GHG Per Capita as a Misaligned Climate Indicator: Evidence from a Multi-Country Assessment Using Absolute and Sectoral Metrics

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1. Abstract

Per capita greenhouse gas (GHG) emissions are widely used in global climate assessments and policy debates as proxies for national responsibility and environmental impact. Despite their popularity, these indicators may lack methodological robustness when evaluated through the lens of indicator theory and environmental typologies. This study critically examines the conceptual and practical limitations of per capita GHG emissions as environmental impact indicators.

Drawing on the DPSIR framework and established indicator criteria, including sensitivity, comparability, interpretability, and causal alignment we assess the validity of the per capita approach across three contrasting national contexts: India, Slovakia, and Palau. Using harmonized data under the UNFCCC reporting framework, we segment emissions by sector and simulate the effect of structural variables such as trade balance, energy mix, and population size.

Our findings indicate that per capita GHG metrics often misrepresent actual environmental pressure and are inconsistently aligned with impact-oriented evaluation. Particularly in structurally asymmetric countries, they obscure both the magnitude and source of emissions, leading to flawed cross-country comparisons. We argue that GHG per capita functions primarily as a pressure indicator but is frequently misused to imply climate impact or moral responsibility.

This misapplication distorts policy narratives and can undermine the fairness and accuracy of climate accountability assessments. The study concludes by proposing a typology-aware approach to emissions reporting that integrates both absolute and contextualized metrics for a more nuanced understanding of national climate responsibility.

Keywords: Greenhouse gas emissions, Per capita indicators, DPSIR framework, Climate responsibility, Indicator validity, Cross-country comparability

2. Introduction

Per capita indicators, such as Gross Domestic Product (GDP) per capita or emissions per capita, are widely used across various scientific disciplines and societal areas due to their simplicity and capacity for quick comparisons between countries or regions. Common indicators include per capita energy consumption, healthcare expenditure per capita, military expenditure per capita, and water consumption per capita. Despite their utility for immediate comparisons, these indicators fail to account for complex structural factors, such as income inequality, demographic variations, technological levels, or infrastructure efficiency.

Per capita indicators are frequently criticized for their tendency to distort real conditions within a country, as average values do not reflect the distribution of resources or wealth among the population. **"What we measure affects what we do; and if our measurements are flawed, decisions may be distorted; if our performance metrics are flawed, so too may be the conclusions we draw from them"** *(Stiglitz et al., 2009)*[13].

In reality, countries with large populations may show lower per capita values despite substantial absolute impacts. Moreover, such values fail to capture equity in access to essential resources or the scale of environmental externalities, often leading to misleading conclusions about a country's prosperity or climate responsibility.

Environmental indicators, by contrast, are expected to represent measurable, interpretable, and policy-relevant proxies of environmental status, pressure, or impact. According to Bell and Morse (2008)[17] argue that effective sustainability indicators should be reliable, recent, regularly updated, and allow for cross-country comparisons, reflecting essential qualities for comparability and responsiveness in environmental metrics.. In the context of climate change, these indicators must also reflect physical causality, particularly when assessing the contribution of anthropogenic greenhouse gas (GHG) emissions to atmospheric forcing.

GHG emissions per capita have become a dominant metric in global climate discourse, frequently cited in political negotiations, advocacy efforts, and intergovernmental assessments. However, when evaluated through the lens of indicator theory, their appropriateness as impact-oriented indicators remains questionable. Specifically, their statistical simplicity may come at the cost of misrepresenting actual environmental burdens, particularly in cross-country comparisons involving population asymmetries and structural differences.

This study examines the limitations of per capita indicators by analyzing three contrasting national profiles (India, Slovakia, and Palau) highlighting how population scale and economic structure influence indicator reliability. Using a combination of sectoral segmentation under the UNFCCC framework, emissions clustering, and simulation modeling, we assess whether GHG per capita indicators meet the criteria of effective environmental indicators and explore the implications of their continued use in climate responsibility assessment.

A. Indicator Theory Framework

Environmental indicators are tools for simplifying complex environmental data into measurable, interpretable, and policy-relevant metrics. According to OECD (2003)[18], effective indicators should be analytically sound, policy-relevant, and measurable over time. Bell and Morse (Bell and Morse, 2008)[17] highlight reliability, responsiveness to change, and cross-context comparability. UN DESA (2007)[19] emphasizes alignment with physical or social causality, especially in sustainability assessments.

In established typologies such as the DPSIR framework (Gabrielsen & Bosch, 2003)[20], indicators are categorized as drivers, pressures, states, impacts, or responses. GHG emissions per capita are often used to assign responsibility or compare climate performance, but functionally they reflect pressure, not impact. Their widespread use as impact proxies overlooks structural differences between countries (e.g. trade, energy mix, development stage), leading to limited comparability and weak causal alignment.

The objective of this study is therefore to assess whether the GHG per capita metric meets the theoretical and methodological expectations placed on environmental indicators, especially when applied at the national scale for assessing climate responsibility. This includes evaluating its internal coherence (sensitivity, comparability), conceptual alignment (with pressure/impact typologies), and its robustness under structural variation.

B. Research Problem and Hypothesis

The widespread reliance on GHG emissions per capita as an environmental indicator raises critical methodological and interpretive concerns—particularly when used in intergovernmental negotiations or for benchmarking national climate performance. While its simplicity offers intuitive appeal, this study questions whether the metric withstands scrutiny when examined through the lens of indicator theory, typological classification, and empirical structural variation.

Research Question:
Does the GHG per capita indicator meet the essential criteria of a valid environmental impact indicator when applied to countries with significantly different demographic and sectoral profiles?

Hypothesis:
We hypothesize that per capita GHG indicators systematically fail to capture actual climate impact across structurally diverse countries, leading to misinterpretation of national responsibility.

This formulation guides the structure of the paper, which evaluates indicator coherence, typological alignment, and empirical robustness using a comparative model involving India, Slovakia, and Palau.

3. Methods

All GDP and population data were sourced from reputable sources, such as the *World Bank Open Data* (*World Bank Open Data*, 2023)[16], and all greenhouse gas (GHG) emissions data were obtained from the *Emissions Database for Global Atmospheric Research – EDGAR (EDGAR, 2024)*[2], managed by the EU Joint Research Centre. The EDGAR database provides a time series of greenhouse gas emissions for all countries and anthropogenic sectors from 1970 to 2023, enabling the tracking of year-over-year changes and country comparisons. All GDP and GDP per capita figures mentioned in this document are calculated using the constant 2015 US$ method, which allows for real economic value comparisons over time, eliminating inflation effects. Population data from the World Bank Open Data derives from the following sources: (1) United Nations Population Division. World Population Prospects: 2022 Revision[3]; (2) Statistical databases and publications from national statistical offices; (3) Eurostat: Demographic Statistics; (4) United Nations Statistics Division. Population and Vital Statistics Report (various years). For the purposes of the case study, we employed the methodology provided by UNFCCC (2016)[14].

