Decomposing Carbon Emissions: LMDI with Country-Specific Insights and Panel Data Analysis

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Abstract

The ongoing planetary crisis has prompted us to conduct this study, which analyzes 18 leading polluters over the period from 1995 to 2023. The countries considered are the United States of America, Mexico, and Canada in North America; India, China, Japan, Russia, and Iran in Asia; Germany, France, the United Kingdom, Poland, Italy, and Ukraine in Europe; and South Africa, Egypt, Algeria, and Nigeria in Africa. The study aims to determine the factors influencing CO2 emissions based on the improvised version of the Kaya identity, focusing on clean energy and fossil fuels. To be precise, population (POP), economic activity factor (EAF), clean energy intensity (CEI), energy transition (ET), and emission per unit of non-renewable energy (EM_NRE) are considered in the present work. Logarithmic Mean Divisa Index (LMDI) has been employed for analyzing individual countries because of the structural differences and varying energy grids. Further, a long-run relationship has been studied using long-run estimators suitable for the four panels. The results suggest that each factor impacts the level of carbon emissions differently. The panel consists of integrated economies with distinct structural differences; hence, historical economic shocks impact the nations in different ways. The result manifests that the countries must increase the share of clean energy in their power grid.

Keywords: Renewable energy, Non-renewable energy, Carbon emissions, LMDI, Kaya identity

JEL Codes: Q32, Q42, Q43, Q53

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INTRODUCTION

Extreme climatic conditions and their ripple effects can be witnessed across the globe, which has prompted world economies to frame suitable policies to bring down emissions. However, of all the greenhouse gases (GHG), researchers specifically focus on carbon emissions as they are the leading contributors to global warming (Rahman and Ahmad, 2019). From 2015 to 2017, Hanif (2018) claims that the Earth's temperature has risen by nearly 1.27 degrees Celsius. Therefore, it is crucial to understand the key drivers of carbon emissions to achieve decarbonized growth (Khan et al., 2020). An increase in urbanization, industrialization, the use of fossil fuels, and ever-increasing energy consumption leads to a rise in emissions; thus, global economies are considering several measures, both individually and collectively, to mitigate GHG emissions (Ali et al., 2021).

Decomposition and decoupling of CO_2 emissions are the two major techniques to break down its effects. Decomposition refers to the process of analyzing and breaking down the factors that contribute to carbon emissions. To put it differently, this method helps academicians understand the nuanced factors driving increases or decreases in carbon emissions (Hua et al., 2022). On the other hand, decoupling is a process that examines the association between GDP growth and CO_2 emissions. The idea is to measure whether the link between the two variables weakens or disappears, determining that economic expansion occurs naturally and gradually through reduced energy consumption (Du et al., 2022).

Thus, the present study focuses on decomposing the factors driving the carbon emissions using the Logarithmic Mean-Divisia Index (LMDI) in the selected 18 top polluters to gain country insights. For this, the traditional Kaya identity has been improvised, considering clean energy and fossil fuel energy. In addition, the current study has also employed long-run estimation techniques for the panels composed based on geographical proximity, i.e., North America, Asia, Europe, and Africa. The period of the study ranges from 1995 to 2023 for long-run analysis. The findings reveal that each factor impacts the level of carbon emissions differently. The panel consists of integrated economies with distinct structural differences; historical economic shocks impact the nations differently.

The remaining research work is structured as a review of the literature followed by research methodology, analysis and interpretation, conclusion, policy implications, and lastly, limitations and scope for future research.

REVIEW OF LITERATURE

An extensive review of the literature has been undertaken in the present research work. The section on the review of literature is of utmost importance in understanding the body of existing knowledge deeply and thoroughly. However, it is generally strenuous to identify appropriate research articles and papers. The new method of reviewing the literature, i.e., the systematic literature review, has a rigorous step-by-step procedure to be followed for including the research papers in the study, setting aside any biases.

PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) is gaining the attention of researchers worldwide. The PRISMA flowchart is used to describe the procedure that has been followed in the present research work. Systematic Literature Review, precisely, PRISMA, safeguards the practice of selective reporting and discretionary/arbitrary decisions. For the present research work, the Scopus database and the Web of Science database have been selected.

After applying the search string and appropriate inclusion criteria, the documents (933 documents and 146 documents) were retrieved from the Scopus and the Web of Science databases. The articles were checked for duplicates in both databases, and it was found that only 1 document matched in both databases. Reviewing abstracts is a vital step to ensure the purification and filtration of the research articles and the relevance of the academic literature in the review process. Thus, 222 documents and 13 documents were selected from Scopus and Web of Science, respectively. After the abstract and full-text scrutiny, 174 documents have been studied in-depth for the analysis. The list is available upon request.

The research papers were largely eliminated based on their abstracts. The abstracts focusing on water quality, specific industries, rather than a sovereign body, spatial-temporal patterns, analysis of a major event on carbon emission, emission trading system, and the impact of government policies on carbon emission are outright rejected for further review.

