ABSTRACT

Sustainable energy development (SED) is central to achieving global Sustainable Development Goals (SDGs), yet there remains a dearth of comprehensive empirical studies exploring the interactions between economic growth, environmental pressures, and governance in driving SED, particularly within the D8 countries. This research investigates the dynamic interplay between economic factors (GDP, energy intensity, public-private partnerships), environmental pressures (CO_2 emissions, GHG emissions, natural resource rents), and institutional factors (regulatory quality and political stability) in influencing SED across Bangladesh, Egypt, Indonesia, Iran, Malaysia, Nigeria, Pakistan, and Turkey from 2008 to 2022. Employing robust econometric methodologies, including fixed effects models, generalized least squares, panel-corrected standard errors and interaction models, the study provides a nuanced analysis of these relationships.

Main findings reveal that while economic growth enhances SED, its benefits are often counterbalanced by environmental trade-offs unless supported by strong institutional frameworks. Notably, regulatory quality positively moderates the GDP-SED relationship, while political stability exhibits a paradoxical role in both enhancing and hindering the environmental dimension of SED.

Similar to economic growth, CO_2 can drive the transition to sustainable energy in countries with good governance through the effectiveness of legal frameworks, policies, and strict environmental standards, thereby minimizing the impact of CO_2 and promoting the adoption of renewable energy. However, governments that overly prioritize political stability complicate the relationship between CO_2 and SED in a negative way. While stability provides safety, it hampers innovation and breakthroughs, especially in a global context aimed at sustainable energy goals. Conservatism and dependence are the key factors slowing down this process.

This research contributes valuable insights for policymakers aiming to harmonize economic growth, environmental sustainability, and governance improvements, providing actionable pathways for D8 countries to advance their energy transitions in alignment with the SDGs.

Keywords: *sustainable energy development, economic factors, environment factors, institutional factors, D8 countries.*

emissions into a driver for sustainable energy initiatives, creating a pathway for achieving energy transition goals. The following hypothesis explores how robust regulatory mechanisms can positively moderate the relationship between CO_2 emissions and SEDI. Consequently, the authors propose the hypothesis:

H11: RQ positively moderates the relationship between CO_2 and SEDI.

CHAPTER 3: RESEARCH METHODOLOGY

3.1. Data collection

The data for this study on Sustainable Energy Development (SED) in D8 countries was sourced primarily from the Developing 8 (D8) database, which consolidates a wide array of economic, environmental and institutional indicators specific to these nations. Focusing on Bangladesh, Egypt, Indonesia, Iran, Malaysia, Nigeria, Pakistan, and Turkey, this database is particularly well-suited for examining the developmental challenges and opportunities within these countries. The selected timeframe, 2008-2022, captures recent advancements and shifts in sustainability and innovation within the D8, aligning with global initiatives on climate action and sustainable development goals.

The data from the D8 database draws from reputable sources like the World Bank, International Energy Agency (IEA), and World Intellectual Property Organization (WIPO), ensuring data consistency, quality, and relevance to the study's objectives:

(https://developing8.org/d-8-baseindbasic-social-and-economic-indicators) and World Bank Indicators Data

(https://databank.worldbank.org/source/world-development-indicators).

3.2. Model Specification

In this study, we examine the effects of economic, environmental, and institutional factors on Sustainable Energy Development (SED) in D8 countries from

2008 to 2022. To achieve this, a series of econometric models are specified and estimated. Each model is designed to isolate the impact of specific types of variables, allowing us to evaluate how economic conditions, environmental pressures, and institutional quality contribute to SED. This approach also enables us to observe any interdependencies among these factors over time.

Stage 1: Economic Factors

Motivated by theories of sustainable energy development and prior empirical research (Singh & Kumar, 2022; Inglesi-Lotz, 2016; Halkos & Tsirivis, 2023; Fan & Hao, 2020; Emir & Bekun, 2019; Alola et al., 2023; Md et al., 2024), this study examines the role of economic factors in influencing Sustainable Energy Development (SED). The theoretical framework considers SED as a function of Gross Domestic Product (GDP), Energy Intensity (EI), Public-Private Partnership Investments in Energy (PPPE), and macroeconomic control variables such as Inflation (IF), Trade Openness (TO), and Population (POP). These variables collectively capture the direct and indirect impacts of economic growth, energy efficiency, and investment mechanisms on sustainable energy transitions.

$$\mathbf{SEDI_{it} = f(GDP_{it}, EI_{it}, PPPE_{it}, IF_{it}, TO_{it}, POP_{it})}$$

This theoretical model aligns with findings from prior studies that emphasize the role of economic stability, energy efficiency, and investment dynamics in achieving energy sustainability. GDP measures economic growth and capacity for renewable energy investment (Halkos & Tsirivis, 2023). EI reflects the efficiency of energy consumption, which, if high, may hinder sustainable energy adoption due to increased emissions (Emir & Bekun, 2019). PPPE represents collaborative investment models that facilitate green energy projects (Md et al., 2024). Control variables (IF, TO, POP) capture broader macroeconomic conditions and demographic pressures that influence energy demand and policy effectiveness (Nguyen et al., 2024; Duc, Hong & Vo, 2021).

Model 1: Baseline Model of Sustainable Energy Development (SED) with economic factors

$$\mathbf{SEDI_{it} = \beta_0 + \beta_1 Econit_{it} + \gamma 1 \cdot Control_{it} + u_{it}}$$

Where

$\mathbf{SEDI_{it}}$ is the Sustainable Energy Development score measuring for country *i* in year *t*.

$\mathbf{Econ_{it}}$ represents economic factors (GDP, PPPE, EI)

$\mathbf{Control_{it}}$ represents control variables (IF, TO, POP)

$\boldsymbol{\beta_0}$ is the intercept term.

$\mathbf{u_{it}}$ is the error term.

This theoretical model aligns with findings from prior studies that emphasize the role of economic stability, energy efficiency, and investment dynamics in achieving energy sustainability. GDP measures economic growth and capacity for renewable energy investment (Halkos & Tsirivis, 2023). EI reflects the efficiency of energy consumption, which, if high, may hinder sustainable energy adoption due to increased emissions (Emir & Bekun, 2019). PPPE represents collaborative investment models that facilitate green energy projects (Md et al., 2024). Control variables (IF, TO, POP) capture broader macroeconomic conditions and demographic pressures that influence energy demand and policy effectiveness (Nguyen et al., 2024; Duc, Hong & Vo, 2021).

Model 2: Fixed Effects Model (FEM) for Economic Factors

$$\mathbf{SEDI_{it} = \alpha_0 + \beta_1 Econ_{it} + \gamma 1 \cdot Control_{it} + u_{it}}$$

Where

$\boldsymbol{\alpha_0}$ represents the country-specific fixed effects control for unobserved heterogeneity across countries.

Model 3: Fixed Effects Model (REM) for Economic Factors

$$\mathbf{SEDI_{it} = \alpha_0 + \beta_1 Econ_{it} + \gamma 1 \cdot Control_{it} + u_{it} + \epsilon_{it}}$$

Where

$\mathbf{u_{it}}$ is the random effect for country i, assumed to be uncorrelated with the independent variables.

$\boldsymbol{\epsilon_{it}}$ is the error term

To account for unobserved heterogeneity across countries, both Fixed Effects (FEM) and Random Effects (REM) models are employed. The FEM controls for country-specific time-invariant factors, ensuring robust coefficient estimates for time-varying predictors.

Model 4: Generalized Least Squares (GLS) for Economic Factors

$$\mathbf{SEDI_{it} = \beta_0 + \beta_1 Econ_{it} + \gamma 1 \cdot Control_{it} + u_{it}}$$

where

GLS accounts for heteroskedasticity or autocorrelation in the panel data.

Model 5: Panel Corrected Standard Errors (PCSE) for Economic Factors

$$\mathbf{SEDI_{it} = \beta_0 + \beta_1 Econ_{it} + \gamma 1 \cdot Control_{it} + u_{it}}$$

where

PCSE addresses issues with cross-sectional dependence and provides robust standard errors.

Model 6: Interaction Model for Economic Factors (GDP_RQ, GDP_PS)

$$\mathbf{SEDI_{it} = \beta_0 + \beta_1 Econ_{it} + \gamma 1 \cdot Control_{it} + \delta_1 (GDP \times RQ)_{it} + \delta_2 (GDP \times PS)_{it} + u_{it}}$$

Where

$(GDP \times RQ)_{it}$ stands for the interaction term between GDP and Regulatory Quality.

$(GDP \times PS)_{it}$ stands for the interaction term between GDP and Political Stability.

δ_1, δ_2 stand for coefficients for the interaction terms.

Stage 2: Environment Factors

Motivated by theories of environmental sustainability and prior empirical research (Zaman & Abd-el Moemen, 2017; Xu et al., 2023; Abdulraqeb et al., 2024; Jia & Zhu, 2024; Wang et al., 2018; Owusu & Asumadu-Sarkodie, 2016; Candra et al., 2023), this study examines the role of environmental factors in shaping Sustainable Energy Development (SED). The theoretical framework considers SED as a function of Carbon Dioxide Emissions (CO2), Greenhouse Gases (GHG), Rents from Natural Resources (RN), and PM25 (PM25), alongside control variables such as Inflation (IF), Trade Openness (TO), and Population (POP). These variables encapsulate the multifaceted relationship between environmental pressures, policy responses, and sustainable energy transitions.

The baseline relationship is modeled as:

$$\mathbf{SED_{it}=f(CO2_{it},GHG_{it},RN_{it},PM25_{it},IF_{it},TO_{it},POP_{it})}$$

This framework is built on findings that highlight the critical role of environmental degradation in prompting energy transitions. CO2 and GHG reflect the environmental externalities of conventional energy consumption, which drive policy interventions and innovations in renewable energy (Zaman & Abd-el Moemen, 2017; Xu et al., 2023). RN captures the reliance on natural resource rents, which can either impede or facilitate sustainable energy transitions depending on governance quality (Abdulraqeb et al., 2024; Jia & Zhu, 2024). PM25, as an indicator of air quality, underscores the health and environmental costs of energy systems reliant on fossil fuels (Wang et al., 2018). Control variables such as IF, TO, and POP account for broader macroeconomic and demographic conditions that shape energy demand and transition policies (Nguyen et al., 2024; Engel-Cox & Chapman, 2023).

