concerning economic growth and energy utilization. (Surya, et al., 2021) specifically explored the connection between the utilization of renewable energy sources and economic development and found a positive correlation between the two. However, (Yang et al., 2022) discovered a bi-directional link between the utilization of nonrenewable energy foundations, economic development, and renewable energy sources. (Ramzan et al., 2022) utilized a standard production function to explore the association linking sustainable energy depletion and economic development in nine countries surrounding the Black Sea and the Balkans. They indicated that the exploitation of renewable energy resources contributes to economic expansion, and that there is a long-term stability concerning the two. (Wang, Yang, et al., 2023) further concluded that in Balkan and Black Sea countries the renewable energy has a substantial influence on economic development.

According to (Joaqui-Barandica & Manotas-Duque, 2023), investment in the renewable energy industry is influenced by macroeconomic factors, particularly in countries where support is lacking. A study by (Basri, 2021) explored the association among renewable energy consumption and actual gross domestic product in the United States, revealing a positive correlation between the two. This finding is coherent with previous inquiries which suggests that national wealth is a significant handler of renewable resources consumption in Group-7 countries (Radmehr et al., 2021). The heterogeneous panel cointegration test conducted by (Saqib, 2022) further demonstrated a long-term symmetry connecting consumption of renewable energy and actual gross domestic product, indicating that economic development over time is strongly correlated with increased renewable use of energy in a group of OECD nations.

(Surya et al., 2021) revealed a positive correlation between the utilization of renewable resources and economic development in 19 developed and developing countries. Proponents of the feedback hypothesis argue that the existence of bidirectional causality confirms the relationship between the utilization of renewable energy and economic progression. The increased use of renewable energy is expected to contribute to economic growth due to this dependence. Renewable energy is considered a suitable source of energy for these countries because of its favorable economic impact (Bhuiyan et al., 2022).

This study is significant for investigating the interplay between trade openness, GDP, and high technology and renewable energy initiatives to achieve carbon neutrality in OECD. It evaluates persistent global concerns, such as climate change and the rise in carbon emissions, by analyzing the influence of technological progress and eco-friendly laws on sustainability. This research aims to offer an understanding of OECD's role in mitigating environmental risks and advancing a sustainable, low-carbon future, with a particular emphasis on its rapidly evolving economy.

Furthermore, this study aims to elucidate the significant influence of high technology in the post-COVID era on economic dynamics, environmental aspects, and energy consumption. This study offers critical perspectives on OECD endeavors to address climate change and attain carbon neutrality, with special emphasis on its pivotal position in the global economy. Further, highlights the importance of renewable energy sources and eco-friendly technologies, demonstrating their ability to reduce carbon emissions and foster economic growth without causing ecological harm.

Considering the above discussion, the topics of renewable energy, trade openness, and high technology to design eco-friendly policies are the focus of this research. In addition, this research examines whether technological progress aids the objective of carbon neutrality while decelerating carbon emission. However, section 2 highlights the review of literature, section 3 reported the data and methodology. While section 4 describes the results and discussion, and section five explains the conclusion and policy implications.

2 Literature Review

According to (Wang, Li, et al., 2023), gross domestic product enlargement is the predominant feature that has a substantial and affirmative influence on the adoption of renewable resources in 23 European countries between 1990 and 2013, as determined through a panel data analysis.(Sun & Heshmati, 2021) attribute Malaysia's rapid economic expansion and openness to international trade as the primary drivers behind the increase in energy consumption since 1985. Additionally, (Shah et al., 2022) have established a link between technological advancements and a reduction in energy consumption in manufacturing and industrial processes, as well as a decrease in carbon dioxide emissions, a potent greenhouse gas.

(Iqbal et al., 2023) conducted an analysis to investigate the inspiration of External Straight Asset or foreign direct investment, trade openness, green energy, decarbonization, and development of economic on energy consumption in the United Arab Emirates (UAE) using the (ARDL) Autoregressive Distributed Lag bounds testing method, the (VECM) Vector Error Correction Model, and the method of Granger Causality test. The findings of the analysis showed that these factors had a substantial influence on energy consumption in the UAE. The findings found that the international trade has a negative influence on energy consumption as it leads to the use of energy-efficient equipment because of the connection among international trade and the development of economic (Udeagha & Ngepah, 2021). Additionally, economic development and green power have a confirmed influence on the utilization of energy due to external debt or foreign direct investment, international trade, and decarbonization emanations, but these factors have resulted in a decrease in total energy demand (Khan & Ahmad, 2021).

