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Towards Economic Growth and a Sustainable Future: Insights Beyond the Environmental Kuznets Curve

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Abstract

This study explores the dynamic nexus between economic growth and sustainable development for 92 countries across high, upper-middle, lower-middle and low-income groups. We validate the environmental Kuznets curve (EKC) hypothesis from a novel perspective. We employ a novel technique of Narayan *et al*. (2016) through simple cross-correlation estimates and a panel causality technique. The analysis covers data from 1990 to 2022 using annual data. Our findings show that the EKC hypothesis is supported for five out of 92 (5%) countries and that income growth will increase sustainable development for 50 (54%) countries. Notably, the analysis reveals that as income level rises, sustainable development will decrease (increase) within high-income (middle and low-income) countries in the future. The panel causality analysis finds a significant causal relationship across countries. We also address theory and policy implications.

Keywords: EKC hypothesis, economic growth, sustainable development, cross-correlation

JEL Classification: Q01, Q56, O44

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1. Introduction

As long argued, an inverted U-shaped curve typically represents the standard environmental Kuznets curve (EKC) hypothesis (Grossman and Krueger, 1995). Because the EKC describes a positive association between economic growth and environmental degradation in the early stage of development, following the inflexion point, economic growth reduces environmental degradation (Narayan *et al.*, 2016). EKC studies extensively focus on economic growth and environmental pollutants, which are negative environmental sustainability indicators. This include urban air pollution (Grossman and Krueger, 1995), carbon emissions (Almeida *et al.*, 2024; Narayan *et al.*, 2016), water footprints (Paolo Miglietta *et al.*, 2017) and energy consumption (Shahbaz *et al.*, 2019c), which may not capture the complete spectrum of environmental impact. Also, this omits the role of environmental sustainability efforts, which have a favourable environmental impact. Noticeably, less attention has been paid to the relationship between economic growth and positive environmental indicators such as sustainable development (Almeida *et al.*, 2024). Substituting pollutants with sustainable development can reconceptualise the definition and the curve shape (Ul Haq *et al.*, 2024), as illustrated in Figure 1A (see Appendix). Reframing the standard EKC is important because it shifts the focus from environmental pollutants to actively promoting long-term sustainable growth for policymakers and regulators (Almeida *et al.*, 2024; Ul Haq *et al.*, 2024). Moreover, considering a positive environmental indicator also broadens the applicability of the EKC hypothesis by offering a U-shaped curve relationship and a complete understanding of the role of economic growth in fostering environmental sustainability.

In his book “Principles of Economics”, Mankiw (2016) asserted that an important issue in modern society is the trade-off between maintaining a clean environment and achieving a higher income level. Recently, societies have grappled with the intricate balance between environmental sustainability and economic growth, rendering it one of the foremost global challenges (Ul Haq *et al.*, 2023). This issue is pressing across countries, regardless of human development or income levels. Developing countries often prioritise economic growth, relying heavily on exploitation of material resources, which leaves them unprepared to address environmental degradation and the disruption of ecological imbalances (Nguyễn and Phan, 2023). Despite the imbalance in socioeconomic advancement and sustainable development in emerging countries, World Bank data indicate that high-income countries are also major sources of carbon emissions due to their high per capita consumption of materials. High-income countries have been recognised as having the highest per capita emissions of greenhouse gases, causing more severe environmental deterioration (Wilmoth *et al.*, 2022). While developed economies spearhead innovative and technological solutions to combat critical environmental issues such as carbon emissions, climate change and global warming, enhancing economic growth and sustainable development have become serious concerns for economists and socially responsible stakeholders worldwide. These issues can severely affect the ecological balance and sustainability in the long run. Following the assertion of the critical importance of balancing economic growth and environmental sustainability, it is imperative to delve into the role of gross domestic product (GDP) per capita in lagging or leading sustainable development. Furthermore, policymakers and socially responsible stakeholders might be tempted to provide a better understanding of how well countries from different income levels advance towards achieving sustained, inclusive and sustainable economic growth. Thus, this study explores how the GDP per capita of high, middle and low-income countries is related to sustainable development.

Economic growth is a fundamental measure of an economy's health and is a pivotal nexus between growth and sustainability (Uddin, 2020). The centrality of economic growth has long been acknowledged for its significance in improving life standards, raising incomes and reducing poverty to achieve the World Bank's twin goals of "ending extreme poverty and boosting shared prosperity" (WB, 2015). Each country strives to optimise economic growth by building new production abilities, technological advancements, governance reforms and other long-term policies (Bustos and Yıldırım, 2022). Similarly, emerging markets and developing countries are immersed in maintaining and promoting socioeconomic advancement (Nguyễn and Phan, 2023), causing ecological degradation driven by extensive globalisation (Shahbaz *et al*., 2019b), burgeoning international trade (Nguyễn and Phan, 2023) and excessive digitalisation (Haq and Huo, 2023). This situation seriously threatens sustainable development, necessitating investigation into the relationship between income growth and sustainable development.

Sustainable development has emerged as a key concern in recent decades, with governments and international organisations acknowledging the imperative of concentrated national plans for a sustainable future. According to the International Energy Agency, ensuring net-zero emissions by 2050 will require massive investments, estimated at nearly $5 trillion annually by 2050 (Sternfels *et al.*, 2023). Governments worldwide are promoting sustainable development practices and implementing country-specific policies to achieve national sustainability plans and a set of 17 United Nations Sustainable Development Goals (SDGs) to achieve sustainable development by 2030. Notably, SDG 8 has become a critical task for countries that aim to "promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all" (SDG 8). As described by Nguyễn and Phan (2023), national sustainable development involves sustainability in three core pillars: economic, environmental and social. The present study focuses on the economic dimension, exploring the relationship between GDP per capita and sustainable development across countries at diverse income levels.

Our study makes both theoretical and empirical contributions. Theoretically, we augment standard EKC theory (Grossman and Krueger, 1995) by reconceptualising the standard EKC hypothesis as a reverse EKC (REKC) and offering another way to test the EKC hypothesis. Given that environmental degradation captures the negative side of environmental impact (Almeida *et al*., 2024), GDP per capita affects sustainable development, which can exhibit a U-shaped curve if fully consistent with standard EKC (Narayan *et al*., 2016). From an empirical perspective, using a quadrant scenario approach based on the cross-correlation coefficient (CCC) to uncover the relationship between GDP per capita and sustainable development across lags/leads, we add fresh insights to related research (Narayan *et al*., 2016; Shahbaz *et al*., 2019c; Ul Haq *et al*., 2024) that rising GDP per capita in the past will lead to reducing sustainable development in the future for high-income countries compared to middle-income and low-income ones. Moreover, middle-income and low-income countries tend to improve their sustainable development with rising income levels in the future.

The rest of the paper is structured as follows. Section 2 reviews the related studies on the subject. Section 3 presents a data description and the estimation approach. Section 4 reports the empirical results. The final section presents the conclusion and implications.

2. Review of Related Studies

Generally, the EKC theory postulates a historical shift from negative to positive links between GDP per capita and environmental degradation. Initially, economic growth may contribute to environmental degradation, but after a certain point, it lessens environmental degradation, suggesting that a growing income level has a positive effect in the short run; however, after a certain level is achieved, it becomes negative in the long run (Narayan *et al*., 2016). Rapid economic growth accelerates resource consumption and waste production and augments environmental vulnerability (Nguyễn and Phan, 2023). Nevertheless, advanced countries have begun to pay attention to environmental issues and policymaking. The literature contains widespread but inconclusive knowledge on the linkage between economic growth and the environment relating to the EKC hypothesis (Almeida *et al*., 2024; Narayan *et al*., 2016; Shahbaz *et al*., 2019c). Regardless of earlier research, the present study reinforces the EKC hypothesis by exploring the linkage between GDP per capita and sustainable development.