For this document's analysis, three countries were selected to provide a diversified view of economic and environmental indicators relevant to the year 2023:

a) **India** ranks 6th globally in terms of GDP and 3rd in terms of greenhouse gas emissions (CO_{2eq}). As a significant global emitter, India contributes approximately 7.8% of worldwide GHG emissions (EDGAR, 2023)[2], and its share continues to grow. The country is currently the world's most populous nation.

b) **Slovakia** ranks 62nd globally in GDP and 87th in GHG emissions (CO_{2eq}), contributing about 0.003% of global GHG emissions (EDGAR, 2023)[2]. It is among the smaller countries in terms of population and is part of the EU27 grouping.

c) **Palau** ranks 185th by GDP and 175th in terms of GHG emissions (CO_{2eq}), contributing approximately 0.085% of global GHG emissions (EDGAR, 2023)[2]. Palau is a small island state comprising 26 islands in Oceania, with a low population but relatively high per capita emissions.

This diverse sample provides an adequate mix of indicators that serves as a basis for further in-depth research.

C. Indicator Selection

To assess economic output and living standards, the GDP per capita metric (constant 2015 US$) was used, following the definition in the *World Bank Metadata Glossary (World bank, 2024)*[16]. This indicator facilitates international comparisons of economic output without the influence of exchange rates and offers a basic overview of each country's prosperity. This standard calculation provides a general sense of a country's welfare;

however, upon deeper analysis, it reveals limitations, such as the absence of factors like income distribution or the varying scale of different economies.

This indicator was deemed appropriate given the aim to compare economic performance across countries with different economies and population sizes, such as Slovakia, Palau, and India. The following formula was used to derive the GDP per capita indicator:

$$GDP\ per\ Capita_{(\ country,year)} = \frac{GDP\ constant\ 2015\ US\$_{(country,year)}}{Population_{(country,year)}}$$

To measure environmental impact, the GHG emissions per capita metric was employed, commonly used to compare environmental burdens among countries. However, this metric provides only a superficial view, as it does not account for structural differences between national economies or the sectoral breakdown of emissions. The GHG emissions per capita indicator was calculated using the following formula:

$$GHG\ Emissions\ per\ Capita_{(country,year)} = \frac{GHG\ Emissions_{(country,year)}}{Population_{(country,year)}}$$

Lastly, we extended the analysis with a demonstration of sectoral analysis based on the UNFCCC methodology, which divides emissions by sector (e.g., energy, transportation, industry, agriculture).

During the analyses, inconsistencies were noted in the EDGAR database concerning the calculation of per capita emissions for Palau. EDGAR reports a value of 65.28925 tons CO_{2eq} per capita (2023). Given a total GHG emission volume of 1.50165 Mt CO_{2eq} (2023), this suggests a population of approximately 43.5 thousand, which conflicts with population data provided by the World Bank, derived from the UN World Population Prospects dataset or official data from Palau’s government on palaugov.pw. Consequently, we set Palau's real population in 2023 at 18,058, which was then reflected in our analyses and recalculations of per capita values. This discrepancy highlights potential inaccuracies in the EDGAR database, likely due to inconsistent data sources for population figures. We have informed the EDGAR database manager at the EU Joint Research Centre of the discrepancies identified.

D. Analytical Approach

In analyzing per capita indicators, the following methodological approaches were employed:

a) International Comparison of Per Capita Values: By comparing GDP and GHG emissions data for India, Slovakia, and Palau, we examined the differences that average per capita values fail to capture. Data sources were drawn from academic databases.

b) Sectoral Analysis by UNFCCC: To address the limitations of per capita metrics, we focused on sectoral segmentation, which allowed us to identify the impacts of economic structure and energy infrastructure by sector.

c) Simulation Modeling: Through simulation scenarios, we identified the conditions under which Slovakia’s per capita emissions could match India’s value, taking into account growth indicators of population and emissions in both countries.

E. Critical Evaluation of Per Capita Methods

In the discussion, we relied on critical perspectives from prominent economists and researchers such as Joseph Stiglitz, Amartya Sen, and Lukáš Kratochvíl, who warn of the risks and inaccuracies inherent in using per capita indicators. Their views underscore the limitations that per capita metrics pose in the context of diverse economies with differing distributions of wealth, infrastructure, and environmental strategies.

The comparative model does not aim to quantify precise emissions impacts, but rather to evaluate the representational capacity of per capita indicators within diverse national contexts.

4. GDP per capita: An Incomplete Picture of a Country's Economic Status

GDP per capita is frequently used in evaluating the economic performance and standard of living of countries. Table TAB.1 provides an overview of the performance of the countries analyzed based on this indicator. Higher GDP per capita values may suggest a higher standard of living and prosperity, but their significance is limited.

TAB 1. – Basic Economic Indicators for Selected Countries (2023)

Country	GDP (constant 2015 US$) in Mil.	GDP Share	Population (ths.)	Population Share	GDP per capita (constant 2015 US$)
India	3 199 055.0	3.4463%	1 428 627.7	17.945%	2 239.3
Slovakia	104 288.2	0.1123%	5 426.7	0.068%	19 217.5
Palau	225.4	0.0002%	18.1	0.001%	12 480.6
World	92 827 055.1	100.0000%	8 024 997.0	100.000%	11 567.2

The data in Table TAB.1 provides a basic comparison of economic performance and population size for the countries analyzed within a global context. They show absolute values for GDP and population as well as their shares of the world's GDP and population. GDP per capita serves as an indicator of average economic output per inhabitant in each country.

These values, however, represent exclusively quantitative data and offer no further context on the socio-economic situation or quality of life in the respective countries. Average GDP per capita values provide only a simplified comparison between countries of different sizes and economic output. These figures should therefore be understood as purely numerical indicators, devoid of interpretation related to living conditions, income distribution, or development level. As a result, they only offer basic comparisons of economic and demographic dimensions without additional conclusions.

Relying solely on GDP per capita to compare countries can be misleading and insufficient for comprehensive evaluation, as this indicator, though quantitatively accurate, fails to capture several essential factors necessary for assessing economic and social conditions:

1. Income Distribution Inequalities: GDP per capita calculates the average economic output per inhabitant but does not consider wealth distribution within the population. A high GDP per capita value can mask deep income inequalities, where only a small portion of the population holds a significant share of wealth, while the majority may be at low-income levels. This indicator, therefore, does not reflect the real economic situation for most inhabitants of a country.
2. Social and Economic Conditions: GDP per capita does not provide information on living conditions, such as access to healthcare, education, infrastructure, or social services. Countries with similar GDP per capita values may have vastly different levels of quality of life and access to essential needs, meaning this indicator can lead to erroneous conclusions about the real standard of living of the population.