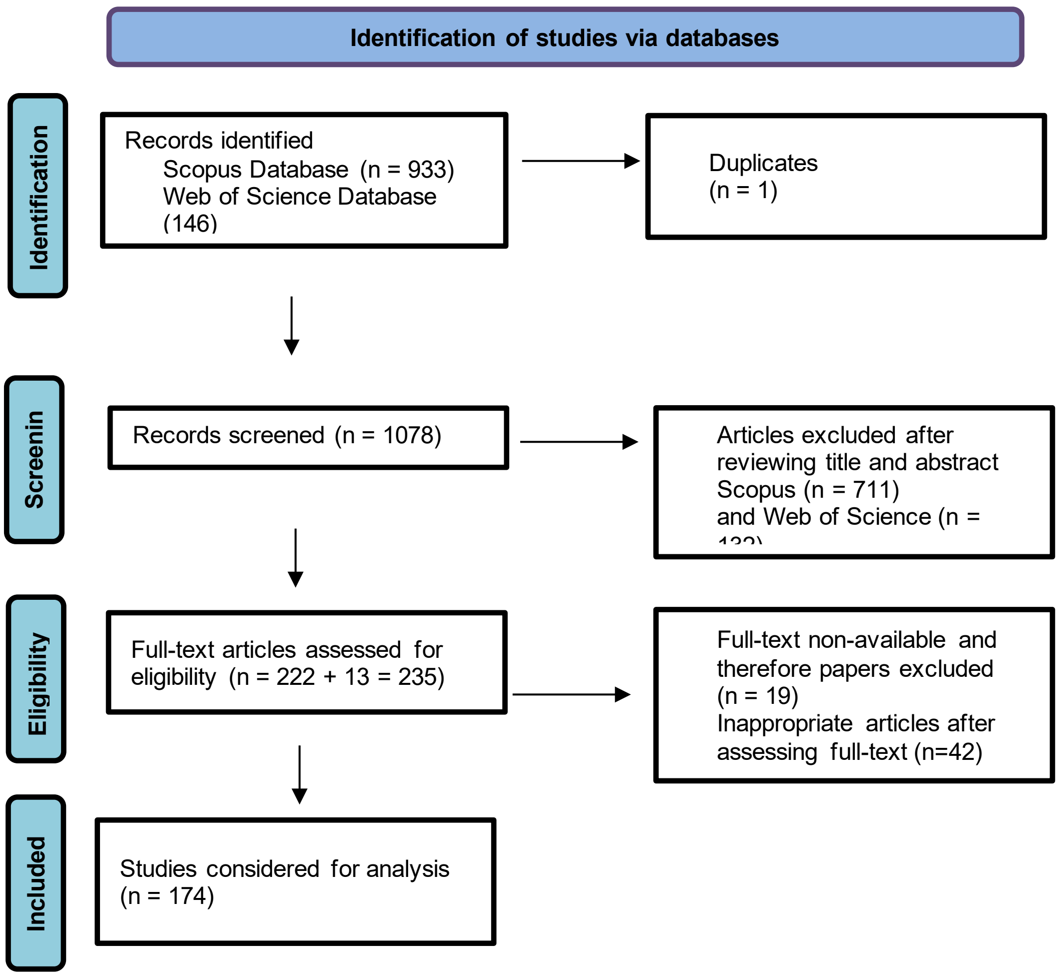
Data Extraction

A total of 235 documents with the following characteristics were selected in the data extraction phase:

1. The document must be a research article and not a conference paper, book chapters, review papers, editorials, etc.
2. The article must be in the English language.
3. The article must relate to the field of social sciences, economics, econometrics, and finance; business, management, and accounting.

4. The extracted papers are affiliated with selected carbon-emitting countries.

Flowchart 1: PRISMA



Research Gap

The environmental and economic perspectives of sustainability have been widely researched. However, amidst the ongoing planetary crisis, climate change, and international commitments, we found that the current work can add to the prior literature in a significant way. First, our study focuses on building panel data based on geographical proximity (Gonzalez-Val and Pueyo, 2019). Paramati et al. (2017) found that the emissions of one country significantly impact neighboring countries as well. Thus, creating panels based on geographical proximity is an addition to prior work. It highlights the regional differences, unlike the previous studies, which classify the sample countries based on high-income or low-income economies or some strategic international group. Diverse panels consisting of structurally different economies clubbed based on geographical proximity highlight the increasing role played by international cooperation on a global level.

Second, our study aims to determine the factors driving the emissions based on the improved Kaya identity, unlike in the previous studies focusing on the conventional form of the Kaya identity. To elaborate, we have undertaken the improvised Kaya identity focusing on renewable and non-renewable energy (RE and NRE, respectively) (Hua et al., 2022). Thus, LMDI has been applied to understand the driving factors and gain insights into individual countries. Previous studies have largely ignored a self-sufficient methodology for decomposing the driving factors of emissions, i.e., LMDI, for a long time (Ang, 2004; Pachauri, 2014). LMDI can handle zero or negative values and fully decomposes the variable without leaving any residuals.

