From mass tourism to low-carbon futures: a tiered pathway for sustainable tourism

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From Mass Tourism to Low-Carbon Futures:
A Tiered Pathway for Sustainable Tourism

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Abstract

Tourism fuels economic growth yet simultaneously exacerbates carbon emissions, presenting a critical sustainability challenge. This study examines the complex relationship between tourism dependency, economic growth, and carbon emissions by employing a tiered analytical framework. Using panel data from 2000 to 2020, we demonstrate that increased tourism volume (arrivals) tends to elevate per capita CO_2 emissions, particularly in highly tourism-dependent economies. In contrast, tourism quality, when measured through receipts and yield, can mitigate environmental pressures by incentivising sustainable infrastructure and low-carbon innovations. The analysis reveals significant heterogeneity across dependency tiers, including inverted-N emissions dynamics and rebound effects, underscoring the importance of adaptive, phase-sensitive governance. Policy moderation results highlight that environmental accounting (e.g. SEEA-Tourism) and carbon pricing are most effective when tailored to a country's dependency profile and enforcement capacity. The findings offer a practical roadmap for aligning tourism growth with climate goals, providing nuanced insights for policymakers navigating the trade-offs between economic development and environmental sustainability.

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Highlights:

- Mass tourism increases emissions, whereas high-quality tourism mitigates environmental pressure.
- EKC shows rebound effects; governance must adapt to development phase.
- SEEA-Tourism and carbon pricing work best when tailored to context.
- Findings guide policy by aligning tourism with climate responsibilities.

Classification: Environmental Economics; Tourism Economics, Climate policy and Governance, Applied econometric

Keywords: Tourism dependency; Environmental Kuznets Curve (EKC); carbon emissions; sustainable tourism; carbon tax; SEEA-Tourism; panel data analysis; tourism yield; climate policy

1. Introduction

Tourism has become one of the most rapidly expanding sectors within the global economy, contributing substantially to income generation, employment creation, and the promotion of intercultural understanding (UNWTO, 2022). However, this growth entails a critical contradiction: while tourism supports socio-economic advancement, it is concurrently a major contributor to environmental degradation, particularly through the emission of greenhouse gases, such as carbon emissions.

This tourism-emission paradox arises from the inherently carbon-intensive nature of key tourism activities, including air and road transportation, accommodation, and recreational services, all of which are heavily reliant on energy consumption (Becken & Simmons, 2002; Lenzen et al., 2018). As international tourist arrivals continue to increase globally, the associated carbon emissions have escalated correspondingly, exacerbating challenges to climate change mitigation and raising concerns regarding the environmental sustainability of tourism-driven development strategies (Sun et al., 2022). Particularly, some of the most desirable tourist destinations, including small island nations, coastal regions, and biodiversity hotspots, are also among the most vulnerable to the impacts of climate change. Thus, understanding and addressing the tourism–emissions paradox is essential for shaping a more sustainable future for global travel. It requires a careful balance between fostering tourism's benefits and minimising its environmental footprint through innovations in policy, technology, and traveller behaviour.

The Environmental Kuznets Curve (EKC) theory originally proposed by Kuznets (1955) offers a valuable conceptual framework for better understanding the dynamics between economic growth and environmental degradation within the tourism sector. In tourism contexts, the EKC framework raises critical questions regarding whether tourism-driven economic growth inevitably exacerbates emissions or can ultimately facilitate greener practices as incomes and environmental consciousness rise. Some evidence suggests that advanced tourism economies can achieve emission reductions through investments in sustainable infrastructure and the implementation of effective regulations and eco-friendly practices (Lee & Brahmasrene, 2013;

Katircioglu et al.,2014), ecological modernisation theory argues that credible measurement and pricing can decouple growth from emissions (Mol & Spaargaren, 2000; Jänicke, 2008).

Recent systematic reviews indicate that the tourism-extended EKC remains highly contested and context-dependent (Sun et al., 2022). Factors such as energy dependence, governance quality, and technological capacity significantly shape the tourism–emissions nexus, revealing the necessity of context-sensitive analyses. Although existing studies have explored heterogeneity in the tourism and emissions relationship mainly in terms of income levels and destination characteristics (e.g., Paramati et al., 2017; Ozturk et al. (2023)), they often overlook a critical dimension: countries' structural dependence on tourism itself. Economies differ substantially due to their reliance on tourism. A uniform analytical approach that treats all countries alike risks overlooking these critical contextual differences, potentially leading to ineffective or even counterproductive policy recommendations.

To address this gap, this study adopts a tiered analysis framework based on tourism dependency, explicitly capturing structural differences across economies. Specifically, our research will focus on the following questions:

1 whether the effect of tourism on per-capita CO_2 emissions differs across these dependency tiers

2 whether value-based indicators (receipts, yield) mitigate emissions relative to volume-based measures (arrivals)

3 how the adoption of System of Environmental-Economic Accounting (SEEA)-Tourism and carbon taxes moderates the emissions impact within each tier

Our contribution is threefold. First, we define clear dependency tiers to reveal heterogeneity masked by EKC-style models. Second, we focus on tourism yield and demonstrate that high-value, low-volume strategies can reduce emissions, even when rising arrivals tend to increase them. Third, we quantify how SEEA-Tourism and carbon taxes operate differently by tier and translate those results into a practical policy roadmap.

2. Literature Review

2.1 EKC and Tourism Studies

The EKC hypothesis has become a key framework in environmental economics for analysing the long-term relationship between economic development and environmental quality. The theory originally proposes an inverted U-shaped trajectory, where environmental degradation typically measured through indicators like CO_2 emissions initially increases with economic growth during industrialization phases, but eventually declines after reaching a specific income threshold (Grossman & Krueger, 1995, Chen et al., 2019, Ehigiamusoe, 2020, Ghosh, 2020, Arouri et al., 2023;). However, as demonstrated by Copeland and Taylor (2003), Dinda (2004), and Stern (2015), the EKC's empirical validity varies significantly depending on contextual factors such as the type of environmental pollutant examined, national characteristics and the sectoral composition of economic growth.

In the tourism context, the EKC hypothesis has been adapted to assess whether tourism-led economic growth exhibits a similar nonlinear pattern in terms of carbon emissions. Several studies have explored the existence of a tourism-specific EKC. Katircioglu and Celebi's (2014) study of Turkey found supporting evidence for the EKC hypothesis, suggesting emissions eventually decline with advanced tourism development through technological adoption and policy interventions. Similarly, Lee and Brahmasrene (2013) confirmed the EKC hypothesis in a panel of ASEAN countries, noting that long-run tourism growth could be decoupled from emissions through appropriate investments in green technologies and sustainable tourism practices. Expanding this perspective, Porto and Ciaschi (2021) integrated tourism within the EKC framework. Analysing the data from 18 Latin American countries (1995–2013). Their findings reveal that tourism generally increases CO_2 emissions, but the stringency of environmental regulations mediates this relationship. The introduction of an Environmental Legal Index, capturing both international commitments and domestic regulatory frameworks, highlights the moderating role of governance quality.

