ASSESSMENT OF ENERGY SYSTEMS

Measuring an Environmental Index: Climate Change & Renewable energy perspective.

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Introduction

The environmental challenges facing the world today demand a comprehensive and data-driven approach to assessing sustainability performance. Climate change, greenhouse gas emission, and the transition to renewable energy required robust indicators to measure progress and guide policymaking.

Over the past years, various environmental indices have been developed to track and compare countries' performance. The table below shows a summary of some relevant indicators developed:

Table 1 : Review of some sustainable index: key indicators and focus area.

Index	Developer	Focus	Key Indicators
Environmental Performance Index (EPI)	(Morse, 2019)	Environmental health and ecosystem vitality	Air quality, water resources, climate change policies
Climate Change Performance Index (CCPI)	(Burck et al., 2025)	Climate protection efforts	GHG emissions, renewable energy, energy use and climate policies
Sustainable Development Goal (SDG) Index	(*Sustainable Development Report 2024*, n.d.)	UN SDG progress	SDG indicators
Climate Risk Index (CRI)	(*Climate Risk Index 2025.Pdf*, n.d.)	Extreme weather event impacts	Disaster fatalities, economic losses, affected population
Low Carbon Economy Index (LCEI)	(Pwc, 2017)	Transition to a low-carbon economy	Carbon emissions per GDP, decarbonization rate
Environmental Quality Index (EQI)	(USEPA, 2020)	Environmental quality (risks & changes)	Climate variability, deforestation, land degradation
Energy Indicators for Sustainable Development	(Vera & Langlois, 2007)	Sustainable energy development	Energy consumption per capita, energy intensity, CO_2 emissions
Energy Indicators for Tracking Sustainability in Developing Countries	(Kemmler & Spreng, 2007)	Energy sustainability tracking in developing countries	Energy use, renewable energy share, efficiency metrics

Energy Indicators for Sustainable Development in Baltic States	(Streimikiene et al., 2007)	Sustainable energy development in Baltic States	Energy security, environmental impacts, energy intensity
Sustainable Energy Development Index (SEDI)	(Iddrisu & Bhattacharyya, 2015)	Measuring sustainable energy development	Technical sustainability, economic sustainability, social sustainability, environmental sustainability, institutional sustainability

While these studies were impactful and show how important it is to measure an index in the field of sustainability, they often have certain limitations. Many indices assess a wide range of environmental factors but lack a dedicated focus on renewable energy and climate change mitigation. Also, more indices focus on global ranking, making it difficult to extract country-specific insights for smaller nations. Many African countries, including those in our study, suffer from data gaps or inconsistent reporting in global indices. Current indices do not fully integrate both climate change and renewable energy performance into single composite measures. To address these gaps, our study develops a custom Environmental Index focused on climate change and renewable energy perspective for 10 African countries: *Algeria, Benin, Botswana, Cameroon, Côte d'Ivoire, Ghana, Senegal, Togo, Tunisia and Zambia*. The rationale behind selecting these countries includes the fact that these countries exhibit varied levels of fossil fuel dependency and renewable energy adoption. Some are highly exposed to climate risk, while others have strong policy commitments.

The aim of this report is to analyse the performance of these selected countries using a composite Environmental Index. The assessment will focus on the year 2020, with a comparative analysis spanning 2000 to 2020 to identify trends in climate and renewable energy performance. Based on this evaluation, the study will provide policy recommendations to guide future sustainable efforts, tailored to each country's progress and challenges.

I. Methodology

1. Selection of relevant indicators

Indicators will be chosen based on their relevance, data availability and ability to measure environmental sustainability effectively. They will be divided into 02 main groups: Climate change indicators (with a focus on GHG emission and air quality) and Renewable energy and Energy transition indicators.

