Reassessing Jason Hickel's Sustainable Development Index: An Analysis and Insights from Turkiye

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Summary: This study explores the causal dynamics between Jason Hickel's Sustainable Development Index (SDI) and renewable energy use in Turkiye (1990-2019). Using Johansen cointegration and Granger causality tests, results reveal a one-way causality from SDI to renewable energy, indicating that sustainability frameworks can drive energy transition, but not vice versa. The study suggests revising SDI to better capture decarbonization dynamics and positive externalities such as air quality and health gains. Findings imply that sustainability demands integrated strategies beyond technological change, offering actionable insights for policy and advancing SDI as both a normative and diagnostic tool.

Keywords: Sustainable development, Renewable energy, Granger causality, Jason Hickel, Environmental sustainability

JEL: Q1, Q42, Q56, O13

Introduction

The relationship between sustainable development and renewable energy has evolved over time. In the late 20th century, growing concerns about the impacts of traditional energy sources on the environment and human health led to increased interest in renewable energy as a more sustainable alternative (Armaroli and Balzani 2007; Omer 2008). The United Nations Conference on Environment and Development (UNCED), also known as the Earth Summit, held in Rio de Janeiro in 1992, marked a major turning point in the global recognition of the importance of sustainable development and the role of renewable energy in achieving it (Weiss 1992).

Since then, the use of renewable energy has grown rapidly, driven by technological advancements, declining costs, and policy support. The adoption of the Paris Agreement in 2015, which aims to limit global temperature rise to well below 2°C above pre-industrial levels, has further increased the importance of renewable energy in achieving sustainable development (Clémençon 2016). Moreover, sustainable development has become a central focus of global development efforts and is widely recognized as a critical challenge facing humanity in the 21st century (Yılmaz and Şensoy 2023; Dincer 2000). While progress has been made in some areas, many challenges remain, and the implementation of sustainable development remains an ongoing process.

Today, renewable energy is seen as a key component of a sustainable energy system, and countries around the world are investing in renewable energy and other clean technologies to reduce their dependence on fossil fuels, improve energy access and security, and reduce greenhouse gas emissions (Yilmaz and Sensoy 2022; Sachs et al. 2019). The relationship between sustainable development and renewable energy continues to evolve as new technologies emerge and as the world works towards a more sustainable future (Barreto, Mkihira, and Riahi 2003).

1. From HDI To SDI: Conceptual Background And Research Motivation

Especially the weaknesses in the calculation of Human Development Index (HDI) constituted the main motivation of this study. This index, which many researchers have tried to develop, is still being discussed. Jason Hickel's *"SDI"* has undoubtedly added a new dimension to this debate, but it has not ended the debate. Jason Hickel's SDI was developed as a critical response to the HDI, which he argues inadequately reflects the ecological costs embedded in conventional models of human progress. While Hickel's critique effectively highlights the disproportionate emphasis placed on economic growth and material consumption within mainstream development paradigms, it is important to situate his intervention within the broader trajectory of sustainability scholarship. Since the publication of the Brundtland Report, sustainable development has been widely recognized as a multidimensional construct that includes environmental integrity, social equity, and economic viability. From this perspective, Hickel's position can be understood more as a critique of how development policies are implemented in practice, rather than a fundamental rejection of the theoretical inclusion of environmental and social dimensions in development models. Although the HDI is often referenced in critiques of sustainability metrics, it was originally designed to measure human well-being without explicitly accounting for ecological performance. Recent adaptations, such as the Planetary Pressures-Adjusted HDI developed by the United Nations Development Programme, along with regionally customized indices, have attempted to address this gap by incorporating environmental indicators. In this context, Hickel's SDI offers a complementary framework that retains the core indicators of the HDI but introduces ecological footprint as a normalizing variable. This adjustment aims to reframe development assessment by emphasizing the necessity of achieving human well-being within the Earth's biophysical limits (Hickel 2020). The present study approaches the SDI not as an alternative to existing indices, but as a normative tool that enables empirical inquiry into the association between sustainable development and specific sectoral dynamics, with a particular focus on renewable energy use in Turkiye. Another motivation of this study is that Hickel's SDI is an index open to development and draws attention to increasing environmental problems.