Third, previous studies have largely concentrated on decomposing the influencing factors of emissions for specific sectors; however, the present work focuses on national-level factors (Jia et al., 2021; Du et al., 2021; Hua et al., 2022). Further, based on the suitability of the data, appropriate long-run estimation techniques have been applied to the selected four panels.

Therefore, the present study is crucial for interregional comparisons and formulating adequate policies to curb environmental deterioration.

RESEARCH METHODOLOGY

The present study aims to decompose the factors driving CO_2 emissions in the selected carbon-emitting nations during the period 1995-2023. To note, the period 1995-2023 has been considered while estimating long-run coefficients in the panel data analysis, while the period 1995-2022 has been considered while estimating LMDI. LMDI is used to gain knowledge about the background of individual countries and the impact of historical economic shocks; thus, it did not seem fit to forecast the data for one additional year. However, concerning long-run estimation, we have used a simple moving average to calculate the data point for one year, i.e., 2023. The Union of Concerned Scientists reports the top 15 polluters emitting carbon during the period 1750-2021 (Figure 1). In the current study, pre-formed international treaties or regional groups are not considered for investigating their contribution to the adverse climate situation. Keeping in view the comprehensive list published by the Union of Concerned Scientists, we have selected the countries that genuinely contribute to increasing the carbon footprint. Further, the continents of the selected countries have been identified based on geographical proximity to run the econometric tools on panel data. Further, only South Africa appears in the consolidated list published by the Union of Concerned Scientists, but to make it a panel data and comparable with other continents, we have included three more countries which are having high emissions in Africa. The highest polluting country is South Africa, followed by Egypt, Algeria, and Nigeria (Ayompe et al., 2021).

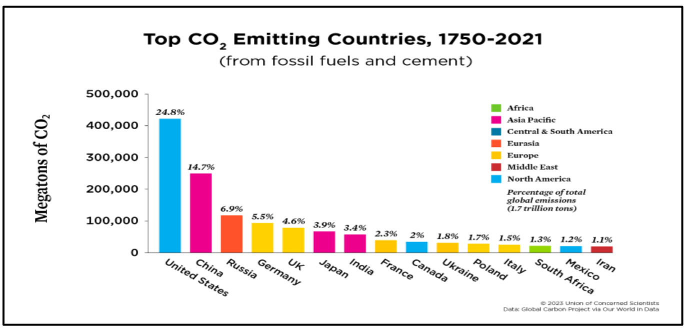


Figure 1: Top Carbon-Emitting Countries during 1750-2021
Source: 2021 Union of Concerned Scientists

Ang (2004) proposed LMDI to ascertain the driving forces that influence carbon emissions. There are two methods to quantify the factors driving energy consumption or carbon emissions: structural decomposition analysis (SDA) and index decomposition analysis (IDA)'. SDA is based on the traditional input-output model inspired by the Laspeyres method. However, it faces a lot of shortcomings because of its inability to explain high residual values in decomposing carbon emissions. LMDI is one of the two IDA methods that is widely used by researchers. Further, IDA-LMDI consists of two methods, LMDI-I and LMDI-II, which are based on additive and multiplicative approaches, respectively (Rivera-Niquepa et al., 2023).

Decomposition of factors influencing carbon emissions

The traditional kaya identity considers 'population, GDP per capita, energy intensity, and carbon intensity' (Jia et al., 2021; Du et al., 2022; and Fan et al., 2022); however, the improvised/extended version captures other relevant factors as well, for instance, 'population, economic activity factor, clean energy intensity, energy transition, and emissions per non-renewable energy' (Hua et al., 2022; Lin et al., 2015). Thus, the extended version of Kaya's identity focuses on renewable and non-renewable energy.

To elaborate, it is observed that the original Kaya identity does not differentiate between energy sources, and carbon intensity is also aggregated. For instance, a country may reduce emissions by shifting from coal to gas, but it still relies on fossil fuels. However, the extended version captures the shift in the energy portfolio from fossil fuels to cleaner, renewable alternatives. Moreover, now the data for fossil fuel use or renewable energy deployment is available, thus allowing us to conduct a more granular analysis.

The present study enhances the regional differences by employing LMDI on individual countries and examining how various events during the time period considered in the study have altered the carbon emissions from Period 0 to Period 1.