Within the EKC hypothesis strand, studies have explored the cross-correlation between GDP per capita and environmental pollutants over lags (past) and leads (future). For instance, Narayan *et al*. (2016) studied the cross-correlation between economic growth and carbon emissions for 181 countries at various income levels covering the period 1960–2008. They found that only 12% of the sampled countries adhered to the EKC hypothesis and that a rise in income reduced future carbon emissions for 49 economies. Shahbaz *et al*. (2019c) investigated the cross-correlation relationship between globalisation and energy consumption for 86 countries from 1970 to 2015. They revealed that the EKC hypothesis holds for 64 economies, suggesting that a rise in globalisation will drive a decrease in energy consumption in the future for countries across income levels. Recently, Almeida *et al*. (2024) validated the EKC hypothesis across 158 countries and 44 regions by examining the relationship between GDP per capita and carbon emissions and supported a heterogenous environmental-economic nexus across both countries and regions.

Additionally, Uddin (2020) investigated the effect of GDP per capita on environmental degradation for 115 countries from 1990 to 2016. They found that financial development plays a catalysing role in decreasing carbon emissions across countries at all income levels; however, financial development fosters the negative effect of economic growth (GDP per capita) on two global greenhouse effect indicators: methane (CH_4) emissions and the concentration of fine particulate matter ($PM_{2.5}$). Using regression analysis and net savings as a sustainable development measure, Nguyễn and Phan (2023) found that exports and imports significantly contribute to sustainable development; however, GDP per capita fails to affect sustainable development in developing countries. The relationship between tourism industry development and CO_2 emissions was investigated by Ochoa-Moreno *et al*. (2022) using cointegration and causal dynamic ordinary least squares approaches from 1995 to 2018 for 20 Latin American countries. They found that tourism revenue has a negative relationship with CO_2 concentration conditional on income level; as total tourism revenue increases, it positively affects CO_2 across upper-middle income countries. Therefore, the EKC hypothesis holds true for some countries, but it depends on their income level.

Awaworyi Churchill *et al*. (2018) also found evidence in support of the EKC hypothesis for the panel of OECD countries as a whole (mixed for country-specific) from 1870 to 2014. For the Middle East and North Africa (MENA) countries, studying the causal effect of per capita income, foreign direct investment (FDI) and energy use on CO_2, Gorus and Aslan (2019) found that the EKC hypothesis does not hold for panel data; however, in the case of Algeria, Egypt, Sudan and Turkey, the results support the EKC hypothesis from 1980 to 2013. Energy use and FDI inflow also cause high CO_2 emissions and pollution, respectively. Similarly, Shahbaz *et al*. (2019a) concluded that FDI and GDP per capita show a positive relationship between biomass energy consumption and CO_2 for 1990–2015 in MENA countries. A similar subject has been under investigation in some emerging countries, such as Brazil, Russia, India, China, South Africa and Turkey (the BRICST countries). For example, Meng *et al*. (2022) found that trade diversification, green innovation and renewable energy use were negatively associated with CO_2 emissions from 1995 to 2020. However, economic growth intensifies environmental degradation when considering the increased consumption-based carbon emissions.

Previous literature has also claimed that economic growth fosters environmental degradation in developing countries. For instance, Sethi *et al*. (2020) found that economic growth in India directly contributed to environmental degradation in the short run over the period 1980–2015. Examining the same subject in the Organisation of the Petroleum Exporting Countries (OPEC) from 1992 to 2015, Moutinho *et al*. (2020) found that economic growth in oil-producing countries increases environmental degradation regardless of having heavy investments in projects on energy efficiency, energy savings or renewable energy projects.

However, studies on the relationship between GDP per capita and sustainable development using the cross-correlation approach are still lacking (Almeida *et al*., 2024; Ul Haq *et al*., 2024); since to inquire how GDP per capita leads and will lead to sustainable development in the future has become an important concern for governments and policymakers. Theoretically, it has become equally important to validate the standard EKC hypothesis through introducing sustainable development with economic growth, which is an indicator of environmental sustainability (Ul Haq *et al*., 2024) rather environmental pollutants (Grossman and Krueger, 1995). Countries have been intimating to ensure sustainable development to meet United Nations SDGs (Ul Haq *et al*., 2023) and that net-zero emission targets be used to address enormous ecological risks over the last few decades (Eisenmenger *et al*., 2020). In the meantime, how sustainable development has reacted in the past and will change in the future due to increasing income levels has yet to be uncovered on a global scale (Ul Haq *et al*., 2024).

3. Data and Estimation Approach

3.1 Data description

This study explores the relationship between GDP per capita and sustainable development for 92 countries. Drawing from the data-driven sample selection criterion, we used the annual data for GDP per capita and sustainable development index from 1990 to 2022. The data for GDP per capita were sourced from the World Development Indicators and denominated in US dollars. The sustainable development index (SDI)[1] by Hickel (2020) was used as a proxy for nationwide sustainable development. Following Hickel (2020), the coefficient of SDI for each year was obtained as the quotient of "development index" and the "ecological impact index". Furthermore, the development index is measured as the geometric mean of three

1 See Hickel (2020) for a more detailed discussion on the construction of a sustainable development index.

indices: education index, life expectancy index and modified income index. The ecological impact index is the average overshoot of the per capita carbon emissions and material footprints, indexed on a natural exponential scale. The SDI data were retrieved from SDI (2023). To compare the results, we categorise sampled countries in light of varying income stages, underpinned by a logical premise: countries are at different economic development stages, as reflected by their disparate per capita incomes. This disparity is postulated to influence the extent of sustainable development directly. Thus, following the World Bank's country classifications by income level, we categorise the 92 countries into four groups: high-income, upper-middle-income, lower-middle-income and low-income countries. Among these, there are 35 high-income countries (Australia, Austria, Barbados, Belgium, Canada, Chile, Cyprus, Czechia, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Malta, Netherlands, New Zealand, Norway, Panama, Poland, Portugal, Republic of Korea, Romania, Singapore, Slovakia, Spain, Sweden, Switzerland, UK, USA and Uruguay), 26 upper-middle-income countries (Albania, Belize, Botswana, Brazil, Bulgaria, China, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Fiji, Gabon, Guatemala, Jamaica, Mauritius, Mexico, Namibia, Paraguay, Peru, Russia, South Africa, Thailand and Togo), 25 lower-middle-income countries (Algeria, Benin, Bolivia, Cambodia, Cameroon, Republic of the Congo, Ghana, Guinea, Haiti, Honduras, India, Kenya, Lesotho, Mongolia, Myanmar, Nepal, Nicaragua, Niger, Papua New Guinea, Philippines, Samoa, Sri Lanka, Tanzania, Ukraine, Zambia and Zimbabwe) and six low-income countries (Burundi, Central African Republic, The Gambia, Sierra Leone, Uganda and Yemen).

The basic statistics provide means, standard deviations and unconditional correlations for each country's GDP per capita and sustainable development[2]. In high-income countries, the mean and standard deviation are relatively higher than in the middle and lower-income groups, suggesting a higher probability of fluctuations over time in high-income countries (Narayan *et al*., 2016). In addition, unconditional correlations reveal varied relationships across income groups. Among high-income countries, 33 of the 35 show significant negative correlations, indicating that rising income often corresponds with decreased sustainable development. In contrast, only 12% of the upper-income countries exhibit a negative correlation, while 80% of the upper-middle-income countries have significant positive correlations. All the lower-middle-income and low-income countries show a positive correlation. Overall, approximately 58% of the countries, mainly belonging to the middle-income and low-income groups, display positive correlations, while 39% of the sample exhibit negative correlations, primarily among the high-income countries.