Accordingly, this study seeks to empirically examine the directional relationship between sustainable development and Renewable energy consumption (% of total final energy consumption) in Turkiye through the lens of Jason Hickel's SDI. Utilizing annual data spanning from 1990 to 2019, the research applies the Johansen-Juselius cointegration test to identify potential long-run equilibrium relationships and the Granger causality test to determine the direction of causality. By doing so, the study not only contributes to the empirical validation of Hickel's normative framework but also offers policy-relevant insights into the dynamics of sustainability-oriented development strategies. The subsequent sections present a review of the relevant literature, outline the methodological approach, discuss the empirical findings, and conclude with reflections on policy implications and theoretical contributions.

2. Literature Review

The evolving discourse on sustainable development has increasingly emphasized the need to transcend traditional economic indicators and adopt multidimensional frameworks that capture both social welfare and environmental integrity. The Human Development Index (HDI), introduced as a humane alternative to GDP, incorporates health, education, and income dimensions. However, it has been widely criticized for its failure to account for environmental degradation and its implicit endorsement of economic growth without ecological constraint (Hickel 2020, 2019). In response, Jason Hickel proposed the Sustainable Development Index (SDI), which maintains the core elements of HDI but penalizes countries with high per capita carbon emissions and material footprints. By doing so, SDI reorients development assessment away from affluence and toward sufficiency within planetary boundaries. This framework is aligned with broader critiques in the literature that challenge the empirical viability of "green growth" and call for the integration of biophysical limits into development theory (Hickel and Kallis 2020).

Earlier non-income-based approaches to development, such as the Physical Quality of Life Index (PQLI) and the Social Development Index (Ray 2007; Kantiray 1989), paved the way for multidimensional assessments. Biswas and Caliendo (2002) emphasized that such indices yield more robust cross-national comparisons, particularly in contexts where income alone fails to reflect social well-being. Kumar's (2017) application of the Social Development Index in India further underscored the significance of policy design, showing that both development and non-development expenditure shape outcomes.

Recent methodological innovations have also enhanced the granularity and relevance of sustainable development indicators. For instance, Mastini and Kallis (2022) critique conventional indices for using arithmetic mean aggregation, which they argue obscures critical trade-offs. They propose the Integrated SDI using the Multidimensional Synthesis of Indicators method to capture interdependencies among indicators. Similarly, Shah (2025) applies optimization-based weighting to sustainability dimensions, ensuring that composite indices reflect context-specific priorities. Regionally, Çalıkoğlu and Łuczak (2024) compare HDI and a newly constructed SDI across EU countries using TOPSIS and bilinear ordering, revealing both convergence and spatial disparities. Xu, Deng, and Zhang (2023) extend this line of inquiry by identifying policy blind spots in China's sub-national sustainability performance, while Pham, Dao, and Vu (2024) demonstrate the utility of the SDI framework in local-level assessments through Delphi and SPOTIS methods.

Hickel's argument that renewable energy must be situated within broader systems of equity and ecological sufficiency finds empirical resonance in several studies. For example, Ülger and Kasap (2025) report that renewable energy consumption positively influences SDI in BRICS-T countries, while R&D investments yield mixed results, depending on institutional quality. Wang, Rani, and Amjad (2025) similarly demonstrate that renewable energy and environmental governance jointly promote green growth in South Asia. Yet, as Mastini, Kallis, and Hickel (2021) caution, technological innovation alone is insufficient without structural transformation. Renewable energy, while central to the sustainability transition, cannot by itself overcome ecological overshoot unless supported by democratic participation and sufficiency-oriented policies Hickel (2020).