3. Environmental and Sustainability Aspects: GDP per capita does not account for the environmental impacts of economic production or the sustainability of economic growth. A country with high GDP per capita, which achieves economic performance at the expense of natural resources or the environment, may face long-term sustainability issues. This aspect is crucial for assessing development and quality of life in the context of global challenges like climate change.

4. Economic Structure: GDP per capita does not consider the economic structure of countries, such as the proportion of industry, services, and agriculture. Countries with similar GDP per capita values may have

very different economic foundations, affecting the stability of their economic growth and resilience to economic crises. This structural diversity is fundamental for the proper comparison of national economies.

Using GDP per capita alone can therefore lead to erroneous conclusions about the actual prosperity, quality of life, and developmental level of countries. For a more complete and accurate assessment, this indicator must be supplemented with additional socio-economic, environmental, and structural metrics that provide a comprehensive picture of the situation within a country.

The summary of data in the table TAB.1 confirms the need to supplement GDP per capita analysis with additional indicators that better reflect wealth distribution, levels of industrial development, and access to essential services in individual countries. By focusing on GDP, proponents of the program overlook the fact that GDP is not synonymous with welfare (David R. Henderson, 2010)[4].

In the article *"The Fallacy of Global Comparisons Based on Per Capita Measures"* (Kratochvíl & Havlíček, 2024)[8]. authors criticize the use of per capita indicators, such as GDP per capita, in international comparisons. They argue that such indicators can be misleading because they do not account for population differences and can distort the true economic and environmental impact of countries. For example, countries with large populations may show low greenhouse gas emissions per capita, creating the impression that they are more environmentally friendly, even when their total emissions are high. The authors propose that when evaluating and comparing countries, absolute values or other metrics that better reflect the actual state and impact of countries at a global level should be used.

5. Per Capita Emissions: A Confusing Indicator of Climate Change Impact

Similar to GDP per capita, the per capita emissions indicator is commonly used to assess the environmental impact of countries. This indicator expresses the average value of greenhouse gas (GHG) emissions per inhabitant and allows for quick comparisons among countries. Nonetheless, this indicator often leads to erroneous conclusions, as it does not account for structural differences between economies, population factors, or the specifics of industrial development in countries.

TAB.2 – International Comparison of Environmental Indicators (2023)

Country	GHG Emissions (Mt CO_{2eq})	GHG Emissions Share	Population (Ths)	GHG Emissions per capita (kg CO_{2eq})
India	4 133.6	7.805%	1 428 627.7	**2 893.4**
Slovakia	44.8	0.085%	5 426.7	**8 250.9**
Palau	1.5	0.003%	18.1	**83 065.7**
World	52 962.9	100.000%	8 024 997.0	**6 599.7**

Significant differences in per capita emissions among countries may not accurately reflect the real environmental impact. Table TAB.2 illustrates the comparison of per capita emissions for India, Slovakia, and Palau. The data indicates that a country with a smaller population, such as Palau, exhibits disproportionately high per capita emissions, which can create the impression that it has a greater environmental impact. However, this approach fails to recognize that the absolute volume of Palau's emissions is negligible compared to countries with large populations, like India, which produces a significant share of global emissions, despite its relatively low per capita emissions.

Per capita emissions also fail to account for structural and technological differences between countries. For instance, India has a large population and a growing industrial sector, but the average per capita emissions may obscure the actual volume of emissions arising from its overall economic and industrial development. Conversely, countries like Palau and Slovakia exhibit high per capita emissions, which are partly a result of their small populations but not necessarily high industrial or environmental burdens.

What does this mean for us?
Does it imply that Slovakia needs to expend 2.9 times more per capita emissions to sustain life in the country? Or does it suggest that Palau is so environmentally unfriendly that it is an 11-fold worse GHG emitter per capita compared to India?

Although mathematically valid, per capita values can obscure the real climatic burden imposed by a country's total emissions.

Justification
When assessing the impact of produced emissions on the atmospheric system, it is essential to monitor the total emissions generated by individual countries. Only aggregate data on absolute emissions provides a valid picture of direct impacts on the atmosphere and the climate system. Climate forcing is driven by absolute atmospheric concentrations of GHGs, which are not influenced by the statistical construct of per capita values. This approach applies to other GHGs, whose concentration in the atmosphere significantly influences temperature balance and radiative processes. As a result, per capita values are rather overvalued than scientifically rigorous indicators that are critical in assessing the impact of greenhouse gases on the climate system.

A climatologically correct interpretation would therefore require considering a country's absolute emissions, which are very low in the case of Palau, indicating that its influence on the global climate is minimal. India, even with relatively low per capita emissions, has a significantly higher climate impact due to its large population and high total emissions volume.

In 2023, Palau's GHG emissions accounted for only 0.0363% of India's total emissions and merely 0.0028% of global emissions. Based on these data, it is evident that India can generate in one day the same amount of emissions that Palau produces in approximately 7.5 years or Slovakia in a period of 92.3 days. In comparison to Slovakia's values, India achieves the annual volume of Slovak emissions in 4 days. This disparity confirms that absolute emission volumes are incomparably more precise indicators of environmental impact than per capita values, which only consider the average per inhabitant and do not capture the actual impact on the global climate.

India's year-over-year increase in emissions in 2023 was 222.2 Mt CO_{2eq}, an amount that Slovakia would produce over a five-year period. This data demonstrates that countries with large populations and developed industrial sectors contribute significant absolute emissions volumes, increasing their overall influence on the global climate, regardless of lower per capita emissions values.
To gain a more detailed view of the distribution of emissions across different countries, we created clusters for 208 countries based on per capita emissions values, normalizing these figures to tons CO_{2eq} per capita for ease of comparison. This approach allows us to examine individual countries in smaller numerical categories, providing a basis for a more thorough assessment of differences in per capita emissions, as illustrated in TAB.3.

TAB.3 – Comparison of Per Capita Emissions by Defined Clusters (2023)

CID	Emissions per capita min (t per capita)	Emissions per capita max (t per capita)	Countries	Total Emissions	Global Emissions share	Africa	Americas	Asia	Europe	Oceania
1	50		3	156.1	0.3%	0	1	1	0	1
2	25	49.99999	5	639.1	1.2%	0	0	5	0	0
3	15	24.99999	13	11 388.6	22.0%	0	4	5	1	3
4	10	14.99999	16	18 380.0	35.5%	2	3	5	6	0
5	5	9.999999	59	11 149.4	21.6%	5	12	14	27	1
6	2.5	4.999999	48	6 995.8	13.5%	12	18	10	4	4
7	1	2.499999	50	2 832.1	5.5%	29	11	9	0	1
8	0	0.999999	14	176.7	0.3%	8	0	2	1	3
		TOTALS	**208**	**51 717.78**	**100.0%**	**56**	**49**	**51**	**39**	**13**

Table TAB.3 Description:

