LOW-CARBON DEVELOPMENT INDEX

2024

Luana Kimley

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Introduction

The goal of this paper is to develop a robust framework for constructing a Low-Carbon Development Index (LCDI) that measures a country's progress towards sustainable development by incorporating environmental and social aspects along with economic development and governance that targets lower emissions. Low-Carbon Development is crucial in combating climate change and achieving sustainable development goals.

The Low-Carbon Development Index (LCDI) provides a comprehensive metric for assessing a country's progress towards sustainable development objectives. By considering environmental, social, economic, and governance indicators, the LCDI offers a broad perspective on a nation's efforts to reduce carbon emissions while fostering inclusive growth and good governance practices. This index serves as a valuable tool for policymakers, stakeholders, and researchers to evaluate the effectiveness of policy interventions, identify areas for improvement, and track long-term sustainability trends.

Theoretical Framework

In theory, a country with low-carbon development will have a high proportion of natural forest area that can act as *carbon sink*, human development index (HDI), gross domestic product (GDP) per capita, freshwater resources, renewable energy consumption, access to sustainable energy, agreed to the relevant governance, and low emissions. This includes abundant forest area for carbon sequestration, high HDI signifying quality of life and development, strong GDP per capita indicating economic well-being, and ample freshwater resources. At the heart of this development model is an energy sector transitioning away from fossil fuels, evidenced by high renewable energy consumption and widespread access to sustainable energy. Furthermore, commitment to international climate agreements such as the Paris Agreement and the countries' commitment in the overall initiatives of United Nations for Climate Change Conventions (UNFCCC) demonstrates strong governance structures. The Paris Agreement as the most recent UNFCCC initiative, is a legally binding international treaty on climate change. It was adopted by 196 Parties at the UN Climate Change Conference (COP21) in Paris, France, on 12 December 2015. It entered into force on 4 November 2016. Its overarching goal is to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels" and pursue efforts "to limit the temperature increase to 1.5°C above pre-industrial levels."[1]

The ultimate outcome of the LCD is demonstrably low emissions across various sectors of the economy. However, achieving this ideal requires careful balancing of development

[1] https://unfccc.int/process-and-meetings/the-paris-agreement

goals with environmental sustainability, as economic growth can sometimes lead to increased pressure on natural resources.

This framework will also give an overview of a country's progress towards reaching sustainable development goals[2] (SDGs), more specifically:

- **SDG 13: Climate Action** – by reducing greenhouse gas emissions and tracking forest area, which acts as a carbon sink.

It also indirectly connects to other SDGs, such as:

- **SDG 7: Affordable and Clean Energy** – by promoting renewable energy production.
- **SDG 6: Clean Water and Sanitation** – through the indicators for water resources management (fresh groundwater abstracted, fresh surface water abstracted, and renewable freshwater resources per capita).
- **SDG 12: Responsible Consumption and Production** – by looking at air emissions.
- **SDG 15: Life on Land** – forest area is a key indicator for this SDG.
- **SDG 10: Reduced Inequalities** – while not directly measured, HDI (Human Development Index) can be a proxy indicator for social equality.
- **SDG 8: Decent Work and Economic Growth** – GDP is a basic indicator of economic development.

Methodology

The research follows several systematic steps as outlined below:

1. Defining the indicators for LCDI through expert consultation.
2. Collecting and selecting data from the secondary sources, i.e. World Bank, United Nations.
3. Imputing missing data by applying the MICE (Multiple Imputations by Chained Equations) algorithm. The multiple imputation method, which provides several values for each missing value, can more effectively represent the uncertainty due to imputation. MICE is a robust, informative method of dealing with missing data in datasets[3]. The procedure 'fills in' (imputes) missing data in a dataset through an iterative series of predictive models.
4. Conducting multivariate analysis, covering: Pearson Correlation Coefficient, Principal Component Analysis, Clustering.
5. Normalising the data points using Min-Max normalisation technique.

[2] https://sdgs.un.org/

[3] https://cran.r-project.org/web/packages/miceRanger/vignettes/miceAlgorithm.html

6. Selecting appropriate weightings for each indicator in the LCDI through expert consultation.
7. Calculating the final composite index using the defined formulas.
8. Comparing the LCDI results with other relevant existing indexes, i.e. Sustainable Development Goals (SDGs) Index.
9. Present the findings of the LCDI through an interactive website.

Defining indicators for LCDI

The goal of this framework is to develop Low-Carbon Development Index (LCDI) that measures a country's progress towards sustainable development by incorporating environmental and social aspects along with economic development and governance that targets lower emissions. To comprehensively assess a country's progress towards low-carbon development, a variety of indicators were chosen. In consultation with a senior scientist from CIFOR-ICRAF (World Agroforestry), the following indicators were selected based on their relevance to its:

1) **Environmental aspect:**
   a) **Renewable energy** – reflects a country's progress in shifting towards cleaner energy sources and reducing reliance on fossil fuels.
   b) **Forest area** – forests play a crucial role in carbon sequestration, absorbing CO_2 from the atmosphere. Higher forest area indicates a country's capacity to mitigate climate change.
   c) **Water resources** – a higher availability of water reduces the energy required for extraction. This translates to lower carbon emissions from energy production.
   d) **Emissions** – emissions refer to the release of greenhouse gases like carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) due to human activities. Lower emissions are considered a target for achieving sustainable development.
2) **Social aspect:**
   a) **Human Development Index (HDI)** – composite index that considers a country's achievements in three basic dimensions of human development: health, education, and a decent standard of living. A high HDI can indicate a population's capacity to adapt to and contribute to sustainable development practices.
3) **Economic aspect:**
   a) **GDP (Gross Domestic Product)** – a broad measure of a country's economic output. While not a direct indicator of environmental sustainability, it is included to acknowledge the need for economic growth to support investments in low-carbon technologies and infrastructure. Notably, GDP per capita is one of the indicators within the Human Development Index (HDI), highlighting its significance in assessing overall human development and well-being.
4) **Governance:**

a) Governance – Compliance towards goals for emissions reduction and adaptation and outlining the principles of cooperation and accountability among countries can reflect a country's commitment to achieving low carbon development.

Data Selection

To offer a balanced picture of the latest advancements, ensure relevance for decision-makers, and maximise data quality within the LCDI, the dataset used must be up-to-date data from the most recent five years (2019-2024).

The variables in the dataset also need to be carefully curated to avoid endogeneity. In statistics, endogeneity refers to the correlation between the independent variable and unexplained variation (or "error") in the dependent variable[4]. Endogeneity may lead to bias in the results of statistical tests. This is a crucial issue in statistics because endogeneity may undermine the validity of inferences and lead to incorrect conclusions. To do this, focus on exogenous variables is needed, looking for indicators that are less likely to be directly impacted by other variables within the framework.

The data used for this index is found through public datasets accessible through the United Nations and World Bank, which are:

1. **Forests – Forest area**
   - *Indicator 1b* - Dataset with data on forest area across countries over the years. The variable I will be using will only be the proportion of forest area compared to the total land area of the most recent year (2020).
     - **Strengths**: easily measurable, provides insight into land-use change and potential carbon sequestration.
     - **Weaknesses**: may not reflect the health or biodiversity of the forest, can be influenced by factors unrelated to climate policy.
2. **Governance**
   - *Indicator 4a* – Dataset with data on various environmental governance, the relevant ones for this topic would be data from the Paris Agreement and UN Framework Convention on Climate Change. The Paris Agreement is important as it agrees that in the future, access to fossil fuel-based energy will need to be constrained and efforts should be made to keep global warming below 1.5°C.
     - **Strengths**: indicates commitment to climate action, promotes international cooperation.
     - **Weaknesses**: relies on self-reporting and may not reflect actual implementation, focuses on national goals, not local-level goals.
3. **Human Development World Index**

[4] https://www.statisticssolutions.com/what-is-endogeneity/

- *Indicator 2a, 3a* – Dataset with data on HDI composing of various factors that contributes to the HDI. Calculation of HDI also considers the GDP per capita of countries, so it considers both social and economic aspects. I will only be using the HDI composite index for the most recent year (2021).
    - **Strengths**: captures broader well-being and development, reflects potential for successful climate policies.
    - **Weaknesses**: not a direct indicator of climate performance, can mask internal inequalities.

4. **Freshwater**
    - *Indicator 1c* – Dataset on several aspects of freshwater. I will only be using data on Internal renewable freshwater resources (flows) for the most recent year (2020).
        - **Strengths**: essential for life and sustainability, water stress can hinder climate adaptation.
        - **Weaknesses**: availability influenced by geographic and climatic factors, not just policy, data quality and consistency can be an issue.
5. **Trends in Greenhouse Gas Emissions**
    - *Indicator 1d* – Dataset with data on total greenhouse gas emission, including a breakdown of data for CH_4, CO_2, and N_2O for the year 2015 and 2020. The data I will be using will be the CH_4, CO_2, and N_2O for the most recent year (2020). Using a breakdown of the data instead of the total will provide a more nuanced picture of a country's emissions profile.
        - **Strengths**: direct measures of key pollutants.
        - **Weaknesses**: can be difficult to attribute emissions to specific sectors or activities.
6. **Sustainable Energy for All**
    - *Indicator 1a* – Dataset with data on electricity access and consumption. The data I will be using is the data on access to clean fuels and technologies for cooking for the year 2021, as it reduces reliance on biomass fuel and data on renewable energy consumption for the year 2020.
        - **Strengths**: addresses a major source of household air pollution, can reduce reliance on traditional biomass fuels, which can help conserve forests.
        - **Weaknesses**: does not necessarily capture the efficiency or sustainability of the clean fuels and technologies.
7. **Region**
    - Region groups data which allows analysis on the Low Carbon Development for each region, allows highlighting of regional disparities across the globe.

