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ENVIRONMENTAL AND ECOSYSTEM PERFORMANCE IN LATIN AMERICA AND AFRICA: AN EXPLORATION USING EPI, SDG, AND DATA MINING

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Abstract

Our research objectives are to reveal the characteristics and trends of environmental health, ecosystem vitality, and climate change for countries in Latin American & Caribbean, North Africa, and Sub-Saharan Africa from 2012 to 2022, relate these trends to their respective sustainability performance, and finally provide environmental policy recommendations with high sustainability effects. The data we use combine Environmental Performance metrics with sustainable development goals agreed by United Nation members. Using data mining techniques, we found two clusters that cross-out geographical boundaries for 2022 and 2012. One cluster dominates the other in all environmental indicators but environmental health, and their differences increased in the last 10 years. Based on our findings, we recommend countries in both clusters to focus on environmental policies that improve environmental health and climate change conditions, but at different rates. These environmental policy recommendations have positive multiplier effects on poverty, health, gender, inequality, and economic progress.

Keywords

Environmental Performance Index, Sustainable Development Goals, Latin America, Africa, Data Mining, Performance Clusters

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1. Introduction

Our research objective is to reveal characteristics and trends for Latin American & Caribbean (LAC) and African countries in terms of environmental performance in general, and more specifically, trends on environmental health, ecosystem vitality, and climate change that may help prioritize environmental policies with strong effects on sustainability goals. The first step is to find appropriate clusters that break geographical boundaries, and then to identify the environmental characteristics and trends from 2012 to 2022 in those clusters, and finally recommend environmental policies with high sustainability effects.

Previous environmental performance studies have included LAC and African countries with all countries of the world or focused in one region only. The limitation of global studies is that African metrics are so low respect to developed rich countries that African countries are just grouped at the bottom by default, western developed countries appear at the top, and LAC countries appear at the middle. This global setup hides the diversity within African and LAC countries. The main limitation of regional studies is that geography becomes the most determinant factor for analysis, as if Africa and LAC were not sharing economic and natural resource characteristics and similar environmental challenges. For these reasons, we propose to analyze a combined LAC and African data set that would be appropriate for discovering clusters that break geographical boundaries and highlight environmental characteristics not presented in the literature before. Knowing these two continents are internally diverse, we answer the following questions: What are the clusters that would LAC and African countries belong using data mining techniques? What are the characteristics and trends for these clusters from 2010 to 2022? Can we provide environmental policy recommendations with high sustainability effects based on these clusters?

In what follows, we present a literature review for sustainability, environmental performance index and clusters. Then, we expand on our methodology and data mining approach, to continue with a cluster exploration and empirical results. Finally, we present our conclusions.

2. Literature Review

2.1 SDGs and EPI Connection

Sustainability is usually defined as the development that meets the needs of the present without compromising the needs of the future generations to meet their needs (Brundtland, 1987), and the three pillars of sustainability are Environment, Economy, and Equity (social justice). Tracking these 3E's is fundamental at the firm and country levels. The Governance and Accountability Institute publishes annual sustainable impact reports for large S&P 500 and Russell 1000 public traded companies since 2002. At the country level, the Sustainable Development Goals Transformation Center publishes reports on the 17 sustainable development goals (SDG) agreed by United Nation members since 2015 (Sachs et.al., 2023). While the SDG goals track the 3E's, there is an older and parallel effort to measure more accurately just the environmental pillar.

The Environmental Performance Report (EPI) is an initiative to provide scientific and credible data to guide policymaking of environmental policies. It is done by the Yale Center for Environmental Law & Policy (YCELP) at Yale University and the Center for International Earth Science Information Network (CIESIN) at Columbia University in partnership with the World Economic Forum. The first EPI report, a pilot attempt released in 2006 included 133 countries, and after nine subsequent reports released every other year, the number of countries increased up to 180 in 2022. The EPI calculation itself has evolved over time too, and authors claim it has become better and better with every new release due to methodology changes, new data availability, lessons from previous methodologies, advances in environmental science and statistical refinements (Hsu 2016, Wendling 2018).

Having good environmental metrics is not only key for environmental and sustainability policies, but it is also critical for research. The EPI reports have the most comprehensive metrics for environmental health, ecosystem vitality, and climate change vitality issues for most countries of the world.

The EPI score is a construct of environmental policy objectives that are supported by issue categories, and these, in turn, are based on performance indicators. As it can be seen in Figure 1, the last EPI score released in 2022 is a weighted average of three policy objectives called Environmental Health (EH), Ecosystem Vitality (EV), and Climate Change (CC) (Wolf 2022). Each policy objective is also a weighted average of 11 issue categories, and in turn, these issues categories are weighted averages of 40 performance indicators. It should be mentioned the number of policy objectives was two rather than three in previous versions and the objective weights evolved from 50/50, to 30/70, then 40/60, and finally 20/42/38 in 2022 (Esty 2006, 2008; Emerson 2010, 2012; Hsu 2014, 2016; Wendling 2018,2020; Wolf 2022).[i] In terms of other index elements, the number of issue categories increased from 6 to 11, and the number of performance indicators went up from 16 to 40 overtime (ibid). All these methodological changes to calculate the EPI implies that we cannot use EPI data as if it were time series because EPI, EH, EV, and CC annual scores are not comparable or equivalent over time (Wendling 2018).[ii] However, it is well suited for data mining techniques, and this is the approach we use in this paper.