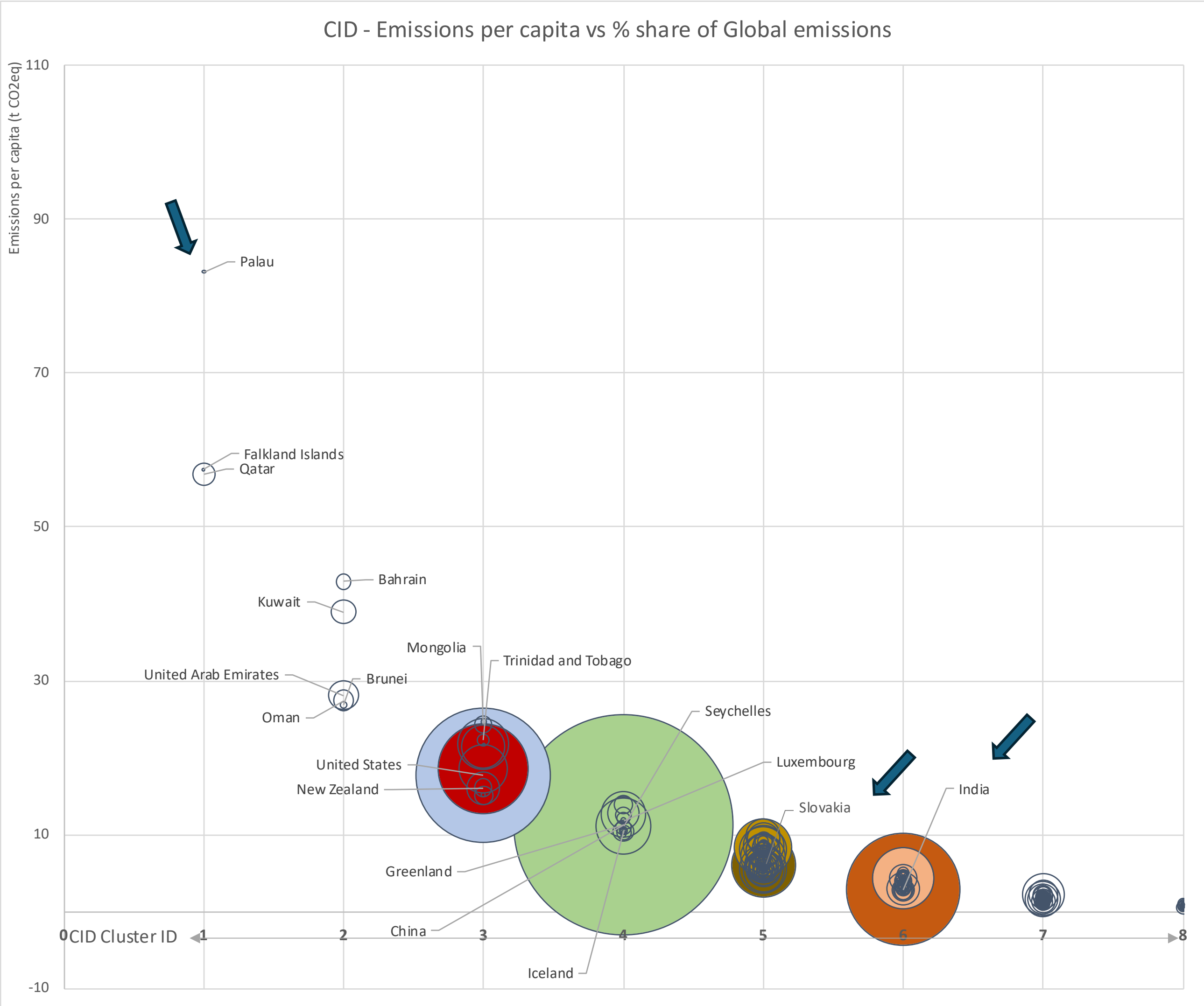
- CID – Cluster ID: Cluster identifier based on per capita emissions values.
- Emissions per capita min (t per capita): The lower emissions per capita boundary (in tons) for countries included in the cluster.
- Emissions per capita max (t per capita): The upper emissions per capita boundary (in tons) for countries included in the cluster.
- Number of Countries: The total number of countries included in the defined range of per capita emissions for each cluster.
- Total Emissions (Mt CO_{2eq}): Absolute emissions value (in Mt CO_{2eq}) produced by countries within the cluster.
- Share of Global Emissions: The percentage share of emissions from countries within the cluster out of total global emissions.
- Africa...Oceania: The number of countries within the cluster from each continent.

The table demonstrates that countries with large populations, such as India, fall into clusters with relatively lower per capita emissions values, which may create a misleading impression of their environmental performance. India is the dominant member of its cluster (CID 6), contributing nearly 58.7% of the total emissions within the cluster. When Egypt and Indonesia's contributions are included, the cluster's share reaches 80.5%, while other countries in the cluster contribute insignificantly. This concentration reveals that globally dominant economies with high absolute emissions can give a misleading impression of their ecological impact when only per capita metrics are used.

Conversely, Slovakia is part of Cluster CID 5, where it produces 0.4% of the cluster's emissions but has high per capita emissions due to its small population. This cluster includes 59 countries with diverse economies. In terms of total emissions, 80% of this cluster is composed of only 17 countries, while the remaining countries, including Slovakia, represent an insignificant portion. For a better perspective, this cluster includes smaller emitters, such as Aruba, the Cayman Islands, Bermuda, the Cook Islands, Saint Pierre and Miquelon, Saint Helena, Ascension, and Tristan da Cunha. Despite having very high per capita emissions, these countries emit more than double the amount of India's emissions per capita.

Palau, with its high per capita emissions, is part of Cluster CID 1, where it contributes 1% of the cluster's emissions, which comprises countries with high per capita values. This cluster is almost entirely dominated by Qatar, whose emissions are more than one hundred times higher than Palau's. Despite high per capita emissions values in this cluster, their absolute environmental burden on a global scale is considerably smaller than that of countries with large populations and lower per capita emissions values.

CHART.1 – Comparison of Per Capita Emissions by Defined Clusters



The Chart 1 illustrates the comparison of each cluster according to per capita emissions values and their share of global emissions. The graph clearly shows that countries with high per capita emissions, particularly countries with low populations, can belong to the same cluster as large economies like China or the USA, which have low per capita values but high absolute emissions. This mismatch confirms that classifying countries based on per capita emissions leads to significant disparities that do not accurately reflect a country's real environmental impact on a global level.

Large countries have very low per capita emissions values, which can create the impression that they are environmentally responsible. While this average is calculated correctly, it does not serve as a metric for environmental responsibility. In reality, Greenland ranks in the same cluster (4) as China in terms of per capita emissions, while in absolute terms, Greenland produces only 0.67 Mt CO_{2eq}, compared to China's 15,943 Mt CO_{2eq}. This contrast represents a significant disproportion, distorting the actual emissions picture. Similarly, Mongolia ranks in the same cluster (5) as the USA, once again highlighting disparities in assessments. Such mathematical classifications, while technically correct, are misleading in a climate context because they do not reflect the real impact of individual countries on the global climate.

