“The deterioration of the environmental performance index that compares hazard management across cities and countries”

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THE DETERIORATION OF THE ENVIRONMENTAL PERFORMANCE INDEX THAT COMPARES HAZARD MANAGEMENT ACROSS CITIES AND COUNTRIES

Abstract

Government entities play a critical role in designing and implementing effective mitigation and adaptation strategies to address climate change. At the same time, cities are key actors in applying local environmental policies. This paper evaluates and compares the environmental performance of urban areas and countries to identify the most effective level of governance. To achieve this, an innovative quantitative index is computed: the Deterioration of Environmental Performance Index (DEPI). This composite index offers valuable insights into the sustainability of territorial development strategies. The DEPI's annual evolution is examined for ten OECD countries and their respective urban areas over the period 2001–2020. Statistical analysis reveals that, in most cases, national-level environmental management outperforms urban areas. Specifically, all countries with non-ambiguous results exhibit lower DEPI scores (indicating better performance) than their corresponding urban areas, except for New Zealand. The results for Belgium, South Korea, and the United States of America are inconclusive. These findings highlight the vulnerability of cities to climate-related risks. In summary, national governments seem to demonstrate greater effectiveness than cities in managing five key environmental challenges: air pollution, river flooding, coastal flooding, wildfires, and heatwaves.

Keywords urban, environmental performance, index, climate change

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INTRODUCTION

Humans are fundamentally integrated into a global ecosystem, as emphasized by Dasgupta (2021). Therefore, household and government decisions are relevant because they have long-lasting implications for this complex ecosystem. Due to the intricate interconnectedness of these systems, the deterioration of one area can exacerbate risks in others, triggering a cascading escalation of crises (Von Uexkull & Buhaug, 2021; Shi et al., 2019; Matsumoto et al., 2019; Aminzadeh, 2007). Regarding these issues, governmental authorities have the capacity for effective action due to their legislative authority. Moreover, environmental policy design is increasingly influenced by territorial dynamics. Relations between national and local authorities have evolved from predominantly hierarchical or competitive arrangements toward systems of multi-level governance. The latter is marked by mutual interdependence and clearly differentiated roles (Balme & Ye, 2014). A nation's economic identity represents a complex, interconnected matrix of numerous factors, such as market systems, trade routes, natural resources, and population distribution. It extends beyond being

a simple aggregate of cities. However, cities are hubs of economic dynamism that play a vital role in national economic growth. Economic output from the largest metropolitan regions is often similar to that of significant nations (Matsumoto et al., 2019). In parallel, a nation's environmental performance is not a simple aggregation of urban areas. It is a sophisticated interplay among cities, rural spaces, and adherence to policies enforced at different levels. Hence, data at the local and national levels are examined and compared for a comprehensive understanding of a nation's environmental performance (Eisenack & Roggero, 2022). Furthermore, Matsumoto et al. (2019) highlighted the capacity and relevance of the local scale to address climate change. With more than half of the global population, cities generate 80% of the worldwide GDP and contribute significantly to greenhouse gas (GHG) emissions, generating more than 70% of energy-related CO_2 emissions. The impact of climate change poses a severe threat to cities, especially those in low-lying coastal regions, which are exposed to an increasing risk of flooding. Current estimations predict that global flood losses in the world's largest coastal cities could reach 52 billion USD by 2050 (Matsumoto et al., 2019).

As they face these issues, cities have the potential to mitigate and adapt to climate change. Many climate policies are implemented at the city or regional level. In many countries, urban municipalities have at least partial authority over various sectors, such as spatial planning, transport, and waste services. This allows them to drive climate action through local regulations and strategic planning. Moreover, technically feasible low-carbon policies can reduce emissions from key urban sectors by almost 90% by 2050. Thus, it would generate substantial savings in the long term. Economic growth can also be stimulated through the job creation needed to implement these policies (Matsumoto et al., 2019). Despite cities' involvement in addressing climate change-related challenges, their full potential can only be harnessed through effective collaboration with regional and national governments, according to the Coalition for Urban Transitions (Coalition of Urban Transition, 2019). This report underscores the crucial role of national governments in supporting economic growth and mitigating climate change effects through urban transformation. National governments can contribute by financing sustainable urban infrastructure, shaping global agendas, and endorsing city- and community-led climate initiatives. Nonetheless, local governments control less than one-third of the potential GHG emissions reduction within their jurisdiction (Coalition of Urban Transition, 2019). However, following the Paris Climate Agreement, some cities have set ambitious GHG emission reduction targets that often exceed those of their respective national governments (Matsumoto et al., 2019). Moreover, addressing environmental challenges needs precise quantification and communication of environmental risks, resources, and performance. Assessing environmental performance is a complex task. It is particularly challenging to encapsulate within a single index, as it involves multiple ecosystem interactions. A composite index appears to be a relevant approach for capturing the multidimensional nature of human activity with ecosystems. In addition, information about a territory's environmental status is generally more accessible and interpretable as a single numerical value with a standardized scale than a set of disparate indices (OECD, 2008).