Variable Modification

Paris Agreement – One Hot Encoding

The Paris Agreement variable is one hot encoded to represent if a country signed the agreement or not. A value of 1 indicates that the country signed the agreement and the value 0 indicates otherwise.

UNFCCC – Transformed to Years Since Joined

The UNFCCC variable has been updated to reflect the duration of a country's membership rather than just the year it joined. This adjustment offers a more nuanced understanding of each nation's commitment by indicating the length of time they've been engaged with the convention.

Table 1 describes the final version of indicators modified and their sources of data.

Table 1: Proposed LCDI indicators and sources of data

Indicator	Availability (Country)	Time	Source	Type	Unit of Measurement
Proportion of Forest Area	Complete	2020	United Nations Statistical Division	Hard (Output)	% of total land area
Governance – Paris Agreement	Complete	-	United Nations Statistical Division	Soft (Input)	Yes or no
Governance - UNFCCC	Complete	-	United Nations Statistical Division	Soft (Input)	Years since joined
Human Development Index	Missing 2 countries	2021	United Nations Development Programme	Hard (Output)	0-1
Freshwater	Missing 13 countries	2020	United Nations Statistical Division	Hard (Output)	Billion cubic metres
Greenhouse Gas (GHG) Emissions	Missing 4 countries	2020	World Bank	Hard (Output)	Thousand metric tonnes
Access to Clean Fuel and Technologies for Cooking	Missing 6 countries	2020	World Bank	Hard (Output)	% of population
Renewable Energy Consumption	Missing 3 countries	2020	World Bank	Hard (Output)	% of total final energy consumption
Region	Complete	-	United Nations Statistical Division	Soft (Input)	N/A

The complete dataset, along with the methodology employed, can be accessed at the following GitHub repository: https://github.com/luanakimley/low-carbon-development-composite-index.

Imputation of Missing Data

Excessive missing data in key areas can introduce significant bias into models and calculations for Low Carbon Development, leading to potentially misleading conclusions. While imputation is an alternative, the high number of missing values per country could introduce significant uncertainty and compromise the analysis. Variables under the environmental aspect that covers freshwater, forest area, clean fuel access, renewable energy consumption, and GHG emissions, have at least four missing values across countries. Thus, to ensure data reliability, the countries removed are Monaco, San Marino, and Nauru. The imputation of the other missing values was analysed on the data produced by the MICE predictions (Table 2).

Table 2: Results from the imputation of the other missing values by the MICE predictions

	freshwater		hdi		cooking_clean_fuel_and_technologies_access		co2_emissions		methane_emissions		nitrous_oxide_emissions		country
	self	other	self	other	self	other	self	other	self	other	self	other	
27	NaN	NaN	NaN	NaN	NaN	91.609610	NaN	NaN	NaN	NaN	NaN	NaN	Libya
41	NaN	220.980074	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	Seychelles
62	NaN	NaN	NaN	0.553039	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	Democratic People's Republic of Korea
71	NaN	-193.460871	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	Kiribati
75	NaN	NaN	NaN	NaN	NaN	91.527688	NaN	NaN	NaN	NaN	NaN	NaN	Lebanon
78	NaN	86.137278	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	Marshall Islands
79	NaN	179.464382	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	Micronesia (Federated States of)
85	NaN	210.255103	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	Palau
88	NaN	NaN	NaN	NaN	NaN	75.546587	NaN	153119.614546	NaN	28112.023527	NaN	11860.351677	State of Palestine
91	NaN	102.670654	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	Samoa
100	NaN	-89.508143	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	Tonga
103	NaN	0.102766	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	Tuvalu
114	NaN	NaN	NaN	NaN	NaN	77.604639	NaN	NaN	NaN	NaN	NaN	NaN	Bulgaria
122	NaN	160.796766	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	Montenegro
178	NaN	69.216666	NaN	NaN	NaN	47.009998	NaN	NaN	NaN	NaN	NaN	NaN	Liechtenstein

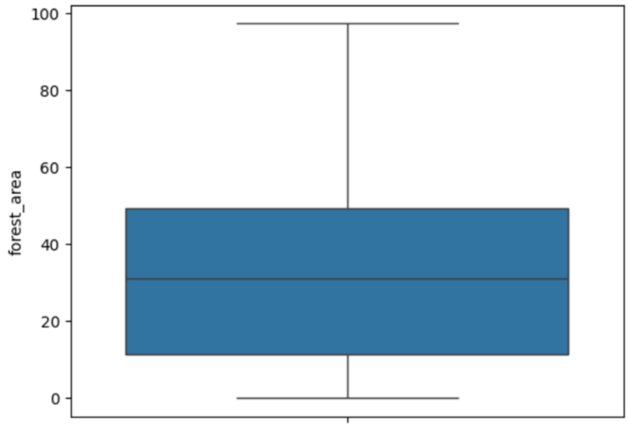
The freshwater data for Kiribati and Tonga contained negative values after imputation with the MICE algorithm. These values are unrealistic for internal renewable freshwater resources. This likely stems from negative correlations with other variables in the dataset. As an initial step, these negatives values were substituted with zero. This aligns with the known freshwater scarcity faced by these island nations[5,6].

Through observation of box plots and analysis of the underlying data, while some countries exhibit values outside the typical interquartile range (IQR), they represent valid extreme values rather than outliers (Figure 1). This variation is expected, given the diverse economic structures and energy consumption patterns of countries in the dataset. Specific factors, such as economic size, industrialisation level, and population size, likely explain the higher values observed for certain nations.

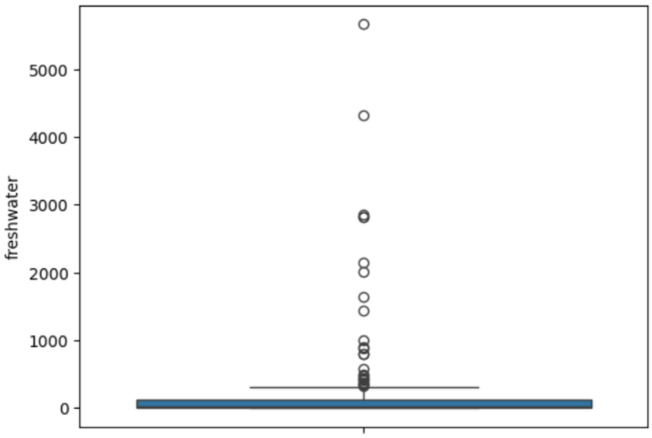
[5] https://reliefweb.int/report/tonga/water-security-risk-climate-change

[6] https://www.preventionweb.net/news/water-water-everywhere-not-drop-drink-adapting-life-climate-change-hit-kiribati

- Forest Area

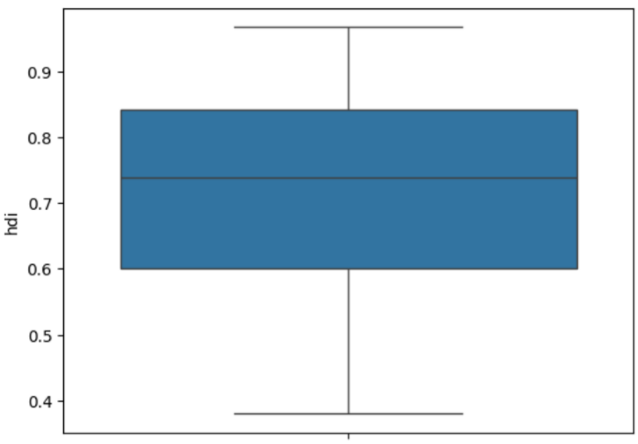


- Freshwater

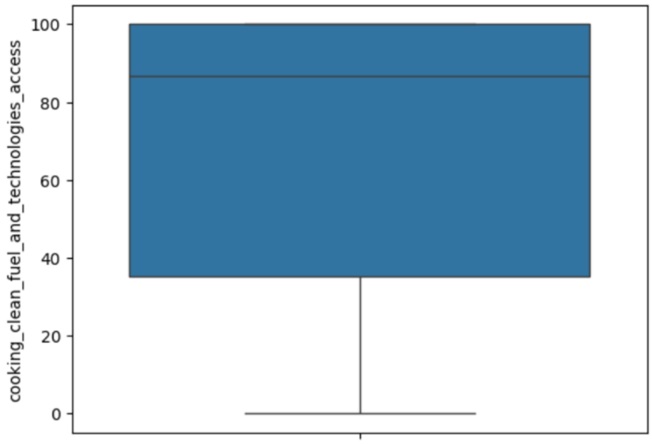


	country	freshwater
8	Australia	492.0
23	Brazil	5661.0
31	Canada	2850.0
34	Chile	885.0
35	China	2812.9
36	Colombia	2145.0
46	Democratic Republic of the Congo	900.0
51	Ecuador	442.4
77	India	1446.0
78	Indonesia	2018.7
85	Japan	430.0
101	Madagascar	337.0
103	Malaysia	580.0
110	Mexico	409.0
116	Myanmar	1002.8
120	New Zealand	327.0
125	Norway	382.0
130	Papua New Guinea	801.0
132	Peru	1641.0
133	Philippines	479.0
140	Russian Federation	4312.0
182	United States of America	2818.0
186	Venezuela (Bolivarian Republic of)	805.0
187	Viet Nam	359.4