Moreover, the additive decomposition method of LMDI-I has been used. Table 1 depicts a comprehensive overview of the variables used in the study. The data related to GDP, population, renewable and non-renewable energy, and carbon emissions have been extracted from the World Development Indicators and Our World in Data. The following equations help in understanding the framework of the model used.

$$Carbon\ Emissions = POP_p * EAF_p * CEI_p * ET_p * EM\_NRE_p * \alpha_p \text{ - (Eqn. 1)}$$

$$\mathbf{C = POP * GDP/POP * RE/GDP * NRE/RE * C/NRE} \text{ (Eqn. 2)}$$

Here, 'p' denotes the respective region or province taken into consideration. Further, the carbon emissions emanating from varied levels of energy use change from period 0 (C_0) to period 1 (C_T). Therefore, we attempt to find out how much variation in carbon emission arises due to alterations in respective explanatory variables. The following equations depict the variations in carbon emissions over the period into different explanatory variables/factors.

$$\Delta\, Carbon\, Emissions\ _{POP}^{t,\ t-1} = \Sigma \frac{Carbon\ Emissions^{t} - Carbon\ Emissions^{t-1}}{\ln Carbon\ Emissions^{t} - \ln Carbon\ Emissions^{t-1}} * \ln \frac{POP^{t}}{POP^{t-1}} \text{ (Eqn. 3)}$$

$$\Delta\, Carbon\, Emissions\ _{EAF}^{t,\ t-1} = \Sigma \frac{Carbon\ Emissions^{t} - Carbon\ Emissions^{t-1}}{\ln Carbon\ Emissions^{t} - \ln Carbon\ Emissions^{t-1}} * \ln \frac{EAF^{t}}{EAF^{t-1}} \text{ (Eqn. 4)}$$

$$\Delta\, Carbon\, Emissions\ _{CEI}^{t,\ t-1} = \Sigma \frac{Carbon\ Emissions^{t} - Carbon\ Emissions^{t-1}}{\ln Carbon\ Emissions^{t} - \ln Carbon\ Emissions^{t-1}} * \ln \frac{CEI^{t}}{CEI^{t-1}} \text{ (Eqn. 5)}$$

$$\Delta\, Carbon\, Emissions\ _{ET}^{t,\ t-1} = \Sigma \frac{Carbon\ Emissions^{t} - Carbon\ Emissions^{t-1}}{\ln Carbon\ Emissions^{t} - \ln Carbon\ Emissions^{t-1}} * \ln \frac{ET^{t}}{ET^{t-1}} \text{ (Eqn. 6)}$$

$$\Delta\, Carbon\, Emissions\ {}^{t\,,\ t-1}_{EM\_NRE} = \Sigma\, \frac{Carbon\ Emissions^{t} - Carbon\ Emissions^{t-1}}{\ln Carbon\ Emissions^{t} - \ln Carbon\ Emissions^{t-1}} * \ln \frac{EM\_NRE^{t}}{EM\_NRE^{t-1}} \text{ (Eqn. 7)}$$

Table 1: Detailed Description of Variables

Abbreviations	Variables	Units
C	Total carbon emissions	Tonnes
RE	Total renewable energy consumption used	Tonnes of oil equivalent
GDP	GDP with respect to the selected country	Current US$
POP	Total population of the selected region	-
NRE	Total non-renewable energy consumption used	Tonnes of oil equivalent
EAF	Economic Activity Factor	GDP/P
CEI	Clean Energy Intensity	RE/GDP
ET	Energy Transition	NRE/RE
EM_NRE	Emissions per unit of non-renewable energy	C/NRE

Source: Authors' Computation

Interpretation of Ratios

1. GDP per Capita (EAF): It is generally assumed that as economic activity increases, production increases, and thereby energy consumption increases. This eventually leads to a rise in carbon emissions.
2. Clean Energy Intensity (CEI): CEI can have dual effects on the level of carbon emissions. First, an increase in CEI can positively increase emissions because of the large green infrastructure required for installation. Second, an increase in CEI can lower emissions because of the benefits reaped from the consumption of renewable energy at a later stage. Moreover, CEI is a result of two variables, i.e., renewable energy consumption (REC) and GDP; hence, the change in either of the two variables can alter the value of CEI. For instance, if GDP increases and REC remains negligibly unchanged, then the CEI decreases and negatively contributes to emissions. This can be interpreted as an improvement in energy efficiency.
3. Energy Transition (ET): It is a ratio of NRE consumption and RE consumption. Generally, ET negatively contributes to emissions when the share of RE increases and NRE consumption decreases. On the contrary, if a country consumes NRE sources more than RE sources, then the emissions will increase.
4. Emissions per Non-Renewable Energy (EM_NRE): The ratio is a result of CO_2 emissions and NRE consumption. If the emissions increase with respect to the consumption of NRE as compared to the prior period, then it positively contributes to emissions. On the contrary, if EM_NRE decreases, then it suggests the effective

utilization of NRE with lower emissions, thus it negatively contributes to carbon emissions.

5. Population (POP): The total population increases energy consumption and hence, emissions. However, if the population belongs to advanced nations and is aware of the available sustainable energy sources, then the emissions would be reduced.

LMDI has been analyzed for individual countries because of the structural differences and varying energy grids. It makes sense to comprehend the driving factors of the emissions for the countries individually for better clarity. However, because of the meaningful geographical proximity, a long-run relationship has been studied using long-run estimators suitable for the four panels. For instance, we have applied Driscoll-Kraay Standard Errors with Fixed Effects in North America and Africa and Generalized Least Squares in Europe and Asia. The methodology ensures robustness by addressing cross-sectional dependence and heteroskedasticity while maintaining efficiency in long-run estimation. Given that key economic differences are already modeled, adding country effects would not significantly change the conclusions and might introduce unnecessary complexity.

