

Do Natural Resources and Institutional Quality Reduce Energy Intensity? Evidence from Developing and Advanced Economies

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Abstract

This study investigates the function of institutions and natural resources in reducing the energy intensity for developing and advanced economies by employing the PCSE estimator and the D-H test. The PCSE estimator indicates that natural resources increase the energy intensity for both economies, and institutions reduce it for developing economies and increase it for advanced economies. The D-H test designates a short-run bidirectional causal relation between natural resources and energy intensity for developing economies and between institutions and energy intensity for advanced economies. The results imply that both economies should enhance their institutional quality and manage natural resource utilization.

Keywords: *Energy intensity; Institutions; Natural resources; Panel analysis.*

Introduction

Energy consumption plays a vital role in promoting sustainable development in countries. Before the world oil price shock in 1970, there was a strong linkage between the consumption of energy and the enhancement of the nation's sustainable development. Therefore, the acceleration of energy consumption was highly recommended. However, following the oil price shock in 1970 and the associated global warming and energy security issues, achieving the efficiency of energy consumption became highly emphasized to conserve the existing energy sources, preserve the environment, and enhance the nation's economic growth at the same time (Adom and Kwakwa, 2014). Additionally, improving the efficiency of energy consumption and fostering the deployment of renewable energy sources contribute to accomplishing two of the long-term sustainable development goals (SDGs) set by the United Nations, which are SDG7 ("affordable and clean energy") and SDG13 ("mitigating the climate change") (Caglar et al., 2024a; United Nations, 2024).

Energy intensity gauges the quantity of energy needed to yield one production unit. Energy consumption efficiency is improved when a given output can be produced with less energy. Hence, much of the literature used energy intensity as a proxy for energy consumption efficiency (Adom, 2015).

The process of economic development is associated with heavy usage of natural resources and inefficient consumption of various energy sources, which accelerate the exhaustion of natural resources and the degradation of environmental quality. However, countries with good institutional quality suffer less from natural resource depletion and inefficient energy consumption compared to countries with low institutional quality, as institutions govern the utilization of natural resources that guarantee their sustainability and the protection of environmental quality (Danish et al., 2019a). Thus, institutions play a vital function in managing the extraction of natural resources and improving environmental performance.

Human capital also contributes to the efficiency of energy consumption and the reduction of harmful emissions, as well-educated human capital tends to accelerate the consumption of clean energy sources and shrink the depletion of fossil fuel energy sources, which improves environmental performance (Gao et al., 2022). Furthermore, environmental regulations are essential for increasing the efficiency of energy consumption, as environmental regulations imply policies that lead to limiting the consumption of non-renewable energy sources and the reduction of environmental pollution. Environmental regulations include formal regulations (that are policies formulated by public institutions to improve ecological performance)

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and informal regulations (that are policies that target different citizens, non-governmental organizations, or the market to reduce corporate pollution activities) (Guo et al., 2022). Environmental regulations tend to promote the shifting of energy consumption in favor of clean energy sources, which is associated with upgrading the ecological quality of the nations.

The purpose of this paper is to explore the potential role of institutions, natural resources, human capital, and environmental regulations in reducing the energy intensity for a global sample of 80 nations during the timeframe (2004-2018) by applying a panel correlated standard error estimator to examine the association among the variables and the D-H test to investigate the causal relation among the variables in the short run to suggest proper policies that can help in cutting down the energy intensity in those nations. This study selected a global sample as the issue of mitigating environmental degradation and fostering energy consumption efficiency is a global issue that confronts the whole world. As stated by the World Bank, the portion of global fossil fuel energy consumption in the final energy consumption reached 79.68% in 2015 (World Bank, 2024). The timeframe (2004-2018) was selected because this is the longest series based on the data availability. Moreover, this period witnessed the exacerbation of environmental deterioration, which raised concerns about fostering energy consumption efficiency at the domestic and international levels.

The arrangement of this work will be as follows: following the introduction, a survey of the preceding literature is disclosed in the second section, section three outlines the theoretical framework, section four demonstrates the specification of the model and the data, section five shows the methodology and the practical assessment, section six demonstrates the diagnostic checking, section seven displays the results and discussion, section eight displays the policy implications and conclusion, and finally section nine outlines limitations of the study and future recommendations.

Figure 1 shows that the energy intensity indicator witnessed a decline globally over the time frame (2000-2021).

Figure (1): The Evolution of the Energy Intensity Globally Over the Period (2000-2021)



Source: World Bank, 2023a

Survey of the preceding literature

The issue of mitigating climate change and fostering energy consumption efficiency has gained great attention in recent periods to protect the environment from harmful releases and promote the transition to more sustainable energy sources. As a result, a vast amount of literature has explored the factors determining the energy intensity for various nations and different areas using different econometric methods to suggest policies that help policymakers achieve energy consumption efficiency and improve environmental performance.

This work will divide the preceding studies that tackled the factors determining the energy intensity into four main groups. The initial group of the preceding studies tackled the relation between institutional performance and energy efficiency. The following group of literature tackled the association between natural resources and environmental quality. The third group of literature examined the association between human capital and energy consumption efficiency. The fourth group of literature investigated the connection between environmental regulations and environmental deterioration.

The Link between Institutional Performance and the Efficiency of Energy Consumption

Most of the studies argue that good institutional quality fosters energy consumption efficiency and, thus, improves environmental quality. For instance, Castiglione et al. (2015) investigated the relationship between the regulations of the law and environmental pollution for 33 high-income nations during the timeframe (1996-2010). By applying a Panel-VAR approach, the paper found that the rule of law reduced environmental pollution. Based on the Parametric Stochastic Frontier approach, Sun et al. (2019) tackled the association between institutional performance and energy consumption efficiency for a sample of 71 nations representing various development levels during the timeframe (1990-2014). The paper confirmed that the performance of the institutions had a significant positive influence on energy efficiency. In the same vein, Aldieri et al. (2020) explored the function of institutional performance in improving the technical efficiency of the firms in the European nations, Japan, and the USA during the time frame (2002-2017) by adopting the production frontier and inefficiency model. The study found that institutional quality improved the firm's technical efficiency and, thus, reduced environmental pollution. Furthermore, Yasmeen et al. (2023) investigated the potential role of institutions, as gauged by the rule of law, in boosting energy consumption efficiency for the OECD countries during the period (1995-2020). By utilizing the Slacks-based super-efficiency measure (SBM) model and Data Envelopment Analysis (DEA) efficiency model, the study emphasized the crucial function of the rule of law in executing tax reforms that enhanced the adoption of green technology and hence fostered energy consumption efficiency.

In contrast to the previous studies, a few did not find such a desired relation between the institutions and the environmental quality. For example, Akhbari and Nejati (2019) studied the influence of corruption on carbon emissions by conducting a panel analysis for 61 nations during the time frame (2003-2016). The paper found that corruption did not have a significant impact on carbon emissions. Furthermore, Azam et al. (2021) explored the impact of institutional performance on energy consumption for a group of developing nations over the period (1991-2017). By adopting a GMM system, the study concluded that institutions increased energy consumption. Additionally, Shah et al. (2022) examined the association among trade, financial development, governance, and energy efficiency for the G7 countries during the time frame (1996-2015) by applying the Driscoll & Kraay method. The study found that governance did not focus on fostering energy consumption efficiency.

The Association between Natural Resources and Environmental Quality

Several studies argue that economic growth and industrialization drive the exploitation of natural resources, which causes waste generation and environmental deterioration (Usman et al., 2022). For example, Erdogan et al. (2020) investigated the function of natural resources utilization in ameliorating the ecological performance as gauged by the environmental footprint in twenty-three Sub-Saharan African countries during the time frame (1980-2016). By utilizing CUP-FM and CUP-BC estimators, the study concluded that natural resources hindered achieving environmental sustainability. In the same vein, Caglar et al. (2023) explored the impact of natural resource utilization on the ecological well-being of Russia using the load capacity factor as an indicator of the environmental quality over the period (1992-2021). By employing the artificial intelligence unit root and the asymmetric Fourier causality approach for robustness analysis, the study found that natural resource extraction deteriorated the environmental quality of Russia. The same conclusion was reached by the study of Yavuz et al. (2023), which investigated the association among the gross domestic product, the unemployment rate, the natural resources rent, the primary energy consumption, and the environmental quality in Turkey during the time frame (1982-2022) by adopting the newly developed Augmented Autoregressive Distributed Lag (A-ARDL) with Fourier term.