There is no universally accepted definition of a composite index. In this paper, the definition proposed by Greco et al. (2019) is adopted: "A composite index might reflect a complex system that consists of numerous 'components,' making it easier to understand rather than reducing it to its 'spare parts'." The proliferation of composite indices in recent years reflects the growing need to convey complex, multidimensional realities through simplified and meaningful measures. As the urgency to address climate change intensifies, the number of environmental indices has surged, each assessing a specific aspect of environmental conditions. However, to the best of our knowledge, no composite index currently exists that quantitatively measures environmental performance at the city and national levels. This index facilitates comparisons between different jurisdictional levels, providing a more comprehensive understanding of environmental governance. Thus, a quantitative composite index – the Deterioration of Environmental Performance Index (DEPI) – is developed to examine and compare the environmental performance of governmental entities at both the city and national levels.

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1. LITERATURE REVIEW

In a publication from the United Nations Industrial Development Organization, nine city-level sustainability indices were reviewed in 2017. The dimensions that are included in the Green City Index (GCI) are interesting. It is designed to evaluate and rank the environmental performance and aspirations of major cities worldwide. It evaluates cities using approximately 30 indices spread over eight to nine categories, depending on the region, due to data constraints. These categories include CO_2 emissions, energy, buildings, land use, transport, water and sanitation, waste management, air quality, and environmental governance. Sixteen of these indices are quantitative measures, and the other fourteen are qualitative and assess the city's environmental policies. The combination of quantitative and qualitative indices reflects both current environmental performance and its ambitions to become greener. The Green City Index evaluates both *de facto* and *de jure* environmental performance at the urban level (Gong & Lyu, 2017). However, this approach is not applicable at the national level due to its methodological design and the nature of the data employed. In contrast to the GCI's city-specific scope, footprint-based indices (such as those measuring environmental, energy, water, or final consumption footprints) can be computed across various economic actors and scales, including the national level. They provide a comparative measure of human demand versus the planet's ecological capacity for regeneration. These indices symbolize the quantity of biologically productive land (i.e., global hectares) needed for resource regeneration and waste neutralization (Gadrey & Jany-Catrice, 2016). However, variations in national data sources and assumptions about biological productivity introduce significant uncertainties undermining cross-country comparisons. Similarly, the net environmental contribution (NEC) assesses the environmental impact of economic activities. The NEC framework is grounded in the concept of sustainable development. It evaluates the extent to which a product, service, company, or sector contributes positively or negatively to the environment. It considers various environmental dimensions, including climate, water, air, biodiversity, and resources. The NEC calculation involves (i) to identify the main environmental impact of the product life cycle, service, or sector considered, (ii) to quantify the environmental performance relative to the previously identified environmental impact during the life cycle steps, (iii) to normalize performance by comparing it to the best available technique or practice (a baseline for environmental impact measurements) and (iv) these scores are aggregated to generate a final NEC score.

The NEC scores range from –100% to +100%, where negative values indicate net environmental degradation and positive values suggest a net environmental benefit. The global average serves as the NEC 0% point. For instance, firms may use it to identify areas for environmental improvement, while investors can assess the ecological responsibility of their portfolios. Policymakers may also rely on it to inform the design of more sustainable regulations (NEC, 2019). However, the metric of interest should account for local ecological conditions, rather than depending solely on global or sectoral averages. It cannot be used to evaluate local or country-wide environmental context and compare it to a broader average.