Several studies have established that trade openness has various consequences on domestic energy consumption (M. Zhang et al., 2021). Notably, it enhances resource utilization and realizes greater economies of scale. Furthermore, the advancement of renewable energy technologies hinges on international trade (Al-Farsi & Hayyan, 2023).

The inference of international trade on domestic consumption of energy is multifaceted (Xu et al., 2023). Research indicates that economic output, exports, and imports are reciprocally linked in both the short and long term (Fannoun & Hassouneh, 2019). However, in the medium term, there is no evidence to suggest an instrumental association linking international trade and the exploitation of renewable energy sources. Similarly, no long-term connection between global marketing and increased reliance on renewable energy has been established (Ilechukwu & Lahiri, 2022).

A study of Middle Eastern countries by (Li et al., 2022) found that higher volumes of international trade are associated with increased local energy consumption. The association between international trade and the utilization of energy is non-linear, with U-shaped relationships observed in high-income nations and an inverted U shape in middle- and low-income countries (Le, 2022).

The development of renewable resources is currently posing a significant dispute to society, and foremost factor which is generating energy disparity (M. Zhang et al., 2022);(Malik et al., 2022). (Hesselink & Chappin, 2019) have suggested that disparities in resources, aspirations, and technological advancements contribute to the variation in the adoption of energy-efficient technology across countries.

The aim of this study is to fill gaps which are found in literature by employing trade openness, economic growth and high technology. Numerous studies employed various factors as employed this work to highlight the importance of renewable energy, so that countries can mitigate climate change and significantly acquire sustainability. That's why this study employed trade openness, economic growth and high technology to promote renewable energy to decelerate fossil fuel energy and encourage the environmental quality. (Padhan et al., 2020) reported that the utilization of renewable

energy in OECD states has exhibited a substantial growth from 36.6 million metric tons of smear with oil corresponding in 1998 to 304.9 million metric tons of lubricant counterpart in 2017.

In the perspective of above discussion, delineated points appeared. This work employed various techniques such as PMG, MG, DFE, FMOLS and DOLS, to spotlight the complex connection between renewable energy and trade openness, economic growth, and high technology. Sarfraz et al. (2022a) analyzed the connection between trade openness and renewable energy and clean energy in newly developed countries, whereas studied the connection between energy transition and environmental quality in rising nations. Jianguo et al. (2022b) employed time-series data to examine the relationship between green energy and environmental sustainability in Chile, while Chishti et al. (2024) explored the interplay between green growth, environmental sustainability, and energy in BRICS nations. In summary, our literature review indicates that there is a lack of empirical research that simultaneously utilizes the PMG, MG, DFE, FMOLS, and DOLS methodologies in OECD to investigate these relationships. This paper aims to address research gaps by employing the PMG, MG, DFE, FMOLS, and DOLS methodologies to examine the relationship between in OECD economies.

3 Data and Methodology

The inference of international trade on domestic consumption of energy is multifaceted (Xu et al., 2023). Research indicates that economic output, exports, and imports are reciprocally linked in both the short and long term (Fannoun & Hassouneh, 2019). However, in the medium term, there is no evidence to suggest an instrumental association linking international trade and the exploitation of renewable energy sources. Similarly, no long-term connection between global marketing and increased reliance on renewable energy has been established (Ilechukwu & Lahiri, 2022).

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$$y_{it} = \alpha + \rho y_{i,t-1} + X_{it}'\beta + \eta_{it} \qquad [1]$$

Whereas Y_{it} stands for renewable energy, lagged value of $Y_{i,\,t-1}$, and X_{it} describes the trade openness, economic growth, and high technology, "i" denotes subgroups and t for time frame "1979-2022". Further, countries in the group are of variant features which may fluctuate the flow of the data. However, to estimate heterogeneous data with a suitable technique and context, we employed a dynamic panel framework, as this analysis investigates the dynamic contrast of economic development, trade openness, technical advancement, and renewable energy. To address the issue of data characteristics such as heterogeneity, and cross-sectional dependency. We utilized pooled mean group estimators, mean group and dynamic fixed effect, as described by Pesaran and Smith (1995) and Pesaran, Shin, and Smith (1996). Our approach follows the ARDL standard outlined by Loayza and Ranciere (2006).

$$\Delta(\mathrm{Zi})\,t = \sum_{h=1}^{n-1} \rho^{i}{}_{h}\,\Delta(Zi)_{t-h} + \sum_{h=0}^{m-1} \gamma^{i}{}_{h}\,\Delta(Y_i)_{t-h} + \lambda^{i}[(\mathrm{Zi})_{t-1} - \{\delta^{i}{}_{0} + \delta^{i}{}_{1}(Yi)t - 1\}]\eta_{it} \qquad [2]$$

Reducing climate change via implication of trade openness, economic growth and high technology are the core parameters which are participating in encouraging implications of renewable energy, that contribute to Y, which includes technological innovation, economic growth, and openness to international trade. Most of the sentences included in square brackets indicate a decline in development over time (Demetriades and Hook-Law, 2006).