2.2 Heterogeneity Study in Tourism's Environmental Impacts

Understanding the environmental impacts of tourism necessitates recognizing the substantial heterogeneity that exists across countries in terms of economic development, institutional capacity, and environmental governance. Applying a one-size-fits-all approach risks obscuring crucial differences in how tourism influences carbon emissions in diverse national contexts. A significant body of literature classifies countries into developed and developing economies, emphasizing that policy responses, technological capabilities, and environmental regulatory frameworks often diverge sharply.

Sun et al. (2022) provide a comprehensive systematic review showing that the environmental effects of tourism differ markedly between these groups, with developing countries generally experiencing higher emissions due to weaker governance structures and less stringent environmental standards. This is consistent with Zaman et al. (2016), who demonstrate that rapid tourism growth in developing economies is frequently associated with elevated carbon emissions, primarily due to energy-intensive infrastructure and lax regulatory environments. In contrast, developed countries often exhibit a weaker or even negative relationship between tourism and emissions, owing to their stricter environmental regulations, broader adoption of clean technologies, and stronger societal support for sustainability.

Furthermore, advanced econometric approaches, such as quantile regression, have proven particularly useful in capturing this heterogeneity within the emissions distribution. Aziz et al. (2020), for example, provide compelling evidence from BRICS countries using a method of moments quantile regression approach. Their findings indicate that tourism consistently and positively correlates with carbon emissions, especially at higher quantiles, suggesting that environmental impacts are more pronounced in high-pollution contexts. Supporting this perspective, Porto and Ciaschi (2021) apply instrumental quantile regression to a panel of 18 Latin American countries, incorporating tourism activity, GDP, energy consumption, and an innovative Environmental Legal Index. Their results reveal that the shape and turning point of the tourism-extended EKC vary significantly across emission deciles, with robust legal and institutional frameworks playing a crucial role in mitigating emissions. These studies underscore the importance of considering country-specific economic and institutional characteristics when evaluating tourism's environmental impacts and highlight the value of quantile-based analyses in uncovering nuanced distributional effects.

A substantial portion of the literature treats countries as homogeneous units, obscuring how structural reliance on tourism conditions carbon lock-in, fiscal capacity, and regulatory effectiveness. Economies in which tourism constitutes a core export face markedly different constraints and trade-offs compared to more diversified peers. In high-dependency economies, tourism behaves like a core export with scale effects and carbon lock-in while in low-dependency settings, aggregate emissions are driven elsewhere, so tourism's EKC may be flat unless targeted policy amplifies niche efficiency gains. A tiered analysis based on tourism dependence can offer clearer insights into how the relationship between tourism and emissions evolves across varying levels of tourism intensity. Given these insights, this study adopts a specific approach by categorising countries into three tiers based on tourism dependency, which is defined as the extent to which a country's economy relies on tourism-related activities for GDP.

3 Data and Methodology

3.1 Data Description

3.1.1 Global Data

This study utilises a balanced panel dataset comprising 177 countries over the period from 2000 to 2020. The dataset provides a comprehensive and comparative foundation for examining the relationship between tourism activity and environmental outcomes across diverse national contexts. The primary dependent variable is carbon dioxide (CO_2) emissions per capita, using as a proxy for environmental pressure associated with economic activity and tourism development.

The key explanatory variables in this study are designed to capture multiple dimensions of tourism. In past studies, arrivals are the most popular variable used to proxy tourism demand. However, relying solely on volume-based metrics, such as tourist arrivals, can overlook important contextual factors, including regulatory strength, technological advancements, and tourist behaviour. Specifically, international tourism arrivals represent the volume of inbound tourists, while international tourism receipts reflect the economic value generated by the inbound tourism. To further capture the qualitative aspect of tourism, this study also includes a third variable: tourism yield, defined as the ratio of tourism receipts to arrivals. This metric enables us to differentiate between low-value, high-volume tourism and higher-value forms of tourism, such as luxury, business, or eco-tourism.

To isolate the effect of tourism on environmental outcomes, a set of control variables is included, consistent with prior empirical literature. These variables comprise GDP per capita, energy consumption, renewable energy consumption and population density. All continuous variables are expressed in natural logarithmic form. Table 1 summarises the descriptive statistics for all key variables used in the analysis. Notably, the data show wide variation across countries in tourism, economic and environmental indicators, highlighting the heterogeneity that motivates the tiered analytical approach in this study.

Table 1: Descriptive Statistics (global data)

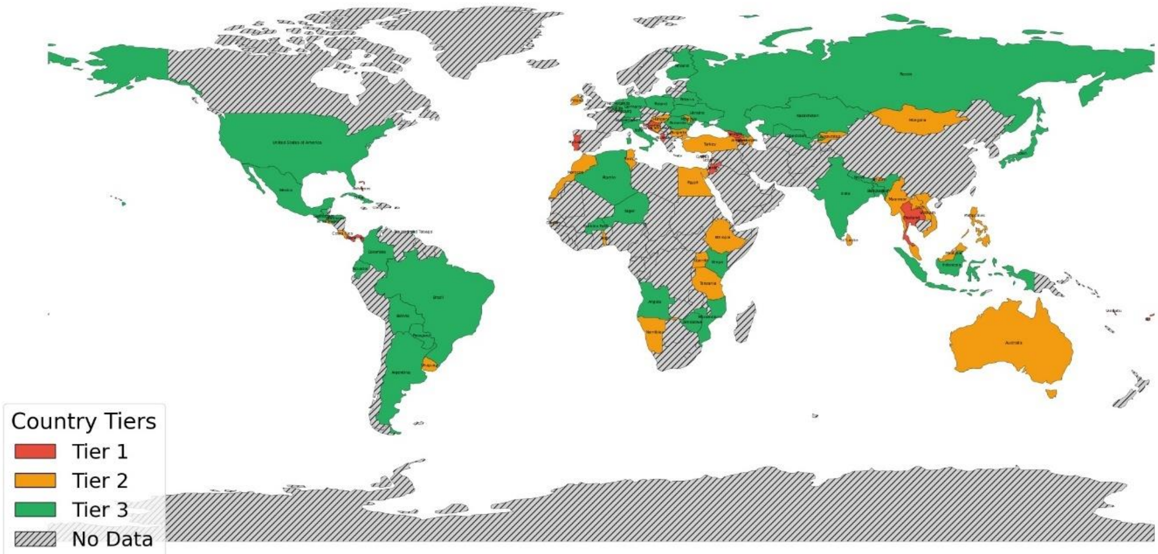
Variable	Obs	Mean	Std. Dev.	Min	Max
Tourism Arrivals	2,407	10,500,000.000	24,000,000.000	5,600.000	183,000,000.000
Tourism Revenue per Capita	2,091	1,233.532	4,627.717	0.432	73,738.340
Annual CO_2 Emissions per Capita	2,436	4.389	5.029	0.047	33.975
GDP per Capita	2,436	13,245.650	19,339.460	110.461	123,733.000
Energy Consumption	2,436	24,953.910	30,430.540	105.110	188,294.000
Population Density	2,436	436.556	1,952.064	1.543	21,530.000
Renewable Energy Consumption	2,436	4,727.841	13,079.030	0.000	153,271.300

System of Environmental-Economic Accounting (SEEA)	2,058	0.510	1.039	0.000	4.000
Carbon Tax Dummy	588	0.352	0.478	0.000	1.000

3.1.2 Tiered Data

Using the most recent pre-pandemic data from 2019, countries can be categorised into three tiers based on the share of tourism receipts relative to GDP: Tier 1 (high tourism dependency, >10%), Tier 2 (medium tourism dependency, 3–10%), and Tier 3 (low tourism dependency, <3%). A series of one-way ANOVA tests were conducted to test for significant differences for all variables across the tiers. The test results strongly reject the null hypothesis, indicating statistically significant differences among the tiers for all examined variables. The null hypothesis assumes equal means across the groups (H_0: $\alpha_1 = \alpha_2 = \alpha_3$). Appendix A Table 1 presents the 117 countries categorised by tourism dependency tier and presents a country-level reference for understanding how structural differences influence the relationship between tourism dependency and national emissions levels. For detailed descriptive statistics of the tiered country groups, please refer to Appendix A Table 2.