This study situates itself within this growing body of literature by empirically testing the directional relationship between SDI and renewable energy use in Turkiye. The Granger causality analysis confirms a one-way effect from SDI to renewable energy consumption, suggesting that sustainable development, when defined through the lens of ecological responsibility, can act as a driver of energy transition. This finding contrasts with assumptions that renewable energy adoption autonomously enhances sustainability metrics. Instead, it supports a more nuanced view in which development strategies must integrate social, economic, and environmental goals simultaneously. Furthermore, the study echoes Bartelmus's (2008) critique of aggregate indices and affirms the need for physical accounting systems that reflect environmental thresholds more accurately.

To summarise, the SDI provides a valuable normative and empirical tool for assessing the ecological coherence of development pathways. This study analyzes the directional effect of SDI on renewable energy consumption by empirically testing this relationship, which is often hypothetical in the literature, in the case of Turkiye. The one-way relationship (SDI → RNW) detected in the Granger causality test reveals that sustainable development policies can trigger energy transition; however, the increase in energy consumption alone will not improve SDI. This supports that sustainability is possible with more holistic development strategies beyond energy policies.

3. Econometric Methodology and Dataset

In this section, the Granger Causality test method is used to analyze the relationship between Hickel's theory of sustainable development and renewable energy consumption (% of total final energy consumption. The causality tests developed by Clive W. Granger, who received the Nobel Prize in Economics in 2003 with Robert F. Engle in his article published in Econometrica in 1969, are widely used today not only in economics and econometrics, but also in basic sciences, engineering, and medical sciences (Papageorgiou and Tsaklidis 2021; Elbedour et al. 2022; Yao and Ge 2023; Pastorino and Zanin 2023; Kornilov et al. 2020). By definition, variable X is said to be a Granger-cause of Y if the history of a random variable X provides a better prediction of the future of another random variable Y, after considering all possible relevant factors and non-random information (Engle 1982; Granger 1969; Yıldırım 2021). Although the concept of causality in the context of Granger is not widely accepted in philosophy of science because it is a functional and pragmatic definition, the phenomenon of Granger-causality is close to Suppes' (1970) definition of causality, which is accepted in philosophy of science. Contemporary philosopher James Woodward emphasizes that perhaps more attention should be paid to Granger's concept, given the inadequacy of causality definitions in the philosophy of science (Woodward 2008).

Today's Granger-causality tests differ in theory and practice from the way they were first proposed in 1969. Both the developments in time series analysis and the gradual decrease in the cost of computing have added new dimensions to the Granger causality tests. The aim of this study is to analyze some innovations in the literature on Granger causality tests on a methodological and intellectual basis.

The data to be used are annual data sets covering the years 1990-2019 for Turkiye. The variables and descriptions of the model to be installed can be found below:

Table 1. Descriptive Variables and Sources

Varible	Descriptive	Source
SDI	Sustainable Development Index	https://www.sustainabledevelopmentindex.org/
RNW	Renewable energy consumption (% of total final energy consumption)	World Bank, International Energy Agency, and the Energy Sector Management Assistance Program

Note: Annual data between 1990 and 2019 were used for all variables. All variables are included in the model at their level.

In this context, the studies in the literature were examined and the main hypotheses of the research were established as follows:

H_0: There is a reciprocal Granger causality relationship between the Sustainable Development Index and Renewable energy consumption (% of total final energy consumption).

H_{1a}: There is no reciprocal Granger causality relationship between the Sustainable Development Index and Renewable energy consumption (% of total final energy consumption).

H_{1b}: There is a Granger causality relationship from the Sustainable Development Index to Renewable energy consumption (% of total final energy consumption).

H_{1c}: There is a Granger causality relationship from renewable energy consumption (% of total final energy consumption) to the Sustainable Development Index.