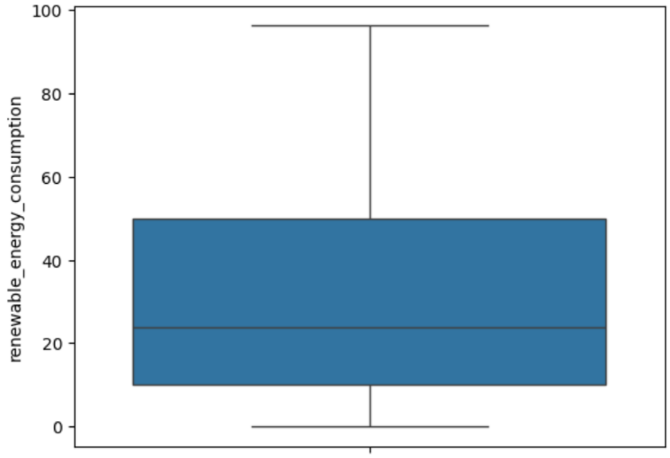
- Human Development Index



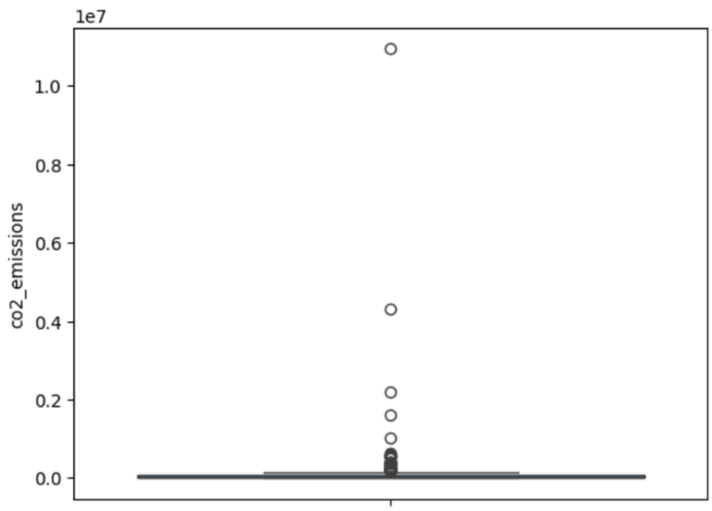
- Access to Clean Fuel and Technologies



- Renewable Energy Consumption

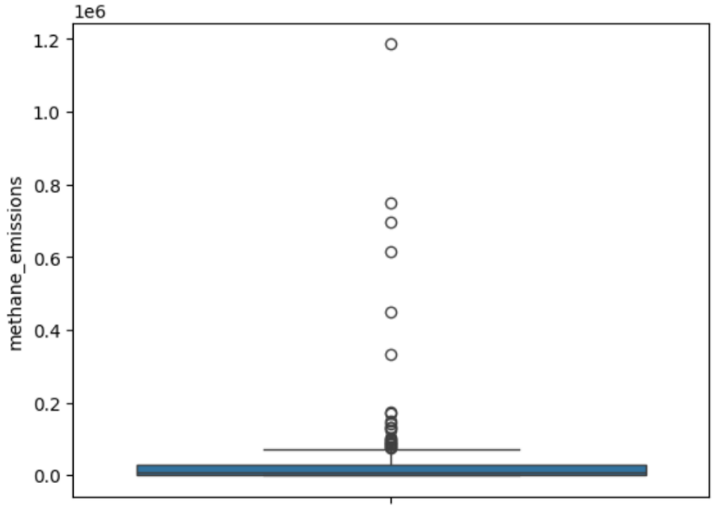


- CO2 Emissions



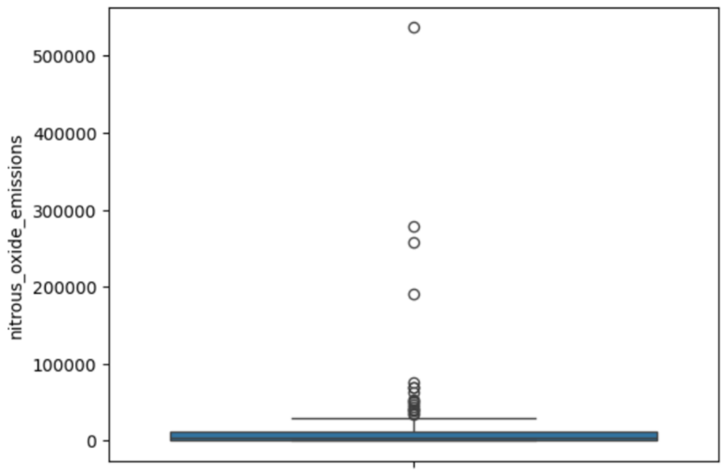
	country	co2_emissions
2	Algeria	161563.0
8	Australia	378996.8
23	Brazil	414138.8
31	Canada	516873.7
35	China	10944686.2
52	Egypt	210752.3
61	France	267154.7
65	Germany	603350.5
77	India	2200836.3
78	Indonesia	563197.0
79	Iran (Islamic Republic of)	616561.3
80	Iraq	163511.5
83	Italy	281286.8
85	Japan	1014064.7
87	Kazakhstan	211896.7
103	Malaysia	245139.3
110	Mexico	383131.4
127	Pakistan	184111.2
134	Poland	279223.8
137	Republic of Korea	569681.8
140	Russian Federation	1618271.0
147	Saudi Arabia	513555.8
157	South Africa	393241.6
159	Spain	202705.8
168	Thailand	265478.9
174	Turkey	407406.2
178	Ukraine	165663.6
179	United Arab Emirates	188088.7
180	United Kingdom of Great Britain and Northern I...	308650.3
182	United States of America	4320532.5
187	Viet Nam	355323.1

- Methane Emissions



	country	methane_emissions
2	Algeria	8.654392e+04
6	Argentina	1.310357e+05
8	Australia	1.314848e+05
13	Bangladesh	8.890400e+04
23	Brazil	4.492140e+05
31	Canada	1.001434e+05
35	China	1.186285e+06
36	Colombia	7.715640e+04
58	Ethiopia	9.464558e+04
77	India	6.976547e+05
78	Indonesia	3.339949e+05
79	Iran (Islamic Republic of)	1.746420e+05
80	Iraq	8.591697e+04
110	Mexico	1.434809e+05
123	Nigeria	1.510598e+05
127	Pakistan	1.694282e+05
140	Russian Federation	6.172273e+05
147	Saudi Arabia	1.026305e+05
168	Thailand	7.589278e+04
175	Turkmenistan	1.248186e+05
182	United States of America	7.482414e+05
186	Venezuela (Bolivarian Republic of)	9.759423e+04
187	Viet Nam	7.961924e+04

- Nitrous Oxide Emissions



	country	nitrous_oxide_emissions
6	Argentina	51061.49889
8	Australia	49331.81586
23	Brazil	191103.25170
30	Cameroon	62399.45337
31	Canada	47080.30993
35	China	536920.21030
58	Ethiopia	53761.30355
61	France	36202.71508
65	Germany	33815.10860
77	India	279003.79150
78	Indonesia	75595.64259
79	Iran (Islamic Republic of)	39719.80826
110	Mexico	43291.23439
123	Nigeria	41196.30278
127	Pakistan	68971.75355
140	Russian Federation	69231.05118
174	Turkey	38132.07296
182	United States of America	258002.35600

Figure 1: Outlier checking by using boxplots and IQR to indicate countries with potential outliers

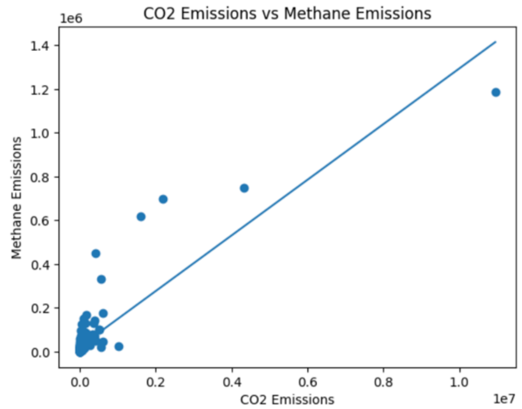
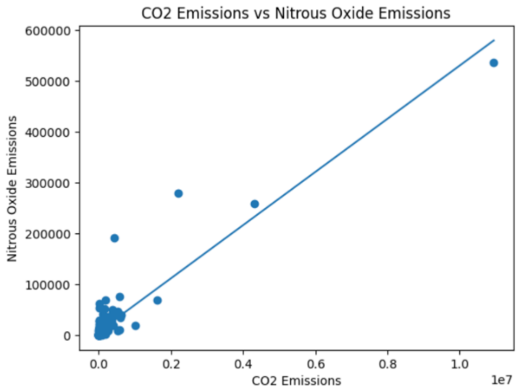
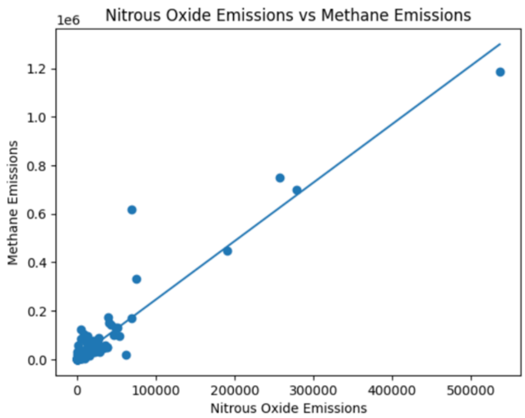
Multivariate Analysis

Independent Variable – Independent Variable Correlation

Analysis on the relationships between these three variables (CO2 – Methane, CO2 – Nitrous Oxide, Methane – Nitrous Oxide) showed that these variables are strongly correlated with each other and is statistically significant, as its p-value is less than 0.05 (Table 3).

