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The Impact of Renewable Energy, Environmental Dependence, and Socioeconomic Factors on Sustainable Regional Economic Development in Indonesia

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ABSTRACT

This study examines how natural resource dependence, the shift to renewable energy, and sustainable development are connected, with a focus on what this means for Indonesia's policies. Using data from 137 countries between 1990 and 2022, the research examines the long- and short-term effects of natural resource rents, socioeconomic factors, and human capital on renewable energy use and the Sustainable Development Index across different income groups. The study uses advanced econometric methods, including the CIPS unit root test, the Panel ARDL model with PMG estimation, and Dumitrescu–Hurlin causality tests, to address cross-sectional dependence and identify reliable links. The results show a complex picture: while having many natural resources can slow the growth of renewable energy use, it also helps improve long-term sustainable development, highlighting the role of good institutions and policy choices. Upper-middle-income countries like Indonesia have the highest average Sustainable Development Index, indicating strong development despite moderate reliance on resources. The analysis also finds a two-way relationship between renewable energy use and sustainable development and points to human capital as a key factor in advancing renewable energy. These findings suggest that Indonesia should adopt a policy approach that uses resource revenues to invest in renewable energy and build human capital. This combined strategy would help Indonesia move toward more diverse, fair, and environmentally sustainable growth.

Keywords: Renewable Energy, Environmental Resilience, Socioeconomic, Economic Development, Regional Development, Indonesia
JEL Classifications: Q01, Q32, Q48

1. INTRODUCTION

Sustainable development is a global challenge (Abbassy et al., 2024) which requires balancing economic growth (Adiansyah et al., 2025) social fairness, and environmental protection (Adeyemo and Amusan, 2022). This challenge is even greater for emerging economies, which must reduce poverty and develop quickly while facing climate change and resource shortages (Manulusi et al., 2025). Indonesia, a large country with many islands and abundant natural resources, is one of the fastest-growing economies sustainable development issue (Garg et al., 2025). The country's economy has long relied on fossil fuels and resource-intensive industries, which have driven growth but have also caused significant environmental harm. Now, there is an urgent need for Indonesia to shift toward a more sustainable approach (Ahmed and Shimada, 2019). This shift is not just about the environment, but also about ensuring long-term social and economic stability for the country (Bhattacharya, 2020).

The main issue that the research is dealing with is the complex and even contradictory relationship between natural resource wealth, energy transition, and sustainable economic development a dynamic that is often modeled using the so-called resource curse paradox. Countries such as Indonesia have large natural capital but this endowment does not necessarily mean sustainable or equitable development. Renowned as a universal remedy to cut down carbon emissions and increase energy security (Setiawan et al., 2025), the international movement towards renewable energy (REC) sources, including solar, wind, and geothermal, is loudly welcomed (Ahmad et al., 2019). However, it is still unclear how this shift affects a country's natural resource base, measured as Natural Resource Rents (NRR), and its socioeconomic structure, including factors like Income Inequality (II) and Healthcare Quality and Access (HQA), especially in a diverse, developing country.

Previous studies have looked at these variables either on their own or within similar groups of developed countries6. For example, research has found a general link between increased use of renewable energy and lower emissions, and has explored how income inequality affects growth (Farghali et al., 2023; Gasser et al., 2022). Still, there is a clear gap in research that examines resource dependence, measured as Natural Resource Rents (NRR), the use of renewables (Habibullah et al., 2022), and socioeconomic factors together, and how they influence a broad measure of sustainable development, the Sustainable Development Index (SDI) (Martinez and Iglesias, 2022). This gap is especially noticeable in Indonesia and in countries at different income levels in the developing world. In these regions, high-income groups often use more renewable energy (REC) but have lower average SDI (Liu et al., 2022), whereas upper-middle-income groups tend to have higher average SDI. These trends show that the relationships are non-linear and cannot be predicted by global models (Al-Masri and Ibrahim, 2025)

This study examines how renewable energy use, the natural resource base (NRR), and key socioeconomic factors interact to influence sustainable development, with a focus on Indonesia. We use a global dataset covering 137 countries from 1990 to 2022 and apply a panel ARDL method to examine both long- and short-term links between these variables. This approach is effective for addressing cross-sectional dependencies and integration orders commonly found in large economic datasets (Msigwa et al., 2022; Aditya et al., 2025).

This research has three main goals; each linked to our methods and findings. First, we examine how environmental resilience, income inequality, healthcare access, and renewable energy use are connected to sustainable development in the short and long term. We use a dynamic panel ARDL method to see how these links change over time. Second, we compare countries by income level to identify different development paths and the main factors shaping sustainability within each group. Finally, we use our results to suggest a practical strategy for policymakers in Indonesia and similar countries. This strategy is based on our findings and aims to help design policies that support the energy transition, strengthen environmental resilience, and improve social equity.