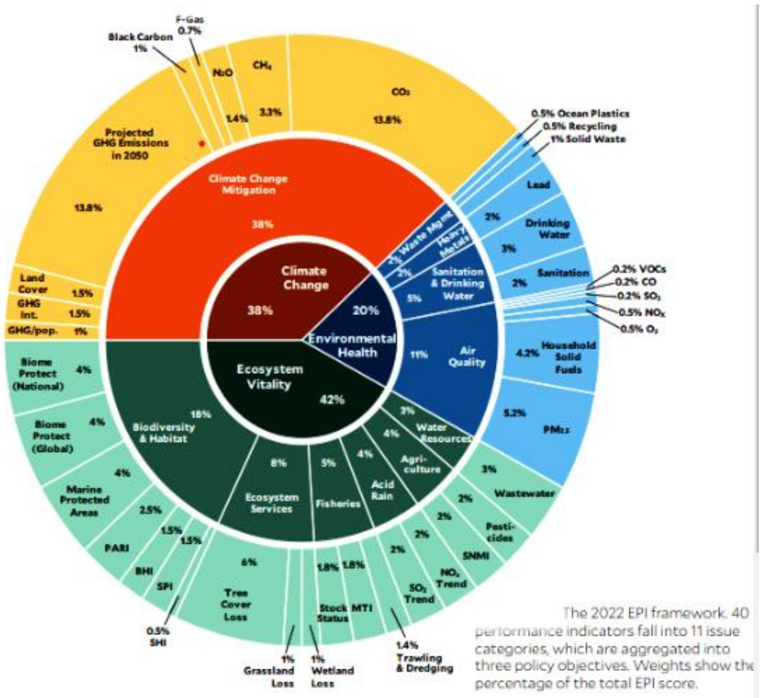

Figure 1. EPI 2022, 3 Policy Objectives, 11 Categories, 40 Performance Indicators
Source: Wolf 2022.

It is found in the literature, that while the EPI score focuses only on the environmental pilar of sustainability, the EPI is directly related to five of the 17 SDGs, and these five SDGs, in turn, are strongly related to all other SDGs. The EPI policy objective Environmental Health (EH) directly relates to Clean Water and Sanitation (SDG #6). The EPI policy objective Climate Chang (CC) directly relates to Affordable Clean Energy and Climate Change (SDGs #7 and #13). Finally, the EPI policy objective Ecosystem Vitality (EV) directly relates to Life Below Water and Life on Land (SDGs #14 and #15). The EPI does not include metrics for other SDGs, for instance, on poverty, hunger, good health, quality education, or gender equality, all key to achieve sustainability. However, SDGs are deeply interconnected through synergies and trade-offs that are key for designing effective sustainable policies.

Most countries do not have enough resources to focus on the entire 17 SDG goals, and in fact, it is better to be selective by focusing on the goals that maximize positive synergies and minimize negative trade-offs. The five environmental SDGs that are directly related to EPI scores, are good picks for sustainable policies. It has been found Clean Water, Affordable Energy, and Climate Change (SDG #6, #7, and #13) are among the most synergistic goals and considered drivers of sustainable progress (Independent Group of Scientists, 2023). The other two goals, Life Below Water and Life on Land (SDGs #14 and #15) have high synergy rates with poverty and gender equality, but on the trade-off side, Life Below Water and Life on Land are the most negatively affected by progress in other areas as economic growth and sustainable cities (Barbier & Burgess, 2019; Pham-Truffert, et.al., 2020; Randers et.al., 2019). The argument that an indirect policy to reduce poverty and gender equality would be better than a direct policy is based on two general findings. The first finding is that poverty, health, gender, and inequality (SDG #1, #3, #5, and #10) are predominantly systemic buffers that have no multiplier effect on other goals (Pham-Truffert et.al.,2020). The second finding is that focusing directly on food and economic growth (SDGs #2, #8) is risky because they can act as multipliers of trade-offs (ibid). So, a sound policy orientation for sustainability would be to focus on the five SDGs related to environmental goals rather than the SDGs related to the economy and social justice directly. These five environmental SDGs are positive drivers to achieve UN social and economic sustainable goals and avoid or minimize the risk of having negative effects by acting directly on social justice and economic goals.

2.2 Empirical Evidence Review for SDGs, EPI, and Clustering

In general, the world is not on track to achieve the 17 SDGs agreed by 2030, it is more off track than four years ago, and the situation is even more challenging for Latin American and African countries (Independent Group of Scientists, 2023). It has been found Climate Change and Life Below Water (SDGs #13 and #14) are far and very far from their 2030 targets, respectively. In terms of climate change, the world is already seen the unprecedented effects of hurricanes, wildfires, floods and damages on agriculture production, fisheries, forests, and ecosystems. Climate change could force as many as 216 million people to move within their countries by 2050, and a 1.6ºC of global warming could cause a 200 percent increase in human displacement across Africa (Independent Group of Scientists, 2023). Climate change, pollution, habitat destruction, subsidies for fishing, overfishing and lack of funding makes the Life Below Water (SDG#14) very far from its 2030 goal. In terms of Life on Land (SDG #15), species are becoming extinct at unprecedented rates due to overharvesting of species, agricultural expansion, logging, and deforestation specially in Latin America and Africa; only 32 % of countries are on track to achieve their national biodiversity targets (Independent Group of Scientists, 2023). There is no progress in drinking water and sanitation (SDG #6)[iii] and there is a backward trend in universal access to electricity (SDG #7).[iv] From the 675 million that lack electricity in the world, 4 in 5 reside in Sub-Saharan Africa, around 20% of African population faces hunger, 22% lack basic drinking water and 54% lack basic sanitation services (Sachs 2023, Independent Group of Scientists, 2023). LAC is the region most affected by the Covid-19 pandemic because of its large informal sector and unequal access to vaccines. The pandemic not only slowed economic activity, tourism, and direct investment, but also affected education levels, increased gender-based violence, and accelerated illegal destruction of marine and terrestrial biodiversity (Independent Group of Scientists, 2023).