ANALYSIS AND INTERPRETATION

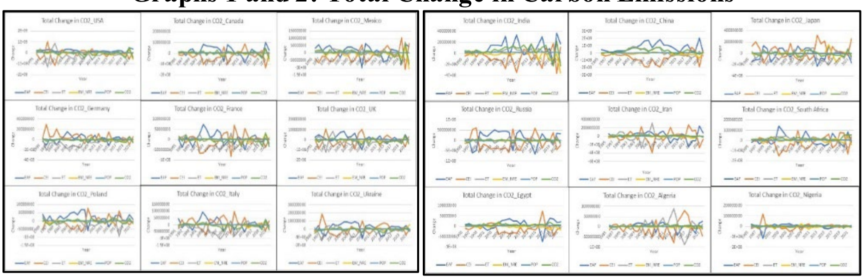
The nations possess different objectives, policies, and rules & regulations to move towards sustainable development goals. This makes the selected countries structurally different, and thus, it is well-suited to observe the driving factors of the carbon emissions emanating in the countries individually. The net-zero emission target of every country is different, and so is its blueprint to achieve the same. For instance, China aims to reduce carbon emissions by 2030 and attain carbon neutrality by 2060 in response to climate change (United Nations, 2020). Similarly, different countries adopt different policies and ideologies to reach the net-zero target.

Country Insights

LMDI has been applied to gain individual country insights. The following graphs give an idea of how economic shocks impact an economy with different intensities and magnitudes. To put it differently, every nation has varied resilience to economic shocks. It is found that the countries relying more on renewable sources are better off and emit less carbon in the atmosphere. Conversely, rapid economic growth often leads to a surge in energy consumption and demand, resulting in higher carbon emissions. While shifting from fossil fuels to cleaner technologies generally helps in lowering emissions, this is not necessarily the case for Asian economies.

Finally, transitioning from traditional energy sources to green alternatives contributes to a reduction in emissions. The citizens of developed nations are aware of the importance of sustainability, while the people in developing nations prioritize growth over climate. The results obtained vary in accordance with the individuality and different structures of the selected nations. Thus, we can say that carbon emission is driven by all the factors collectively chosen with respect to Kaya Identity.
Graph 1 and Graph 2 represent the total change in carbon emissions with respect to driving factors in all countries.

Graphs 1 and 2: Total Change in Carbon Emissions



Source: Authors' Contribution

Series of Events in Individual Countries

The selected period includes various crisis periods and other country-specific policies and regulations that impact the level of carbon emissions. For instance, the years 1997, 2001, 2008, 2012, 2015, 2020, and 2021 witnessed major historic events such as the Asian financial crisis, the dot-com bubble burst, the global financial crisis, the European sovereign debt crisis, the commodity crisis, COVID-19, and the Russia-Ukraine war, respectively. These events significantly disrupted global economies. Additionally, countries have also introduced various policies to improve their energy grids, for instance, the Clean Energy Act of 1999 in the USA, the replacement of non-fossil fuel obligation (NFFO) with renewable obligation mechanism (RO) in the UK in 2002, Germany experiencing Jevon's paradox, and the renewable energy program in 2011 in Algeria. Thus, different graphs exhibit the role played by each explanatory variable in individual economies. LMDI provided valuable country-specific insights, revealing the reasons behind variations in impact, magnitude, and intensity of variables based on each nation's unique economic structure and resilience.

Panel Data Analysis

North America

It is crucial to evaluate the long-run association between the selected driving factors of carbon emissions in the panel. Geographical proximity holds an important function to play in the long run; thus, we conduct a panel study in this context. The variables were checked for stationarity using the second-generation unit root test propounded by Pesaran (2007). The findings reveal that the variables exhibit stationarity either at the level or after first differencing. Table 2 presents the results of the same.

Table 2: Stationarity of Variables: America

Variables	Stationary
CO2	First Difference
EAF	First Difference
CEI	Level
ET	First Difference
EM_NRE	First Difference
POP	First Difference

Source: Authors' Contribution

We applied the Driscoll-Kraay Standard Errors with fixed effects, as it is best suited to our model. The method is used when the panel suffers from the issue of cross-sectional dependence (CSD). CSD was confirmed by applying the Breusch-Pagan LM test of Independence. The results for descriptive statistics are exhibited in Table 3.

Table 3: Descriptive Statistics – North America

Variable	Mean	Std. Dev.	Min	Max
EAF	4.38912	0.35063	3.62587	4.88269
CEI	-2.6376	0.32518	-3.0064	-1.9688
ET	0.84657	0.24809	0.48687	1.28262
EM_NRE	-1.5915	0.05609	-1.6919	-1.5093
POP	8.01539	0.39469	7.4669	8.52282
CO2	9.02198	0.4996	8.48691	9.76161

Source: Authors' Creation

The descriptive statistics indicate that the means of the variables are EAF (4.389), CEI (-2.637), ET (0.846), EM_NRE (-1.59), POP (9.01), and CO2 (9.022).