3.1 ADF and PP Unit Root Tests

Commonly used tests to determine whether a time series has a unit root are the Enhanced Dickey-Fuller (ADF) and Phillips-Perran (PP) tests. The following three equations are used when performing the ADF test (Dickey and Fuller 1981; Enders and Lee 2012):

$$\Delta y_t = \beta y_{t-1} + \sum_{i=1}^{p} \delta \Delta y_{t-i} + u_t \qquad (1)$$

$$\Delta y_t = a + \beta y_{t-1} + \sum_{i=1}^{p} \delta \Delta y_{t-i} + u_t \qquad (2)$$
$$\Delta y_t = a + yt + \beta y_{t-1} + \sum_{i=1}^{p} \delta \Delta y_{t-i} + u_t \qquad (3)$$

With the ADF test, it tries to determine whether the variable y has a unit root by testing the following hypotheses:

$$H_0: \beta = 0, H_1: \beta < 0$$

In the PP unit root test, the following model is used (Phillips and Perron 1988):

$$y_t = a + \rho y_{t-1} + u_t \qquad (4)$$

The error term *(u_t)* in the model is assumed to be white noise, since the test statistics required to perform the PP test are limited and at the same time the problematic sample distributions depend on the correlation structure of the error terms. More precisely, the distributions depend on the ratio ${\sigma^2}/{\sigma_u^2}$ (Maddala and Kim 1999).

σ^2, which is called the variance of the sum of the error terms in the ratio:

$$\sigma^2 = \lim_{n\to\infty} n^{-1} E\left[\left(\sum_{j=1}^{n} u_j\right)^2\right] \qquad (5)$$

The so-called variance of the error terms σ_u^2:

$$\sigma_u^2 = \lim_{n\to\infty} n^{-1} \sum_{j=1}^{n} E(u_j)^2 \qquad (6)$$

It is calculated with the help of formulas.

In the PP test, two test statistics are used, in the form of Z_p and Z_t, modeled constant term and calculated differently depending on whether there is a trend or not. When $\sigma^2 = \sigma_u^2$, the asymptotic table values of the tests are used, since the limited distributions of the Zp and Zt test statistics are the same as the *$n(\rho - 1)$* and t-statistics, respectively (Azam et al. 2020). ADF and PP unit root test results are given in Table 2:

Table 2. Unit Root Test Results

Variable	Test Equation	Lag	Method	
			Aug. Dickey Fuller	**Philips-Perron**
SDI	*Intercept*	*I(0)*	-2.2900[a] (0,6965)	-2.3716[b] (0.1581)

		I(1)	-5.3198[a] (0.0002)*	-5.3196[b] (0.0002)*
	Intercept and Trend	I(0)	-1.4733[a] (0.8156)	-1.3450[b] (0.8556)
		I(1)	-5.8285[a] (0.0003)*	-5.8930[b] (0.0002)*
RNW	*Intercept*	I(0)	-1.5793[a] (0.4800)	-1.6019[b] (0.4688)
		I(1)	-5.1845[a] (0.0003)*	-5.8228[b] (0.0000)*
	Intercept and Trend	I(0)	-1.3222[a] (0.8619)	-0.8306[b] (0.9507)
		I(1)	-5.7611[a] (0.0004)*	-6.8029[b] (0.0000)*

Note: *, denotes significance at 1% level. [a], denotes Aug. Dickey Fuller value and [b], denotes Philips-Perron adj. t-Stat value. **Source:** Research finding. (Authors' compilation from Eviews 11 (IHS Global Inc)).

Both ADF and PP test results showed that all variables are stationary at first difference, that is, they are integrated in *I(1)*.

3.2 Johansen Cointegration Test

Since the variables used in the study are stationary in their first differences, the Johansen-Juselius cointegration test can be applied to the related series. Johansen cointegration test shows long-term relationships between variables and is based on VAR analysis. For this reason, it is necessary to determine the optimal lag length before the cointegration test (Gonzalo and Pitarakis 2002). In Table 3 below, lag length values can be examined in terms of different criteria.