Focusing on the five environmental SDG goals seem to be reasonable and practical for LAC and African countries. Prioritization is necessary because of scarce resources, the evident deterioration in environmental conditions during the last ten years, and the positive synergies from these environmental SDGs to the other economic and social justice goals. It is reasonable and practical to explore how a prioritization policy focusing on only environmental goals could provide significant sustainability results. For this, let us explore in more detail the EPI reports for LAC and African countries from 2006 to 2022.

In terms of values for EPI, Environmental Health (EH), Ecosystem Vitality (EV) and Climate Change (CC), the characteristics are:

- Shared geography and climate seem to be a 'natural line of comparison, and countries often think of themselves as being similar and compare themselves with their neighbors' (Esty 2006, 2008). However, countries in Africa and Latin America show wide environmental scores within their regions, ranks vary between 36 to 108 within Latin America& Caribbean (LAC), and between 36 to 180 within Africa. This wide range of scores also applies to EH, EV, and CC. As Esty (2008) states, 'how a country and government use its natural endowment is still a factor' because geographical location is important but not everything.
- Top performers are usually developed and industrialized countries from Europe, Asia, and the Americas. Costa Rica is the only outlier from LAC that appears in the top five from 2008 to 2014, but not in 2022.

- Most Latin American countries are usually mid-rankers in EPI, EH, EV, and CC, between the top and bottom countries.
- The countries at the bottom are very poor countries, densely populated industrializing countries with stressed ecosystems and arid countries with limited natural resources. In general, the countries at the bottom are more diverse than those at the top and include most Sub-Saharan African countries (SSA) (Esty 2006, 2008; Emerson 2010, 2012; Hsu 2014, 2016; Wendling 2018,2020; Wolf 2022).
- It is a constant overtime that real GDP per capita (GDPpc) is highly correlated with EPI and EH, not highly correlated but still positively correlated with EV, and less correlated with CC.
- Countries at the bottom show significantly high deltas compared to small deltas for the countries at the top (Emerson 2012; Hsu 2016; Wendling 2020; Wolf 2022).[v]
- The big gains for countries with values at the bottom of the EPI list are done with EH improvements, decrease of child mortality, more access to water and sanitation, but do not show evident EV improvements because climate change and greenhouse emissions are still on the rise for them (Emerson 2012; Hsu 2016).

In terms of grouping countries, the EPI team made clustering efforts to help governments identify peer countries in 2006, 2008, and 2010 with limited success (Esty 2006). Six clusters were identified in 2006 after including all countries and 16 indicators available. LAC countries are clustered with Asian countries with mid-range scores, good water systems, poor air quality, and all have ‘relative intact natural systems but growing resource pressures (Esty 2006). Sub-Saharan African (SSA) countries are clustered in other group with few countries from Asia, all with very poor scores on EH but mid-range to good scores on EV indicators, and most suffered political and social conflicts (Esty 2006). Seven clusters were identified in 2008 and 2010 after including all countries and 25 indicators. However, because the seven groups in 2008 included too many geographically disperse countries and were difficult to explain (Esty 2008), authors made logarithmic transformations to some indicators in 2010 and created more accurate groupings (Emerson 2010).[vi] In this third attempt, North African countries (NAF) are in Cluster 1 with Middle Eastern and South Asian countries sharing poor EH indicators but average on ecosystem indicators. Most Sub-Saharan African (SSA) countries are in cluster 3 mixed with countries with very poor EH but good CC indicators. LAC and some African countries appear in cluster 4, ‘geographically disparate countries’ rich on natural resources, limited development, and average performance on many indicators (Emerson 2010). Cluster 5 includes African and Asian countries with ‘productive natural resources,’ ‘political strife,’ poor EH performance, below average climate change, and low air pollution. Other LAC countries appear in clusters 6 and 7, with more developed countries and higher air and greenhouse per capita emissions.

We can conclude from these global clustering efforts the following,

- Clustering methodology matters to go beyond geographical clusters.
- North African (NAF) and Sub-Saharan (SSA) countries seem to belong to different clusters.
- Latin American& Caribbean (LAC) countries are more varied than African countries and appear clustered in 3 out of 6 groups in 2006, and 4 out of 7 in 2010.
- There are some countries in Latin America and Africa that may belong to similar clusters.

The EPI team did not continue grouping all world countries after 2010 because the results were not clear to guide governmental environmental policies. On the one hand, these efforts included all countries of the world, so the lense was too high and unfocused on LAC and African countries. On the other hand, groups were based on 16 or 25 indicators that are too granular, or the lense was too low to give a more general perspective. For these reasons, we will limit our country sample to just LAC and African countries to zoom in their characteristics, and the metrics for clustering will be EPI policy ratios rather than EPI indicators itself. As it was shown in Figure 1, the EH, EV, and CC, are EPI policy ratios based on granular environmental indicators. By limiting our sample to LAC, SSA, and NAF countries, and using EPI, EH, EV, and CC we expect to find clusters that break geographical proximity but at the same time it provides useful hints for environmental management.

3. Methodology and Data Mining Approach

Our study focuses on the EPI, EH, EV, and CC variables for 2022 and its 10-year change. There are 83 countries reported in the 2022 report for LAC, NAF, and SSA, but only 79 have full data.[vii] This sample size, 79, is well suited to give us a 95% confidence level and 1% of margin of error. Given that environmental performance is correlated to GDP, and environmental policies require economic resources, we complement these environmental variables with GDP per-capita (GDPpc) to reflect country economic wealth for 2022 and 2012 from the World Development Indicators data set.

The density distributions for EPI, EH, EV, CC and GDPpc for 2022 and 2012 do not follow the shape of well-known parametric distributions, like for instance the normal distribution. Instead, these shapes are better approached with Kernell distributions with two or 3 peaks, and no clear patterns. For this reason, we use plot box indicators to identify some data characteristics for all countries, as well as, for our three LAC, SSA, NAF regions, as shown in Table 1.