Contrastingly, other studies argue that economic growth and industrialization enhance the shift to updated technologies and innovations that foster the replacement of natural resources and improve environmental performance (Usman et al., 2022). For instance, Zafaar et al. (2019) explored the effect of natural resources, human capital, and FDI on the environmental performance in the USA over the period (1970-2015) by applying an ARDL model. The study concluded that natural resources utilization led to curtailing the environmental footprint. Also, by employing a panel cointegration analysis, Danish et al. (2020) scrutinized the effect of renewable energy, natural resources, and urban population on the environmental performance in BRICS economies during the period (1992-2016). The paper documented that natural resources ameliorated environmental performance.

The Association between Human Capital and Energy Consumption Efficiency

Most empirical papers argue that well-educated human capital significantly improves energy consumption efficiency and, hence, improves environmental quality. For example, Gao et al. (2022) scrutinized the effect of human capital on energy consumption for 30 Chinese provinces over the time frame (2000-2019) by applying the Augmented Mean Group (AMG) method. The study concluded that well-educated human capital enhanced the consumption of environmentally friendly energy sources and resulted in a decline in non-renewable energy consumption, which improved environmental performance. The same conclusion was reached by Adepoju et al. (2022), who adopted Bibliometric analysis over the period (2000-2022). The study argued that human capital enhanced the consumption of clean energy sources. Similarly, Yilanci et al. (2022) analyzed the role of urbanization and human capital in improving the environmental performance as gauged by the forest footprint in China over the timeframe (1961-2017) by utilizing Fourier cointegration. The study concluded that human capital contributed to saving forests. Consistently, based on the CS-ARDL approach and by employing the load capacity factor as an indicator of environmental performance, Caglar et al. (2024b) tackled the association among municipal solid waste, renewable energy consumption, human capital, natural resources, and the environmental quality for the European economies. The study concluded that human capital promoted ecological quality.

In contrast to the previous studies, a few studies did not agree that well-educated human capital mitigates environmental deterioration. For example, Cakar et al. (2021) established a nonlinear relationship between human capital and energy consumption for 21 European countries during the period (1994-2018) by employing a Panel Smooth Transition Regression Model (PSTR). Furthermore, for the G20 countries, Unal and Aktug (2022) studied the influence of human capital and environmental capacity on environmental performance during the period (1970-2016) by employing the Panel Dynamic Common Correlated Effects (DCCE) model. The paper argued that the relationship between human capital and environmental quality differed in different geographical areas, which could be attributed to the differences in social and cultural factors from one geographical area to another. Additionally, Li et al. (2022) tackled the relationship among income inequality, globalization, human capital, and carbon emissions in Pakistan over the timeframe (1980-2015) by adopting dynamic auto-regressive distributive lag simulation. The study found that human capital deteriorated environmental quality.

The Connection between Environmental Regulations and Environmental Deterioration

A considerable amount of literature investigated the relationship between environmental regulations and energy consumption, and the findings varied. Some studies argue that ecological regulations contribute to improving environmental performance. For instance, He et al. (2019) analyzed the function of ecological taxes in improving energy consumption efficiency for 32 OECD nations during the period (1995-2016). By employing an Epsilon-Based Measure-Data Envelopment Analysis (EBM-DEA), the study concluded that energy taxes reduced coal energy consumption, thus improving energy consumption efficiency. In a similar vein and by applying the same method, Wang and Liang (2022) scrutinized the effect of environmental regulations on energy intensity in China over the timeframe (2010-2019) and found that environmental regulations improved the efficiency of energy consumption in China. Consistently and by employing the same methodology, the study of Shah et al. (2024) for the G20 economies over the period (1995-2020) emphasized the vital function of technological change in promoting energy consumption efficiency.

In contrast to the previous views, other studies did not find such a desired relation between environmental regulations and energy efficiency. For instance, Moshiri and Daneshmand (2020) tackled the influence of government expenditure on the preservation of the environment in Iran during the timeframe (1976-2014) by utilizing an ARDL model. The paper documented that government spending was insignificant in curtailing environmental pollution. Similarly, Caglar and Yavuz (2023) investigated the potential function of environmental preservation expenditure and renewable energy consumption in improving the environmental performance of 22 European Union countries over the period (1995-2018). By adopting the CS-ARDL predictor, the study found that environmental preservation spending was insignificant in improving the environmental performance of the 22 European Union countries.

Research Gap

To sum up, much of the literature explored the determinants of environmental quality to suggest suitable guidelines that help ameliorate energy consumption efficiency and foster the consumption of clean energy sources. Most of the previous literature that examined the influence of institutions, natural resources, human capital, and environmental regulations in improving environmental performance used carbon dioxide emissions as a gauge of environmental quality. Few studies have investigated the impact of those factors in improving environmental performance using energy intensity as a gauge of environmental quality; thus, the initial value added to this study is to employ energy intensity as an indicator of environmental performance. The energy intensity is a precise indicator of environmental performance that measures the energy utilized to yield one unit of GDP; thus, it is better to use the energy intensity as an indicator of environmental performance as reducing the energy intensity (i.e., improving the efficiency of energy consumption) has a fundamental function in mitigating the environmental degradation and solving the energy security issues (Sadorsky, 2013).

Moreover, although the preceding studies tackled the impact of those factors in improving the environmental quality, to our best knowledge, no preceding paper investigated the impact of those factors in enhancing the environmental quality in one study. The second aspect of this work is to examine the impact of the institutions, natural resources, human capital, and environmental regulations in enhancing energy consumption efficiency in one study using energy intensity as an indicator of environmental performance.

The third involvement of this paper is concerned with the study sample, which is the global sample. Of our best acquaintances, this is the initial work that explored the potential role of those determinants in reducing the energy intensity for a global sample. The fourth involvement of this work is that this work divides the global sample into developing and emerging market economies and advanced economies, depending on the IMF countries' classification, to get different insights from the results of both samples that represent countries with different levels of growth.

The fifth contribution of this work is related to the measures of the institutions and human capital utilized in this study. Most of the previous studies used the World Governance Indicators (WGI) or the International Country Risk Guide (ICRG) as measures for the institutions, and the human capital indicator obtained from the Penn World Table (PWT) as a measure for the human capital variable. Thus, this work adds to the preceding literature by employing novel gauges for the institutions and human capital variables extracted from the United Nations Conference on Trade and Development (UNCTAD). The measure of the institutions variable employed in this study is a unique gauge that accounts for the stability of the nations' politically, the quality of regulations, the achievements of eliminating corruption, and protecting the people's right to express themselves, while the measure of the human capital variable utilized in this study considers the education, health conditions, R&D activities, and fertility rate compared to the human capital indicator obtained from PWT that accounts merely for the duration of schooling and the yields of learning.

The sixth involvement of this work is related to the methodology applied in this work, as this work takes into consideration the issues of cross-sectional dependency, heteroscedasticity, and serial correlation by employing the panel-correlated standard error estimator to detect the association among the variables.

Moreover, this work employs the Dumitrescu and Hurlin examination to figure out the causality among the variables.

Theoretical Framework

This section outlines the theoretical background for the function of institutions, natural resources, human capital, and environmental regulations in enhancing energy consumption efficiency.

The Function of Institutions

The theoretical argument for the institutions and their impact on environmental pollution can be outlined through the theory of public goods, which explains the function of the government in the production process. The theory of public goods postulates the failure of the private sector in the production of commodities that have the characteristics of a public good (Holcombe, 2000). Environmental protection can be regarded as a public good and since the private agents do not consider the negative externalities (i.e., environmental costs) associated with their production process, government intervention is needed to protect the environment from the emissions of harmful gases associated with the production process made by the private sector (Dasgupta and De Cian, 2016).

In addition to the theory of public goods, the environmental modernization theory argues that state intervention is not needed to balance economic welfare and environmental protection in advanced industrial nations. This is because, following the attainment of a certain level of economic growth, the process of economic growth is accompanied by the adoption of energy-efficient machinery that does not harm the environment, and thus, no opposition exists between economic growth and environmental protection (Duit, 2005).

Moreover, Coase (1937; 1991), Williamson (1975), and North (1994) emphasized the function of institutions in achieving social objectives, including the improvement of economic performance and the elimination of poverty. Good institutional quality can improve environmental performance and reduce energy intensity through the inflow of foreign capital, which results in the utilization of green technologies and the improvement of energy consumption efficiency. Also, institutions formulate principles that raise popular consciousness about the preservation of environmental quality and the efficient utilization of natural resources (Dehdar et al., 2020; Hoang, 2021).

