

SUSTAINABILITY INDICES

REPORT

From indices to strategic insights





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EXECUTIVE SUMMARY

This report analyses global sustainability using the **Environmental Performance Index**, the **ND GAIN Index**, the **Global Sustainable Competitiveness Index**, and the **Global Commons Stewardship Index**. Countries were grouped into clusters based on their performance across environmental, climate readiness, governance, social, biodiversity, and resource use parameters. Quantitative tools, such as K-means clustering, ANOVA, mean and standard deviation, Z-score analysis, radar charts, violin plots, skewness and kurtosis, geo-mapping, and deviation from global averages, helped identify patterns, outliers, and the strengths and weaknesses of each cluster. The report presents each cluster's main problems, the reasons behind them, the supporting visual and statistical evidence, and clear recommendations. Overall, it provides a comparative and data-driven understanding of global sustainability performance, highlighting how countries can move toward more resilient, low-carbon, and environmentally responsible development.

OBJECTIVES OF THE REPORT

- **Understanding** the performance of countries across various global indices.
- **Critically analyzing** the cause of variation in performance across indices and metrics.
- **Providing policy recommendations** through a consulting lens.
- **Assessing** the interlinkages between indicators to understand holistic country performance.
- **Benchmarking** country performance against global best practices to highlight leaders and transition pathways.
- **Facilitate cross-country comparisons** to foster learning, cooperation, and knowledge transfer on sustainability governance.

BACKGROUND AND RELEVANCE OF SUSTAINABILITY METRICS

Sustainability is now central to global policy, economic planning, and environmental protection. Countries differ widely in their resources, climate risks, institutions, and environmental outcomes, so standardised global indices are essential to compare performance fairly and understand which countries are leading or lagging and why. This project uses four major sustainability indices that together offer a broad view of environmental performance, climate readiness, resource management, and stewardship of global commons.

EPI (Environmental Performance Index), published by Yale and Columbia, aims to evaluate how well countries manage environmental health and sustainability. It measures performance in areas like air quality, water & sanitation, climate change mitigation, biodiversity, and ecosystem vitality.

ND GAIN Index, published by the University of Notre Dame, assesses how prepared nations are for climate change by measuring their vulnerability and readiness. It shows how exposed nations are to climate risks and how strong their economic, governance, and social systems are in adapting to those challenges.

GSCI (Global Sustainable Competitiveness Index), published by Solability, evaluates long-term competitiveness through natural capital, governance, social capital, resource intensity, and economic sustainability. It emphasizes resilience and inclusive growth by integrating environmental stewardship, institutional quality, and socio-economic well-being.

GCSI (Global Commons Stewardship Index), published by the Sustainable Development Solutions Network, Yale Centre for Environmental Law and Policy, and the Centre for Global Commons at the University of Tokyo, measures stewardship of global environmental commons, including aerosols, biodiversity loss, greenhouse gases, nutrient cycles, marine ecosystems, and water cycles.

COMMON METHODOLOGY

INTRODUCTION TO K-MEANS CLUSTERING

K-means clustering is an **unsupervised machine learning method** that divides a dataset into a specified number of groups or K clusters.

The main objective of the algorithm is to arrange the data points in such a way that the similarity between the points in the same cluster is higher than the similarity between the points in different clusters. The algorithm assigns **each data point** to the **closest cluster centroid** and then updates the centroids based on these assignments. It repeats these steps until the cluster centroids become stable and the assignments do not change significantly.

This method is often used in **customer segmentation, image analysis, pattern recognition, and exploratory data analysis.**

WHY K-MEANS CLUSTERING?

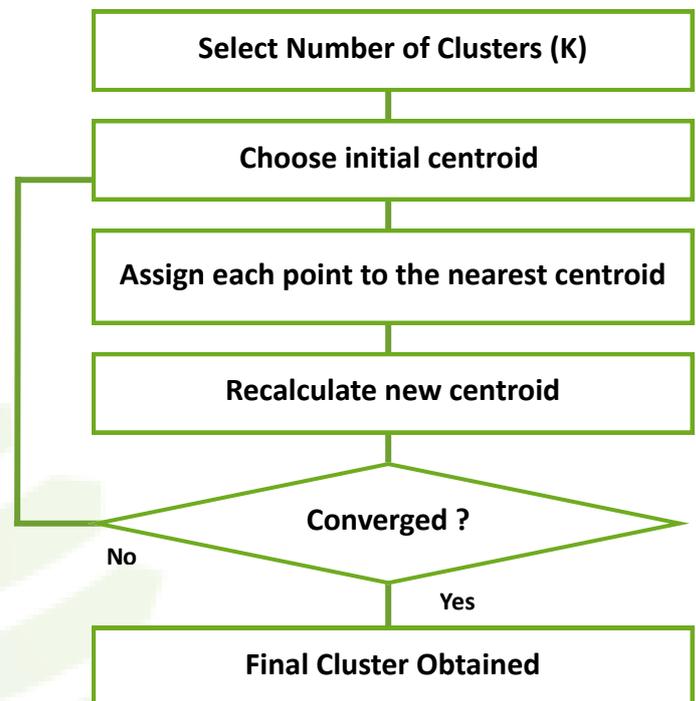
The main reason for employing k-means cluster analysis is its **capability to unveil latent patterns in a dataset.** When the data structure is not obvious, it offers a quick way to find the underlying clusters based on the most similar elements.

This method is extremely useful in cases where the goal is to **classify observations into separate categories** to carry out further analysis.

Its **speed and ease of application** are great advantages, especially when dealing with large datasets. Besides, the algorithm's direct result clusters depicted by centroids make the interpretation straightforward and thus facilitate the decision-making processes.

In short, the argument for k-means clustering is to reveal the underlying structure of data without any labels, to decrease the data volume, and thus to gain deeper insights by generating internally coherent, homogeneous groups.

ALGORITHM BEHIND K-MEANS CLUSTERING



DETERMINING THE NUMBER OF CLUSTERS

The number of K is of utmost importance in K-means clustering analysis.

K-means minimises the **Within-Cluster Sum of Squares (WCSS)**, which is the distance between points and their cluster centroid. **Higher K means lower WCSS** (clusters are tighter), whereas **lower K means higher WCSS** (clusters are broader).

If the number of K is less than required, different patterns, behaviours, or statistics get lumped into one cluster and important variation and insights in the data are lost.

Similarly, **too many clusters break one coherent group** into multiple forced micro-clusters, destroying interpretability and misrepresenting the true underlying structure.

So the number of k determines how the algorithm balances **compactness vs. simplicity.**

INTERPRETATION OF CLUSTER CENTROIDS

Cluster centroids represent the central point or “average profile” of each cluster formed by the k-means algorithm. This point effectively **summarizes the typical characteristics** of the observations within that cluster.

Higher or lower values **in particular dimensions indicate the dominant traits** of the group.

For example, in a dataset containing demographic or behavioral variables, a centroid might reveal that a certain cluster represents younger users with higher activity levels. By comparing centroid values across clusters, meaningful distinctions can be identified.

These interpretations help **translate the numerical output** of the clustering process **into practical insights**. Centroids provide a basis for labelling clusters, understanding group behavior, and informing strategic decisions such as targeting specific segments or tailoring interventions. Thus, analyzing cluster centroids is a key step in deriving an actionable understanding from k-means clustering results.

DERIVATION OF OPTIMAL CLUSTERS

An **elbow chart** is a commonly used method in k-means clustering to identify the optimal number of clusters in a dataset. It works by plotting the number of clusters (k) on the x-axis against the **within-cluster sum of squares (WCSS)** or inertia on the y-axis, which measures how tightly data points are grouped within each cluster.

As the number of clusters increases, WCSS consistently decreases because dividing data into more clusters naturally improves compactness. In the initial stages, this decrease is steep, indicating that adding clusters significantly improves the model. However, beyond a certain value of (k), **the reduction in WCSS becomes marginal**, meaning additional clusters do not add much explanatory value. This change in the rate of decrease creates a visible bend or “**elbow**” in the curve. The cluster count at this elbow is considered optimal because it achieves a good **balance between clustering accuracy and model simplicity**, avoiding unnecessary complexity.

Elbow Method for K

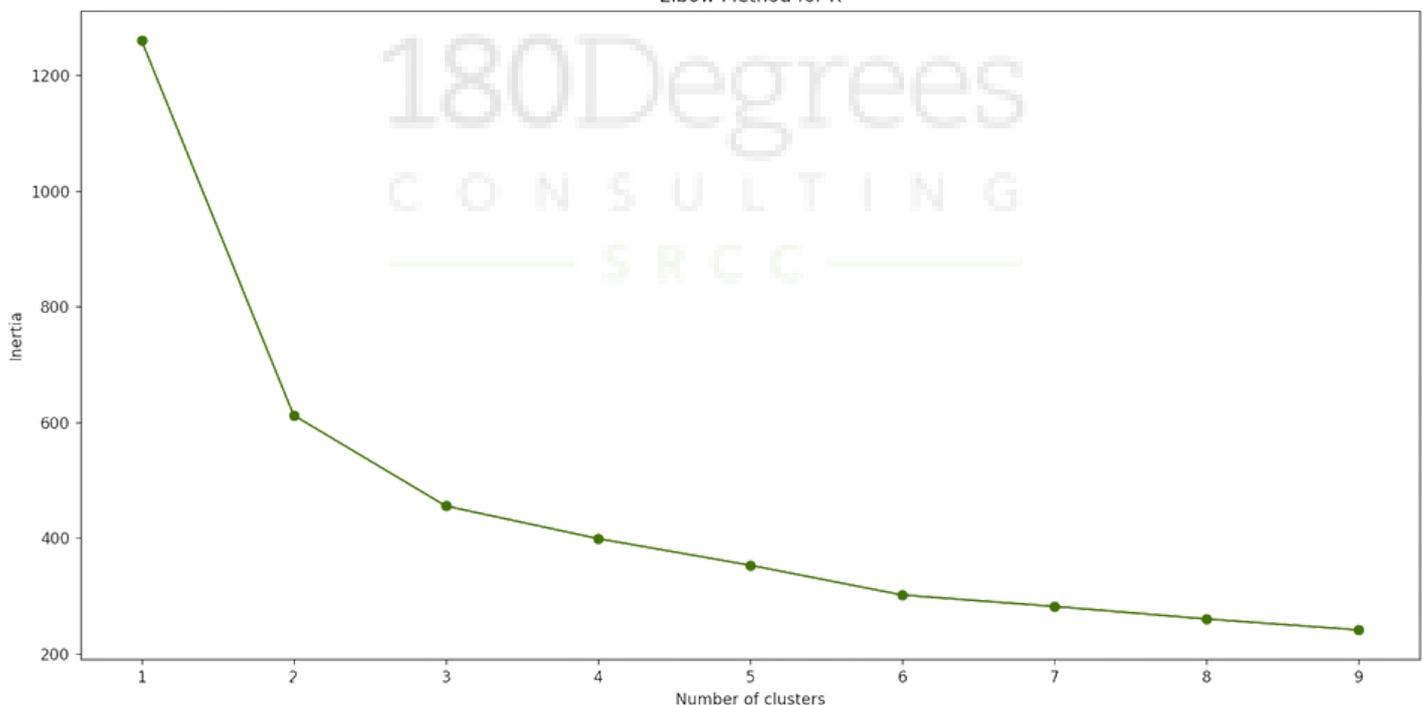


Fig 1:- Elbow Chart deriving optimal number of clusters for Indices

(This elbow chart and all others have been created using a Python Script, code for which can be found [here](#))

ND-GAIN

INDEX —————

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INTRODUCTION TO THE INDEX

The ND-GAIN Index, developed by the University of Notre Dame's Global Adaptation Initiative, measures how **vulnerable** countries are to climate change and how prepared they are **to adapt** by combining two key dimensions: vulnerability, assessed through **36 indicators** that capture exposure, **sensitivity**, and **adaptive** capacity across six sectors including food, water, health, ecosystem services, **human habitat**, and infrastructure, and readiness, which **evaluates** a country's social capacity and governance. All indicators are normalised on a **0-1 scale** to produce an overall score **that reflects** both the **urgency** of adaptation needs and the **feasibility** of implementing solutions. The index is widely used by **policymakers**, researchers, and **global organisations** because it is based on **transparent**, publicly available data and provides a consistent basis for **comparing climate** risks and adaptation **capacities** across nations.

OVERVIEW OF KEY ASSESSMENT PARAMETERS

Protected Change in Biodiversity

This indicator reflects how a country's biodiversity is shifting by tracking species numbers, habitat quality, and ecosystem stability. It highlights how climate change and human activities can damage natural systems and weaken them.

Ecological Footprint

The ecological footprint measures a country's impact on nature by assessing resource use and waste production, then comparing that to the biosphere's ability to manage it. It indicates whether a country stays within its ecological limits. A lower footprint suggests sustainable consumption.

Protected Biome

This gauges how well and to what degree ecological areas are protected. By evaluating ecosystem protection, a nation's ability to preserve habitats and promote climate change resilience is demonstrated. It reflects whether critical systems such as forests, wetlands, and grasslands are being conserved, restored, or degraded over time.

Engagement in International Conventions

This measure shows a nation's level of involvement in international environmental agreements. It shows the country's dedication to meeting global standards, sharing responsibility, and adapting to climate change.