2 The results of basic statistics and unconditional correlations are available upon request.

Figure 1: Scatterplot of GDP per capita and sustainable development index

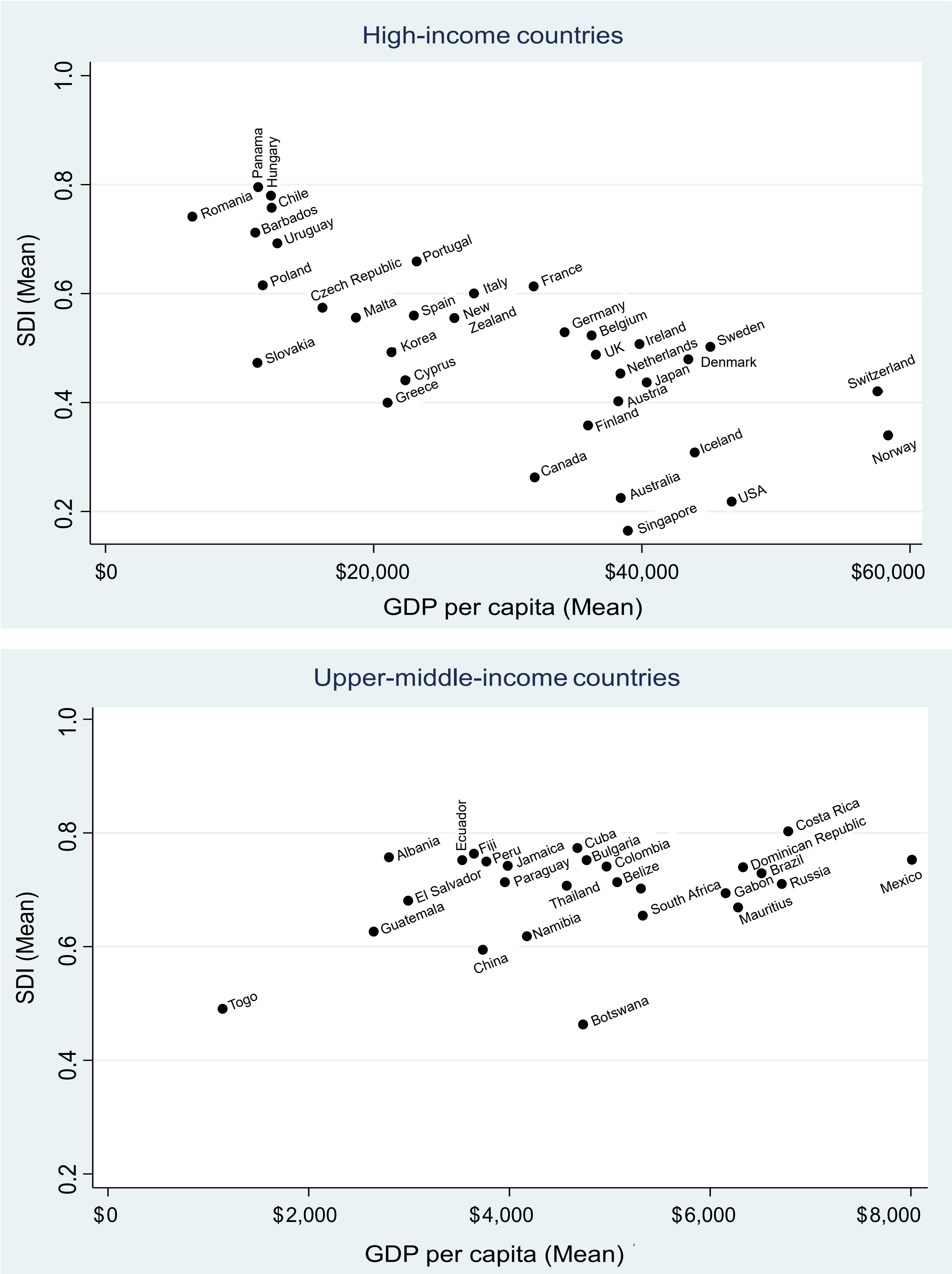
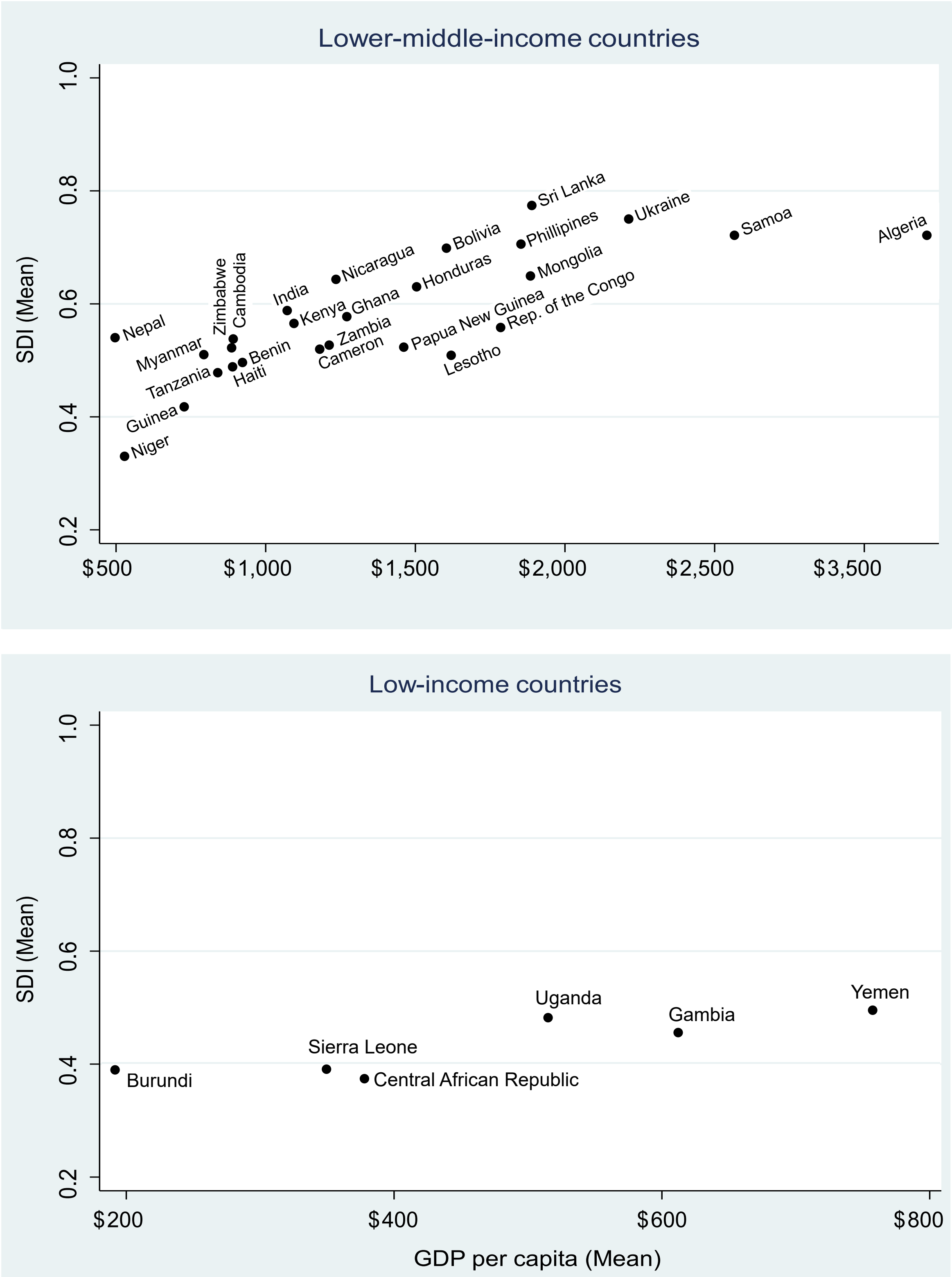


Figure 1: Continuation



Note: The mean values for GDP per capita and sustainable development index (SDI) were denominated in US dollars and annual values from Hickel (2020), covering the period from 1990 to 2022 respectively.