Clustering reveals that differences in evaluating environmental burdens can be substantial when only average values per capita are used, creating a risk of misinterpretations in the context of national climate responsibility.

This point is further supported by Uslaner, who, in his article The Pitfalls of Per Capita, highlights that per capita emissions overlook fundamental structural differences between countries. Large countries with enormous populations, such as India, may have lower per capita emissions because their emission burden is spread across billions of inhabitants; however, this does not mean their absolute environmental impact is any less significant (Eric M. Uslaner, 1976)[6].

Similarly, Kratochvíl et al., in their study *The Fallacy of Global Comparisons Based on Per Capita Measures*, argue that using per capita averages in country comparisons often leads to erroneous conclusions, as it ignores absolute emission values and differences in technological development (Lukáš Kratochvíl, Jan Havlíček, 2024)[8].

Per Capita Emission Equalization Simulation

To illustrate the limitations of the per capita emissions indicator, we conducted a simplified simulation to show the conditions under which Slovakia's per capita emissions would equal India's. For this scenario, we used data from Table 1 and took into account the following parameters:

a) Annual population growth (World Bank, 2023)[16]: for India, +0.8%, and for Slovakia, -0.1%.
b) Annual GHG emissions growth rate for India at +6.06% (EDGAR, 2023)[2].
c) Slovakia would need to achieve the same per capita emissions level as India.

The simulation results are presented in TAB.4.

TAB.4 – Simulation Scenario of Per Capita Emission Equalization between Slovakia and India

Country	GHG Emissions (Mt CO_{2eq})	Population (Ths)	GHG Emissions per capita (kg CO_{2eq})
India	4 384.0	1 440 056.7	3 044.4
Slovakia	16.5	5 421.3	3 044.4

Interpretation of Simulation Results:

a) Slovakia would need to reduce its emissions by -63.139% to reach the same per capita emissions level as India.
b) Global emissions would rise by +222.2 Mt CO_{2eq} due to India's emissions growth, as India continues to grow at +6.06% year over year. This increase represents 94% of India's annual emissions growth from 2022–2023 (EDGAR, 2023)[2], which would have a markedly negative impact on the atmosphere.
c) Even after a hypothetical alignment of per capita emissions with Slovakia, India would remain the third-largest GHG-emitting country globally, with an 8% share of global emissions, continuing to have a significant negative impact on the climate system.
d) Slovakia's emissions would fall to a level of 16.5 Mt CO_{2eq}, placing it among countries with a minimal share of global emissions, comparable to small developing Caribbean nations.

To put this into perspective, in 2023, 80% of global emissions were produced by only 24 countries, which collectively generated 42,441.86 Mt CO_{2eq} (EDGAR, 2023)[2]. The remaining 186 countries contributed only 20% of global emissions. Under this scenario, Slovakia would join 83 countries that together produce just 8% of global emissions, representing only 51% of China's year-over-year emissions growth for 2023.

Alternative Clustering Based on Population Index

We created Table 5 and the corresponding Chart 2 as evidence that the assessment of a country's environmental impact can be processed more accurately than with per capita emissions indicators alone. A completely new and distinct clustering approach, based on the Population Index (IP), which we defined as the population value in millions, along with absolute emissions values, provides a more realistic picture of each country's actual share in global emissions. This approach allows for consideration of both population size and each country's real contribution to global emissions, eliminating the distortions caused by per capita averages. The results of this alternative approach underscore the importance of absolute values and regional differences, which per capita metrics fail to capture accurately.

TAB.5 – Comparison of Emissions Based on Population Index and Defined Clusters (2023)

CID	IP min (M popul.)	IP max (M popl.)	Countries	Total Emissions	Global Emissions share	Africa	Americas	Asia	Europe	Oceania
1	1400		2	20077.5	38.8%	0	0	2	0	0
2	100	1399.999999	13	14903.5	28.8%	4	3	6	0	0
3	50	99.999999	14	6101.7	11.8%	3	1	6	4	0
4	10	49.999999	64	7938.4	15.3%	24	12	16	10	2
5	5	9.999999	30	1606.1	3.1%	6	4	8	11	1
6	2.5	4.999999	19	783.6	1.5%	5	4	6	4	0
7	1	2.499999	16	222.1	0.4%	7	1	3	5	0
8	0	0.999999	50	84.9	0.2%	7	24	4	5	10
		TOTALS	**208**	**51 717.78**	**100.0%**	56	49	51	39	13

Table Description:

- CID – Cluster ID: Cluster identifier based on the Population Index (IP).
- IP min (Millions): The lower population boundary (in millions) for countries included in the cluster.
- IP max (Millions): The upper population boundary (in millions) for countries included in the cluster.
- Number of Countries: The total number of countries included within the defined population range for each cluster.
- Total Emissions (Mt CO_{2eq}): Absolute emissions value (in Mt CO_{2eq}) produced by countries in the cluster.
- Share of Global Emissions: Percentage share of emissions from countries within the cluster out of total global emissions.
- Africa...Oceania: Number of countries in each cluster located on each continent.

Table 5 categorizes countries into eight clusters (CID) based on population size, expressed in millions of inhabitants. These clusters show the relationship between a country's population size and its share of global emissions, where this distribution disregards per capita emissions values and instead focuses solely on the absolute emissions of each cluster.

Countries in clusters with the highest population index (CID 1 and CID 2) dominate global emissions totals. CID 1, which includes countries with populations over 1.4 billion, consists of only two countries: China and India and accounts for as much as 38.8% of global emissions. CID 2, containing countries with populations ranging from 100 to 1.4 billion, includes 13 countries and accounts for 28.8% of global emissions.

The following clusters (CID 3 and CID 4), which encompass countries with populations between 10 and 100 million, collectively hold a 27.1% share of global emissions. Although significant, this share is notably lower compared to clusters with the largest populations. These clusters include a larger number of medium-sized countries, indicating that a greater number of moderately populated countries contribute less to emissions than a smaller group of highly populated nations.

On the other hand, countries with populations below 10 million (clusters CID 5 through CID 8) contribute only 5.2% of global emissions, with the smallest cluster (CID 8), containing populations under 1 million, contributing just 0.2% to total emissions. This confirms that countries with smaller populations have a very minimal share of global pollution, regardless of their per capita emission values.

The regional distribution across clusters shows that the largest emissions primarily originate from Asia, linked to high population numbers and industrial development in this region. European countries are mostly represented in smaller clusters, while Africa and Oceania have a share in lower CID clusters with a reduced impact on global emissions.

Overall, this table underscores the necessity to consider absolute emissions values and population size when assessing actual environmental impact, as per capita values alone can create a misleading impression of national climate responsibilities.