Projected Change of Cereal Yields

Under future climate scenarios, this factor identifies anticipated changes in the production of staple crops. It draws attention to the stability of rural livelihoods and agriculture as well as the fragility of national food systems.

Agriculture Capacity

Agriculture capacity demonstrates how technologically sophisticated, structurally sound, and climate-adaptable the agriculture sector is. It demonstrates resilient farming methods, market access, and irrigation.

Regulatory Quality

The indicator assesses how stable, equitable, and effective the regulatory environment is. By facilitating effective policies, promoting innovation, and fortifying institutions to handle emerging risks, high regulatory quality aids in climate adaptation.

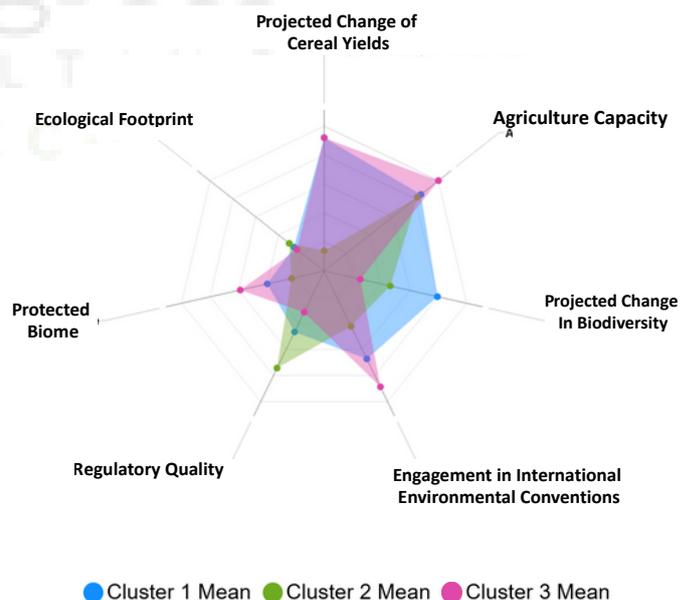


Fig 2:- Cross Cluster Radar Chart



Fig 3:- Cluster-Wise World Map

Cluster Assignment ● 1 ● 2 ● 3

CLUSTER 1

Cluster 1 includes **large countries** such as India, China, Brazil, Australia, Japan, and the United States. The radar chart indicates that this cluster does well in projected changes in biodiversity and cereal yields. However, it **struggles** with **protected biome coverage** and **regulatory quality**. Countries like India, China, and Brazil have strong biological and agricultural potential, but they still face issues with governance and conservation.

Developed countries such as the United States and Japan show a similar pattern. They perform well in outcomes but have weaker coverage of protected areas. Cluster 1 represents countries with good natural outcomes but **weaker regulatory and conservation systems**.

CLUSTER 2

Cluster 2 includes mainly **high-income European countries** like Germany, France, Sweden, Switzerland, the Netherlands, Denmark, and the United Kingdom. The radar chart indicates that this cluster has the **best regulatory quality**.

These countries have **strong institutions** and enforce environmental regulations well. Their ecological footprint is **moderate**. However, the projected change in cereal yields is low.

This means their agricultural systems may be **more sensitive** to climate change. Their involvement in international **environmental agreements** is also **lower** than expected. The coverage of protected biomes and agricultural capacity is **moderate**. This cluster shows countries with strong institutional capacity but **weaker agricultural adaptation**.

CLUSTER 3

Cluster 3 consists of many **developing countries**, such as Bangladesh, Nigeria, Ethiopia, Kenya, Nepal, and Peru, along with some **resource-rich** countries like Qatar, Kuwait, and the United Arab Emirates.

The radar chart reveals that Cluster 3 has **strong agricultural capacity** and a high projected change in cereal yields. It also indicates **strong engagement** in international environmental agreements. However, this cluster has the **lowest projected change** in biodiversity and the poorest regulatory quality. Countries demonstrate **strong international participation** but face high ecological vulnerability. Middle Eastern economies show similar governance weaknesses despite their economic strength. This cluster contains countries with **strong agricultural potential** but **high risks** to biodiversity and **weak regulatory control**.

PROBLEMS

CLUSTER 1: DEVELOPED SUSTAINABLE NATIONS

The first cluster of countries shows a very obvious and urgent **structural problem** that comes from the lack of **ecological protection** in relation to the size of their economic and agricultural activities. These countries, in general, have big, high-output agricultural systems and heavily utilize the land, but the **laws and institutions** that are supposed to protect biodiversity have **not been updated** to the same level.

The problem is not in their ability to produce or manage resources but in the **continual shortage** of areas with biomes that are legally protected.

On top of that, they have a **pattern of enforcement of regulations** that is also inconsistent: even though there are environmental rules, they are only slightly enforced in different sub-national areas, and the system of supervision that is there is not very standard, deep, or continuous in the long run. Consequently, **conservation results** are still low, although in the short run, there are relatively positive biodiversity trends.

The **bigger problem** is that the economy and agriculture are growing faster than the institutions can put the needed restrictions, thus making **ecosystem sustainability** in the long run very unstable.

CLUSTER 2: VULNERABLE AGRICULTURAL NATIONS

The second cluster is **struggling** with a totally different problem that structurally can be referred to as a **governance paradox**. These countries have the **best regulatory quality** in the entire dataset, which means they have robust legal systems, well-designed institutions, functional rule of law frameworks, and relatively stable administrative structures.

However, these strong systems lead to surprisingly **poor agricultural outcomes**: cereal yields are the lowest of all three clusters, which is a strong indication of deep agricultural vulnerability. The fact that high regulatory quality does not lead to strong agricultural performance is a **clear sign** of the significant **implementation gap**.

This gap might be caused by several **underlying factors**, such as high exposure to climate, inflexible agricultural sectors, lack of investment in climate, resilient farming, going structurally away from agriculture towards advanced manufacturing and services, or simply **institutional fragmentation** between **agricultural** and **environmental agencies**.

CLUSTER 3: ENVIRONMENTALLY CONCIIOUS NATIONS

The third group contains countries that, on the one hand, show a strong worldwide environmental commitment but, on the other hand, do not have the **institutional capacity** to put these commitments into practice.

These countries have the **worst regulatory quality**, which is the **main reason** for their poor biodiversity recovery, although they officially allocate large areas as protected. The low enforcement level, lack of staff and budget, and socio-economic factors result in the most common **nature conservation** and **ecological vulnerability**.

Cluster 3's main issue is **institutional fragility**: these countries still fail to implement agreements despite their willingness and formal participation.

Additionally, **high agricultural capacity** and **strong projected cereal yields** coexist with vulnerability to climate shocks, land degradation, and socio-economic pressures that often **force** communities to use natural resources unsustainably.



Fig 4:- Cluster-Wise Mean Values Comparison

ANOVA / KRUSKAL–WALLIS TEST (SIGNIFICANCE OF DIFFERENCES)

Parameter	Cluster 1: Developed Sustainable Nations	Cluster 2: Vulnerable Agricultural Nations	Cluster 3: Environmentally Conscious Nations
Cereal Yields	Highest (0.85): Efficient and resilient agricultural systems	Extremely-Low (0.13, median 0.0): Critical agricultural distress	High (0.84): Efficient and sustainable agriculture
Agricultural Capacity	High (0.88–0.92): Well-developed infrastructure and technology use	Moderate-High (0.75): Infrastructure exists but underperforming yields	Highest (0.92): Technologically advanced and efficient capacity
Biodiversity Change	High (0.73): Positive biodiversity growth trends	Moderate (0.43): Variable ecological conditions	Lowest (0.23): Slower biodiversity recovery despite protection efforts
Protected Biome Coverage	Moderate (0.36): Sustainable land management practices	Low (0.21): Poor protection and weak conservation enforcement	High (0.54): Leading in global conservation efforts
Environmental Engagement	Moderate–High (0.62): Consistent participation in global conventions	Low (0.39): Weak global cooperation and inconsistent engagement	Highest (0.82): Strong international environmental cooperation
Regulatory Quality	Moderate (0.55): Effective governance and policy implementation	Highest (0.68): Strong regulatory design but poor implementation outcomes	Low (0.29): Weaker governance but strong societal cooperation
Ecological Footprint	Moderate (0.24): Sustainable consumption and balanced impact	Low (0.28): Inefficient resource utilization	Lowest (0.22): Minimal environmental footprint and sustainable consumption

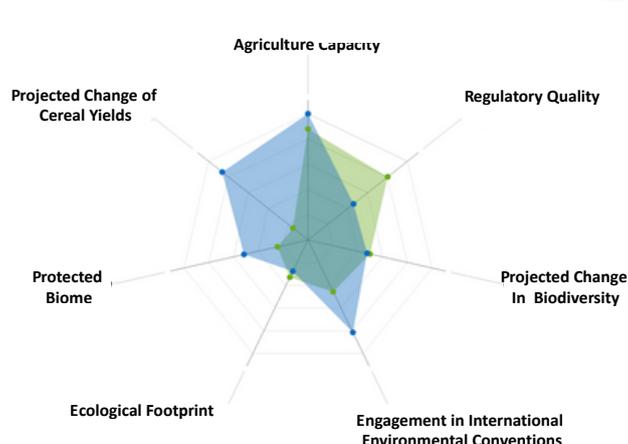


Fig 5:- Cluster 2: Vulnerable Agricultural Nations

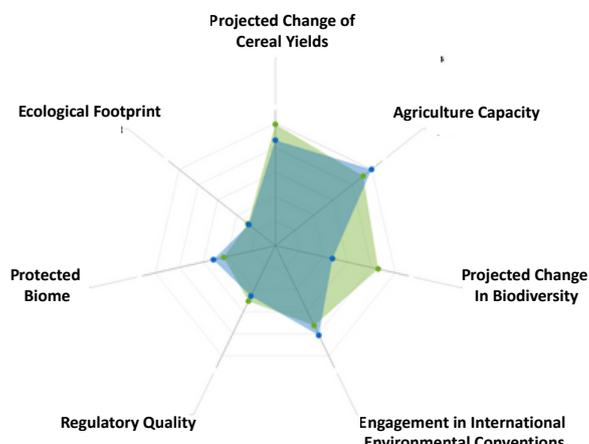


Fig 6:- Cluster 1 Developed Sustainable nations

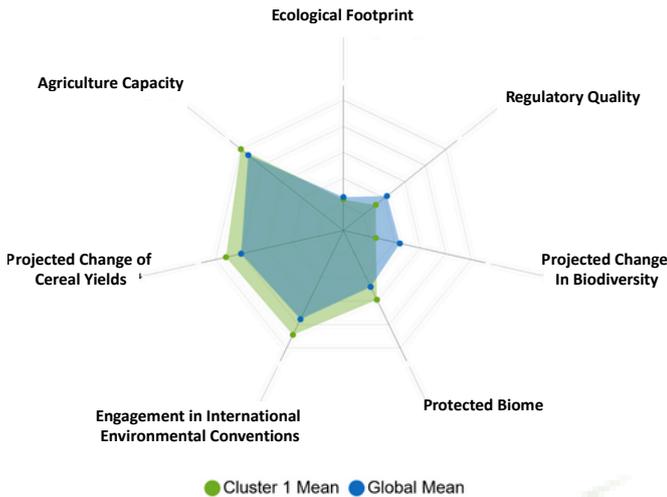


Fig 7:- Cluster 3: Environmentally Concious Nations

RECOMMENDATIONS

CLUSTER 1: DEVELOPED SUSTAINABLE NATIONS

Countries in Cluster 1 need a strategic adjustment of their robust production systems, which is in contrast with their comparatively weak ecological safeguards. These countries maintain **stable agricultural output** and **moderate biodiversity conditions**, but their main weakness is the **lack of enough protected biomes**, and the enforcement of environmental protection is not consistent. The lack of strong legal protection for ecological assets makes these countries vulnerable in the long run, especially when land use pressures from agriculture, industry, and infrastructure are increasing. Resolving these structural issues will not only preserve natural capital but also maintain biodiversity and ensure long-term productivity.

Recommendations:

- **Expand Protected Areas:** Raise the level of legal protection for forests, wetlands, and biodiversity hotspots to be in line with international standards (e.g., 30x30 framework).
- **Strengthen Regulatory Enforcement:** Enhance monitoring, compliance, and environmental inspections by using digital tools and satellite-based systems.

- **Integrate Conservation into Development Planning:** Ensure that land use plans incorporate ecological sensitivity indices to prevent ecosystem fragmentation.
- **Adopt Nature, Positive Agriculture:** Support regenerative farming practices, crop diversification, and reduced chemical use through incentives.
- **Improve Sub, National Coordination:** Provincial/state-level implementation should be strengthened to reduce the differences in enforcement between regions.

CLUSTER 2: VULNERABLE AGRICULTURAL NATIONS

Countries in Cluster 2 show a **governance paradox**: these are the countries that, despite having the most **robust regulatory systems**, have the **lowest agricultural yields** and **limited biodiversity recovery**. The first task for these countries is to identify and deal with the causes of the fragility of agriculture, whether the factors are climate exposure, **policy misalignment**, or structural changes that result in less cultivation, accompanied by ecological protection that is still at a very low level compared to what can be expected of high-capacity states. By **refocusing institutional strength** on viable results, countries in Cluster 2 will be able to turn regulatory potential into real gains in productivity and ecosystem health.