Table 3: GHG variables with strong correlations

Comparison	Visualisation	Pearson Correlation Coefficient

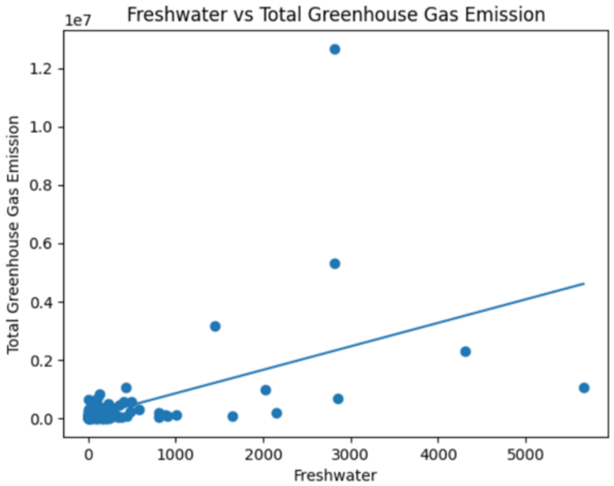
CO2 Emissions – Methane Emissions		Statistic: 0.8713289063109838 P-value: 4.973987356102599e-60 Strong positive correlation
CO2 Emissions – Nitrous Oxide Emissions		Statistic: 0.9144258990015703 P-value: 9.005204804933132e-76 Strong positive correlation
Methane Emissions – Nitrous Oxide Emissions		Statistic: 0.9447326582698592 P-value: 5.414736503017543e-93 Strong positive correlation

To prevent multicollinearity[7] before doing Principal Component Analysis and as these three variables have the same unit of measurement, the variables were combined into one single variable, i.e. total greenhouse gas emissions.

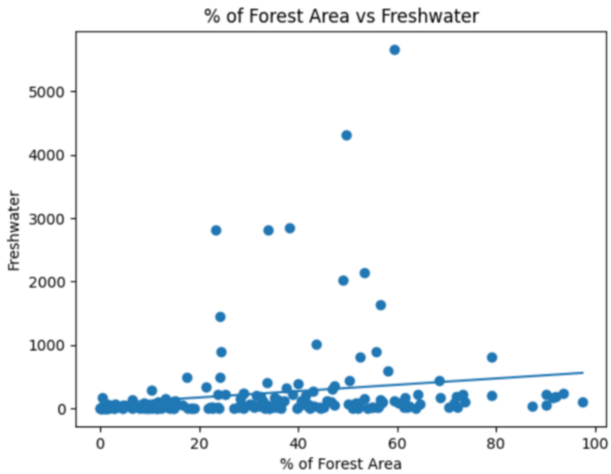
Other statistically relevant correlations that are observed include: freshwater – GHG emissions, % of forest area – freshwater, % of forest area – Paris Agreement, Paris Agreement – UNFCCC, UNFCCC – HDI, HDI – clean cooking fuel and technologies access, HDI – renewable energy consumption, and clean cooking fuel and technologies access – renewable energy consumption (Table 4).

[7] https://www.ibm.com/topics/multicollinearity

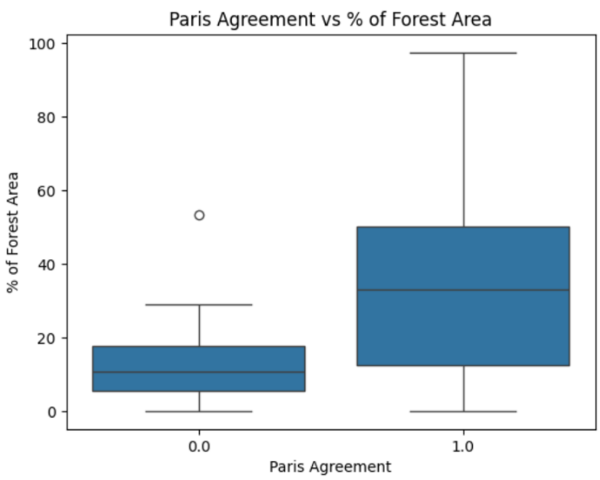
Table 4: Variables with statistically relevant correlations

<table>
<tr><th>Comparison</th><th>Visualisation</th><th>Pearson Correlation Coefficient</th></tr>
<tr><td>Freshwater – GHG Emissions</td><td>
</td><td>Statistic:
0.5216544072522764

P-value:
1.1869154457156548e-14

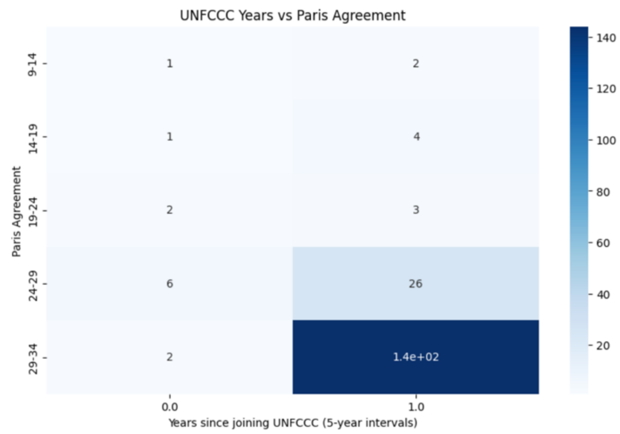
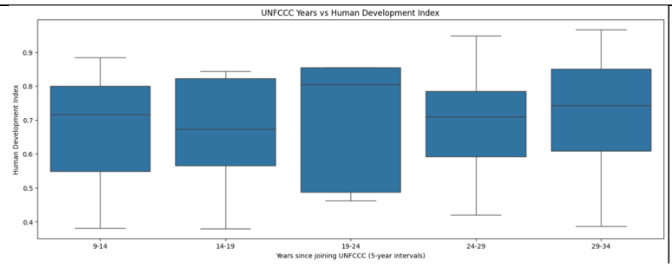
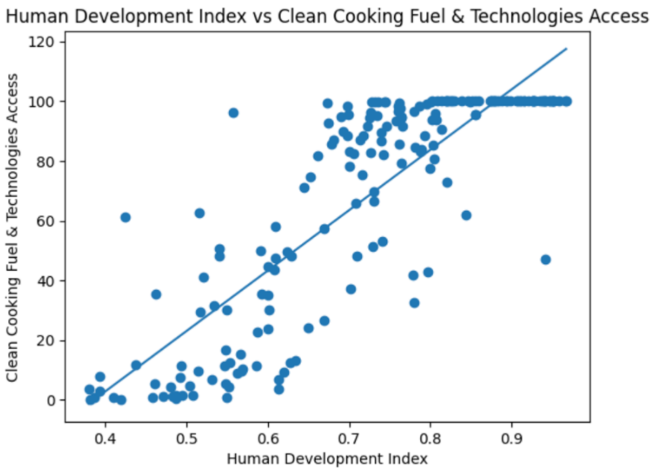
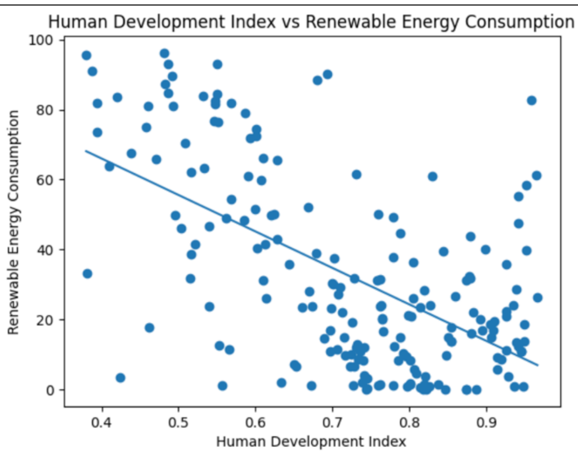
Moderate positive correlation</td></tr>
<tr><td>% of Forest Area – Freshwater</td><td>
</td><td>Statistic:
0.16634107381468424

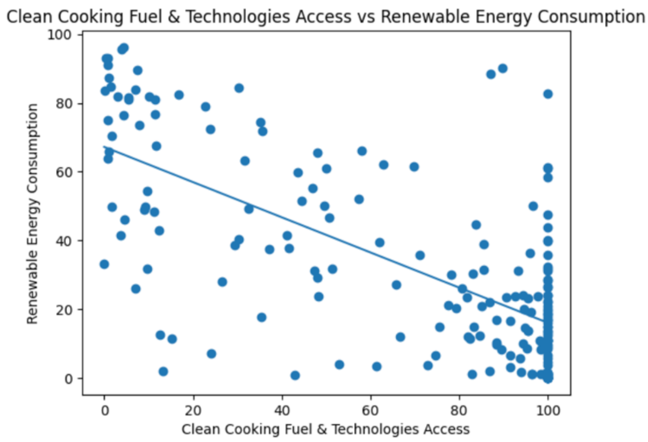
P-value:
0.021806209496635

Weak positive correlation</td></tr>
<tr><td>% of Forest Area – Paris Agreement</td><td>
</td><td>Statistic:
0.19974048175899659

P-value:
0.005727941709423815

Weak positive correlation</td></tr>
</table>

Paris Agreement - UNFCCC		Statistic: 0.34032215172585417 P-value: 1.5533593764074703e-06 Moderate positive correlation
UNFCCC – HDI		Statistic: 0.17723906903454137 P-value: 0.014431079317944741 Weak positive correlation
HDI – Clean Cooking Fuel and Technologies Access		Statistic: 0.8452123264623711 P-value: 4.786128020407497e-53 Strong positive correlation
HDI – Renewable Energy Consumption		Statistic: - 0.5836332623395772 P-value: 9.819864676476043e-19 Moderate negative correlation

Clean Cooking Fuel and Technologies Access – Renewable Energy Consumption		Statistic: - 0.6860017824712298 P-value: 9.146048468072575e-28 Moderate negative correlation

Based on these findings, it is evident that there is a strong positive correlation between HDI and access to clean cooking fuel and technologies. This correlation aligns with findings from Pachauri, et al.[8], who emphasised the far-reaching consequences of limited clean cooking access on health, gender, equity, climate, and air quality worldwide.

