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Article

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The Impact of Economic Complexity, Usage of Energy, Tourism, and Economic Growth on Carbon Emissions: Empirical Evidence of 102 Countries

Aniqa Arslan[1], Arslan Qayyum[2], Mosab I. Tabash[3]*, Kiran Nair[4], Muhammad Asad Ullah[5], Linda Nalini Daniel[5]

[1]Shaheed Benazir Bhutto University, Pakistan, [2]Institute of Business Management, Karachi, Pakistan, [3]Al Ain University, Al Ain, United Arab Emirates, [4]Abu Dhabi University, United Arab Emirates, [5]Institute of Business Management, Pakistan, [5]Higher Colleges of Technology, Abu Dhabi, United Arab Emirates. *Email: mosab.tabash@aau.ac.ae

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ABSTRACT

This study tries to investigate the impact of economic complexity, usage of energy, tourism, and economic growth on carbon emissions. Economic complexity, economic growth, air travel, and renewable and non-renewable energy consumption have all been the subject of several studies looking at environmental impact on humans. In light of the Environmental Kuznets Curve concept, it is critical to re-evaluate environmental challenges in today's complex economy. For this purpose, we took the data of 102 countries ranging from 1994 to 2018 and divided such countries into low-income and high-income groups on the basis of GDP per capita. This study applied static models such as pooled, random, and fixed effects. In addition to that, it also applies dynamic model i.e. step-wise system GMM approach for testing the individual and combined effects by controlling for endogeneity. Our results show that tourism has positive and significant impact on carbon emissions. Moreover, the effects are more pronounced for high-income groups. Economic complexity has negative and positive effect on carbon emissions for high-income groups and low-income groups respectively. Moreover, GDP has negative and positive effect on carbon emissions for low-income groups and high-income groups. Our results are consistent by using step-wise system GMM and are robust in nature. Hence, static and dynamic models provide same results with minor differences. This study divides the 102 countries into low-income and high-income groups on the basis of their GDP per capita. It applied static and dynamic models for checking the impact of ecological footprints, economic complexity index, and air travel on environment by supporting Environment Kuznets Curve.

Keywords: Economic Complexity, Usage of Energy, Tourism, Economic Growth, Carbon Emissions
JEL Classifications: O44, Q01, Q57

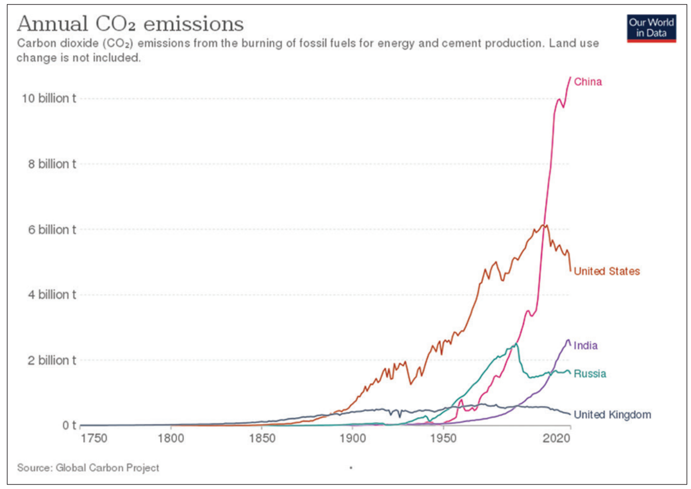
1. INTRODUCTION

Renewable capacity of Earth is used each year, while at the same time, we consume resources that have been built up over time and accumulate garbage in environment. This is the paradox of humanity's current situation (Abbasi et al., 2020). Our future ability to collect resources at the same rate will be hampered by this process, which could result in ecological overshoot and ecosystem collapse. Several factors such as energy consumption, environmental deterioration, and ecological footprints (Ulucak and Lin, 2017) effect environment by incorporating adjustments to biophysical conditions and economic systems. Tourism and foreign travel, as well as economic intricacy and energy use, accounted for most of the developments in an economic system. Tourism plays a vital role in the development of economic growth. China, for instance, has begun to employ tourist attraction strategies like simplified immigration controls to encourage inbound foreign travel, which creates jobs and strengthens China's and Japan's lacklustre economies, respectively. According to UNWTO predictions, tourism is expected to climb by 3.3% annually between 2010 and 2030, reaching 1.8 billion in that year, even if tourism benefits an economic growth (Destek, 2020) and long-term development objectives, it is responsible for around 8% of the world's global carbon emissions, due to the demand for accommodation, conveyance, and growth in food supply and leisure activities (Abbasi et al., 2021; Sharif et al., 2019; Adedoyin et al., 2020). Many countries establish tourism as a local leading industry, resulting in high investment in industry of tourism. Nevertheless, tourism rapidly increases carbon emissions. Tourism accounted for 8% of global greenhouse gas emissions in 2013 (Chen et al. 2018). Moreover, by 2025, the worldwide carbon footprint of tourism will have increased by 40%, with CO_2 emissions exceeding 6.5 billion tonnes. China now has the world's most tourists i.e. 60.74 million international overnight visits and 5 billion domestic tourists in 2017. The scope of national tourism operations will develop in tandem with the rapid growth of national tourism demand, transportation convenience, and consumption. Promoting reduced tourism-related carbon emissions has become a primary concern now a day under sustainable development goals (Huang et al., 2021).