Recommendations:

- **Target Agricultural Resilience:** Facilitate the use of climate-resilient crops, modernise irrigation systems, and encourage adaptive farming practices.
- **Reassess Policy Incentives:** Redirect agricultural subsidies and incentives to support productivity and sustainability goals.
- **Strengthen Implementation Mechanisms:** Improve the ground enforcement of policies through local-level administrative capacity by moving beyond policy formulation.
- **Expand Biome Protection:** Raise the extent of protected areas to demonstrate ecological responsibility.

- **Cross-Ministerial Coordination:** Coordinating ministries across agriculture, water, climate, and land activities will lead to the prevention of the occurrence of contradictory policies and better implementation.

CLUSTER 3: ENVIRONMENTALLY CONSCIOUS NATIONS

Cluster 3 countries have a pressing problem with the implementation of their policies. They are **highly engaged internationally**, and their **agricultural potential looks promising**, but they are still put down by their poor regulatory quality and limited institutional capacity. In fact, **biodiversity recovery** is almost **non-existent** in these countries despite them having some of the largest protected areas, since these **protections** are **poorly managed** and **enforced**. Governance gaps contribute to inadequate monitoring as well as the lack of staff, and it is also difficult to prevent the **encroachment** or overexploitation of resources. In such countries, policy recommendations should revolve around the issues of **strengthening institutions, enforcement**, and local participation in conservation, as well as **converting the international commitments** into **concrete, financed programs** at the national level. Moreover, it is very important to strengthen the state's ability to carry out policies since that is the way to both reduce vulnerability and pave the way for sustainable development.

Recommendations:

- **Build Regulatory and Enforcement Capacity:** Increase environmental and agricultural agencies' staff, training, and the allocation of the budget.
- **Operationalise Protected Areas:** Empower local communities by implementing participatory land management and benefit-sharing schemes.
- **Mobilise Climate & Nature Finance:** Leverage robust international engagement to open the door to global funds (GCF, GEF, Adaptation Fund).

CROSS-CLUSTER RECOMMENDATIONS

1. Providing Governance and Regulatory Support: With the highest regulatory quality, Cluster 2 can support Clusters 1 and 3 in upgrading their law enforcement systems, institutional frameworks, transparent monitoring, and policy harmonisation areas, which are both other clusters' areas of significant weaknesses.

2. Dissemination of Agricultural Productivity and Biodiversity Management Knowledge: As a result of Cluster 1 having strong cereal yields and positive biodiversity trends, it can help Clusters 2 and 3 in the development of climate-resilient agriculture, precision farming, and balanced landscape planning that increases yields without harming ecosystems.

3. Communicating Community-Driven Conservation and Low-Footprint Development Frameworks: The advantages of Cluster 3 in worldwide environmental engagement and large protected biomes can be a source of strength for Clusters 1 and 2 by providing inclusive, low-cost conservation models and demonstrating sustainable consumption patterns.

4. Deepening Protected Biome Coverage and Enforcement: While Cluster 2 brings enforcement capacity and Cluster 3 reflects experience in managing large protected areas, they can collectively aid Cluster 1 to surpass its major challenge: the shortfall of biome protection.

5. Joint Support by Turning Global Pledges into Practical, Well-Regulated Initiatives: By guiding biodiversity restoration and agricultural scaling, Cluster 1, along with Cluster 2, which provides institutional reforms and regulatory structuring, can be of help to Cluster 3 in going beyond the international commitment.

GLOBAL SUSTAINABLE COMPETITIVENESS INDEX —————

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INTRODUCTION

INTRODUCTION TO THE INDEX

The Global Sustainable Competitiveness Index, first published in 2012, is one of the most comprehensive frameworks for **evaluating national performance through a sustainability lens**. Unlike GDP, which captures only market-based transactions and overlooks environmental health, social welfare, governance quality, education, and overall quality of life, the GSCI provides a far more holistic and future-oriented assessment.

The index is built on two hundred and sixteen quantitative indicators sourced from the **World Bank**, the **IMF**, and **several United Nations agencies**. Its reliance on measurable data removes subjective bias and ensures that countries are evaluated on actual performance. These indicators are analysed in their original form and further processed through advanced techniques, including **deep learning artificial intelligence tools** that cleanse data, detect correlations, and identify long-term trends.

This method produces a clear, multidimensional profile of each nation, highlighting structural strengths, exposing vulnerabilities, and projecting future competitiveness. Several governments now use the GSCI as an **official benchmark** to guide sustainable development strategies.

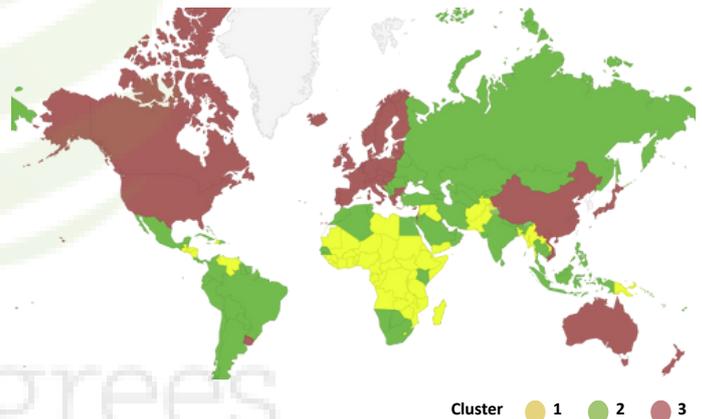
OVERVIEW OF KEY ASSESSMENT PARAMETERS

To capture the full spectrum of sustainable competitiveness, the GSCI groups its two hundred and sixteen indicators into six interconnected sub-indices that define a nation’s long-term outlook.



Fig 8:- Cluster Parameters

- **Natural Capital** assesses ecological conditions, resource availability, and environmental depletion.
- **Resource Efficiency** and **Intensity** measures how effectively a nation uses its resources in an increasingly constrained world.
- **Social Capital** captures health, safety, equality, freedom, and overall life satisfaction.
- **Intellectual Capital** and **Innovation** reflects a country’s capacity for knowledge creation, creativity, and high-value industry development.
- **Economic Sustainability** evaluates the strength, diversity, and long-term resilience of economic systems.
- **Governance Efficiency** measures institutional quality and the ability of the state to support sustainable wealth generation.



Cluster 1 2 3

Fig 9:- Cluster-Wise World Map

Cluster 1 covers mid-income economies like India & Indonesia that are near the world average, with balanced, moderate performance and weaker innovation. Their radar charts show small gaps, and violin plots have narrow mid-level ranges.

Cluster 2 covers advanced economies such as the USA, Europe, Japan, and Singapore that score highly across all indicators, seen in dominant radar charts, low skewness, and tight high violin ranges.

Cluster 3 consists of weaker performers like African nations, Pakistan and Afghanistan, marked by low governance and fragile economies, reflected in large negative deviations and wide low violin distributions.

The detailed problems, underlying reasons, and tailored recommendations for each cluster will be addressed in the subsequent sections of the report.

ANALYSIS

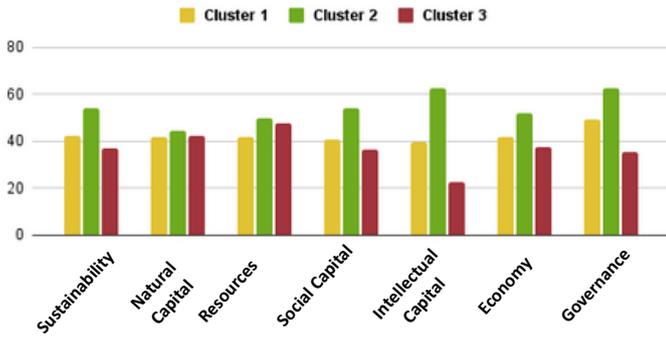


Fig 10:- Bar Chart on Cluster-Wise Average of Parameters

From the **bar chart**, it becomes clear that each cluster displays a distinct structural profile.

Cluster 1 performs moderately well but is held back by weaker natural and social capital, limiting its long term growth potential.

Cluster 2 stands out as the strongest and most transition-ready, with high governance, intellectual capital, and competitiveness, though it must keep adapting to sustain its lead.

Cluster 3 shows the weakest systemic capacity, with low governance and intellectual capital and inefficient use of natural resources, preventing it from converting its moderate natural capital into sustainable progress.

coordination, slow policy implementation, and limit innovation diffusion.



Fig 12:- Violin Plots : Sustainable Competitiveness

Cluster 1 maintains middle-level sustainable competitiveness without distinct strengths.

Cluster 2 consistently leads in sustainable competitiveness driven by strong institutions and innovation.

Cluster 3 scores the lowest because structural weaknesses restrict long-term resilience.



Fig 11:- Violin Plots : Social Capital

The **violin plot** shows clear contrasts across clusters. **Cluster 1** has moderate but uneven social capital, with varying levels of trust that lead to inconsistent reform outcomes.

Cluster 2 demonstrates the highest and most cohesive social capital, enabling strong cooperation, smooth reform adoption, and effective collective action.

Cluster 3 has the weakest social capital, marked by low trust and fragmented networks that hinder

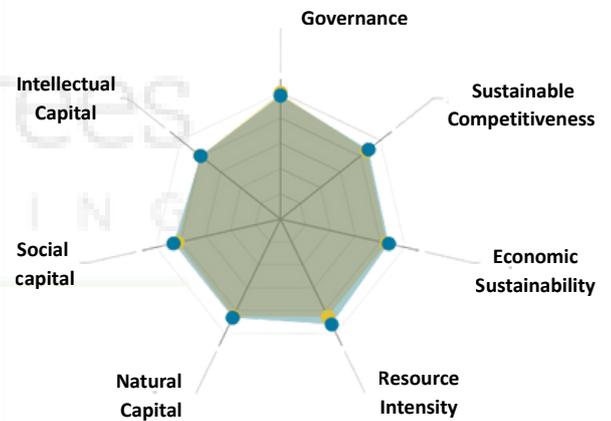


Fig 13:- Radar Chart : Cluster 1

The **radar chart** shows that Cluster 1 performs **closest** to the **world average** across most dimensions, with neither strong outperformance nor severe underperformance. Governance and social capital are slightly above average, reflecting reasonable **institutional stability** and moderate levels of **societal trust**. The near-balanced but slightly uneven shape of the chart reinforces that Cluster 1 is a transitional group.

ANALYSIS

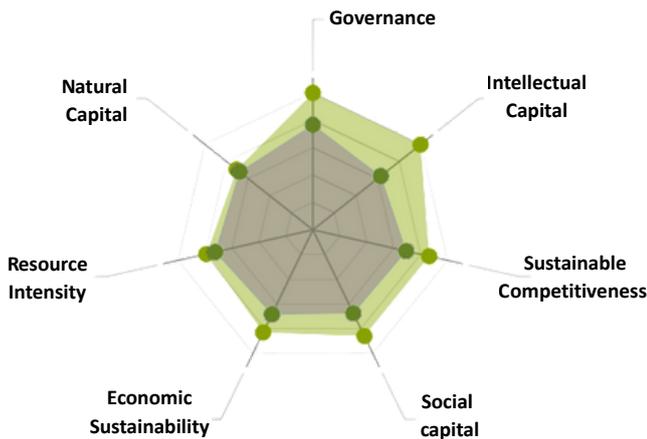


Fig 14:- Radar Chart : Cluster 2

The radar chart for Cluster 2 reveals a consistently **strong performance** across nearly all dimensions compared to the world average. Innovation capacity is slightly lower than the cluster’s other strengths, but remains above the world average. Overall, the balanced and outward-expanding shape of the chart reflects a **highly capable** and **well-aligned cluster**.

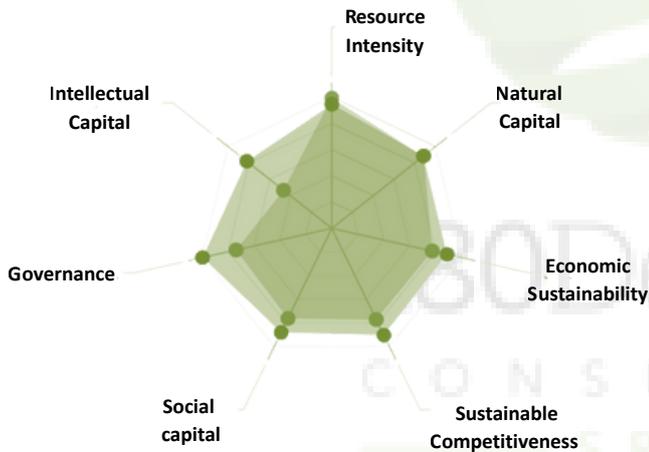


Fig 15:- Radar Chart : Cluster 3

The radar chart for Cluster 3 shows a consistently **lower performance** across all indicators when compared to the world average. This represents economies operating below potential, where governance inefficiencies, weak social collaboration, and limited innovation capacity show **stagnation**. Such systemic weaknesses undermine policy implementation, reduce institutional adaptability, and slow the diffusion of technology and knowledge. These nations face barriers to reform adoption, sustainable development, and **long-term economic resilience**, remaining vulnerable to both internal and external shocks.