1.1. Climate change indicators

a. Total greenhouse gas emissions including LULUCF (Mt CO_2e)

This indicator is a measure of annual emissions of the six greenhouse gases (GHG) covered by the Kyoto Protocol from the energy, industry, waste, agriculture, and land use, land use changes, and forestry (LULUCF) sectors, standardized to carbon dioxide equivalent values. This indicator tracks a country's carbon footprint and its contribution to global warming (Total Greenhouse Gas Emissions Including LULUCF (Mt CO2e) | Data, n.d.).

b. Carbon dioxide (CO2) emissions excluding LULUCF per capita (t CO2e/capita)

This is the total annual emissions of carbon dioxide (CO2), from the agriculture, energy, waste, and industrial sectors, excluding LULUCF, standardized to carbon dioxide equivalent values divided by the economy's population. This measure allows comparison of environmental impact across countries with different population sizes(EDGAR - The Emissions Database for Global Atmospheric Research, n.d.).

c. Carbon dioxide (CO2) emissions from Power Industry (Energy) (Mt CO2e)

A measure of annual emissions of carbon dioxide (CO2) from electricity and heat generation. Since the power industry is one of the major sources of emissions, reducing these emissions is crucial for climate goals (*Carbon Dioxide (CO2) Emissions from Power Industry (Energy) (Mt CO2e) | Data*, n.d.)

d. PM2.5 air pollution, mean annual exposure (micrograms per cubic meter)

Population-weighted exposure to ambient PM2.5 pollution is defined as the average level of exposure of a nation's population to concentrations of suspended particles measuring less than 2.5 microns in aerodynamic diameter, which are capable of penetrating deep into the respiratory tract and causing severe health damage (*Global Burden of Disease Study 2019 (GBD 2019) Air Pollution Exposure Estimates 1990-2019 | GHDx*, n.d.)

1.2. Renewable energy and Energy transition indicators

a. Fossil fuel energy consumption (% of total)

This indicator highlights the country's dependency in fossil fuel comprises coal, oil, petroleum, and natural gas products (OECD/IEA, 2014) *b. Renewable energy consumption (% of total final energy consumption)*

Renewable energy consumption is the share of renewable energy in total final energy consumption. It indicates the country's progress towards a cleaner energy transition (IEA, IRENA, UNSD, World Bank, WHO., 2023).

c. Renewable electricity output (% of total electricity output)

Renewable electricity is the share of electricity generated by renewable power plants in total electricity generated by all types of plants (© OECD/IEA, 2018)

d. Energy intensity level of primary energy (MJ/$2017 PPP GDP)

Energy intensity level of primary energy is the ratio between energy supply and gross domestic product measured at purchasing power parity. Energy intensity is an indication of how much energy is used to produce one unit of economic output. Lower ratio indicates that less energy is used to produce one unit of output (IEA, IRENA, UNSD, World Bank, WHO., 2023).

e. Access to clean fuels and technologies for cooking (% of population)

Access to clean fuels and technologies for cooking is the proportion of total population primarily using clean cooking fuels and technologies for cooking. This indicator shows the progress of energy transition (IEA, IRENA, UNSD, World Bank, WHO., 2023).

2. Data collection and construction of the database

Based on the chosen countries, data has been collected from reliable global databases such as World Bank. The database is structured to include values for the year 2000 and comparative data from 2020 to assess progress over time.

3. Data normalization

Since indicators have different units and scales, normalization is required. We will use min-max normalization, transforming values into scales from 0 to 100.

4. Assignment of weighting, direction and aggregation

Indicators are weighted equally, given their equal importance in defining environmental performance. Climate change-related indicators negatively impact the index (direction of -1) while renewable energy-related indicators positively impact the index (+1 direction). A summary of these points can be given as follows:

Table 2: Weight, direction and aggregation methodology applied

iCode	IndName	Weight	Direction	Level	Type	Parent
I0.1	Total greenhouse gas emissions	1	-1	1	Indicator	I0
I0.2	Carbon dioxide (CO2) emissions	1	-1	1	Indicator	I0
I0.3	Carbon dioxide (CO2) emissions from Power Industry (Energy)	1	-1	1	Indicator	I0
I0.4	PM2.5 air pollution,	1	-1	1	Indicator	I0
I1.1	Fossil fuel energy consumption	1	-1	1	Indicator	I1
I1.2	Renewable energy consumption	1	1	1	Indicator	I1
I1.3	Renewable electricity output	1	1	1	Indicator	I1
I1.4	Energy intensity	1	1	1	Indicator	I1
I1.5	Access to clean fuels and technologies for cooking	1	1	1	Indicator	I1
I0	Climate change indicators	1	-1	2	Aggregate	EI
I1	Renewable energy and Energy transition indicators	1	1	2	Aggregate	EI
EI	Environmental Index	1	1	3	Aggregate	

At the end of the study, the EI will have a score ranged from 0 to 100 with higher score representing better environmental performance. A higher EI implies that the country has lower emissions, a cleaner energy mix and better air quality. Conversely, a decline EI reflects environmental degradation, higher pollution level, and unsustainable energy profile.