	EPI		ENV. HEALTH		ENV. VITALITY		CLIMATE CHANGE		GDPpc	
	EPI2012	EPI2022	EH2012	EH2022	EV2012	EV2022	CC2012	CC2022	GDPpc2012	GDPpc2022
ALL-MAX	53.9	56.2	60.0	62.7	62.7	64.7	75.3	79.9	34793.0	34420.1
ALL-Q3	42.9	46.2	39.6	43.1	43.8	51.1	47.3	50.2	12975.9	14732.9
ALL-MEDIAN	36.4	40.1	25.3	28.3	37.8	43.6	41.1	35.5	6952.7	7692.4
ALL-Q1	31.4	32.3	19.4	21.1	31.7	35.5	27.9	29.0	2094.4	2381.2
ALL-MIN	23.7	24.9	9.3	10.9	18.5	20.9	11.1	17.9	814.3	708.2
ALL-IQR	11.5	13.9	20.2	22.0	12.1	15.6	19.4	21.2	10881.6	12351.8
LAC-MAX	53.9	56.2	60.0	62.7	58.3	57.8	70.8	79.9	34793.0	34420.1
LAC-Q3	44.8	49.6	49.9	53.0	45.7	51.4	53.2	55.6	18983.0	22102.2
LAC-MEDIAN	40.55	45.55	41.15	44.95	38.25	44.60	39.90	40.75	12589.02	14980.10
LAC-Q1	33.9	40.0	34.0	36.8	32.2	37.3	27.8	33.9	9514.4	9933.4
LAC-MIN	23.7	26.1	20.8	21.1	18.5	24.9	11.1	26.7	3027.5	2799.1
LAC-IQR	10.9	9.5	15.9	16.2	13.5	14.1	25.5	21.7	9468.5	12168.9
NAF-MAX	33.6	40.7	37.5	43.2	39.5	43.7	33.7	48.3	11270.7	12780.8
NAF-Q3	33.1	38.1	37.1	42.6	38.1	39.1	33.6	38.9	10849.8	11984.1
NAF-MEDIAN	29.00	29.60	25.30	31.50	32.20	32.70	25.20	28.50	10279.86	10577.71
NAF-Q1	25.9	28.0	20.1	23.1	28.5	29.4	19.4	23.0	5939.9	5816.1
NAF-MIN	25.8	27.6	16.3	17.6	27.3	27.2	19.2	20.9	4711.1	3570.6
NAF-IQR	7.3	10.1	17.0	19.5	9.6	9.7	14.2	15.9	4910.0	6168.0
SSA-MAX	50.0	55.6	51.3	57.6	62.7	64.7	75.3	73.7	31680.7	29834.9
SSA-Q3	41.4	44.2	24.0	26.6	45.6	50.8	47.2	48.8	5211.7	5528.9
SSA-MEDIAN	34.45	35.65	20.30	21.45	38.80	43.20	42.00	34.25	2608.41	2954.77
SSA-Q1	31.1	31.0	18.4	19.7	31.9	36.2	31.0	27.0	1655.4	1922.7
SSA-MIN	25.5	24.9	9.3	10.9	20.2	20.9	16.1	17.9	814.3	708.2
SSA-IQR	10.3	13.2	5.6	6.9	13.7	14.6	16.2	21.8	3556.3	3606.2

Table 1: Box Plot Indicators for EPI, EH, EV, CC, and GDPpc per Region (2012, 2022)

Source: This study

For EPI, the general index for environmental performance, and considering the scores in EPI2012 and EPI2022, there is an increase of the median from 36.4 to 40.1, and an increase of the interquartile range (IQR) from 11.5 to 13.9 (Table 1). So, there is an overall improvement of EPI with a higher IQR in the last 10 years. Some countries improve and others are just left behind. To explore what happens regionally, the medians for LAC are the highest, followed by SSA's and then NAF's. All their medians increase, but not all IQRs. In fact, the IQR for LAC decreases. So, LAC is particular in showing higher EPI performance with less IQR, while the other two regions show higher EPI with higher IQR.

For GDPpc, the indicator of economic wealth, and considering the entire sample, there is an increase of the median for GDPpc2012 and GDPpc2022, from $6.9k to $7.7k, and an increase of the interquartile range (IQR) from $10.8k to $12.3k (Table 1). So, there is an increase of economic wealth with more dispersion in the last 10 years. Clearly LAC has the highest medians, SSA the lowest, and NAF is in between. All three regions show higher medians with higher dispersion from 2012 to 2022, and SSA shows strong outliers.[viii] These outliers have GDPpc levels equal to LAC most wealthier countries.

We already mentioned the median for the EPI increased from 2012 to 2022 when considering all countries. However, EH, EV, and CC, the arguments of the EPI score, did not follow the same pattern. The median for EH and EV increased, from 25.3 to 28.3, and 37.8 to 43.6, respectively (Table 1). However, the median for CC decreased from 41.1 to 35.5 (Table 1). So, climate change (CC) did not improve, but this negative effect on EPI was more than compensated by the increments in environmental health (EH) and ecosystem vitality (EV). Furthermore, regional trends differ from the general trend. The EV for NAF shows practically the same median and IQR from 2012 to 2022; the median CC for SSA decreases and it increases for LAC and NAF (Table 1).

In summary, this first approach to analyze our data distribution indicators shows that there is an improvement of EPI scores and GDPpc with higher IQR. At the same time, geographical regions also show improvements with higher dispersion, creating conditions for clustering countries beyond geographical regional boundaries.

We can also argue that this clustering effort should consider all five variables together, EPI, GDPpc, EH, EV, and CC. On the one hand, the medians for EH, EV, and CC increase or decrease with higher IQRs, and the three geographical regions do not follow equal trends. So, the possibility of clustering with cross geographical regions is also present for EH, EV, and CC, as it was for EPI and GDPpc. Furthermore, each variable offers a different ranking. For GDPpc and EH, the ranking from highest to lowest median is LAC 1st, NAF 2nd and SSA 3rd. For the case of EPI and CC, NAF is the 3rd; for EV LAC's and SSA's are practically the same. Because every variable is distributed differently and offers different information to our clustering effort, we will use all five variables together.