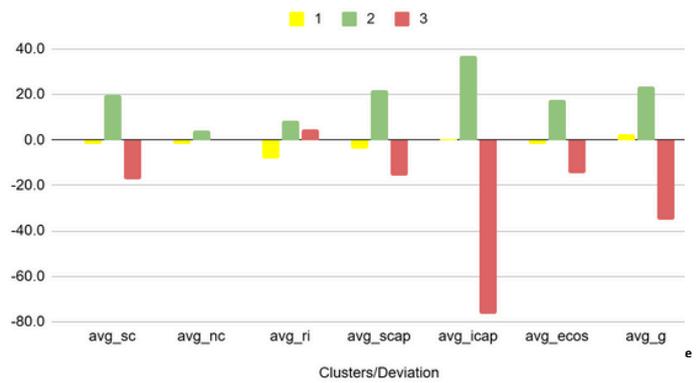


Fig 16:- Average Deviation from Parameters

Cluster 1

It shows a **very small negative deviation** from the world average in social capital, indicating marginal underperformance. This suggests that community trust, safety, civic participation, and social cohesion are **slightly weaker** than the global benchmark but not critically low. The deviation is small enough to show that the foundational social systems exist, yet they are not strong enough to accelerate sustainable development or convert economic activity into long-term social stability.

Cluster 2

It shows a **strong positive deviation** from the world average, clearly leading in social capital. This implies high interpersonal and institutional trust, strong civic networks, effective law enforcement, and high social well-being. The positive deviation also reinforces that countries benefit from a reinforcing feedback loop where high social trust reduces transaction costs, attracts investment, and helps the economy and institutions maintain **long-term resilience**.

Cluster 3

It shows **significantly negative deviation** from the world average in social capital, indicating severe **social fragility**. Low social trust, relationships, insecurity, and limited civic participation contribute to creating barriers to economic and innovation activity. This deep deviation reflects and highlights a structural and foundational challenge rather than a temporary performance gap, suggesting that without improvements in security, social cohesion, and civic engagement, other development policies are unlikely to succeed.

PROBLEMS

CLUSTER 1: THE CHALLENGE OF TRANSITION AND SYSTEMIC MEDIOCRITY

These countries are struggling to achieve the necessary performance increase to break into the **high-performing tier**. They lack a single parameter strength to use as a lever for change.

The consistent, small **negative** scores in all parameters indicate that the issue isn't one bottleneck but a need for **balanced, moderate improvement** across the entire system. Their average status suggests **systemic deficiencies** are preventing effective resource utilization and **institutional development** required for sustainable growth.

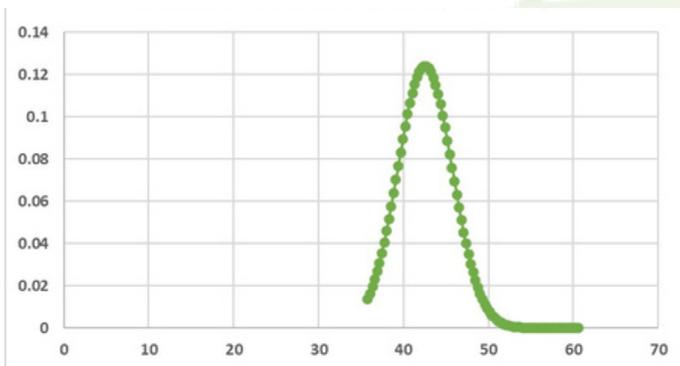


Fig 17:- Kurtosis Curve : Cluster 1

Through Kurtosis, it is found that the right tail arises from nations that are innovation active or resource efficient outliers, while others lag. This means innovation and resource efficiency are **unevenly developed** within the cluster. Violin plots back this as well and further suggests that the countries in this cluster don't have **stable economies** and lack **economic resilience**.

CLUSTER 2: SUSTAINING LEADERSHIP AND DECOUPLING GROWTH FROM RESOURCE USE

While it excels overall, the parameter it performs **worst** in is **Resource Intensity**. Despite its high economic and governance scores, its consumption and production methods are still relatively resource-intensive compared to the world average. This highlights a **long-term risk**: its current success model is not entirely sustainable and requires urgent focus on **decoupling economic activity** from environmental impact to maintain the essential **competitive advantage**.

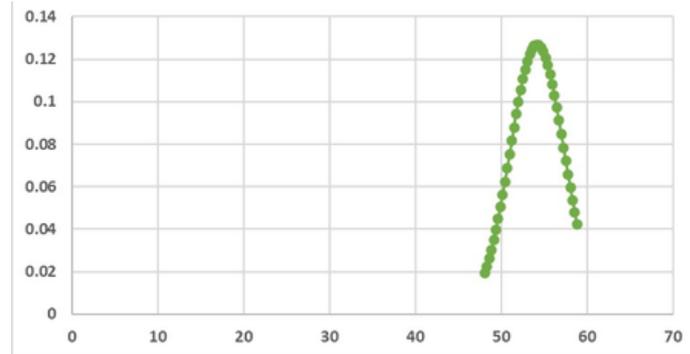


Fig 18:- Kurtosis Curve : Cluster 2

In Kurtosis, the left tail reflects some countries facing fiscal or **institutional stagnation** despite overall high development. These outliers may have high innovation but slower policy adaptability.

CLUSTER 3: OVERCOMING FOUNDATIONAL DEFICIENCIES IN CAPITAL AND INSTITUTIONS

The severe lack of Intellectual Capital shows these nations are not **investing** enough in the future drivers of sustainable growth. This weakness is compounded by critically poor governance scores, which indicate **weak institutions, corruption, or instability**.

This combined institutional and **intellectual deficit** is the root cause that prevents them from efficiently utilizing their natural resources and human capital, resulting in their high and **unsustainable Resource Intensity** and overall low sustainable competitiveness.

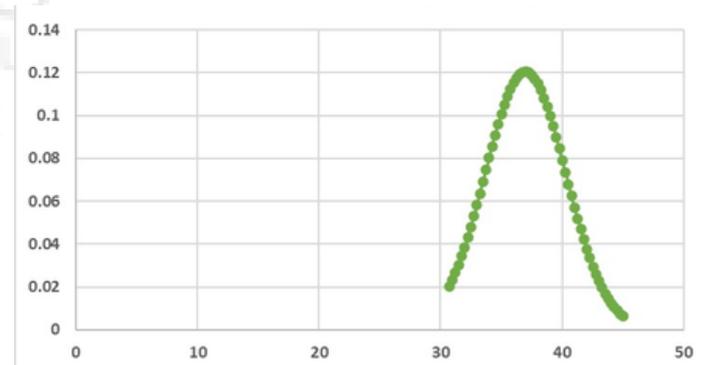


Fig 19:- Kurtosis Curve : Cluster 3

The right-side tail suggests a small segment performing better than the cluster average, but not enough to shift the group upward.

Overall, the cluster shows **structural stagnation** where most units remain locked at low scores with only a few outliers showing upward movement.

REASONING

CLUSTER 1

Government innovation policies are fragmented, with multiple ministries handling overlapping agendas, sending mixed signals to the industry.

Despite having funding agencies, funds move slowly through compliance layers, and poor coordination leads to overlapping schemes instead of a clear national strategy. The industry, dominated by MSMEs, lacks the capacity to absorb new technologies and invests little in R&D or design. As a result, innovation stays incremental rather than frontier-pushing. These countries spend under **1% of GDP on R&D** and have **few research centers**, resulting in fewer patents, stagnant productivity, and limited industrialization.

Government neglect and poor infrastructure have **weakened education quality**, employability, and productivity, while a disconnect with industry leaves research misaligned with real-world needs.

CLUSTER 2

Countries in cluster 2 have high GDP, industrial complexity, built infrastructure, and high consumption, which automatically create **high**

absolute resource demand. Therefore, the problem is the consumption structure and economic composition. So, there is high structural consumption and resource heavy lifestyle, which cannot be fully regulated by the government.

Innovation in the cluster is **strong and consistent**, but not directed toward resource efficiency. Frequent advances focus on technology and productivity rather than market efficiency, as these resource-rich countries **prioritize growth** over sustainability and efficiency.

CLUSTER 3

Countries in this cluster have **weak bureaucratic** and administrative capacity, with a long right-tailed kurtosis showing most perform poorly and few excel. Their weak implementation ability and **political instability** create uncertainty in governance.

Large deviations from world averages in business-related indicators show **high transaction costs**, weak rule-of-law, and limited investor confidence. Wide violin distributions in financial indicators point to fragmented credit markets, poor lending structures, and limited innovation in finance.

Cluster ● 1 ● 2 ● 3

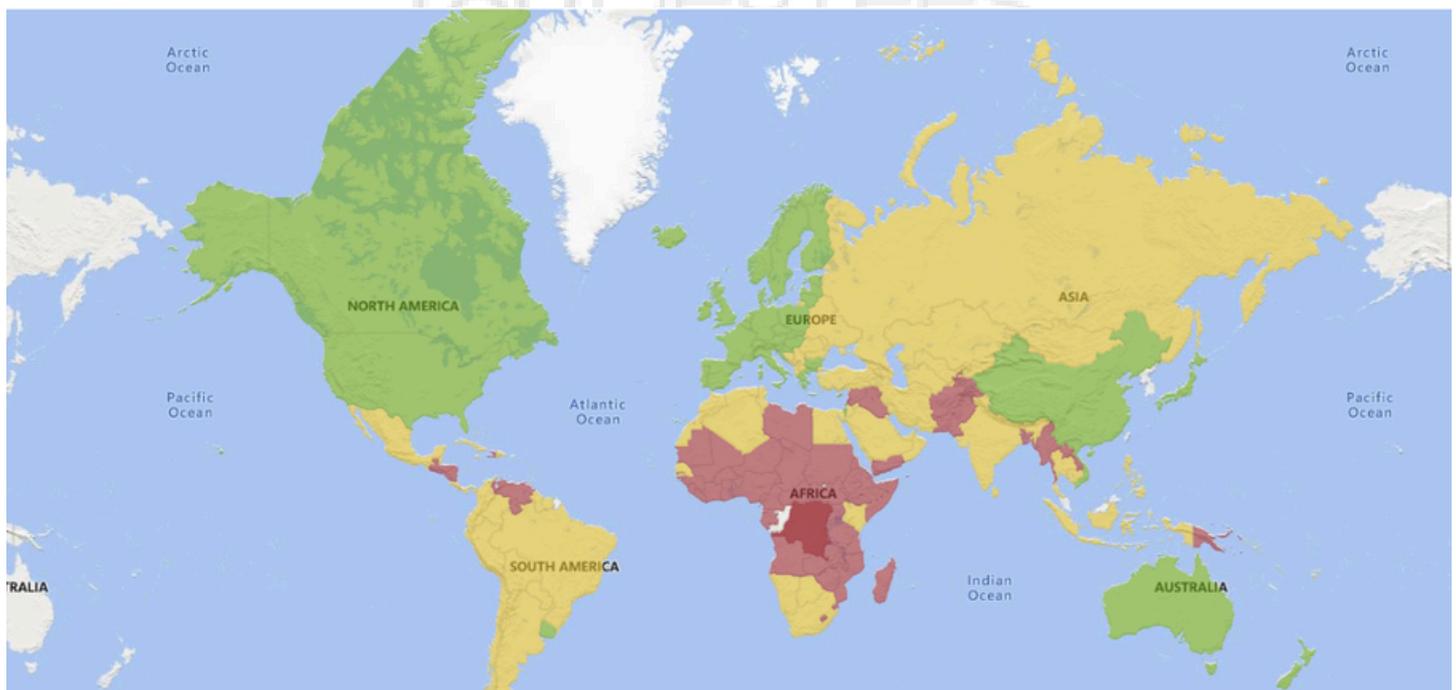


Fig 20:- Cluster-Wise World Map

OUR RECOMMENDATIONS

CLUSTER 1

1) Innovation Coordination Mission:

Establishing an Innovation Coordination Mission under the central government, as this cluster suffers from fragmentation across ministries and duplicate schemes. This mission can **allocate budgets** efficiently and **reduce administrative delays** as well. This will be a national-level mission, which may take **1-2 years** in formulation and implementation, as per the complexities in each country. A similar mission has been done in **Singapore** and **South Korea**.

2) Absorptive Capacity Enhancement Program:

This will be a skill and technology upgradation program that will train the firms and provide the necessary resources at **subsidised rates**. Since this cluster suffers from poor absorptive capacity, firms use redundant technology for manufacturing, which will help them learn **lean processes** and **design thinking**. Public awareness and participation of industry leaders will be necessary for this. The program will target MSMEs and those firms where the absorptive capacity is the lowest and will try to enhance the short-run capacity of the firms, which may take up to 5 years. A similar program has been implemented in Ireland and Malaysia.

3) Collaborative R&D and Technology Pooling:

The focus of this program will be to create **shared platforms** where firms pool technologies, laboratories, and technical personnel for common R&D needs, reducing the cost burden. Universities and sector-wise innovation hubs will play a vital role in this, and it may take **1-3 years** to successfully operate it. Universities and firms should be linked and coordinated heavily. A mandate can be formed that **20-30%** of research funding be linked to patents licensed, prototypes built, or industry partnerships.

4) University-Industry Innovation Mandate:

Since cluster 1 countries do research in universities that rarely transform into commercialisation, there is a need for better coordination between these two. This program will ensure that **20-30%** of public research funding must be tied to industrial patents,

prototypes, or licensed technologies, not just academic publications. It may take **2-5 years** to see visible output.

5) Government as First Buyer:

After developing their absorptive capacity, there have to be people to buy those products, and the government should step in to be the first buyers, which would encourage the producers to continue.