Transitioning to country-level indices, the Environmental Performance Index (EPI), developed by Yale University in 2022, provides a data-driven assessment of national environmental sustainability. It evaluates 180 countries based on 40 performance indicators across 11 issue categories and three policy objectives: climate change management, environmental health, and ecosystem vitality. These indicators collectively measure how closely countries adhere to established international environmental policies. The index is aggregated at multiple levels, with each variable weighed according to its contribution to the total score. The EPI can also be disaggregated by issue category, policy objective, peer group, and country (Wolf et al., 2022). In addition, the Environmental Policy Stringency (EPS) Index, developed by the OECD, assesses the stringency of environmental policies, particularly those addressing climate change and air pollution. The EPS reflects the explicit or implicit cost of environmentally harmful behaviors, with variables selected based on legal regulations encompassing a broad range of policies. Stringency is measured on a 0 to 6 scale, where 0 represents nonexistent policies and 6 indicates the most stringent. The index is calculated using the minimum and maximum sample values of each instrument. It can be further disaggregated by market-

based vs. non-market-based instruments, as well as into subcomponents that distinguish between policies offering incentives and those imposing penalties for environmental actions (Botta & Koźluk, 2014). However, the composite scores of the EPI and EPS do not differentiate between policy design and actual compliance, which ultimately determines actual environmental performance. They do not incorporate *de facto* evaluative components. An alternative method for measuring environmental performance is the application of principal component analysis (PCA) to environmental variables, as demonstrated in the Brazilian context by Ribeiro (2023). His study examined 27 subnational units and assessed local climate commitment along two dimensions. He incorporated a weighted sum of binary indicators capturing participation in climate mitigation and/or adaptation policy processes and the linear average growth rate of greenhouse gas emissions for each unit between 2005 and 2020. These indicators generated annual policy and emissions profiles for each subnational entity. The PCA results revealed no correlation between engagement in policy processes and emissions outcomes (Ribeiro, 2023). Consequently, these findings highlight the need to evaluate environmental performance using physical, observable outcomes rather than policy participation alone.

While each of these metrics provides valuable insights, none appear to focus exclusively on observed environmental impacts using a consistent methodology across both time and space. Thus, building on these structured and comprehensive indices, a composite index that captures shifts in environmental outcomes over time is built. This approach assesses *de facto* environmental performance at local and national levels across multiple dimensions. Importantly, a methodology that facilitates comparisons over time is developed while ensuring the measure remains accessible and easily interpretable for a non-expert audience.

2. METHOD

2.1. Concept and dimensions definition

Environmental performance for governmental entities primarily refers to the outcomes of policies and human activities that directly or indirectly impact the ecosystem. These policies span a wide variety of policies due to the multifaceted nature of environmental concerns. Quantitative measures are only included in this evaluation to capture the 'on-the-ground' effects of human activity. The selected variables are intended to reflect the outcomes of human activity and environmental management policies. Some variables are more likely to be consequences of local actions, whereas others are more likely to be determined at the national level. Together, they evaluate policy efficiencies to manage climate change and human impact at both levels. Accordingly, the indices assess six key dimensions on an annual basis.

2.1.1. *Air pollution management*

Air pollution is estimated as the mean population exposure to fine particulate matter (PM2.5). "2.5" indicates that particulate matter has a diameter of less than or equal to 2.5 micrometers, approximately 3% of the diameter of a human hair sample. It is calculated considering the population distribution across different areas with varying pollution levels. Hence, as a population-weighted measure, it provides a more accurate representation of individuals' average exposure to PM2.5 within each territory. Research has established a direct causal link between PM2.5 exposure and cardiovascular disease incidence and death rates. Notably, improvements in life expectancy in the United States have been partially attributed to reductions in ambient fine particulate air pollution exposure (Liu et al., 2019). Total GHG emissions are used to account for this dimension. As more than 70% of GHG emissions can be attributed to cities, it appears relevant to monitor and compare their efforts at the national level. Moreover, local governments usually have room for urban planning, greatly influencing GHG emissions (Matsumoto et al., 2019).