4. Cluster Exploration and Results

4.1 Cluster Characteristics

The best number of clusters for 2022 and 2012 are two, and we call them C-ONE and C-TWO. This number of clusters for 2022 is based on the highest silhouette score possible, and boxplot exploration that confirms clear separation for EPI, LnGDPpc, EH, and CC. For 2012, the highest silhouette score is for three clusters, but our boxplot exploration only confirms clear separation for EPI. So, we selected two clusters also for 2012 based on the second-best silhouette score, and boxplot confirmation of clear separation for LnGDP, EH, and EPI.

To illustrate the characteristics of each cluster, we use a four-axel radar map to plot centroids (average values) for 2012 and 2022 (Figure 2). The radar map for C-ONE is inside the one for C-TWO in both years, and the distances per axis highlight the different route these clusters went in ten years. The distance between clusters for the EPI axis has increased because the EPI for the C-TWO increased from 41 to 46.7 while the EPI for the C-ONE diminished from 33.8 to 33.6. This increment in EPI distance occurs with similar GDPpc percentual increments, 7% ($267) and 8% ($1,261) for C-ONE and C-TWO, respectively.

The two radar maps also illustrate the distance between clusters remained the same for EH, and increased for EV and CC. For environmental health (EH), the performance of both clusters increased evenly, and their distances remained the same. For ecosystem vitality (EV), the distance increased because there is a much more significant increment for C-TWO than C-ONE. Finally, for climate change (CC), as it was for EPI, the distance increases because there is a deterioration for C-ONE and an increase for C-TWO.

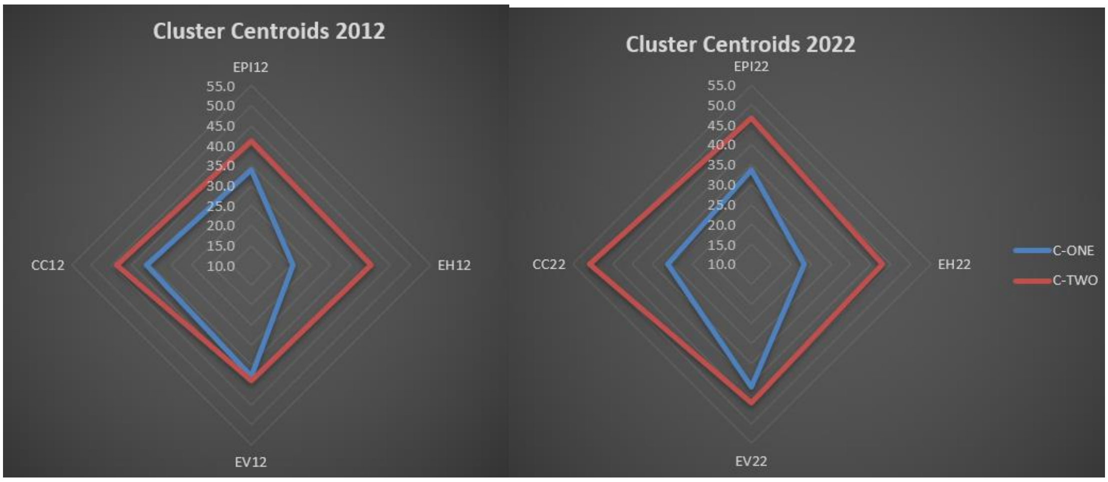

Figure 2: Cluster Centroids 2012 and 2022

Source: This study

In summary, the two clusters are more apart in 2022 than 2012 for all variables but EH, that remains the same. After 10 years, there is a significant improvement in EPI scores and CC scores for C-TWO and a clear deterioration in both variables for C-ONE. What are the countries in these two clusters?

Cluster one (C-ONE) and Cluster two (C-TWO) are predominantly represented by SSA and LAC countries, respectively. By 2012, 85.7% of the C-ONE countries were from SSA, but this rate went down to 79% by 2022. Similarly, the LAC share in the C-TWO cluster diminishes from 73% in 2012 to 69% in 2022. So, geographical proximity is still an important characteristic for grouping our clusters, but it is weaker in 2022 than 2012.

The list of countries for C-ONE and C-TWO is stable over time and only few countries move out from one cluster into the other. By 2022, C-ONE, includes 43 countries: 34 SSA countries, four NAF countries (Algeria, Egypt, Morocco, and Sudan) and five LAC countries (Bolivia, Guatemala, Haiti, Honduras, and Nicaragua). The countries that were not in C-ONE ten years before were Algeria, Bolivia, and Nicaragua, indicating these three countries deteriorated their environmental performance enough to be clustered with the C-ONE group. More precisely, Bolivia and Nicaragua remain in the border regions of both clusters for EPI, LnGPDpc, EH, and EV, but decreased considerable their CC scores and this put them out of the C-TWO cluster. In the case of Algeria, it is included with the C-ONE cluster because of significant decrease in EPI and its CC component.

The list of countries for C-TWO is also stable and includes 36 countries by 2022: 25 LAC countries, one NAF (Tunisia) and 10 SSA countries (Botswana, Cape Verde, Dijibouti, Equatorial Guinea, Eswatini, Gabon, Mauritius, Namibia, Sao Tome and Principe, and Seychelles). The two countries that were not in C-TWO ten years earlier are Dijibouti, and Namibia, indicating these two countries improved their environmental performance enough to be clustered with the C-TWO group. A closer look at their individual variables, Dijibouti and Namibia improved their EPI scores significantly, and this in turn was boosted by significant improvements in EV and CC scores.