CLUSTER 2

1) Decoupling and Circular Transition Mandate:

To address the risk of resource depletion linked to high consumption patterns, a national-level Decoupling Mandate is required to shift Cluster 2 economies away from the take-make-dispose model. This will realign policies so that growth is no longer tied to material-intensive production. The mandate will rely on instruments such as carbon taxes, Cap and Trade, and taxes on virgin materials and landfill use, making pollution and waste more expensive. Finland's early carbon tax illustrates how fiscal tools can reshape market behaviour. The formulation and implementation can take **2-4 years** due to the need for cross-ministerial coordination.

2) Mandatory Circular Economy Implementation Program:

To prevent long-term resource pressure from production and consumption, industries must adopt Circular Economy principles. This includes enforcing **Extended Producer Responsibility** and Right to Repair laws, while public procurement prioritises low resource use, recycled content, and energy efficiency to drive circular innovation within **3-5 years**. Strong monitoring and compliance mechanisms will be essential to ensure widespread adoption and accountability.

3) Mission Driven Innovation for Resource Conservation:

To reduce the risk of economic stagnation if innovation becomes misaligned with sustainability needs, innovation systems must be redirected. To reduce the risk of economic stagnation if innovation

becomes misaligned with sustainability needs, innovation systems must be redirected toward missions that lower resource use and environmental impact.

Key missions include **Industrial Symbiosis**, where waste becomes input for other industries, Material Science development for lightweight or bio-based alternatives, and Digital Resource Optimisation using IoT, AI, and advanced data systems. The Kalundborg industrial symbiosis model demonstrates long-term collaborative efficiency gains, reduced emissions, and significant material and energy savings. These missions typically show measurable outcomes over **5-10 years**.

4) Green Collar Workforce and Vocational Expansion:

To avoid skill mismatches as industries transition to circular and digital systems, investments in **technical and vocational training** are essential. A dual system of vocational training similar to Germany's model can equip workers with industry-ready skills through structured apprenticeships and practical learning. These programs can demonstrate workforce improvements within **3-6 years** as training cohorts enter green collar sectors.

5) Government Stress Testing for Institutional Adaptability

To counter slow policy adaptability despite strong institutions, a national Stress Testing exercise is needed to evaluate how ministries, regulatory systems, and industrial hubs respond to future resource shocks and technological changes. This process will identify bottlenecks in regulations, **coordination issues** across ministries, and gaps in infrastructure planning, enabling governments to redesign their frameworks for faster transition. Stress Testing may take **1-2 years** and will support greater institutional agility.

CLUSTER 3

1) Strengthening Intellectual Capital through Education and Skills Development

To address very low intellectual capital, Cluster 3 countries must prioritise investments in basic,

secondary, and tertiary education. Following the example of **South Korea's** transformation from the 1960s to the 1980s, national strategies should shift from rote-based learning toward innovation-oriented skills. This requires improving basic education quality, ensuring lower secondary completion, and expanding **STEM** and **vocational training**.

Countries should raise funding for universities, research institutions, and R and D while fostering strong linkages between academia and industry. **Digital literacy** should be integrated across all education levels by introducing coding, data skills, and IT support training. Governments can support private sector innovation by offering tax incentives, grants for research investment, and creating a balanced national IP policy that protects inventors while maintaining access to knowledge. The overall aim is to develop robust tertiary and technical skill systems through expanded TVET programs, STEM incentives, apprenticeships, and national digital skills missions.

2) Improving Governance Quality through E-Government and Institutional Reforms

To strengthen governance and reduce corruption, Cluster 3 countries should adopt E-government systems that increase transparency, reduce bureaucratic discretion, and improve service delivery. **Rwanda, Kenya, and Ghana** have shown how such reforms can be tailored to local contexts.

National governments should invest in broadband, electricity, devices, and civil service ICT training while implementing citizen-centric digital design, interoperability standards, e-transaction legality, and strong data protection frameworks. Development partners can support these reforms by financing digital infrastructure, funding public sector skills programs, facilitating regional peer learning, and supporting sandbox regulation for emerging technologies. The private sector should co-develop interoperable systems with government IT teams, offer locally adapted solutions, and sponsor digital literacy initiatives. Civil society and academia can enhance accountability by monitoring inclusion and evaluating E-governance reforms.

GLOBAL COMMONS STEWARDSHIP

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INTRODUCTION

INTRODUCTION TO THE INDEX

The **Global Commons Stewardship Index (GCSI)** is an internationally recognised measurement framework to assess countries' progress in managing and conserving the **global commons**, i.e., shared natural systems organised in ways that **transcend national boundaries**. These systems encompass the atmosphere, oceans, biodiversity, freshwater systems, and land systems. Since no individual country "owns" the global commons, it is a **shared responsibility** to care for and protect these systems. The GCSI offers an assessment of how well each country is contributing to that shared responsibility.

ABOUT SPILLOVER EFFECT

A spillover effect is an **unintended consequence** that an economic or environmental action in one country creates for other countries. In the context of ecological sustainability, spillover effects occur when a country's practices, including consumption, production, or trade practices, have an **adverse environmental impact** that extends **beyond its boundaries**. These effects often occur out of sight of domestic policymakers, but can have profound implications on a **global scale**. For instance, a country may enjoy a reputation for being environmentally sound because it has low carbon emissions. Yet, if that country imports a significant portion of manufactured goods from another country where the **manufacturing process** utilises coal-based industries, pollution generated by the consumption of those goods abroad is a spillover effect that is associated with the **consuming country's behaviour**. All of these environmental pressures are **hidden within supply chains** and, as a result, distort the true environmental impact.

OVERVIEW OF THE PARAMETERS

AEROSOLS

Emissions of **sulfur dioxide, nitrogen oxides, and black carbon** have impacts on regional climate regimes and the cryosphere.

GHG EMISSIONS

Emissions of greenhouse gases [in **CO₂-equivalents**] and, for relevant countries, greenhouse gases embodied in **fossil fuel exports**.

TERRESTRIAL BIODIVERSITY LOSS

A variety of indicators are used to measure risks to, and protections for, **biodiversity resources on land and freshwater ecosystems**.

MARINE BIODIVERSITY LOSS

Measures risks and protections for biodiversity resources in countries' **exclusive economic zones**.

NUTRIENT CYCLES

Measure emissions and management of **phosphorus** and **nitrogen** that may result in disruptions to these biogeochemical cycles.

WATER CYCLE

Measure **human use of water resources** that may result in disruptions to this biogeochemical cycle.

OVERVIEW OF THE CLUSTERS

CLUSTER 1

Cluster 1 primarily comprises Eastern Europe, Central Asia, parts of Latin America, West Asia, and North Africa. These countries are mostly **upper-middle-income** or **transitioning** economies with expanding industrial bases and moderate integration into global trade.

Their spillover weaknesses lie in greenhouse gas emissions and nutrient cycle pressures, driven by **fossil-fuel dependence**. While environmental governance frameworks exist, enforcement remains **uneven**, and production systems remain carbon and nutrient-intensive. Their domestic impact is **moderate**, but their international spillover footprint is meaningfully **high**, reflecting both export-oriented manufacturing and relatively resource-heavy development pathways.

OVERVIEW OF THE CLUSTERS

CLUSTER 2

Cluster 2 primarily comprises Western Europe, North America, advanced East Asian economies (Japan, South Korea, and Singapore), and the Gulf region. These are **high-income**, consumption-driven countries with mature regulatory frameworks, **advanced environmental standards**, and strong monitoring systems. Domestically, they perform relatively well in terms of air quality, emissions control, and biodiversity protection within their borders. However, they also have the **highest spillover footprints** globally, driven by their massive demand for imported food, minerals, energy, timber, and manufactured goods.

This externalizes environmental harm to producer countries, particularly in terms of **GHG emissions, nutrient cycle, aerosols, and TBL** embedded in global value chains. Their economic model, based on **outsourcing** resource-intensive production, creates **indirect pressure** on ecosystems in the Global South. Reducing these spillovers requires **systemic reforms**: sustainable supply-chain laws, deforestation-free imports, and the use of green blended finance and impact investing.

CLUSTER 3

This cluster covers much of the **Global South**, including South Asia, Sub-Saharan Africa, Southeast Asia, and parts of Latin America. These countries are generally **low-income** with limited industrial capacity and high dependence on natural resources. Despite infrastructure challenges, Cluster 3 is the **best-performing group** in terms of spillover impact, as its global environmental footprint remains small relative to wealthier nations. Their primary weakness lies in the **water cycle**, driven by water-intensive agriculture, inadequate wastewater treatment, groundwater depletion, and vulnerability to climate variability.

Many of these countries are also commodity exporters, **supplying water-intensive goods** (such as rice, cotton, sugar and metals) to high-income nations, which deepens **local water stress** without proportionate economic returns. Strengthening water governance, improving irrigation efficiency, investing in wastewater treatment, and supporting **climate-resilient agricultural systems** remain critical to sustaining their relatively good global spillover performance.

Cluster ● 1 ● 2 ● 3



Fig 21:- Cluster wise divisions of countries

STATISTICAL ANALYSIS & PROBLEM IDENTIFICATION

CORRELATION

Correlation of parameters measures how strongly two **environmental indicators move together** across countries. A positive correlation means that when one parameter performs poorly, the other tends to perform poorly as well, revealing shared drivers or linked environmental pressures. Analysing these correlations helps **identify patterns**, common underlying causes, and clusters of issues that tend to co-occur. It also helps determine whether improvements in one parameter are likely to influence another, guiding more **integrated** and **efficient policy** interventions.



Fig 22:- Correlation between parameters of the index

The strong correlation between **aerosols**, **GHG emissions**, and **terrestrial biodiversity loss** reflects their shared link to industrial activity, fossil-fuel use, and land-use change. Countries with high emissions typically rely on **carbon-intensive energy** and **large-scale manufacturing**, which also release aerosols. These same activities, along with agriculture, cause biodiversity loss. These parameters reinforce each other: energy systems and production patterns that generate emissions also create air pollution and exert direct pressure on ecosystems and wildlife. Thus, they require **multifaceted policies** addressing the root issues.

STANDARD DEVIATION

Standard deviation measures how **widely data values spread** around their mean. A high standard deviation indicates large variation, while a low one shows the data is tightly clustered. It helps identify

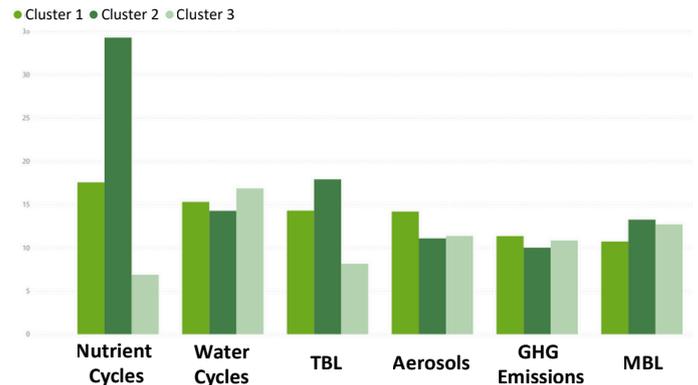


Fig 23:- Cluster wise Standard Deviation of parameters

which parameters differ most across countries or clusters, revealing uneven performance. The **nutrient cycle** shows the highest standard deviation for clusters 1 and 2. In contrast, the **water cycle** exhibits the highest standard deviation in Cluster 3, indicating that countries and clusters differ significantly in water management, agricultural intensity, and nutrient management. Such unevenness requires **flexible, context-specific policies** rather than uniform rules. Solutions must be tailored to each cluster’s agricultural structure, resource availability, and regulatory capacity.

ANOVA

ANOVA (Analysis of Variance) is a statistical method used to determine whether the means of groups differ significantly. It compares **between-group variance** with **within-group variance**. A high **F-statistic** indicates that group means are far apart relative to internal variability, suggesting that the groups are **statistically different**.

Anova Table

Parameter	P score	F score
Aerosol	4.54E-63	426.4767
TBL	2.78E-44	208.395
GHG	6.68E-67	488.3403
NC	1.92E-11	29.1529
MBL	3.34E-47	234.7049
WC	1.50E-30	111.6046

A **high F-score** for aerosols and greenhouse gas emissions (GHG) indicates that the differences between clusters are significantly larger than the differences within each cluster, meaning the clusters are **statistically distinct** on these parameters. This occurs because GHG emissions and aerosol formation are strongly influenced by countries' energy systems, industrial structures, and consumption levels.

High-income, consumption-driven economies produce significantly more **embedded emissions** and aerosols through global supply chains, while lower-income clusters contribute far less. The large separation between cluster means, combined with relatively consistent values within clusters, creates a strong ANOVA signal. This demonstrates that **aerosol** and **GHG spillovers** are key **structural differentiators** across clusters.