Despite this, Pesaran and Shin (1995) and (Zhong et al., 2024) have shown that the assumptions and results of the PMG and MG processes outperform other methods in econometrics. Due to short-range factors of PMG such as intercepts, the rate at which long-term stability ethics are adjusted, and the slip-up variance might vary between countries in their initial estimate. This is a crucial aspect. On the other hand, slope coefficients must be homogenous in the long run. A long-term relationship between the variables under study with an error-correction term coefficient of at least two and a negative sign is necessary for the methodology's effectiveness, consistency, and validity. Additionally, the error-correction model's generating residual must not be serially correlated for PMG estimates to be considered exogenous (Eberhardt and Teal, 2010).

(Pesaran et al., 1999) developed the MG estimator, which is the second method introduced in 1999. This method involves estimating separate regressions for each country and calculating unweighted average coefficients. It does not impose any restrictions on the analysis of economic processes, allowing all factors to vary and be heterogeneity in the short-run and long-run. To ensure the legitimacy and reliability of this approach, a minimum of 30 countries must be included, as recommended by (Pesaran et al., 1999) and similar studies.

Dynamic Fixed Effects (DFE) estimators are bound by the requirement of having identical coefficients for the cointegrating vector across all panels and over time, like the constraints imposed on Pooled Mean Group (PMG) estimators. Additionally, DFE models incorporate panel-specific intercepts and restrict the amendment factor and short-range speed factor to be equal or less. To account for intra-group correlation and related standard errors, cluster parameters are incorporated into the DFE estimator (Blackburne and Frank 2007). The presence of endogeneity between error and a lagged dependent variable can lead to simultaneous equation bias, as noted by Baltagi et al. (2000). The Hausman test may be employed to detect endogeneity, or alternatively, to address it, the use of instrumental variables may be considered.

Pooled Mean Group or Mean Group, or Dynamic Fixed Effect?

The findings indicate that the PMG estimator outperforms the MG estimators in estimating efficiency underneath the statement of a long-range slope of homogeneity, which aligns with the objective of this analysis (Pesaran, Shin, et al., 1999). To determine whether there is a significant difference between the PMG, MG, and DFE estimators, the Hausman test was employed. The null hypothesis speculates that there is no discernible distinction amongst the Pooled Mean Group and Mean Group estimates. Given this, the null hypothesis is not considered to have a substantial impact, and thus, the PMG estimator is preferred for its superior performance. Conversely, uncertainty the hypothesis null is rejected, it implies a substantial conflict concerning the Pooled Mean Group and Mean Group estimators, and in this case, the average estimator is utilized to account for discrepancy.

(Phillips & Hansen, 1990) introduced the idea of long-term integration among the parameters in the presence of cointegration. Fully modified OLS (FM-OLS) significantly incorporated data related issues such as endogeneity, and serial correlation.

$$RE_t = \beta_0 + \beta_1 TO_{it} + \beta_2 EG_{it} + \beta_3 HT_{it} + \eta_t \qquad [3]$$

RE describes renewable energy, TO shows trade openness, EG stands for economic growth and HT for high technology, $\beta_0, \beta_1, \beta_2 and \beta_3$ defines coefficients, t for time, i for subgroups which are 25 and η for error term. While Dynamic Ordinary Least Square (DOLS) is suitable in the presence of cointegration which significantly and efficiently incorporated the leads and lags of parameters effectively.

4 Results and Discussion

The data suggests that the usual level of utilization of renewable resources is 22.86 terajoules (TJ), with a range of 0 to 26.99 TJ. It is anticipated that technological advancements will occur at an average annual rate of 8.75 times. Unfortunately, there is a lack of diversity in this area. The average trade openness is approximately 72.29 units, and this value remains relatively stable. In terms of US dollars, the GDP per capita has a moderate logarithmic shape of 10.18 units in real terms.