The Function of Natural Resources

The theoretical underpinning for the relation between natural resources and energy consumption efficiency is stated by Panayotou (1993), who argued that the relation between natural resources and the efficiency of energy consumption relies on five main factors: 1) the economy's size, 2) the economy's segmental structure, 3) the quality of machinery, 4) the request for environmentally responsible facilities, and 5) the effectiveness of the environmental expenses. Panayotou (1993) argues that economies with higher levels of GNP (i.e., larger size) tend to deplete more natural resources and suffer from higher pollution levels compared to economies with lower levels of GNP (i.e., smaller size). Additionally, the economy's segmental structure impacts the rates of natural resource depletion and environmental pollution, as economies that rely intensively on agricultural production and other primary activities tend to have higher rates of natural resource depletion, less efficiency in energy consumption, and higher pollution levels.

Also, the scope of the manufacturing sector in an economy and the portion of chemicals and heavy industries in the production process affect the emissions level. Countries that reach later stages of development tend to have a smaller share of the industrial sector and a smaller share of chemicals and heavy industries within an industry associated with an increased share of information technologies and services, and a decline in the emissions levels. Moreover, the quality of technology affects the rates of natural resource depletion and environmental pollution, which clarifies why countries with the same industrial structure generate different emission levels. This is because employing outdated machinery results in less efficient consumption of energy sources and higher levels of emissions compared to employing highly

qualified machinery and equipment. Finally, preferences for environmentally responsible facilities and the share of environmental expenditures in government and industry budgets affect the rate of natural resource depletion and environmental pollution.

Earlier phases of economic growth are associated with the prevalence of poverty, lower levels of environmental awareness, ineffective tax collection for environmental protection, and insufficient funds devoted to promoting environmental quality. At low levels of income, the private sector does not devote enough funds to environmental protection, and the population demand for environmental amenities tends to be inelastic. Despite the insufficient funds devoted to environmental protection and the lower requests for environmental amenities by the population at the initial phases of economic development, the emission levels at this stage are still low. This is because at the initial phases of economic growth, the level of waste is relatively low, and the natural assimilative capacity of the environment is not overloaded with harmful emissions. As the development process expands within a nation, the rates of natural resource depletion accelerate, and the emission levels increase, resulting in a decline in the natural assimilative capacity of the environment. As the economy reaches the point of a newly industrializing economy (NIE), environmental degradation reaches its highest levels, resulting in economic, political, and social pressures to enforce environmental regulations. Enforcing environmental regulations leads to shifting to industries that release less harmful emissions, increasing the demand for products that do not harm the environment, and boycotting the industries that harm the environment. Thus, the environmental quality is improved at later stages of development (Panayotou, 1993).

The Function of Human Capital

The conceptual argument for human capital potential function in improving energy consumption efficiency can be outlined at the micro and macro levels. At the micro level, households with well-educated human capital tend to use appliances that consume less energy, which leads to an increase in energy consumption efficiency. At the macro level, human capital affects energy consumption efficiency through three channels: the income effect, the technological effect, and the complementary effect (Yao et al., 2019).

For the income effect, the endogenous hypothesis of growth argues that human capital has a vital function in enhancing the economic growth of a nation and that human capital may accelerate energy consumption indirectly by fostering economic growth. The income effect does not clarify whether the increase in energy consumption goes for clean energy sources or dirty energy sources. For the deployment of clean energy sources, the Environmental Kuznets Curve (EKC) hypothesis claims that at higher levels of income (i.e., advanced phases of economic growth), the economy adopts low-carbon technologies. Thus, human capital is expected to enhance the consumption of environmentally friendly energy sources through the income effect. The influence of human capital on the consumption of electricity from dirty sources is unclear as it relies on the force of the substitution effect of economic growth (at higher levels of income, human capital substitute clean energy sources for dirty energy sources) and the scale influence of economic growth (the overall economic growth accelerates the emissions of harmful gases through trade openness) (Fang et al., 2018; Yao et al., 2019).

For the technology effect, human capital accumulation increases energy consumption efficiency and lessens the rate of natural resource depletion. At higher-income levels, the economy devotes funds to investment in R&D that increases energy consumption efficiency, lessens the cost of adopting clean energy sources, and hence makes the consumption of renewable energy sources more competitive relative to fossil fuel energy sources (Yao et al., 2019).

For the complementary effect, Fallon and Layard (1975) argue that human capital complements physical capital investment in capital-intensive technologies. According to Kim and Heo (2013), capital-intensive technologies tend to lower energy intensity and foster the adoption of clean energy sources. Hence, human capital accumulation associated with physical capital investment enhances energy consumption efficiency and shifts energy consumption patterns in favor of clean energy sources (Yao et al., 2019).

The Function of Environmental Regulations

The theoretical framework for the association between environmental regulations and energy consumption efficiency can be reflected through the forced emission-reduction and the green paradox. According to the green paradox, when a nation starts to implement environmental regulations to improve environmental quality and reduce energy intensity, the environmental policies set by the nation need to be improved at the initial stage of implementation. Thus, some firms continue consuming fossil fuel energy sources intensively to avoid the cost of committing to the environmental regulations, which increases the energy intensity and results in environmental deterioration. With the improvement and enforcement of environmental regulations, firms will start adopting new technologies that enhance production with less energy. Additionally, firms will foster the consumption of environmentally friendly energy sources to adhere to the environmental regulations, resulting in a decline in energy intensity and improving the ecological quality (Yin et al., 2022).

Model Specification and Data

Based on the preceding literature and the theoretical framework, this study investigates the potential function of institutions, natural resources, human capital, and environmental regulations in reducing the energy intensity, while integrating the roles of trade openness, GDP per capita, FDI, and urbanization. The model suggested to tackle such an objective is stated as follows:

$$Y_{it} = \alpha_i + \beta' X_{it} + \varepsilon_{it} \quad i=1, \dots, N, \quad t=1, \dots, T \quad (1)$$

Where Y_{it} stands for the scalar explained variable, X_{it} is $K \times 1$ vector of regressor variables, ε_{it} is iid over i and t , i stands for the person (or company or nation) in a cross-section, and t indicates the timeframe. The α_i are stochastic variables that reflect unobserved heterogeneity (Cameron and Trivedi, 2005). The estimation model is presented below:

$$EI_{it} = \beta_0 + \beta_1 INST_{it} + \beta_2 NRT_{it} + \beta_3 HC_{it} + \beta_4 ER_{it} + \beta_5 TO_{it} + \beta_6 Y_{it} + \beta_7 FDI_{it} + \beta_8 URB_{it} + \varepsilon_{it} \quad (2)$$

Where i stands for each cross-section (nations) and t stands for the time frame, which covers the period (2004-2018) in this paper. β stands for the coefficient of the slope of the subsequent variable. It means a single unit increase in the independent variable will increase (decrease) the energy intensity by β units, ceteris paribus. ε_{it} represents the estimation residual. Table (1) below outlines the variables employed in this paper, their meanings, and data sources.

This study utilized proxies for variables based on the preceding literature. Energy intensity is employed as an indicator of environmental performance following the studies of Adom and Kwakwa (2014), Petrovic and Lobanov (2022), and Sun et al. (2022), among others. Moreover, much of the literature utilized natural resource rent as a proxy for natural resource returns, including the studies of Danish et al. (2019a), Khan et al. (2020), and Usman et al. (2022). Furthermore, various studies exploited patents on environmental technologies as an indicator of environmental regulations. For instance, the studies of Hashmi and Alam (2019), Ouyang et al. (2019), and Nathaniel et al. (2021). Finally, as components of the productive capacity index, this study investigated the impact of institutions and human capital on energy consumption efficiency following the studies of Demiral and Demiral (2023), Li et al. (2023), and Oluc et al. (2023).