Model 7: Baseline Model of Sustainable Energy Development (SED) with environment factors

$$\mathbf{SEDI_{it} = \beta_0 + \beta_1 Envi_{it} + \gamma 1 \cdot Control_{it} + u_{it}}$$

Where

$Envi_{it}$ stands for Environmental factors (CO2, GHG, PM25, RN).

Model 8: Fixed Effects Model (FEM) for Environment Factors

$$\mathbf{SEDI_{it} = \alpha_0 + \beta_1 Envi_{it} + \gamma 1 \cdot Control_{it} + u_1}$$

Model 9: Fixed Effects Model (REM) for Economic Factors

$$\mathbf{SEDI_{it} = \alpha_0 + \beta_1 Envi_{it} + \gamma 1 \cdot Control_{it} + u_{it} + \epsilon_{it}}$$

Model 10: Generalized Least Squares (GLS) for Environment Factors

$$\mathbf{SEDI_{it} = \beta_0 + \beta_1 Envi_{it} + \gamma 1 \cdot Control_{it} + u_{it}}$$

Model 11: Panel Corrected Standard Errors (PCSE) for Environment Factors

$$\mathbf{SEDI_{it} = \beta_0 + \beta_1 Envi_{it} + \gamma 1 \cdot Control_{it} + u_{it}}$$

Model 12: Interaction Model for Environment Factors (C02_RQ, C02_PS)

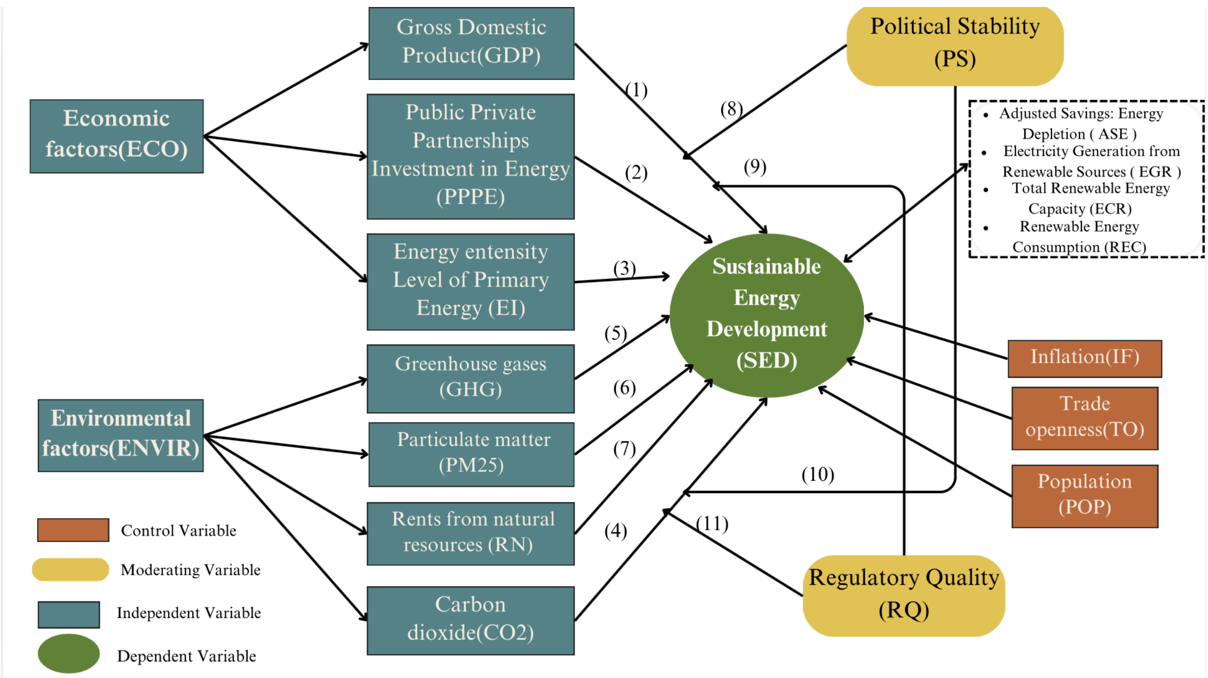
$$\mathbf{SEDI_{it} = \beta_0 + \beta_1 Econ_{it} + \gamma 1 \cdot Control_{it} + \delta_1 (CO2 \times RQ)_{it} + \delta_2 (CO2 \times PS)_{it} + u_{it}}$$

Where

$(CO2 \times RQ)_{it}$ stands for the interaction term between CO2 emissions and Regulatory Quality.

$(CO2 \times PS)_{it}$ stands for the interaction term between CO2 emissions and Political Stability.

Figure 3.1. Proposed research model



Source: Authors' compilation

3.3. Variable measurement

3.3.1. Dependent variable: Sustainable energy development score (SEDI)

Adjusted Savings: Energy Depletion (ASE)

Energy depletion is the ratio of the value of the stock of energy resources to the remaining reserve lifetime (capped at 25 years).

Zu's (2023) research pointed out a seemingly paradoxical relationship: a 1% increase in energy depletion (understood as greater use or consumption of energy) leads to a 0.7390417% improvement in natural resources. This can be explained by energy transition and innovation solutions. The overexploitation of fossil fuels -

non-renewable energy sources cause issues such as pollution and depletion of natural resources. Consequently, the transition to " clean energy ” is being accelerated rapidly and strongly. Moreover, non-renewable energy sources are finite; as they become more expensive and scarce, industries are compelled to innovate energy use to reduce production costs while minimizing negative environmental impacts.

Electricity Generation from Renewable Sources (EGR)

Electricity Generation from Renewable Sources (GWh) is a measure of the total amount of electricity produced using renewable energy sources, expressed in gigawatt-hours (GWh).

When discussing the development of sustainable energy industries, two fundamental criteria must be considered: the generation of electricity from renewable energy sources and the efficient consumption of these energy resources. These criteria serve as the foundation for shaping the sustainable future of the energy sector.

The impact of electricity generation from renewable energy sources on the advancement of sustainable energy is groundbreaking, offering effective solutions to critical environmental, economic, and social challenges. Simultaneously, it lays a solid groundwork for fostering long-term sustainability, meeting current energy demands while safeguarding the planet for future generations.

Total Renewable Energy Capacity (ECR)

Total Renewable Energy Capacity (ECR) measures the total amount of electricity generated from renewable energy sources in a country. This indicator includes energy consumption from resources: Bioenergy, Hydropower, Solar and Wind . The unit of this measure is MW.

The studies by Arimura (2021) and Pokharel (2021) also used this index to examine its impact on environmental policies related to energy. In their research, the authors employed ECR as one of the factors to measure the development of the renewable energy sector. Countries with high clean energy consumption levels demonstrate diversity in their industrial structure and a lack of dependence on natural resources. Additionally, higher renewable energy consumption reflects efficiency and potential for future development.

Renewable Energy Consumption (REC)

Renewable Energy Consumption (REC) is an indicator that measures the proportion of renewable energy consumed relative to the total final energy consumption (%).

Many studies have used this indicator to examine the relationship and impact of renewable energy consumption on socio-economic growth, such as the study by Bhattacharya (2016) for the 38 leading green energy consuming countries. In this research, the indicator is used to assess the development of the new energy sector through its economic and environmental impacts.

The rationale of using Principal Component Analysis (score) on key variables: *Adjusted Savings (Energy Depletion) (ASE), Renewable Energy Consumption (ECR), Renewable Energy Generation (EGR), and Total Renewable Energy Capacity (REC)*, to create the SEDI (Sustainable Energy Development Score) is explained by:

One of the key strengths of score in constructing the SEDI score is its ability to *reduce dimensionality.* This is crucial because the variables involved in measuring sustainable energy development are often highly correlated, which can introduce multicollinearity and complicate the analysis. For instance, EGR and REC are both measures of renewable energy but capture different dimensions of energy supply (production vs. capacity). Instead of treating these variables separately, which may lead to redundancy and less efficient analysis, score identifies the principal components that summarize the common variance among all four indicators. By focusing on the most significant principal component, score reduces the data's complexity while retaining essential information, leading to a cleaner and more manageable index. This is particularly important in policy analysis and sustainability assessments, where simplicity and clarity are critical for guiding decision-making.

Secondly, score ensures that each variable in the model contributes appropriately to the final index, regardless of its original scale or unit of measurement.

For example, ASE is typically measured as a percentage or ratio, while ECR, EGR, and REC are often measured in energy units (e.g., gigawatt-hours). If these variables were combined without standardization, their differences in scale would disproportionately affect the SEDI. Additionally, score addresses this challenge by standardizing each variable (e.g., using z-scores) so that all variables contribute equally to the index, allowing for a fairer aggregation. The use of standardized variables ensures that the SEDI score is not biased by the inherent magnitude of any single variable, making the index more representative of sustainable energy development overall.

Finally, score captures the underlying trends in energy sustainability that are not immediately apparent from analyzing individual indicators alone. It identifies the latent patterns in the data, such as the relationship between energy depletion (ASE) and renewable energy consumption (ECR), which may be obscured when these variables are treated in isolation. By focusing on the common variance captured in the principal component, score helps uncover the most significant drivers of sustainable energy development, offering insights that are not readily available from a mere summation of individual variables. This holistic approach is valuable for policymakers and researchers aiming to assess and track progress in energy sustainability, as it reflects the interconnectedness of various energy-related factors, such as the transition to renewable energy and the management of non-renewable resources.

In consolidation, score is a highly suitable method for constructing the SEDI score because it simplifies complex, correlated data into a manageable composite index that preserves the key relationships between indicators. It ensures that each variable is appropriately weighted and contributes meaningfully to the final score. Score also reveals latent patterns in the data that would otherwise be difficult to detect, providing a more comprehensive, insightful measure of sustainable energy development.