Figure 1: World map of countries by tourism dependency tiers



Among Tier 1 countries, where tourism accounts for a significant share of economic output, are often small island developing states (SIDS), popular tourist destinations, and economies with limited diversification. These countries are particularly vulnerable to climate change and external shocks affecting tourism flows. The high volume of tourism activity relative to economic size can lead to disproportionately high emissions per capita or per tourist, especially when sustainability practices are underdeveloped.

Tier 2 countries have a balanced relationship with tourism, benefiting economically without being overly reliant. This group often represents a transitional phase in the EKC, where the trade-off between growth and sustainability becomes especially pronounced.

Tier 3 countries, with low tourism dependency, generally show emissions shaped by broader economic activities beyond tourism.

In Figure 1, the map complements Appendix A Table 2 by illustrating the global distribution of countries with high, moderate, and low tourism dependency. It highlights regional clustering patterns and differences in tourism reliance, providing a visual context for the tiered analysis presented in this study.

3.1.3 Policy Indicator - SEEA-Tourism and Carbon Tax Policies

In tourism, standardised accounting (SEEA-Tourism) and carbon pricing should strengthen technique effects and bring earlier decoupling, when governance capacity is sufficient. For example, Fiji, with a tourism dependency of 24.7%, has managed to maintain relatively low carbon emissions per capita of 1.48 tons. Fiji's case highlights the potential effectiveness of SEEA-Tourism framework when it is supported by robust policy design like green hotel certification schemes and the promotion of low-carbon transport.

In this study, SEEA-Tourism adoption is measured using an aggregated index, reflecting the extent to which a country has implemented comprehensive tourism-related environmental-economic accounting frameworks. Appendix A figure 1 Countries with higher SEEA scores are shown in blue, while those with lower or no implementation are shown in red. This visual comparison helps visualize the trajectory of environmental accounting systems.

To strengthen this integrated governance approach, the analysis further considers carbon tax policies which is captured as a binary variable, set to 1 if a country has implemented a national-level carbon tax, and 0 otherwise.

3.2 Methodology and Model Specification

Our main specification employs two-way fixed effects (FE) with a panel error-correction model (ECM). FE identifies effects from within-country changes while absorbing time-invariant heterogeneity and common shocks. The ECM is warranted by cointegration among CO_2, income, and tourism variables, and it separates long-run elasticities from short-run adjustments via an interpretable error-correction term.

3.2.1 Baseline regression model

A Hausman specification test was conducted to determine the appropriate estimation strategy between fixed effects and random effects models. The test results (χ^2 (5) = 23.19, p = 0.0003) strongly reject the null hypothesis of no systematic difference in coefficients. This indicates that the fixed effects model is more appropriate for the data, as it accounts for unobserved heterogeneity that may be correlated with the regressors.

We estimate three distinct model specifications. In the first model, tourism is measured by international tourist arrivals $TourrArriv_{it}$, capturing the volume of visitors entering each country. The second model replaces this with international tourism receipts $TourrRep_{it}$, to reflect the economic value of tourism rather than its physical scale. The third and most refined specification introduces tourism yield, defined as tourism receipts per arrival, $\frac{TourrRep_{it}}{TourrArriv_{it}}$, capturing average tourist spending. The general econometric model is specified as follows:

$$CO2_{it} = \alpha_0 + \alpha_1 Tour_{it} + \sum_j \sigma_j X_{it} + \mu_i + \lambda_t + \epsilon_{it} \quad (1)$$

Where $C02_{it}$ represents the per capita carbon emissions for country i at time t. X_it represents the vector of control variables (GDP per capita, energy consumption per capita, renewable energy consumption per capita, and population density), μ_i are country fixed effects, λ_t are time fixed effects, and $\epsilon_{it}$is the idiosyncratic error term. The tourism variable $Tour_{it}$ is alternately specified across the following three models:

$$CO2_{it} = \alpha_0 + \alpha_1 TourrArriv_{it} + \sum_j \sigma_j X_{it} + \mu_i + \lambda_t + \epsilon_{it} \quad (1a)$$

$$CO2_{it} = \alpha_0 + \alpha_1 TourrRep_{it} + \sum_j \sigma_j X_{it} + \mu_i + \lambda_t + \epsilon_{it} \quad (1b)$$

$$CO2_{it} = \alpha_0 + \alpha_1 \frac{TourrRep_{it}}{TourrArriv_{it}} + \sum_j \sigma_j X_{it} + \mu_i + \lambda_t + \epsilon_{it} \quad (1c)$$

3.2.2 Tiered Regression Model

To examine the environmental implications of varying levels of tourism dependence, we employ a tiered regression model. This approach enables us to assess whether the relationship between tourism and environmental outcomes differs across countries with varying levels of reliance on tourism as an economic driver, specifically those with low, moderate, and high reliance.

$$CO2_{it}^{k} = \alpha_0^k + \alpha_1^k Tour_{it} + \sum_j \sigma_j^k X_{it} + \mu_i^k + \lambda_t^k + \epsilon_{it}^{\mathrm{k}} \text{ , where k } \in \{1,2,3\} \quad (2)$$

Here, k denotes the tourism dependence tier, with *k=1* for high-dependence countries, *k=2* for moderate-dependence, and *k=3* for low-dependence countries. Similarly, the tourism variable $Tour_{it}$ is alternately specified across the following three models:

$$CO2_{it}^{k} = \alpha_0^k + \alpha_1^k TourrArriv_{it} + \sum_j \sigma_j^k X_{it} + \mu_i^k + \lambda_t^k + \epsilon_{it}^{\mathrm{k}} \text{ , where k } \in \{1,2,3\} \quad 2(a)$$

$$CO2_{it}^{k} = \alpha_0^k + \alpha_1^k TourrRep_{it} + \sum_j \sigma_j^k X_{it} + \mu_i^k + \lambda_t^k + \epsilon_{it}^{\mathrm{k}} \text{ , where k } \in \{1,2,3\} \quad 2(b)$$

$$CO2_{it}^{k} = \alpha_0^k + \alpha_1^k \frac{TourrRep_{it}}{TourrArriv_{it}} + \sum_j \sigma_j^k X_{it} + \mu_i^k + \lambda_t^k + \epsilon_{it}^{\mathrm{k}} \text{ , where k } \in \{1,2,3\} \quad 2(c)$$

3.2.4 Revisit the EKC

The EKC hypothesis is a widely studied framework that explores the relationship between environmental degradation and economic development. We regress per capita carbon emissions on GDP per capita and its squared term, adopting a quadratic specification widely employed in the empirical literature (Grossman & Krueger, 1995; Panayotou, 1993; Dinda, 2004; Selden & Song, 1994; Holtz-Eakin & Selden, 1995; Stern, 2004).