Source: Authors' own calculation

We also plotted the relationship between GDP per capita and sustainable development. To do this, Figure 1 shows a scatterplot of GDP per capita and corresponding sustainable development across income levels, showing the basic link between GDP per capita and sustainable development. Despite higher GDP per capita in high-income countries, more middle-income countries display more sustainable development with relatively lower per capita income than high-income groups. This scenario is because high-income countries also transmit emissions of greenhouse gasses and have the highest per capita consumption of material resources (Wilmoth *et al.*, 2022), potentially limiting their sustainable development due to resource-intensive lifestyles and energy-intensive industries.

3.2 Estimation approach

Since these static correlations do not predict future trends, a dynamic CCC approach by Narayan *et al.* (2016) was applied to examine how GDP per capita is negatively or positively correlated with sustainable development in the past (lags) and future (leads). The CCC between GDP per capita (x) and sustainable development (y_t) can be estimated as follows:

$$CCC = \frac{\sum(x_t - \bar{x})(y_{t+k} - \bar{y})}{\sqrt{(x_t - x)^2 (y_{t+k} - \bar{y})^2}} \tag{1}$$

where $\bar{x}$ and $\bar{y}$ represent the average real GDP per capita and sustainable development, respectively. Given 33 annual observations for each variable, we have $x_1, x_2, x_3, \ldots, x_{33}$ and $y_1, y_2, y_3, \ldots, y_{33}$. Before the CCC estimation, the Hodrick–Prescott (HP) filter was applied as a data-smoothing technique to detrend all the series using the lambda parameter (λ) as $\lambda = 100$.

In computing the CCC between real GDP per capita and sustainable development, when $k = 0$, contemporaneous correlations CCC_0 between these variables are observed. When $k = 1$, we observe CCC_1 between x_t and a one-period lead or future year of sustainable development, as delineated in Equation 1 by y_{t+1}. Similarly, when $k = 2$, we observe CCC_2, which suggests a cross-correlation between x_t and a two-period lead or two future years of sustainable development; in contrast, when $k = -1$, this implies that there exists a cross-correlation (CCC_{-1}) between x_t and the previous year or a one-period lag of sustainable development. In this study, we compute the CCC for $k = \pm 20$, since twenty lags/leads are adequate for assessing annual time series data dynamics (Narayan *et al.*, 2016). Another key reason for fitting Equation 1 to 20 lag/lead periods is the availability of sufficient data.

This study applies the CCC approach by Narayan *et al.* (2016) for its effectiveness in capturing the dynamic relationship between GDP per capita and sustainable development (Ul Haq *et al.*, 2024), providing insights into the lag/lead relationship, which may not be captured using other multivariate approaches, where the problem of limited ability to capture relationship over time and multicollinearity may affect the evidence supporting the EKC hypothesis (Almeida *et al*., 2024). This approach provides simple and easy-to-implement lag/lead estimates in real-world applications (Shahbaz *et al*., 2019c) and insightful insights to understand the temporal evolution of the EKC hypothesis in the past and future (Shahbaz *et al*., 2019b).

According to Narayan *et al*. (2016), CCC results for each country are fully consistent with the EKC hypothesis if a positive average cross-correlation exists between the current income level and past (lag) level of carbon emissions and a negative cross-correlation exists between the current level of income and future (lead) carbon emissions. This suggests that carbon emissions will decline with the progression in income over time (Almeida *et al*., 2024). Our interpretations of these pairs differ from previous studies (Almeida *et al*., 2024; Narayan *et al*., 2016; Shahbaz *et al*., 2019c). Unlike the EKC hypothesis, we consider sustainable development a positive indicator of environmental sustainability rather than carbon emissions and environmental degradation, which are negative environmental indicators. Therefore, if our CCC results support the EKC hypothesis, the curve will be U-shaped rather than an inverted U-shape. We called this the reversed EKC hypothesis. Instead, this study follows the motivations of Ul Haq *et al*. (2024) to classify cross-correlation coefficients into quadrant scenarios, where each plot is enclosed by the interaction of the *x*-axis (correlation) and *y*-axis (lags/leads) and has four quadrants. These quadrants are classified as follows: average CCC lead coefficient is positive (Quadrant I), average CCC lag coefficient is positive (Quadrant II), average CCC lag coefficient is negative (Quadrant III) and average CCC lead coefficient is negative (Quadrant IV). The quadrant scenario approach-based interpretations and the scenario-based relationship between GDP per capita and sustainable development as being partially and fully consistent or inconsistent with the REKC are described in Table 1.

Table 1: Scenario-based interpretations and REKC consistency criteria.

Scenario	Average CCC (lags/leads)	Origin	Scenario interpretations	Result
Scenario 1	(+/+)	(Quadrant I/ Quadrant II)	If income level has led to positive sustainable development in the past (lags), it will positively influence sustainable development in the future (leads).	Partially consistent with REKC
Scenario 2	(–/–)	(Quadrant III/ Quadrant IV)	If income level has led to negative sustainable development in the past, it will negatively influence sustainable development in the future.	Partially inconsistent with REKC
Scenario 3	(–/+)	(Quadrant III/ Quadrant I)	If income level has led to negative sustainable development in the past, it will positively influence. sustainable development in the future.	Fully consistent with REKC
Scenario 4	(+/–)	(Quadrant II/ Quadrant IV)	If income level has led to positive sustainable development positively in the past, it will negatively influence sustainable development in the future.	Fully inconsistent with REKC

Source: Authors' own explanations based on Almeida et al. (2024), Narayan *et al.* (2016) and Ul Haq *et al.* (2024)

4. Empirical Results

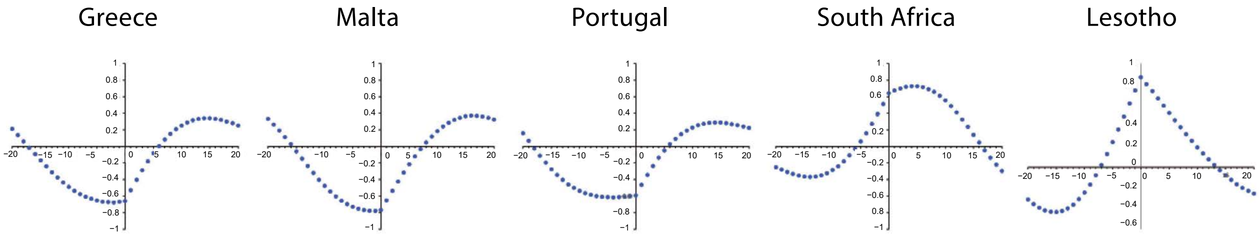
4.1 Empirical evidence from cross-correlation approach

Table 2 illustrates the results of CCC between GDP per capita and sustainable development based on a quadrant scenario approach over 20 lags (past) and 20 leads (future) spanning the period from 1990 to 2022. The sum of the 20 lags (leads) of CCCs is reported in column 2 (column 4) and the average CCCs for both lags/leads are in columns 3 and 5, respectively. Panel A in Table 2 shows that the CCCs between GDP per capita and sustainable development are negative in the past (lags) and positive in the future (leads) for Greece, Malta and Portugal. These results support a reversed EKC hypothesis and align with the conventional EKC idea. CCC is positive for Barbados for both lags/leads, partially aligning with the EKC hypothesis. Overall, for four out of the 35 countries, an increase in GDP per capita will enhance sustainable development. Against the backdrop of the REKC hypothesis, we find that Canada, Germany, Hungary, Panama and Romania demonstrate a positive average cross-correlation in the past and a negative correlation in the future, which is fully inconsistent with the REKC hypothesis. These findings also imply that past rising income levels have led to increased sustainable development; however, they will reduce sustainable development in the future. We find negative CCCs for 26 out of the 35 high-income countries across both lags and leads. These results are partially inconsistent with the REKC and imply that rising income levels have led, and will lead, to attenuated sustainable development in the future for these high-income countries.