Table 1: Eigenvalues and Variance Explained by Each Component

Component	Eigenvalue	Difference	Proportion of Variance	Cumulative Proportion
Comp1	2.25037	1.12641	56.26%	56.26%
Comp2	1.12396	0.556299	28.10%	84.36%
Comp3	0.56766	0.509645	14.19%	98.55%
Comp4	0.05801	-	1.45%	100%

Table 2: Eigenvectors (Loadings) for Each Component

Variable	Comp1	Comp2	Comp3	Comp4
zASE	-0.3811	-0.5824	0.7170	-0.0383
zECR	0.6360	-0.0926	0.3005	0.7047
zEGR	0.6387	0.0047	0.3056	-0.7061
zREC	-0.2057	0.8076	0.5497	0.0570

Table 3: Proportion of Variance Explained by Each Principal Component

Principal Component	Variance Explained (%)
Comp1	56.26%
Comp2	28.10%
Comp3	14.19%
Comp4	1.45%

The score results show that the first principal component (Comp1) accounts for 56.26% of the total variance in the data. This indicates that the first component is the most dominant, reflecting the major trends within the underlying variables. The eigenvalues corresponding to the first two components are significantly higher than those of the subsequent components, suggesting that these two components capture the most essential information about sustainable energy development in the D8 countries. The second principal component (Comp2), explaining 28.10% of the variance, also contributes substantially to the overall dynamics. The remaining components (Comp3 and Comp4), however, explain only a small proportion of the variance, indicating that they provide less meaningful or redundant information. This finding suggests that the first two components are sufficient to understand the majority of the factors influencing sustainable energy development, making them crucial for constructing the SEDI score.

In terms of the component loadings, the variables Adjusted Savings (Energy Depletion), Renewable Energy Consumption, Renewable Energy Generation, and Total Renewable Energy Capacity exhibit varying degrees of correlation with the principal components. For instance, Comp1 has strong positive loadings on Renewable Energy Consumption (zECR) and Renewable Energy Generation (zEGR), indicating that these factors contribute most significantly to the first principal component. This component likely captures the extent to which a country is transitioning towards renewable energy and away from energy depletion, which are key aspects of sustainable energy development. Conversely, Comp2 is strongly correlated with Total Renewable Energy Capacity (zREC), suggesting that this component represents the structural capacity of a nation's renewable energy sector, such as installed capacity for renewable energy production. The resulting SEDI score, derived primarily from Comp1, offers a comprehensive measure of a country's progress towards sustainable energy development. By reducing the dimensionality of the data into a single score, the SEDI index provides policymakers and researchers with an efficient tool to assess and compare the performance of D8 countries in terms of sustainable energy development.

3.3.2. Independent variable: Economics factors

GDP per Capita (GDP)

Gross Domestic Product (GDP) per capita is a widely recognized indicator used to assess the average income per individual within an economy (Nepal et al., 2021). The natural logarithm of GDP per capita (expressed in current USD) offers a refined analytical approach to examining its impact on sustainable energy development trends. In their study of ASEAN-5, Masud et al. (2018) also utilized the natural logarithm of GDP to highlight the adverse effects of income inequality on environmental sustainability. The authors argue that achieving sustainable development in rapidly urbanizing regions necessitates a careful balance between economic growth and equitable income distribution.

GDP per capita reflects the average income of individuals within a country and plays a pivotal role in the financial development of that country. As income levels rise, so does the demand for services and products. Additionally, as income increases, there is a growing focus on product quality and environmental sustainability. This indicates that when financial resources are available and wealth is accumulated, both individual and business saving and investment activities tend to rise, fostering the expansion of both domestic and international markets. Consequently, investments are not only directed towards traditional sectors but also shift towards sustainable products, services, and energy solutions to improve environmental quality. Electric vehicles serve as a prime example of this shift. In fact, electric vehicles are not a new form of transportation; they originated in the 19th century and have over 100 years of history. Through various stages of development, electric vehicles have become widely known and prevalent in the market. One of the key drivers of this growth is the robust GDP growth. According to a study by Sotnyk (2020) in the U.S. market, GDP growth ranks second among the factors driving the development of the electric vehicle market.

Energy Intensity Level of Primary Energy (EI)

Energy intensity level of primary energy is the ratio between energy supply and gross domestic product measured at purchasing power parity. Energy intensity is an indication of how much energy is used to produce one unit of economic output. Lower ratio indicates that less energy is used to produce one unit of output. The relationship between energy intensity (EI) and the ecological footprint is positive, indicating that higher energy intensity is associated with worsening environmental sustainability (Khan 2022). Higher Energy Intensity (EI) indicates lower energy efficiency, which reflects inefficiency and a corresponding increase in CO2 emissions, often linked to reliance on fossil fuels. Abbasi's (2022) empirical research demonstrates a substantial rise in emissions as the intensity of fossil fuel consumption increases, both in the short and long term. Consequently, nations, particularly those with developed economies, are increasingly prioritizing the transition from non-renewable to sustainable energy sources, thereby contributing to a reduction in EI. A lower EI not only enhances economic productivity by reducing energy costs but also facilitates investments in renewable energy and sustainable infrastructure, thereby fostering more robust growth in sustainable energy development.

Public Private Partnerships Investment in Energy (PPPE)

Public Private Partnerships in energy (current US$) refers to commitments to infrastructure projects in energy (electricity and natural gas transmission and distribution) that have reached financial closure and directly or indirectly serve the public.

Public-private partnership (PPP) investments in energy are positively correlated with consumption-based CO2 emissions. Specifically, investments in non-renewable energy sources contribute to an increase in these emissions (Zeeshan Khan, 2020). A developed nation not only emphasizes economic issues but also recognizes its environmental responsibilities. As a result, promoting alternative energy through increasing PPP investments in "green" energy is a logical step. Clearly, this highlights the influence of PPP investments in energy on the development of sustainable energy.

3.3.3. Independent variable: Environmental factors

In recent decades, there has been a growing fascination in the relationship between sustainable energy development, CO2 emissions, PM25, GHG and RNR. Carbon dioxide emission is an integral variable in various models, including climatic, economic, and ecological models. It's fundamental to understand how human behaviors affect the ecosystem and climate system. The CO2 variable (metric tons per capita) represents the concentration of CO_2 in the atmosphere, which may be affected by variables such as carbon footprint and environmental effect. CO_2 emissions are a significant environmental factor in this investigation. According to Qi, Zhang & Karplus (2014), renewables and CO_2 emissions have a negative relationship, the CO_2 emissions reductions due to increased renewables are offset in each year. Sustainable energy development could assist D8 nations make investments in cleaner, more sustainable energy sources, reducing reliance on fossil fuels and minimizing CO_2 emissions. Focusing more on sustainable energy development reduces CO_2 emissions and improves quality of life.

Particulate matter (PM25)

PM25 is also another estimation for Environmental factors in this research that usually originates mainly from vehicle exhaust or through the burning of organic fuels in industry. Based on Ul-Haq, Z., Mehmood, U., Tariq, S., & Mariam, A. (2023), renewable energy and PM25 have a negative relationship in which renewable energy plays a crucial role to decrease PM25 concentration by using data from 1998 to 2020 in South Asian countries. Besides, converting to renewable energy sources, such as solar, wind, and hydropower, may extensively eliminate air pollution emissions, particularly PM2.5.

Greenhouse gases (GHG)

Greenhouse gases are made up of CO_2 totals, all human-caused environmental CH_4 resources, N_2O various sources, F-gases (HFCs, PFCs, and SF_6), as well as short-cycle combustion of biomass (such as burning waste from agriculture and forests) but which includes other types of biomass igniting (which include items such as fires in forests, post-burn deterioration, peat fires, and decay of depleted peat forests). The possibilities for an environmentally friendly energy system are examined by Niels and Meyer (2014), who demonstrated that if a renewable energy approach is founded on a mix of productivity, renewables, and the completion of development of materials in the industrialized nations, thermal power is not required.

Rents from natural resources (RN)

Rents from natural resources are the primary value of natural resources, defined as the value delivered by nature. The quantity of "rents" indicates how efficiently a nation uses its natural resources. Challenges like resource reliance may arise if this rate is large but not invested sustainably. Natural resource exploitation produces revenue, but if it fails to be managed responsibly, it may also have negative environmental effects. Natural resource rents assist nations in keeping an eye on the extent of extraction and balancing it with long-term development plans. According to Fu & Liu (2023), the research findings asserted that natural resources asymmetrically influence sustainable development; otherwise, mineral rents and natural gas rents positively and forest rents adversely affect sustainable development from 1990 to 2020. In order to diversify supply and prevent dependence on a single source of financial resources, natural resource revenues can be utilized to fund development programs including infrastructure, healthcare, education, and renewable energy. Although natural resource revenues present numerous concerns, they can also be an incredible chance to support sustainable development. To fully leverage natural resources, countries require a long-term development strategy that incorporates suitable financial, environmental, and social policies.

3.3.4. Independent variable: Institutional factors

Regulatory Quality (RQ)

Theo Kaufmann, Kraay & Mastruzzi (2010), regulatory quality is a component index which forms part of the Global Innovation Index's (GII) legal environment index group. It is one of the six all-inclusive global governance indices created by the World Bank (the Worldwide Governance Index, or WGI for short). We may use the index or estimate that shows the government's capacity to carry out sensible policies to assess this index. According to Perera & Lee (2013), an improvement of institutional quality has stimulated commercial activity in Asia's low-income nations, and this success might lead to an noteworthy increase in carbon emissions. Following this research, there is a negative relationship between regulatory quality and sustainable energy development. But a regulatory framework that is stable, accessible, obvious and effective will promote technical innovation, encourage investment in renewable energy projects, and foster a positive business climate. The development of appropriate policy interventions to lessen the severity of climate change in the future for most of the Asia-Pacific nations was made possible by Annamalaisamy & Vepur Jayaraman (2023).

Political Stability and Absence of Violence (PS)

The awareness of the possibility of instability in politics and/or politically motivated violence, including terrorist activity, is measured by political equilibrium and the absence of aggressive behavior or terrorism. The estimate provides the overall index score of a nation in units of a normative distribution, which comes in between about -2.5 to 2.5. Though political stability is often regarded as advantageous to sustainable energy development, this is crucial to highlight that in some cases, such as in upper-middle-income countries, political instability might not materially impair initiatives to promote sustainable development (Rana et al., 2019). This demonstrates how intricately political considerations and sustainable energy transformations are related. Furthermore, as indicated by Abdul et al. (2023), the investigation showed that political stability and the UAE's advancements in renewable energy production and energy mix diversification were positively correlated. Stable administration enables consistent energy regulations, which facilitates the implementation of environmentally friendly energy initiatives; reliable government additionally encourages public acceptance for renewable energy movements, making it essential for successful execution and political stability boosts investor confidence, which results in rising investment in renewable energy projects.