To capture potential nonlinearities beyond the traditional form, we also include a cubic specification, which allows for N-shaped or more complex relationships when the standard U-shaped or inverted U-shaped patterns do not adequately fit the data.

$$CO2_{it}^{k,ekc1} = \beta_0^k + \beta_1^k GDPpc_{it} + \beta_2^k \left(GDP_{pc_{it}}\right)^2 + \sum_j \sigma_j^k X_{it} + \epsilon_{it}^{k,ekc1} \quad (3a)$$

$$CO2_{it}^{k,ekc1} = \beta_0^k + \beta_1^k GDPpc_{it} + \beta_2^k \left(GDP_{pc_{it}}\right)^2 + \beta_2^k \left(GDP_{pc_{it}}\right)^3 + \sum_j \sigma_j^k X_{it} + \epsilon_{it}^{k,ekc1} \quad (3b)$$

β_1^k captures the initial effect of GDP per capita for k tires separately and the β_2^k measures the potential turning points. Vector X_{it} includes control variables including energy consumption, renewable energy share, and population density.

Then we extend the EKC framework by including tourism-specific variables, along with relevant macroeconomic controls, to assess whether the EKC holds in the presence of tourism activity and how tourism interacts with economic development to shape environmental outcomes. A tourism-augmented EKC model is specified with an extra term $Tour_{it}$:

$$CO2_{it}^{k,ekc1} = \beta_0^k + \beta_1^k GDPpc_{it} + \beta_2^k \left(GDP_{pc_{it}}\right)^2 + \beta_3^k Tour_{it} + \sum_j \sigma_j^k X_{it} + \mu_{it}^{k,ekc1} + \lambda_{it}^{k,ekc1} + \epsilon_{it}^{k,ekc1} \quad (4)$$

The tourism-extended EKC framework addresses growing evidence in the literature suggesting more complex and nuanced environmental trajectories. Gössling & Hall (2006) and Ozturk et al., (2023) show that tourism's environmental impacts often evolve in nonlinear or discontinuous ways, particularly in destinations experiencing high tourism intensity. To better capture these dynamics, this study adopts an extended EKC model framework. Specifically, if both the linear and quadratic terms are statistically significant, the model stops at the quadratic specification. However, if significance is not confirmed, a cubic term is included to allow for more complex nonlinear patterns.

$$CO2_{it}^{k,ekc2} = \gamma_0^k + \gamma_1^k Tour_{it} + \gamma_2^k Tour_{it}^2 + \gamma_3^k Tour_{it}^3 + \sum_j \sigma_j^k X_{it} + \mu_{it}^{k,ekc2} + \lambda_{it}^{k,ekc2} + \epsilon_{it}^{k,ekc2} \quad (5)$$

3.2.5 Incorporating Policy Moderators

To assess how environmental policy instruments shape the relationship between tourism and carbon emissions, we further extend our empirical models to include policy-related variables $Policy_{it}$ and interaction terms $Tourismyield_{it} * Policy_{it}$. We consider two policy moderators: the carbon tax and the SEEA-Tourism, and their interactions with tourism yield, as yield reflects the economic value per tourist and allows us to assess whether policy measures encourage a shift toward higher-value, lower-impact tourism models.

The general policy-augmented model can be specified as follows:

$$CO2_{it}^k = \delta_0^k + \delta_1^k Tourism_{it} + \delta_2^k Policy_{it} + \delta_3^k (Tourismyield_{it} * Policy_{it}) + \sum_j \sigma_j^k X_{it} + \mu_i^k + \lambda_t^k + \epsilon_{it}^k \text{ , where } k \in \{1,2,3\} \quad (6)$$

4. Empirical Results

4.1 Baseline regression

4.1.1 Unit root and Cointegration test

To examine the stationarity properties of the panel data, we applied the Fisher-type unit root test developed by Maddala and Wu (1999), which combines individual Augmented Dickey–Fuller (ADF) tests across cross-sectional units. As reported in Table 2, several key variables, including carbon emissions per capita, tourist arrivals, energy consumption, renewable energy consumption, and tourism revenue per capita, were found to be non-stationary at levels but stationary after first differencing, indicating they are integrated of order one, I(1). In contrast, GDP per capita, tourism yield, and population density were stationary at a level, implying they are I(0) processes.

Given this mixture of integration orders (I (0) and I (1)), we proceeded to test for the presence of long-run relationships among the variables using the Kao panel cointegration test. As shown in Table 3, the test results provide strong evidence of cointegration in the global panel as well as for Tier 1 and Tier 2 datasets. All major Kao statistics are statistically significant at the 1% level in these cases, rejecting the null hypothesis of no cointegration. Based on these findings, it is methodologically sound to estimate long-run relationships using panel fixed-effects regressions in levels. Additionally, to capture both short- and long-term dynamics and reinforce the robustness of our results, an Error Correction Model (ECM) will also be employed in subsequent analysis.

Table 2: Fisher-Type Unit Root Test

Variable	Chi² Stat (Level)	p-value (Level)	Chi² Stat (1st Diff)	p-value (1st Diff)	Integration Order
Carbon Emissions per Capita (log)	216.200	0.764	929.240	0.000	I (1)
GDP per capita (log)	473.960	0.0	--	--	I (0)
Tourist Arrivals (log)	230.770	0.511	376.100	0.000	I (1)
Tourism Receipt per Capita (log)	236.580	0.211	316.350	0.000	I (1)
Tourism Yield (log)	334.400	0.0	--	--	I (0)
Energy Consumption (log)	213.150	0.808	889.940	0.000	I (1)
Renewable Energy Consumption (log)	263.950	0.073	1,143.180	0.000	I (1)
Population Density (log)	436.270	0.0	--	--	I (0)

Table 3: Kao Panel Cointegration Test Results

Test Statistic	Global	Tier 1	Tier 2	Tier 3
Modified Dickey–Fuller t	-3.031*** (0.001)	-5.037*** (0.000)	-2.603*** (0.005)	2.748*** (0.003)
Dickey–Fuller t	-2.694*** (0.004)	-3.725*** (0.000)	-2.853*** (0.002)	3.564*** (0.000)
Augmented Dickey–Fuller t	-1.528* (0.063)	-4.471*** (0.000)	-2.766*** (0.003)	5.833*** (0.000)

Unadjusted Modified Dickey–Fuller t	-3.826*** (0.000)	-5.251*** (0.000)	-3.317*** (0.001)	0.980 (0.164)
Unadjusted Dickey–Fuller t	-3.143*** (0.001)	-3.798*** (0.000)	-3.202*** (0.001)	1.724* (0.042)

Note: Asterisks (*) denote significance at conventional levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

4.1.2 Baseline regression

Table 4 presents the baseline fixed-effects regression estimates across three models, each utilising a distinct tourism indicator as the key independent variable: international tourist arrivals (eq1a), tourism receipts (eq1b), and tourism yield (eq1c). All models control for significant macroeconomic and environmental variables.