CHART.2 – Comparison of Absolute Emissions by Defined Clusters

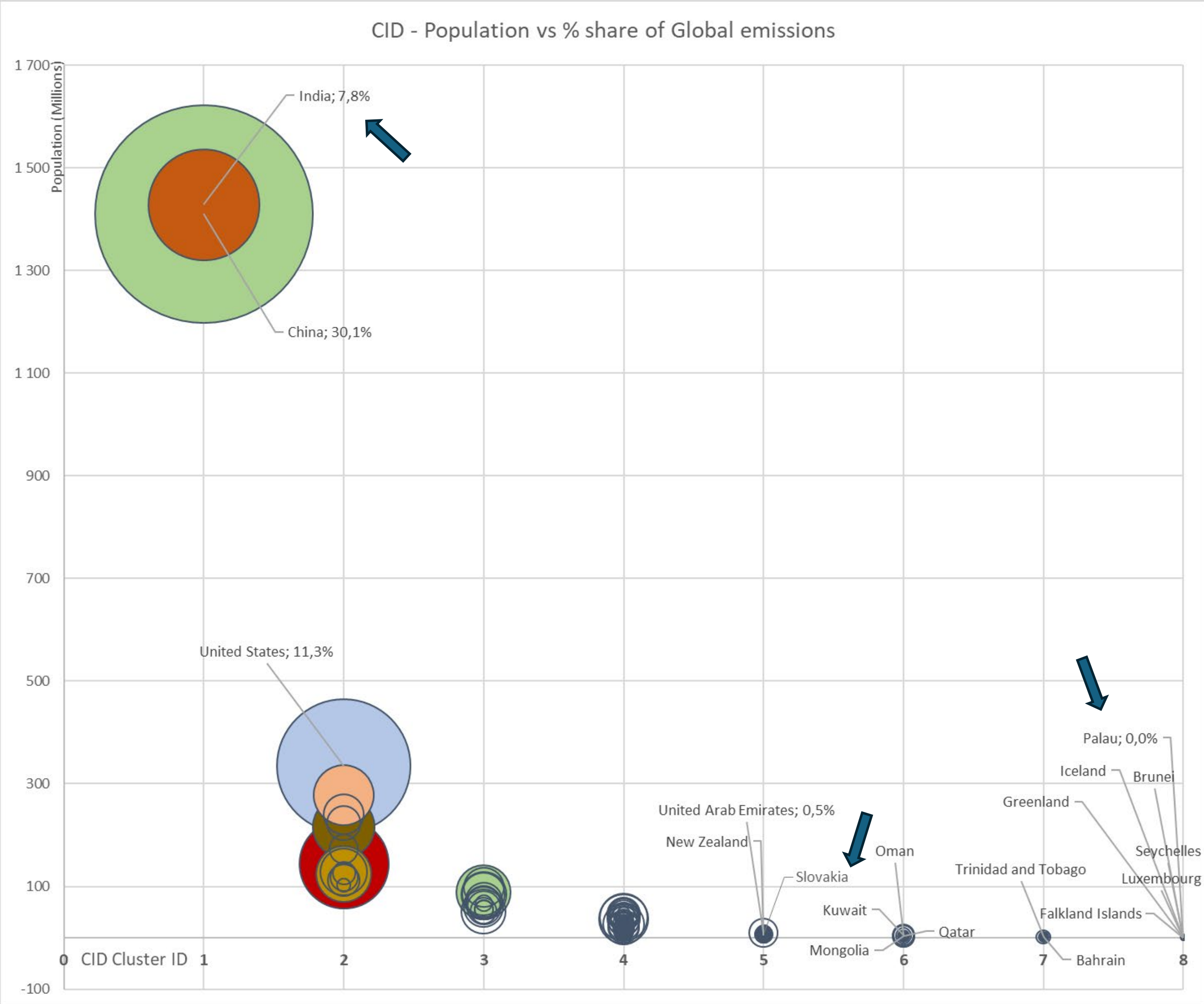


Chart 2 illustrates the relationship between countries' populations and their percentage share of global greenhouse gas emissions. It shows that large countries, like China and India, have a significant share of the world's population (30.1% for China and 7.8% for India), contributing a major portion to global emissions. China is the leading emitter, accounting for approximately 30.1% of global emissions, while India contributes 7.8%. The United States, with a much smaller population than India and China, holds an 11.3% share of global emissions, indicating a high level of emissions per capita.

Countries with smaller shares of the world's population, such as Slovakia, New Zealand, and certain Middle Eastern countries (e.g., Kuwait, Qatar, Bahrain), have a relatively low share of global emissions, even though some exhibit high per capita emissions. However, their overall contribution to global emissions is negligible compared to the major emitters, reinforcing the importance of absolute emissions values in assessing the true impact on the global climate.

At the other end of the spectrum are small states, such as Palau, Seychelles, and Bahrain, whose contributions to global emissions are almost negligible, despite high per capita emissions values. This demonstrates that when comparisons are based solely on per capita values, certain countries may be erroneously considered significant contributors to global pollution, even though their total impact is minimal.

The chart clearly indicates that absolute emissions values provide a more accurate picture of the environmental impact of individual countries on global warming. Countries with high absolute emissions volumes, especially those with large populations and developed industries, represent a critical environmental factor on a global scale. Consequently, global climate policies and strategies should focus primarily on large emitters, as reducing their emissions would have the most significant positive impact on the climate.

The results presented here reveal that per capita emission indicators may introduce systematic distortions when used to assess national contributions to global emissions. Using the per capita emissions indicator does not capture the true environmental impact of countries, which may lead to incorrect conclusions in the formation of climate policies and emission reduction strategies.

6. A More Comprehensive Perspective on GHG Emissions within a Country

To address broader environmental impact considerations, we developed a more detailed perspective on the emissions structure across different sectors within individual countries. This approach enables a shift from simple per capita emissions values to a more nuanced evaluation by sector, providing a clearer picture of each country's actual contribution to global emissions.

For illustration, we analyzed the sectoral breakdown of emissions in India, covering emissions from various economic activities, such as energy production, transportation, industry, and agriculture. Data from sources like JRC and EDGAR are organized according to sectors defined in the UNFCCC framework, allowing us to consider the distinctions between different sectors of emissions generation.