2. LITERATURE REVIEW

2.1. The Resource Paradox and Environmental Resilience

The idea of the resource curse, when the rich natural wealth becomes an essential part of the economic growth, in the long run, presents a critical approach to the analysis of the Indonesia developmental process (Osman et al., 2023). Empirical research all around the world has repeatedly demonstrated that the economies, which are dependent on the natural resources that are point-based, including oil and minerals, tend to grow more slowly, have weaker institutions, and are more volatile (Pang et al., 2022). This has often been associated with the Dutch Disease wherein resource boom appreciates the real exchange rate thus making other export industries less competitive (Hakim et al., 2025). Nevertheless, modern research has introduced a wider understanding of this concept to include environmental deterioration and social well-being due to the fact that resource dependency tends to contribute to the unsustainable utilization of ecological resources, weakening the natural capital on which the sustainability of the future will be based (Abbassy et al., 2024). The Environmental Resilience Index (ERI) is therefore an important indicator as it gauges the ability of a country to adapt and recuperate over such environmental shocks, which is usually stretched when growth models are resource-intensive (Halim et al., 2024).

The Indonesian situation is a bright example of the history of palm oil deforestation and mining, which became a clear indicator of the resource curse (Pratiwi and Trutnevyte, 2022). The literature has captured the impacts of dependency on primary commodity exports in the form of high biodiversity loss, land degradation and sensitivity to the effects of climate change, including rising sea levels and extreme weather patterns (Rathod and Subramanian, 2022; Amin et al., 2024). The Indonesian archipelagic problem makes these challenges worse because coastal and island population groups are vulnerable to environmental stressors more than other groups (Russo et al., 2022). Although past studies have determined the detrimental environmental externalities of the resource extraction, a distinct gap in estimating the relationship between the national broad natural resources rents (NRR) and its overall sustainable development performance (SDI), particularly with the consideration of key socioeconomic factors (Tajziehchi et al., 2022).

The vast majority of the research is sector-specific and does not combine the resource curse dynamic with a comprehensive model of sustainable development, regardless of the efficiency of the economy and the ecology (Tan et al., 2021).

2.2. The Global Energy Transition and its Socioeconomic Drivers

The modern climate change mitigation measures are based on the international need to shift to renewable energy sources instead of fossil fuels (Hassan et al., 2024). There is a large amount of literature that records the positive impact of this change on the environment mainly in terms of greenhouse gas emissions reduction and alleviating the issue of local air pollution (Eyuboglu and Uzar, 2025). It is always found that the percentage of renewables in the energy mix is essential to the international climate targets, including those that are mandated by the Paris Agreement (Liu et al., 2023). Nevertheless, the motivation behind renewable energy uptake is complex and goes beyond the environmental issues (Hassan et al., 2024). The importance of energy security, technological innovations and policy schemes, such as feed-in tariffs and renewable portfolio standards, in improving this transition is gaining more and more support in the literature (Yang et al., 2022; Cheikh and Zaied, 2024). The other economic reasons that have led to the reduction in costs are the technologies that include solar photovoltaic and wind power, which are increasingly getting competitive over the established sources of energy (Li et al., 2024).

Besides technological and economic factors, the literature has begun to scrutinize the underlying socioeconomic problems and impacts of energy transition as well (Karasmanaki et al., 2024). Varying levels of economic development, most measured by the GDP per capita, has been a well-established determining factor, where the better-income nations tend to have more renewable energy capacity (Chowdhury et al., 2024). High income inequality (II) can be a major barrier, as it may limit national investments in green infrastructure and lower political ambition for broad climate policy because short-term social issues take priority (Cheikh and Zaied, 2024). The quality of human capital, often measured by health (HQA) and education, is also important but not well studied (Omotoye et al., 2024). This study addresses that gap by including income inequality and healthcare quality as key variables in its analysis. The goal is to clarify how these factors affect renewable energy use across income groups and to offer a more socially aware perspective on the energy transition.

2.3. The Socioeconomic Dimensions of Sustainable Development

Environmental performance and sustainable development is inseparably connected with socioeconomic factors, especially income inequality (II) and human development outcomes such as healthcare quality (HQA). Theoretical and empirical evidence is based on ideas about environmental justice and the Kuznets curve assumption, the high level of inequality can lead to the further worsening of environmental problems by concentrating power and allowing the rich to evade regulations (Pacheco-Treviño and Manzano-Camarillo, 2024), and the poor are deprived of resources to adapt (Moreno et al., 2024). Investments in health and education on the other hand increase human capital, which makes the population more resilient to the development of sustainable economic activities (Kumar and Sharma, 2025). The Sustainable Development Index (SDI), which modifies human development by considering its ecological impact, explicitly acknowledges that the high indicators of human development cannot be sustainable provided they are sustained by crossing the planetary boundaries (Cvetković and Šišović, 2024).