One of the results from the literature review is the strong correlation between LnGDPpc and EPI when considering all countries in the globe. Because we already mentioned our cluster distributions are not Normal distributions, and we have outliers within our two clusters that we don't want to exclude, we use Spearman correlations and their respective *p*-value criteria for significance (Anderson et.al., 2020, p. 963). We found a positive and significant Spearman correlation, $r_s = .609$ ($p < .001$), between these two variables for all our countries in 2022 (Table 2). However, when considering C-ONE and C-TWO separately, the correlation between EPI and LnGDP for 2012 and 2022 are negative and statistically not significant to reject the hypothesis these correlations are zero (Table 2). These results show GPDpc and EPI do not have a clear linear relationship for C-ONE and C-TWO countries separately, in other words, more economic output per person may be related positively with EPI in some cluster countries, and negatively in others, so there is no trend.

	2022				2012			
Sample	**EPI22 and LnGDP22pc**	**EPI22 and EH22**	**EPI22 and EV22**	**EPI22 and CC22**	**EPI12 and LnGDP12pc**	**EPI12 and EH12**	**EPI12 and EV12**	**EPI12 and CC12**
All countries	0.609 (*p* <0.001)	0.594 (*p* <0.001)	0.549 (*p* <0.001)	0.805 (*p* <0.001)	0.278 (*p* =0.993)	0.298 (*p* =0.99))	0.526 (*p* <0.001)	0.756 (*p* <0.001)
C-ONE countries	-0.133 (*p* =0.429)	0.119 (*p* =0.484)	0.823 (*p* <0.001)	0.459 (*p* =0.007)	-0.296 (*p* =0.080)	-0.175 (*p* =0.298)	0.586 (*p* <0.001)	0.710 (*p* <0.001)
C-TWO countries	0.001 (*p* =0.992)	-0.041 (*p* =0.787)	0.391 (*p* =0.011)	0.657 (*p* <0.001)	-0.172 (*p* =0.263)	-0.164 *p* =0.289)	0.465 (*p* =0.003)	0.821 (*p* <0.001)

Table 2. Spearman correlation (r_s) and *p*-values for 2022 and 2012

Source: This study

In terms of environmental variables, we expect EH, EV, and CC to be positively correlated with EPI, because these are the arguments of the EPI score with 20%, 42%, and 38%, respectively for 2022 (Figure 1). Given these weights, we would expect EV to be the most influential to EPI. However, we found a different pattern when considering all 79 countries, CC is the most correlated to EPI and statistically significant with r_s values of .805 and .756 ($p < .001$) for 2022 and 2012, respectively (Table 2). For C-ONE countries, the most correlated with EPI and statistically significant is EV for 2022 ($r_s = .823$, $p < .001$) and CC for 2012 ($r_s = 0.710$, $p < .001$). For C-TWO countries the most correlated with EPI and statistically significant is CC with $r_s = .657$ and $r_s = .821$ for 2022 and 2012, respectively (Table 2). We can also notice for C-TWO in Table 2, EV has positive correlations with EPI in 2022 and 2012, .391 and .465, that are lower than the correlations before, but still statistically significant. The environmental policy implications seem to be that C-ONE countries and C-TWO countries may focus on EV and CC indicators to improve their EPI scores significantly. What about EH policies?

The Spearman correlations between EH and EPI are too low to reject the hypotheses that are different from zero. As it can be seen in Table 2, EH and EPI for both years have low Spearman correlation values and their *p*-values are significantly greater than .10. This result gives another perspective to environmental policies directed to improve directly environmental health conditions, for instance improving access to drinking water and sanitation. Our results suggest that such policies included in EH would not improve EPI scores for C-ONE and C-TWO countries, and for this reason we will focus on exploring more about EV and CC policies.

4.2 Cluster Exploration for Recommended Environmental Policies

Assuming governments of countries in our two clusters would like to improve their EPI scores, let us explore in more detail our recommendations that C-ONE and C-TWO countries may want to focus on policies that improve EV and CC conditions. For this, let us use percentage changes for EPI, EV, and CC from 2012 to 2022.

Sample	EPI-Δ and EV-Δ	EPI-Δ and CC-Δ
All countries	0.711 (p <0.001)	0.925 (p <0.001)
C-ONE countries	0.608 (p <0.001)	0.903 (p <0.001)
C-TWO countries	0.597 (p <0.001)	0.905 (p <0.001)

Table 3. Spearman correlation (r_s) and *p*-values for 10-year % changes
Source: This study

As it can be seen in Table 3, all six correlations are statistically significant ($p < .001$), and there are two levels of Spearman correlations, the super high for CC- Δ ($r_s > .90$), and high for EV- Δ ($.60 < r_s < .71$). These results suggest that CC increments are more influential to EPI increments than EV increments, and this holds for C-ONE and C-TWO countries.

Let us explore more about successful paths for C-ONE and C-TWO countries that combine -environmental policies for CC- Δ and EV- Δ using the information from plots in Figure 3.