Human-caused greenhouse gas emissions amplify the warming effect, resulting in global warming. The large percentage is carbon dioxide produced by the combustion of fossil fuels such as coal, oil, and natural gas. Coal in China and huge oil and gas industries, many of which are state-owned by OPEC and Russia, are the largest polluters. Carbon dioxide levels in the atmosphere have increased by around 50% over pre-industrial levels as a result of sapient emissions. Electricity production and transportation are significant emitters, with fuel power plants accounting for 20% of carbon emissions. Additionally, deforestation and other land use changes emit carbon dioxide and methane. Agriculture is the primary source of anthropogenic methane emissions, followed by natural gas venting and fugitive emissions from the fossil-fuel industry (Ozturk, 2017). Livestock is the primary generator of agricultural methane. Nitrogen is emitted by agricultural soils in part as a result of fertilisers. Similarly, gases emitted by refrigerants account for a disproportionate share of overall human emissions. At present emissions rates of approximately six and a half tonnes per person per year, temperatures may have increased by 1.5°C (2.7°Fahrenheit) over pre-industrial levels by 2030, which is the maximum limit by the G7 and the ideal target set by the Paris Agreement (Figure 1).

Economic complexity also adds to the acceleration of environmental deterioration or pollution, as measured by this index (Balsalobre-Lorente et al., 2022; Hidalgo, 2021). Economic complexity, like classical economics, emphasises the duality of economic inputs and outputs. The economic complexity technique uses really well data from a large number of economic actions to discover both abstract production elements and how they combine into thousands of products Bashir et al. (2022). This is achieved by reducing the dimensionality of data such as product exports, employment by industry, or patents by technology Chu et al. (2023). These methods, which are connected to matric factorization and are common in machine learning, can be used to estimate a location's potential for diversity and growth (Hidalgo, 2021). Using economic complexity, major financial institutions dispersed across regions, cities, and even nations may get a complete picture of their productive potential. It aims to explain how economic activity in cities, countries, or a specific region reflects the ability of people to grow. Their productivity is also influenced by factors such as economic expansion, urbanisation, and population growth. In spite of the overwhelming evidence that economic complexity is crucial to lowering environmental emissions, economic complexity has an economic disadvantage in terms of environmental deterioration, such as growing carbon emissions (Baloch et al., 2021; Shahzad et al., 2021).

Figure 1: Annual carbon emissions



The total amount of energy used in manufacturing, commercial, and residential operations is also included in the definition of energy consumption. However, an upsurge in carbon dioxide emanations may occur as a result of an increase in energy use. Carbon emissions from non-sustainable/renewable sources are directly linked to the amount of energy consumed Destek et al. (2020). Emissions must be reduced without affecting economic growth in order to lift energy stream and productivity, while enhancing energy conservation programmes to reduce energy waste (Nguyen et al., 2021; Dogan and Ozturk, 2017). Travel and tourism to other countries has a significant impact on global carbon emissions, but so does energy use. During this time period, energy consumption grew and carbon emissions rose until 2017, when the latter decreased somewhat for Kuwait. Even when energy usage rose or fell, international travel climbed steadily between 2009 and 2018. As the economy of a country develops, ecological deprivation lingers to growth until it reaches a particular degree of expansion, at which time it begins to decrease. As shown by Kuznets hypothesis economic complexity is critical. Economic growth makes it possible for governments to invest in renewable energy and financial prosperity, which in turn helps to mitigate environmental damage (Shahbaz et al., 2020; Adedoyin et al. 2020).

This study is different from the previous in the sense that it uses static and dynamic models for panel data analysis. Pooled, random, and fixed effects were used for static models, whereas, step-wise system GMM was used for dynamic panel data analysis in both low-income and high-income countries. Hence, we will check the application of Kuznets Curve by using static and dynamic models.

This study evaluates the environmental implications of the economic complexity index, foreign travel or tourism, and energy consumption in various countries; that is, how and whether they contribute to environmental degradation. Understanding how and whether or not these indicators are a factor in environmental degradation is critical.

Following are the remaining sections: Section-II presents existing literature. The data and methodology are discussed in detail in Section-III. The findings are discussed in Section-IV. Section-V concludes and presents policy implication with direction for the future.

2. LITERATURE REVIEW

Economic complexity is a measure of the prolific ability of large economic systems (usually areas, regions, or countries) known as "economic complexity index." Developed and fast-developing countries have higher economic complexity indices than less developed countries, indicating greater economic progress. The economic complexity index includes a wide range of economic activities, and while this can be useful as an indicator of economic growth, it can also be a sign of environmental congestion and pollution. In the meantime, Dogan et al. (2019) conducted analyses for countries at various phases of development to determine whether economic complexity contributes to environmental degradation (Nathaniel, 2021) and found an important influence on the ecology is exerted by economic complexity index, which fluctuates across the nations. When the economic activities connected with economic complexity are taken into account, environmental degradation in low- and middle-income countries is exacerbated. Low and middle-income countries need to change their existing industrial strategies to boost economic growth and also at the same time preserving the environment and sustainability.