III. Data Analysis and Results

1. Data Analysis

Before conducting the analysis, the following preprocessing steps were applied: Filtering the data to retain only years 2000 and 2020, Handling missing values through interpolation (we used the function TREND in excel) and normalizing indicators.

The selected indicators grouped into two mains sub-index, as illustrated in the figure below, explain the repartition.

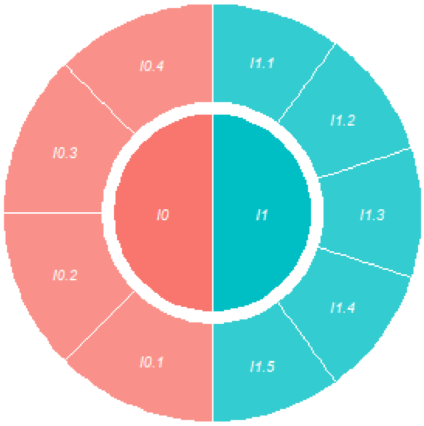

Figure 1: Environmental Index Framework

We also plot the correlation matrix among our indicator for 2000 and 2020 (respectively).

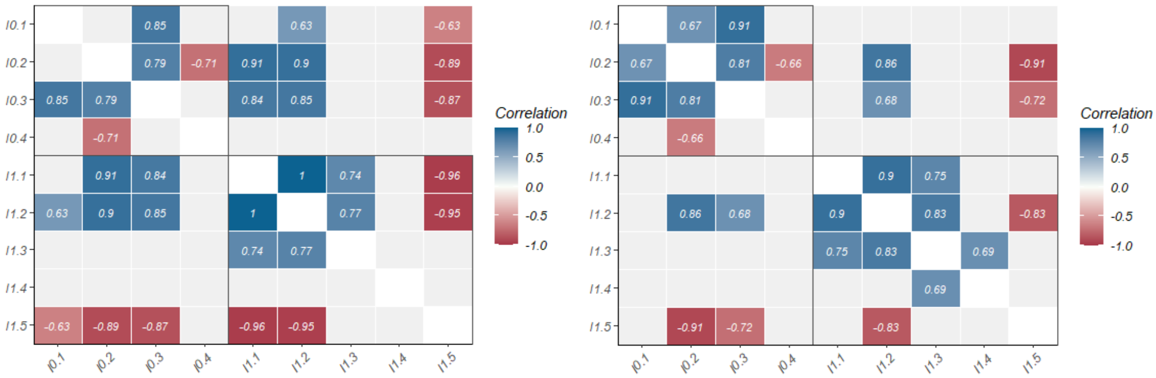

Figure 2: Correlation matrix plot among indicators (respectively for 2000 and 2020)

They have different correlation matrixes because of the variable of data from 2000 to 2020. The indicators in 2000 do not follow the same trends in 2020 due to several reasons. The correlation number between most indicators is close to 1 (or -1) showing the strong relationship between each other.

After data normalization, we plotted the following graphs to see the range excepted (between 0-100) for the year 2000 and 2020, respectively.

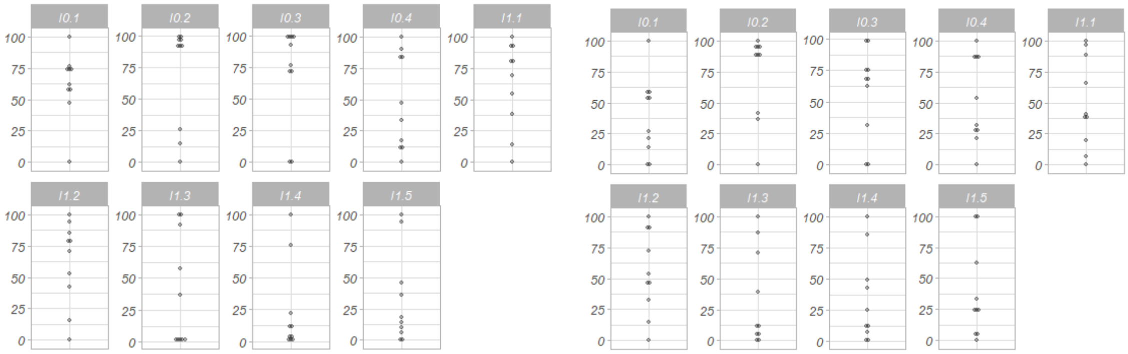

Figure 3: Histogram of normalized data showing data repartition between 0 and 100 (respectively for 2000 and 2020)