3.3.5. Control variables

Inflation Rate (INF)

Inflation rate is quantified by the yearly rise of the already included GDP deflator, which depicts the progression of fluctuation in expenses across the entirety of the economy. The proportion of GDP in stable regional currency to GDP in contemporary local currency trading is known as the hidden GDP deflator. Based on the research of Runguo et al. (2024), inflation rates have an extremely consequential impact on renewable energy utilization. In other words, with the study of Andrew et al. (2024), the uncontrolled implications of inflation on investments could limit the attainment of construction-related Sustainable Development Goals in Nigeria.

Trade Openness (TO)

According to Fujii (2019), trade openness is described as the proportion of GDP to overall trading, which is a significant variable that is frequently employed for cross-national research on an extensive variety of topics. According to Taimur et al. (2022), The regulatory function of trade openness (TO) is more specifically: Trade openness (TO) has had an adverse legislative influence on the quality of the environment, particularly in lower- and middle-income nations. Nevertheless, the association among TO with GDP growth has been demonstrated to have a detrimental influence on the natural environment across all income levels.

Population (POP)

Population (POP) by year is the change in the number of people in a population over time. It is one of the drivers of the environmental crisis and underlies almost every environmental problem (Alkaher at el, 2019). It is broadly recognized that excessive population growth imposes unsustainable pressures on the environment, even when supported by the most advanced and strategically managed technologies (Ehrlich, 1971). Bridgeman (2017) further asserts that no environmental issue becomes simpler to resolve as population growth accelerates. These perspectives underscore the significant impacts of population growth (POP) on ecosystems, urging nations to adopt comprehensive and effective measures to address population challenges.

The long-term environmental pressures cannot be mitigated solely through conventional technological solutions or standard social policies. The critical need for integrated strategies that harmonize population management with advancements in sustainable practices. As environmental issues grow more intricate, implementing robust sustainability initiatives becomes imperative. These efforts not only mitigate ecological damage but also catalyze significant investment in and development of renewable energy industries.

Table: Summary of variables and measurements

Category	Variable	Measurement	Source
		Dependent Variables	
		(SED index)	
ASE	Adjusted Savings, Energy Depletion	(% of GNI)	D8
EGR	Electricity Generation from Renewable Sources	(GWh)	D8
ECR	Total Renewable Energy Capacity (MW)	Including breakdown by: Bioenergy, Hydropower, Solar (on-grid/off-grid), Wind (onshore)	D8
REC	Renewable Energy Consumption	(% of total final energy consumption)	WB
		Independent Variables	
		Economic factors	
GDP	GDP per Capita		D8
EI	Energy Intensity Level of Primary Energy	(MJ/$2017 PPP GDP)	WB

PPPE	Public Private Partnerships Investment in Energy	(current US$)	WB
	Environmental factors		
CO2	CO_2 Emissions per Capita and by Sector	(Cement, Coal, Gas, Oil)	D8
PM25	PM25 Air Pollution, Mean Annual Exposure	(micrograms per cubic meter)	WB
GHG	Greenhouse Gas, total		EDGAR
RNR	Rents from Natural Resources	(% of GDP) (Coal, Oil, Natural Gas, Minerals, Forest)	D8
	Institutional factors		
RQ	Regulatory Quality	Index or estimate reflecting the ability of the government to implement sound policies.	WB
PS	Political Stability and Absence of Violence	Estimate of political stability and safety.	WB
	Control Variables		
IF	Inflation Rate	(Annual %)	D8
TO	Trade Openness	(% of GDP)	D8
POP	Population, total		WB

3.4. Research methodology

Across both stages, the research adheres to a structured, systematic process that combines theoretical rigor with empirical precision. The development of the SEDI score using Principal Component Analysis (PCA) provides a foundational dependent variable for both stages. Standardization of variables ensures consistency across models, while interpolation techniques address missing data, preserving the integrity of longitudinal analyses. Control variables such as inflation, trade openness, and population growth are integrated into all models to isolate the core effects of economic and environmental factors on SEDI.

The first stage of the research process investigates the role of economic factors, namely GDP, Public-Private Partnership in Energy (PPPE), and Energy Intensity (EI), in influencing the Sustainable Energy Development Index (SEDI). The methodology begins with comprehensive data collection from globally recognized sources such as the World Bank, IEA, and D8-specific datasets, spanning 2008 to 2022. This ensures data reliability and comparability across D8 countries (Bangladesh, Egypt, Indonesia, Iran, Malaysia, Nigeria, Pakistan, and Turkey). Following data acquisition, key economic indicators are standardized, allowing for consistent evaluation.

The analysis employs multiple econometric techniques to establish robust findings. The baseline model, framed within the Ordinary Least Squares (OLS) approach, captures the direct relationship between economic factors and SEDI. To account for unobserved heterogeneity across countries, Fixed Effects Models (FEM) and Random Effects Models (REM) are used, with the Hausman test determining the most appropriate specification. Interaction terms such as GDP × Regulatory Quality (RQ) and GDP × Political Stability (PS) are included to assess how institutional factors influence the relationship between economic growth and sustainable energy development. Advanced diagnostics, including variance inflation factors (VIF) and stationarity tests, address multicollinearity and ensure data reliability. Robustness checks through Generalized Least Squares (GLS) and Panel Corrected Standard Errors (PCSE) enhance result validity by correcting for heteroskedasticity and autocorrelation. The first stage thus establishes a comprehensive framework for understanding the interplay between economic growth, institutional quality, and SEDI.

The second stage delves into the impact of environmental factors, including Carbon Dioxide Emissions (CO_2), Greenhouse Gas Emissions (GHG), PM2.5

Concentrations, and Rents from Natural Resources (RN), on SEDI. Similar to Stage 1, data are gathered from reputable international databases, ensuring coverage across the selected timeframe. The integration of environmental indicators into the SEDI framework leverages their relevance to global energy transition and climate goals. The analysis begins with a baseline OLS model, which identifies the direct effects of environmental variables on SEDI. FEM and REM models further dissect these relationships by isolating country-specific and temporal variations.

Interaction models play a pivotal role in this stage, incorporating terms such as $CO_2 \times RQ$ and $CO_2 \times PS$ to explore how governance moderates environmental impacts on SEDI. The moderating effects provide critical insights into policy mechanisms that can mitigate negative environmental externalities while fostering renewable energy adoption. Quantile regression is employed to assess how environmental determinants vary across different levels of SEDI, offering nuanced perspectives on countries at varying stages of sustainable energy development. Diagnostic tests, including Breusch-Pagan and Lagrange Multiplier tests, ensure model robustness by addressing heteroscedasticity and cross-sectional dependence. By synthesizing econometric rigor with theoretical insights, Stage 2 offers a multidimensional understanding of how environmental pressures and governance shape sustainable energy trajectories.

Stata 14 serves as the primary analytical tool, enabling advanced econometric analyses such as FEM, REM, GLS, and PCSE. It also facilitates hypothesis testing at multiple significance levels and the visualization of interaction effects through marginal effects plots. The comprehensive methodological approach ensures that findings are robust, reproducible, and policy-relevant. By bridging economic, environmental, and institutional dimensions, this research contributes actionable insights to the sustainable energy discourse, equipping policymakers and stakeholders with evidence-based strategies for advancing the energy transition in D8 countries.

CHAPTER 4: RESEARCH RESULTS

4.1. Descriptive statistics

The authors have collected data of D8 countries in the period from 2008 to 2022 with 120 observations. The group displays statistical findings in charts with the following precise details:

Table 4.1. Descriptive statistics results

Variable	Obs	Mean	Std. Dev.	Min	Max
SEDI	118	0	1.5	-2.36	5.411
GDP	119	-1.56	1.109	-5.016	0
PPPE	120	20.083	1.191	16.907	22.886
EI	117	-1.449	1.044	-5.54	0
C02	120	.294	.198	0	.693
GHG	120	6.078	.479	5.234	7.051
PM25	120	3.664	.447	2.769	4.358
RN	120	1.716	.895	.231	3.562
IF	120	.098	.081	-.011	.544
TO	120	3.836	.492	3.031	5.174
POP	120	.918	.225	.358	1.335

Sustainable Energy Index (SEDI): SEDI's dataset consists of 118 observations with a mean value of 0 and a standard deviation of 1.5. Based on the high standard deviation, it shows significant fluctuations in sustainable energy development among D8 countries. The minimum and maximum values of SEDI are -2.36 and 5.411, respectively. This low value may reflect the challenges a country faces in its energy transition. These challenges could stem from a lack of investment capital, outdated technology and infrastructure, dependence on fossil fuels, or political issues. Conversely, a higher SEDI value indicates greater progress in innovation and sustainable policies.

Gross Domestic Product (GDP): The GDP variable has a mean value of -1.56 and a standard deviation of 1.109, with a range from -5.016 to 0. This suggests varying levels of economic performance across countries, potentially reflecting the differing impacts of energy transitions. Economies with low GDP values may struggle to invest in sustainable energy infrastructure, while those with higher values are likely better equipped to adopt renewable energy technologies, supporting long-term development goals.

Public Private Partnerships Investment Energy (PPPE): With 120 observations, the PPPE index has a mean value of 20.083 and a standard deviation of 1.191. This reflects consistency and a shared orientation in the sustainable energy development process among D8 countries. The gap between the minimum and maximum PPPE values is not also hard, at 16.907 and 22.88. Additionally, its mean value of 20.083 is relatively moderate. These figures highlight the attention and investment in new energy infrastructure. The variation in data may stem from the economic conditions, technological advancements, and sustainable policies of each country.

Energy Intensity (EI): Energy intensity, averaging -1.4486 with a standard deviation of 1.0436, highlights disparities in energy efficiency across 117 observations. The minimum value of -5.540 represents highly efficient energy use, potentially reflecting advanced economies or nations prioritizing energy conservation. In contrast, less efficient energy systems with a maximum value of 0 pose challenges to sustainable development, as they often entail higher emissions and resource depletion.