The findings are shown in Table 4.

Table 4: Long-Run Coefficients – North America

CO_2	Coefficient	T	P-value
dEAF	5.89	2.46	0.021*
CEI	-1.10	-0.56	0.583
dET	.0101	2.14	0.033*
dEM_NRE	4.68	2.78	0.000*
dlogPOP	-0.052	-1.94	0.064**
Constant	1.699	1.93	0.064**

Source: Authors' Contribution

Note- '*', '**' indicate significance at 5% and 10% respectively.

The results indicate that GDP growth is a crucial factor in influencing carbon emissions in America. The coefficient is positive, substantial, and statistically significant at 95% confidence level. We have seen that GDP per capita is an important driver in the case of the USA, Canada, and Mexico using LMDI. As economic activity spurs, energy consumption rises and eventually emits carbon (Hua et al., 2022). Further, CEI does not affect the emissions significantly. Dogan et al. (2020) report that developing nations make a sincere effort to incorporate renewable energy into their energy grids however, developed nations heavily rely on fossil fuels for boosting economic growth. It was also observed in the results obtained from LMDI that CEI moves in response to the change in GDP for Canada and Mexico. Therefore, the components and effects of CEI are captured in EAF and ET. Next, ET positively influences carbon emissions. An increase in NRE consumption or a decline in RE consumption increases the ratio (ET). Thus, this relation directly affects CO2 (Aimon et al., 2023). Next, as emissions arising per unit of non-renewable energy increase, emissions also go up (Hua et al., 2022). Lastly, the population of developed countries is aware and educated about the problem of climate change[3]. This alters their consumption basket with sustainable products, thus curbing environmental degradation. However, the coefficient is negligible, which indicates that the awareness must be spread on a larger scale, which will influence people to adopt green practices. Moreover, Jiang et al. (2022) point out that the appropriate distribution of the population helps in the reduction of emissions.

Europe

Table 5 suggests the stationarity of the chosen variables.

Table 5: Stationarity of Variables: Europe

Variables	Stationarity
CO2	First Difference
EAF	First Difference
CEI	First Difference
ET	First Difference
EM_NRE	First Difference
POP	First Difference

Source: Authors' Contribution

Generalized least squares have been applied to suit the panel data suffering from the issue of CSD and heteroskedasticity. The descriptive statistics are shown in Table 6.

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[3] https://climatecommunication.yale.edu/publications/analysis-of-a-119-country-survey-predicts-global-climate-change-awareness/#:~:text=The%20contrast%20between%20developed%20and,changes%20in%20local%20weather%20patterns.

Table 6: Descriptive Statistics: Europe

Variable	Mean	Std. Dev.	Min	Max
EAF	4.23667	0.502322	2.80329	4.71119
CEI	-2.8776	0.2831955	-3.5134	-2.2048
ET	1.0305	0.3462452	0.44023	1.97751
EM_NRE	-1.551	0.0461394	-1.6689	-1.4035
POP	7.75535	0.1077783	7.5661	7.92323
CO2	8.59394	0.1673375	8.21923	8.95633

Source: Authors' Creation

The descriptive statistics show that the means of the variables are EAF (4.236), CEI (-2.877), ET (1.0305), EM_NRE (-1.551), POP (7.755), and CO2 (8.593). The findings are reported in Table 7.

Table 7: Long-Run Coefficients - Europe

CO_2	Coefficient	T	P-value
EAF	4.48	3.19	0.001*
CEI	-7.42	-1.58	0.094**
ET	0.00714	0.69	0.091**
EM_NRE	27.24	7.12	0.000*
POP	1.83	5.34	0.000*
Constant	-0.157	-4.33	0.000*

Source: Authors' Contribution
Note- '*', '**' indicate significance at 5% and 10% respectively.

The results suggest that EAF positively and significantly affects carbon emissions. This indicates that as the economic activity of an economy increases, it raises carbon emissions because of higher productivity, demand, and consumption (Jiang et al., 2022). Further, CEI inversely impacts the emissions at a confidence level of 90%. The coefficient is substantially high. This indicates that when countries increase the proportion of renewable energy consumption per unit of output, it promotes sustainability (Hua et al., 2022). Further, ET impacts carbon emissions positively and significantly at a 10% level of significance. This points out that the transition from NRE to RE helps the environment by reducing the amount of carbon emissions. This can either be done by lowering NRE or increasing RE (Zhang et al., 2019; Hua et al., 2022). Lastly, EM_NRE positively and significantly impacted carbon emissions. As the share of NRE surges, so do the emissions (Hua et al., 2022). Additionally, POP positively impacts carbon emissions as opposed to a negative relation between the two variables in the case of North America (Murshed et al., 2021). This might be because of the different economic and social structures of the two panels. Europe is a diverse panel of countries with different economic structures. The EU directives and policies aggressively focus on net-zero targets and reforms to increase the share of RE in the energy portfolio. However, not all countries can adopt these measures at an equal pace. For instance, Germany, Poland, France, and Italy strive to meet common energy transition targets, but Ukraine lags behind all the countries in the European Union. Structural differences make each country unique in handling crises. Some countries rebound quickly, while others take longer to cope with the impacts of a crisis.