In a similar spirit, Can and Gozgor (2017) and Can and Ahmed (2023) examined the effect of economic complexity on France's greenhouse gases using the country as a case study. Along with verifying the Kuznets curve ecological relevance, it was observed that increasing economic complexity index results in decreasing carbon dioxide emissions. To maintain the focus on reducing carbon dioxide emissions and environmental damage, as this data demonstrates, considerable environmental policy actions are required Shahbaz et al. (2020). Renewable and non-renewable energy consumption in African countries (Rafindadi and Usman, 2019) was disaggregated using a carbon-income function while accounting for trade (Nathaniel, Murshed, and Bassim, 2021) and financial development by Nathaniel and Iheonu (2019). Whereas the dependence on fossil fuels increases CO_2 emissions, renewable energy sources have a negligible effect on their reduction in Africa. Shahzad et al. (2021) conducted an additional study into the relationship between economic complexity, energy use, and ecological footprints. For the 1st time, they discovered that economic complexity and the use of fossil fuels significantly contribute to the growth of ecological footprints. Carbon emissions have grown as a result of increased economic activity and the use of fossil fuels. Because fossil fuels are recognised to be non-renewable and harmful to environment, a move away from their use is necessary. A paradigm change in favour of renewable energy innovation is therefore essential for both economic development and environmental quality around the world. According to Gonzalez et al. (2019), the transition to economic complexity in developing nations has been studied using a multi-criteria approach, with an emphasis on determining which sectors of an economy contribute most to economic complexity. The rise of the wood sector needs a more complex economy, which will attract landowners and promote improved forest management services, thus reducing deforestation rates caused by a high demand for timber as an energy source.

Energy use and environmental impact are all linked to international travel. Energy consumption is a necessary part of economic growth and economic activity. According to this theory, use of electricity is essential to economic growth and can result in greenhouse gas emissions, which can have a negative effect on environment. Fossil fuel energy consumption, GDP, urbanisation, and trade openness all contribute to long-term carbon dioxide emissions and consequent environmental deterioration (Al-Mulali et al., 2016). However, the long-term reduction of air pollution can only be achieved by financial degradation. For instance, Pao and Tsai (2010) observed the link amid energy consumption, carbon emissions and economic growth. They found that energy use and carbon emissions have a bidirectional causal link, as does energy consumption and production. Carbon emissions must be reduced as the economy continues to grow through increasing investments in energy supply and lowering wasteful consumption of energy. Zhang et al. (2019) found that industrial output accounts for more than 80% of carbon emissions, whereas emanations through energy-savvy industries account for around 40% of total carbon dioxide emissions China. They further noted that carbon dioxide emissions are largely driven by the expansion of the global economy, while changes in industrial structure and population growth have had only a small impact.

Carbon emissions from renewable and non-renewable energy sources were compared in Hanif et al. (2019), who found that renewable energy consumption reduces carbon emissions whereas non-sustainable energy use increases them. Carbon footprints are characterized by excessive energy consumption, resource scarcity, and demographic change (Danish, 2019 and Destek, 2020). When countries strive to reduce carbon emissions and promote carbon-free economic growth, a shift from non-renewable to utilization of renewable energy channels is unavoidable. Increased investment in clean energy projects and regional collaboration in reducing carbon emissions are both crucial. According to Adams and Nsiah (2019), GMM and completely modified ordinary least squares algorithms can be used to determine if renewable energy adds to carbon diminutions. The empirical results indicated that long-term emissions of carbon dioxide are caused solely by non-renewable energy consumption, not by either renewable or non-renewable energy consumption. Inglesi-Lotz and Dogan (2018), for example, found that reducing carbon emissions through increased use of renewable energy is more effective than increasing non-renewable energy use. For Adedoyin et al. (2020), while economic policy uncertainty has a short-term beneficial effect on climate change, it creates an undesirable aura in the long haul. According to Tang et al. (2017) increasing the number of tourists and the amount of tourism-related output leads to an increase in the amount of carbon emissions. Sun (2016) demonstrated the dynamic behavior of the interaction between technological efficiency, economic growth, tourism, and carbon emissions through the deconstruction of tourism greenhouse gas emissions. He noted that scientific advancements can't keep up with the rate of emissions from tourism. There is also a need for government aid because tourism-related industries, such as air and land transportation, have lagged behind other sectors when it comes to improving energy efficiency Shahbaz et al. (2022). A decrease in tourist-related carbon efficiency can be seen in countries like Taiwan, where carbon emissions from the tourism industry are on the rise. Paramati et al. (2017) found that economic growth and an increase in carbon dioxide emissions are bolstered by tourist spending. In order to accomplish both economic growth and environmental quality, strategies to manage the emissions linked with tourism will be necessary, as this shows that tourism is vital for growth.

Khan et al. (2019), on other hand, examined the relationship between international travel, financial development, renewable energy, and greenhouse gas emissions. They found the presence of one-way causality between financial development and greenhouse gas emissions is found to exist in Asia and the United States, Europe and the rest of the world. Furthermore, in Europe, tourism and renewable energy have a one-way causal relationship, while in the United States, tourism and renewable energy have a one-way causal association (Alola, 2019; Cop 2020). The diversity in causation between locations shows the significance of adjusting government programmes to each region's specificities. In order to ensure that renewable energy is given the attention it deserves, a separate organisation devoted solely to it must be established. Governments should provide low-interest and subsidised financing for environmentally-friendly projects to ensure effective use of energy. The use of ecologically friendly transportation methods, the expansion of service areas, and the promotion of environmentally friendly products via print, electronic, and social media are also crucial in boosting environmentally friendly tourism. There are many ways in which educational curriculum might incorporate environmental sustainability. The environmental impact of economic complexity, foreign travel and tourism, and energy consumption may be quantified by looking at how much of each of these variables contributes to the destruction of the environment. Determine how these factors affect emissions and how they may be maintained economically while fostering growth in the economy. To the best of our insight, economic complexity, tourism, natural resources, and energy use have not been studied together for the two World Bank income classes. The findings of this study show that these features have a clear correlation.