Table 2 (Panel B) shows no evidence supporting the REKC in the upper-middle-income group. The average CCCs between GDP per capita and sustainable development are positive across lags and leads for 20 upper-middle-income countries. This scenario suggests that the rising income level will promote sustainable development in the future, which is partially consistent with the EKC hypothesis. In opposition to the REKC hypothesis, the past income levels in Botswana showed a negative average CCC with lags and leads. These countries are partially inconsistent with the REKC, and the rising income levels have decreased sustainable development in the past (lags) and future (leads). The CCCs are positive across lags and negative across leads for Bulgaria, China, Mauritius and Russia, indicating that the positive relationship between GDP per capita and sustainable development in the past will become negative in the future. These findings are fully inconsistent with the REKC.

Based on average CCCs reported in Table 2 (Panel C), only Lesotho shows negative average CCCs over the lags and positive across leads among the lower-middle-income countries, confirming our REKC proposal. In addition, the average CCCs between GDP per capita and sustainable development are positive for 25 out of the 26 lower-middle-income countries across leads. Overall, increasing incomes for 96% of the lower-middle-income countries are expected to improve sustainable development. These results imply that rising income levels will enhance sustainable development in these countries. These findings support partial agreement with the REKC hypothesis. Opposing the REKC hypothesis, Mongolia shows positive average CCC across the lags and negative across the leads, implying that an increase in income in the past has led to sustainable development and will lead to reduced sustainable development in the future, which is fully inconsistent with the REKC. The CCCs for the sampled low-income group are presented in Table 2 (Panel D) and reveal positive average CCCs across both the lags and leads across all these countries. These findings indicate that rising GDP per capita in low-income countries has improved sustainable development and will encourage sustainable development in low-income countries. These findings are in partial agreement with the REKC hypothesis.

Figure 2: Cross-correlation coefficient (CCC) plots for countries aligned with REKC hypothesis



Source: Authors' own calculation

Averaging CCCs can capture aggregated views and ignore trends and temporal dynamics within individual lag/lead periods. To ensure a substantive and accurate analysis of which countries across the income groups are consistent with the REKC hypothesis, the graphical representation of over 20 lags/leads is crucial (Almeida *et al*., 2024). For these reasons, Figure 2 shows that CCC plots for countries appear to align fully with the REKC hypothesis. Consistent with the average CCC results, Figure 2 presents that Greece, Malta, Portugal and South Africa show U-shaped curves, fully consistent with the REKC hypothesis. Figure 2A (see Appendix) illustrates CCC plots for countries partially consistent with the REKC hypothesis and countries whose increase in income will enhance sustainable development. Generally, these plots outline an inverted U-shaped curve; however, the graph might show that the correlation is positive for the initial few lags/leads but starts to decline and eventually becomes negative as it approaches the 20th lag/lead. This transition is critical in understanding how rising income levels can influence environmental outcomes over time and supports a more robust interpretation of a country's timeline to align with the REKC hypothesis. Many high-income countries are likely to struggle with achieving sustainable development in relation to their national GDP per capita[3]. This possibility suggests that their increasing income levels may lead to adverse environmental consequences, presenting a significant obstacle in achieving sustainable development goals and national sustainability targets.

3 Due to space constraints, the plots for countries fully and partially inconsistent with the REKC are not presented but available upon request.

Table 2: Cross-correlation estimates

Countries	Lags		Leads		Countries	Lags		Leads	
	Sum of corr.	Avg. corr.	Sum of corr.	Avg. corr.		Sum of corr.	Avg. corr.	Sum of corr.	Avg. corr.
Panel A: High-income countries					**Sweden**	−5.2586	−0.2504	−3.3521	−0.1596
Australia	−5.3962	−0.257	−3.043	−0.1449	**Switzerland**	−1.7787	−0.0847	−5.6014	−0.2667
Austria	−4.6212	−0.2201	−3.8834	−0.1849	**UK**	−6.0708	−0.2891	−1.8001	−0.0857
Barbados	4.9051	0.2336	2.8087	0.1337	**USA**	−4.7962	−0.2284	−3.1466	−0.1498
Belgium	−4.0708	−0.1938	−4.6043	−0.2193	**Uruguay**	−7.0442	−0.3354	−1.2241	−0.0583
Canada	0.9517	0.0453	−7.2217	−0.3439	***Panel B: Upper-middle-income countries***				
Chile	−1.0177	−0.0485	−5.4017	−0.2572	**Albania**	4.7738	0.2273	3.8113	0.1815
Cyprus	−4.7673	−0.227	−3.4284	−0.1633	**Belize**	3.9276	0.187	4.6924	0.2234
Czechia	−4.7985	−0.2285	−3.6969	−0.176	**Botswana**	−4.1854	−0.1993	−4.4256	−0.2107
Denmark	−0.2997	−0.0143	−5.5645	−0.265	**Brazil**	5.061	0.241	2.7974	0.1332
Finland	−3.2867	−0.1565	−4.4303	−0.211	**Bulgaria**	2.15	0.1024	−8.0065	−0.3813
France	−1.3202	−0.0629	−6.4251	−0.306	**China**	2.1444	0.1021	−7.2849	−0.3469
Germany	20.1905	0.9615	−7.1776	−0.3418	**Colombia**	5.9484	0.2833	2.6133	0.1244
Greece	−8.051	−0.3834	1.6754	0.0798	**Costa Rica**	5.5488	0.2642	3.0581	0.1456
Hungary	5.7134	0.2721	−6.4723	−0.3082	**Cuba**	5.8974	0.2808	2.5383	0.1209
Iceland	−5.267	−0.2508	−2.9406	−0.14	**Dominican Republic**	5.4805	0.261	3.1574	0.1504
Ireland	−2.9736	−0.1416	−4.6494	−0.2214	**Ecuador**	3.8203	0.1819	4.5717	0.2177
Italy	−0.3612	−0.0172	−5.6724	−0.2701	**El Salvador**	6.8464	0.326	1.5642	0.0745
Japan	−6.7483	−0.3213	−1.6744	−0.0797	**Fiji**	5.778	0.2751	2.8205	0.1343
Republic of Korea	−5.2322	−0.2492	−3.336	−0.1589	**Gabon**	0.5621	0.0268	7.1022	0.3382
Malta	−7.7856	−0.3707	0.6233	0.0297	**Guatemala**	5.3726	0.2558	3.2602	0.1552
Netherlands	−2.7342	−0.1302	−5.0034	−0.2383	**Jamaica**	2.9418	0.1401	5.4309	0.2586
New Zealand	−3.4148	−0.1626	−5.0205	−0.2391	**Mauritius**	0.8445	0.0402	−7.8853	−0.3755
Norway	−1.5132	−0.0721	−5.5797	−0.2657	**Mexico**	4.9355	0.235	3.3717	0.1606
Panama	8.1492	0.3881	−0.3231	−0.0154	**Namibia**	0.1398	0.0067	6.3554	0.3026
Poland	−5.2353	−0.2493	−3.0421	−0.1449	**Paraguay**	6.3152	0.3007	2.1485	0.1023
Portugal	−8.6163	−0.4103	1.551	0.0739	**Peru**	4.9432	0.2354	3.6415	0.1734
Romania	3.0918	0.1472	−7.3694	−0.3509	**Russia**	2.1132	0.1006	−8.5689	−0.408
Singapore	−6.9501	−0.331	−1.2692	−0.0604	**South Africa**	−2.0826	−0.0992	8.3899	0.3995
Slovakia	−3.2734	−0.1559	−5.1975	−0.2475	**Thailand**	7.732	0.3682	0.3463	0.0165
Spain	−4.6028	−0.2192	−3.0604	−0.1457	**Togo**	6.5811	0.3134	1.1009	0.0524