Asia

The variables are stationary either at the level or after first differencing, as shown in Table 8.

Table 8: Stationarity of Variables- Asia

Variables	Stationarity
CO2	First Difference
EAF	First Difference
CEI	First Difference
ET	First Difference
EM_NRE	First Difference
POP	Level

Source: Authors' Contribution

The descriptive statistics are shown in Table 9. The descriptive statistics show that the means of the variables are EAF (3.68), CEI (-2.59), ET (1.12), EM_NRE (-1.499), POP (8.466), and CO2 (9.18).

Table 9: Descriptive Statistics – Asia

Variables	Mean	Std. Dev.	Min	Max
EAF	3.68139	0.605283	2.57244	4.69148
CEI	-2.5924	0.659758	-3.4981	-1.4489
ET	1.12548	0.633995	0.08311	2.35509
EM_NRE	-1.4991	0.097973	-1.6687	-1.3163
POP	8.46679	0.529684	7.78387	9.15142
CO2	9.18208	0.391803	8.4338	10.0392

Source: Authors' Creation

As per the requirement of the data, we have applied generalized least squares on the dataset, and the results are presented in Table 10.

Table 10: Long-Run Coefficients - Asia

CO2	Coefficient	T	P-value
EAF	2.47	1.36	0.073**
CEI	-11.6462	-3.58	0.000*

ET	.0000878	0.33	0.740
EM_NRE	12.394	0.000	0.000*
POP	2.14	0.001	0.001*
Constant	.0076	0.093	0.093**

Source: Authors' Contribution

Note- '*', '**' indicate significance at 5% and 10% respectively.

EAF positively impacts carbon emissions at a confidence level of 90%. This implies that an increase in economic activity is accompanied by a rise in production and consumption, resulting in higher emissions (Onofrei et al., 2022). CEI negatively influences carbon emissions, meaning energy efficiency increases with either a surge in RE consumption or a drop in output measured by GDP (Hua et al., 2022). Further, to our surprise, the energy transition does not affect carbon emissions in the panel data. Asia is a mix of countries with different economic structures. As seen in the results obtained from LMDI, some Asian countries depend on fossil fuels, while others try to introduce RE into the energy portfolio. In addition, the benefits of transitioning to RE are still not reaped by the Asian economies at their full capacity; thus, the positive outlook of transition is still unseen (Kumar et al., 2017). Further, the emissions arising per unit of NRE and population directly affect the carbon emissions. With the growing population in the Asian economies, energy consumption and demand also go up, which ultimately affects higher consumption of NRE, leading to high emissions.

Africa

The variables were checked for stationarity, and it was found that all the variables were stationary either at the level or after first differencing. Further, Driscoll-Kraay Standard Errors with Fixed Effects were applied to suit the requirements of our panel data. The results for descriptive statistics are shown in Table 11.

Table 11: Descriptive Statistics - Africa

Variables	Mean	Std. Dev.	Min	Max
EAF	3.43072	0.2831314	2.69384	3.94136
CEI	-2.7528	0.8321919	-4.7829	-1.5186
ET	1.0042	1.1698264	-0.7477	3.22107
EM_NRE	-1.3153	0.3485065	-1.6451	-0.5402
POP	7.84412	0.2510337	7.45451	8.33953
CO2	8.21094	0.2490769	7.87177	8.65157

Source: Authors' Creation

The descriptive statistics show that the means of the variables are EAF

(3.43), CEI (-2.75), ET (1.004), EM_NRE (-1.3153), POP (7.844), and CO2 (8.210). The findings are observed in Table 12.

Table 12: Long-run Coefficients - Africa

CO2	Coefficient	T	P-value
EAF	.0000214	1.69	0.093**
CEI	.484	0.24	0.105
ET	.0000466	2.85	0.009*
EM_NRE	.0822	1.88	0.071**
POP	1.13	0.38	0.704
Constant	.01569	2.23	0.035*

Source: Authors' Contribution

Note- '*', '**' indicate significance at 5% and 10% respectively.

The results indicate that the increase in economic activity is accompanied by a rise in energy demand and consumption. Therefore, a hike in energy demand results in an increase in carbon emissions (Onofrei et al., 2022). CEI is not affecting emissions significantly. Africa is reliant on the use of non-clean energy sources, and a very small proportion of clean energy sources has been included in the energy portfolio of different African countries (Ibrahim et al., 2021). Therefore, there is a need to increase the share of cleaner energy to reap its benefits. Hydropower, wind, and solar energy can significantly align Africa with sustainability goals. Further, energy transition positively influences carbon emissions at a 10% significance level. This means that as NRE increases and RE decreases, it contributes to carbon emissions (Hua et al., 2022). Lastly, emissions arising from NRE also increase emissions. The population does not significantly affect the carbon emissions in Africa. The result seems to be unexpected, as a large chunk of researchers stipulate that the rising population induces carbon emissions. However, keeping in mind the population density and income inequality, it is concluded that population is not a definitive driver of CO_2 emissions. For instance, Africa has a larger population than Europe; however, the emissions from Europe are seven times those of Africa[4].