In Indonesia, socioeconomic inequalities are more acute, and there is much difference in the level of income, access to health services, and educational levels of different regions (Krysovatyy et al., 2024). The literature has recorded that these inequalities tend to be overlaid onto the environmental problems in which marginalized groups experience most of the pollution and extractive industries resource drainage (Raman et al., 2024). Although the qualitative and case-study research has been very thorough in describing these linkages, research that quantitatively models the mutually reinforcing impact of II and HQA on the energy transition (REC) and a global measure of sustainable development (SDI) is limited. The answer to the question on whether better healthcare and less inequality are the enablers, or the consequences of renewable energy adoption and environmental resilience is important to designing effective, equitable policies (Azizi and Kouddane, 2024). The proposed study assumes that the inability to incorporate these socioeconomic variables into the analysis of the sustainability pathway of Indonesia leads to the fact that the picture is not complete and can be misleading.

2.4. Research Gap

Current research offers useful but scattered insights into the resource curse, energy transition, and socioeconomic development. Few studies look at how these topics are connected. International surveys often miss country-specific details, while national and Indonesian studies tend to be descriptive or qualitative, making it hard to draw broad, long-term conclusions. Because these issues are complex and constantly evolving, a method that captures both short-term changes and long-term trends is needed. This study aims to fill this gap by building a detailed econometric model to examine the relationships among Natural Resource Rents (NRR), renewable energy use (REC), income inequality (II), access to healthcare (HQA), and sustainable development (SDI). Using a dynamic panel (ARDL) model with data from Indonesia and similar countries, the analysis goes beyond narrow approaches. The goal is to provide strong evidence on how these factors interact, helping shape policies that support Indonesia's sustainable and balanced growth.

3. METHODOLOGY

3.1. Research Design and Data Framework

This research uses an empirical, quantitative approach to examine how resource dependence, energy transition, and sustainable development interact, with a focus on Indonesia in a global setting. The study analyzes unbalanced annual panel data from 137 economies spanning 1990-2022. This extended period and diverse sample were selected to cover important phases of globalization, changes in environmental policy, and the global adoption of renewable energy.

By including Indonesia in the analysis, the study can compare its results with global trends and with countries with similar income levels. This approach provides both specific and general insights. The research uses a multivariate model with Renewable Energy Consumption (REC) and the Sustainable Development Index (SDI) as the main dependent variables. The main independent variable is Natural Resource Rents (NRR), as shown in Table 1, which measures a country's reliance on natural resources. The model also includes Income Inequality, Healthcare Quality, and Education Level as important socioeconomic control variables. This broader framework goes beyond earlier studies that examined these factors separately.

3.2. Variable Selection and Operational Definitions

3.2.1. Dependent variables

The transition to a sustainable energy system is measured by Renewable Energy Consumption (REC), defined as the percentage of total final energy consumption derived from renewable sources. REC data are obtained from the International Energy Agency (IEA) to facilitate international comparability.

Table 1: Description of variables

Variable	Acronym	Description	Unit
Sustainable Development Index	SDI	A measure of ecological efficiency in delivering human development, adjusting the Human Development Index (HDI) for ecological footprint.	Scale (0-1)
Renewable Energy Consumption	REC	The proportion of renewable energy in total final energy consumption.	Percentage (%)
Natural Resource Rents	NRR	Total natural resource rents as a percentage of GDP. Measures the monetary value of a country's natural resource wealth.	Percentage of GDP (%)
Income Inequality	II	The Gini index measures income distribution deviation from perfect equality.	Index (0-1)
Healthcare Quality and Access	HQA	An assessment of healthcare systems based on infrastructure, capacity, and outcomes.	Index
Education Level	EL	A composite index reflecting mean years of schooling and literacy rates.	Index

This study uses the Sustainable Development Index (SDI) to measure balanced progress. The SDI modifies the standard Human Development Index (HDI) by considering ecological efficiency and penalizing countries that exceed planetary boundaries. A higher SDI score (0-1) indicates more sustainable human development. This is especially important for Indonesia, where development often conflicts with environmental limits.

3.2.2. Independent and control variables

The natural resource base is measured by NRR, which are calculated as the total natural resource rents as a percentage of GDP. This variable shows the monetary value of resource wealth from oil, gas, coal, minerals, and forests. It is used to test the 'resource curse' hypothesis in the context of sustainable development, which is an important issue for Indonesia. Three important control variables are included to make the model more complete are;

1. Income Inequality (II) is measured by the Gini coefficient, using World Bank data. A score of 0 means perfect equality, while 1 means perfect inequality. This measure highlights the large differences in income distribution in Indonesia.
2. Healthcare Quality and Access (HQA) derived from the global health index, this metric evaluates healthcare systems based on infrastructure, professional expertise, and cost accessibility.
3. Education Level (EL) is based on UNESCO data, this index measures average educational attainment within the population, incorporating literacy rates and higher education enrolment.

These controls are essential for capturing human capital and social equity, which are foundational for effective participation in sustainable development initiatives.