Across all specifications, GDP per capita and energy use exhibit a significant positive relationship with carbon emissions, whereas renewable energy use shows a robust negative effect. The impact of tourism varies by metric: tourist arrivals show a marginally positive effect, while both tourism receipts and yield demonstrate a significant negative association with emissions, suggesting that the economic value of tourism may mitigate its environmental footprint.

4.2 Tiered - Heterogeneity analysis

To explore these differences in depth, fixed-effects panel regressions were conducted for each tier using three tourism-related models: international tourist arrivals (eq 2a), tourism receipts per capita (eq 2b), and tourism yield (receipts per arrival, eq 2c).

In Tier 1 countries, where tourism accounts for a substantial portion of the economy, tourism activity has a complex relationship with emissions. Tourist arrivals have a positive and statistically significant effect on carbon emissions ($\beta = 0.110$, $p < 0.001$),. However, tourism receipts per capita and tourism yield both show negative associations with emissions ($\beta = -0.139$ and -0.028, respectively), implying that high-value or better-managed tourism may contribute less to environmental degradation. In Tier 2 countries, which exhibit moderate tourism dependency, the findings show a mix of reinforcing and mitigating factors. Tourist arrivals continue to have a positive and significant effect on emissions ($\beta = 0.075$, $p < 0.001$). Like Tier 1, tourism yield is negatively associated with emissions ($\beta = -0.075$, $p < 0.001$), reinforcing the value-over-volume insight. In Tier 3 countries, with low tourism dependency, none of the tourism variables show statistically significant relationships with emissions. However, all three tourism indicators are negatively associated, indicating the sector's limited environmental impact at this stage of development. Across all tiers, the control variables perform as expected: GDP per capita and energy consumption are consistent positive drivers of emissions, while renewable energy consumption is a strong and uniform negative driver. This consistency underscores that the energy structure is a fundamental mediator of tourism's environmental impact, regardless of a country's level of tourism dependency.

Table 4: Results of Tiered Regression Analysis on Tourism and Carbon Emissions per Capita

Variables	Global			Tier 1 (High)			Tier 2 (Moderate)			Tier 3 (Low)		
	(eq1a)	(eq1b)	(eq1c)	(eq2a)	(eq2b)	(eq2c)	(eq2a)	(eq2b)	(eq2c)	(eq2a)	(eq2b)	(eq2c)
Tourist arrivals (log)	0.012 *(0.007)*	—	—	0.110*** *(0.017)*	—	—	0.075*** (0.019)	—	—	-0.017 (0.011)	—	—
Tourism Receipt per Capita(log)	—	-0.016* *(0.008)*	—	—	0.028 *(0.021)*	—	—	-0.121* *(0.071)*	—	—	-0.00002 *(0.00003)*	—
Tourism yield (log)	—	—	-0.058*** *(0.010)*	—	—	-0.139*** *(0.022)*	—	—	-0.075*** *(0.019)*	—	—	-0.021 *(0.014)*
GDP per capita (log)	0.062*** *(0.009)*	0.084*** *(0.011)*	0.088*** *(0.009)*	0.055** *(0.026)*	0.130*** *(0.036)*	0.218*** *(0.023)*	0.200*** *(0.020)*	0.185*** *(0.020)*	0.200*** *(0.020)*	0.020 *(0.011)*	0.026** *(0.012)*	0.024* *(0.012)*
Energy Consumption per Capita (log)	0.921*** *(0.018)*	0.986*** *(0.019)*	0.963*** *(0.019)*	0.610*** *(0.046)*	0.645*** *(0.051)*	0.579*** *(0.051)*	0.968*** *(0.032)*	0.994*** *(0.032)*	0.968*** *(0.032)*	1.054*** *(0.030)*	1.041*** *(0.032)*	1.053*** *(0.031)*
Renewable Energy Consumption per Capita (log)	-0.168*** (*0.007)*	-0.157*** *(0.008)*	-0.153*** *(0.008)*	-0.261*** *(0.012)*	-0.260*** *(0.013)*	-0.251*** *(0.013)*	-0.185*** *(0.019)*	-0.179*** *(0.019)*	-0.185*** *(0.019)*	-0.001 *(0.016)*	-0.011 *(0.017)*	-0.002 *(0.017)*
Population density (log)	0.039 *(0.036)*	-0.027 *(0.040)*	0.041 *(0.040)*	0.002 *(0.070)*	-0.135 *(0.084)*	0.010 *(0.083)*	-0.097*** *(0.017)*	0.066 *(0.069)*	-0.022 *(0.015)*	-0.107* *(0.056)*	-0.171*** *(0.058)*	-0.130** *(0.058)*
Within R^2	0.693	0.690	0.698	0.735	0.693	0.716	0.777	0.772	0.777	0.721	0.691	0.710
Countries	116	111	111	21	21	21	32	32	32	38	38	38
Observations	2,399	2,083	2,062	433	409	402	647	647	647	785	751	740

Notes: *** p<0.01, ** p<0.05, * p<0.1. Standard errors in parentheses. All models use country fixed effects

4.3 Revisit the EKC

4.3.1 Baseline EKC (Income-based EKC)

To explore the fundamental relationship between economic growth and environmental degradation, we begin by estimating a baseline EKC model.

As shown in Table 5, the linear GDP term is positive and the squared term is negative across samples, implying an inverted-U relationship. The global turning point (TP) is about 9,897, consistent with mid-income decoupling reported in recent syntheses (Ullah et al., 2023; Ben Jebli & Ben Youssef, 2023). In Tier 1 and Tier 2 countries, the turning points are exceptionally high, exceeding the range of the sample period, consistent with findings that EKC turning points can lie beyond observed ranges when curvature is weak (List & Gallet, 1999; Stern & Common, 2001). suggesting a delayed or potentially monotonically increasing trajectory in the long term. By contrast, Tier 3 turns earlier at 5,746, consistent with lower initial per-capita emissions and less carbon-intensive structures.

We then augment the EKC with tourism activity, arrivals, receipts per capita, and yield alongside the GDP terms to assess how sectoral dynamics shift the income–emissions trajectory. As shown in Table 5, the inverted-U shape persists across tiers, but the turning point moves in informative ways. For the global sample, TPs range from 9,302 (arrivals) to 17,314 (receipts) and 14,656 (yield), showing that sectoral composition can advance or delay decoupling (cf. Galeotti et al., 2022). In Tier 1 tourism lowers the TP. In Tier 2, TPs remain very high implying shallow curvature and a greater need for sustained policy to bend the path. In Tier 3,TPs are low across tourism measures, indicating earlier decline phases as incomes rise. These results align with the broader EKC literature while highlighting the role of sectoral structure in shifting turning points (Dinda, 2004; Stern, 2004).