However, for the purposes of constructing the LCDI, the variable of clean cooking fuel access will be excluded. This decision is based on two primary reasons:

- **Redundancy with HDI**: The strong correlation with HDI suggests that clean cooking access is largely captured within the broader measures of development that the index already includes.
- **Specificity**: While critical, clean cooking access is a relatively narrow aspect of sustainable development. The LCDI aims for a more comprehensive assessment of low-carbon progress, necessitating a focus on broader indicators.

Principal Component Analysis

Principal Component Analysis (PCA) is done to the dataset to reduce its dimensionality while preserving as much of the variability in the data as possible. This technique transforms the original variables into a new set of variables, which is a linear combination of each of the original variables, called principal components.

[8] https://doi.org/10.1038/s41560-021-00911-9

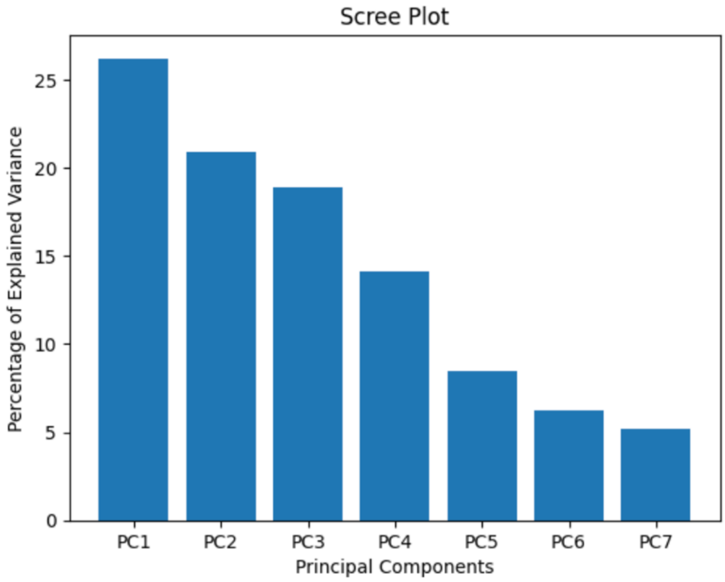


Figure 2: PCA scree plot

The PCA loadings (Table 5) offer insights into how the original variables contribute to the newly constructed principal components.

The principal component analysis reveals complex relationships between the environmental and socioeconomic indicators. In PC1, a contrast emerges between freshwater, GHG emissions, and HDI (positively loaded) versus renewable energy consumption (negatively loaded), suggesting countries with better freshwater access and higher HDI might have lower renewable energy adoption alongside higher emissions. PC2 highlights a potential balance between natural resources (forest area) and renewable energy use, contrasting with HDI. PC3 emphasises engagement with international climate agreements over time, showing a potential trade-off between such commitments and freshwater management. PC4 indicates a possible link between natural resource abundance (forests), HDI, and time since joining the UNFCCC, potentially reflecting policy priorities. PC5 suggests connections between deforestation, greenhouse gas emissions, and challenges in balancing economic development with environmental concerns. Finally, PC6 highlights potential trade-offs between water resource management, climate change mitigation, and other sustainability factors.

Table 5: PCA loadings for each indicator

	PC1	PC2	PC3	PC4	PC5	PC6
forest_area	14.0	37.0	-16.0	81.0	-22.0	30.0
freshwater	44.0	32.0	46.0	8.0	-10.0	-68.0
paris_agreement	29.0	35.0	-52.0	-10.0	71.0	-10.0
years_since_unfccc	34.0	27.0	-38.0	-50.0	-62.0	14.0
hdi	51.0	-42.0	-22.0	19.0	-7.0	-10.0
renewable_energy_consumption	-38.0	61.0	5.0	-9.0	-5.0	-5.0
total_greenhouse_gas_emission	43.0	14.0	54.0	-18.0	23.0	63.0

Cluster Analysis

For the cluster analysis, the first six principal components (PC1 to PC6) are applied as it explains 94.8% of the variance (Figure 2). The cluster will be colour-coded based on the cluster and the region the country is in (Table 6).

Table 6: Colour code for regional groups in the cluster analysis

Region	Colour
African Group	**Blue**
Asia-Pacific Group	**Green**
Eastern European Group	**Red**
Group of Latin American and Caribbean Countries (GRULAC)	**Orange**
Western European and Other Regional Groups	**Purple**

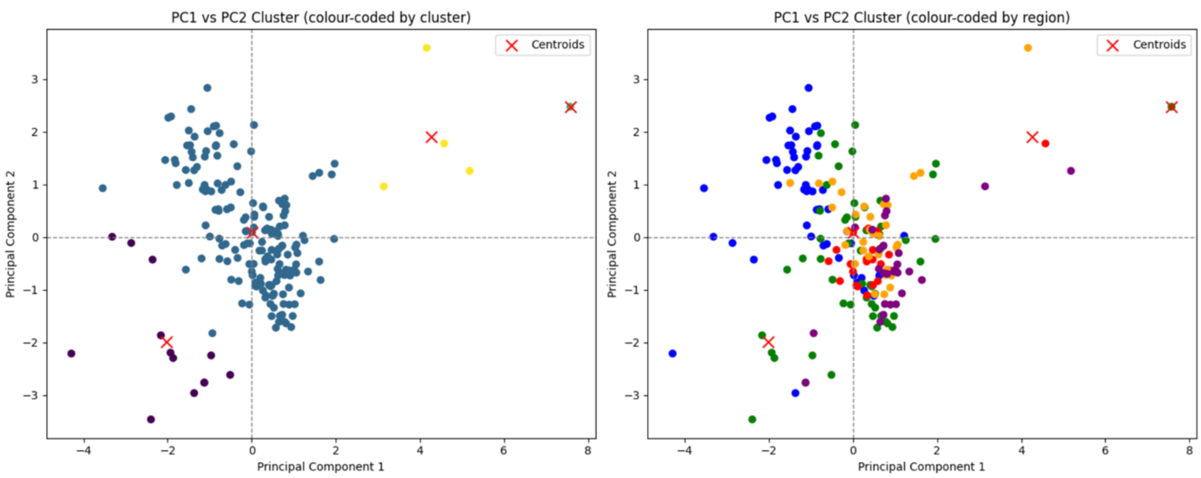


Figure 3: Cluster visualisation of PC1 and PC2 colour-coded by cluster and region

A cluster analysis visualisation for PC1 and PC2, two components that shows the most variance of the data (47.1%) can be seen on Figure 3. Countries from the African Group tend to cluster on the left side of the plot, indicating negative values along PC1. Additionally, most of these countries have positive values along PC2. This pattern suggests that countries in the African Group tend to exhibit certain commonalities in their environmental and socioeconomic characteristics, such as lower HDI, yet higher freshwater resources and forest area. However, there are no significant distinguishable patterns observed among other regional groups based solely on the PC1 vs PC2 plot. An interesting finding is that China is clustered by itself, with high PC1 and PC2 loadings, showing that it has distinct characteristics compared to other countries, including very high GHG emissions. Overall, in the other cluster analysis done, no significant clusters or differences between different PCs were found between regions.

Normalisation

For this dataset, the chosen normalisation procedure is the min-max normalisation method. This method scales the feature (indicator) to a range between 0 and 1 based on their minimum and maximum values. The formula used for min-max normalisation is:

$$Xnorm = \frac{X - Xmin}{Xmax - Xmin}$$

Where:

- X is the original value of the feature,
- $Xmin$ is the minimum value of the feature,
- $Xmax$ is the maximum value of the feature, and
- $Xnorm$ is the normalised value.

No scale adjustments were deemed necessary for this dataset as the min-max normalisation method already scales the values between 0 and 1, preserving the relative differences between them. This method was chosen as it preserves the meaningful patterns or variations between the data. It also exhibits reduced sensitivity to outliers, which is important given the dataset's broad range of data points.

Weighting and Aggregation

Each of the indicators' scores are calculated based on their categories (environmental, socioeconomic, and governance) to make sub-indices for each category, which is then combined to make a final Low-Carbon Development Index.

For each sub-indices, different weightings for each indicator are defined based on their importance in the LCD.

Environmental Score

Table 7: Weighting for each environmental indicator

Indicator	Weighting
Forest Area	5%
Freshwater	5%
Renewable Energy Consumption	10%
GHG Emissions	80%

GHG emissions are the most crucial environmental indicators for assessing countries' emission levels and the primary contributors to climate change[9]. Mitigating emissions is central to any low-carbon development strategy; hence, the highest weighting emphasises the importance of reducing emissions intensity and fostering sustainable practices across sectors. While also a factor, forest area, freshwater, and renewable energy consumption do not capture the wide dimension of low-carbon development, so lower weightings are assigned.

The formula used to calculate the Environmental Score is as follows:

$$Environmental\ Score = \frac{Forest\ Area + Freshwater + 2\ Renewable\ Energy\ Consumption + 16\ GHG\ Emissions}{20}$$

Socioeconomic Score

Table 8: Weighting for each socioeconomic indicator

Indicator	Weighting
Human Development Index	100%

As there is only one indicator in the socioeconomic aspect, therefore the socioeconomic score is equal to the HDI.

The formula used to calculate the Socioeconomic Score is as follows:

$$Socioeconomic\ Score = HDI$$

Governance Score

Table 9: Weighting for each governance indicator

Indicator	Weighting
UNFCCC	40%
Paris Agreement	60%

[9] https://www.sciencedirect.com/science/article/abs/pii/S2213138819300116

The weighting for the UNFCCC (40%) and the Paris Agreement (60%) reflects their pivotal roles in global climate governance and shaping countries' commitments to carbon reduction. The slightly higher weighting for the Paris Agreement acknowledges its newer and more stringent targets, signalling a shift toward stronger international cooperation and a heightened focus on achieving meaningful emissions reductions.