3. THEORETICAL FRAMEWORK, EMPIRICAL MODEL AND DATA

From the existing literature, we deduce that energy consumption, economic complexity, travel, growth, and natural resources can have a direct relationship with carbon emissions. Moreover, three interaction terms can also be analyzed to see their combined effect on greenhouse gases i.e. (a) the combined effect of economic complexity and energy consumption (Khan et al., 2019; Hidalgo, 2021). (b) The joint effect of economic complexity and air travel or tourism (Nathaniel and Iheonu, 2019; Hidalgo, 2021), and (c) The collective effect of economic growth and air travel (Sun, 2016; Hidalgo, 2021). All the above mentioned relationships can be examined as mentioned in conceptual framework as framed in Figure 2.

Following theoretical framework, we model a general carbon emissions function by including mentioned determinants of carbon emissions. Although the Kuznets curve has been widely examined in the literature, this study extends the concept by including the following:

$$CPC = f\,(ECI, EU, NR, AIR, GDP) \tag{1}$$

With the use of summary statistics and pairwise correlations for the relevant variables in equation-1, we were able to perform the analysis setting out in the equation.

ECI is an index of economic complexity, EU is energy consumption in log form, NR is log of natural resources; AIR is log of air travel, and whereas CPC is carbon emissions per capita in log form; and LGDP is economic growth per capita in log form. All of these variables have been collected from different data sources and their measurement have been described in Table 1. The model includes dummy entities, and I is their n-1 coefficients. The two income groups and the combined group are evaluated using equation two. The fixed effect model only looked at the intercept differences between the entities because it didn't include any dummy variables (Wooldridge, 2015). The error factor of the country is ignored. It was intended to study the real-world mechanisms through which people and organisations change. For this purpose, this study took the data of from different indicators of World Bank which was unbalanced panel in nature. The WDI (World Development Indicators) have divided the countries into high-income and low-income countries on the basis of different indicators such as GDP per capita. This study took into account these two stream of countries and applied mentioned-below empirical techniques on them separately for comparison.

Table 1: Description of variables

Symbol	Variable	Data source	Measurement
CPC	Carbon emissions per capita	World development indicator	Metric tons per capita
ECI	Economic complexities Index	ATLAS dataset	Index values
EU	Energy usage	World development indicator	Usage in tera joule
NR	Natural resources	World development indicator	Rents of oil, gas, coal, mineral, forest
AIR	Air travel	World development indicator	Number of passengers
GDP	Gross domestic product	World development indicator	GDP in US $

4. EMPIRICAL APPROACH

For empirical purpose, we apply pooled OLS, fixed effect, and random effect which are static in nature. It is the dynamic ARDL model (system GMM) that accounts for heteroscedasticity, endogeneity and dependent variable measurement error when evaluating serial correlation (Arellano and Bond, 1991). There are no fixed- or random-effects properties in pooled OLS, therefore the model does not account for individual and/or temporal influences on regressors' intercepts and/or slopes. Air travel, energy consumption, economic complexity, coal rents, and economic growth all play a role in determining how much CO_2 emissions are emitted. The following model is used for analysis:

$$LCPC_{it} = \beta_{0i}+\beta_{1i}\ ECI_t+\beta_{2i}\ LEU_t + \beta_{3i}\ LNR_t+\beta_{4i}\ LAIR_t+\beta_{5i}\ LGDP_t+D_{in\text{-}1}+\varepsilon_i \quad (2)$$

When the country (or income bracket, in this case) effect is included in the regression, dummy variables are included, as a result, the pooled OLS becomes least squares dummy variables (LSDV). The error term ε_i is used to describe each variable's customary interpretation. The individual and group errors can be studied in the random-effects models, which incorporate both between-entity and within-entity error variances (time component error). This study used the following three static models for analysis i.e.

Pooled effect:

$$LCPC_{it} = \beta_{0i} + \beta_{1i}\,ECI + \beta_{2i}\,EU + \beta_{3i}\,NR + \beta_{4i}\,AIR + \beta_{5i}\,GDP + \beta_{6i}\,ECI{*}\,EU + \beta_{7i}\,ECI{*}\,AIR + \beta_{8i}\,AIR{*}GDP + \varepsilon_i \quad (A)$$

Fixed effect:

$$LCPC_{it} = \beta_{0i} + \beta_{1i}\,ECI + \beta_{2i}\,EU + \beta_{3i}\,NR + \beta_{4i}\,AIR + \beta_{5i}\,GDP + \beta_{6i}\,ECI{*}\,EU + \beta_{7i}\,ECI{*}\,AIR + \beta_{8i}\,AIR{*}\,GDP + \mu i\ (dummy)\ n\text{–}1 + \varepsilon_i \quad (B)$$