CLUSTER MEDIAN DEVIATION FROM GLOBAL MEDIAN

Cluster 1

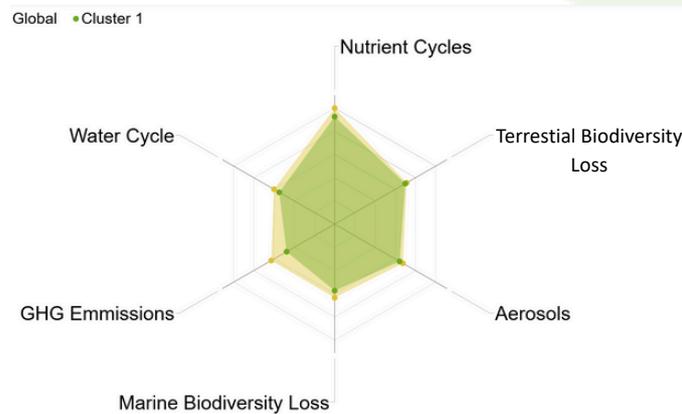


Fig 24 :- Radar chart of Cluster 1

The cluster performs the **closest** to the global median. There are **no extreme deviations** from the median in either direction. Its highest deviation is **greenhouse gas emissions**, at **24.3%**, and its **lowest** is **terrestrial biodiversity loss**, at **2.11%**. Thus, cluster one has good efficiency and is located in the middle of the spectrum, neither high nor low on any parameter. Therefore, this pattern suggests that Cluster 1 exhibits **moderate** environmental performance.

Cluster 2

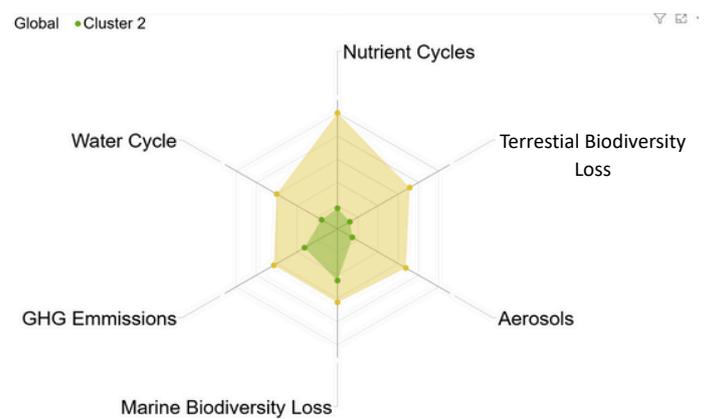


Fig 25:- Radar chart of Cluster 2

This cluster has performed the **worst** owing to its **high deviations** from the global mean. To illustrate, the best result from cluster two is the lowest score in **marine biodiversity loss (MBL)**, **29.7%**. Their worst performance is reflected in **terrestrial biodiversity loss (TBL)**, **82.9%** where they deviate the most from the global median.

Cluster 3

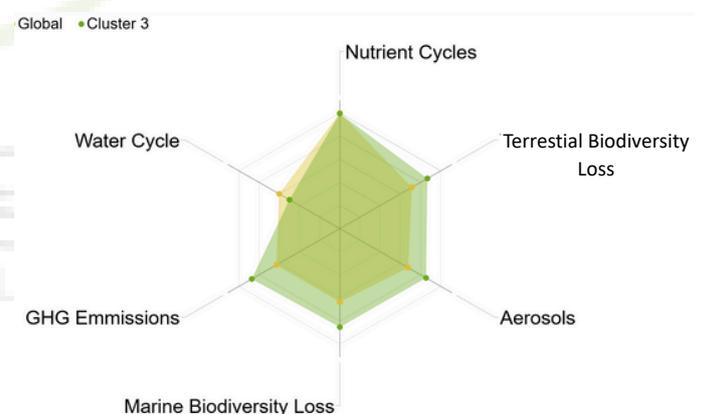


Fig 26 :- Radar chart of Cluster 3

Cluster 3 has the highest level of **GHG emissions**, which is **38.9%** higher than the global median. The next two parameters with the highest increase relative to the worldwide median are **marine biodiversity loss** at **34.3%** and **aerosols** at **26.5%**. The parameter that is **relatively stable** for Cluster 3 is **nutrient cycles** at **0.5%**, which is similar to the global median. Hence, the most critical components for Cluster 3 are emissions, pollution, and resource conservation.

POLICY RECOMMENDATIONS

CLUSTER 1

1) MMRV (Measurement, Monitoring, Reporting, and Verification) Framework

Methane Monitoring Collaboration: The real-time collection of methane data and detection of leaks across natural gas supply chains will be achieved by using **satellite remote sensing**, **ground sensors**, and advanced tools such as **PureWest's Prove Zero**.

Standardised Emissions Reporting: Globally accepted MMRV frameworks with ISO 14067-aligned **third-party verification** should be adopted to standardise emissions reporting and gain public trust.

Precision Agri-Tech Deployment: Practices like **sensor-based** nutrient application, controlled environment agriculture, and **precision irrigation** are to be deployed in Latin America and MENA, with digital platforms providing insights and **micro-finance** to support farmers in optimisation.

Integrated Data Platforms: Gather satellite, sensor, and operational data for all-inclusive emissions and nutrient cycle management, thus aiding in the development of policies and **scenario modelling** for mitigation.

Policy Enforcement Using MMRV: International **financial** and **technical assistance** to be provided to countries in need through the use of **MMRV data** to regulate climate policies, such as carbon pricing and emissions caps.

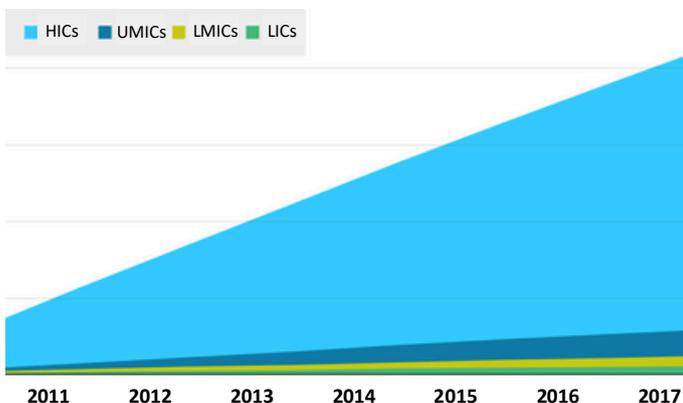


Fig 27:- High Income Countries (HICs) were responsible for more than 80% of imported CO2 emissions from 2010-17

Capacity Building and Knowledge Sharing: Through the transfer of **technology** and **developing networks**, the whole cluster will be made **competent** in MRV implementation, thus making climate accountability sustainable.

CLUSTER 2

1) Concessional Blended Funds for Reducing Spillover (CBFRS)

Blended Finance: Combining philanthropic funds along with private sector funds to attract private resources towards developing sustainability projects in developing nations. Blended finance improves the **risk-reward** profile for an investment, as the majority of risk in the form of offering first-loss coverage is borne by the **philanthropic entities**.

Outcome-Based Financing: Providing benefits to projects based on the impact they are creating in the form of **reducing** the interest rates charged and reducing the **risk of greenwashing**.

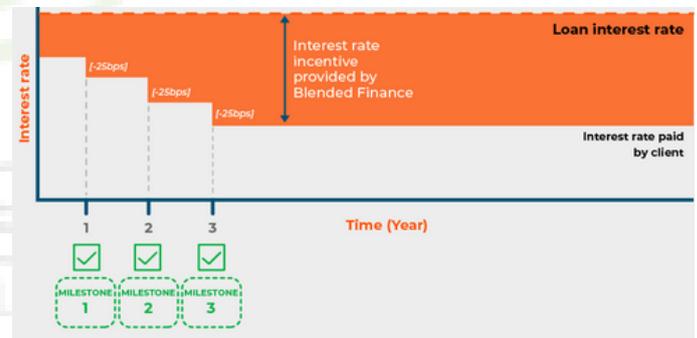


Fig 28:- Interest rates reducing mechanism on achievement of sustainability impact followed by IDB Invest

Implementation: All states must develop a specialised fund for outcome-based financing of international sustainability projects. The Annual Government Budget must fund the fund, and a fixed percentage must be set as the minimum amount. The fund can be deployed in 3 ways:

- i) Directly funding international projects via government institutions
- ii) Deploying funds in existing funds like Mirova Gigaton Fund, Catalytic Transition Fund, etc.
- iii) Funding organisations such as International Finance Corporation (IFC), Global Environment Facility (GEF), etc.

2) Expanding the Kimberly Process's Mandate to include Rare Earth Minerals

Kimberly Process: The Kimberley Process is an international **certification scheme** designed to prevent the trade of conflict diamonds (diamonds that are used to **finance wars**). It requires participating countries to certify rough diamond shipments as **conflict-free** through strict controls, documentation, and government oversight. It aims to stop diamond revenues from funding armed rebel groups and destabilising regions.

Expanding Mandate to REMs: As identified earlier, TBL, Aerosol, and GHG emissions have a **high correlation**. One major industry affecting the three parameters is the **REMs mining industry**, whose demand has skyrocketed due to its use in EVs and clean energy. Expanding the Kimberley Process to include REMs would introduce traceability, certification, and responsible sourcing standards. Mandatory disclosure and verified clean production would ensure importing countries only purchase **sustainably extracted** minerals.

3) Digitalisation of EUDR & CBAM

European Union Deforestation Regulation: An EU legislature requiring companies to verify that the products they sell in the EU are **produced sustainably**, and they aren't sourced from land that has been **degraded**. They must meet all applicable laws of the originating country and must be accompanied by a formal **due diligence statement** before entering the EU market. To do so, operators must **trace** their supply chains, including GPS coordinates, and they must also **document** every production site where the commodity is cultivated.

Usage of digital tools: Digital tools can be leveraged to bring efficient digital **traceability** and **monitoring** tools, which can provide the mapping of geographic, land-use data, the continued monitoring of land use, the ability to identify current and future risks of land clearing and the ability to automatically generate the **necessary documentation** for submission to the EU's information system.

Carbon Border Adjustment Mechanism: CBAM is an EU regulation that compels businesses importing **carbon-intensive** products into the EU to pay a carbon price, equivalent to that which would be applicable to similar carbon-intensive products manufactured within the EU.

Reforms - CBFRS, Digital-Tools & Credit-Finance: To maximise the effectiveness of CBAM and decrease the **administrative burden** on countries, businesses should invest in **automated digital solutions** capable of automating emission data collection, calculation, and reporting so as to **reduce error** and help facilitate compliance for businesses.

Furthermore, CBAM Revenue should be allocated via **blended finance** so as to provide financial support to poorer and developing countries. Lastly, building **technical capacity** and capability within exporting nations through training robust **MRV systems** and providing supportive institutions, will enable exporting nations to be capable of their processes correctly and eventually adopt low-carbon production techniques.

CLUSTER 3

Micro-irrigation at scale: Using **drip** and **sprinkler irrigation** of crops that need lots of water, particularly in South Asia and Sub-Saharan Africa, to increase crop per drop. This approach also **minimises** nutrient runoff and soil erosion, further enhancing long-term farm sustainability.

Alternative water sources for agriculture include reusing **municipal wastewater** to irrigate fodder, industrial, and tree crops, easing pressure on freshwater. In coastal or energy-rich states, **renewable-powered desalination** can support high-value horticulture, freeing dam and groundwater reserves for staple imports. This enables **30-50%** lower water use and **20-40%** higher yields. Additionally, integrating these systems supports circular water economies, turning waste streams into productive agricultural inputs, thereby **reducing the overall cost** of irrigation infrastructure for farmers and municipalities alike.

ENVIRONMENTAL PERFORMANCE

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INTRODUCTION TO THE INDEX

The Environmental Performance Index (**EPI**) is a globally recognised benchmarking tool used to evaluate how effectively countries manage **environmental sustainability** and public health outcomes. It provides a **data-driven** summary of national environmental performance across areas such as **climate change mitigation**, air and water quality, ecosystem vitality, **waste management**, and biodiversity protection. Because environmental challenges are interconnected and extend beyond political borders, the EPI enables **cross-country** comparison, **accountability**, and policy improvement. By ranking nations based on quantifiable indicators, the EPI helps governments, researchers, and global institutions understand progress, **identify gaps**, and strengthen strategies for achieving long-term environmental **resilience** and **sustainability**.

OVERVIEW OF KEY ASSESSMENT PARAMETERS

Air Quality Issue

This indicator measures how a country’s air quality impacts human health and the environment. It tracks pollutants such as PM2.5, ozone, and nitrogen dioxide that contribute to respiratory and cardiovascular diseases and broader environmental degradation. It highlights how industrial activity, transportation patterns, population density, and regulatory policies collectively influence air cleanliness, ecological stability, and long-term public health outcomes across communities.

Ecosystem Vitality

This indicator assesses how well a country is preserving the health and stability of its natural ecosystems. It evaluates factors such as habitat protection, species conservation, and land-use practices, all of which influence ecological balance and long-term sustainability. It also reflects how effectively nations manage pressures like deforestation, land degradation, and resource overuse, capturing the impact of human activity and environmental policies on overall ecosystem resilience and biodiversity.

Sanitation

This indicator evaluates a country’s access to safe sanitation services and effective waste management systems. It considers factors such as sewage treatment, infrastructure coverage, and hygiene practices, which directly influence public health and environmental quality. It reflects how investment, policy, and population needs shape sanitation outcomes and long-term community well-being.

Climate Change Mitigation Issue

This indicator measures how effectively a country is reducing greenhouse gas emissions and transitioning toward low-carbon development. It considers factors such as renewable energy adoption, energy efficiency, and policy implementation that influence long-term climate resilience. It reflects how national strategies and actions contribute to limiting global warming and promoting sustainable growth.