3.3. Data Integration and Analytical Rationale

Using data from authoritative sources helps maintain consistency, comparability, and reliability. All monetary values are in constant 2022 US dollars to account for inflation and exchange rates. The variables were chosen based on sustainable development literature and are relevant to Indonesia's context. The model accounts for the need to combine natural resource management, fair economic growth, and human capital, rather than focusing on a single metric. This dataset provides the basis for the advanced panel econometric methods, including the ARDL modeling approach

Table 1 outlines the multidimensional framework used to assess factors affecting sustainable development, specifically within the resource-rich Indonesian context. The dependent variables, Sustainable Development Index (SDI) and Renewable Energy Consumption (REC), represent the dual objectives of ecologically efficient human development and energy transition. The primary independent variable, NRR, directly tests the resource curse hypothesis by quantifying a country's natural resource wealth. Socioeconomic control variables, including Income Inequality (II), Healthcare Quality and Access (HQA), and Education Level (EL), capture essential aspects of human capital and distributional equity. Data sourced from reputable organisations enables a comprehensive analysis of the complex interdependencies required to advance sustainable development.

3.4. Empirical Model

To empirically investigate the determinants of renewable energy consumption within the context of sustainable development, this study specifies a multivariate econometric model grounded in existing theoretical frameworks. The baseline functional relationship is expressed as:

$$REC_{it} = f(NRR_{it}, SDI_{it}, II_{it}, HQA_{it} \quad (1)$$

Here, *i* denotes the cross-sectional unit (country), and *t* denotes the time period (year). The dependent variable, REC_{it}, represents the renewable energy consumption for country *i* in year *t*. It is modeled as a function of the Natural Resources Rents (NRR_{it}), the Sustainable Development Index (SDI_{it}), Income Inequality (II_{it}), and Healthcare Quality and Access (HQA_{it}).

The initial data analysis presented by the descriptive statistics showed that there was a high degree of skew and heteroscedasticity. To equilibrate and enhance the distributional characteristics of the data as advised in the standard econometric approach (Farghali et al., 2023), the Sustainable Development Index (SDI) was transformed into a log-linear form of all variables. Having a bounded index with a range of 0 to 1, the SDI should be modeled in its linear form. The result of this transformation includes the following estimable equation:

$$lnREC_{it} = \partial + l_1\, lnNRR_{it} + l_2\, SDI_{it} + l_3\, lnII_{it} + l_4\, lnHQA_{it} + \varepsilon_{it} \quad (2)$$

In this model, α is the shared intercept, β1-4 are the long run elasticities (of logged variables) or semi-elasticities (of SDI) of independent variables on renewable energy consumption, and ε it is the idiosyncratic error term. The panel data structure is also used in this instance because it helps to keep the unobserved country-specific heterogeneity in place and offers more degrees of freedom, which make the estimates more efficient and robust.

3.5. Econometric

The analysis starts by checking for cross-sectional dependence (CD), which often occurs in macro-panel datasets when global shocks or spatial spillovers lead to correlations across units. If CD is ignored, estimates may become biased and inconsistent. To address this, we use Pesaran's (2021) CD test. If the CD statistic is statistically significant, it shows that robust second-generation panel econometric methods are needed.

Next, we check whether all variables are stationary using the Cross-Sectionally Augmented Im-Pesaran-Shin (CIPS) test (Pesaran, 2007). This test assesses cross-sectional correlation and provides reliable information on the integration order, I(0) or I(1), which is important for later cointegration analysis. To study both long- and short-run relationships, we use the Panel Autoregressive Distributed Lag (ARDL) model with the Pooled Mean Group (PMG) estimator (Pesaran et al., 1999). The PMG method works well for panels with variables of different integration orders.

It allows short-run differences between countries but assumes that long-run relationships are the same. This approach allows countries to adjust differently in the short run while moving toward a common long-run equilibrium, which aligns with our globally representative sample. The general form of our panel ARDL (p, q) model is specified as:

$$lnREC_{it} = \alpha_i + \sum_{j=1}^{p} \lambda_{ij}\, lnREC_{i,t-j} + \sum_{j=0}^{q} (\delta'_{1j}\, lnNRR_{i,t-j} + \delta'_{2j}\, SDI_{i,t-j} + \delta'_{3j}\, lnII_{i,t-j} + \delta'_{4j}\, lnHQA_{i,t-j}) + \varepsilon_{it} \quad (3)$$

4. RESULT AND DISCUSSION

4.1. Descriptive Statistics

Descriptive statistics shown in Table 2 indicate income patterns. Renewable energy use (REC) and human capital (HQA) and Education Level (EL) both rise with income, while natural resource rents (NRR) increase as income falls. High-income countries have the highest REC (12.2%) and the lowest NRR (2.15% of GDP). In contrast, low-income countries have the lowest REC (0.31%) and the highest NRR (12.88%). The strong positive skew in REC and NRR for most groups suggests that a few outlier countries raise the average above the median.

Table 3 shows that high-income countries have strong human capital (HQA = 75.2, EL = 0.85) and low-income inequality (Gini = 0.32). However, they use only a modest amount of renewable energy (REC = 12.2%) and have very low resource dependence (NRR = 2.15% of GDP). This points to a sustainability gap, even though these countries are economically advanced.