2.1.2. *Climate hazard management*

Governments are responsible for protecting their population and infrastructure from the consequences of global warming. Thus, this dimension includes flood, fire, and heat risks. Climate change-induced floods that impact populations and buildings are evaluated in terms of the share of population and built-up area exposed to river and coastal flooding. This accounts for the corresponding human risk, material damage, and water pollution as-

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sociated with such events. The chosen return period is 50 years. Therefore, in any year, the probability of a flood reaching a similar intensity as a one-in-fifty-year flood is 2%. Due to ecosystem deregulation, important flood events are estimated to increase on all continents over time. A fifty-year return period seems adequate to account for the intensity of such an important environmental catastrophe. However, their frequency might increase.

In addition, Wang et al. (2021) show that the engineering benefits of structural measures to enhance drainage system capacity are greatest when considering a 50-year return period. And these measures typically fall under public-sector responsibility. Climate deregulation also involves an increase in fire, partly due to drought and strong winds. Fire risk is no less disastrous than flood risk in terms of human health, material damage, and endangered animals. Moreover, fires instigate a series of subtle and delayed environmental events, including air pollution due to smoke plumes, which eventually contribute to land and water contamination through deposition, toxic runoff water pollution, and additional environmental hazards resulting from the combustion of various materials (Martin et al., 2016). This risk is illustrated by the share of the population exposed to at least one forest fire. Its reduction over time should reflect the government's efforts to prevent fires and protect people. The increase in temperature and government response is proxied by the share of the population exposed to strong heat stress. Strong heat stress is calculated via the Universal Thermal Climate Index (UTCI) for an equivalent temperature greater than 32 degrees Celsius. The UTCI considers air temperature, wind, radiation, and humidity and assesses the impact of atmospheric conditions on the human body (OECD, n.d.). This kind of temperature can destroy physical and social infrastructures in combination with the effects of extreme storms and drought. Moreover, a temperature rise could increase the demand for space cooling, skyrocketing energy consumption during high-demand peaks (Matsumoto et al., 2019).

2.1.3. Community life management

The share of recycled waste of total waste produced by a territory illustrates the effectiveness of policies aimed at waste reduction and recycling. Waste management should improve at every level to limit its impact on society. Moreover, local entities usually have direct power over waste treatment; thus, they can differentiate among levels (Matsumoto et al., 2019). The availability and network size of public transport for the population are considered via the share of the population living less than 10 minutes from a public transport stop. It is a public measure that can help reduce GHG emissions by encouraging the population to use collective transport rather than personal motorized vehicles. Furthermore, extensive research has conclusively shown that low-density urban areas that lack efficient public transport networks tend to report higher GHG emissions (Matsumoto et al., 2019). Therefore, territories that act to promote and develop their public transport might observe a reduction in GHG emissions over time.

2.1.4. Energy management

This dimension is the share of renewable energy in the energy mix of a given territory, the carbon intensity of energy used, and a measure of energy consumed per capita. Urban development processes and infrastructure play a prominent role in energy use in territories (Larson et al., 2012). Thus, it should be considered by governments at every decision level. Including those metrics in the overall index allows us to follow their evolution and account for territorial efforts to provide efficient and 'greener' energy to its population. The Green City Index also accounts for this dimension using similar measures that are not detailed in their public reports, i.e., renewable energy consumption, energy intensity, and energy consumption.

2.1.5. Natural capital management

Green areas and forest management are based on the ratio between their surface and built-up areas. The share of protected areas is also included in the considered territory. Policies to enhance vegetation and expand green spaces can effectively mitigate the adverse effects of extreme heat and flooding (Matsumoto et al., 2019). Furthermore, evidence strongly supports that proactive implementation in such areas can significantly lower climate change threats to biodiversity (Hannah, 2008). However, there is a lack of new protected areas designated for climate change mitigation.

2.1.6. Water management

This dimension has two outcomes. First, wastewater pollution (measured by the average concentration of hazardous chemicals in natural water[1]) threatens biodiversity and could lead to hazards for human health. This is a prominent issue because freshwater ecosystems have already experienced significant depletion (Albert et al., 2021). Secondly, the responsibility of government entities to mitigate pressure on water resources is included in estimating the water wasted through the leakage rate. Identification, repairs, and investments in network maintenance can reduce leaks. Local and national governments can implement these actions. This outcome is also accounted for in the NEC framework.