Table 2: *(continued)*

Countries	Lags		Leads		Countries	Lags		Leads	
	Sum of corr.	Avg. corr.	Sum of corr.	Avg. corr.		Sum of corr.	Avg. corr.	Sum of corr.	Avg. corr.
Panel C: Lower-middle income countries					**Nicaragua**	3.6718	0.1748	4.7774	0.2275
Algeria	4.6053	0.2193	3.7400	0.1781	**Niger**	6.641	0.3162	1.2002	0.0572
Benin	5.659	0.2695	2.9194	0.139	**Papua New Guinea**	5.2592	0.2504	3.2018	0.1525
Bolivia	4.5546	0.2169	4.0237	0.1916	**Philippines**	4.9982	0.238	3.6142	0.1721
Cambodia	6.6339	0.3159	1.6133	0.0768	**Samoa**	4.5553	0.2169	3.9635	0.1887
Cameroon	4.3295	0.2062	4.0978	0.1951	**Sri Lanka**	4.7283	0.2252	3.7575	0.1789
Republic of the Congo	0.147	0.007	7.6464	0.3641	**Tanzania**	6.2278	0.2966	2.0193	0.0962
Ghana	5.6928	0.2711	2.6516	0.1263	**Ukraine**	6.4124	0.3054	1.7709	0.0843
Guinea	6.7955	0.3236	1.2078	0.0575	**Zambia**	5.5608	0.2648	2.7661	0.1317
Haiti	3.8183	0.1818	4.8181	0.2294	**Zimbabwe**	2.8281	0.1347	4.188	0.1994
Honduras	4.746	0.226	3.8138	0.1816	***Panel D: Low-income countries***				
India	5.6251	0.2679	2.9092	0.1385	**Burundi**	5.9161	0.2817	2.019	0.0961
Kenya	5.2637	0.2507	2.9037	0.1383	**Central African Republic**	6.1361	0.2922	0.2509	0.0119
Lesotho	−0.8591	−0.0409	4.9456	0.2355	**The Gambia**	5.5645	0.265	3.0053	0.1431
Mongolia	6.957	0.3313	−0.8351	−0.0398	**Sierra Leone**	4.1692	0.1985	4.4105	0.21
Myanmar	5.9199	0.2819	2.5212	0.1201	**Uganda**	5.3671	0.2556	3.2244	0.1535
Nepal	4.881	0.2324	3.7111	0.1767	**Yemen**	3.9401	0.1876	2.9582	0.1409

Notes: Corr. (Correlation) and avg. (Average).

Source: Authors' own calculation

Table 3: Summary of average lags/leads based on CCC

OIC countries	(−)/(−)	(+)/(+)	(−)/(+) or REKC	(+)/(−)	Total
Panel A: High-income countries	26	1	3	5	35
Percentage **(%)**	74.29%	2.86%	8.57%	14.29%	–
Panel B: Upper-middle-income countries	1	19	1	4	25
Percentage **(%)**	4.00%	76.00%	4.00%	16.00%	–
Panel C: Lower-middle-income countries	0	24	1	1	26
Percentage **(%)**	0.00%	92.31%	3.85%	3.85%	–
Panel D: Low-income countries	0	6	0	0	6
Percentage **(%)**	0.00%	100.00%	0.00%	0.00%	–
Total average lags/leads	27	50	5	10	–
Percentage **(%)**	29.35%	54.34%	5.43%	10.87%	–
Total countries across income levels					n = 92

Source: Authors' own calculation

Table 3 summarises the results of the average lags/leads based on the CCC. For five out of the 92 countries, approximately 5% of the sampled countries, there is clear evidence supporting the REKC hypothesis. Secondly, by shifting the focus to the future, a crucial question emerges: can an increase in income pave the way for sustainable development in the future? We discover that for 50 countries (54%), growth in GDP per capita will enhance sustainable development in the future, comprising 19 of the upper-middle-income and 24 of the lower-middle-income countries. In contrast, only one of the high-income countries is expected to enhance sustainable development from a rise in income. Concerning the proposal of our quadratic scenarios approach, 29.35% of the countries are consistent with the first scenario (partially inconsistent with the REKC), 54.34% with the second scenario (partially consistent with the REKC), 5.43% with the third (fully consistent with the REKC) and 10.87% with the fourth (fully inconsistent with the REKC). These findings contradict those of Narayan *et al.* (2016), who concluded that rising income levels would reduce carbon emissions in high-income countries, but are consistent with those of Almeida *et al.* (2024). Given the declining trend in sustainability among high-income countries, it supports the assessment of the United Nations Department of Economics and Social Affairs (Wilmoth *et al.*, 2022). This situation suggests that countries with higher per capita income tend to have the highest per capita emissions of greenhouse gases and consumption of material resources. Our results corroborate with those of Ul Haq *et al*. (2024), who emphasised that increasing economic growth across high-income countries exacerbates sustainable development challenges and hinders achieving sustainable development goals and national plans. Furthermore, the rising economic growth in these countries also poses environmental challenges for the global green economy.

4.2 Robustness check: panel Granger causality test

We repeated the analysis to verify the robustness of our cross-correlation results and the symmetric causal relationship between GDP per capita and sustainable development using the Dumitrescu and Hurlin (2012) panel causality technique. This approach offers accurate estimates with precision for small datasets (Hasan *et al*., 2023). To fulfil the minimum lag selection requirements, we ended up with no more than nine lag orders considering the time series length. We estimated the panel causality analysis between GDP per capita and sustainable development for each panel and each country separately to thoroughly capture in-depth relationships between underlying variables across countries based on their income level. The panel causality test results are reported in Table 4. These results reveal strong panel causality between GDP per capita and sustainable development across the four income groups. Based on *Z*-bar statistics, the causal analysis indicates that high-income countries have stronger relationships than middle-income countries. The *Z*-tilde statistics further validate the evidence of panel Granger causality.

Table 4: Panel Granger causality results

Dependent variable: sustainable development	*Z*-bar statistics	*Z*-tilde statistics
Panel A: High-income countries	158.300***	25.970***
Panel B: Upper-middle-income countries	136.930***	22.492***
Panel C: Lower-middle income countries	129.620***	21.202***
Panel D: Low-income countries	84.2880***	13.999***

Notes: *** denotes statistical significance at the 1% level.
Source: Authors' own calculations

Table 5: Panel Granger causality country-wide results

Panel A		Panel B		Panel C: *continued*	
Country	**Z-bar stat**	**Country**	***Z*-bar stat**	**Country**	***Z*-bar stat**
Australia	67.1146***	Albania	94.9299***	Haiti	129.1709***
Austria	29.4472***	Belize	182.6960***	Honduras	167.8162***
Barbados	87.3589***	Botswana	55.5270***	India	20.2932***
Belgium	124.4247***	Brazil	197.9998***	Kenya	178.4863***
Canada	78.4834***	Bulgaria	157.5861***	Lesotho	165.5798***
Chile	179.1506***	China	278.8155***	Mongolia	282.1347***
Cyprus	66.4773***	Colombia	101.2729***	Myanmar	103.2256***
Czechia	65.1153***	Costa Rica	283.1992***	Nepal	101.8457***
Denmark	73.3933***	Cuba	130.4636***	Nicaragua	30.1131***
Finland	33.5573***	Dominican Republic	95.0541***	Niger	108.3003***
France	37.3176***	Ecuador	135.9071***	Papua New Guinea	16.5101**
Germany	152.6102***	El Salvador	97.8217***	Philippines	16.9330***
Greece	490.2463***	Fiji	32.4401***	Samoa	27.8703***
Hungary	63.5013***	Gabon	124.5916***	Sri Lanka	29.6080***
Iceland	105.0187***	Guatemala	48.8941***	Tanzania	85.0235***
Ireland	51.6760***	Jamaica	50.2128***	Ukraine	48.8247***
Italy	323.2837***	Mauritius	216.0053***	Zambia	188.2250***
Japan	229.6563***	Mexico	39.7719***	Zimbabwe	92.2114***
Uruguay	57.7055***	Namibia	151.8430***	**Panel D**	
Republic of Korea	230.0307***	Paraguay	46.0353***	**Country**	***Z*-bar stat**
Malta	252.9254***	Peru	40.1213***	Burundi	22.4234***
Netherlands	36.2975***	Russia	15.7181**	Central African Republic	142.1250***
New Zealand	38.9391***	South Africa	150.0469***	The Gambia	118.0411***
Norway	70.7986***	Thailand	285.1191***	Sierra Leone	410.9371***
Panama	173.2077***	Togo	59.9485***	Uganda	112.1134***
Poland	115.6250***	**Panel C**		Yemen	124.3095***
Portugal	29.3574***	**Country**	***Z*-bar stat**		
Romania	91.9127***	Algeria	40.1990***		
Singapore	71.1086***	Benin	77.4816***		
Slovakia	78.7014***	Bolivia	112.1176***		
Spain	553.8109***	Cambodia	36.4351***		
Sweden	38.6962***	Cameroon	21.3494***		
Switzerland	19.0364***	Republic of the Congo	70.9141***		
UK	27.6999***	Ghana	86.7110***		
USA	144.7034***	Guinea	295.9617***		

Notes: Panel A = High-income countries, Panel B = Upper-middle-income countries, Panel C = Lower-middle -income countries and Panel D = Low-income countries. *** and ** denote statistical significance at the 1%, and 10% levels, respectively.