TAB.6 – India's GHG Emissions, Segmented by Substance and Major Sectors as Defined by UNFCCC

Substance	Agriculture	Buildings	Fuel Exploitation	Industrial Combustion	Power Industry	Processes	Transport	Waste	TOTAL
CO_2	30.6	221.8	133.6	619.0	1 377.0	233.5	339.8	-	**2 955.18**
CH4 in CO_{2eq}(GWP100)	567.6	39.0	100.4	4.2	1.1	0.4	2.2	124.7	**839.60**
F-gases in CO_{2eq}(GWP100)	-	-	-	-	-	68.7	-	-	**68.75**
N_2O in CO_{2eq}(GWP100)	192.5	8.4	0.2	5.4	23.0	16.5	7.3	16.8	**270.03**
TOTAL CO_{2eq}	**790.7**	**269.1**	**234.2**	**628.6**	**1 401.1**	**319.1**	**349.3**	**141.5**	4 133.55

Table 6 provides a detailed breakdown of greenhouse gas emissions in India, segmented by type of substance (e.g., CO_2, CH_4, F-gases, N_2O) and by major sectors as defined by the UNFCCC framework, including agriculture, industry, transportation, and energy. The Global warming potential 100 (GWP100) index was used to convert each substance into CO2eq according to the IPCC AR5 methodology (EDGAR, 2024)[2]. The data indicates that the largest share of emissions originates from the power industry segment, where fossil fuels represent a substantial portion of CO_2 production. Along with industrial combustion and transportation, this sector significantly contributes to the country's emissions load, despite India's efforts to develop renewable energy sources. This segmentation illustrates variations in emission loads across different sectors, offering a more accurate view of emission sources than a mere total emissions figure would provide.

In India's case, the Power Industry sector (UNFCCC 1.A.1) produced around 1,401.1 Mt CO_{2eq} in 2023, encompassing all emissions linked to primary energy production (including electricity and heat) and emissions from refineries and other energy-intensive industries.

To obtain a more precise view of emissions related to electricity generation in India, several specific factors must be considered:

a) Isolate emissions directly associated with electricity production; if specific data are unavailable, values can be estimated based on India's energy mix using the Carbon Emissions Factor (CEF).

b) Obtain data on annual electricity production in TWh units, which would allow better comparison with other countries; in India, the gross annual electricity production for the period 2022–2023 was 1,843.81 TWh (Ministry of Statistics and Programme Implementation, 2024)[11].

c) Consider the share of individual sources in electricity production; in India, approximately 77.2% of energy was generated from fossil fuels (coal, oil products, gas) during 2022–2023, with this amount increasing by 6.1% year-over-year (Ministry of Statistics and Programme Implementation, 2023)[10] (Ministry of Statistics and Programme Implementation, 2024)[11].

d) Obtain information on distribution losses within the grid, which in India amount to approximately 19.27% (India Central Electricity Authority, Ministry of Power, 2024)[7]. These losses significantly impact the efficiency of produced energy utilization and are unrelated to population size (Briseño, Hugo; Rojas, Omar, 2020)[1].

A similar sectoral analysis was conducted for Slovakia (Table 7), where emissions are segmented across sectors, with industrial production and transportation being the largest contributors. Unlike in India, Slovakia's Power Industry sector contributes less to overall emissions, as Slovakia has invested in low-emission, coal-free sources, while India continues to expand its coal-based high-emission sector. Coal consumption in India grew by 9.9% year-over-year in 2023 (ENERDATA, 2024)[5], whereas India's population growth in 2023 was only 0.8% (World Bank)[16]. This approach further highlights why average per capita emissions values are insufficient for accurately evaluating the environmental impact of countries, as they do not reflect differences in sectoral structures of economies.

TAB.7 shows greenhouse gas emissions in Slovakia, segmented by major sectors and specific gases. The largest share of emissions originates from the energy and industrial processes sectors, similar to India, though on a smaller scale.

The transportation sector has a smaller share of Slovakia's total emissions compared to India, which relates to differences in infrastructure and population size. Slovakia's sectoral emissions structure indicates a lower overall emissions volume, although focusing solely on per capita emissions could lead to misinterpretations of its share in the global environmental impact.

TAB.7 – Slovakia's GHG Emissions, Segmented by Substance and Major Sectors as Defined by UNFCCC

Substance	Agriculture	Buildings	Fuel Exploitation	Industrial Combustion	Power Industry	Processes	Transport	Waste	TOTAL
CO_2	0.1	4.4	5.7	8.0	5.1	4.1	7.6	-	**34.86**
CH4 in CO_{2eq}(GWP100)	1.5	0.2	0.8	0.0	0.0	0.0	0.0	3.3	**5.91**
F-gases in CO_{2eq}(GWP100)	-	-	-	-	-	0.7	-	-	**0.74**
N_2O in CO_{2eq}(GWP100)	1.3	0.0	0.0	0.0	0.1	1.6	0.1	0.2	**3.27**
TOTAL CO_{2eq}	**2.9**	**4.6**	**6.4**	**8.1**	**5.2**	**6.4**	**7.7**	**3.5**	**44.78**

The sectoral analysis provides deeper insight into the differences between countries and how they generate emissions. For instance, more than 50% of vehicles in India are over 20 years old (Road Transport Year Book, 2023)[12], which creates a significant emissions burden in transportation, regardless of the population size. In 2000, India had 48.9 million registered vehicles, and by 2020, this number had increased to 326.3 million (Road Transport Year Book, 2023)[12]. This represents a 567% growth, while the population increased by only 32% (World Bank)[16]. This disparity shows that emissions from motor vehicles grew faster than the population, highlighting how demographic and technological characteristics influence per capita emissions in ways that do not correspond to the actual environmental impact.

Based on the above findings, it is clear that only through sectoral analysis can we accurately assess each country's share of global emissions and obtain data relevant for developing effective climate policies.

7. Indicator Typology and Policy Relevance

Environmental indicators are commonly organized according to the DPSIR framework[20]: **Driving forces, Pressures, States, Impacts, and Responses**, which is widely adopted in environmental policy assessments by the European Environment Agency (EEA), UNEP, and other institutional bodies. The framework serves to clarify the role and interpretive limits of specific indicators in environmental monitoring and decision-making.

The GHG per capita indicator, calculated as total national emissions divided by population, conceptually belongs to the "Pressure" category. It reflects the anthropogenic burden placed on atmospheric systems rather than the actual environmental outcomes. Nevertheless, it is frequently misinterpreted as an "Impact" indicator, suggesting responsibility for observed climate effects or moral attribution at the country level—despite lacking direct causal linkage to atmospheric outcomes.

"Despite their classification as pressure indicators, GHG per capita metrics are often interpreted as proxies for impact or responsibility, which creates misalignment with their theoretical role and policy utility."

This typological confusion contributes to flawed comparative narratives—for instance, countries with low per capita emissions may appear environmentally benign despite high total emissions or significant exported externalities (e.g. through embedded emissions in global trade).

By explicitly situating GHG per capita within the DPSIR structure, this study emphasizes the importance of respecting typological coherence in climate assessment. It also highlights the need to supplement per capita metrics with composite approaches that account for absolute emissions, sectoral segmentation, and country-specific structural contexts to avoid misattributed climate responsibility in policy debates.

8. Discussion

The results of our analysis reveal significant limitations in using per capita emissions and GDP per capita indicators to assess the environmental and economic impact of countries. Although these average values are often used for international comparisons, they do not account for the specific conditions of individual countries and their sectors, which can distort the true impact of countries on global climate and their level of economic prosperity.