2. Finding from index measurement

All parameters put together and methodology well applied, we can observed significant change in Environmental Index (EI) ranking across the analysed countries from 2000 to 2020 by the following table:

Table 3: Comparative ranking for Environmental performance

2000			**2020**		
uCode	Rank	EI	uCode	Rank	EI
BEN	5	53.84	BEN	4	48.62
BWA	8	45.26	BWA	5	46.67
CIV	6	50.27	CIV	6	45.2
CMR	2	74.28	CMR	2	71.6
DZA	10	20.84	DZA	10	25.58
GHA	4	59.65	GHA	9	30.49
SEN	7	45.37	SEN	7	39.29
TGO	3	66.5	TGO	1	72.42
TUN	9	33.77	TUN	8	34.73
ZMB	1	84.71	ZMB	3	71.17

While some countries improved their positions, others experienced a decline. The following bar plot shows the progression of selected countries in environmental performance with the contribution of climate change and renewable energy and energy transition indicators.

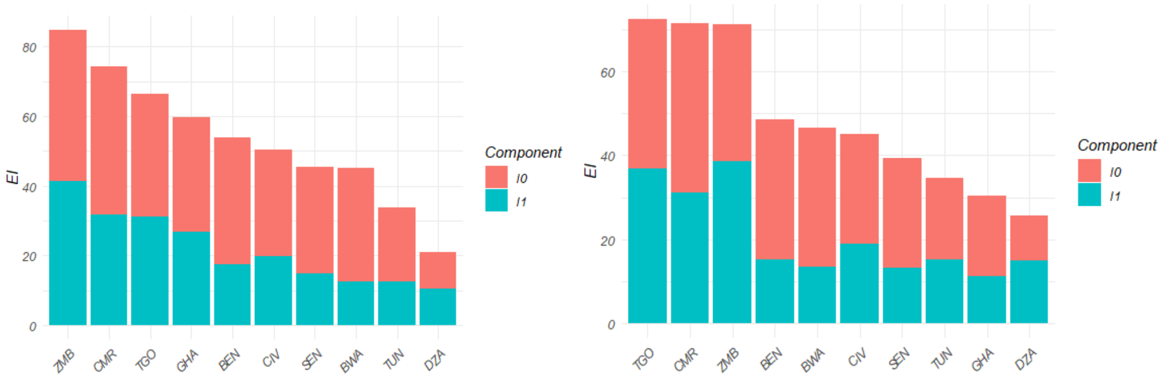

Figure 4: Ranking of Environmental index performance

A grouped bar plot could highlight the evolution of environmental performance for proper analysis and interpretation.