The formula used to calculate the Governance Score is as follows:

$$Governance\ Score = \frac{2\ UNFCCC + 3\ Paris\ agreement}{5}$$

Low-Carbon Development Index

Sub-Index	Weighting
Environmental Score	50%
Socioeconomic Score	37.5%
Governance Score	12.5%

Assigning the highest weighting (50%) to the Environmental Score ensures the LCDI primarily reflects a country's environmental performance and its direct link to a low-carbon trajectory. This aligns with the core objective of the index. Measures within the Environmental Score are directly tied to carbon emissions.

Giving a substantial weighting (37.5%) to the Socioeconomic Score recognises that sustainable development and the transition to a low-carbon economy are intertwined with factors like human development and economic capacity. Countries with higher socioeconomic scores may have a greater ability to invest in clean technologies, infrastructure, and education that support the transition.

While a smaller weighting (12.5%) is assigned to the Governance Score, it still plays a crucial role. Good governance, accountability, and commitment to international agreements are indicators of a supportive regulatory environment important for long-term success. But despite that, commitment does not always equal to full compliance.

The formula used to calculate the Low-Carbon Development Index (LCDI) is as follows:

$$LCDCI = \frac{4\ Environmental\ Score + 3\ Socioeconomic\ Score + Governance\ Score}{8}$$

Correlation Between the LCDI and Other Indexes

Understanding the correlation between the Low-Carbon Development Index (LCDI) and other existing indexes is crucial for assessing its effectiveness and relevance in the broader context of sustainable development. By examining the relationships between the

LCDI and established indices such as the Sustainable Development Goals (SDGs) Index and the Environmental Performance Index (EPI), we can gain valuable insights into how well the LCDI aligns with key indicators of environmental sustainability, socioeconomic development, and governance.

To do this, calculation of Pearson Correlation Coefficient with scatterplot visualisation is done between the indices.

LCDI – Sustainable Development Goals Index

The correlation analysis between the Low-Carbon Development Index (LCDI) and the Sustainable Development Goals Index (SDGI) reveals a robust positive relationship, with a correlation coefficient of 0.719. The associated p-value, which is significantly below the conventional threshold of 0.05, suggests strong statistical significance. This indicates that countries with higher LCDI scores tend to exhibit stronger alignment with the Sustainable Development Goals (SDGs), highlighting the interconnectedness between low-carbon development efforts and broader sustainable development objectives. The findings underscore the importance of considering environmental sustainability alongside socioeconomic and governance factors in achieving comprehensive development goals.

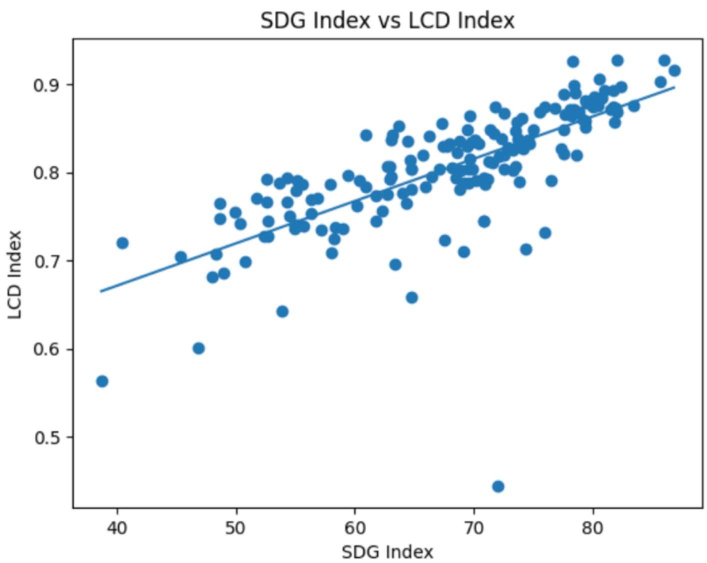


Figure 4: Scatterplot depicting the relationship between LCDI and SDGI

LCDI – Environmental Performance Index

Similarly, an examination of the correlation between the LCDI and the Environmental Performance Index (EPI) demonstrates a significant positive association, with a correlation coefficient of 0.694 and a p-value of 4.74e-27. This suggests a robust relationship between a country's low-carbon development performance and its environmental performance as measured by the EPI. Countries that score higher on the EPI tend to also perform well in terms of low-carbon development, indicating the critical role of environmental sustainability in fostering a low-carbon economy and society. The strong correlation underscores the need for integrated policy approaches that address both environmental quality and carbon emissions reduction to achieve sustainable development objectives effectively.

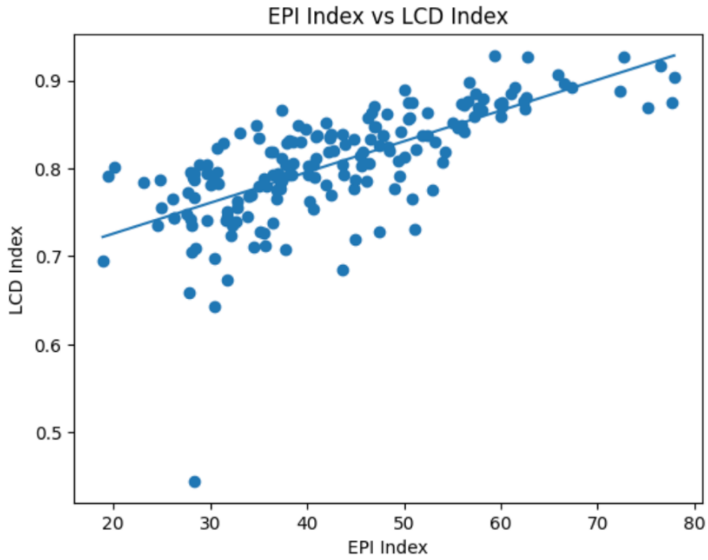


Figure 5: Scatterplot depicting the relationship between LCDI and EPI

Visualisation of the LCDI and Country Ranks

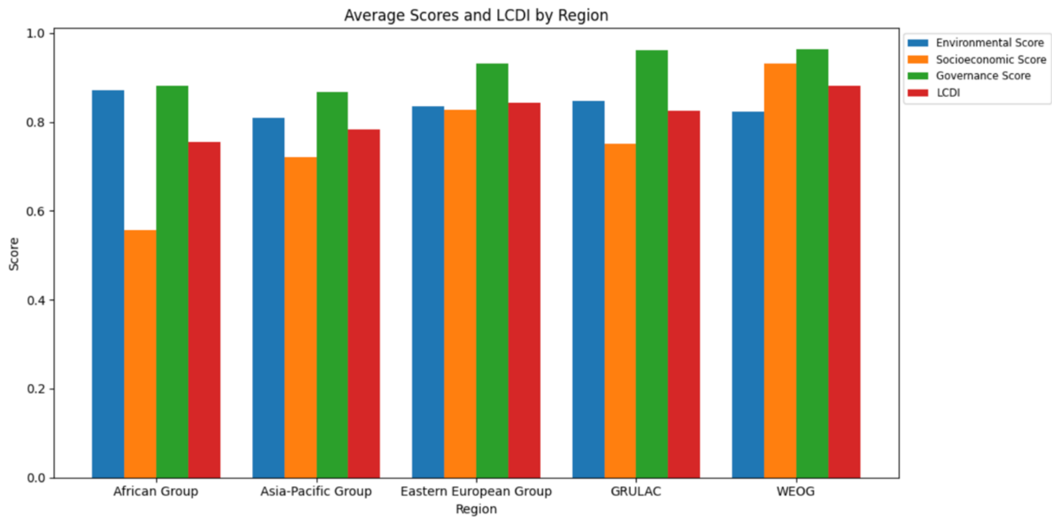


Figure 6: Average value of indicator scores and LCDI by region

The top 10 ranks of the LCDI are dominated by Western Europe (WEOG) countries, with some Eastern Europe (EEG) countries appearing in the top 20. The EU has set a goal to reduce its net greenhouse gas emissions by 90% by 2040, aiming to become the world's first climate-neutral continent, as announced by the European Commission ahead of elections in June 2024[10]. Among the top 30 countries, two developed Asian nations stand out: Singapore (21st) and the Republic of Korea (27th). Singapore has announced ambitious plans to achieve net zero emissions beyond 2050, while South Korea was the first East Asian nation to declare net zero emissions by 2050[11].

The bottom 10 ranks of the LCDI are dominated by African and Asia-Pacific countries, showcasing contrasting differences. The low rankings of African nations are primarily attributed to low Human Development Index (HDI) scores and limited commitment to the global climate change agenda. An exception is China, as while the Asia-Pacific region faces significant impacts from climate change, it also contributes substantially to the issue gearing by its tremendous economic growth. This region generates roughly half of the world's carbon dioxide (CO2) emissions and is home to five of the largest greenhouse gas-emitting countries. Given Asia's significant current emissions and expected future growth, the policies of major CO2-emitting nations such as China and India will be crucial for global emission reduction efforts[12]. Table 10 presents a list of countries categorised by their regions, environmental, socioeconomic, and governance scores, along with their corresponding LCDI ranks.