Source: Authors' own calculations

We further report the bidirectional causality between both time series, as shown in Table 5. The results reveal a significant bidirectional causality between GDP per capita and sustainable development for each country, with their *Z*-bar statistics indicating a highly interconnected relationship. These findings validate that GDP per capita Granger causes sustainable development for at least one cross-section unit and reject the null hypothesis of non-causality at a 1% significance level in most cases. Panel and bi-directional Granger causality tests validate our CCC results and confirm that sustainable development is a significant function of growth at a 1% significance level, except for Russia and Papua New Guinea, where it is significant at a 10% significance level.

5. Conclusion and Implications

To test the reversed EKC (REKC) hypothesis, this paper examined the relationship between GPD per capita and sustainable development of 92 high, upper-middle, lower-middle and high-income countries. We used a novel cross-correlation coefficient approach and panel Granger causality test for the period 1990–2022. This study proposed and validated the REKC using a novel quadrant scenario approach based on average cross-correlation lag and lead mechanism.

Our cross-correlation results show a noteworthy relationship between GDP per capita and sustainable development across income levels. Specifically, CCC results highlight that in five (around 5%) of the 92 countries, there is justifiable evidence supporting the REKC hypothesis, primarily comprising high-income countries. Subsequently, 50 countries (around 54%) partially agree with the REKC hypothesis, mostly from the upper-middle, lower-middle and low-income groups. Moreover, 27 countries (29%), predominantly high-income, show partial disagreement with the REKC and 10 countries (11%), mainly from the high-income and upper-middle-income groups, fully disagree with the REKC. Although the results demonstrate agreement with the REKC for high-income countries, underlying insights advocate that high-income countries experience a more significant decline in sustainable development than countries in the upper-middle, lower-middle and low-income groups. This discrepancy is because the rising income of the latter groups is expected to lead to more sustainable development in the future. It is important to note that while countries may not necessarily show agreement with the REKC, the relationship between income levels and sustainable development can be explained through a quadrant scenario approach, capturing a more nuanced view of the REKC agreement across diverse income classes.

As for the Granger causality results, GDP per capita shows a strong causal relationship with economic growth. Interestingly, the causality is significant across each income group, indicating a strong linkage between income growth and sustainable development. We also identified a significant bi-directional country-wide causality between GDP per capita and sustainable development. While both panel and bi-directional Granger causality results reveal that income growth stimulates sustainable development, the nature of that relationship varies significantly by income group, suggesting that the impact of GDP per capita on sustainable development diminishes as income levels decrease.

This study offers a few theoretical implications. Firstly, the proposal of the REKC hypothesis having a U-shaped curve implies that as income level rises, sustainable development initially declines; however, after reaching an inflection point, sustainable development increases with a rise in GDP per capita. Secondly, as per the conventional EKC hypothesis, although measuring negative environmental sustainability indicators is appropriate to determine environmental degradation with rising income growth, positive environmental sustainability indicators, *i.e.*, sustainable development, may reverse the proposed relationship defined in EKC theory. In addition, the overall environmental well-being is determined not only by negative environmental indicators, *i.e.*, CO_2 emissions but also by actively promoting and enhancing sustainable development across countries, which are positive environmental sustainability indicators.

Our findings imply that policymakers and regulators should recognise the role of rising income growth across countries, particularly high-income countries, in designing policies for sustainable development. Currently, economic growth prevents many countries from improving sustainable development and in the future, more countries will encounter sustainability challenges as their income growth progresses. Secondly, although developing countries prioritise economic growth over sustainable development, they are not at their optimal level of economic growth and resource consumption; therefore, their sustainable development is more favourable than that of high-income countries. Moreover, lower-income countries have attenuated resource consumption and unsaturated industrial and technological development, making them less environmentally harmful than high-income countries. According to the United Nations Department of Economics and Social Affairs (Wilmoth *et al*., 2022), economies with the highest per capita emissions of greenhouse gases and consumption of material resources are those where the GDP per capita is highest. Governments of more affluent economies are more obligated to redesign their policies to rapidly achieve net-zero emission targets by 2050 and implement strategies to decouple human economic activity from environmental degradation. Thirdly, a one-size-fits-all approach to environmental policy and sustainable development goals may be insufficient, highlighting the need for tailored sustainable policies and long-term goals that recognise the specific stages of economic and sustainable development of each group of countries. Lastly, adoption of green technologies and sustainable practices should be encouraged at both public and corporate levels, thereby strengthening the synergy between economic growth and sustainable development. For instance, improving green certificate programmes for industries and products can support businesses in adopting sustainable practices and helping consumers make environmentally conscious choices, leading to a more desirable sustainable development and economic growth nexus.

Our study has limitations. Firstly, the CCC approach is prone to third-factor influence and averaging lags/leads can mask significant trends and does not establish direct causality. Secondly, further research can benefit from considering a multivariate panel regression model to examine whether sustainable development is a significant function of growth. In terms of findings, this study is subject to generalisability as we introduce a reverse version of the EKC. Future research could examine the relationship between globalisation (Shahbaz *et al.*, 2019b) and foreign direct investment (Shahbaz *et al.*, 2019a) in the context of sustainable development to validate the REKC hypothesis further. Finally, averaging CCC findings can mask significant trends within the individual lag and lead periods. Therefore, findings should be considered carefully before implementing policies and future sustainable initiatives.