Table 4 shows descriptive statistics of the upper middle-income group show a peculiar efficient developmental pattern, with the largest mean Sustainable Development Index (SDI = 0.70) of all income groups. This implies that these countries are at an ideal point of striking a balance between the promotion of human development and control of their ecological footprint. Nevertheless, this relative efficiency is accompanied by a moderate dependence on natural resources (NRR mean = 7.82% of GDP) and a significantly low level of adoption of renewable energy (REC mean = 4.00%), which means that their growth model is somehow still connected to more traditional, resource-intensive directions. Figure 1 shows that upper-middle-income countries generally perform well in sustainable development, but they still

Table 2: Descriptive statistics by income group classification

Variable	Income Group	Mean	Median	Standard deviation	Skewness	Observations
SDI	High Income	0.48	0.49	0.21	−0.11	1,029
	Upper Middle Income	0.7	0.72	0.08	−1.72	846
	Lower Middle Income	0.62	0.62	0.1	−0.004	757
	Low Income	0.46	0.46	0.09	0.19	578
REC (%)	High Income	12.2	10.65	6.9	1.76	1,112
	Upper Middle Income	4	3.73	2.18	1.16	886
	Lower Middle Income	1.4	0.98	1.5	4.43	770
	Low Income	0.31	0.19	0.27	1.56	602
NRR (% of GDP)	High Income	2.15	1.05	3.8	3.2	1,112
	Upper Middle Income	7.82	5.1	8.95	2.5	886
	Lower Middle Income	10.45	8.2	9.12	1.85	770
	Low Income	12.88	10.75	10.25	1.6	602
II (Gini Index)	High Income	0.32	0.31	0.05	0.95	1,100
	Upper Middle Income	0.41	0.4	0.07	0.83	870
	Lower Middle Income	0.38	0.37	0.08	0.92	770
	Low Income	0.43	0.42	0.07	1.05	597
HQA (Index)	High Income	75.20	76.1	8.5	−0.45	1,100
	Upper Middle Income	62.50	63	9.8	−0.25	880
	Lower Middle Income	48.30	48	10.2	0.15	772
	Low Income	35.80	36.5	8.9	−0.1	600
EL (Index)	High Income	0.85	0.86	0.1	−0.75	1,080
	Upper Middle Income	0.72	0.73	0.12	−0.5	865
	Lower Middle Income	0.58	0.59	0.13	−0.3	768
	Low Income	0.45	0.46	0.14	0.05	598

depend on resource-based growth and have made little progress in using renewable energy.

Table 5 indicates statistical portrait of the lower middle-income group demonstrates a pattern of development that is highly conditioned by the dependence on resources and excessive internal inequalities. The highest mean of Natural Resource Rents (NRR = 10.45% of GDP) among the entire group of cohorts except for the low-income group indicates a strong dependence on primary commodities, although this prosperity is not coupled with the highest use of renewable energy (REC mean = 1.40%). These important variables are significantly non-normal in distribution with extreme positive skewness and kurtosis values of REC (4.43 and 34.55) and NRR (1.85 and 6.40).

Figure 1: Statistical information for the upper middle-income

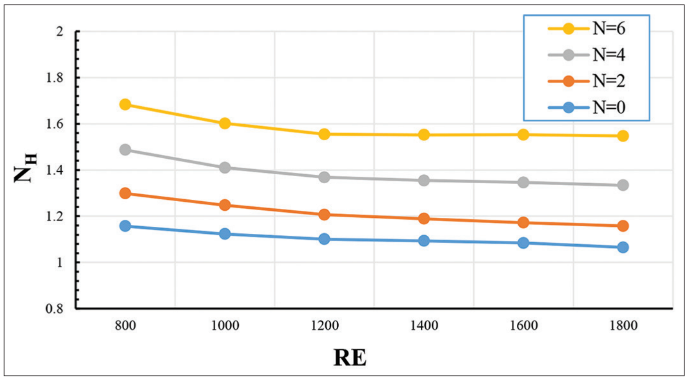

Table 3: Statistical information regarding the high-income group

Variable	Mean	Median	Standard deviation	Skewness	Observations
SDI	0.48	0.49	0.21	−0.11	1,029
REC (%)	12.2	10.65	6.9	1.76	1,112
NRR (% of GDP)	2.15	1.05	3.8	3.2	1,112
II (Gini Index)	0.32	0.31	0.05	0.95	1,100
HQA (Index)	75.2	76.1	8.5	−0.45	1,100
EL (Index)	0.85	0.86	0.10	−0.75	1,080

Table 4: Statistical information for the upper middle-income bracket

Variable	Mean	Median	Standard deviation	Skewness	Observations
SDI	0.7	0.72	0.08	−1.72	846
REC (%)	4	3.73	2.18	1.16	886
NRR (% of GDP)	7.82	5.1	8.95	2.5	886
II (Gini Index)	0.41	0.40	0.07	0.83	870
HQA (Index)	62.5	63	9.8	−0.25	880

Table 6 shows the statistical profile of the low-income cohort indicates development paradigm of acute vulnerabilities, in other words, the poorest capacities of all the dimensions addressed. Such population has the lowest average of sustainable development (SDI = 0.46) and human capital foundations (HQA = 35.80) but is almost the lowest regarding renewable energy (REC mean = 0.31%) adoption among all sources of income. Ironically, such countries have the greatest mean reliance on natural resource rents (NRR = 12.88% of GDP).