Table 10: Country ranks of LCDI result

#	Country	Region	Environmental Score	Socioeconomic Score	Governance Score	LCDI
1	Norway	WEOG	0.885	0.966	0.983	0.928
2	Sweden	WEOG	0.895	0.952	0.983	0.927
3	Iceland	WEOG	0.888	0.959	0.983	0.926
4	Finland	WEOG	0.885	0.942	0.965	0.916
5	Liechtenstein	WEOG	0.879	0.942	0.965	0.913
6	Switzerland	WEOG	0.842	0.967	0.983	0.906
7	Denmark	WEOG	0.846	0.952	0.983	0.903
8	New Zealand	WEOG	0.847	0.939	0.983	0.898
9	Austria	WEOG	0.858	0.926	0.965	0.897
10	Estonia	Eastern European Group	0.87	0.899	0.965	0.893
11	Slovenia	Eastern European Group	0.854	0.926	0.948	0.893
12	Canada	WEOG	0.828	0.935	1.0	0.89
13	Luxembourg	WEOG	0.84	0.927	0.965	0.888

[10] https://www.theguardian.com/environment/2024/feb/06/eu-lays-out-plan-to-cut-greenhouse-emissions-by-90-by-2040
[11] https://www.sciencedirect.com/science/article/pii/S2949753123000346
[12] https://www.imf.org/en/Publications/fandd/issues/2021/09/asia-climate-emergency-role-of-fiscal-policy-IMF-dabla

#	Country	Region	Environmental Score	Socioeconomic Score	Governance Score	LCDI
14	Latvia	Eastern European Group	0.873	0.879	0.948	0.885
15	Ireland	WEOG	0.817	0.95	0.965	0.885
16	Netherlands	WEOG	0.807	0.946	0.983	0.881
17	Belgium	WEOG	0.818	0.942	0.93	0.878
18	Germany	WEOG	0.794	0.95	0.983	0.876
19	Spain	WEOG	0.824	0.911	0.983	0.876
20	Portugal	WEOG	0.848	0.874	0.983	0.875
21	Singapore	Asia-Pacific Group	0.809	0.949	0.913	0.874
22	Australia	WEOG	0.789	0.946	1.0	0.874
23	United Kingdom of Great Britain and Northern Ireland	WEOG	0.798	0.94	0.983	0.874
24	Czechia	Eastern European Group	0.829	0.895	0.983	0.873
25	Lithuania	Eastern European Group	0.85	0.879	0.948	0.873
26	Greece	WEOG	0.833	0.893	0.965	0.872
27	Republic of Korea	Asia-Pacific Group	0.799	0.929	0.983	0.871
28	Croatia	Eastern European Group	0.85	0.878	0.93	0.87
29	Malta	WEOG	0.81	0.915	0.965	0.869
30	France	WEOG	0.813	0.91	0.965	0.868
31	Italy	WEOG	0.816	0.906	0.965	0.868
32	Cyprus	Asia-Pacific Group	0.825	0.907	0.913	0.867
33	Uruguay	GRULAC	0.868	0.83	0.965	0.866
34	United Arab Emirates	Asia-Pacific Group	0.788	0.937	0.948	0.864
35	Chile	GRULAC	0.842	0.86	0.965	0.864
36	Israel	WEOG	0.805	0.915	0.93	0.862
37	Slovakia	Eastern European Group	0.837	0.855	0.965	0.86
38	Japan	Asia-Pacific Group	0.781	0.92	0.983	0.858
39	Poland	Eastern European Group	0.812	0.881	0.965	0.857

#	Country	Region	Environmental Score	Socioeconomic Score	Governance Score	LCDI
40	Costa Rica	GRULAC	0.868	0.806	0.965	0.857
41	Panama	GRULAC	0.859	0.82	0.948	0.855
42	Bahrain	Asia-Pacific Group	0.797	0.888	0.965	0.852
43	Hungary	Eastern European Group	0.823	0.851	0.965	0.851
44	Sri Lanka	Asia-Pacific Group	0.867	0.78	0.983	0.849
45	Saint Kitts and Nevis	GRULAC	0.823	0.838	0.983	0.849
46	Georgia	Eastern European Group	0.845	0.814	0.965	0.848
47	Montenegro	Eastern European Group	0.873	0.844	0.757	0.848
48	Romania	Eastern European Group	0.835	0.827	0.965	0.848
49	Albania	Eastern European Group	0.861	0.789	0.965	0.847
50	Seychelles	African Group	0.839	0.802	1.0	0.845
51	Peru	GRULAC	0.871	0.762	0.983	0.844
52	Gabon	African Group	0.941	0.693	0.896	0.842
53	Bahamas	GRULAC	0.827	0.82	0.965	0.842
54	Qatar	Asia-Pacific Group	0.793	0.875	0.93	0.841
55	Brazil	GRULAC	0.866	0.76	0.965	0.839
56	Bhutan	Asia-Pacific Group	0.929	0.681	0.948	0.838
57	Antigua and Barbuda	GRULAC	0.81	0.826	0.983	0.838
58	Bulgaria	Eastern European Group	0.838	0.799	0.948	0.837
59	Argentina	GRULAC	0.797	0.849	0.965	0.837
60	Trinidad and Tobago	GRULAC	0.822	0.814	0.965	0.837
61	Colombia	GRULAC	0.867	0.758	0.948	0.836
62	Grenada	GRULAC	0.837	0.793	0.965	0.836
63	Paraguay	GRULAC	0.883	0.731	0.965	0.836
64	Kuwait	Asia-Pacific Group	0.793	0.847	0.965	0.835

#	Country	Region	Environmental Score	Socioeconomic Score	Governance Score	LCDI
65	Malaysia	Asia-Pacific Group	0.823	0.807	0.965	0.835
66	Andorra	WEOG	0.84	0.884	0.67	0.835
67	Mauritius	African Group	0.819	0.796	1.0	0.833
68	Ecuador	GRULAC	0.846	0.765	0.983	0.833
69	Palau	Asia-Pacific Group	0.847	0.797	0.878	0.832
70	Thailand	Asia-Pacific Group	0.821	0.803	0.965	0.832
71	Bosnia and Herzegovina	Eastern European Group	0.86	0.779	0.861	0.83
72	Barbados	GRULAC	0.812	0.809	0.965	0.83
73	Guyana	GRULAC	0.862	0.742	0.965	0.83
74	Fiji	Asia-Pacific Group	0.865	0.729	0.983	0.829
75	Saudi Arabia	Asia-Pacific Group	0.761	0.875	0.965	0.829
76	Serbia	Eastern European Group	0.839	0.805	0.843	0.827
77	Cuba	GRULAC	0.839	0.764	0.965	0.827
78	Armenia	Eastern European Group	0.814	0.786	0.983	0.825
79	Oman	Asia-Pacific Group	0.794	0.819	0.948	0.823
80	Belarus	Eastern European Group	0.826	0.801	0.861	0.821
81	Dominica	GRULAC	0.841	0.74	0.983	0.821
82	Republic of Moldova	Eastern European Group	0.83	0.763	0.948	0.82
83	Brunei Darussalam	Asia-Pacific Group	0.836	0.823	0.739	0.819
84	Marshall Islands	Asia-Pacific Group	0.839	0.731	1.0	0.819
85	North Macedonia	Eastern European Group	0.841	0.765	0.896	0.819
86	Samoa	Asia-Pacific Group	0.868	0.702	0.965	0.818
87	Dominican Republic	GRULAC	0.838	0.766	0.896	0.818
88	Mexico	GRULAC	0.798	0.781	0.983	0.815

#	Country	Region	Environmental Score	Socioeconomic Score	Governance Score	LCDI
89	Belize	GRULAC	0.86	0.7	0.965	0.813
90	Kazakhstan	Asia-Pacific Group	0.785	0.802	0.948	0.812
91	Maldives	Asia-Pacific Group	0.803	0.762	1.0	0.812
92	Saint Lucia	GRULAC	0.828	0.725	0.983	0.809
93	Botswana	African Group	0.841	0.708	0.965	0.807
94	Azerbaijan	Eastern European Group	0.805	0.76	0.948	0.806
95	Suriname	GRULAC	0.866	0.69	0.913	0.806
96	Venezuela (Bolivarian Republic of)	GRULAC	0.847	0.699	0.965	0.806
97	Tunisia	African Group	0.813	0.732	0.983	0.804
98	Jordan	Asia-Pacific Group	0.81	0.736	0.983	0.804
99	Mongolia	Asia-Pacific Group	0.806	0.741	0.983	0.804
100	Nicaragua	GRULAC	0.869	0.669	0.948	0.804
101	Philippines	Asia-Pacific Group	0.833	0.71	0.965	0.803
102	Bolivia (Plurinational State of)	GRULAC	0.841	0.698	0.965	0.803
103	Jamaica	GRULAC	0.84	0.706	0.948	0.803
104	Viet Nam	Asia-Pacific Group	0.818	0.726	0.965	0.802
105	Lao People's Democratic Republic	Asia-Pacific Group	0.889	0.62	0.948	0.796
106	Guatemala	GRULAC	0.884	0.629	0.948	0.796
107	Nepal	Asia-Pacific Group	0.898	0.601	0.965	0.795
108	Algeria	African Group	0.784	0.745	0.983	0.794
109	Tonga	Asia-Pacific Group	0.809	0.739	0.896	0.794
110	Turkmenistan	Asia-Pacific Group	0.792	0.744	0.948	0.794
111	Congo	African Group	0.909	0.593	0.93	0.793
112	Zambia	African Group	0.914	0.569	0.983	0.793
113	Honduras	GRULAC	0.881	0.624	0.948	0.793
114	Uzbekistan	Asia-Pacific Group	0.794	0.727	0.983	0.792
115	Cameroon	African Group	0.901	0.587	0.965	0.791