Carbon Dioxide Emissions (CO2): CO2 emissions, with a mean of 0.294 and a standard deviation of 0.198, range from 0 to 0.693. These figures illustrate significant differences in emissions levels, emphasizing the urgent need for global action to curb greenhouse gases. Regions with higher CO2 emissions are often associated with energy systems reliant on fossil fuels, while those at the lower end of the scale may have successfully integrated renewable energy sources or implemented stringent environmental regulations.

GHG (GreenHouse Gas) : The relatively low standard deviation (0.479) indicates limited variation in greenhouse gas emissions among the D8 countries, reflecting a certain level of uniformity in emission levels. The relatively small gap between the minimum and maximum values (5.234 to 7.051) and the mean value (6.078) further suggests that greenhouse gas emissions among the D8 countries are comparable. However, this difference also has significant implications for "environmental health." Countries with lower GHG indices often effectively manage and implement environmental solutions and focus on investing in the sustainable energy sector.

PM25 Air Pollution (PM25) : The mean annual PM25 exposure across the dataset is 3.6638 µg/m³, with a standard deviation of 0.4461. The minimum recorded value of 2.7691 µg/m³ represents regions with relatively clean air, likely due to strict air quality regulations, widespread use of renewable energy, or lower industrial activities. In contrast, the maximum value of 4.3583 µg/m³ indicates areas with severe air pollution, often associated with reliance on fossil fuels, industrial emissions, and urban congestion. PM25 is a critical indicator of environmental and public health concerns. Elevated PM25 levels are directly linked to respiratory diseases and cardiovascular issues, underscoring the urgent need for transitioning to cleaner energy systems. Reducing PM25 pollution through sustainable energy practices is essential for achieving climate goals, protecting health, and fostering sustainable economic development.

RN (Rent from Natural Resources) : The significant differences in natural resource dependency and economic structure among the D8 countries are reflected in the relatively high standard deviation (3.147). The RN values range from 0.341 to 14.926, with an average of 5.612. This wide range clearly indicates a substantial disparity in resource-based economic activities. Within the same group of countries, some focus heavily on mining industries, while others have more diversified economies spanning multiple sectors and rely less on natural resources.

IF (Inflation Rate) : Different economic conditions and monetary policies have resulted in significant variations in inflation rates among D8 countries, as reflected by the relatively high standard deviation (4.189). The lowest inflation rate within the D8 group is 1.032, indicating macroeconomic stability in that country. However, such a low inflation rate may also reflect weak purchasing power and sluggish economic activity. Conversely, one country has an inflation rate as high as 19.237, the highest in the group, highlighting intense inflationary pressures. This could result from economic instability or expansive monetary policies. The mean value of 7.352 indicates that, on average, D8 countries face moderate inflation, which could impact economic performance and efforts toward sustainable energy development.

TO (Trade Openness) : Trade openness can contribute to accelerating sustainable energy development through investment, collaboration, and technology transfer. The TO index has a relatively high standard deviation of 12.438, indicating significant differences in the level of trade integration among D8 countries. This variation reflects disparities in trade policies and the ability to engage in international markets. Due to specific trade policies and a focus on domestic economies, one country has a TO value of 29.684, the lowest in the group. In contrast, the country with the highest TO value (72.391) demonstrates active engagement in economic globalization. However, on average, D8 countries are making efforts toward trade integration, as evidenced by the mean value of 45.763.

POP (Population Total) : The D8 countries exhibit relatively uniform population growth rates, as indicated by the low standard deviation (0.732). The highest population growth rate among the D8 countries is 3.921%, which may reflect policies encouraging childbirth to adjust the population structure. Conversely, the country with the lowest population growth rate, only 0.512%, might be implementing population policies or benefiting from high levels of socio-economic development. On average, the D8 countries have a population growth rate of 1.843%, which could impact energy development due to the increasing demand for energy, resource depletion, and environmental pollution.

4.2. Pearson correlation coefficients matrix

Following the descriptive analysis of the observed data, employing a correlation matrix to analyze potential interactions among the model's predictor variables.

Based on the data analysed in Table, there exists correlation between Sustainable Energy Development - index and GDP, Public Private Partnerships Investment in Energy, energy intensity, CO2 emissions, Greenhouse gas, PM25, Rents from Natural Resources, inflation, trade openness, population growth. To confirm our position, our team will keep on for operating relevant tests and extensively analyze the regression data. Furthermore, despite the strong statistical importance of the independent variables, all correlation coefficients are below 0.886, which suggests there's no sign of severe multicollinearity in the model, according to Hair (2010).

Table 4.2. Pairwise correlations results

Variables	(SEDI_score)	(GDP)	(PPPE)	(EI)	(C02)	(GHG)	(PM25)	(RN)	(IF)	(TO)	(POP)
SEDI	1.000										
GDP	0.399***	1.000									
PPPE	0.223**	0.009	1.000								
EI	-0.287***	0.160*	0.017	1.000							
C02	0.424***	0.553***	0.166*	0.302***	1.000						
GHG	0.364***	0.281***	0.252***	0.343***	0.886***	1.000					
PM25	-0.368***	-0.602***	-0.060	-0.068	-0.477***	-0.322***	1.000				
RN	-0.536***	0.204	-0.17	0.69	0.325*	0.260*	-0.008	1.00			

		**	4*	7***	**	**		0			
IF	0.162*	0.006	0.013	0.213**	0.292***	0.299***	0.229**	0.327***	1.000		
TO	0.125	0.633***	-0.173*	0.139	0.183**	-0.150*	-0.587***	0.241***	-0.138	1.000	
POP	-0.374***	-0.110	-0.063	0.463***	-0.377***	-0.262***	0.188**	0.250***	-0.084	-0.034	1.000

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Source : Authors analysis from Stata 14

As can be seen in Table, it shows the relationships with among variables

The positive interaction demonstrates that whenever GDP grows, so does the aggregate index (SEDI_score), demonstrating that economic activity is favorably correlated to general sustainable development or environmental indicators (0.399).

SED-index has a weak positive correlation with Public Private Partnerships Investment in Energy (0.223). This indicates that as Public Private Partnerships Investment in Energy index rises, the SED index tends to improve significantly but the relationship is not strongly connected .

SED-index has a moderate negative correlation with energy intensity (-0.287). This suggests that while Energy Intensity (EI) grows, the value of SEDI_score falls.

SED-index displays a relatively positive correlation with CO2 emissions (0.424). This indicates that as CO2 emissions increase, the SED index tends to increase strongly.

SED-index demonstrates a positive correlation with the Greenhouse gas (0.364). This suggests that as Greenhouse gas increases, the SED index tends to increase slightly.

SED-index suggests a negative relationship with PM25 (-0.368). This suggests that as PM25 increases, the SED index tends to downward slightly.

SED-index reflects a strong negative correlation with Rents from Natural Resources (-0.536). This indicates that as Rents from Natural Resources increase, the SED index tends to decrease more significantly.

SED-index illustrates a weak positive relationship with inflation (0.162). This suggests that as the inflation rises, the SED index tends to decrease partially.

The SED-index exhibits a little positive interaction, indicating that trade openness (TO) may have an approximate beneficial link with SEDI_score (0.125). It also means that as trade openness increases, the SED index continues upward modestly.

The contrary related demonstrates that since the population (POP) grows (-0.374), the SEDI_score value continues downwards.

4.3. Multicollinearity

To investigate the key determinants of sustainable energy development in D8 countries, a multicollinearity analysis was performed, with the results meticulously summarized in the table below :

Table 4.3. Variance inflation factor results

	VIF	1/VIF
CO2	13.397	.075
GHG	12.565	.08
TO	4.378	.228
EI	3.724	.269
PM25	3.06	.327
GDP	3.046	.328
POP	2.65	.377
RN	2.482	.403
IF	1.422	.703
PPPE	1.172	.853

Mean VIF	4.79	.

Source : Authors analysis from Stata 14

The Variance Inflation Factor (VIF) is a statistical tool used to evaluate the presence and severity of multicollinearity among independent variables in a regression model. Generally, a VIF within the range of 1 to 10 is considered acceptable, indicating that multicollinearity is not a concern.

Based on the results of VIF presented in the table above, it is evident that the VIF values for the variables CO2 (13.307) and GHG (12.565) are higher than the common threshold of 10, indicating a potential multicollinearity issue for these two variables. The remaining variables, including EI (3.724), TO (4.378), PM25 (3.06), GDP (3.046) , POP (2.65), RN (2.482), IF (1.422), and PPE (1.172), fall within the acceptable range, suggesting no significant multicollinearity concerns. This indicates that the relationship between these variables and the dependent variable is less likely to be skewed by multicollinearity.

Moreover, the data shows that multicollinearity is not a significant issue overall, as the average VIF value is 4.79, which lies within the range of 1 to 10.

Thus, while the average values and all variables do not show multicollinearity problems, to further enhance the reliability and precision of the model and minimize the effects of multicollinearity, additional diagnostic tests.

4.4. Stationary test

The data in this study was collected from 2008 to 2022 for the D8 group of countries, covering a period of 14 years. Therefore, a stationary test was conducted to ensure accuracy and prevent bias. The results of the model test are presented in the table below:

Table 4.4. Fisher-type unit root test results

All samples

Variable	z statistic	p value
SEDI_score	-4.0614	0.0000
GDP	-5.4149	0.0000
PPPE	-8.4165	0.0000
EI	-7.6426	0.0000
CO2	-4.4646	0.0000
GHG	-3.0484	0.0012
PM25	-4.3732	0.0000
RN	-3.6393	0.0001
IF	-1.2284	**0.1097**
TO	-4.2167	0.0000
POP	-2.4686	0.0068

Source : Authors analysis from Stata 14

The stationarity of a variable is indicated by its p-value. A variable is considered significant if the p-value is less than 0.05.

Based on the results in Table 4.4, it can be seen that most variables, such as SEDI, GDP, PPPE, CO2, EI, GHG, PM25, RN, TO and POP, have a high level of statistical significance, with p-values ranging from 0.0000 to 0.00012. This means that these variables are stable over time and suitable for use in subsequent analyses.

However, the results also show that the variable IF is not statistically significant, with a p-value of 0.1097.