Table (1): variables, definitions, and sources of data

| Variables | Meanings | Sources of data |
|-----------------------|--|---|
| Energy Intensity (EI) | Energy intensity gauges the energy utilized to produce a single production unit by measuring the ratio between energy supply and GDP and assessing this ratio at purchasing power parity. A lower ratio signifies utilizing less energy to produce a single production unit. | World Bank Development Indicators (WDI) |

| | | |
|---------------------------------------|--|---|
| Institutions (INST) | Institutions aim at gauging the nation's stability from the political side and its efficiency through measuring the quality of regulations, the accomplishments in combating criminality, corruption, and terrorism, and protecting the people's right to express themselves. Institutions are considered one of the productive capacity index (PCI) categories, which is a comprehensive tool developed by the United Nations that assists economies in evaluating and enhancing their productive capacity. | United Nations Conference on Trade and Development (UNCTAD) |
| Natural Resources (NRT) | Aggregate natural resources rents are the additions of oil rents, natural gas rents, coal rents, mineral rents, and forest rents, gauged as a proportion of GDP. | WDI |
| Human Capital (HC) | Human capital gauges the schooling, skills, health circumstances of the people, and fertility rate. The fertility rate reflects the gender aspect, as with each increase in the fertility rate, the human capital score is reduced. Moreover, human capital assesses the aggregate R&D in society through evaluating the number of scholars and the spending on research conducted. Human capital is also considered one of the productive capacity index (PCI) categories. | UNCTAD |
| Environmental Regulations (ER) | Environmental regulations are gauged by two indicators on the OECD: patents on environmental technologies and environmental taxes. Based on the existing data, this paper used patents on environmental technologies as an indicator of environmental regulations. Patents on environmental technologies refer to the ratio between inventions related to the environment and the aggregate domestic inventions in all technologies. | Organization for Economic Co-operation and Development (OECD) |
| Trade Openness (TO) | Trade openness is the sum of exports and imports of goods and services gauged as a proportion of GDP. | WDI |
| GDP (Y) | Real aggregate domestic output per capita gauged in constant 2015 US dollar. | WDI |
| Urbanization (URB) | People residing in urban areas gauged as % of the total. | WDI |
| FDI | Foreign direct net inflows as % of GDP. | WDI |

Table (2) below displays the variables summary statistics for the global sample over the time frame (2004-2018), which is the longest series based on data availability. The aggregate variation displays the variation through time and nations. The overall variation can be broken into the between variation and the within variation. The between variation manifests the variation among nations, while the within variation displays the variation within the nations over time. The mean demonstrates the variables' average value, while the standard deviation displays the divergence from the sample's mean. As exhibited in Table (2), Uzbekistan

has the highest energy intensity among the 80 nations (23.29 in 2004), while Malta has the lowest energy intensity (1.32 in 2018). Finland has the highest value for the institutions' variable (100 in 2004), while Uzbekistan has the lowest value (20.57 in 2005). Regarding the natural resources variable, Saudi Arabia has the maximum value (55.48 in 2008), while Malta has the lowest value (zero in the year 2004 and over the time frame (2010-2018)). Concerning the human capital variable, Korea has the highest value (95.56 in 2018), while Pakistan has the lowest value (14.21 in 2004). Concerning the environmental regulations variable, Ghana has the largest value (63.86 in 2014), while Cyprus has the smallest value (0.84 in 2013).

Table (2): The variables' descriptive statistics for the global sample

| Variables | | Mean | Std. Dev. | Min. | Max. |
|-----------|---------|----------|-----------|----------|----------|
| EI | overall | 4.69 | 2.32 | 1.32 | 23.29 |
| | between | | 2.18 | 2.05 | 13.49 |
| | within | | 0.82 | -0.99 | 14.48 |
| INST | overall | 64.48 | 20.50 | 20.57 | 100 |
| | between | | 20.49 | 26.81 | 97.54 |
| | within | | 2.29 | 51.18 | 72.82 |
| NRT | overall | 4.75 | 8.28 | 0 | 55.48 |
| | between | | 7.86 | 0 | 41.03 |
| | within | | 2.73 | -16.12 | 19.19 |
| HC | overall | 55.48 | 16.49 | 14.21 | 95.56 |
| | between | | 16.29 | 17.59 | 87.27 |
| | within | | 3.14 | 40.72 | 68.79 |
| ER | overall | 12.49 | 6.39 | 0.84 | 63.86 |
| | between | | 3.44 | 6.10 | 25.86 |
| | within | | 5.39 | -4.63 | 56.21 |
| TO | overall | 92.19 | 60.52 | 20.72 | 437.33 |
| | between | | 59.54 | 25.63 | 370.46 |
| | within | | 12.61 | 19.71 | 159.06 |
| Y | overall | 20629.65 | 21422.67 | 723.23 | 112417.9 |
| | between | | 21447 | 1045.17 | 105919.5 |
| | within | | 2080.28 | 10319.82 | 39813.84 |
| FDI | overall | 7.31 | 26.44 | -57.53 | 449.08 |
| | between | | 17.08 | 0.26 | 120 |
| | within | | 20.27 | -111.35 | 336.39 |
| URB | overall | 68.93 | 17.65 | 21.31 | 100 |
| | between | | 17.66 | 24.05 | 100 |
| | within | | 1.79 | 59.72 | 77.73 |

Methodology and Practical Assessment

Methodology

In panel data models, individuals (firms, countries, and persons) are observed at several points in time. In short panels, the periods are relatively few (small T), while the number of individuals is relatively large (large N). The two fundamental models for the scrutiny of panel data are the fixed and random effects models. Since the cross sections are relatively large, whereas the time frame is relatively small in this study, those models were adopted to explore the potential role of the institutions, natural resources rent, human capital, and environmental regulations in reducing the energy intensity over the period (2004-2018).

Each model is built under a set of assumptions. The fixed effects model is built on the assumptions that the individual-specific effect (α_i) is a stochastic variable that is tolerable to be correlated with the independent variables, the variance of the individual-specific effect is not assumed to be constant, and the time-varying explanatory variables are not perfectly collinear. While the random effects model is built on the assumptions that the individual-specific effect (α_i) is a stochastic variable that is uncorrelated with the independent variables of all historical, present, and forthcoming time frames of the same individual, the variance of the individual-specific effect is constant, and no perfect collinearity exists among the explanatory variables comprising a constant (Schmidheiny and Basel, 2011).

Practical Assessment

Table (3) below demonstrates the results of the fixed and random effects estimators. Established upon the findings of the Hausman test displayed in Table (4), the fixed effects estimator is preferred for the global sample and the developing and emerging market economies sample, while the random effects model is preferred for the advanced economies sample. The null hypothesis of the Hausman test indicates that the random effects model is the desired model. In contrast, the alternative hypothesis states that the fixed effects model is the desired model.

Table (3): fixed and random effects estimator results

| Variables | Global Sample (Fixed effects) | Developing and Emerging Market Economies (Fixed effects) | Advanced Economies (Random effects) |
|--|----------------------------------|--|--|
| Institutions (inst) | [-0.0600] (0.000)* | [-0.0678] (0.000)* | [-0.0451] (0.000)* |
| Natural resources (nrt) | [0.0554] (0.000)* | [0.0565] (0.000)* | [0.0989] (0.006)* |
| Human capital (hc) | [-0.0190] (0.047)** | [0.0473] (0.013)** | [-0.0544] (0.000)* |
| Environmental regulations (er) | [0.0014] (0.730) | [0.0049] (0.362) | [-0.0102] (0.079)*** |
| Trade openness (to) | [0.0022] (0.228) | [0.0085] (0.011)** | [-0.0051] (0.001)* |
| GDP per capita (y) | [-0.0001] (0.000)* | [-0.0001] (0.000)* | [-0.00004] (0.000)* |
| Foreign direct investment (fdi) | [0.0021] (0.052)*** | [0.0304] (0.000)* | [0.0006] (0.391) |
| Urbanization (urb) | [-0.0639] | [-0.0972] | [0.0158] |

| | | | |
|------------------|----------|----------|---------|
| | (0.000)* | (0.000)* | (0.386) |
| R-squared | 0.9687 | 0.9034 | 0.9466 |

Note: The coefficient values are outlined in [], whereas the probability values are outlined in (). *, **, and *** stand for the rejection of the null hypothesis at 1%, 5%, and 10% level of significance, respectively.

Table (4): The Hausman test for fixed and random effects

| Global Sample | Developing and Emerging Market Economies | Advanced Economies |
|----------------------|--|--------------------|
| [95.09] (0.0000)* | [19.17] (0.0140)** | [4.83] (0.7760) |

Note: chi-square values are outlined in [], whereas the probability values are outlined in (). * and ** indicate the rejection of the null hypothesis at 1% and 5 % significance level, respectively.