Random effect:

$$LCPC_{it} = \beta_{0i} + \beta_{1i}\,ECI + \beta_{2i}\,EU + \beta_{3i}\,NR + \beta_{4i}\,AIR + \beta_{5i}\,GDP + \beta_{6i}\,ECI{*}\,EU + \beta_{7i}\,ECI{*}\,AIR + \beta_{8i}\,AIR{*}\,GDP + \textstyle\prod_i + \varepsilon_i \quad (C)$$

However, the static model does not take into account slope variability, endogeneity or serial correlation in its equations. Through the use of instrumental variables, System-GMM enables the introduction of endogenous design into the model. The term "endogeneity" refers to a correlation between the error term and the dependent variable that is causally linked to the model's variables (Wooldridge, 2013). For this purpose, endogeneity can be characterised as the impact of historical events, together on the model's dependent variable and its autonomous variables, or as the time-dependent causal relationship between the regressors and the explanatory variable itself. Using a dynamic model makes sense when the variable to be studied is influenced by its prior realisations. The following four models were used for testing step-wise GMM.

$$LCPC_{it} = \beta_{0i} + \beta_{1i}\,CPC_{t\text{-}1} + \beta_{2i}\,ECI_{t\text{-}1} + \beta_{3i}\,LGDP_{t\text{-}1} + \beta_{4i}\,ECI{*}\,EU + \beta_{5i}\,ECI{*}\,AIR + \beta_{6i}\,AIR{*}\,GDP + \varepsilon_i \quad (3)$$

$$LCPC_{it} = \beta_{0i} + \beta_{1i}\,CPC_{t\text{-}1} + \beta_{2i}\,LEU_{t\text{-}1} + \beta_{4i}\,LGDP_{t\text{-}1} + \beta_{4i}\,ECI{*}\,EU + \beta_{5i}\,ECI{*}\,AIR + \beta_{6i}\,AIR{*}\,GDP + \varepsilon_i \quad (4)$$

$$LCPC_{it} = \beta_{0i} + \beta_{1i}\,CPC_{t\text{-}1} + \beta_{2i}\,LAIR_{t\text{-}1} + \beta_{3i}\,LGDP_{t\text{-}1} + \beta_{4i}\,ECI{*}\,EU + \beta_{5i}\,ECI{*}\,AIR + \beta_{6i}\,AIR{*}\,GDP + \varepsilon_i \quad (5)$$

$$LCPC_{it} = \beta_{0i} + \beta_{1i}\,CPC_{t\text{-}1} + \beta_{2i}\,LNR_{t\text{-}1} + \beta_{3i}\,LGDP_{t\text{-}1} + \beta_{4i}\,ECI{*}\,EU + \beta_{5i}\,ECI{*}\,AIR + \beta_{6i}\,AIR{*}\,GDP + \varepsilon_i \quad (6)$$

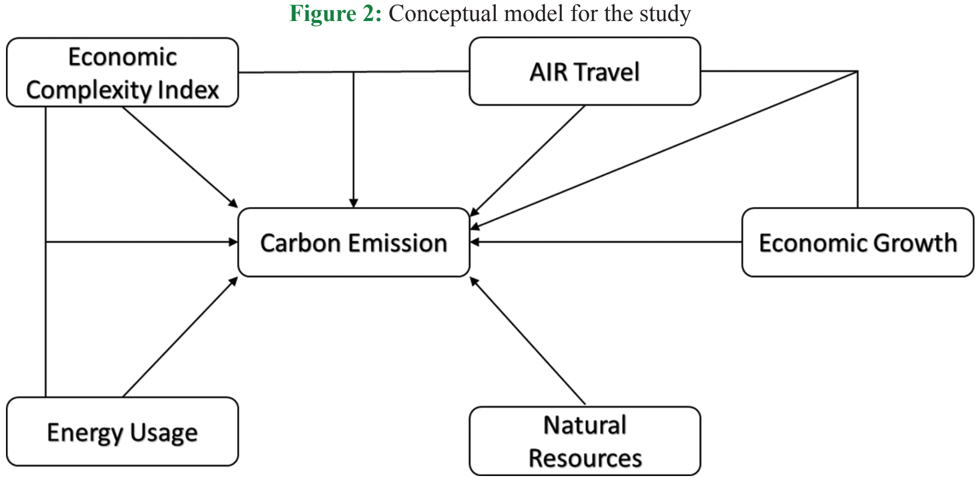
5. EMPIRICAL RESULTS AND THEIR DISCUSSION

Table 2 presents descriptive statistics. After that, we do estimates for each of the income groups we're looking at. Finally, we

Table 2: Descriptive statistics

Variables	Obs.	Mean	SD	Min	Max
CPC	2513	4.8393	6.3448	0.0152	67.0423
ECI	2599	0.2196	0.9276	−2.6911	3.8551
EU	2503	135.3014	98.2105	32.1091	604.1602
NR	2533	0.1417	0.7301	0	20.2273
AIR	2598	15200000	52100000	0	722000000
GDP	2513	12134.43	16693.45	175.5479	61365.73