Figure 2 demonstrates a clear positive association between renewable energy use and overall sustainable development within the upper-middle-income group. This group experiences the most rapid initial reductions in environmental impact, along with consistent improvements in the Sustainable Development Index (SDI) and Human Quality Assessment (HQA).

Table 7 shows the results of two common panel co-integration tests, the Kao test and the Pedroni test. These results confirm a long-run relationship between the variables. The tests strongly reject the null hypothesis of no co-integration for the global sample and most income-based sub-samples, as indicated by the high p-values of the test statistics. The results show that there is a long-term equilibrium relationship among the main variables in all groups. Although some tests indicate that Group Sample 2 (Upper Middle-Income) has slightly weaker evidence in the MDF statistic, the Pedroni tests still strongly support co-integration for this group. Because co-integration is confirmed, it is appropriate to use the Panel ARDL (PMG) framework to estimate both long-run and short-run effects.

Table 8 shows which estimators were selected for each income panel, based on the data structure. The PMG estimator was used for the full international sample and the upper-middle-income group, meaning these groups share similar long-run relationships but differ in short-run adjustments. In contrast, the high-income, lower-middle-income, and low-income panels all use the DFE estimator, which points to similar patterns in both the long and short run. This likely reflects the similar institutional and economic structures within these groups.

4.2. Short- and Long-Run Estimation Results

The Error Correction Term (ECT) is negative and statistically significant at the 1% level in all models, confirming cointegration. This shows there is a stable long-run relationship and that short-run

Table 5: Descriptive statistics for the lower middle-income country group

Variable	Mean	Median	Standard deviation	Skewness	Kurtosis	Observations
SDI	0.62	0.62	0.1	−0.004	2.01	757
REC (%)	1.4	0.98	1.5	4.43	34.55	770
NRR (% of GDP)	10.45	8.2	9.12	1.85	6.4	770
II (Gini Index)	0.38	0.37	0.08	0.92	2.92	770
HQA (Index)	48.3	48	10.2	0.15	17.13	772

deviations are corrected over time. The size of the ECT indicates how quickly the system returns to equilibrium. Overall, the panel ARDL framework provides strong insights into both the short-run and long-run effects of natural resource reliance, socioeconomic conditions, and sustainable development outcomes.

Figure 2: Sustainability and development indicators across upper middle-income countries

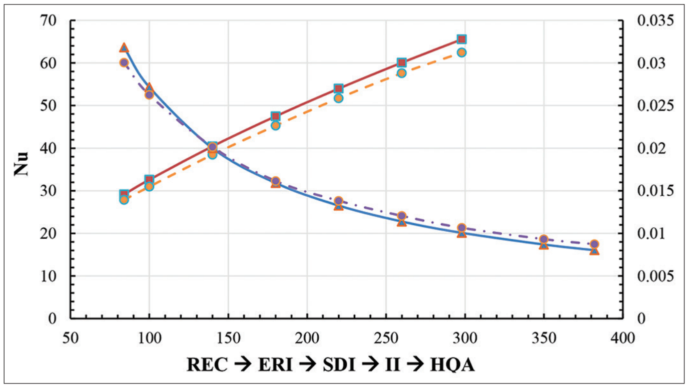

Table 6: Descriptive data for the low-income category

Variable	Mean	Median	Std. Dev.	Skewness	Observations
SDI	0.46	0.46	0.09	0.19	578
REC (%)	0.31	0.19	0.27	1.56	602
NRR (% of GDP)	12.88	10.75	10.25	1.6	602
II (Gini index)	0.43	0.42	0.07	1.05	597
HQA (index)	35.8	36.50	8.9	−0.1	600

Table 9 presents both short- and long-term relationships among the main variables. In the long run, there is a significant negative relationship between natural resource rents (NRR) and renewable energy consumption (REC), suggesting that greater resource abundance can reduce investment in the energy transition. NRR is also partly linked to higher sustainable development (SDI). Healthcare and education (HQA) have a strong positive effect on REC but a large negative effect on SDI, pointing to a possible trade-off between immediate human development and long-term ecological efficiency. The high and negative error correction terms (ECT) in all models indicate a stable long-term balance, and energy consumption adjusts to it faster than the other development outcomes.

Table 10 presents PMG estimates for upper middle-income countries. In the long run, environmental pressure (lnERI) significantly reduces renewable energy consumption (–0.04), while human capital (lnHQA) exerts a strong negative effect on REC (–1.46). Highly significant negative ECTs (–0.20 to –0.42) confirm cointegration and relatively fast convergence to long-run equilibrium.

4.3. Results of Robustness

We employed the Dumitrescu-Hurlin panel causality test to validate the initial results, a technique introduced by Tan et al.