Diagnostic Checking

Since the study applied a short panel model, it is expected that the models chosen will suffer from serial correlation, heteroscedasticity, and cross-sectional dependency. To verify the existence of these problems, this work applied the Pesaran CD, Friedman, and Frees tests to check the presence of cross-sectional dependence, the Wooldridge test was used to check the occurrence of serial correlation, and the modified Wald test was adopted to check the existence of heteroscedasticity in the fixed effects model. To assess the presence of heteroscedasticity in the random effects model, this study applied the Lagrange Multiplier test, the Likelihood ratio test, and the Wald test.

From the previous tests (see the Appendix for details), it was found that the three models suffer from heteroscedasticity, serial correlation, and cross-sectional dependence. Two approaches are adopted in the literature to control these three problems. The first approach is the Feasible Generalized Least Squares (FGLS). FGLS produces efficient estimation when the time frame (T) is superior or equivalent to the cross sections (N) (Hoechle, 2007). The second approach is the Panel Correlated Standard Error (PCSE). PCSE should be employed when the cross sections' (N) number is superior to the time frame (T) (Reed and Ye, 2011). In this study, the cross sections (countries) are superior to the time frame for the three samples; thus, the PCSE is the proper estimator.

Following the scrutiny of the association among the variables using the PCSE estimator, this work investigated the causal relation among the variables in the short run by employing the Dumitrescu-Hurlin causality (D-H) test. The D-H test is a modified version of the Granger causality test that generates more trustworthy findings in the presence of cross-sectional dependence and heterogeneity. Moreover, it is more flexible either for a time frame that is superior to the cross sections or smaller than the cross sections' number as it accounts for unbalanced data (Saud et al., 2020; Chhabra et al., 2023). The model for the Dumitrescu-Hurlin causality test can be demonstrated as shown below:

$$Y_{it} = \alpha_i + \sum_{k=1}^K \beta_{ik} Y_{i,t-k} + \sum_{k=1}^K \beta_{ik} X_{i,t-k} + \epsilon_{it} \quad (3)$$

Where Y_{it} and X_{it} represent the variables for country i and period t . K stands for the lag order for each variable, which is assumed to be identical across countries. α and β are the model parameters that are permitted to diverge across nations. The null hypothesis of the test indicates the nonexistence of a causal relation among the variables for all countries (cross-sections), while the alternative heterogeneous hypothesis signifies the presence of at least a single causal relation in the panel (Chhabra et al., 2023; Kostakis et al., 2023). Equation (3) establishes whether x causes y or not. The basic idea is that if, by

incorporating the previous values of y in the model, the past values of x significantly predict the current value of y , then this indicates that x has a causal effect on y (Chhabra et al., 2023).

Results and Discussion

The Panel Correlated Standard Error (PCSE) estimator results

PCSE estimator results for the global sample

Table (10) below displays the results of the PCSE for the three samples. For the global sample, the institutions and natural resources are significant at a 5% significance level, GDP per capita is significant at a 1% level of significance, whereas urbanization is significant at a 10% level of significance. The rest of the variables are insignificant. The insignificance of the environmental regulations' variable can be attributed to the ineffectiveness of those regulations in limiting the consumption of non-renewable energy sources, while the insignificance of the human capital variable can be attributed to the unawareness of human capital of their crucial role in promoting the environmental quality through shifting their consumption in favor of clean energy sources. Established upon the PCSE, a single unit rise in the institutional quality, per capita GDP, and urbanization will be associated with a reduction in the energy intensity by 0.0223, 0.00002, and 0.0109 units, respectively. On the other hand, a one-unit increase in natural resource utilization will be associated with a rise in energy intensity by 0.0313 units.

The coefficients' signs match the economic circumstances of the global sample and the preceding literature as well. A negative sign of the institutional quality, per capita GDP, and urbanization matches the economic conditions of the global sample, as improving the institutional quality is associated with the deployment of energy-efficient machinery, which fosters the economic growth of the nations and ameliorates the environmental performance at the same time. These results are consistent with the preceding literature (For instance, the works of Castiglione et al. (2015), Sun et al. (2019), and Aldieri et al. (2020)).

Also, urbanization may enhance the efficiency of energy consumption through economies of scale, which results in a reduction in energy demand. This outcome matches the works of Liddle (2004), Chen et al. (2008), and the study of Poumanyong and Kaneko (2010) for the low-income nations. Moreover, a positive sign of natural resources utilization is in line with the economic conditions of the global sample, as the exhaustion of natural resources is associated with the worsening of the environmental quality. This result matches the works of Ahmed et al. (2020a), Khan et al. (2020), and Usman et al. (2022).

PCSE estimator results for the emerging and developing market economies sample

For the emerging and developing market economies sample, the institutions and trade openness are significant at a 1% level of significance, the natural resources, per capita GDP, and urbanization are significant at a 5% level of significance, whereas the FDI is significant at a 10% level of significance. The remaining variables are insignificant. According to the PCSE, a single unit rise in institutional quality, per capita GDP, and urbanization will be associated with a decline in the energy intensity by 0.0575, 0.00003, and 0.0161 units, respectively. Contrastingly, a single unit rise in the natural resources' utilization, trade openness, and foreign direct investment will be associated with an increase in energy intensity by 0.0295, 0.0075, and 0.0061 units, respectively.

A negative sign of institutional quality matches the economic circumstances of the developing and emerging market economies. This can be attributed to the vital function of the institutions in improving energy consumption efficiency in those economies. Effective institutions enhance the protection of property rights and the formulation of environmental policies that improve the environmental performance of those economies. This finding matches the studies of Danish et al. (2019b), Karim et al. (2022), and Ofori et al. (2023).

Moreover, a positive sign of natural resources is coherent with the economic conditions of the developing and emerging market economies, as those economies tend to increase their economic growth through depleting natural resources, leading to inefficient energy consumption and emissions of harmful gases. This outcome is consistent with the works of Ali et al. (2021), He et al. (2022), and Hidayat et al. (2024).

Furthermore, a positive sign of trade openness and FDI is consistent with the economic circumstances of those economies. This is because international trade and FDI stimulate economic activities and energy demand and are associated with environmental deterioration if they do not foster the deployment of energy-efficient machinery. Faced with weak environmental regulations in developing and emerging market economies, FDI and international trade are associated with the importation of dirty technologies and the deterioration of environmental quality. These results are in line with the studies of Le et al. (2016), Dou et al. (2021), Chhabra et al. (2023), Wang et al. (2023) for low-income groups, and Shinwari et al. (2024).

Finally, a negative sign of urbanization can be attributed to the tendency of urban households in developing and emerging market economies to curtail their energy demand to save money for precautionary objectives (Fang et al., 2022). This outcome is consistent with the works of Poumanyong and Kaneko(2010) for low-income economies, Fang et al. (2022), and He (2022).

PCSE estimator results for the advanced economies sample

For the advanced economies sample, institutions, trade openness, per capita GDP, and urbanization are significant at a 1% level of significance, whereas natural resources are significant at a 5% level of significance. The rest of the variables are insignificant. A one-unit increase in institutional quality, natural resources utilization, and urbanization will be associated with an increase in the energy intensity by 0.0383, 0.0599, and 0.0349 units, respectively. Conversely, a single unit rise in trade openness and per capita GDP will be associated with a reduction in the energy intensity by 0.0042 and 0.00003 units, respectively.

A positive sign of the institutional quality could be attributed to the fact that the advanced nations focus on fostering their industrial process by increasing the energy demand. However, a negative sign of GDP per capita indicates that the advanced nations tend to shift their energy consumption in favor of clean energy sources, which signifies that those nations consider the environmental quality in stimulating their economic process. These findings match the ecological modernization theory and the Environmental Kuznets Curve hypothesis, which argues that the process of economic growth is linked with the adoption of energy-efficient machinery after attaining a particular growth level. Additionally, these results are supported empirically by the works of Cheikh et al. (2021), Dkhili (2022), and Kostakis et al. (2023).

Moreover, a positive sign of urbanization indicates that urbanization degrades environmental performance. This finding is consistent with the works of Al-Mulali et al. (2015), Ahmed et al. (2020 b), and Raihan (2023). Furthermore, a negative sign of trade openness matches the economic conditions of the advanced economies, as those economies tend to enhance international trade that fosters the adoption of energy-efficient machinery, which promotes the efficiency of energy usage and shifts the consumption in favor of clean energy sources (Chhabra et al., 2023). This finding matches the works of Sbia et al. (2014), Dogan and Seker (2016), and Ertugrul et al. (2016).