Table 01

Descriptive Statistics

Variables	Mean	Std. Dev.	Min	Max
Renewable energy	22.87	2.32	0	27.01
Trade openness	72.31	2.14	10.73	333.54
Economic growth	10.19	0.49	7.84	11.39
High technology	8.76	1.91	3.18	13.17

An examination of renewable energy consumption in the United States was conducted using the PMG estimators developed by Pesaran, Shin, and Smith (1999). These estimators were designed by the economists Pesaran, Shin, and Smith to evaluate the asymptotic properties of parameter estimates. To ensure the validity of the analysis, it is crucial to verify that the variables of interest are all ordered in ascending order. According to Im and Pesaran (1995), two additional unit-root methods have been developed, while Maddala and Wu (1995) have proposed a third approach. As evidenced by Table 2, all variables exhibit a root.

Table 02

Results of the Panel Unit-Root

	Level		**First Difference**	
	Im, Pesaran & Shin (2003)	Maddala & Wu (1999)	Im, Pesaran and Shin (2003)	Maddala and Wu (1999)
Renewable Energy	-1.39	1.85	-8.12	-22.93

Trade Openness	-1.95	-0.72	-4.55	-8.65
Economic Growth	-1.94	2.49	-7.48	-21.29
High Technology	-1.31	-0.43	-5.16	-8.07

*** shows significance at the 1% level.

According to the findings of this study, all variables under assessment are found to be stationary at the first-order difference, indicating that the ARDL method is the utmost proper analytical method for the given dataset.

Table 3 displays the findings of the Pooled Mean Group (PMG), Mean Group (MG), and Dynamic Fixed Effect estimators (DFE), alongside the Hausman Description test (h-test), which assessed the models' efficiency and consistency. Previous research has demonstrated a strong positive relationship between the reliance on renewable energy sources and long-term economic development, as measured by GDP per capita. However, the PMG estimate suggests that the GPC has a short-term negative impact on the use of renewable energy sources.

Table 3

The Dynamic Models of PMG, MG, and DEF

	PMG		**MG**		**DFE**	
Renewable Energy Use	**Short**	**Long**	**Short**	**Long**	**Short**	**Long**
Err Corr.	-0.31***		-0.48***		-0.07***	
	(-0.05)		(0.05)		(0.01)	
TO	0.02		0.02		0.06	
	(0.01)		(0.01)		(0.02)	
EG	-0.33*		0.28		0.22	
	(0.18)		(0.33)		(0.66)	
HT	-0.08		-0.08		-0.05	
	(-0.01)		(0.11)		(0.09)	
Hausman Test			4.1(0.13) *			0.93(0.81) *
TO		0.02*		0.03		0.09
		(0.01)		(0.06)		(0.01)
EG		0.57***		4.42**		1.99**
		(0.04)		(1.83)		(0.97)
HT		-0.01		-0.29		0.31
		(0.02)		(0.47)		(0.33)
Constant	5.65***		0.97		0.37	
	(1.05)		(3.51)		(0.69)	

***, **, *indicate significance level at the 1%, 5%, and 10% levels of significance. (*p*-value is within the parenthesis)

The EG coefficient does not have an immediate impact, but its effects are significant and long-term, like the findings of the MG estimator. The DFE calculation predicts a long-term increase in renewable energy consumption, although there is no immediate influence. The Hausman test confirms the long-term homogeneity restrictions. The Hausman specification test results show that PMG estimators are superior to both the MG and DFE estimators. This supports the null hypothesis of the regressor homogeneity restriction. The PMG estimate suggests that unrestricted trade is necessary for increasing the long-term use of renewable energy.

In accordance with the findings of PMG, it can be concluded that trade liberalization has no immediate impact on the utilization of renewable energy sources. This suggests that the estimates provided by MG and DFE conflict with those of PMG. While technical progress may have long-term negative consequences for the economy, these effects are minimal and insignificant. This suggests

that advancements in technology do not enhance the supply-side economics of renewable energy. The short-term usage of renewable energy is not considered by technical advancements, as evidenced by Table 3. A comparison of these results with the general findings will allow for an evaluation of the country's features soon (as shown in Table 4). It is noteworthy that the use of renewable energy in the economies of the Netherlands and Norway has been significantly influenced by technological progress in a relatively brief period.