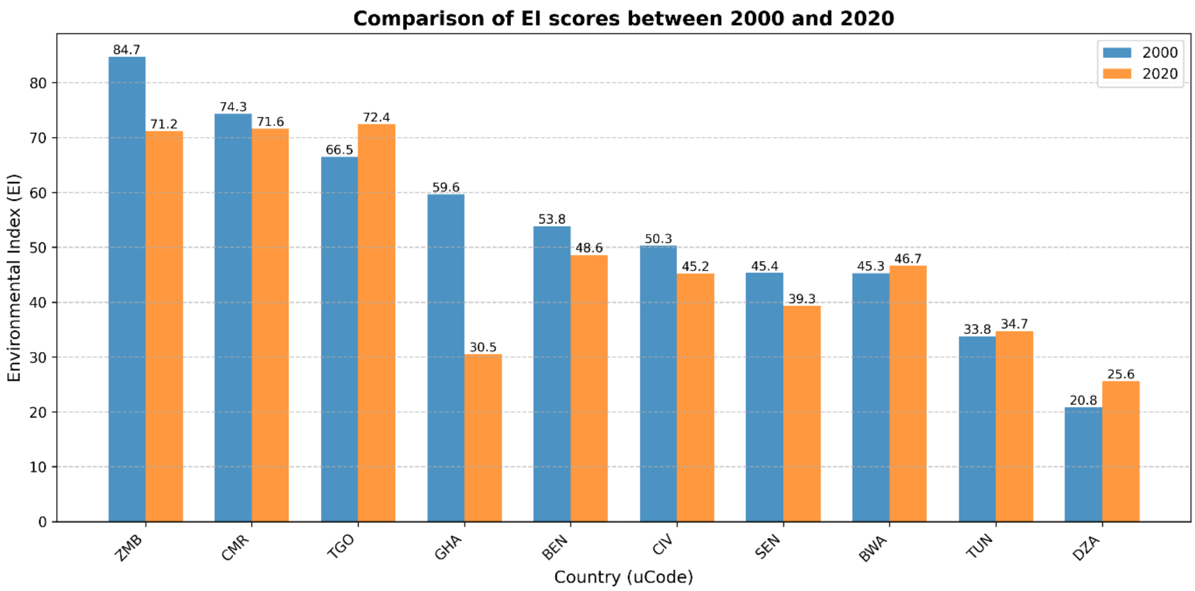

Figure 5: Comparison of EI score between 2000 and 2020

Togo (TGO) moved from 3rd to 1st place, showing the highest improvement in environmental performance. Cameroon (CMR) maintained its 2nd position, with only a slight decrease in its EI score. Benin (BEN) improved from 5th to 4th place, while Botswana (BWA) climbed from 8th to 5th place, indicating progress in sustainability efforts. Côte d'Ivoire (CIV) retained its 6th place, but its EI decrease from 50.27 to 45.2, suggesting environmental challenges that need to be addressed. Senegal (SEN) presents the same trend by keeping its 7th place, with a decrease in its EI index from 45.37 to 39.29, indicating a worsening environmental situation. Ghana (GHA) and Zambia (ZMB) saw significant declines, with Ghana dropping from 4th to 9th place and Zambia from 1st to 3rd place, reflecting worsening environmental conditions. Algeria

(DZA) and Tunisia (TUN), while remaining at the bottom, showed slight improvement in their EI scored.

IV. Policy recommendations

Based on data analysis and trends observed between 2000 and 2020, some policy recommendations could be proposed for all of them and closely for each country. In overall, the following table shows what to do with actionable steps.

Table 4: Policy recommendations for overall studied countries

What to do?	Actionable steps
Reduce GHG emission	▪ Implement carbon pricing mechanism (e.g., carbon tax or cap-and-trade systems) ▪ Develop climate-smart agriculture to reduce emission from land use and forestry
Accelerate renewable energy (R.E) adoption	▪ Subsidize and incentivize investment in R.E ▪ Phase out fossil fuel subsidies and reinvest them into clean energy projects. ▪ Expand access to off-grid renewable systems (especially in rural areas)
Improve Energy mix and Efficiency	▪ Set national target for renewables in the electricity mix ▪ Promote energy audits and certifications for industries and public buildings.
Combat air pollution	▪ Promote or strengthen waste management systems to prevent open burning and air contamination ▪ Promote electric mobility

By country, we may suggest some tailor recommendation according to their performance.

Table 5: Policy recommendations for each studied country

Country	Focus
Togo (TGO)	Scale successful policies, focus on maintaining leadership in renewables.
Cameroon (CMR)	Improve air quality and energy progress (expand their renewables)
Benin (BEN)	Strengthen emission controls and scale clean energy.
Botswana (BWA)	Invest in air pollution reduction and sustainable electricity.
Côte d'Ivoire (CIV) and Senegal (SEN)	Reverse decline through renewable energy policy and GHG regulation.
Zambia (ZMB) and Ghana (GHA)	Recover top position with better energy policy, enforce emission regulations and reforestation
Tunisia (TUN) and Algeria (DZA)	Continue progress with stronger renewable energy investments.

Conclusion

Throughout this study, EI serves as a composite indicator designed to capture a country's overall performance. It is derived from multiple normalized indicators obtained from World

Bank database, focusing on two main environmental dimensions: climate (with focus on Greenhouse gases emission and air quality) and Renewable energy (and Energy transition). Based on data analysis, we were able to observe trend from 2000 to 2020 for selected countries with overall good environmental performance for Togo and bad performance for Tunisia. Improving the EI score requires a multi-dimensional approach, grounded in robust data and targeted interventions. Countries must act decisively on clean energy, emissions reduction, and air quality management to ensure environmental sustainability. Policy recommendations suggested were not only practical but also aligned with global climate goals and regional development priorities.

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