Table 3. Determining the Optimal Lag Length

Lag	LogL	LR	FPE	AIC	SC	HQ
0	0.218859	NA	0.003912	0.131936	0.227924	0.160479
1	46.71254	**82.65543***	**0.000168***	**3.015743***	**2.727780***	**2.930117***
2	48.29259	2.574896	0.000203	2.836488	2.356548	2.693777
3	54.18077	8.723231	0.000179	2.976353	2.304438	2.776557

Note: LR indicates sequential modified LR test, FPE final prediction error, AIC Akaike information criterion, SIC Schwarz information criterion and HQ Hannan-Quinn information criterion**. Source:** Research finding. (Authors' compilation from Eviews 11 (IHS Global Inc)).

According to the data in Table 3, the most appropriate lag length in terms of all criteria is indicated with a (*) sign. Accordingly, the optimal lag length was determined as 1 (k=1) in terms of related variables.

Once each variable is confirmed to be *I(1)* and the optimal lag length is established, the next step is to examine possible cointegration relationships among the series. The Johansen cointegration test was used to investigate the cointegration relationships between the variables. The reason for choosing the Johansen method is that there is no obligation to determine which variable to take as an endogenous variable when performing the test, and it clearly considers the error structure of the data process by allowing interactions in determining the relevant economic variables (Habimana, Månsson, and Sjölander 2021). The Johansen multivariate cointegration test is used to test the relationships between non-stationary variables using the following VAR model.

$$\Delta y_t = \sum_{i=1}^{k-1} \pi_i \Delta y_{t-1} + \pi_i \Delta y_{t-k} + \varepsilon_t \qquad (7)$$

Here, y is the observation vector of the non-stationary variables SDI and RNW in size $nx1$, and π_i and π are coefficient matrices in size nxn. The rank of the π matrix reveals the long-run relationship between the variables and is equal to the number of independent cointegrating vectors. Søren Johansen and Juselius (1990) cointegration test can be applied when the first difference of each series is stationary. With the help of the Johansen cointegration test, the cointegration relationship is analyzed in a long-term and vector way in terms of equation systems formed by more than one series. If there is a cointegration relationship between the series, it is understood that the series have long-run relationships. Since the Johansen cointegration test is vector, it is based on the VAR (Vector Autoregressive) model, and the significance of the cointegration vectors is tested with the Trace test and the Maximum Eigenvalue test.

In terms of trace statistics, the H_0 hypothesis is constructed as r=0, that is, there is no cointegration. The H_1 hypothesis shows that there is a $r \leq 1$ (at least one) cointegration relationship. If the calculated trace statistic is greater than the critical value, the H_0 hypothesis is rejected and it is understood that there is at least 1 cointegration relationship. According to the Max-Eigen test, the H_0 hypothesis indicates that there is no r=0 cointegration relationship, while the H_1 hypothesis indicates the existence of a r=1 cointegration relationship. If the calculated Max-Eigen statistic is greater than the critical value, the H_0 hypothesis is rejected and it is understood that there is 1 cointegration relationship. That is, if the rank of π is equal to 0, there is no cointegration relationship between the variables. For this purpose, two tests, the Max-Eigen (ɥ$_{Max\text{-}Eigen}$) and the Trace (ɥ$_{Trace}$) test, were developed (Soren Johansen 1991).

Johansen cointegration test results are given in Table 4.

Table 4. Johansen Cointegration Test Results

Hypotheses	**ɥ$_{Trace}$**	**Critical Value**	**Prob.**
No Cointegration	1.209.119	1.232.090	0.0546**
There is at least 1 Cointegration	0.100430	4.129.906	0.7944
	ɥ$_{Max\text{-}Eigen}$	**Critical Value**	**Prob.**
No Cointegration	1.199.075	1.122.480	0.0366*
There is at least 1 Cointegration	0.100430	4.129.906	0.7944

Note: * and ** denote significance at 5% and 10% levels, respectively. **Source:** Research finding. (Authors' compilation from Eviews 11 (IHS Global Inc)).