Table 5: EKC turning points & shapes (income-only and tourism-augmented)

Tier	Income EKC — TP	Shape	+Arrivals — TP	Shape	+Receipts pc — TP	Shape	+Yield — TP	Shape
Global	9,897	Inverted-U	9,302	Inverted-U	17,314	Inverted-U	14,656	Inverted-U
Tier 1	34,945	Inverted-U	15,874	Inverted-U	25,498	Inverted-U	111,437	Inverted-U

Tier 2	343,000	Inverted-U	268,000	Inverted-U	18,552,000	Inverted-U	199,457,375	Inverted-U
Tier 3	5,746	Inverted-U	5,232	Inverted-U	6,565	Inverted-U	7,092	Inverted-U

Notes: TP = implied GDP per capita at the turning point , Shapes from signs on quadratic terms. Significance: *** p<0.01, ** p<0.05, * p<0.1

4.3.3 Tourism-extended EKC

Our estimates support a tourism-extended EKC in which value metrics explain emissions dynamics more cleanly than raw volume. As shown in Table 6, at the global level, tourism receipts per capita and tourism yield follow a statistically significant inverted-U: increases in value are associated with higher CO_2 per capita at lower ranges, flatten around the middle of the distribution, and become negative beyond a mid-to-upper turning region; by contrast, arrivals do not exhibit a stable nonlinear association once value is controlled.

In Tier 1, arrivals trace an inverted-N: marginal effects are negative at low arrival ranges, turn positive through the midrange, where variance and model fit peak and become negative again . While receipts per capita, however, display a cleaner inverted-U with an earlier, more precisely estimated turning region, while yield shows no robust nonlinear pattern. In Tier 2 ,), arrivals and yield each produce a conventional inverted-U with relatively shallow curvature and late turning points, whereas receipts per capita follow an inverted-N marked by a tightly estimated mid-segment rise bounded by negative tails, indicating a more volatile association over the distribution.

In Tier 3, arrivals again form an inverted-N characterised by small-base volatility and alternating signs across quantiles, while receipts per capita and yield present well-defined inverted-U shapes with comparatively early turning point.

Table 6: Tourism-extended EKC

Tier	Arrivals	Receipts pc	Yield
Global	—	Inverted-U	Inverted-U
Tier 1	Inverted-N	Inverted-U	—
Tier 2	Inverted-U	Inverted-N	Inverted-U

Tier 3	Inverted-N	Inverted-U	Inverted-U

Notes: Shapes based on significant polynomial terms ,. "—" indicates no significant nonlinear pattern.

4.3.4 Sensitivity analysis

We test whether results hinge on our tier cut-offs by re-estimating all EKC models using alternative thresholds (<4%, 4–12%, >12%). Turning points for the income-only and tourism-augmented models (arrivals, receipts per capita, yield) remain broadly consistent with the baseline, and the global EKC stays inverted-U for receipts per capita and yield. Tier patterns are also stable overall: Tier 1 again shows inverted-N for arrivals and inverted-U for receipts/yield. Minor shifts appear in Tier 2 (arrivals from inverted-U to inverted-N) and Tier 3 (yield from inverted-U to inverted-N), reflecting reclassification and reduced precision in some subsamples. These changes do not alter our main conclusions. The framework output is presented in Appendix A, Table 4

4.4. Policy indicators

The SEEA-Tourism framework and carbon tax policies represent two important approaches to reducing tourism-related carbon emissions and promoting global sustainability goals As shown in Table 7, the adoption of SEEA is significantly associated with lower emissions globally (–0.020***), with the strongest effects observed in Tier 1 (–0.029***) and Tier 2 (–0.024**).However, in low dependence, the effect is smaller (–0.004***), likely because tourism emissions are already less central to overall emissions profiles.

Additionally, carbon taxes, as broad fiscal measures, exhibit significant reductions globally (–0.033**) and particularly in Tier 2 countries (–0.103***). The interaction terms further highlight this contextual dependence. For example, the interaction between carbon tax and tourism yield is significant and negative only in Tier 2 (–0.013***), reinforcing that carbon taxes are most effective where tourism is important but not dominant.

Table 7: Summary of Regression Results Including Policy Moderators

	Global	Tier 1	Tier 2	Tier 3
Carbon tax	-0.033**	0.098	-0.103***	-0.030
SEEA	-0.020***	-0.029***	-0.024**	-0.004***
Carbon tax × Tourism yield	-0.004*	0.012	-0.013***	-0.003

SEEA × Tourism yield	-0.002***	-0.004***	-0.002*	-0.006***

Notes: *** p<0.01, ** p<0.05, * p<0.1.

6. Robust checks

The ECM specification captures both short-run dynamics and the adjustment process toward long-run equilibrium, using a lagged error correction term derived from the cointegrating relationship among the variables. The estimated model is:

$$C02_{it} = \alpha + \beta_1 GDP_{it} + \beta_2 Tour_{it} + \beta_3 EnergyCon_{it} + \beta_4 Pop_{it} + \beta_5 RenewEnerg + \varepsilon_{it} \quad (7)$$

CO_2 emissions per capita are modelled as a function of GDP per capita, tourism activity, energy consumption, population, and renewable energy consumption. This equation captures how these factors jointly determine long-run emission levels. Then models the short-run dynamics measured by differenced terms Δ and lagged error correction term ECM_{it-1} derived from the residuals of the equation (7) toward long-run equilibrium:

$$\Delta C02_{it} = \alpha + \beta_1 \Delta GDP_{it} + \beta_2 \Delta Tour_{it} + \beta_3 \Delta EnergyCon_{it} + \beta_4 \Delta Pop_{it} + \beta_5 \Delta RenewEnerg + \phi ECM_{it-1} + \mu_{it} \quad (8)$$

The results, summarised in Table 8, reinforce the robustness of the main findings. Across most subsamples, short-run GDP growth, international tourism arrivals, and energy consumption have statistically significant and positive effects on carbon emissions. Renewable energy consumption displays a strong and consistently negative impact on emissions across all tiers, reaffirming its critical role in environmental mitigation strategies.

The lagged error correction term is negative and highly significant in all regressions, providing strong evidence of long-run cointegration among the variables. Adjustment speeds vary across development tiers: Tier 1 countries exhibit the fastest correction rate (–0.366), followed by Tier 2 (–0.217), and Tier 3 (–0.094). This pattern suggests that higher-dependency economies adjust more rapidly to long-run equilibrium, possibly due to mature policy frameworks and more responsive energy systems.

Table 8: Summary of ECM Regression Results

Variable	Full Sample	Tier 1 (High)	Tier 2 (Moderate)	Tier 3 (Low)
ΔGDP	0.042***	0.050 (ns)	0.059*	0.060**
$\Delta Tour$	0.029***	0.067**	0.046***	-0.021 (ns)
ΔEnergyCon	0.595***	0.494***	0.674***	0.002(ns)
ΔPop	-0.513**	-0.289(ns)	-0.030*	0.001(ns)

ΔRenewEnerg	-0.138***	-0.177***	-0.140***	-0.135***
ECM_(it-1)	-0.169***	-0.366***	-0.217***	-0.094***

Notes: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

7. Discussion and Policy Implications

This study offers a comprehensive evaluation of the dynamic relationship between tourism dependency and carbon emissions, employing a multi-tiered analytical framework and integrating policy moderation analysis. The baseline fixed-effects regressions suggest that higher tourism volumes, proxied by arrivals, are consistently linked to increase per capita CO_2 emissions. In contrast, tourism quality indicators, such as receipts and yield, demonstrate negative associations with emissions, suggesting that high-value tourism can help alleviate environmental pressures, these findings align with prior studies, including Lee and Brahmasrene (2013) and Font et al. (2021).