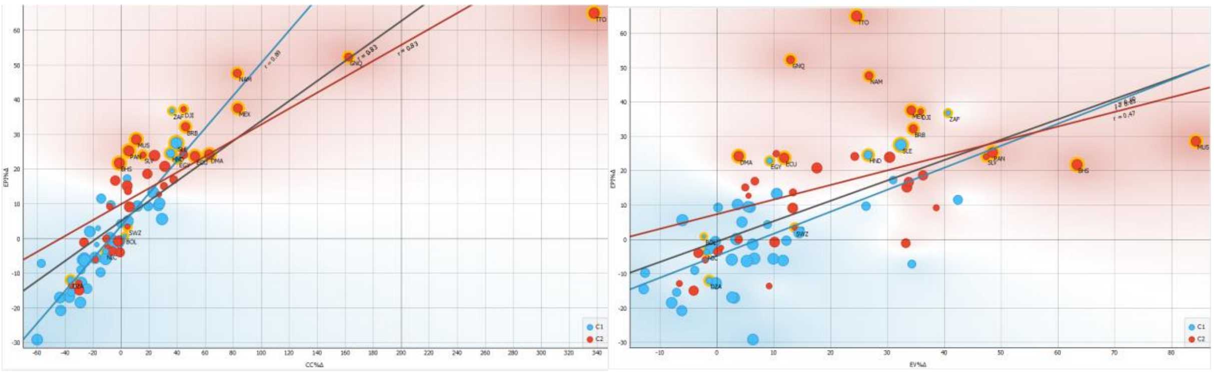

Figure 3. Plot Clusters CCΔ - EPIΔ and EVΔ - EPIΔ

Source: This study

In general, most C-TWO countries (red dots) appear at the top/right side of both plots in Figure 3, and most C-ONE countries (blue dots) appear at the bottom/left side. Starting with the CC plot, the countries with CCΔ higher than 60% and EPIΔ higher than 40% are Trinidad and Tobago (TTO), Guinea Bissau (GNO), Namibia (NAM), and Mexico (MEX), all in the C-TWO cluster. However, these countries do not have high EVΔ in the other plot, their EVΔ are modest, from 10% to 20% only (Figure 3). There are other C-TWO countries with significantly higher EV increments, for instance Mauritius (MUS), Bahamas (BHS), Panama (PAN) and El Salvador (SLV) with EVΔ equal and above 50%, but their EPI%Δ and CC%Δ are just between 20 and 30%. So, C-TWO countries looking to increase EPI scores may do better focusing on environmental policies that deliver high CC and modest EV increments. Good examples are Trinidad and Tobago, Guinea Bissau, Namibia, and Mexico.

Namibia is an interesting case with implementation of CC and EV policies. Out of 180 countries in the world, only four are on track to reach net-zero emissions by 2050, and Namibia is one of them (Wolf 2022).[ix] In terms of EV policies, Namibia improved its Biodiversity & Habitat score significantly over the past decade, ranking 11th in the issue category. Namibia's deep commitment to biodiversity and environmental protection is embedded in its history. Namibia was the first African country to incorporate the environment into its constitution. Following its independence in 1990, the government returned ownership of its wildlife to the people, employing a successful, community-based management system that gave its citizens the right to create conservancies (Conniff, 2011; WWF, 2011). Today, Namibia has 148 protected areas covering 37.89% of its terrestrial environment and 1.71% of its Exclusive Economic Zone (UNEPWCMC, 2018; Wendling 2018).

Mexico receives the top score in the LAC region for Ecosystem Vitality but ranks 15th on Environmental Health (EPI2020). These EV efforts include the Marine Protected Area of Revillagigedo, the largest no-fishing area in North America (IUCN, 2017) and supports nearly 360 species of fish, coral colonies, and four species of sea turtle (Bello, 2017; Wendling 2020).

There are other examples of countries that focused successfully on CC and EV policies, for instance Seychelles and The Bahamas. Despite the daunting economic challenges faced by Sub-Saharan African countries, Seychelles successfully reduced green gases emissions and other air pollutants and committed to marine protection through a 'Blue Economy' plan ((Mohabeer & Roberts, 2021; Wendling 2020). Because of these efforts, Seychelles ranks 1^{st} in the overall EPI score for its geographical region and 38^{th} in the world (Wendling 2020). The Bahamas is the highest scoring nation in LAC, earning an EPI score of 56.2 and a rank of 28 out of 180 countries. The island nation has nearly flattened its greenhouse gas emissions trajectory, pledging as part of its Paris Agreement Nationally Determined Contribution (NDC) to reduce 2030 emissions by 30% compared to its business-as-usual trajectory. The Bahamas is also a peer-leader in habitat conservation. The country has met the Aichi

Biodiversity Target of protecting 10% of its coastal and marine areas, further pledging to protect 20% under the Caribbean Challenge Initiative (Knowles et al., 2017). The Bahamas have also designated 34% of its terrestrial ecosystems as protected area, far exceeding the Aichi Target of 17% (Wolf 2022).

By looking at C-ONE countries in Figure 3, it seems C-ONE countries need median scores in both CCΔ and EVΔ to get median EPIΔ. C-ONE countries do not get EPI increment scores above 40%, so their target is to get the median EPIΔ, and this is correlated with median for both CCΔ and EVΔ. Examples are Honduras (HND), South Africa (ZAF) and Sierra Leone (SLE). These countries have all scores between 20 and 40 %. Given the low level of GDPpc of C-ONE countries respect to C-TWO countries, as well as lower general EPI scores, the challenges are how to meet some sustainable efforts when there are several needs and conditions under civil unrest, weak governance, and poverty (Wendling 2020). It is really challenging to get the resources to focus on CC and EV improvements at the 20-40% level.

South Africa is an example of CC and EV mild policies with significant effect on its EPI score. South Africa is the second-largest economy in Africa, with a growing population as well as an increasing demand for energy. Currently, coal makes up the largest share of the South African energy system, meeting around 70% of installed power generation capacity. However, South Africa has excellent natural resources enabling large scale renewable energy production from solar and wind power. To unlock this potential, Denmark has been collaborating closely with South Africa on wind resource assessments (Wendling 2020). South Africa designated 20 new marine protected areas in 2019, covering 5% of national marine territory across different marine ecosystems (South African National Biodiversity Institute, 2019; Wendling 2020).

Wastewater treatment is an important EV policy with huge impact in EPI scores for C-ONE countries. In Africa, no Sub-Saharan African country performs well in the wastewater treatment indicator, and most C-ONE countries are from Africa. A total of 20 countries in C-ONE receive scores of 0 in this category. The highest performing nation in the African region is Eswatini, where a network of 10 wastewater treatment plants has put the country's performance on the wastewater treatment indicator ahead of wealthier nations like Belgium and Norway (Eswatini Ministry of Health, 2019). Eswatini's success points to the possibility of improving water resources in developing countries under the right conditions, despite the challenges posed by geographical diversity, rapid urbanization, and poorly monitored pollution (Wendling 2020).