The hypothesis H_0 established in terms of the Trace statistics in the upper part of Table 4 indicates that there is no cointegration (r=0), while the hypothesis H_1 indicates that there is $r \leq 1$ (at least one) cointegration. In the Table 4, it is seen that the Trace statistic of the H_0 hypothesis is greater than the critical value at the 10% significance level. Therefore, this indicates that there is at least one cointegration. In terms of the Max-Eigen test, the H_0 hypothesis shows that there is no cointegration relationship, and the H_1 hypothesis shows that there is only one cointegration. Since the Max-Eigen statistics of the H_0 hypothesis in Table 4 is greater than the critical value at the 5% level, the H_0 hypothesis is rejected. In this respect, it is understood that there is only one cointegration in terms of Max-Eigen cointegration approach. As a result, it has been determined that there is one cointegrating vector according to Traze and Max-Eigen statistics. Therefore, there is a long-term relationship between variables.

3.3 Granger Causality Test Application

Causality in statistics refers to the relationship between a time series variable and its future estimated values. The concept is expressed in the Granger sense as the effect one variable (X) has on another (Y). If the past values of X enable more accurate prediction of Y, then X is considered to be the cause of Y in the Granger sense.

In this section, Granger causality test will be applied to determine the direction of the relationship between the variables. Granger's causality test is done with the help of the following equations:

$$\Delta X_t = a_X + \sum_{i=1}^{m} \beta_{X,i} \Delta X_{t-i} + \sum_{i=1}^{m} \gamma_{X,i} \Delta Y_{t-i} + u_{X,t} \quad (8)$$

$$\Delta Y_t = a_Y + \sum_{i=1}^{m} \beta_{Y,i} \Delta Y_{t-i} + \sum_{i=1}^{m} \gamma_{X,i} \Delta X_{t-i} + u_{Y,t} \quad (9)$$

The null hypothesis of the test for equation (8) is: $H_0: \sum_{i=1}^{m} \gamma_{X,i} = 0$

The null hypothesis of the test for equation (9) is: $H_0: \sum_{i=1}^{m} \gamma_{Y,i} = 0$

In the Granger sense, causality can run both from X to Y and from Y to X. This is known as bidirectional causation. In the model, equation (8) shows causality from RNW to SDI, and equation (9) shows causality from SDI to RNW. In equation (8), first the dependent variable is included in the model with the appropriate lag, and then the other variable is included in the model with the same lag.

The Granger causality test is very sensitive to the number of lags, and the direction of causality may change depending on the number of lagged terms. For this reason, the Granger causality test can be performed for different lags, or the lag length can be determined separately for the independent variables in the model. In the literature, lag values are generally considered to be the same size as 12 or 24 in studies using monthly data, and 4 and 8 or 12 in studies using seasonal data. The appropriate lag length was previously determined as 1 in Table 3. (k=1). Accordingly, the results of the Granger Causality Test can be seen in the Table 5:

Table 5. Granger Causality Test Results

Dependent variable: SDI		
Excluded	***Chi-sq***	***Prob.***

RNW	0.017930	0.8935
Dependent variable: RNW		
Excluded	***Chi-sq***	***Prob.***
SDI	6.389211	0.0115*

Note: *, denotes significance at 1% level. **Source:** Research finding. (Authors' compilation from Eviews 11 (IHS Global Inc)).

3.4 Research Findings

The study aimed to investigate the relationship between sustainable development and renewable energy consumption within the context of the selected country, and to propose solutions for improving Jason Hickel's Sustainable Development Index (SDI). To achieve this objective, econometric techniques commonly employed in analysis, namely the Johansen-Juselius cointegration test and the Granger causality test, were utilized.