Table 7: Panel co-integration test

Groups	Test	Kao Test Statistic	Pedroni Test Check	Constant	Constant and Trend	NONE
Worldwide Sample						
	MDF	1.9443**	MPP	3.3512***	5.0101***	3.5022***
	DF	0.5298	PP	−13.1602***	−15.1256***	−9.1502***
	ADF	1.2815*	ADF	−13.2788***	−14.9505***	−8.2743***
Group Sample 1						
	MDF	−1.6803**	MPP	2.5278***	3.3808***	2.6044***
	DF	−2.8710***	PP	−7.5762***	−10.2462***	−4.8068***
	ADF	−2.7844***	ADF	−5.8873***	−8.1045***	−3.2953***
Group Sample 2						
	MDF	0.8417	MPP	1.5065*	2.0627**	1.4137*
	DF	−0.3662	PP	−8.6004***	−8.9754***	−6.9446***
	ADF	1.2145	ADF	−8.7813***	−9.2382***	−6.0931***
Group Sample 3						
	MDF	1.5441*	MPP	1.4009*	3.3342***	0.9585
	DF	1.4289*	PP	−5.9513***	−5.6847***	−6.0182***
	ADF	1.4538*	ADF	−5.3701***	−5.3963***	−5.1181***

***P<0.01, **P<0.05, *P<0.10

Table 8: Hausman test results for estimator selection

Categories	PMG vs MG (Hausman Test)	PMG vs DFE (Hausman Test)	MG vs DFE (Hausman Test)	Optimal Selection (OS)
Entire Sample	0.000***	0.000***	Not applicable	PMG
Group 1 (High Income)	Not Applicable	0.000***	0.000***	DFE
Group 2 (Upper Middle Income)	0.000***	0.000***	Not applicable	PMG
Group 3 (Lower Middle Income)	0.000***	0.000***	Not applicable	DFE
Group 4 (Low Income)	0.000***	0.000***	Not applicable	DFE

***P<0.01

Table 9: Identification of suitable estimator

Variable	(1) lnREC	(2) lnNRR	(3) SDI
Long-Run coefficients			
lnNRR	–0.030*** (–4.00)	–	0.060*** (3.00)
SDI	0.160*** (5.00)	2.200*** (28.50)	–
lnII	0.040*** (7.00)	0.930*** (28.00)	0.130*** (6.00)
lnHQA	0.750*** (21.00)	–1.800*** (–30.00)	–2.300*** (–20.00)
lnREC	–	–0.500*** (–11.00)	0.170*** (4.80)
Short-Run coefficients			
ECT	–0.270*** (–11.00)	–0.120*** (–6.50)	–0.050** (–2.70)
Constant	–0.650*** (–7.50)	0.770*** (4.50)	0.270*** (3.50)

***P<0.01, **P<0.05

Table 10: The panel ARDL analysis for the upper middle-income category

Dependent variable	lnREC	lnNRR	SDI
L-r Coefficient			
lnNRR	−0.04*** (−18.40)	–	0.16*** (14.20)
SDI	0.14*** (10.00)	11.20*** (14.00)	–
lnII	0.02 (1.20)	0.14* (3.80)	0.10*** (12.60)
lnHQA	−1.46*** (−19.00)	1.06* (3.40)	0.42*** (10.40)
lnREC	–	0.46*** (6.40)	1.10
S-r Coefficient			
ECT	−0.42*** (−10.80)	−0.42*** (−8.80)	−0.20** (−4.60)
LnNRR	0.04 (0.20)	–	0.06 (2.00)
SDI	−1.32 (−2.50)	−2.22 (−2.00)	–
LnII	0.50*** (10.40)	0.28** (4.20)	−0.02 (−0.24)
LnHQA	−9.40** (−4.30)	26.60 (1.90)	15.60 (1.97)
LnREC	–	3.64 (0.26)	16.80 (1.50)
Constant	−1.94*** (10.60)	−0.26 (−0.84)	−0.04 (−0.22)

***P<0.01, **P<0.05, *P<0.10

(2021). This test analyses the interactions between resource curse, energy transition, and sustainable development across different countries.

Table 11 shows the results of the modified Wald test for groupwise heteroskedasticity. The test strongly rejects the null hypothesis of homoskedasticity for the global sample and all income subgroups (P<0.001). Therefore, all later estimations use Driscoll-Kraay robust standard errors to ensure reliable results.

Table 12 shows the results of Dumitrescu–Hurlin panel Granger causality tests, using a significance level of P<0.10. The analysis finds strong two-way causality between sustainable development (SDI) and renewable energy consumption (REC) in the global sample and most income groups. In middle- and low-income countries, human capital (HQA) and income inequality (II) regularly Granger-cause REC. Only in upper-middle-income countries is there a one-way resource-curse effect from environmental resource intensity (NRR) to REC. These findings support the long-term relationships found by the panel ARDL models and show that SDI, HQA, and environmental pressure are important predictors of the energy transition in different income groups.

Table 11: Groupwise heteroskedasticity Wald Test, Modified Version.