Discussion

On the continuum representing sustainability, Europe seems to appear on the higher end, followed by America, Asia, and Africa. The justification is as follows-

It has been observed that Europe performs better in terms of energy transition and clean energy intensity, which indicates energy efficiency while moving towards renewable energy, thereby lowering the environmental burden. On the contrary, clean energy intensity is not

[4] https://www.orfonline.org/expert-speak/population-drives-climate-change

substantially significant in influencing carbon emissions in America. This indicates that though the share of renewables might have increased, it is still incapable of displacing fossil fuels completely. Also, a report by the U.S. Energy Information Administration has observed that America primarily relies on fossil fuels for energy consumption, with a simultaneous expansion of renewable energy infrastructure[5]. Though population reduces the environmental burden only in the case of America, because the three developed nations (USA, Canada, and Mexico) have been clubbed as one panel. The rest of the panels are a mix of emerging and developed economies. Thus, it can be claimed that the American population is aware and has significantly altered their consumption basket to incorporate sustainable products[6]. Further, the benefits of transitioning from NRE to RE have not been completely reaped by the Asian economies (Kumar et al., 2017), as can be observed by the positive, insignificant coefficient of energy transition. Lastly, Africa performs poorly because of a relatively smaller coefficient in the case of ET and an insignificant coefficient of CEI, indicating no improvement in energy efficiency.

It is suggested that economies must try to incorporate renewable sources in their respective energy grid; however, a balance between fossil fuels and non-fossil sources should be maintained. Germany is experiencing Jevons' paradox, which makes the clean energy grid resistant to promoting sustainability. Portillo et al. (2024) have observed the environmental burden caused by the life cycle of introducing renewables in the long run. Thus, too much reliance on renewables can be harmful because of large installations requiring the use of fossil fuels and thereby having harmful impacts on the environment.

CONCLUSION

The objective focuses on determining the factors influencing CO_2 emissions using the LMDI applied to individual countries, thereby analyzing the long-term link using a suitable data-specific methodology between chosen factors and emissions in a panel-data setup. The objective considers carbon emissions as the outcome variable, and the factors are based on the Kaya identity. The results suggest that each factor impacts the level of carbon emissions differently. The panel consists of integrated economies with distinct structural differences; hence, historical economic shocks impact the nations in different ways. For instance, oil shocks impacted oil-producing nations and oil-importing nations differently; the Asian crisis had a different

[5] https://www.eia.gov/energyexplained/us-energy-facts/

[6] https://www.pewresearch.org/science/2023/06/28/majorities-of-americans-prioritize-renewable-energy back-steps-to-address-climate-change/

impact on the economies; the financial crisis impacted all the nations, however, with different intensities, and so on. Thus, each of the shocks had an impact on economic growth, which thereby impacted the manufacturing industries, energy use, and emissions. Thus, the resilience of each country/panel to economic shocks varies significantly.

To elaborate, in the case of North America, the EAF, ET, and EM_NRE surge CO_2 emissions (Hua et al., 2022; Aimon et al., 2022). Further, CEI does not influence emissions. Dogan et al. (2020) report that developed nations largely rely on fossil fuels to spur economic growth. Lastly, the population is aware of and demands sophisticated products (Thøgersen, 2021). Second, in the case of Europe, it is found that the EAF, ET, EM_ NRE, and POP positively influence carbon emissions (Jiang et al., 2022; Zhang et al., 2019; Hua et al., 2022; Murshed et al., 2021). However, the CEI negatively influences emissions (Hua et al., 2022). In the case of Asia, EAF, EM_NRE, and POP increase emissions (Onofrei et al., 2022). CEI negatively impacts emissions, as found in Hua et al. (2022). Lastly, it is found that ET is insignificant in influencing emissions. It is reported that the Asian economies have still not reaped the benefits of transitioning to renewable sources at full capacity (Kumar et al., 2017). In the case of Africa, it is found that the EAF, ET, and EM_NRE positively impact carbon emissions (Onofrei et al., 2022). CEI and population do not affect emissions significantly (Ibrahim et al., 2021).

FUTURE DIRECTION

Despite several efforts to address the research gaps identified in the previous research work, the current work leaves a scope for future academicians. The present research focuses on overarching global trends while estimating long-run coefficients rather than focusing on country-specific deviations, and thus, including country-specific effects seemed redundant. However, future academicians may incorporate country-specific effects to highlight the regional differences. Also, future work can address the decoupling effect to explain the complex association between growth and emissions. Third, future academicians may focus on considering a structural break that influences all the economies and hints at significant alterations of the energy consumption and production processes, like Covid-19. Lastly, modern methodologies like artificial neural network (ANN) can be employed to decompose the factors influencing the emissions (Fan et al., 2022).

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