2.2. Computation

First, each outcome is classified as positive or negative based on its marginal effect on the environment. For instance, the mean concentration of PM2.5 and population exposure to fire are considered negative, whereas the proportion of protected areas accessible by public transport is positive. The calculations are performed at local and national levels to ensure comparability. The variables and their respective classifications are presented in Table 1. Then, the annual evolution of each variable is computed using an index with a base-100 as a reference for the analysis period. This approach allows us to account for environmental outcomes independently of their measurement units, facilitating their aggregation. Additionally, the base-100 enables the comparison of values and trends over time, addressing scale discrepancies between national and city-level measures. Then the variables are aggregated within each category using a geometric mean. An imperfect substitution method is applied to incorporate sustainability into the framework, ensuring that no single dimension can fully compensate for another (Greco et al., 2019; Gadrey & Jany-Catrice, 2016). No weighting is applied, as all outcomes are considered equally important. Moreover, the lack of established theoretical guidance on jointly assessing these outcomes prevents the determination of a robust weighting scheme. At the city level, differences are considered while minimizing information loss. Local-level results require an additional aggregation at the national level. A unique average value across the available locations is computed by applying a simple arithmetic mean to the index results for each country's local components and year. This process yields an average value that captures the evolution of "negative outcomes" in environmental performance variables across each level and year. Although this study does not compare cities within the same country, the index is fully suited for such analyses. Overall categorical DEPI is then derived as the unweighted geometric mean of the base-100 normalized outcomes. This metric enables us to assess whether environmental management is (i) deteriorating or (ii) improving. Ultimately, it provides insights into the evolution of negative environmental outcomes over time.

2.3. Mathematical definition of DEPI

The DEPI index illustrates changes in environmental outcomes at different levels. Thus, this is an index of environmental performance evolution. Mathematically, the Deterioration of Environmental Performance Index is written as follows:

$$DEPI_{c,TL,t} = \frac{1}{N_{TL}} \times \sum_{n_{TL}=1}^{N_{TL}} \left(\sqrt[N_n]{\prod_{n_n=1}^{N_n} \left[\frac{v_{n,c,TL,t}}{v_{n,\,c,TL,0}} \times 100 \right]} \right), \quad (1)$$

where c is the country, t is the year and TL is the Territorial Level (national or local). N_{TL} is the number of territorial levels (equals 1 for country). v_n is the variable of marginally negative environmental outcome and N_n is the number of variables in the "negative" category. DEPI is compared with a base of 100 used as a reference. A result greater (less) than 100 indicates that outcomes increase (decrease) relative to the baseline level. Environmental performance is better when the DEPI is less than 100, as we evaluate the environmentally harmful outcomes with this index.

1 e.g., groundwaters, rivers, lakes, and exclusive economic zone sea areas.

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2.4. Data selection

Public data availability poses challenges for assessing the environmental status of cities and countries. Environmental indicators are collected more frequently at the national and city levels. Moreover, objective measures of environmental performance are relatively scarce for historical analyses. An index based on metadata provided by OECD statistics is built to address these limitations, following a thorough investigation of public databases. This enables further comparative analysis across locations. At the city level, the OECD Cities Statistics database encompasses various dimensions, including economic, environmental, and territorial organization, through 112 indicators. It covers 41 countries, incorporating data on 1,389 cities and 1,271 functional urban areas (FUAs). The OECD has established a standardized definition of FUAs across the countries studied. A FUA is defined as a city along with its commuting zone, representing its economic and functional significance, as reflected in the daily commuting patterns of its inhabitants. Using FUAs instead of administrative city boundaries provides a more relevant framework for the environmental performance index. The administrative delimitation of a city arbitrarily constrains the analysis, as it does not align with economic reality from a territorial perspective. FUA values are primarily derived by downscaling indices from regional data, assuming the variable of interest follows the same distribution as population density. Additionally, FUA values are computed by aggregating local administrative data at the FUA level or by processing geolocated data using geographic techniques (OECD, 2022). First, relevant variables from the OECD Cities Statistics at the FUA level were identified, as they are less frequently collected than those at the national level. Once identified, we then searched for their counterparts at the country level to enable comparison. However, we could not account for all dimensions outlined in the conceptual framework. Among the 112 indices in the Cities Statistics database, 88 were calculated for FUAs. Only seven environmental dimensions are covered: air pollution, protected areas, public transport, green spaces, flood risk, fire risk, and heat stress. Unfortunately, data on protected areas, green spaces, and public transport access are only available for 2017, 2020, and 2022. Additionally, information on the share of the population exposed to flood risk is only available for 2015. As a result, we excluded it from the application, as its variation over time could not be analyzed. Therefore, the application measures a reduced version of the DEPI. Due to data limitations, only two of the six theoretical dimensions are considered: air quality and climate hazard management. As the effort to collect data intensifies, the DEPI could be completed in the future. This applied constrained version serves as an illustrative demonstration of the framework.