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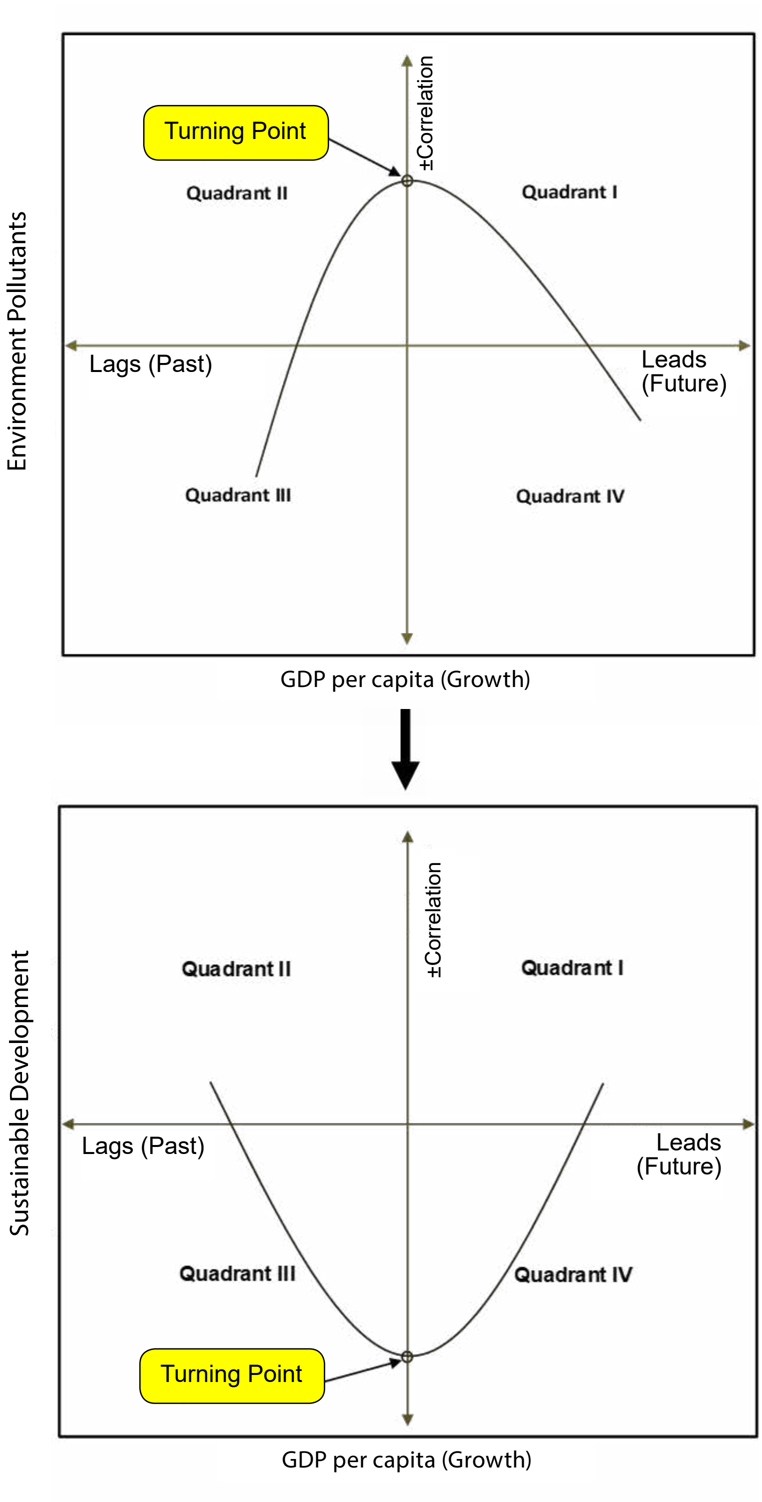
Appendix

Figure 1A: Environmental Kuznets curve transformation



Source: Adapted from Ul Haq *et al*. (2024)

Figure 2A: Cross-correlation coefficient (CCC) plots for countries for which an increase in income will enhance sustainable development in the future

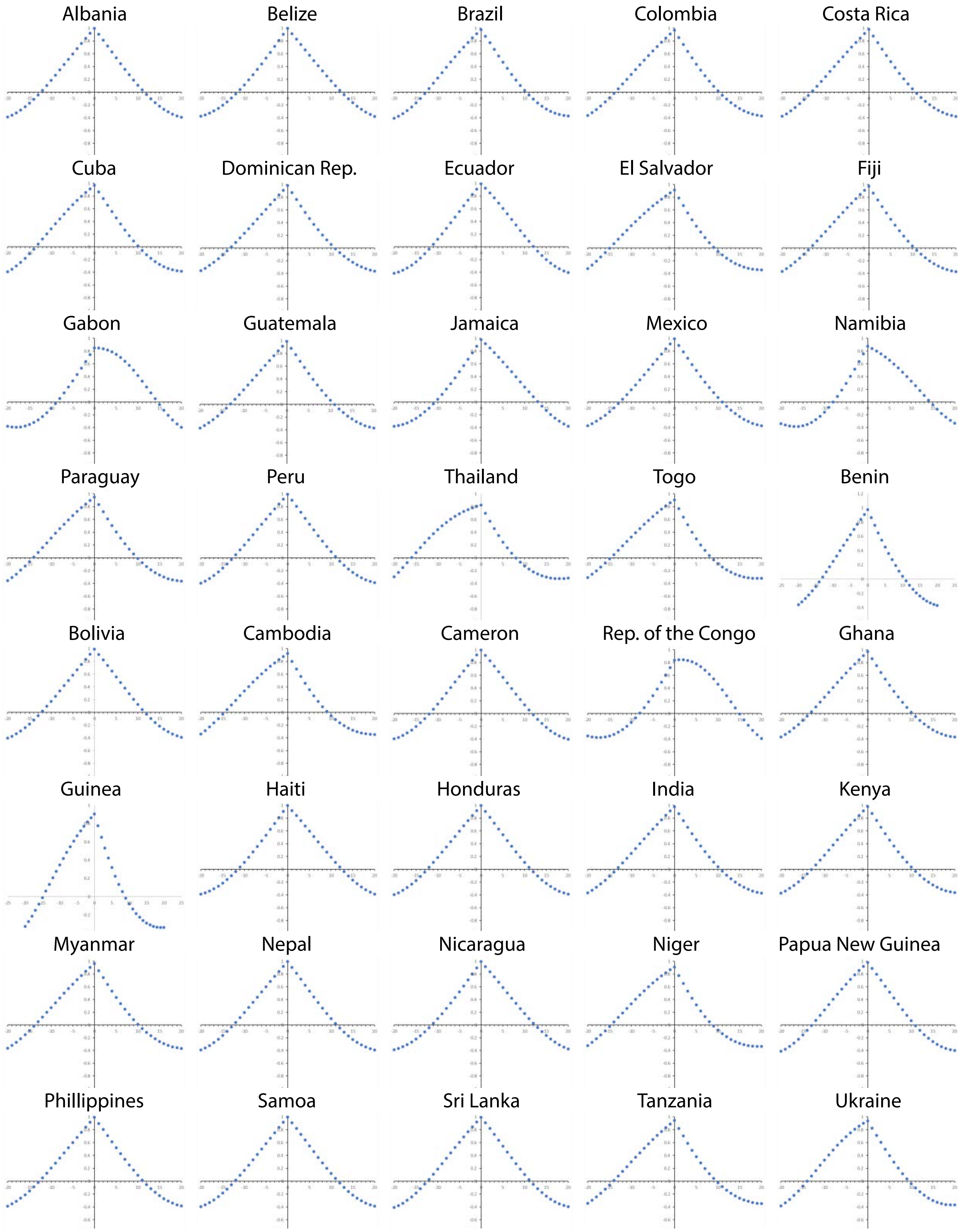
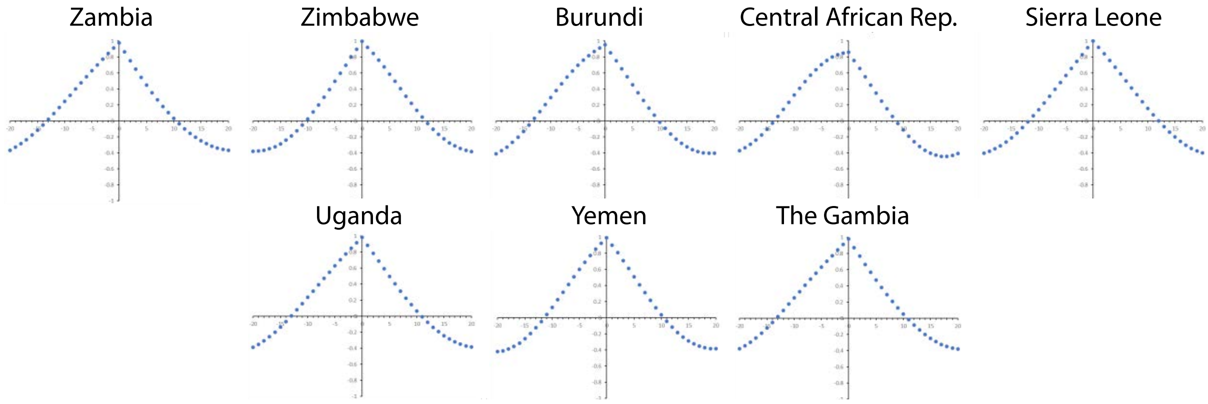


Figure 2A: Continuation



Source: Authors' own calculation

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