#	Country	Region	Environmental Score	Socioeconomic Score	Governance Score	LCDI
116	Myanmar	Asia-Pacific Group	0.885	0.608	0.965	0.791
117	Ukraine	Eastern European Group	0.804	0.734	0.913	0.791
118	El Salvador	GRULAC	0.839	0.674	0.948	0.791
119	Indonesia	Asia-Pacific Group	0.804	0.713	0.965	0.79
120	Russian Federation	Eastern European Group	0.722	0.821	0.965	0.79
121	Egypt	African Group	0.788	0.728	0.965	0.788
122	Morocco	African Group	0.813	0.698	0.948	0.787
123	Papua New Guinea	Asia-Pacific Group	0.903	0.568	0.983	0.787
124	Tajikistan	Asia-Pacific Group	0.841	0.679	0.896	0.787
125	Eswatini	African Group	0.883	0.61	0.93	0.786
126	Zimbabwe	African Group	0.909	0.55	1.0	0.786
127	Micronesia (Federated States of)	Asia-Pacific Group	0.849	0.634	0.983	0.785
128	Bangladesh	Asia-Pacific Group	0.825	0.67	0.965	0.784
129	Kenya	African Group	0.874	0.601	0.965	0.783
130	Cabo Verde	African Group	0.83	0.661	0.948	0.781
131	Cambodia	Asia-Pacific Group	0.875	0.6	0.948	0.781
132	Solomon Islands	Asia-Pacific Group	0.898	0.562	0.965	0.78
133	Tuvalu	Asia-Pacific Group	0.824	0.653	0.983	0.78
134	Uganda	African Group	0.9	0.55	0.983	0.779
135	Equatorial Guinea	African Group	0.852	0.65	0.861	0.777
136	South Africa	African Group	0.787	0.717	0.913	0.776
137	Kiribati	Asia-Pacific Group	0.845	0.628	0.948	0.776
138	Vanuatu	Asia-Pacific Group	0.846	0.614	0.983	0.776
139	Sao Tome and Principe	African Group	0.871	0.613	0.878	0.775
140	Ghana	African Group	0.858	0.602	0.948	0.773
141	Comoros	African Group	0.859	0.586	0.965	0.77
142	United Republic of Tanzania	African Group	0.909	0.532	0.93	0.77

#	Country	Region	Environmental Score	Socioeconomic Score	Governance Score	LCDI
143	Togo	African Group	0.891	0.547	0.948	0.769
144	Nigeria	African Group	0.881	0.548	0.965	0.767
145	Haiti	GRULAC	0.885	0.552	0.93	0.766
146	Democratic Republic of the Congo	African Group	0.933	0.481	0.948	0.765
147	Namibia	African Group	0.836	0.61	0.948	0.765
148	Guinea-Bissau	African Group	0.927	0.483	0.948	0.763
149	Rwanda	African Group	0.89	0.548	0.896	0.763
150	Côte d'Ivoire	African Group	0.87	0.534	0.965	0.756
151	Liberia	African Group	0.939	0.487	0.826	0.755
152	Malawi	African Group	0.885	0.508	0.965	0.754
153	Ethiopia	African Group	0.891	0.492	0.965	0.751
154	Sudan	African Group	0.863	0.516	0.983	0.748
155	Democratic People's Republic of Korea	Asia-Pacific Group	0.835	0.554	0.965	0.746
156	Mozambique	African Group	0.907	0.461	0.948	0.745
157	State of Palestine	Asia-Pacific Group	0.804	0.716	0.6	0.745
158	Senegal	African Group	0.86	0.517	0.965	0.744
159	Turkey	Asia-Pacific Group	0.8	0.855	0.191	0.744
160	Madagascar	African Group	0.9	0.487	0.878	0.742
161	Benin	African Group	0.861	0.504	0.965	0.74
162	Guinea	African Group	0.882	0.471	0.983	0.74
163	Sierra Leone	African Group	0.897	0.458	0.948	0.739
164	Gambia	African Group	0.864	0.495	0.965	0.738
165	Pakistan	Asia-Pacific Group	0.825	0.54	0.965	0.736
166	Lesotho	African Group	0.843	0.521	0.948	0.735
167	Mauritania	African Group	0.824	0.54	0.965	0.735
168	United States of America	WEOG	0.518	0.927	1.0	0.732
169	Djibouti	African Group	0.833	0.515	0.948	0.728
170	Timor-Leste	Asia-Pacific Group	0.843	0.566	0.757	0.728
171	Burkina Faso	African Group	0.88	0.438	0.983	0.727
172	Syrian Arab Republic	Asia-Pacific Group	0.8	0.557	0.93	0.725
173	Lebanon	Asia-Pacific Group	0.813	0.723	0.365	0.723
174	Central African Republic	African Group	0.913	0.387	0.948	0.72
175	Libya	African Group	0.799	0.746	0.278	0.714

#	Country	Region	Environmental Score	Socioeconomic Score	Governance Score	LCDI
176	Kyrgyzstan	Asia-Pacific Group	0.834	0.701	0.261	0.712
177	Iran (Islamic Republic of)	Asia-Pacific Group	0.753	0.78	0.33	0.71
178	Mali	African Group	0.87	0.41	0.965	0.709
179	Niger	African Group	0.883	0.394	0.948	0.708
180	Chad	African Group	0.873	0.394	0.965	0.705
181	Angola	African Group	0.888	0.591	0.261	0.698
182	India	Asia-Pacific Group	0.662	0.644	0.983	0.695
183	Afghanistan	Asia-Pacific Group	0.818	0.462	0.826	0.685
184	Somalia	African Group	0.903	0.38	0.704	0.682
185	Eritrea	African Group	0.889	0.493	0.348	0.673
186	Iraq	Asia-Pacific Group	0.786	0.673	0.104	0.658
187	Burundi	African Group	0.892	0.42	0.313	0.643
188	Yemen	Asia-Pacific Group	0.803	0.424	0.33	0.602
189	South Sudan	African Group	0.837	0.381	0.017	0.564
190	China	Asia-Pacific Group	0.052	0.788	0.983	0.444

Note: WEOG = West European and Other Groups; EEG = Group of Eastern European States; GRULAC = Group of Latin America and Caribbean Countries

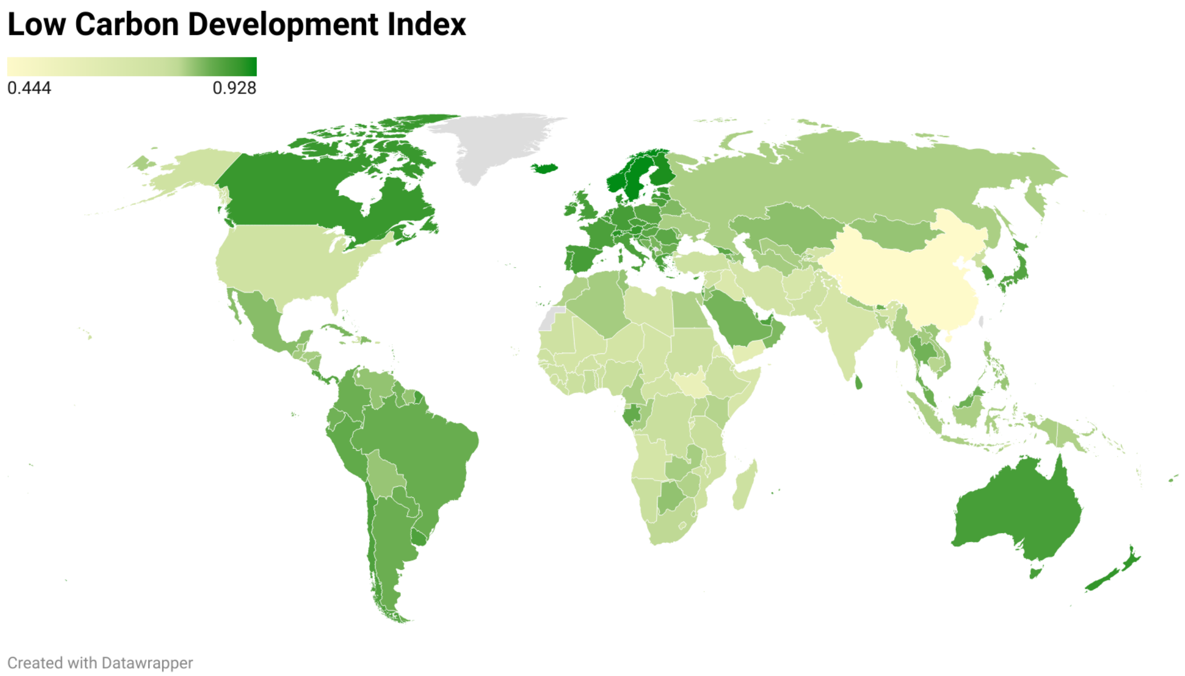


Figure 7: Map illustrating LCDI values, with countries colour-coded accordingly

An interactive visualisation of the LCDI map and bar chart can be found in the "web-visualisation" folder of this GitHub repository: https://github.com/luanakimley/low-carbon-development-composite-index/tree/main/web-visualisation.

Concluding Remark

Low-Carbon Development is pivotal in addressing climate change and attaining sustainable development goals. This paper aims to develop a robust framework for constructing a Low-Carbon Development Index (LCDI) that assesses a country's progress towards sustainable development by integrating environmental and social dimensions with economic development and governance to target lower emissions. Various statistical analyses are employed, including defining indicators for the LCDI through expert consultation, collecting and selecting data from secondary sources, and imputing missing data, and multivariate analysis techniques are conducted, followed by normalizing the data points. The findings reveal a strong positive correlation between the LCDI and the Sustainable Development Goals Index (SDGI), with a correlation coefficient of 0.719 and a significantly low p-value, indicating robust statistical significance. Additionally, the correlation between the LCDI and the Environmental Performance Index (EPI) demonstrates a substantial positive association, with a correlation coefficient of 0.694 and a p-value of 4.74e-27, underscoring a robust link between a country's low-carbon development performance and its environmental performance measured by the EPI.

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