4.5. Regression results

Table 4.5. Regression results

	ECO factors			ENVIR factors		
	OLS	**FEM**	**REM**	**OLS**	**FEM**	**REM**

GDP	0.697***	-0.161	0.148			
	[4.93]	[-0.86]	[0.95]			
PPPE	0.255***	-0.0470	-0.0417			
	[2.69]	[-0.94]	[-0.80]			
EI	-0.497***	-0.509***	-0.351**			
	[-3.81]	[-2.92]	[-2.27]			
CO2				2.812***	-0.912	2.812***
				[2.77]	[-0.44]	[2.77]
GHG				0.888**	3.973***	0.888**
				[2.15]	[4.76]	[2.15]
PM25				0.0841	-0.138	0.0841
				[0.37]	[-0.82]	[0.37]
RN				-1.599***	-0.506***	-1.599***
				[-17.72]	[-3.31]	[-17.72]
IF	3.804***	2.304**	2.634**	6.320***	1.971**	6.320***
	[2.62]	[2.11]	[2.43]	[7.05]	[2.52]	[7.05]
TO	-0.293	-0.718*	-0.361	1.209***	0.497	1.209***
	[-0.95]	[-1.92]	[-1.10]	[5.12]	[1.48]	[5.12]
POP	-0.817	-1.927***	-1.823***	0.875**	-1.002**	0.875**
	[-1.37]	[-3.88]	[-3.62]	[2.56]	[-2.51]	[2.56]
_cons	-3.251	4.282**	3.327*	-9.858***	-23.73***	-9.858***
	[-1.20]	[2.51]	[1.91]	[-2.93]	[-4.72]	[-2.93]
N	117	117	117	118	118	118

Note: *; **; *** correspond to the significance level of 10%; 5%; 1%

Source : Authors analysis from Stata 14

Economic Factors (ECO)

Moving to the first group of independent variables of the study, the Economic Factors (ECO), and its impact on sustainable energy development (SED). The results in Table 4.5 indicate that, in the Ordinary Least Squares (OLS) regression model, GDP has a significant positive impact on the development of this sector. However, in the Fixed Effects Model (FEM) and Random Effects Model (REM), GDP does not achieve statistical significance. Despite this, GDP maintains its positive directional impact, playing a role in driving the development of sustainable energy.

Next, the results from the OLS model also demonstrate the positive and statistically significant impact of the PPPE factor on SED. This confirms the contribution of public-private partnerships in driving the transition to sustainable energy. However, similar to GDP, PPPE does not achieve statistical significance in the subsequent FEM and REM models.

Unlike the two factors mentioned above, EI shows a negative impact with high statistical significance across all three models: OLS, FEM and REM. This indicates that higher energy intensity hinders the development of renewable energy. Additionally, high EI leads to harmful environmental impacts due to increased emissions. Furthermore, a higher EI reflects lower energy efficiency or, in other words, energy waste. This issue needs to be addressed and improved by nations before transitioning to renewable energy sources.

Environment Factors (ENVIR)

Continuing to the second group of dependent variables, Environmental Quality (ENVIR), the data results show that CO2 emissions positively impact sustainable energy development and hold high statistical significance in both the OLS and REM models. This suggests that with increasing CO2 emissions, D8 countries are becoming more conscious and proactive in improving the environment through energy transition measures.

The GHG factor, which shares similar characteristics with CO2, also demonstrates a positive impact on sustainable development. However, this indicator shows statistical significance across all three models: OLS, FEM, and REM. The PM25 index, which carries significant implications for air quality, does not exhibit statistical significance across all three models.

Regression results in all three models: OLS, FEM, and REM consistently indicate the negative impact of RN on the development of renewable energy, with relatively high statistical significance. Countries that derive substantial income from natural resources naturally prioritize leveraging this opportunity by focusing on resource extraction and export. Consequently, the motivation for investment, innovation, and transitioning to sustainable energy is diminished.

From another perspective, excessive exploitation of natural resources exacerbates environmental degradation. Rather than transitioning to renewable energy, these countries may choose to address immediate short-term environmental issues to minimize costs.

Finally, based on the results in Table 4.4, the control variables, including IF, TO, and POP, exhibit varying influences on the impact of the Economic Index and Environmental Index on sustainable energy development (SED).

Firstly, higher inflation rates enhance the positive effects of both ECO and EVIR on the robust growth of sustainable energy across all three models. However, unlike IF, TO and POP have different effects on the two groups of independent variables. Market expansion reduces the impact of economic factors on SED and is statistically significant only in the FEM model. In contrast to the ECO variables, greater trade openness among the D8 countries amplifies the positive impact of environmental factors on the development of “green” energy. This finding is statistically significant in the OLS and REM models.

The POP index tends to weaken the influence of ECO on SED, with statistical significance observed in the FEM and REM models. This implies that as population growth increases, the economic factors of a country (as considered in this study) have a diminished effect on the energy transition process. Regarding the impact on EVIR, the POP index is statistically significant across all three models. However, in the OLS and REM models, population growth enhances the impact of environmental factors on the development of new energy sources. Yet, in the FEM model, environmental factors' effects on the renewable energy transition are reduced due to rapid population growth. This inconsistency may stem from differences in population policies among the D8 countries.

Because the results of the OLS - FEM - REM regression models still present limitations such as a lack of statistical significance and inconclusive directional impact, the authors suspect the existence of flaws in the model. The authors refrain from drawing definitive conclusions from this model and instead emphasize the need to address and rectify the model's limitations to enhance the overall effectiveness and reliability of the study.

4.6. Method comparison test

To find out the most suitable regression model for the research among Pooled OLS, Fixed Effects Model (FEM), and Random Effects Model (REM), the authors conducted three pairwise tests: OLS - FEM, OLS - REM, and FEM - REM. The results are presented in the table below :

Table 4.6. Method comparison test results

Test	ECO	ENVIR
F-test	OLS and FEM	
F	52.75	23.74
Prob > F	0.0000	0.0000
Conclusion	Reject H_o	Reject H_o
Fit method	FEM	FEM
Breusch - Pagan test	OLS and REM	
chibar2(01)	299.71	190.90

Prob > chi2	0.0000	0.0000
Conclusion	Reject H_o	Reject H_o
Fit method	REM	REM
Hausman test	FEM and REM	
Chi2	4.05	597.62
Prob > Chi2	0.6695	0.0000
Conclusion	Accept H_o	Reject H_o
Fit method	REM	FEM
The best fit model	REM	FEM

Source : Authors analysis from Stata 14

The tests were conducted to determine the most suitable model for each dependent variable, ECO and ENVIR:

For economic factors (ECO), an F-test was performed to compare the OLS and FEM models, with the null hypothesis H_0 stating that the OLS model is appropriate. The results showed rob > F=0.0000, which is smaller than the 5% significance level, leading to the rejection of H_0 . This indicates that the FEM model is more suitable than the OLS model.

Next, the authors compared the OLS and REM models using the Breusch-Pagan test, with the null hypothesis H_0 stating that the OLS model is appropriate. The test results showed Prob > Chi2=0.0000, confirming that the REM model is more appropriate than the OLS model for ECO.

Finally, the Hausman test was used to compare the FEM and REM models, with the null hypothesis H_0 stating that the REM model is appropriate. The results showed Prob > Chi2=0.6695, leading to the acceptance of H_0. Therefore, ***the REM model was determined to be the most suitable for ECO.***

Similarly to ECO, for ENVIR, the authors first conducted an F-test to compare the Pooled OLS and FEM models, with the null hypothesis H_0 stating that the OLS model is appropriate. The results indicated Prob > Chi2=0.0000, leading to the rejection of H_0 and demonstrating that the FEM model is more suitable than the OLS model.

Subsequently, the authors performed the Breusch-Pagan test to evaluate the OLS and REM models, with the null hypothesis H_0 stating that the OLS model is appropriate. With Prob > Chi2=0.0000, the null hypothesis was rejected, showing that the REM model is more suitable than the OLS model for ENVIR.

Finally, to compare the FEM and REM models, the authors used the Hausman test, with the null hypothesis H_0 stating that the REM model is appropriate. The results showed Prob > Chi2=0.0000, leading to the rejection of H_0. ***Therefore, the FEM model was concluded to be the most suitable for ENVIR among the three models.***

It is worth noting that the model has heteroscedasticity and does not have autocorrelation due to (pro>chi2 = 0.000) under FEM model and(Prob>F = 0.0532) under Wooldridge test. So the authors utilise the following models to overcome such noise of heteroscedasticity.

4.7. Feasible Generalized Least Squares method (FGLS) and Panel-Corrected Standard Errors (PCSE)

Following the correction of the variance problems, the outputs of the GLS and the robustness check of PCSE consider are shown in Table 4.7 in the following order:

Table 4.7. Feasible Generalized Least Squares method (FGLS) and Panel-Corrected Standard Errors (PCSE) results

	ECO factors		ENVIR factors	
	FGLS	PCSE	FGLS	PCSE

GDP	0.524***	0.697***		
	[3.51]	[3.89]		
PPPE	0.0538	0.255***		
	[0.98]	[2.83]		
EI	-0.212*	-0.497***		
	[-1.65]	[-3.21]		
CO2			2.647***	2.812***
			[2.94]	[2.62]
GHG			0.0940	0.888**
			[0.28]	[2.31]
PM25			-0.101	0.0841
			[-1.05]	[0.46]
RN			-0.801***	-1.599***
			[-9.17]	[-13.07]
IF	-0.221	3.804**	0.576	6.320***
	[-0.18]	[2.24]	[0.80]	[5.45]
TO	-0.500**	-0.293	0.108	1.209***
	[-2.46]	[-1.15]	[0.76]	[5.56]
POP	-2.301***	-0.817	-0.590*	0.875**
	[-5.61]	[-1.39]	[-1.65]	[2.26]
_cons	3.164**	-3.251	0.340	-9.858***
	[1.97]	[-1.36]	[0.15]	[-3.27]
N	117	117	118	118

Note: *; **; *** correspond to the significance level of 10%; 5%; 1%

Source : Authors analysis from Stata 14

Based on the results from the method presented in Table 4.7, the authors observe that *GDP* has a significant impact on the development of sustainable energy, and this relationship is *positive* with a high level of significance in both the FGLS and PCSE models. Therefore, *hypothesis H1 is accepted*. The results indicate that as a country's GDP increases, it tends to focus more on developing renewable energy sectors. This trend is easy to understand. As economies grow, nations prioritize long-term sustainable development, and renewable energy becomes a global choice to foster this progress. Additionally, economic growth provides countries with stronger financial resources, making large-scale sustainable projects like wind power, solar energy, and hydropower more feasible. According to D8 Organization Economic Cooperation, the average GDP of the eight D-8 countries increased by approximately 25.6% from 2008 to 2022. Over this period, most of these nations relied heavily on fossil fuels. However, recent developments show that these countries are increasingly investing in renewable energy projects. For instance, Bangladesh, the poorest country in D-8 (D8 Organization Economic Cooperation) is working on one of its largest projects, the Rooppur Nuclear Power Plant (Light Castle Partners, 2024), as its GDP has improved by approximate 300% from 2008 to 2022 (D8 Organization Economic Cooperation). Moreover, as incomes rise, environmental awareness among citizens increases, and they are more willing to pay for sustainable energy (Shao 2018). Additionally, renewable energy is seen as a sector with strong future growth potential, and financially stronger countries hope to take advantage of this by exporting electricity, which could significantly boost the development of this sector.