Table 4

25 Member States from OECD

Countries	Constant	Trade Openness	Economic Growth	High Technology
Netherlands	-0.25***	0.01	-0.77	1.98*
Norway	-0.55***	0.01	-0.82	0.16*
France	-0.67***	0.002	0.36	-1.03**
Iceland	-0.01	0.003	0.404	-0.05*
United States	-0.48***	0.014	-0.92	-0.78**
Australia	-0.52***	0.001	0.29	0.02
Belgium	0.00***	0.004	-0.503	0.19
Finland	-0.32***	0.013***	-0.88	0.09
Greece	-0.14	-0.014	-0.26	0.03
Ireland	0.61	0.302	0.189	0.07
Israel	0.95	0.48	0.82	0.87
Italy	-0.06	-0.002	-1.302***	0.11
Japan	-0.78***	0.004	0.86	0.01
Korea, Rep.	-0.47***	-0.002	-1.048	0.33
Luxembourg	-0.41***	0.005*	-0.42	0.01
Portugal	-0.78***	0.024**	-1.47	0.13
Austria	-0.34***	0.001	-1.107	-0.12
Canada	-0.14***	0.004**	0.109	-0.02
Denmark	0.00***	-0.006	1.47	-0.08
Germany	0.04	0.007	-1.091	-0.09
New Zealand	-0.14***	0.001	0.299	0.1
Spain	-0.37***	0.002	-2.37	-0.001
Sweden	-0.63***	0.006	-0.22	-0.05
Switzerland	-0.73***	0.003	-1.023	-0.13
United Kingdom	0.09**	-0.003	0.77	-0.09

The utilization of energy resources that is renewable energy in United State, France, and the Iceland has decreased due to recent technological advancements. However, there has been a minor but anticipated rise in the consumption of renewable energy in states like as Luxembourg, South Korea, Italy, Japan, Israel, Greece, Australia, and Belgium. Additionally, a small but unexpected amount of renewable energy consumption was observed in countries like Canada, the United Kingdom, Austria, Germany, and Denmark.

The ARDL results were analyzed using two single-equation estimators, DOLS and FMOLS (Table 3). The DOLS framework, which is part of the mixed order, provides the essential benefit of integrating related variables into a cointegrated framework. The DOLS method involves regressing a variable, and the I(1) form is used for variables such as p and -p, while the I(0) form includes a constant term. Our approach considers potential drawbacks such as endogeneity and small sample bias.

The PMG estimator's results, as depicted in Table 5, indicate that economic growth has a substantial impact on the consumption of renewable energy sources. The PMG estimator's findings reveal that trade openness has both positive and negative consequences. However, in terms of the influence of innovative breakthroughs in renewable energy technology, the DOLS estimator produces results that are quite like those of the PMG estimator. The DOLS analysis found that technological advancements had a negative impact on the utilization of renewable energy. The FMOLS technique for heterogeneity cointegrated sheets was assessed manipulating Pedroni's (2001) decisive factor, as shown in Table 5.

Table 5

FMOLS and DOLS Results

Renew Energy	**FMOLS**		**DOLS**	
	Coefficient	**Std. Err**	**Coefficient**	**Std. Err**
Trad Openness	0.79	0.002	-0.35	0.09
Economic Growth	2.35	0.008	1.31	0.17
High Technology	0.47	0.003	-0.113	0.17
	R Square	0.86	R Square 0.81	

Adj R^2 0.83

Adj R^2 0.86

The Fully Modified Model with Ordinary Least Squares (FMOLS) is a dynamic panel estimator that has several advantages over its counterparts. It is designed to address regressor endogeneity caused by cointegration relationships by modifying the Ordinary Least Squares method. Not only is the FMOLS estimator asymptotically accurate, but it is also highly efficient. It is capable of handling first-stage residuals with long-term coefficients. Theoretically, the FMOLS findings are in line with expectations. The FMOLS statistics reveal that long-term economic growth in 25 OECD nations significantly supports renewable energy use. In contrast, non-OECD nations prioritize reducing CO_2 emissions and ensuring energy security over OECD nations.

The benefits of increased trade openness are evident on both the demand and supply sides of the renewable energy market, as illustrated in Table 5. On the one hand, global market competition has enhanced the efficiency of local businesses in the renewable energy sector. On the other hand, the liberalization of trade has led to an expansion of renewable energy resources in OECD countries. As depicted in Table 5, the positive and significant coefficient associated with technical progress indicates that the utilization of renewable energy is escalating rapidly in tandem with technological advancements. However, the outcomes of the other estimators employed in this research contradict this finding. When the long-range factor is established to be heterogeneous, the FMOLS estimator produces a distinct set of results. Though economic systems may be comparable across OECD countries, technological progress varies among them.