Focusing on environmental policies that deliver high CC and modest EV scores for C-TWO countries, and on policies that deliver median scores for both CC and EV for C-ONE countries, needs to be done carefully to avoid unintended trade-offs, as it is shown in the SDG literature. CC is directly related to energy and climate (SDGs #7 and #13) and EV is directly related to ocean life and land ecosystems (SDGs #14 and #15). We know from the SDG literature that focusing on energy and climate (CC) can magnify co-benefits and trade-offs with other sustainable objectives (Pham-Truffert 2020). For instance, improvements on energy access, expansion of renewable energy, and improving energy efficiency are strong multipliers of positive and negative effects, confirming the strong systemic role of energy (Pham-Truffert 2020). There are possible entry points from CC to create virtuous cycles and avoid trade-offs. For instance, renewable energy and energy efficiency (CC) present opportunities to improve water quality (EH), and actions toward reduced water pollution can support sustainable management of natural resources (EV) (Pham-Truffert 2020).

Investing in EV policies is less risky than doing it on CC policies because trade-offs are small. It has been demonstrated that investing in ocean life and land ecosystems magnify co-benefits and buffer trade-offs, enable co-benefits, and entail relatively small risks of trade-offs (Pham-Truffert 2020). For instance, a plan that starts with preserving land ecosystems (EV), serve climate policies (CC), and such actions can support natural habitats and biodiversity (EV) creating a virtuous cycle (Pham-Truffert 2020). Similarly, protecting marine and coastal ecosystems (EV) has strong co-benefits creating conditions for resilient and adaptive capacity to climate-related hazards and natural disasters (CC), as well as, integrating climate change measures with national policies (CC) (Pham-Truffert 2020).

5. Conclusions

The three research questions for this paper were: What are the clusters that would LAC, NAF, and SSA countries belong using data mining techniques? What are the characteristics and trends for these clusters from 2010 to 2022? Can we provide environmental policy recommendations with high sustainability effects based on these clusters?

Using mining data tools, we found two clusters for the 79 LAC, NAF and SSA countries. Cluster C-ONE with 43 countries, mostly from the African regions, and cluster C-TWO with 36 countries, mostly from the LAC region. Both clusters include LAC, NAF, and SSA countries showing that environmental characteristics (EPI, EH, EV, and CC) are not fully determined by geographical proximity. Using radar maps for EPI, EH, EV, and CC, all C-TWO values are higher than C-ONE values. There is also a trend to increase the distance between C-TWO and C-One values from 2012 to 2022 for EPI, EV, and CC. The distance for EH remains the same. So, the two clusters are more differentiated in 2022 than 10 years earlier.

In terms of policy recommendations to increase EPI scores, we recommend countries from the C-TWO group to focus on environmental policies that deliver high CC increments and low EV increments. Examples to follow are Namibia and Mexico. For C-ONE countries we recommend environmental policies that deliver medium CC and EV increments. Examples to follow are South Africa and Eswatini. The recommendations to focus on CC and EV environmental policies have high sustainability effects based on their multiplier effects on poverty, health, gender, inequality, and economic progress, as found in the SDG literature.

This study is limited to descriptive data mining exploration because of the type of EPI data available. The next step would be to move into casual relationships for CC and EV for the understanding of continued investment in environmental health and a nation's best course of action to direct and correct investments in ecological practices throughout its sustainable ecosystem. This framework would introduce the concepts of environmental speed, velocity, inertia, momentum, and fit to determine optimal CC and EV paths.

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[i] The policy objective weights are 50/50 in most EPI reports from 2006 to 2022. However, because EH was highly correlated with the EPI and countries with high EH scores would also have high EPI scores independently of their EV scores, the EH weight was reduced to 30% in 2012, and corrected again to 40 % for the 2018 and 2020 reports (Emerson 2012, Wendling 2018, 2020). Climate Change and Energy was an issue category within EV from 2006 to 2020, but then it was separated into a third policy objective called Climate Change (CC) for the 2022 report because climate change became the focus at the United Nations by 2015 (Esty 2006, Wendling 2020, Wolf 2022).

[ii] The only set of time series data comes from an explicit attempt done by the authors to develop scores for 2000 to 2010 using the 2012 methodology.

[iii] The world's population with safe drinking water increased from 62 to 74 % between 2000 to 2020, but 2.2 billion still do not have it. More people have access to adequate and equitable sanitation and hygiene, but 3.4 billion still lack sanitation services and 1.9 billion lack basic hygiene services (Independent Scientists, 2023).

[iv] While 90% of the world population has access to electricity, 675 million people lack of it. From them, 4 in 5 reside in Sub-Saharan Africa (Sachs 2023, Independent Scientists 2023).

[v] As a methodological note, these 10-year changes or deltas are presented as changes in scores rather than relative percentual changes. So, the same delta may provide different percentual change depending on the original base score. We will use % changes rather than these deltas in our data mining exploration below.

[vi] Logarithmic transformations increased variation within variables, and with more variation clusters were more accurate (Emerson, 2010).

[vii] Our final data includes 30, 5, and 44 LAC, NAF, and SSA countries, respectively. Eritrea, Mauritania, Cuba, and Venezuela were excluded from the initial list of 83 countries in the EPI 2022 report. A sample of 79 out of 83 has a 94% statistical confidence level and 1% margin of error. So, our sample represents well the population.

[viii] Upper outliers are observations equal or higher than Q3 + 1.5 * IQR.

[ix] The other 3 countries are Denmark, United Kingdom, and Botswana (Wolf 2022).