Figure 2: Conceptual model for the study



quantified the contribution of endogenous variables on carbon emissions using static models and system GMM approaches. The median real GDP per capita is $12,134.43 with a standard deviation of $16693.45. The average energy usage (as a % of GDP) is $135. Carbon emissions per capita (CPC) average $4.84, having standard deviation of $6.34 indicating that there is little variance in its observation. As a proportion of GDP, air transportation costs $1.5 billion, whereas economic index cost $0.22 billion. Compared to economic challenges (worth $0.972 billion), air travel (worth $5.2 billion) has a larger standard deviation. Table 3 reveals the correlation (correlation) between the variables. A statistically significant (P=0.05) correlation exists between real GDP per capita and CPC. All predictors, with the exception of energy usage, show a positive connection with CPC. This study applies ADF and PP unit root tests. Fortunately, both tests yield nearly identical results for determining data stationarity. All variables are significant at I (0) or I (1) in Table 4. The data must be stationary at level or maximum at first difference to proceed with the System-GMM approach as it takes first difference and level data simultaneously.

Table 5 compares the two World Bank income categories. A pooled OLS (or Least Squares dummy variables) model, a Fixed Effect model, and a Random Effect model, and GMM-model in Table 5 for the statistical analysis of the data. ECI is showing positive and significant results in all three models of pooled, fixed, and random effects for low-income groups. Lower income countries are showing a change of 1% in ECI will cause an increase of carbon emission per capita by 7%, 4.35%, and 1.62% in pooled, fixed, and random effects respectively. However, high income countries have negative and significant impact of ECI on CPC i.e. 0.318%, 0.215%, and 1.18% in three used models respectively. It is clear from this data that ECI contributes to increased atmospheric concentrations of carbon dioxide. It is important to note that high income countries create more complex structure of economy thereby moving towards greener environment. Consequently, it decreases carbon emissions in the economy. These results are evident from the past studies i.e. (Doğan et al., 2021; Pata, 2021).

EU is showing negative and significant results in all three models of pooled, fixed, and random effects for low-income groups and for high-income groups as well. Lower income countries are showing a change of 1% in EU will cause a decrease of carbon emissions per capita by 9.76%, 12.55%, and 24.12% in pooled, fixed, and random effects respectively. However, high income countries have slighter negative and significant impact of EU on CPC i.e. 7.23%, 3.53%, and 6.61% in three used models respectively. Shahzad et al. (2021) found the same thing, suggesting that increased energy use is a factor in rising CO_2 emissions. NR is showing positive and significant results in all three models of pooled, fixed, and random effects for low-income groups and for high-income groups as well. Lower income countries are showing a change of 1% in NR will cause an increase of carbon emissions by 9.85%, 5.12%, and 3.33% in pooled, fixed, and random effects respectively. However, high income countries have more positive and significant impact of NR on CPC i.e. 10.9%, 13.1%, and 14.7% in three used models respectively. These results are supported by Kwakwa et al. (2019) and Yu-Ke et al. (2022).

AIR is showing positive and significant results in all three models of pooled, fixed, and random effects for low-income groups. Lower income countries are showing a change of 1% in AIR will cause an increase of carbon emissions by 11.8%, 21.6%, and 23.4% in

Table 3: Correlation matrix

Variables	CPC	ECI	EU	NR	AIR	GDP
CPC	1.0000					
ECI	0.6528**	1.0000				
EU	−0.6464***	0.8145*	1.0000			
NR	0.5790**	0.6383**	0.5953***	1.0000		
AIR	0.8331***	0.5361**	0.5671**	0.5041**	1.0000	
GDP	0.7512**	0.3176**	0.5576***	0.7015***	0.5652**	1.0000

*P<10% **P<5% ***P<1%

Table 4: Unit root analysis

Variables	Augmented dickey-fuller test (ADF)		Phillip-perron (PP) test		Integration
	At levels	First difference	At levels	First difference	
Panel A: High-income countries					
CPC	−4.8138***	-	−5.1329***	-	I (0)
ECI	−1.6114	−9.2553***	−1.7451	−13.8731***	I (1)
EU	−1.6742	−5.2457***	−1.6523	−9.2751***	I (1)
NR	−4.0073***	-	−4.4089***	-	I (0)
AIR	−3.6396***	-	−3.7902***	-	I (0)
GDP	−1.8895	−5.7796***	−2.3040	−9.3974***	I (1)
Panel B: Low-income countries					
CPC	−2.2546	−6.6801***	−2.2012	−8.6281***	I (1)
ECI	−0.8914	−6.3065***	−1.0696	−12.5012***	I (1)
EU	−0.0454	−6.6176***	0.0864	−7.5312***	I (1)
NR	−3.1791**	-	−3.2611**	-	I (0)
AIR	−3.1884**	-	−3.8318***	-	I (0)
GDP	−3.1186**	-	−2.7246*	-	I (0)