Across all specifications, the baseline income–emissions relationship follows an inverted-U, but tourism variables shift the timing and stability of decoupling in tier-specific ways. Globally, the baseline income-emissions relationship follows an inverted-U pattern, which persists when tourism variables are introduced. However, the influence of tourism on the timing and stability of this decoupling varies significantly across dependency tiers.

Tier 1, for these economies, the baseline income-emissions decoupling occurs late. Tourism policy, however, offers a powerful lever to lower the turning point, enabling decoupling at a lower income level. While tourism receipts maintain a stable inverted-U path, the relationship for tourist arrivals flips to an inverted-N. This pattern indicates a high risk of "scale rebound," where initial environmental gains are overwhelmed by tourist volume, straining fragile ecosystems. This evidence strongly advises that SIDS and similar destinations must consciously shift their tourism sector from mass volume to high-value, low-volume segments to secure sustainable economic futures and avoid ecological overshoot.

Tier 2, both baseline and tourism-augmented EKCs exhibit an inverted-U shape, but decoupling occurs relatively late. In extended models, the relationship for tourism receipts switches to an inverted-N, consistent with spending surges outpacing regulatory capacity..

Tier 3, these economies experience early turning points across baseline and tourism-augmented models. However, tourist arrivals exhibit an inverted-N shape in extended models, likely due to small-market volatility and uneven enforcement.

Policy Implications

Tourism decarbonisation will not be achieved with one-size-fits-all policies. Our tiered dependency framework reveals heterogeneity that is masked in conventional EKC work, demonstrating that the same policy instrument performs differently across contexts. By distinguishing between tourism volume and value, we identify a concrete lever for decoupling. The resulting policy roadmap is necessarily tier-specific, as illustrated in Figure 2.

For Tier 1 country with high dependency, the late turning points and a rebound risk from arrivals, policy must both pull the peak forward and prevent reversals. General fiscal instruments are insufficient. Instead, measures should include short-term statutory SEEA-style environmental-economic accounting to target major emission sources and adopt a value-over-volume strategy. Tie land leases to sustainability performance, set a predictable carbon-price floor, and retrofit high-traffic transport corridors to align investment with decarbonisation.

For Tier 2 country with moderate dependency, with a late-peaking EKC and a risk of inverted-N rebounds from spending, policy should focus on stabilizing the post-peak decline. This highlights the need for long-horizon policy instruments, such as credible measurement and predictable carbon pricing to ensure that value growth does not trigger mid-cycle environmental rebounds

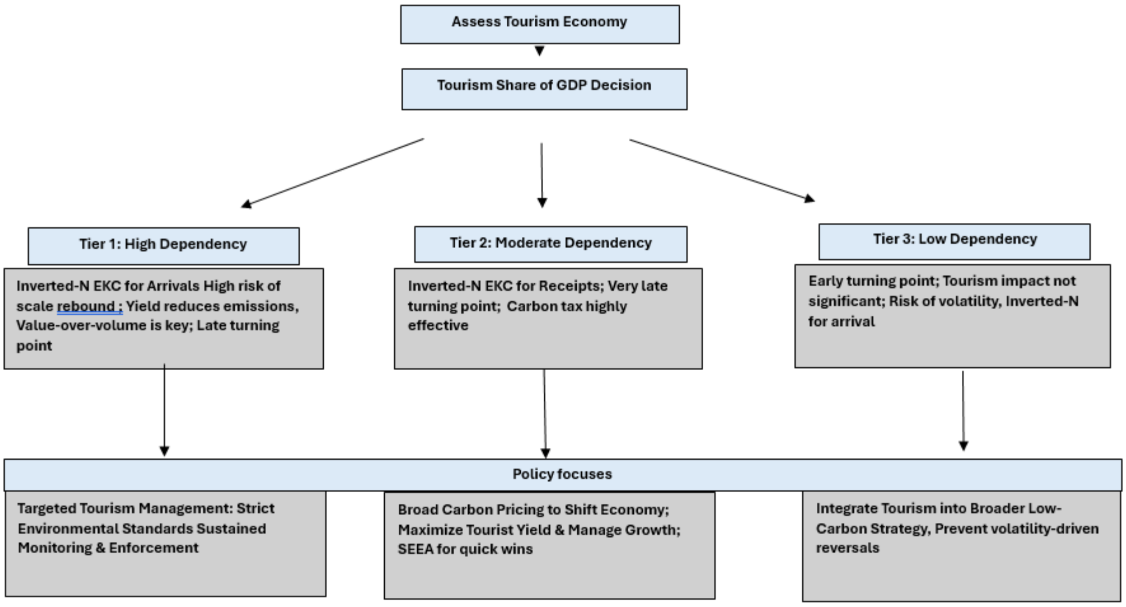
For Tier 3 with low dependency: the goal is to protect early gains from being reversed by volatile growth. These countries start with foundational measurement and steady enforcement including light-touch SEEA, basic standards, routine audits, and scale high-value/low-volume niches such as certified nature/culture to avoid arrival-driven rebounds.

8. Conclusion

Our tiered dependency framework shows that heterogeneity masked in conventional EKC work matters: the same policy instrument performs differently across contexts. Separating tourism volume from tourism value identifies a concrete lever for decoupling, volume tends to raise emissions, while value mitigates them. Policy-wise, the roadmap is tier-specific. In high-dependency destinations, late turning points and arrivals-driven rebound risks call for statutory SEEA-style reporting, in moderate-dependency settings, where peaks arrive late and receipts can flip to inverted-N under capacity strain, a forward carbon-pricing path with revenue recycling, In low-dependency economies, early turning points must be protected.

Several limitations warrant acknowledgment. First, policy variables such as SEEA adoption and carbon tax implementation are captured using binary or proxy indicators, which may not fully reflect differences in enforcement rigor or policy design quality. Future research could address this by constructing composite indices that account for policy scope, enforcement strength, and actual outcomes.