5 Conclusions and Policy Implementation

Prior research has not considered the factors of economic development, trade openness, and technical progress with regards to the resilience of OECD nations to the usage of renewable energy. However, this study has addressed this gap in knowledge and provided a significant contribution to literature. The findings of this study are supplementary comprehensive and extensive than any research on the subtleties of renewable resources consumption in OECD nations. The researchers utilized various analytical techniques, including panel and country-specific analyses, to gather large amounts of data. While economic development ultimately supports renewable energy in the long term, it has the opposite effect in the short term.

This research provides a foundation for further investigation into the relationship between economic growth, trade openness and energy usage in emerging countries. Studies by (Khan & Ahmad, 2021)

and (Iqbal et al., 2023) support the existence of a positive long-term association in Malaysia, while (Sun & Heshmati, 2021) and (Wang, Li, et al., 2023) have found similar results in BRICS and Japan, respectively. (Al-Farsi & Hayyan, 2023), (M. Zhang et al., 2021) and (Xu et al., 2023) have also revealed a positive association in South Africa and Pakistan, respectively. The empirical findings suggest that there has been a rise in the use of renewable energy due to increased international trade. Previous research, including studies by Chang, (Ilechukwu & Lahiri, 2022), (Li et al., 2022), (Si & Rahman, 2024) and (Le, 2022), has also shown a long-term association between these variables.

According to this analysis, there is a statistically significant correlation between technological advancement and the utilization of renewable energy sources in OECD countries. As a result of technological progress, the dependence of OECD nations on renewable energy has increased significantly. The use of renewable energy and technological advancement varies among countries soon.

The implementation and promotion of renewable energy sources requires technological progress in any nation. To minimize the environmental impact of renewable energy production, more advanced technology is necessary. OECD countries have greater entrance to and exploitation of modern technology sources for renewable power generation due to their high incomes, technical advancements, and involvement in international trade. As a result, these countries are more inclined to advance in ecologically beneficial consequences such as renewable resources manufacture.

It has been discovered that there is a significant relationship between economic growth, free trade, technological advancement, and the use of renewable power, particularly in OECD states. This research also addresses certain statement associations for these nations. To promote development of economic growth, international trade, and technical development towards the widespread use of renewable energy, it is essential to understand the complex interconnections among these components. For instance, the improvement of environmental health in OECD countries could be achieved through technological innovation and increased use of renewable energy. To attain ambitious goals like expanding renewable energy use, OECD nations will need to implement policies that encourage trade openness, technological innovation, and long-term economic development. Consequently, carbon emissions in the long run will be reduced.

The promotion of economic growth can be enhanced through measures that promote the production and utilization of renewable energy sources. It is essential to invest in technological advancements to encourage the global adoption of renewable energy. Carbon pricing is a crucial element of any climate initiative aimed at fostering the development of new renewable energy sources.

Reference

Al-Farsi, R., & Hayyan, M. (2023). Paving the way for advancement of renewable energy technologies using deep eutectic solvents: A review. In *Renewable and Sustainable Energy Reviews*. https://doi.org/10.1016/j.rser.2023.113505

Basri, R. (2021). Renewable Energy Use, Real GDP, And Human Development Index In Bangladesh: Evidence From Simultaneous Equation Model. *International Journal of Management and Economics Invention*. https://doi.org/10.47191/ijmei/v7i4.01

Bhattacharya, M., Inekwe, J. N., & Sadorsky, P. (2020). Consumption-based and territory-based carbon emissions intensity: Determinants and forecasting using club convergence across countries. *Energy Economics*. https://doi.org/10.1016/j.eneco.2019.104632

Bhuiyan, M. A., Zhang, Q., Khare, V., Mikhaylov, A., Pinter, G., & Huang, X. (2022). Renewable Energy Consumption and Economic Growth Nexus—A Systematic Literature Review. In *Frontiers in Environmental Science*. https://doi.org/10.3389/fenvs.2022.878394

Chishti, M. Z., Xia, X., & Dogan, E. (2024). Understanding the effects of artificial intelligence on energy transition: The moderating role of Paris Agreement. *Energy Economics*, *131*, 107388. https://doi.org/10.1016/J.ENECO.2024.107388

Destek, M. A., & Sinha, A. (2020). Renewable, non-renewable energy consumption, economic growth, trade openness and ecological footprint: Evidence from organisation for economic Co-operation and development countries. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2019.118537