Prominent economists and statisticians have long highlighted the limited ability of per capita indicators to capture the real picture of the economy, living conditions, and environmental impact. Joseph Stiglitz criticizes GDP per capita for overlooking important factors, such as inequalities, the quality of public services, and environmental consequences (Stiglitz et al., 2009)[13].

Eric Uslaner, in his work The *Pitfalls of Per Capita*, argues that using average per capita values can lead to significantly distorted outcomes (Eric M. Uslaner, 1976)[6]. **Vaclav Smil** emphasizes that energy consumption per capita is not a reliable indicator of a country's efficiency, as it does not account for differences in industrial structure and technological level (Vaclav Smil, 2017)[15]. Finally, **Michal Jasienski** points out that empirical researchers love ratios, statisticians hate them. The simplicity of ratios, when one variable is divided by another, makes them appealing mental tools that yield conclusions easily understood, even if incorrect. And warnings about their misuse are often ignored (Michal Jasieliski and Fakhri A. Bazzaz, 1999)[9].

In the case of per capita emissions, our analysis showed that smaller countries with low populations often exhibit higher per capita emissions values, which may not correspond to their absolute impact on global emissions. Conversely, large-population countries like India achieve relatively low per capita emissions, but the absolute volume of their emissions has a substantial impact on the atmosphere. This difference was evident in the simulation of per capita emissions equalization between Slovakia and India, which demonstrated that simple emissions reductions in smaller countries do not have a comparable effect on global emissions reduction as they would in large economies.

Nonetheless, we often encounter evaluations based on per capita emissions indicators, even in international forums like the Conference of the Parties (COP) or in professional documents from the UN and other international and local organizations. The EDGAR database also regularly publishes this figure, yet without clarifying the methodology behind its presentation. The lack of contextual information regarding the significance and limitations of this indicator can lead to its misuse in assessing countries and their climate responsibility.

Another critical finding is that the sectoral segmentation of emissions, as we conducted in Tables 5 and 6, provides a more detailed and realistic view of the causes and distribution of emissions. In the case of India, the dominant sources of emissions are the energy and industrial sectors, reflecting its economic growth and developing infrastructure. In contrast, Slovakia shows a lower volume of emissions in the transportation sector, related to its smaller population and more developed infrastructure. These differences illustrate that effective emissions assessment and solutions require consideration of the country's context, economic structure, and technological advancements.

The results indicate that, while mathematically accurate, per capita indicators often fail to reflect the actual environmental and economic challenges faced by countries. The per capita emissions indicator can lead to erroneous conclusions because it does not account for total population and the sectoral distribution of emissions. Our study suggests that environmental burden assessments should be based on a combination of absolute data, sectoral emissions, and sector efficiency.

For illustration, we can use an analogy with transportation: using one average speed for all vehicles in a country would also fail to capture the real traffic situation, as it ignores differences between urban and highway driving, various types of roads, and traffic conditions. Similarly, average per capita emissions values distort the real environmental impact of countries by failing to account for structural and sectoral differences. Such comparisons may be mathematically correct but are misleading in terms of climate impact.

In conclusion, to create effective global climate policies, it is essential to use a combination of absolute values and sector-specific emissions, thereby providing a clearer picture of each country's actual contribution to global climate change. These findings are important for developing fair and effective policies that target major emitters, rather than relying on simplified per capita indicators.

9. Conclusion: Caution in Using Global Indicators

This study set out to examine whether greenhouse gas (GHG) emissions per capita fulfill the essential criteria of a valid environmental impact indicator, particularly in cross-country comparisons. Drawing on indicator theory, typological frameworks such as DPSIR, and empirical examples from structurally diverse countries (India, Slovakia, and Palau), our findings suggest that per capita emissions indicators fail to meet core requirements such as sensitivity, comparability, and causal alignment.

One key finding was that countries with large populations, like India, exhibit relatively low per capita emissions, but their total emission volume has a substantial impact on global climate. Conversely, smaller countries with low populations may show high per capita emissions, even though their total contribution to global emissions is negligible. These disparities underscore the importance of supplementing per capita indicators with sectoral analysis and absolute values, which allow for a more precise assessment of environmental impact.

Despite their prevalence in public discourse and international negotiations, GHG per capita metrics should be recognized as pressure indicators. Their frequent interpretation as proxies for impact or climate responsibility constitutes a misclassification that can lead to distorted narratives, especially when comparing countries with vastly different demographic, economic, or infrastructural characteristics.

In terms of impact on our civilization, monitoring emissions in absolute numbers holds far greater significance. Regardless of where emissions originate or how much is attributed per capita, per vehicle, or per livestock, their impact is global and affects every country and every inhabitant of Earth. A system based on absolute values better highlights the responsibility of countries for emission production, as each state has sovereign rights over its industry, trade, and transportation. Until there is a global authority capable of mandating and enforcing emission reductions, monitoring and managing emissions at the national level remains essential.

For effective emissions reduction, tracking absolute numbers is crucial, as the impact of emission reductions in a small state like Palau cannot compare to the impact of reductions in populous countries like India, regardless of the mathematical per capita values.

Similarly, GDP per capita is unable to adequately reflect quality of life, social justice, or wealth distribution within a country. Critics, such as Joseph Stiglitz, Eric Uslaner, and others, highlight the limitations of these average values in capturing the true prosperity and well-being of the population.

From a policy perspective, assessing climate impact requires complementing per capita values with sectoral decomposition, absolute emission volumes, and context-specific indicators that reflect production, trade, and energy intensity. This is particularly important for crafting fair and effective mitigation strategies under global climate frameworks.

Based on our findings, we recommend using more comprehensive approaches to assess the economic and environmental conditions of countries. These approaches should include a combination of absolute and sector-specific data, as well as broader socio-economic indicators. Such methods enable a better understanding of the structural differences among countries and contribute to a more accurate assessment of their true impact on global climate and the living conditions of their populations.

We therefore recommend:

- Reframing GHG per capita as a *supplementary* metric, not a primary indicator of national responsibility;
- Promoting indicator pluralism, where absolute, sector-specific, and equity-sensitive metrics are jointly used;
- Enhancing transparency in international comparisons by clearly distinguishing between pressure and impact indicators.

In conclusion, relying solely on average per capita indicators is insufficient and potentially misleading when forming effective climate policies and assessing economic development. Achieving fair and effective solutions for climate responsibility requires considering the context of each country, its sectoral emissions, population characteristics, and overall economic potential. This comprehensive approach provides a stronger foundation for international cooperation and effective measures in the fight against climate change.

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Data availability
Data sources used in this study include publicly available datasets from the Emissions Database for Global

Atmospheric Research (EDGAR, 2024), the United Nations Population Division, the World Bank Metadata Glossary, and national statistical authorities such as the Ministry of Statistics and Programme Implementation (India) and the Central Electricity Authority (India). All datasets are referenced in the bibliography and were accessed through official portals.

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