D8 countries with *strong public-private investment* in the renewable energy sector also show a *positive impact* on the development of this industry, with a statistical significance of 10% in the PCSE model. This is true for hypothesis H2, which the author initially proposed. This result also aligns with the findings of Qamruzzaman (2023), which demonstrate a statistically significant positive relationship between renewable energy and public-private investment. Typically, renewable energy projects require significant upfront payments and large investments. To meet these conditions, governments need not only a strong initial capital base but also the ability to attract foreign investment. Therefore, a high public-private partnership engagement (PPPE) facilitates the government's access to the energy transition and its development. Malaysia is one of the pioneers in Sustainable Energy Development (SED) within the D8, with its renewable energy capacity reaching 25%, equating to 9,856 megawatts being deployed by 2022. To achieve this, the Malaysian government has made substantial investments in new energy sectors. By 2050, Malaysia plans to invest between 1.2 trillion and 1.3 trillion RM in energy transition projects, aiming for global sustainability goals.

Additionally, the level of *energy intensity (EI)* in these countries has a *negative impact* on the development of "clean" energy, with statistical significance at 99% in the PGLS model and 90% in the FGLS model. *These findings reinforce the hypothesis (H3) proposed by the authors from the beginning.* High energy intensity reflects the reliance of D8 countries on traditional energy sources such as oil, gas, and coal for each unit of GDP. This not only exacerbates environmental problems but also creates competitive pressure against renewable energy. According to statistics from the World Bank and Our World in Data, among these countries, Nigeria's economy is significantly dominated and influenced by non-renewable energy. Over 90% of the country's export revenue and the majority of its income come from oil. Additionally, Bangladesh and Pakistan frequently face energy and financial risks due to their fragile and dependent economies. Furthermore, Iran, a leading country in oil reserves, plays a notable role in this dynamic. Evidently, most countries in the D8 group reflect a "preference" for fuel derived from natural resources. Consequently, the motivation to diversify and transform their energy structures is constrained, hindering investments and development in clean energy sources such as wind and solar energy. Renewable energy not only requires substantial monetary investment but also incurs significant opportunity costs. As a result, these countries find it difficult to make the trade-offs necessary, especially those with relatively weak economies like Turkey, Bangladesh, or Pakistan (Vneconomy, 2024). An energy system based on traditional resources often lacks the adaptability and innovation needed to transition to renewable technologies like solar and wind energy. This further obstructs the progress of clean energy development.

Continuing to examine the impact of environmental factors on sustainable energy development, it is first observed that the relationship between CO_2 emissions and energy development is also *positive*, with the same statistical significance of 90% in both the FGLS and PCSE models. *Hypothesis H4 is initially accepted.* The increase in pollutant emissions has spurred governments and businesses to invest heavily in emission-reducing projects and energy transition technologies. Most D8 countries rely heavily on fossil fuels, so it is unsurprising that six out of eight nations including Bangladesh, Pakistan, Iran, Nigeria, Turkey, and Indonesia are ranked among the 50 most polluted countries globally in 2023 (AQI, 2023). With their "severe" environmental conditions, these governments are compelled to take action to fulfill global obligations. In fact, all D8 countries, except Indonesia, have signed and ratified the Paris Agreement, aiming to protect the environment, reduce emissions, and transition their energy structure (UNFCCC). These nations have committed to minimizing their dependency on fossil fuels and promoting renewable energy development. Moreover, sustainable energy now extends beyond unlimited resources like wind, water, and solar power. With advancements in technology, CO_2 can now be utilized as a resource in new renewable technologies, transforming "negative" impacts into "positive" outcomes and improving environmental quality.

This result is consistent with the findings from the OLS and REM models used earlier. The development of renewable energy is also *positively* affected by *greenhouse gases (GHG)*, with a statistical significance of 95% in the PCSE model. This means that *hypothesis H5 is correct*. The result also demonstrates that the more a country faces issues related to greenhouse gas emissions, the more it tends to develop sustainable energy solutions. Similar to CO_2, these gases are significant contributors to environmental degradation and have even more severe negative effects on public health. Greenhouse gases, especially methane (CH_4) are particularly impactful with their warming effect on the Earth being 28 times greater than CO_2 (VietnamPlus, 2023). Rising global temperatures result in more extreme weather conditions. According to research by Verisk Maplecroft (2021), extreme weather could severely impact the extraction of 40% of the world's oil reserves, equivalent to 600 billion barrels of oil. This would have significant negative consequences for countries heavily reliant on oil, such as those in the D8 group. Therefore, transitioning to clean energy not only demonstrates environmental responsibility but also provides a " Exit sign " for these countries.

In contrast to these environmental factors, Rents from *Natural Resources (RN)* show a *negative* impact on the development of "green" energy with statistical significance at 90% in both models under consideration. This proves that *hypothesis H7 is not rejected*. This result shows that the more a country benefits from natural resources, the harder it becomes to effectively develop renewable energy industries. In the D8 countries, most have high values for the extraction of natural resources, such as Egypt, Indonesia, Malaysia, and Nigeria, where their resource rents (RN) range from 5.14% to 8.55% (Trading Economics, 2024). Iran stands out with an RN of 30.45% of GDP, confirming its position as the second-largest oil reserve holder in the world. It is evident that oil, or fossil fuels in general, provide these countries with a "comparative advantage" for export and production. This makes it difficult for them to reduce extraction or lower the efficiency of non-renewable energy usage to focus on developing a new energy sector. On the other hand, the renewable energy sector could "threaten" their market position due to its near-perfect replacement of traditional energy sources.

However, regarding *PM25* air pollution, the results indicate that this factor does *not have any relationship* with the development of sustainable energy. This contradicts the *hypothesis (H6) that was initially proposed*. This result was also found in all three models : OLS, FEM, and REM conducted in Section 4.5.

Despite this, the authors maintain a perspective supporting a positive relationship between the increase in air pollution PM25 and the development of the alternative energy sector. To explain this viewpoint, the authors argue that when air quality deteriorates significantly, with rising levels of fine particulate matter, countries are compelled to implement long-term solutions to protect public health. The primary source of fine particulate matter is the smoke generated from burning organic fuels in industrial activities. Therefore, governments will address this "root cause" first. To reduce emissions from fossil fuels, transitioning to sustainable energy is likely the best solution. China is a prime example of a "polluted nation," with its PM25 index reaching 500, while a PM25 level of 35 already signals severe air pollution, heavily affecting the respiratory system. In response to this situation, the Chinese government has planned to reduce coal consumption by 30% by 2024, replacing it with renewable energy sources (Nhan Dan, 2024). Within the D8 group, **Bangladesh** and **Egypt** have also made it onto the list of countries with the worst air quality (measured by PM25), ranking 4th and 3rd, respectively. With worsening environmental conditions caused by the overuse of fossil fuels for production and export, energy transition policies may inevitably become the “sooner-or-later” solution for these countries, as China has already done. This has proven true, as Bangladesh has set an ambitious goal of generating 40% of its total energy from renewable sources by 2040, reflecting the country’s commitment to a greener and more sustainable energy landscape. While still emphasizing the role of natural gas energy, Egypt has also set a target to increase renewable energy sources to 40% of the country’s total electricity production, aiming to reduce pollution and align itself with the “ new global trend ” (EVN, 2024).

This approach not only helps improve air quality and mitigate environmental pressure but also addresses the problem of depleting natural resources. As a result, the sustainable energy sector is likely to receive increased investment through activities such as infrastructure development, modern technology adoption, and the production of complementary goods. This strongly contributes to the robust growth of this emerging energy sector.

Control variables such as IF, TO, and POP show significant impacts on the greater development of sustainable energy. From an economic perspective, the authors believe that inflation, trade openness, and population growth can influence the greater expansion of alternative energy development to some extent.