Environmental Health

This indicator evaluates how environmental conditions influence overall human well-being, focusing on clean air, safe drinking water, sanitation systems, and exposure to harmful pollutants. It reflects how a country safeguards its population from health risks linked to contamination, inadequate hygiene, and environmental degradation. It also highlights the role of public infrastructure, regulatory standards, and community access in a safe, healthy living environment that supports long-term resilience and quality of life.

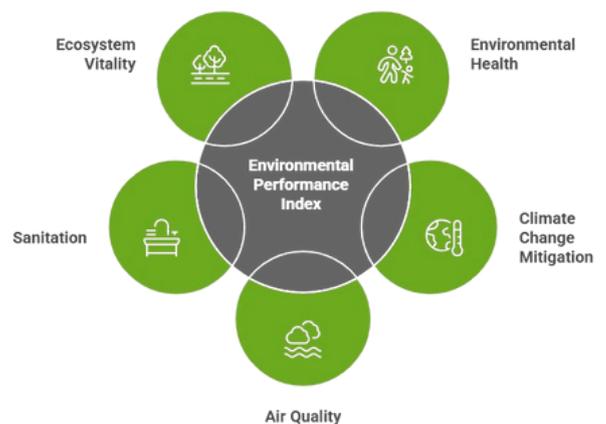


Fig 29:- Parameters

CLUSTER OVERVIEW

CLUSTER 1

Cluster 1 represents the **Mixed/Moderate Performance Cluster**, encompassing a diverse mix of developed nations like Iceland and New Zealand alongside developing economies such as Zambia and South Korea.

These countries maintain balanced environmental outcomes, **excelling in sanitation and ecosystem vitality** while facing **inconsistencies in air quality, health, and climate mitigation efforts**.

Leaders like Iceland demonstrate regulatory strengths in health metrics, yet the group overall requires targeted strategies to bridge gaps in weaker areas and leverage sanitation advantages for broader gains.

CLUSTER 2

Cluster 2 embodies the **High Environmental Performance Cluster**, dominated by **leading European nations** such as Estonia, Luxembourg, Germany, Finland, and the United Kingdom.

These countries achieve exemplary environmental well-being through **robust infrastructure**, excelling in sanitation, air quality, ecosystem vitality, and climate mitigation efforts that set global benchmarks.

Leaders like Estonia pioneer aggressive climate policies, while the group sustains high human health protections and resource conservation, offering models for sustainable development worldwide.

CLUSTER 3

Cluster 3 forms the **Lower Performance or Emerging Economies Cluster**, featuring nations like Trinidad and Tobago, Colombia, Mexico, and Namibia that grapple with foundational environmental hurdles.

These countries confront critical shortcomings in sanitation, air quality, and environmental health, despite pockets of resilience in ecosystem vitality, amid pressures from rapid development and limited infrastructure.

Targeted investments in basic public health protections and pollution controls offer pathways to elevate their standings, drawing lessons from higher performers to foster sustainable progress.

Cluster Assignment

● 1 ● 2 ● 3



Fig 30:- Cross Cluster World Map

ANALYSIS

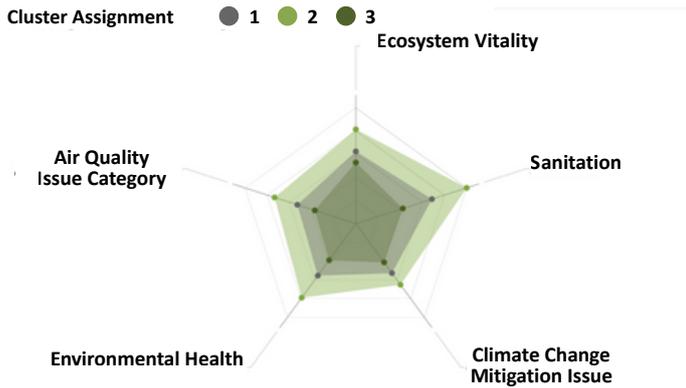


Fig 31:- Cross Cluster Radar Chart

ANOVA

The ANOVA on the Composite Score confirms strong statistical separation between the three clusters, with significantly different means (**C1=47.30, C2=62.50, C3=37.50**). The high F-statistic (**F=222.11**) and near-zero p-value (**5.53E-49**) reject the null hypothesis, confirming that the clusters are meaningfully distinct. This statistical strength reinforces the validity of the three-cluster structure and supports its use for reliable segmentation and deeper metric-level analysis.

VIOLIN PLOT

Sanitation (**Mean = 56.5**) emerges as the cluster's strongest and most consistent indicator, reflected in its narrow, high-positioned distribution. In contrast, Air Quality and Climate Change Mitigation represent the weakest areas, positioned at the lower end of the range (42.0-43.5) with wider distributions, indicating more variable and less reliable performance across member countries.

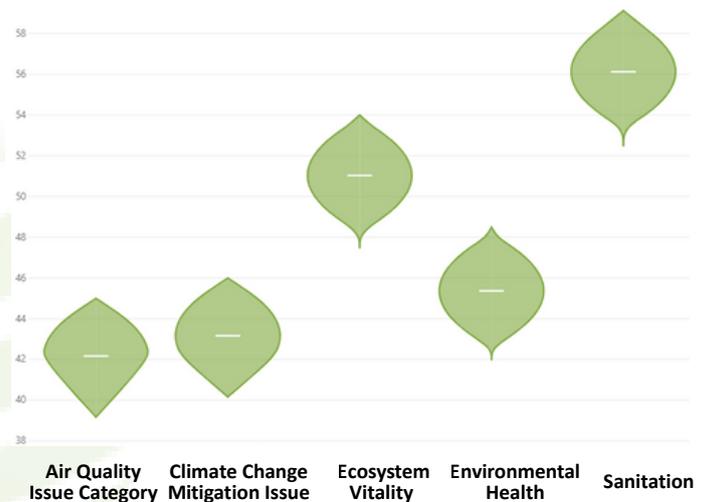


Fig 33:- Violin Chart for Cluster 1

MEAN AND STANDARD DEVIATION

Cluster 1 is characterized by a moderate performance with an **Average Composite Score of 47.3 (SD=5.51)**. While the **mean is stable**, the cluster exhibits **extreme internal variability**, indicated by the high SD in core metrics. Sanitation (SD=22.75) and Air Quality (SD=18.95) show the largest gaps, highlighting a major crisis of internal inequality in public health basics. Its lowest mean performance is in Air Quality (42.17%) and Climate Change Mitigation (43.17%)

CLUSTER 2:

Z SCORES ANALYSIS

The Z-score analysis identifies Cluster 2 as the **top-performing group (Z = +1.35)**, performing well above the average. Its performance remains strong across all metrics, with several countries exceeding +2.0. The cluster stands out in Climate Change Mitigation and Sanitation, positioning it as the **benchmark of environmental excellence**.

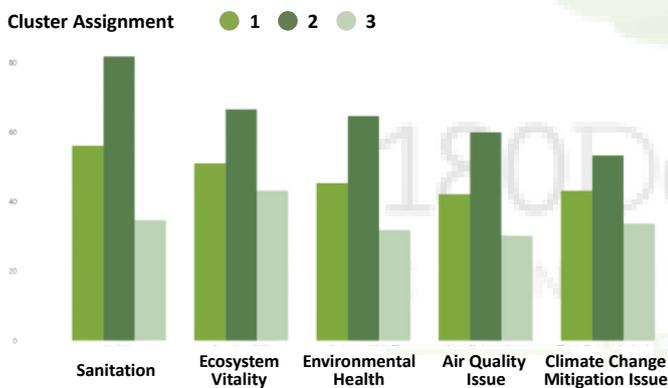


Fig 32:- Clustered Column Chart

CLUSTER 1:

Z SCORES ANALYSIS

The Z-score analysis shows that Cluster 1 sits near the global average (**Z = 0.03**) but contains internal disparity. High performers in Environmental Health lift the mean, while low performers in health and sanitation (around **Z = -1.3**) pull it down. This spread reveals that the cluster's moderate average masks major internal imbalances, highlighting the need for targeted, country-specific interventions.

ANALYSIS

VIOLIN PLOTS

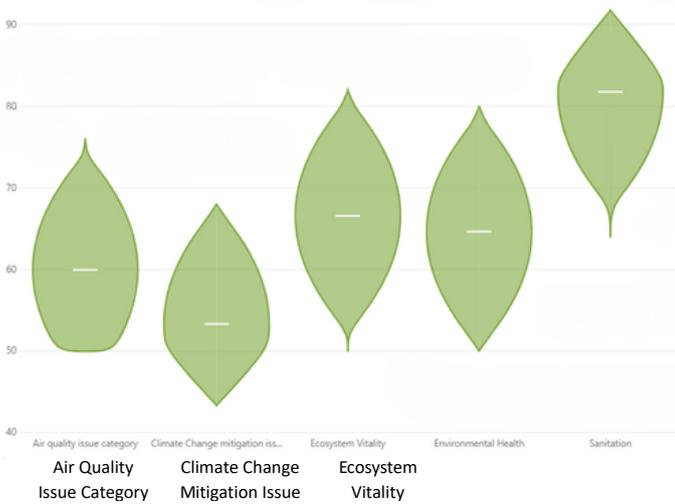


Fig 34:- Violin Chart for Cluster 2

The Violin Plot for Cluster 2 (**Mean = 62.50**) shows strong overall performance with some variation across indicators. Sanitation (**81.77**) stands out as the most consistent strength, while Climate Change Mitigation (**53.3**) and Air Quality (**59.9**) are weaker and more variable, making them key areas for focused improvement moving forward.

MEAN AND STANDARD DEVIATION

Cluster 2 represents the top-performing group with the highest overall score of **62.5 (SD=7.70)**. This cluster demonstrates **superior**, stable performance across all indicators. (Sanitation: **81.77**, Environmental Health: **64.63**). While its SD is slightly higher than Cluster 1, this reflects its overall **success** and strong regulatory framework.

CLUSTER 3:

Z SCORES ANALYSIS

The Z-score analysis identifies Cluster 3 as the lowest performer (**Z = -0.82**), well below the global average. Sanitation and Environmental Health show the largest deficits, with many nations below **Z = -1.0**, indicating major infrastructure and pollution challenges. Although there are limited strengths in Ecosystem Vitality, the overall trend signals an urgent need for targeted investment in foundational environmental health improvements.

VIOLIN PLOTS

The Violin Plot for Cluster 3 (Mean = 37.50) confirms it as the lowest-performing group among the analyzed clusters, with the kernel density curve showing a pronounced skew where most scores **concentrate** near the **bottom** of the **distribution**. This lower-end clustering, combined with the violin's wide tails indicating **high variability**, reveals **inconsistent performance** across regions or subgroups in this cluster.

Air Quality emerges as the most **critical gap** at 30.2, where the narrowest violin width signals low density of higher scores and persistent pollution challenges pulling down overall resilience. In relative terms, **Ecosystem Vitality** at **43.1** acts as a **strength**, reflected by a slightly broader density peak compared to other indicators, though it still falls short of robust benchmarks.

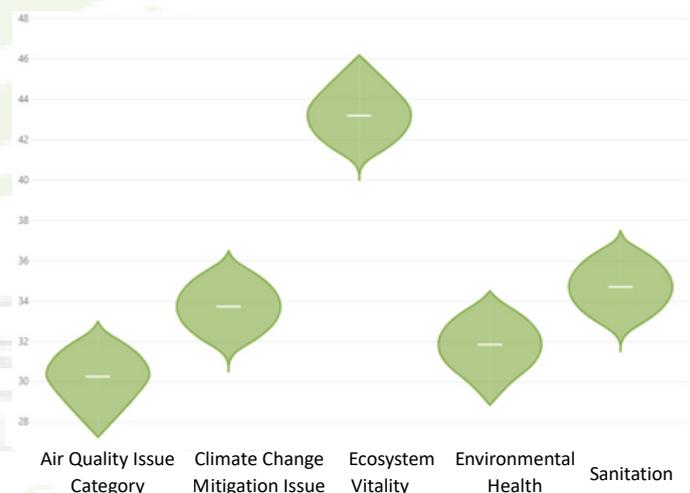


Fig 35:- Violin Chart for Cluster 3

MEAN AND STANDARD DEVIATION

Cluster 3 is the **low-performing group**, scoring significantly below the others with the lowest **Average Composite Score of 37.5 (SD=5.69)**. Its SD is comparable to Cluster 1, but its mean scores are severely low across all metrics, with the **lowest performance** in **Air Quality (30.25)** and **Climate Change Mitigation (33.73)**. Environmental Health (31.84) and Sanitation (34.70) indicate widespread foundational challenges, confirming a need for **fundamental development** and **capacity building**.

PROBLEMS

CLUSTER 1:

Cluster 1 countries face performance stagnation in a mid-tier position due to **weak regulations** and limited capital investment, lagging behind global leaders. Environmental health is their key **vulnerability**, with **disparities** in healthcare and poor air quality lacking effective monitoring. Air quality **fluctuates** from industrial emissions, old vehicles, and **cross-border pollution**, while climate mitigation suffers from policy **implementation gaps** amid **fiscal** and **tech** constraints. Low- and middle-income nations bear a **heavy disease** burden from pollution, especially **affecting children** under five through **indoor air exposure**. Comprehensive reforms in infrastructure and **enforcement** are essential for sustainable progress.