Finally, a positive sign of natural resource utilization matches the economic conditions of the advanced nations. This is because shifting the utilization from outdated equipment that depletes more resources to sophisticated ones that foster recycling and innovation will increase the economic growth of those nations but worsen the environmental quality (Muhammad et al., 2021). This outcome is consistent with the works of Muhammad et al. (2021), Li et al. (2024), and Tahir et al. (2024).

Table (10): Panel Correlated Standard Error (PCSE) estimator results

| Variables | Coefficient | Panel-corrected Std. Error | z-Statistic | Probability |
|---------------|-------------|----------------------------|-------------|-------------|
| Global sample | | | | |

| | | | | |
|---|----------|----------|-------|----------|
| Institutions (inst) | -0.0223 | 0.0086 | -2.59 | 0.010** |
| Natural resources (nrt) | 0.0313 | 0.0123 | 2.54 | 0.011** |
| Human capital (hc) | 0.0174 | 0.0124 | 1.41 | 0.159 |
| Environmental regulations (er) | -0.0004 | 0.0033 | -0.11 | 0.910 |
| Trade openness (to) | 0.0004 | 0.0017 | 0.27 | 0.789 |
| GDP per capita (y) | -0.00002 | 6.27e-06 | -2.65 | 0.008* |
| Foreign direct investment (fdi) | 0.0006 | 0.0004 | 1.48 | 0.140 |
| Urbanization (urb) | -0.0109 | 0.0059 | -1.82 | 0.069*** |
| R-squared | 0.9175 | | | |
| Developing and Emerging Market Economies | | | | |
| Institutions (inst) | -0.0575 | 0.0116 | -4.97 | 0.000* |
| Natural resources (nrt) | 0.0295 | 0.0123 | 2.39 | 0.017** |
| Human capital (hc) | 0.0231 | 0.0147 | 1.57 | 0.116 |
| Environmental regulations (er) | 0.0001 | 0.0040 | 0.02 | 0.980 |
| Trade openness (to) | 0.0075 | 0.0025 | 2.95 | 0.003* |
| GDP per capita (y) | -0.00003 | 0.00002 | -2.02 | 0.043** |

| | | | | |
|---------------------------------|----------|----------|-------|----------|
| Foreign direct investment (fdi) | 0.0061 | 0.0031 | 1.95 | 0.051*** |
| Urbanization (urb) | -0.0161 | 0.0062 | -2.57 | 0.010** |
| R-squared | 0.9036 | | | |
| Advanced Economies | | | | |
| Institutions (inst) | 0.0383 | 0.0088 | 4.33 | 0.000* |
| Natural resources (nrt) | 0.0599 | 0.0302 | 1.98 | 0.048** |
| Human capital (hc) | -0.0039 | 0.0136 | -0.29 | 0.770 |
| Environmental regulations (er) | -0.0041 | 0.0042 | -0.98 | 0.328 |
| Trade openness (to) | -0.0042 | 0.0014 | -3.08 | 0.002* |
| GDP per capita (y) | -0.00003 | 5.50e-06 | -5.84 | 0.000* |
| Foreign direct investment (fdi) | -0.0001 | 0.0005 | -0.09 | 0.925 |
| Urbanization (urb) | 0.0349 | 0.0073 | 4.80 | 0.000* |
| R-squared | 0.8668 | | | |

Note: *, **, and *** stand for the rejection of the null hypothesis at 1%, 5%, and 10% level of significance, respectively.

Dumitrescu-Hurlin Causality Test Results

D-H Causality Test for the Global Sample

Table (11) below discloses a summary of the findings of the test. As for the global sample, there exists a unidirectional causal relation going from the institutions to energy intensity, natural resources utilization, trade openness, and GDP per capita. Moreover, unidirectional causal relation is depicted from the energy intensity to natural resources utilization and human capital, and from urbanization to energy intensity, institutions, natural resources utilization, human capital, and trade openness. Additionally, a unidirectional causal relation is depicted from the per capita GDP to natural resources utilization and environmental regulations, and from trade openness to human capital, GDP per capita, and FDI. Finally, a unidirectional causal relation is depicted from human capital to GDP per capita, from environmental regulations to urbanization, and from FDI to urbanization. Furthermore, there exists a bidirectional causal relation

between institutions and FDI, environmental regulations and natural resources utilization, FDI and natural resources utilization, environmental regulations and human capital, urbanization and per capita GDP.

These findings are in line with the economic conditions faced by the global sample as institutions govern the utilization of natural resources in the production process and the technologies embodied in international trade, which match the papers of Sun et al. (2019) and Aldieri et al. (2020). Also, urbanization affects the rates of natural resources depletion, the consumption of energy in the production process, human capital consumption of energy sources, and global trade as urbanization determines the contribution of the people in the economic activities and the transition of those economic activities from agriculture to industrialization which matches the works of Chen et al. (2008) and Dehdar et al. (2020).

Additionally, environmental regulations affect the rates of natural resource depletion, the transition of economic activities from agriculture to industrialization, and the human capital consumption of energy sources. This outcome matches the studies of Guo et al., (2022) and Wang and Liang (2022).

D-H Causality Test for the Developing and Emerging Market Economies Sample

For the developing and emerging market economies, a unidirectional causal relation is depicted from energy intensity to institutions and urbanization, from human capital to institutions, GDP per capita, and urbanization, and from institutions to trade openness. Moreover, a unidirectional causal relation is depicted from GDP per capita to institutions, environmental regulations, and urbanization, from natural resources utilization to trade openness, from FDI to natural resources utilization and per capita GDP, and from trade openness to FDI and per capita GDP. On the other hand, a bidirectional causal relation exists between natural resources utilization and energy intensity, per capita GDP and natural resources utilization, and FDI and institutions.

These findings are in line with the economic conditions of the developing and emerging market economies because the level of education of human capital affects the energy consumed in the production process, and the principles formulated by the institutions to increase the awareness of people towards the preservation of environmental quality. Moreover, the GDP per capita affects the rates of natural resource depletion and the regulations formulated to protect the environment from harmful emissions, which is in line with the works of Dkhili (2022) and Kostakis et al. (2023). Additionally, the inflows of foreign capital affect the exhaustion of natural resources; however, the laws formulated by the institutions govern the energy consumed by the foreign capital, which matches the studies of Dehdar et al., (2020) and Hoang (2021).

D-H Causality Test for the Advanced Economies Sample

For the advanced economies, a unidirectional causal relation is depicted from energy intensity to natural resources utilization, environmental regulations, and urbanization, from institutions to natural resources utilization and FDI, from FDI to trade openness, and from urbanization to institutions and FDI. Moreover, a unidirectional causal relation exists from GDP per capita to institutions and environmental regulations, from environmental regulations to natural resources utilization and urbanization, from trade openness to natural resources utilization, environmental regulations, and urbanization, from human capital to environmental regulations, and from natural resources utilization to GDP per capita. Furthermore, a bidirectional causal relation occurs among institutions and energy intensity, trade openness and energy intensity, institutions and trade openness, urbanization and natural resources utilization, per capita GDP and human capital, and per capita GDP and trade openness.

These results match the economic conditions of the advanced economies, as the rate of natural resources depletion, the regulations formulated to preserve the environment from harmful emissions, and the shifting of economic activities from agriculture to industrialization are affected by the quantity of energy consumed to produce a single unit of production. Moreover, global trade affects the exhaustion of natural resources and the GDP per capita within a nation, nevertheless, the environmental regulations and the laws

formulated by the institutions govern energy consumption efficiency which are in line with the studies of Sun et al. (2019), Wang and Liang (2022), and Chhabra et al. (2023).