Fannoun, Z., & Hassouneh, I. (2019). The causal relationship between exports, imports and economic growth in Palestine. *Journal of Reviews on Global Economics*. https://doi.org/10.6000/1929-7092.2019.08.22

Hesselink, L. X. W., & Chappin, E. J. L. (2019). Adoption of energy efficient technologies by households – Barriers, policies and agent-based modelling studies. *Renewable and Sustainable Energy Reviews*. https://doi.org/10.1016/j.rser.2018.09.031

Ilechukwu, N., & Lahiri, S. (2022). Renewable-energy consumption and international trade. *Energy Reports*. https://doi.org/10.1016/j.egyr.2022.08.209

Iqbal, A., Tang, X., & Rasool, S. F. (2023). Investigating the nexus between CO2 emissions, renewable energy consumption, FDI, exports and economic growth: evidence from BRICS countries. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-022-02128-6

Jianguo, D., Ali, K., Alnori, F., & Ullah, S. (2022). The nexus of financial development, technological innovation, institutional quality, and environmental quality: evidence from OECD economies. *Environmental Science and Pollution Research 2022 29:38*, *29*(38), 58179–58200. https://doi.org/10.1007/S11356-022-19763-1

Joaqui-Barandica, O., & Manotas-Duque, D. F. (2023). How do Climate and Macroeconomic Factors Affect the Profitability of the Energy Sector? *International Journal of Energy Economics and Policy*. https://doi.org/10.32479/ijeep.14303

Khan, Y. A., & Ahmad, M. (2021). Investigating the impact of renewable energy, international trade, tourism, and foreign direct investment on carbon emission in developing as well as developed countries. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-021-12937-3

Le, T. H. (2022). Editorial: Trade openness, energy usage and environmental quality. In *Frontiers in Energy Research*. https://doi.org/10.3389/fenrg.2022.1001205

Li, Y., Alharthi, M., Ahmad, I., Hanif, I., & Ul Hassan, M. (2022). Nexus between renewable energy, natural resources and carbon emissions under the shadow of transboundary trade relationship from South East Asian economies. *Energy Strategy Reviews*. https://doi.org/10.1016/j.esr.2022.100855

Liu, H., Liu, J., & Li, Q. (2022). Asymmetric Effects of Economic Development, Agroforestry Development, Energy Consumption, and Population Size on CO2 Emissions in China. *Sustainability (Switzerland)*. https://doi.org/10.3390/su14127144

Malik, S. ur R., Rahman, Z. U., & Ibrahim, M. (2022). Validity of Environmental Kuznets Curve in the Malaysian Economy: A Fresh Evidence. *Journal of Economic Impact*. https://doi.org/10.52223/jei4032214

Moslehpour, M., Aldeehani, T. M., Sibghatullah, A., Tai, T. D., Phan, T. T. H., & Ngo, T. Q. (2023). Dynamic association between technological advancement, green finance, energy efficiency

and sustainable development: evidence from Vietnam. *Economic Research-Ekonomska Istrazivanja* . https://doi.org/10.1080/1331677X.2023.2190796

Padhan, H., Padhang, P. C., Tiwari, A. K., Ahmed, R., & Hammoudeh, S. (2020). Renewable energy consumption and robust globalization(s) in OECD countries: Do oil, carbon emissions and economic activity matter? *Energy Strategy Reviews*. https://doi.org/10.1016/j.esr.2020.100535

Pesaran, M. H., Shin, Y., & Smith, R. P. (1999). Pooled Mean Group Estimation of Dynamic Heterogeneous Panels. *Journal of the American Statistical Association*. https://doi.org/10.1080/01621459.1999.10474156

Phillips, P. C. B., & Hansen, B. E. (1990). Statistical inference in instrumental variables regression with i(1) processes. *Review of Economic Studies*. https://doi.org/10.2307/2297545

Radmehr, R., Henneberry, S. R., & Shayanmehr, S. (2021). Renewable Energy Consumption, CO2 Emissions, and Economic Growth Nexus: A Simultaneity Spatial Modeling Analysis of EU Countries. *Structural Change and Economic Dynamics*. https://doi.org/10.1016/j.strueco.2021.01.006

Ramzan, M., Raza, S. A., Usman, M., Sharma, G. D., & Iqbal, H. A. (2022). Environmental cost of non-renewable energy and economic progress: Do ICT and financial development mitigate some burden? *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2021.130066

Saqib, N. (2022). Green energy, non-renewable energy, financial development and economic growth with carbon footprint: heterogeneous panel evidence from cross-country. *Economic Research-Ekonomska Istrazivanja* . https://doi.org/10.1080/1331677X.2022.2054454