Waterfall chart

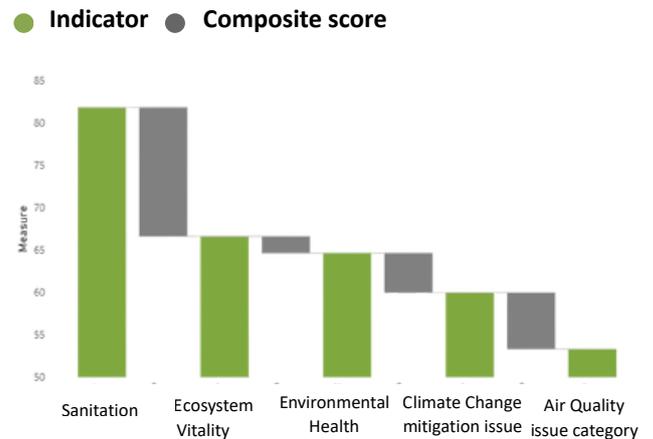


Fig 37:- Waterfall Chart for Cluster 2

CLUSTER 3:

Cluster 3 countries face a sanitation infrastructure crisis, with underdeveloped water and sewage systems leaving millions without hygienic toilets or clean water, fuelling diseases from decades of **underinvestment**. Environmental health falters from polluted air, unsafe water, and chemical exposures that widen urban-rural inequalities and **stifle economic growth**. Climate mitigation stalls amid inconsistent policies and competing development needs, while air quality degrades in urban-industrial zones due to **lax enforcement** and rapid urbanisation, overwhelming healthcare with respiratory issues. Ecosystem vitality suffers from **habitat loss**, weak conservation, and resource overexploitation, like deforestation, as water security crumbles under pollution, overuse, and poor treatment.

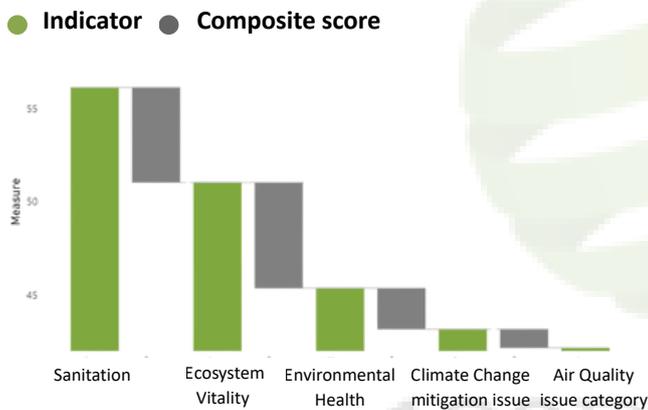


Fig 36:- Waterfall Chart for Cluster 1

CLUSTER 2:

Cluster 2, the best-performing cluster, encounters an implementation gap in climate mitigation despite high policy commitments, where **high variance** reveals uneven progress and slow sector transitions. Sanitation infrastructure masks significant inequalities, with **strong national scores** concealing rural and peri-urban underperformance alongside outlier risks from subnational failures. Biodiversity and ecosystem vitality suffer from economic pressures like **resource exploitation** in forestry and agriculture, driving local declines despite **high aggregate means**. Urban air quality challenges persist beneath good overall scores, marked by **high standard deviations** that highlight stark urban-rural gaps and frequent breaches in city standards.

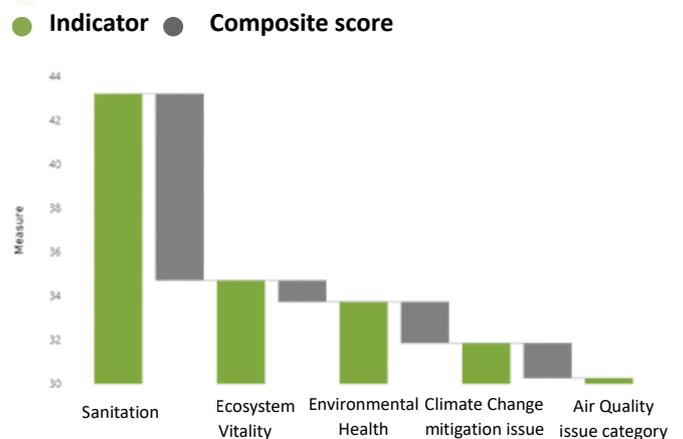


Fig 38:- Waterfall Chart for Cluster 3

POLICY RECOMMENDATIONS

CLUSTER 1

Outcome-Based Sanitation Financing:

Shift to Output-Based Aid (OBA) or Results-Based Financing (RBF), paying NGOs/enterprises only after verified household sanitation facilities. Uganda's OBA vouchers boosted completion rates over traditional grants, targeting low environmental health scores.

Micro-Grid Clean Energy Leasing:

Lease solar/biogas cookstoves via pay-as-you-go models to cut indoor pollution. Kenya's M-KOPA scaled solar systems through mobile financing, improving air quality in low-income areas.

Border Carbon Adjustments (BCA):

Apply tariffs on high-carbon imports to enforce climate action. The EU's CBAM drives decarbonisation in partners like South Korea, mobilising investment for Cluster 1's weak mitigation (43.17 score).

Sovereign Green Bonds:

Issue bonds for air monitoring, grid upgrades, and water renewal. Indonesia/Nigeria/Chile attracted investors for sustainable projects without tax hikes.

Digital Nudging for Ecosystems:

Add real-time resource dashboards to bills for behavioural change. Singapore's nudges cut water use via feedback, boosting vitality without strict rules.

CLUSTER 2

Integrated Climate Policy Solutions:

Integrate carbon pricing, emissions caps, renewable subsidies, and fossil fuel phase-outs with technology transfer. Redirect public-private investments and engage communities to accelerate effective transitions.

Targeted Sanitation Upgrades:

Prioritise rural sanitation infrastructure through river basin management and integrated programmes for hygiene promotion and capacity building.

Ecosystem Vitality Strategies:

Apply payments for ecosystem services, expand protected areas, and use ongoing biodiversity monitoring to adapt policies and enhance conservation.

Urban Air Quality Measures:

Deploy low emission zones, congestion charges, vehicle-industry emission controls, and public engagement initiatives to drive sustained pollution reductions.

CLUSTER 3

Climate Mitigation Leapfrogging Solutions:

Leapfrog fossil fuels by deploying decentralised renewables such as solar mini-grids, photovoltaic systems, biogas, and small hydro for reliable energy access in remote areas, bypassing high-carbon infrastructure and supporting community resilience. Enforce methane leak detection, grant formal forest tenure to local stewards to curb deforestation, and secure external funding for monitoring capacity in states like Haiti and Sudan.

Air Quality Enhancement Strategies:

Eliminate indoor pollution through mass subsidies for clean cooking fuels and high-efficiency stoves targeting rural poor households. Enforce minimum vehicle emission standards with regular urban inspections, and mandate affordable particulate filters on high-polluting industrial sources like brick kilns and power plants.

Sanitation Access Improvement Plans:

Launch national community-led Open Defecation Free (ODF) campaigns with subsidised latrines and behaviour change initiatives. Implement pro-poor lifeline tariffs for heavily subsidised essential water services, and prioritise rural water safety via protected communal points and low-cost household chlorination to curb diseases.

Ecosystem Vitality Protection Measures:

Fund Payments for Ecosystem Services (PES) and secure forest tenure to prevent degradation. Mandate basic wastewater pre-treatment for industrial/municipal discharge.

CONCLUSION

Notre Dame Global Adaptation Initiative Index

The ND-GAIN Index reveals that the capacity to adapt to climate change depends on the **quality** of **governance**, ecological stewardship, and structural conditions a country has.

Cluster 1 countries have **highly productive agriculture**, but their ecological governance is so weak that they are exposed to risks for a long time.

Cluster 2, primarily comprising high-income European countries, is characterised by the strength of the **regulatory sector**. However, the states are faced with a paradox of governance performance as they are struggling with climate-resilient agriculture.

Cluster 3 countries are willing participants in environmental agreements and have **good agricultural potential**. However, weak institutions and poor biodiversity result in increased climate vulnerability of these countries.

The clusters together portray that resilience is not equally distributed and is dependent on the alignment of strong institutions with nature-friendly development.

The Global Sustainable Competitiveness Index

The Global Sustainable Competitiveness Index (GSCI) provides a holistic, data-based measure of national sustainability across natural, social, economic, governance, and innovation indicators. Its cluster analysis shows clear contrasts:

Cluster 1 countries perform around the world average but **lack strong innovation** and stable governance, making them transitional. It needs coordinated innovation and capacity-building reforms.

Cluster 2 is advanced economies that lead overall, but remain highly **resource-intensive** and must decouple growth from environmental impact. This cluster requires circular economy and efficiency transitions.

Cluster 3 countries have the **weakest performance** due to low human capital and poor institutions, preventing effective use of their resources. These countries must focus on education, R&D, and governance.

Environmental Performance Index Analysis

The Environmental Performance Index (EPI) evaluates how effectively countries manage environmental health and ecosystem sustainability across key areas such as sanitation, air quality, climate action, and biodiversity conservation. The clustering results reveal distinct performance patterns: mid-performing countries showing gradual improvements but struggling with consistent enforcement, high-performing countries with strong regulatory systems yet slower progress on deep decarbonisation, and low-performing countries facing infrastructure deficits, pollution challenges, and limited institutional capacity. These differences highlight that environmental outcomes are shaped not only by development level but also by **governance quality** and **long-term policy continuity**. Overall, the EPI illustrates that meaningful environmental progress requires sustained implementation, resource mobilisation, accountability, and knowledge-sharing between clusters to advance global sustainability goals.

Global Common Stewardship Index

The Global Commons Stewardship Index (GCSI) assesses how countries safeguard shared environmental systems across emissions, biodiversity loss, resource stress, and global supply chain impacts. The cluster patterns reveal three profiles: **carbon-dependent** but relatively balanced economies, **high-consumption economies** with strong domestic regulation but high external spillovers, and **low-footprint economies** facing resource and water vulnerabilities. These findings show that sustainability pressures are shaped not just by emissions but by production models, trade structures, and governance capacity. Accordingly, solutions such as stronger MRV systems, blended finance, improved water governance, mineral stewardship, and digital traceability tools (e.g., EUDR/CBAM alignment) are needed.

Overall, the GCSI reinforces that safeguarding global commons demands shared accountability, transparent value chains, and tailored policy action.

GLOSSARY

Kurtosis Test: A statistical measure used to evaluate whether the tails of a distribution are heavier or lighter than those of a normal distribution.

Skewness Test: A statistical measure used to identify the degree and direction of asymmetry in a distribution.

Violin Plots: It shows the distribution of data across different values using a mirrored density curve, making it easy to see where data is concentrated.

Intellectual Capital: The collective knowledge, experience, and innovative capability of any firm or an individual that can be used to create value.

Social Capital: The network of relationships, trust, norms, and social connections that enable individuals or groups to work together effectively.

Bubble Chart: A bubble chart visualises relationships between three variables using circles whose positions represent two variables and whose sizes represent a third.

Radar Chart: A radar chart displays multivariate data across multiple axes arranged radially to highlight strengths, weaknesses, and patterns.

Trade-off Matrix: A trade-off matrix compares alternatives across key criteria to reveal benefits, drawbacks, and optimal decision paths.

ANOVA: A statistical tool used to check whether the means differ significantly across the clusters.

Z Score: A standardisation method that shows how far each cluster's average indicator value is from the global mean, measured in standard deviations.

Waterfall charts: A visual chart that shows how individual indicators add to or subtract from a cluster's overall environmental performance.

Border Carbon Adjustment: A trade policy tool that places a carbon cost on imported goods to ensure foreign producers face the same climate regulations as domestic industries.

Rare Earth Minerals: A group of 17 metallic elements essential for making products like smartphones, electric vehicle batteries, and military equipment. Their extraction and refining are difficult, making supply strategically important.

Global South: A geopolitical term for developing nations mainly in Asia, Africa, Latin America, and the Caribbean. It contrasts with the wealthier "Global North" in terms of development and global influence.

Concessional Funds: Financial resources provided on more generous terms than market loans, usually with low interest rates and long repayment periods. They help developing countries finance development-related projects.

Conflict Diamonds: Diamonds mined in war zones and sold to finance armed conflict against governments. Their trade has led to global initiatives like the Kimberley Process to prevent illegal sales.

EUDR (European Union Deforestation Regulation): A regulation introduced by the European Union to prevent products linked to deforestation or forest degradation from entering EU markets. It requires companies to prove that commodities like cocoa, coffee, timber, palm oil, and rubber are sourced from land not deforested after 31 December 2020.

Greenwashing: A deceptive practice where companies exaggerate or falsely claim their products, policies, or operations are environmentally friendly. It is used to create a misleading impression of sustainability without making real, substantive environmental improvements.

Blended Finance: A financing approach that combines public or philanthropic capital with private sector investment to fund development or climate-related projects. It reduces investment risks and encourages private participation in sectors that might otherwise be unattractive due to low returns or high uncertainty, thus enabling scalable, sustainable impact.

APPENDIX

APPENDIX 1 : Notre Dame Global Adaptation Initiative Index

APPENDIX 2 : Global Common Stewardship Index

APPENDIX 3: The Global Sustainable Competitiveness Index

APPENDIX 4: Environmental Performance Index Analysis