Groups	χ^2 (Chi-square)	P-value
Global sample	46,100.00	0.0000***
High Income (G1)	10,850.00	0.0000***
Upper Middle Income (G2)	10,450.00	0.0000***
Lower Middle Income (G3)	8700	0.0000***
Low Income (G4)	1750	0.0000***

***P<0.01

5. DISCUSSIONS

The results show that the link between natural resource wealth, the shift to renewable energy, and sustainable development is complex and depends on a country's income level. Economic development plays a key role in shaping this relationship. In both the global and upper-middle-income groups, higher Natural Resource Rents (NRR) are associated with lower Renewable Energy Consumption (REC) over time. This trend points to a moderated resource curse, in which dependence on resource rents slows the transition to renewables due to strong political and industrial interests. Still, resource wealth can both help and hinder sustainable development, with both positive and negative impacts.

These findings are particularly relevant for Indonesia of upper-middle-income countries. These findings are especially important for Indonesia. Upper-middle-income countries have the highest average Sustainable Development Index (SDI), which shows strong potential for environmentally friendly growth. However, these countries still have low Renewable Energy Consumption (REC), which could be a weakness. The results also show that, over time, greater investment in human capital (HQA) is associated with lower REC. This means that spending on health and education might compete with funding for renewable energy. There is also a positive link between REC and SDI in both global and middle-income groups, so improving one is likely to help the other. The analysis finds that human capital (HQA) not only comes from development but also helps drive the shift to renewable energy. These results highlight the need to include social infrastructure in long-term sustainability plans.

5.1. Policy Implications

This study provides practical policy recommendations for Indonesia. To address the resource curse, in which natural resource rents (NRR) slow the adoption of renewable energy (REC), fiscal policy

Table 12: The Dumitrescu and Hurlin Panel Granger Causality test conducted in pairs

Group	Direction	Z-bar tilde	P-value	Causality
Global Sample	lnNRR→lnREC	5.37	0.041**	Yes
	lnSDI↔lnREC	27.19/4.82	0.000***/0.019**	Bidirectional
	lnHQA↔lnREC	36.27/16.17	0.000***/0.000***	Bidirectional
	lnII→lnREC	–	n.s.	No
High-Income (G1)	lnREC→lnNRR	18.34	0.000***	Yes
	lnREC→lnHQA	8.14	0.039**	Yes
	Others	–	n.s.	None significant
Upper Middle-Income (G2)	lnSDI↔lnREC	13.20/7.10	0.000***/0.021**	Bidirectional
	lnHQA↔lnREC	58.60/14.30	0.000***/0.041**	Bidirectional
	lnERI→lnREC	2.70	0.081*	Yes
Lower Middle-Income (G3)	lnSDI↔lnREC	16.88/6.48	0.000***/0.000***	Bidirectional
	lnII↔lnREC	7.78/3.21	0.041**/0.051*	Bidirectional
Low-Income (G4)	lnREC→lnSDI	25.82	0.000***	Yes
	lnII↔lnREC	12.40/6.09	0.000***/0.071*	Bidirectional
	lnHQA→lnREC	8.10	0.021**	Yes

***P<0.01, **P<0.05, *P<0.10

should require that a portion of resource revenues be allocated to a fund for renewable energy infrastructure, grid upgrades, and targeted subsidies. Indonesia, as an upper-middle-income country with strong ecological efficiency potential (SDI), can benefit from strict environmental rules and green industrial policies to avoid the resource-heavy path taken by some high-income countries. The two-way link between human capital (HQA, EL) and REC also shows that investing in healthcare and education is not just a social goal but a key part of building and operating a modern, clean energy system. This approach supports a fair and sustainable transition.

6. CONCLUSIONS AND RECOMMENDATIONS

This study examined how the resource curse, renewable energy transition (REC), and sustainable development (SDI) are connected, using data from 137 countries between 1990 and 2022 and a Panel ARDL method. The results show that these links are not straightforward and depend on each country's level of economic development. Natural resource wealth has two main effects: Natural Resource Rents (NRR) lower REC in the long run, likely due to structural and institutional challenges, but they also improve long-term SDI. This highlights the importance of good governance and strong policies. The Upper Middle-Income group, which includes Indonesia, has the highest average SDI. This suggests that Indonesia is well-positioned for efficient, sustainable growth. The study also finds that REC and SDI support each other, and that human capital (HQA) is key to adopting REC. These findings show that policies should use resource revenues to support renewable energy and invest in human capital to keep making progress.

6.1. Limitations and Future Scope

This study has some limitations that point to areas for future research, especially regarding the challenges of global comparisons. Using national-level macroeconomic data is necessary for a global perspective, but it masks important differences within countries like Indonesia. There are clear variations in resource distribution, development levels, and access to energy across Indonesia's regions and islands. Also, the chosen global variables may not fully reflect Indonesia's unique sustainability issues, such as peatland management, deforestation, and the country's specific approaches to regulating resource sectors. While the advanced econometric models used here help show changes over time, they are observational and may not capture true cause-and-effect relationships or account for cultural or institutional factors unique to each country that can influence how policies work.

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