***, **, * represents the significance levels at 1%, 5%, and 10% respectively

Table 5: Pooled, Fixed-Effect and Random-Effect Regression Analysis

Variable/country	Pooled		Fixed		Random	
	Low income	High income	Low income	High income	Low income	High income
ECI	0.0707***	−0.00318**	0.04350**	−0.00215**	0.0162*	−0.0118**
	(0.00881)	(0.0142)	(0.0137)	(0.0021)	(0.0311)	(0.0473)
EU	−0.0976***	−0.0723***	−0.1255***	−0.0353***	−0.2412***	−0.0661***
	(0.0412)	(0.0763)	(0.0726)	(0.0129)	(0.0194)	(0.1010)
NR	0.0985***	−0.109***	0.0512*	−0.1309**	0.0333***	−0.147***
	(0.00616)	(0.00537)	(0.00516)	(0.00153)	(0.0103)	(0.0141)
AIR	0.118*	0.368***	0.216**	0.306**	0.234***	0.2431*
	(0.0177)	(0.0382)	(0.0377)	(0.0040)	(0.0933)	(0.0810)
GDP	−0.273***	0.192***	−0.0230**	0.301**	−0.0906***	0.334**
	(0.373)	(0.464)	(0.517)	(0.282)	(0.0958)	(0.0427)
ECI*EU	0.0127***	−0.0309***	0.0412*	−0.0501**	0.0102**	−0.0242***
	(0.00216)	(0.00337)	(0.00146)	(0.00143)	(0.0133)	(0.0131)
ECI*AIR	0.0216*	−0.0346**	0.0215**	0.0305**	0.0235***	0.0243*
	(0.0147)	(0.0122)	(0.0357)	(0.0021)	(0.0333)	(0.0410)
AIR*GDP	0.0253***	−0.0152***	0.0430**	0.0221***	0.0506***	−0.0354**
	(0.0273)	(0.0264)	(0.0017)	(0.0022)	(0.0100)	(0.0027)
Constant	0.0497	−2.162***	0.0142*	0.909***	0.0599*	0.994**
	(0.0848)	(0.781)	(0.733)	(0.252)	(0.356)	(0.0601)
Year Dummy			yes	yes	yes	yes
R-square	0.54	0.59	0.59	0.62	0.53	0.58
Hausman (P-value)				0.0001	0.0921	

Table 6: Application of step-wise system GMM

Variables	SYS-GMM-ECI		SYS-GMM-EU		SYS-GMM-AIR		SYS-GMM-CR	
	Low income	High income	Low income	High income	Low income	High income	Low income	High income
CPC (t-1)	−0.039**	0.107***	−0.030***	0.198***	−0.0457**	0.725***	−0.0531***	1.039***
	(0.143)	(0.153)	(0.848)	(0.781)	(0.733)	(0.252)	(0.356)	(0.0601)
ECI	0.0198**	−0.0329*						
EU	(0.0190)	(0.00295)	−0.0162*	−0.0118**				
AIR			(0.0311)	(0.0473)	0.0599***	0.1958**		
NR					(0.0649)	(0.0746)	0.0500*	−0.1266***
							(0.00488)	(0.00588)
GDP	−0.318	0.1568***	−0.0416**	0.1106**	−0.1934***	0.2243*	−0.00800**	0.1481
	(0.0177)	(0.0382)	(0.0377)	(0.00400)	(0.0933)	(0.0810)	(0.0407)	(0.0283)
ECI*EU	0.0207**	−0.00218**	0.03350**	−0.0115**	0,0662*	−0.0318**	0.0113*	0.0328*
	(0.00281)	(0.0242)	(0.0437)	(0.00510)	(0.0611)	(0.0773)	(0.0877)	(0.0982)
ECI*AIR	−0.0176***	−0.0223***	−0.0355***	−0.0453***	−0.0512***	−0.0661*	−0.0273**	0.0182*
	(0.0012)	(0.0563)	(0.0526)	(0.0629)	(0.0194)	(0.0101)	(0.0473)	(0.0264)
AIR*GDP	0.0185***	−0.0109**	0.0212*	−0.0309**	0.0433**	−0.0157***	0.0167***	−0.0709**
	(0.0161)	(0.0027)	(0.0013)	(0.0143)	(0.0503)	(0.0161)	(0.0027)	(0.0038)
Constant	3.2731	7.192***	6.0230**	6.3023*	8.0906**	11.334***	10.0599*	12.725**
	(0.373)	(0.464)	(1.517)	(1.282)	(0.0958)	(0.0427)	(0.104)	(0.0128)
AR (1) P-value	0	0	0	0	0	0	0	0
AR (2) P-value	0.2188	0.3331	0.3271	0.4615	0.2051	0.2191	0.3978	0.4676
Hansen P-value	0.2881	0.2142	0.2137	0.2210	0.2311	0.2473	0.2312	0.2263

Robust standard errors are given in parentheses. *P<10%; ** P<5%; P<1%

pooled, fixed, and random effects respectively. However, high income countries have more positive and significant impact of AIR on CPC i.e. 36.8%, 30.6%, and 24.31% in three used models respectively. This is consistent with Tang et al. (2017) who found that expanding the amount of tourism industry output significantly adds to the expansion of tourism-related carbon emissions. However, air travel has a large detrimental impact on the high-income group.