Figure 2-Tiered Tourism Decarbonisation Roadmap



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Appendix

Appendix A

Table 1 Tourism Dependency Countries

Tier 1 - High > 10%			**Tier 2 - Moderate 3%-10%**			**Tier 3 - Low <3%**		
Country	**Share of Tourism in GDP**	**Carbon emission per capita**	**Country**	**Share of Tourism in GDP**	**Carbon emission per capita**	**Country**	**Share of Tourism in GDP**	**Carbon emission per capita**
Albania	15.770%	1.673	Australia	3.440%	16.316	Algeria	0.070%	4.155
Armenia	11.400%	2.164	Azerbaijan	4.160%	3.733	Angola	0.560%	0.681
Aruba	62.110%	7.732	Bhutan	4.390%	2.117	Argentina	1.260%	3.969
Bahamas	31.880%	6.350	Bosnia & Herzegovina	5.980%	6.220	Bangladesh	0.110%	0.575
Cape Verde	25.180%	1.226	Bulgaria	7.040%	6.059	Belarus	2.000%	6.581
Croatia	19.480%	4.473	Comoros	6.080%	0.396	Belgium	1.970%	8.675
Cyprus	12.390%	5.708	Costa Rica	6.650%	1.540	Bolivia	2.390 %	1.937
Fiji	24.700%	1.482	Egypt	4.470%	2.406	Brazil	0.330%	2.282
Georgia	20.130%	2.867	El Salvador	6.190%	1.214	Burkina Faso	1.080%	0.268
Jordan	15.200%	2.319	Ethiopia	3.700%	0.149	Colombia	2.100%	1.893
Lebanon	16.890%	4.428	Gambia	8.660%	0.289	Cuba	2.560%	2.008
Macao	74.740%	1.807	Hong Kong	9.010%	5.597	Ecuador	2.130%	2.310

Maldives	55.380%	4.087	Hungary	6.230%	5.032	Finland	2.230%	7.686
Mauritius	14.020%	3.515	Kyrgyzstan	7.560%	1.393	Germany	1.480%	8.495
Panama	10.110%	3.100	Laos	5.200%	2.636	Guatemala	1.590%	1.129
Portugal	10.240%	4.600	Luxembourg	8.080%	15.741	Honduras	2.230%	1.128
Saint Vincent and Grenadines	28.000%	2.145	Malaysia	6.080%	8.368	India	1.120%	1.881
Seychelles	33.070%	5.045	Moldova	4.490%	1.765	Indonesia	1.640%	2.399
Thailand	11.830%	3.941	Mongolia	4.260%	14.617	Italy	2.570%	5.648
Tonga	11.550%	1.525	Morocco	7.720%	1.898	Japan	0.960%	8.725
Vanuatu	31.500%	0.565	Myanmar	3.330%	0.639	Kazakhstan	1.610%	14.331
			Namibia	3.600%	1.599	Kenya	1.760%	0.387
			Philippines	3.040%	1.295	Mexico	1.980%	3.723
			Sri Lanka	5.240%	0.948	Mozambique	2.090%	0.238
			Tanzania	4.300%	0.277	Nepal	2.340%	0.449
			Togo	3.780%	0.274	Netherlands	2.550%	8.691
			Tunisia	6.400%	2.556	Niger	1.010%	0.110
			Turkey	5.440%	4.718	Norway	1.720%	8.002
			Uganda	3.960%	0.134	Paraguay	1.080%	1.248
			Uruguay	3.750%	1.887	Poland	2.610%	8.312
			Vietnam	3.540%	3.490	Romania	1.680%	3.921
						Russia	1.020%	11.636
						Switzerland	2.950%	4.281
						Trinidad and Tobago	2.020%	27.465
						Ukraine	1.690%	4.937
						United States	1.110%	15.578
						Uzbekistan	2.500%	3.289
						Zimbabwe	1.110%	0.672

Appendix A: Table 2 Descriptive Statistics

Variable	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**
		Global			
Tourism Arrivals	2,407	10,500,000	24,000,000	5,600	183,000,000
Tourism Revenue per Capita	2,091	1,233.53	4,627.72	0.43	73,738.34
Annual CO_2 Emissions per Capita	2,436	4.39	5.03	0.05	33.98
GDP per Capita	2,436	13,245.65	19,339.46	110.46	123,733.00
Energy Consumption	2,436	24,953.91	30,430.54	105.11	188,294.00
Population Density	2,436	436.56	1,952.06	1.54	21,530.0
Renewable Energy	2,436	4,727.84	13,079.03	0.00	15,3271.30

Consumption					
SEEA	2,058	0.51	1.04	0.00	4.00
Carbon Tax Dummy	588	0.35	0.48	0.00	1.00
Tier 1					
Tourism Arrivals	434	6,212,151	11,900,000	38,000	60,000,000
Tourism Revenue per Capita	242	6,001.45	12,162.15	124.70	73,738.34
Tourism Revenue per Arrival	403	705.59	1,064.02	5.59	6,675.20
Annual CO_2 Emissions per Capita	441	3.72	4.38	0.33	29.20
GDP per Capita	441	11,147.13	13,141.96	603.30	90,874.20
Energy Consumption	441	19,471.10	13,461.96	1,595.11	62,959.14
Population Density	441	1,120.12	4,003.93	15.28	21,530
Renewable Energy Consumption	441	1,051.38	1,730.54	0.00	7,738.67
SEEA	357	0.40	0.94	0.00	4.00
Carbon Tax Dummy	21	0.62	0.50	0.00	1.00
Tier 2					
Tourism Arrivals	668	6,509,474	11,400,000	5,600	65,100,000
Tourism Revenue per Arrival	651	632.80	1,662.31	1.23	10,856.76
Tourism Yield	648	1,201.53	1,406.04	11.88	14,349.02
Annual CO_2 Emissions per Capita	672	3.57	4.83	0.05	25.95
GDP per Capita	672	10,436.75	21,269.97	110.46	123,724.30
Energy Consumption	672	16,909.85	20,147.62	288.00	113,106.20
Population Density	672	322.90	1,155.85	1.54	7,150.38
Renewable Energy Consumption	672	2,689.06	3,454.72	0.00	22,311.58
SEEA	567	0.45	1.01	0.00	4.00
Carbon Tax Index	105	0.10	0.31	0.00	1.00
Tier 3					
Tourism Arrivals	785	14,600,000	30,200,000	39,000	183,000,000
Tourism Revenue per Capita	751	111.68	233.12	0.43	1,460.32
Tourism Yield per Arrival	740	811.12	615.16	22.43	3,386.97
Annual CO_2 Emissions per Capita	798	5.34	5.94	0.05	33.98
GDP per Capita	798	8,052.01	16,555.50	2.21	103,532.60
Energy Consumption	798	28,367.18	31,752.44	270.00	165,583.00
Renewable Energy Consumption	794	4,121.12	10,736.48	14.13	78,168.97
Population Density	798	138.63	208.78	5.74	1,277.55
SEEA	735	0.62	1.16	0.00	4.00
Carbon Tax Index	273	0.40	0.49	0.00	1.00

Appendix A: Table 3 Data source

Variable	Measurement	Source
Per capita CO_2 emissions	CO_2 emissions per capita (tonnes)	World Bank
Tourism arrivals	International tourism, number of arrivals	World Bank

Tourism receipts	International tourism, receipts (US$)	World Bank
Energy consumption	Energy use (kg of oil equivalent per capita)	World Bank
Renewable energy consumption	Calculated using % of total final energy consumption (converted to kg of oil equivalent per capita)	World Bank
Output	GDP, current US$	World Bank
Population density	People per sq.km of land area	World Bank
SEEA	Ecosystem accounts value (composite score)	Our World in Data
Carbon tax status	Binary data	Our World in Data

Appendix A Table 4: Sensitivity analysis of Tourism-extended EKC

Tier	Arrivals	Receipts pc	Yield
Global	—	Inverted-U	Inverted-U
Tier 1	Inverted-N	Inverted-U	—
Tier 2	Inverted-N	Inverted-N	-
Tier 3	Inverted-N	-	Inverted-N

Appendix A Figure 1: SEEA-Tourism and carbon emissions across the tiered countries