4.8. Interaction models

To clearly evaluate the impacts of various factors on the development of alternative energy, the author presents the results of two groups of factors: ECO (Economic Factors) and ENVIR (Environmental Factors), as shown in Tables 4.8.1 and 4.8.2 below :

Table 4.8.1. Interaction models (ECON factors) results

	OLS	FEM	REM	FGLS	PCSE
GDP	-0.452***	-0.273	-0.452***	-0.245*	-0.452***
	[-2.73]	[-1.40]	[-2.73]	[-1.72]	[-2.76]
PPPE	0.0954	-0.0545	0.0954	0.0806*	0.0954
	[1.30]	[-1.15]	[1.30]	[1.81]	[1.44]
EI	-0.00207	-0.501***	-0.00207	-0.0328	-0.00207
	[-0.02]	[-3.03]	[-0.02]	[-0.38]	[-0.02]
IF	2.411*	1.483	2.411*	0.561	2.411
	[1.73]	[1.41]	[1.73]	[0.50]	[1.32]
TO	-0.497	-0.745**	-0.497	-0.858***	-0.497
	[-1.37]	[-2.06]	[-1.37]	[-3.92]	[-1.46]
POP	-2.458***	-2.463**	-2.458***	-2.725***	-2.458***
	[-5.09]	[-4.62]	[-5.09]	[-8.88]	[-5.81]
GDP_RQ	**0.0511*** **	**-0.0271** **	**0.0511*** **	**0.0437*** **	**0.0511*** **
	[5.82]	**[-2.57]**	**[5.82]**	**[6.37]**	**[5.37]**
GDP_PS	**-2.104*** **	**-1.243*** **	**-2.104*** **	**-1.353*** **	**-2.104*** **
	[-5.13]	**[-2.73]**	**[-5.13]**	**[-3.25]**	**[-3.96]**
_cons	-0.122	5.043***	-0.122	2.540**	-0.122
	[-0.05]	[3.02]	[-0.05]	[2.00]	[-0.07]
N	117	117	117	117	117

Note: *; **; *** correspond to the significance level of 10%; 5%;1%

Source : Authors analysis from Stata 14

In most models, the results indicate that GDP has a negative impact on the development of renewable energy, with statistical significance ranging from 1% to 5%, and the strongest effect observed in the FGLS model. This reflects that the economies of the D8 countries are heavily reliant on fossil fuels. Indeed, during the research period (2008-2022), these countries repeatedly faced "power shortages" due to their reliance on fossil fuels and the "alarming" levels of pollution. With their natural resource advantages, countries in the D8 such as Iran and Nigeria have become some of the largest reserves of coal and natural gas in the world. Therefore, these countries prioritize the use of available energy and remain dependent on it. Additionally, other countries in the group, such as Malaysia, also exemplify this, with approximately 92% of the country's energy production relying on fossil fuels like coal, oil, and gas. Bangladesh generates 70% of its electricity from fossil fuels, with only about 3% coming from renewable sources. Indonesia has also become one of the world's leading fossil fuel CO_2 emitters, with approximately 43% of the country's electricity coming from coal (Pacific Group, 2024).

However, when *combined with the quality of regulatory (RQ)*, *GDP* demonstrates a more *positive* and statistically significant effect (1% - 5%), as shown through the interaction variable *GDP_RQ*. This result shows that *Hypothesis H8 is initially accepted.*

The higher the quality of governance in a country, the more average income contributes to accelerating the development of the renewable energy sector. High governance quality signifies an effective and transparent legal and policy framework. This creates favorable conditions for the development of alternative energy sectors through tax incentives, investment subsidies, and other enabling mechanisms. Furthermore, as the saying goes, "wealthy citizens make a strong nation". When people's incomes rise and the national economy grows, financial resources allocated to clean energy sectors also strengthen and develop sustainably. Moreover, a country with high average income and strong governance quality becomes a top priority for investors.

Sustainable energy development projects are fueled by these robust investment inflows (Doytch, 2016). A sustainable nation also pays more attention to innovation and technology application. In the context of rising national income, green energy solutions can more easily reach consumers through the influence of social networks, media, and a higher willingness to pay. The study by Shao in China (2018) indicated that the higher an individual's income, the more they care about the environment. Similarly, Liu et al. (2024) found that most people are willing to pay an additional 10% for renewable energy, with the willingness-to-pay rate reaching up to 76%.

On the contrary, the interaction variable *GDP_PS* exhibits a significantly *negative impact* with high statistical significance across all models. *This means that hypothesis H9 is accepted.*

This indicates that, even though political stability is ensured in the D8 countries, it is not sufficient to enable GDP to contribute positively to the sustainable energy sector.

Public-private investment in energy (PPPE) also shows a positive impact on the development of the renewable energy sector, but its statistical significance remains limited. The coefficient for PPPE is only statistically significant at the 10% level in the FGLS model. This result may stem from weak investment and limited financial resources allocated to the sustainable energy sector in the D8 countries during the 2008–2022 period.

Control variables such as inflation (IF) show a positive but weak and inconsistent impact. Meanwhile, trade openness (TO) demonstrates a significantly positive effect, with statistical significance at the 1% level across most models. On the other hand, population growth has a strongly negative and highly significant impact on the development of the renewable energy sector, with statistical significance reaching 99% in all models.

This indicates that while the pressures from international trade contribute to promoting sustainable energy development, renewable energy sources still fail to meet the demands of the increasing population in the studied countries.

Table 4.8.2. Interaction models (ENVI factors) results

	OLS	FEM	REM	FGLS	PCSE
CO2	0.553	-0.367	0.553	1.253	0.553
	[0.40]	[-0.12]	[0.40]	[1.04]	[0.36]
GHG	0.585	3.882***	0.585	0.000375	0.585
	[1.35]	[4.31]	[1.35]	[0.00]	[1.52]
PM25	0.0485	-0.138	0.0485	-0.0947	0.0485
	[0.21]	[-0.80]	[0.21]	[-0.74]	[0.26]
RN	-1.357***	-0.500***	-1.357***	-1.152***	-1.357***
	[-10.49]	[-3.22]	[-10.49]	[-11.02]	[-9.19]
IF	5.803***	1.873**	5.803***	3.048***	5.803***
	[5.36]	[2.13]	[5.36]	[2.82]	[4.04]
TO	1.056***	0.495	1.056***	0.607***	1.056***
	[4.13]	[1.46]	[4.13]	[3.77]	[4.95]
POP	0.491	-1.006**	0.491	0.663**	0.491
	[1.32]	[-2.39]	[1.32]	[2.17]	[1.23]
CO2_RQ	**0.0278****	**-0.00423**	**0.0278****	**0.0279****	**0.0278****
	[2.41]	**[-0.26]**	**[2.41]**	**[2.50]**	**[2.10]**
CO2_PS	**-1.011****	**-0.0154**	**-1.011****	**-1.314*****	**-1.011***
	[-2.18]	**[-0.05]**	**[-2.18]**	**[-2.84]**	**[-1.65]**
_cons	-7.415**	-23.27***	-7.415**	-2.253	-7.415**
	[-2.14]	[-4.38]	[-2.14]	[-0.97]	[-2.40]
N	118	118	118	118	118

Note: *; **; *** correspond to the significance level of 10%; 5%;1%

Moving to environmental factors, the CO2 emissions in the table above indicate that this is not a decisive factor in the development of sustainable energy, as it does not show statistical significance across all five models: OLS, FEM, REM, FGLS, and PCSE. Unlike CO2, although it shares similar characteristics, greenhouse gas emissions (GHG) show a positive impact with high statistical significance (1%) in the FEM model. This suggests that in certain contexts, alternative energy measures and active investments in the renewable energy sector may be undertaken as countries gradually strive to address energy depletion and "overload" emissions, aiming for long-term sustainability. As indicated by the models tested in previous sections, once again, the fine particulate matter (PM25) coefficient is not statistically significant in any of the models.

This confirms that the development of "green" energy has not been significantly affected by the level of air pollution caused by fine dust during the study period.

When the transition is turned, the interaction variable CO2_RQ represents the impact of CO2 emissions when there are changes in regulatory quality. In most models, *CO2_RQ has a positive coefficient and relatively high statistical significance* at the 5% level. Thus, the initial *hypothesis H11 can be accepted.*

Combined with the earlier analysis result, although CO2 emissions do not significantly affect the development of clean energy transitions evidently, these emissions demonstrate *a substantial positive impact* on the development of the new energy sector when coupled with improved regulatory quality.

This further underscores *the critical role of governments* in issuing, implementing, and scaling effective policies for environmental and natural resource management, as well as encouraging and motivating investments in renewable energy. With their unique powers, governments hold the primary responsibility for determining the quality and efficiency of national governance. As such, countries with strong regulatory capabilities are often better positioned to adopt measures that promote energy transitions, laying the groundwork for minimizing the impact of CO2 on the environment and public health. A clear example to support this assertion is Norway. Specifically, according to the 2017 Resource Governance Index (NRGI) assessment, Norway is the country that manages and controls its natural resources the best. According to the Norway Power Market Report, this country has always set the goal of building a sustainable energy system as part of its long-term objectives and is effectively implementing energy transition policies, including completely phasing out coal-fired power generation. Norway's electricity production mainly comes from hydropower. As of 2021, Norway has approximately 1,660 hydroelectric plants with a total installed capacity of 34,183 MW. The size of Norway's renewable energy market, in terms of installed capacity, is expected to grow from 42.07 gigawatts in 2024 to 48.45 gigawatts in 2029.

Meanwhile, the variable CO2_PS, representing the interaction between CO2 emissions and Political Stability and Absence of violence, has a *negative coefficient* and exhibits high statistical significance at the 1% level across all models. Clearly, the initial *hypothesis 10 was correct*.

This paradox can be explained by some following rationales: *Firstly*, the standalone positive impact of CO_2 suggests that emissions create a push toward clean energy solutions, either through regulatory pressure or technological innovation but when political stability factored in, it might hinder the full realization of this positive impact because stable governments may focus more on economic priorities or delay action due to lack of immediate pressures from societal or environmental crises. *Secondly*, in politically stable environments, governments may prioritize maintaining the status quo and economic stability rather than implementing disruptive and costly transitions to sustainable energy; this conservative approach might dampen the urgency to address CO_2 emissions aggressively. Finally, stable political systems might inadvertently enable complacency in addressing CO_2 emissions as policymakers in such systems may focus on maintaining political power through short-term economic gains from carbon-intensive industries, rather than making bold investments in sustainable energy.

Control variables such as inflation and trade openness exhibit a positive impact with statistical significance at the 10% level across all models. It can be said that rising inflation and global trade expansion also contribute to the development of alternative energy. However, population growth shows an impact that is neither stable nor clearly defined.

4.9. Synthesis of Research Hypotheses

Table 4.: Table of Research Hypotheses

Research Hypotheses	Conclusion
Hypothesis 1: GDP positively affects SEDI	Accepted
Hypothesis 2: PPPE positively affects SEDI.	Accepted
Hypothesis 3: EI negatively affects SEDI.	Accepted
Hypothesis 4: CO_2 positively affects SEDI.	Accepted
Hypothesis 5: GHG positively affects SEDI.	Accepted
Hypothesis 6: $PM_{2.5}$ positively affects SEDI	Rejected
Hypothesis 7: RN negatively affects SEDI.	Accepted
Hypothesis 8: PS negatively moderates the relationship between GDP and SEDI.	Accepted
Hypothesis 9: RQ positively moderates the relationship between GDP and SEDI.	Accepted
Hypothesis 10: PS negatively moderates the relationship between CO_2 and SEDI.	Accepted

Source : Authors analysis from Stata 14