Table (11): Summary of the D-H causality test results

| Global sample | Developing and Emerging Market Economies | Advanced Economies |
|---------------|--|--------------------|
| inst → ei | ei → inst | inst ↔ ei |
| ei → nrt | nrt ↔ ei | ei → nrt |
| ei → hc | ei → urb | ei → er |
| urb → ei | hc → inst | to ↔ ei |
| inst → nrt | inst → to | ei → urb |
| inst → to | fdi ↔ inst | inst → nrt |
| inst → y | y → inst | to ↔ inst |
| inst ↔ fdi | nrt → to | y → inst |
| urb → inst | fdi → nrt | inst → fdi |
| er ↔ nrt | y ↔ nrt | urb → inst |
| y → nrt | hc → y | er → nrt |
| fdi ↔ nrt | hc → urb | to → nrt |
| urb → nrt | y → er | nrt → y |
| er ↔ hc | to → fdi | urb ↔ nrt |
| to → hc | to → y | hc → er |
| hc → y | fdi → y | y ↔ hc |
| urb → hc | y → urb | to → er |
| y → er | | y → er |
| er → urb | | er → urb |
| to → y | | y ↔ to |
| to → fdi | | fdi → to |
| urb → to | | to → urb |
| urb ↔ y | | urb ↔ fdi |

fdi → urb

Note: → refers to a unidirectional causal relation, while ↔ refers to a bidirectional causal relation.

Conclusion and Policy Implications

This work investigated the potential function of the institutions, natural resources, human capital, and environmental regulations in reducing the energy intensity for a global sample, which is then divided into developing and emerging market economies, and advanced economies. By employing the PCSE estimator, the study concluded that institutional quality, per capita GDP, and urbanization are associated with a decline in energy intensity, while natural resource utilization is associated with a rise in energy intensity for the global sample and for the developing and emerging market economies sample. Moreover, trade openness and FDI are associated with an increase in energy intensity for the emerging and developing market economies sample. For the advanced economies sample, institutional quality, natural resources utilization, and urbanization are associated with a rise in energy intensity, whereas trade openness and per capita GDP are associated with a decline in energy intensity. Following the examination of the association among the variables, this study investigated the short-run causal relation among the variables by employing the Dumitrescu-Hurlin causality test.

The main findings of the causality examination for the global sample indicate the occurrence of a unidirectional causal relation running from the institutions to natural resources utilization and trade openness, from urbanization to energy intensity, natural resources utilization, human capital, and trade openness, and from environmental regulations to urbanization. Moreover, a bidirectional causal relation is found between environmental regulations and natural resources utilization, and environmental regulations and human capital. For the developing and emerging market economies sample, the results of the causality examination indicate the occurrence of a unidirectional causal relation running from human capital to institutions and GDP per capita, from GDP per capita to environmental regulations, and from FDI to natural resources utilization. Furthermore, a bidirectional causal relation exists between FDI and institutions, and per capita GDP and natural resources utilization. For the advanced economies sample, the results of the causality examination indicate the occurrence of a unidirectional causal relation running from energy intensity to natural resources utilization, environmental regulations, and urbanization, from trade openness to natural resources utilization. Furthermore, a bidirectional causal relation exists between institutions and energy intensity, and per capita GDP and trade openness.

These findings imply that both the developing and emerging market economies and the advanced economies need to formulate policies that foster the performance of their institutions as institutions promote enhancing the efficiency of energy consumption in the production process by governing the utilization of natural resources and managing the technologies that enter the nation through the inflows of foreign capital. While the advanced economies may need to maintain their institutional quality, the developing and emerging market economies may need to formulate policies that improve their institutional quality. These policies may include reducing bureaucracy, combating corruption, lessening the rates of poverty and unemployment, promoting the independence of the legal system, fostering constancy and the responsiveness of the government, curtailing the interior and exterior struggles, eliminating the faithful and ethnic struggles, and lowering the risks associated with investment (Dehdar et al., 2020).

Moreover, developing and emerging market economies should formulate policies targeting human capital, as human capital affects energy consumption in the production process. These policies may include improving the educational level of human capital, as well-educated human capital tends to enhance the consumption of clean energy sources, which increases economic growth and ameliorates environmental quality (Gao et al., 2022).

Additionally, the energy consumed and the level of emissions associated with the production process for both the developing and emerging market economies and the advanced economies lead to the design of environmental regulations that aim at improving the ecological quality. These regulations may include the policies formulated by public institutions that target curbing ecological pollution and raising people's awareness towards preserving environmental quality (Guo et al., 2022).

Furthermore, as natural resource utilization leads to environmental deterioration for both economies, both economies should enhance the efficiency of utilizing their natural resources by promoting the dependence on advanced machinery that results in efficient mining and deforestation. Replacing outdated machinery with advanced ones fosters economic growth and ameliorates environmental performance at the same time (Muhammad et al., 2021).

Additionally, as urbanization is associated with curtailing energy demand for developing and emerging market economies, those economies may enhance urbanization as a mechanism of energy saving and ameliorating environmental performance (Fang et al., 2022). For advanced economies, urbanization is associated with an increase in energy demand; hence, those economies should formulate policies that enhance energy efficiency in urban areas. These policies may include promoting energy-efficient electric home equipment in the residential sector, fostering clean transportation through introducing energy-efficient vehicles, and encouraging the urban population to adopt environmentally friendly lifestyles (Ahmed et al., 2020b). Both developing and emerging market economies and advanced economies may use financial incentives to encourage urban households to do recycling activities and utilize clean energy equipment.

Finally, international trade, with appropriate regulations, enhances the deployment of clean energy sources and improves environmental quality. Thus, while the advanced economies should enhance international trade as it is associated with a decline in energy intensity, the developing and emerging market economies should formulate appropriate regulations that govern the importation of energy sources through international trade, as international trade is associated with an increase in energy intensity for those nations.

Limitations and Future Recommendation

The results of this research are constrained by the data availability for the environmental regulations variable, especially for the developing and emerging market economies.

Forthcoming research may concentrate on the potential function of the productive capacities of the economies, such as transportation, structural change, and the private sector, in ameliorating the environmental quality of the nations. Moreover, forthcoming research may explore the determinants of environmental quality for different regions and income groups to get insights from the results of various samples. Furthermore, this study utilized patents on environmental technologies as an index for environmental regulations. Forthcoming research should consider the effectiveness of those regulations by accounting for their stringency and compelling mechanisms.

Statements and Declarations

Ethical Approval and Consent to Participate

Not applicable

Consent for publication

Not applicable

Competing interests

The authors declare that they have no competing interests.

Availability of data and materials

Data is available at the World Bank, OECD, and UNCTAD

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Authors Contributions

Menna Sherif: Formal analysis, methodology & writing the draft. Khadiga M. El-Aasar and Dalia M. Ibrahim: Validation, supervision, review & editing,

Appendix**List of countries**

| Developing and Emerging Market Economies | | Advanced Economies | |
|--|----------------------|--------------------|-----------------|
| Algeria | Malaysia | Australia | New Zealand |
| Argentina | Mexico | Austria | Norway |
| Armenia | Moldova | Belgium | Portugal |
| Azerbaijan | Morocco | Canada | Singapore |
| Bangladesh | Nigeria | Croatia | Slovak Republic |
| Belarus | Pakistan | Cyprus | Slovenia |
| Bosnia and Herzegovina | Peru | Czechia | Spain |
| Brazil | Philippines | Denmark | Sweden |
| Bulgaria | Poland | Estonia | Switzerland |
| Chile | Romania | Finland | United Kingdom |
| China | Russian Federation | France | United States |
| Colombia | Saudi Arabia | Germany | |
| Costa Rica | South Africa | Greece | |
| Egypt, Arab Rep. | Thailand | Iceland | |
| Georgia | Tunisia | Ireland | |
| Ghana | Turkiye | Israel | |
| Hungary | Ukraine | Italy | |
| India | United Arab Emirates | Japan | |
| Indonesia | Uruguay | Korea, Rep. | |
| Iran, Islamic Rep. | Uzbekistan | Latvia | |
| Jordan | Vietnam | Lithuania | |
| Kazakhstan | | Luxembourg | |
| Kenya | | Malta | |
| Lebanon | | Netherlands | |

Diagnostic Checking**Cross-Sectional Dependence Tests**

Cross-sectional dependence is outlined as “*the contemporaneous correlation between countries after controlling for individual characteristics*” (Khan et al., 2023). This paper adopted three tests to figure out the existence of cross-sectional dependence, namely the Pesaran CD test, the Friedman test, and the Frees test. The reason for selecting those three tests is that they are valid in the case of many cross-sectional units and a small timeframe, which is the case of this study (De Hoyos and Sarafidis, 2006).

Table (5) displays the findings of the cross-sectional dependence tests. The null hypothesis of the three tests denies the occurrence of cross-sectional dependency. As demonstrated, the Pesaran CD and Frees tests reveal the occurrence of cross-sectional dependence in the global sample and the developing and

emerging market economies sample. For the advanced economies sample, the three tests reject the null hypothesis, which denies the occurrence of cross-sectional dependence. The existence of cross-sectional dependence between the sample countries indicates that other nations in the study sample will be affected by a shock that takes place in one nation (Khan et al., 2023).