The findings indicate the existence of a long-term relationship between sustainable development and renewable energy consumption. This supports the notion that sustainable development and renewable energy consumption are interdependent concepts that mutually influence each other over time. In particular, the results of the Granger causality test suggest a causal relationship running from the Sustainable Development Index to renewable energy consumption (as a percentage of total final energy consumption). Consequently, it can be inferred that sustainable development policies and initiatives could positively impact the transition to renewable energy consumption.

Furthermore, the analysis revealed that the optimal lag length for the model is 1, suggesting that the relationship between sustainable development and renewable energy consumption is relatively short-term. This finding emphasizes the need for policymakers to implement sustainable development strategies that continuously support renewable energy consumption to ensure long-term benefits.

In summary, this research contributes to the growing body of literature on sustainable development and renewable energy consumption by providing empirical evidence of their interdependent relationship. The results are expected to be useful for policymakers and practitioners in promoting sustainable development and renewable energy consumption in their respective countries.

Ultimately, the results of this study, as demonstrated by the Johansen cointegration test, show a long-term relationship between the Sustainable Development Index and renewable energy consumption (as a percentage of total final energy consumption). The Granger Causality test further supports the existence of a causal relationship between the Sustainable Development Index and renewable energy consumption, thereby validating the acceptance of Hypothesis H_{1b}. Therefore, policymakers and stakeholders should focus on implementing sustainable development strategies aimed at increasing renewable energy consumption and reducing dependence on fossil fuels.

4. Conclusion and Policy Implications

Renewable energy constitutes an indispensable catalyst for sustainable development. By supplying clean, reliable, and increasingly cost-competitive power, renewable technologies curb greenhouse-gas emissions, moderate climate risk, and at the same time reinforce economic expansion, social inclusion, and ecological integrity. Large-scale diffusion of renewables fosters skilled and semi-skilled employment, crowds in innovation along green value chains, and extends modern energy services to remote or marginalised territories. These spill-overs jointly advance multiple dimensions of the 2030 Agenda, underscoring that climate-aligned energy policy is integral, not peripheral, to holistic development strategy.

The empirical framework employed in the present study relies on the Sustainable Development Index (SDI), formalised as:

$$SDI = \frac{\text{Development Index}}{\text{Ecological impact Index}},$$

thereby capturing the efficiency with which human-development achievements are secured within planetary boundaries. Conventional composites such as the Human Development Index (HDI) omit explicit income terms, yet economic performance influences both life-expectancy and education components; growth is therefore embedded, albeit indirectly. However, long-run sustainability necessitates that economic advancement be achieved without transgressing ecological thresholds. Accordingly, environmental externalities ought to be treated as binding constraints rather than deferred costs.

Time-series analysis indicates an absence of Granger causality from renewable-energy consumption to SDI over the 1990-2019 sample. In other words, increases in the renewable share of final energy use do not automatically translate into higher sustainability scores. While renewable energy remains a necessary pillar of sustainable development, it is insufficient unless accompanied by complementary progress in social equity, governance quality, and resource productivity. This finding tempers technological optimism and highlights the importance of integrated policy mixes that align energy transformation with broader human-development objectives.

Sustainable-development trajectories therefore depend on safeguarding the welfare gains tracked by the HDI, while simultaneously internalising ecological costs, as the SDI seeks to do. Embedding environmental variables directly into composite measures is indispensable; otherwise, headline improvements can mask accumulating ecological debt. The conceptual reformulation advanced by Hickel and collaborators represents a pivotal contribution in this regard. Nonetheless, the current SDI specification could be strengthened by assigning greater weight to drivers of carbon emissions and to the positive externalities generated by renewable-energy deployment, particularly in contexts where decarbonisation co-benefits such as air-quality improvements and health gains are pronounced.

A recalibrated index that more prominently incorporates decarbonisation dynamics would deliver a sharper diagnostic of sustainability performance and furnish policymakers with clearer directional signals. Such an instrument could better differentiate between growth paths that merely shift energy mixes and those that genuinely realign economies within ecological limits, thereby guiding investment and regulatory interventions toward trajectories consistent with both human flourishing and planetary stability.

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