These results are supported by Chapman et al. (2018) and Ciers et al. (2018). A pooled OLS (or LSDV) analysis reveals a positive coefficient for real GDP per capita. However, it shows a negative relationship with low-income level countries. As a result, for high income groups, carbon emissions rose 19.2%, 30.1%, and 33.4%, respectively, while for the low-income group, carbon emissions fell 27.3%, 2.3%, and 9.1% with a 1% increase in real GDP. It is statistically significant at the 1% level for these coefficients. The study of Zhang et al. (2019) shows that economic progress in high-income countries is linked to an upsurge in carbon emissions. However, in low-income countries, real GDP per capita coefficient has little effect on carbon emissions. It is important to note that natural resources have negative values for high-income countries and positive for low-income countries. It is indicating that high-income countries try to reduce carbon emissions by consuming more natural resources in an effective manner. However, the opposite is true for low-income level countries that do not control the usage of natural resources in efficient manner Badeeb et al. (2020). Consequently, carbon emissions increase per capita which reduces environmental sustainability.

For checking the robustness and controlling for endogeneity, we used step-wise GMM for extended analysis. In Table 6, we found that CPC of last year has a negative impact for low-income countries, however, it has positive values for high-income countries. Robust standard errors are given in parenthesis to control for heteroskedasticity. ECI for low-income group has a positive impact on CPC, however, it becomes negative for high-income group (−3.29%). EU has negative and significant impact for both low-income and high-income groups with no significant difference in their magnitudes. AIR for high income countries has more significant impact (19.58%) as compared to low-income countries (5.99%). NR for high-income countries has negative and significant effect as compared to low-income groups. Moreover, GDP has negative impact on CPC for low-income group and positive for high-income group. In sum-up, we can say that the results obtained by using GMM models support the results of static models and hence are robust in nature. Moreover, EKC was found to be true in the models, as expected.

6. CONCLUSION

Given that many economies are becoming increasingly complex, it is important to investigate how economic complexity, energy usage, and tourism affect the environmental Kuznets curve (EKC). A global examination of the human-induced implications of air travel, ECI, and energy usage, as well as economic growth and natural resource depletion, was undertaken. For this purpose, the static and dynamic models were used by taking the data of 102 countries from 1994 to 2018. Predictors of carbon emissions across World Bank income groups are firstly examined. Comparative analysis is then conducted utilising several estimation methods for the combined nations. Our findings are consistent with Nathaniel and Adeleye (2021), who found a strong correlation between environmental degradation and per capita GDP. The empirical findings showed that the nexus between economic growth and carbon emissions have negative relationship for low-income and positive association for high-income groups. Moreover, tourism is positively related with carbon emissions. However, the magnitude of the significance is greater for high-income countries. Economic complexity and natural resources usage have negative and significant relationship with carbon emissions for high-income countries. Tourism is positively related with carbon emissions. Moreover, it is more pronounced for high-income groups.

The study of Zhang et al. (2019) shows that economic progress in high-income countries is linked to an upsurge in carbon emissions. However, in low-income countries, real GDP per capita coefficient has little effect on carbon emissions. It is important to note that natural resources have negative values for high-income countries and positive for low-income countries. It is indicating that high-income countries try to reduce carbon emissions by consuming more natural resources in an effective manner. However, the opposite is true for low-income level countries that do not control the usage of natural resources in efficient manner Badeeb et al. (2020). Consequently, carbon emissions increase per capita which reduces environmental sustainability.

As predicted by the Environmental Kuznets curve, economic growth is positively affected for high-income and negatively affected for low-income groups on carbon emissions respectively. This empirical finding gives light on ways to reduce environmental carbon emissions. In sum, we can say that, static models and dynamic models provide same types of results. Policymakers and other interested parties from all socioeconomic levels should use country resources to boost GDP while limiting environmental damage and sustainability. It's clear that reducing carbon emanations and to slow-down environmental degradation will require considerable changes to current environmental policies and programmes. Economies should recognise the danger of emissions from air transport engines and try to assert better control over energy utilization in order to reduce carbon pollution.

Our empirical research led us to draw policy conclusions on how these countries may better promote long-term sustainability. The experimental results allow us to conclude that diverse sources of energy may not always be environmentally sustainable energy sources. Despite the fact that natural resources are the driving force behind the expansion of energy consumption in low-income countries, however, this is causing damage to the environment. Therefore, low-income nations require immediate strategies to reduce their reliance on natural energy sources, which will improve the quality of the environment over time.

The governments of these nations should devote a greater proportion of their resources to research and development of renewable energy alternatives that improve environmental conditions. Since globalization benefits the environment in all economies, countries like these can reduce carbon emissions by importing energy sources rather than relying on biomass for domestic energy needs.

Perhaps, economic complexity has contributed to environmental degradation in low-income nations. These nations must encourage more innovation in the direction of product specialization and structural transformation in order to produce environmentally friendly, sophisticated products. Economic complexity aids in the development of energy-efficient and environmentally friendly products. Product transformation research and innovation to increase the complexity of the manufacturing process may hasten the country's progress toward reaching sustainable development targets on clean climate change. The administrative system in these nations should formulate measures to stimulate investments into the renewable energy industry.

Improvements in governance (Palea and Drogo, 2020) are a crucial factor in this context because the findings suggest that governance reduces the rate of degradation of the environment, which is also a weakness of this study and can be researched in future. Another limitation of the current study is that it excludes various forms of energy consumption and natural resource categories that may impact the environment as well as regulations on the energy system and sustainable development. Future research may investigate the effects of various forms of energy consumption, particularly for economies such as the OECD and developing nations. The extent of degradation of the environment linked to household energy consumption could be the focus of an additional potential study direction. The broader implications of future research will suggest vital climate welfare measures, especially in the context of sustainable environment.

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