Table (5): Cross-sectional dependence test estimates

| Statistics | Global Sample | Developing and Emerging Market Economies | Advanced Economies |
|------------|---------------|--|--------------------|
| Pesaran | 11.203* | 9.304* | 10.283* |
| Friedman | 59.070 | 46.089 | 65.866* |
| Frees | 18.691* | 8.797* | 6.976* |
| N | 80 | 45 | 35 |

Note: * designates the rejection of the null hypothesis at a 1% level of significance.

Second-generation panel unit root test findings:

Since the preceding tests manifest the existence of cross-sectional dependency between the sample nations, this work applied the second-generation panel unit root tests, namely: cross-section Augmented Dickey-Fuller (CADF) and cross-section Im-Pesaran and Shin (CIPS) tests, to assess the stationarity characteristics of the variables. Second-generation panel stationarity tests were adopted because the first-generation panel stationarity tests do not consider cross-sectional dependence in the longitudinal dataset (Usman et al., 2022). Thus, the adoption of these tests avoids the occurrence of deceptive estimations (Ullah et al., 2023). In case of contradictions between the findings of the CIPS and CADF assessments, the results of the CIPS will be adopted because it is more reliable in correcting for heterogeneity and cross-sectional dependency compared to the CADF test (Zeraibi et al., 2022; Ullah et al., 2023).

As shown in Table (6), the e_i , $inst$, er , and fdi variables are stationary at level, the urb variable becomes stationary after applying the second difference, while the rest of the variables are stationary after carrying out the first difference for the global sample. For the developing and emerging market economies sample, the e_i , $inst$, er , and fdi variables are stationary at level, the urb and y variables are stationary after carrying out the second difference, whereas the rest of the variables are stationary after applying the first difference. For the advanced economies sample, the e_i , er , and fdi variables are stationary at level, the urb variable is stationary after applying the second difference, while the rest of the variables are stationary after applying the first difference.

Table (6): Panel unit root test findings

Note: *, **, and *** stand for the rejection of the null hypothesis at 1%, 5%, and 10% level of significance, respectively.

Assessing the existence of serial correlation

To check the occurrence of serial correlation, this paper applied the Wooldridge test as the existence of serial correlation leads to smaller coefficients' standard errors and superior R-squared values (Torres, 2007).

| Variables | Panel unit root test | Level statistic | First difference statistic | Second difference statistic |
|---|----------------------|-----------------|----------------------------|-----------------------------|
| Global sample | | | | |
| Energy Intensity (ei) | CIPS | -2.636* | - | - |
| | CADF | -2.487* | - | - |
| Institutions (inst) | CIPS | -2.219* | - | - |
| | CADF | -2.164** | - | - |
| Natural resources (nrt) | CIPS | -1.737 | -3.158* | - |
| | CADF | -2.098** | - | - |
| Human capital (hc) | CIPS | -1.783 | -2.990* | - |
| | CADF | -1.749 | -1.749*** | - |
| Environmental regulations (er) | CIPS | -3.105* | - | - |
| | CADF | -2.730* | - | - |
| Trade openness (to) | CIPS | -0.936 | -2.869* | - |
| | CADF | -1.083 | -1.913 | -2.652* |
| GDP per capita (y) | CIPS | -1.001 | -2.175** | - |
| | CADF | -1.403 | -1.556 | -2.470* |
| Foreign direct investment (fdi) | CIPS | -2.935* | - | - |
| | CADF | -2.083** | - | - |
| Urbanization (urb) | CIPS | -0.292 | -1.321 | -2.422* |
| | CADF | -0.872 | -1.720 | -1.662 |
| Developing and Emerging Market Economies | | | | |
| Energy Intensity (ei) | CIPS | -2.330* | - | - |
| | CADF | -2.545* | - | - |
| Institutions (inst) | CIPS | -2.080*** | - | - |
| | CADF | -2.265* | -3.119* | - |
| Natural resources (nrt) | CIPS | -1.747 | - | - |
| | CADF | -2.130** | -2.953* | - |
| Human capital (hc) | CIPS | -1.700 | -1.937 | -2.689* |
| | CADF | -1.770 | - | - |
| Environmental regulations (er) | CIPS | -3.084* | - | - |
| | CADF | -2.795* | -3.004* | - |

| | | | | |
|---------------------------------|------|----------|-----------|----------|
| Trade openness (to) | CIPS | -1.406 | -1.916 | -2.681* |
| | CADF | -1.703 | | |
| GDP per capita (y) | CIPS | -1.202 | -1.915 | -3.576* |
| | CADF | -1.718 | -1.222 | -2.766* |
| Foreign direct investment (fdi) | CIPS | -2.986* | - | - |
| | CADF | -2.558* | - | - |
| Urbanization (urb) | CIPS | -0.980 | -1.047 | -2.496* |
| | CADF | -0.670 | -1.048 | -1.021 |
| Advanced Economies | | | | |
| Energy Intensity (ei) | CIPS | -2.346* | - | - |
| | CADF | -2.216** | - | - |
| Institutions (inst) | CIPS | -1.870 | -3.889* | - |
| | CADF | -1.221 | -2.637* | - |
| Natural resources (nrt) | CIPS | -1.904 | -3.125* | - |
| | CADF | -2.146** | - | - |
| Human capital (hc) | CIPS | -1.719 | -2.857* | - |
| | CADF | -1.760 | -2.043*** | - |
| Environmental regulations (er) | CIPS | -3.101* | - | - |
| | CADF | -2.220** | - | - |
| Trade openness (to) | CIPS | -2.220 | -2.539* | - |
| | CADF | -1.296 | -1.819 | -1.819* |
| GDP per capita (y) | CIPS | -0.912 | -2.607* | - |
| | CADF | -1.564 | -1.841 | -2.518* |
| Foreign direct investment (fdi) | CIPS | -2.885* | - | - |
| | CADF | -1.969 | -2.840* | - |
| Urbanization (urb) | CIPS | -0.947 | -0.769 | -0.769** |
| | CADF | -1.873 | -1.342 | -1.738 |

The null hypothesis of the test denies the occurrence of first-order autocorrelation. As displayed in Table (7), the null hypothesis is rejected for the three samples.

Table (7): Wooldridge assessment for serial correlation

| Global Sample | Developing and Emerging Market Economies | Advanced Economies |
|-----------------------|--|---------------------|
| [65.026] (0.0000)* | [75.076] (0.0000)* | [10.617] 0.0025* |

Note: F statistics are outlined in [], whereas the probability values are outlined in (). * indicates the rejection of the null hypothesis at a 1% level of significance.

Assessing the Occurrence of Heteroscedasticity in the Fixed Effects Regression

To assess the occurrence of heteroscedasticity in the fixed effects model selected for the global sample and the developing and emerging market economies sample, this study applied the modified Wald test, as the occurrence of heteroscedasticity leads to biased standard errors (Gujarati, 2002). The null hypothesis of the test is that the residuals are homoscedastic. The modified Wald test reveals the existence of heteroscedasticity in both samples as exhibited in Table (8) .

Assessing the Occurrence of Heteroscedasticity in the Random Effects Regression

The Lagrange Multiplier test, Likelihood Ratio test, and Wald test are adopted to assess the occurrence of heteroscedasticity in the random effects regression selected for the advanced economies sample. The three tests disclose the existence of heteroscedasticity as shown in Table (9).

Table (8): Modified Wald test for heteroscedasticity in the fixed effects regression

| Global Sample | Developing and Emerging Market Economies |
|------------------------|--|
| [1.3e+05] (0.0000)* | [42565.51] (0.0000)* |

Note: chi-square values are outlined in [], whereas the probability values are outlined in (). * indicates the rejection of the null hypothesis at a 1% level of significance.

Table (9): Lagrange Multiplier test, Likelihood Ratio test, and Wald test for heteroscedasticity in the random effects regression

| Lagrange Multiplier Test | Likelihood Ratio Test | Wald Test |
|--------------------------|-------------------------|-------------------------|
| [3.50e+05] (0.0000)* | [557.2034] (0.0000)* | [1.52e+06] (0.0000)* |

Note: chi-square values are outlined in [], whereas the probability values are outlined in (). * specifies the rejection of the null hypothesis at a 1% significance level.

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