Sarfraz, M., Ivascu, L., Abdullah, M. I., Ozturk, I., & Tariq, J. (2022). Exploring a Pathway to Sustainable Performance in Manufacturing Firms: The Interplay between Innovation Capabilities, Green Process, Product Innovations and Digital Leadership. *Sustainability 2022, Vol. 14, Page 5945*, *14*(10), 5945. https://doi.org/10.3390/SU14105945

Shah, W. U. H., Hao, G., Yan, H., Yasmeen, R., & Jie, Y. (2022). The role of energy policy transition, regional energy efficiency, and technological advancement in the improvement of China's environmental quality. *Energy Reports*. https://doi.org/10.1016/j.egyr.2022.07.161

Si, H., & Rahman, Z. U. (2024). Embracing the digital revolution: Examining the relationship between ICT adoption and carbon emissions in the Persian Gulf. *PLoS ONE*, *19*(6 June), 1–22. https://doi.org/10.1371/journal.pone.0304088

Sun, P., & Heshmati, A. (2021). International Trade and its Effects on Economic Growth in China. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.1667775

Surya, B., Salim, A., Saleh, H., Abubakar, H., Suriani, S., Sose, A. T., & Kessi, A. M. P. (2021). Economic growth model and renewable energy utilization: Perspective of natural resources management and sustainable development of the gowa regency region south Sulawesi, Indonesia. *International Journal of Energy Economics and Policy*. https://doi.org/10.32479/ijeep.11676

Surya, B., Salim, A., Suriani, S., Menne, F., & Rasyidi, E. S. (2021). Economic growth and development of a minapolitan area based on the utilization of renewable energy, Takalar regency, South Sulawesi, Indonesia. *International Journal of Energy Economics and Policy*. https://doi.org/10.32479/ijeep.11502

Udeagha, M. C., & Ngepah, N. (2021). The asymmetric effect of trade openness on economic growth in South Africa: a nonlinear ARDL approach. *Economic Change and Restructuring*. https://doi.org/10.1007/s10644-020-09285-6

Wang, J., Li, W., Haq, S. ul, & Shahbaz, P. (2023). Adoption of Renewable Energy Technology on Farms for Sustainable and Efficient Production: Exploring the Role of Entrepreneurial Orientation, Farmer Perception and Government Policies. *Sustainability (Switzerland)*. https://doi.org/10.3390/su15075611

Wang, J., Yang, J., & Yang, L. (2023). Do natural resources play a role in economic development? Role of institutional quality, trade openness, and FDI. *Resources Policy*. https://doi.org/10.1016/j.resourpol.2023.103294

Xu, J., Moslehpour, M., Tran, T. K., Dinh, K. C., Ngo, T. Q., & Huy, P. Q. (2023). The role of institutional quality, renewable energy development and trade openness in green finance: Empirical evidence from South Asian countries. *Renewable Energy*. https://doi.org/10.1016/j.renene.2023.03.015

Yang, C., Namahoro, J. P., Wu, Q., & Su, H. (2022). Renewable and Non-Renewable Energy Consumption on Economic Growth: Evidence from Asymmetric Analysis across Countries Connected to Eastern Africa Power Pool. *Sustainability (Switzerland)*. https://doi.org/10.3390/su142416735

Zhang, M., Ge, Y., Liu, L., & Zhou, D. (2022). Impacts of carbon emission trading schemes on the development of renewable energy in China: Spatial spillover and mediation paths. *Sustainable Production and Consumption*. https://doi.org/10.1016/j.spc.2022.04.021

Zhang, M., Zhang, S., Lee, C. C., & Zhou, D. (2021). Effects of trade openness on renewable energy consumption in OECD countries: New insights from panel smooth transition regression modelling. *Energy Economics*. https://doi.org/10.1016/j.eneco.2021.105649

Zhang, P., Li, Z., Ghardallou, W., Xin, Y., & Cao, J. (2023). Nexus of institutional quality and technological innovation on renewable energy development: Moderating role of green finance. *Renewable Energy*. https://doi.org/10.1016/j.renene.2023.05.089

Zhong, S., Chen, J., Ur, Z., & Faiz, R. (2024). Quantifying digital economy and green initiatives for carbon neutrality targets : a Kilian bias - adjusted bootstrap model evaluation of China economy. *Environmental Science and Pollution Research*, *0123456789*. https://doi.org/10.1007/s11356-023-31445-0