2.5. Outcome selection – FUA level

The variables selected at the FUA level include: the mean population exposure to PM2.5 air pollution, the proportion of built-up areas exposed to river flooding (with a 50-year return period), the proportion of built-up areas exposed to coastal flooding (50-year return period), the share of the population exposed to at least one forest fire, and the number of days experiencing strong heat stress (UTCI > 32°C). The mean population exposure to PM2.5 is downscaled through geographic processing, using data derived from a geographic shapefile containing boundary information and from the OECD Environment Directorate[2]. The share of built-up areas exposed to river flooding represents an assessment of population exposure. Data were collected using River Flood Hazard Maps at both European and global scales. These maps rely on a regional dataset with a spatial resolution of 250 meters for OECD countries within Europe and the Mediterranean Basin, and a global dataset with a 1-kilometer spatial resolution for other OECD countries. These datasets identify areas susceptible to river flooding based on various return periods. This measure is subsequently disaggregated through geographic processing to derive FUA-level variables. The methodology used to construct the share of built-up areas exposed to coastal flooding is not explicitly documented in the Metropolitan Database documentation or the Climate and Environment Regional Statistics documentation. However, it is reasonable to assume that it follows a similar approach to the river flooding variable. The share of

2 While the exact computation method is not specified, we assume it follows the same approach as the country-level variable.

the population exposed to at least one forest fire is calculated by integrating monthly wildfire perimeters and applying a 5-kilometer buffer. This process uses data from the Joint Research Center (JRC) Global Wildfire dataset. Population exposure is then estimated using the Global Human Settlement Population layer. Finally, FUA-level values are computed through geographic processing. The number of days with strong heat stress (UTCI > 32°C) represents the annual count of days experiencing strong heat stress. The OECD derives this measure using geolocated data from the Copernicus Climate Data Store. The process involves calculating the daily maximum temperature, applying a 32°C threshold, and summing the results annually to produce gridded datasets of strong heat stress days. These datasets are then disaggregated through geographic processing to obtain FUA-level variables.

2.6. Outcome selection – National level

Multiple databases are integrated to compile all necessary information at the national level. The selected variables include the mean population exposure to PM2.5 air pollution, the proportion of built-up areas exposed to river flooding (50-year return period), the proportion of built-up areas exposed to coastal flooding (50-year return period), the percentage of the population exposed to wildfires, and the percentage of the population exposed to extreme heat days (Table 1). The mean population exposure to PM2.5 was derived from the Exposure to PM2.5 in Countries and Regions database. This metric is computed using the Global Burden of Disease 2017 project data, which integrates satellite observations, chemical transport models, and ground-based monitoring station measurements. Population exposure is then estimated using gridded population datasets from the JRC Global Human Settlement project. We use data from the OECD Climate and Environment Regional Database regarding the proportion of built-up areas exposed to river and coastal flooding. National values were computed by aggregating regional shares using an arithmetic mean. This methodology and dataset align with those used for variables measured at the FUA level. However, specific details were not provided in the dataset regarding coastal flooding exposure. The share of the population exposed to wildfires was estimated using the Global Human Settlement Layer population grids, which quantify the population residing in areas classified as having very high or extreme fire danger according to the Fire Weather Index. These data were sourced from the Green Growth Indices database (OECD, 2023). Finally, the percentage of the population exposed to extreme heat days was also obtained from the Green Growth Indices database. In this context, "population exposure" refers to the proportion of the population experiencing at least one to a maximum of fourteen extreme heat days per year, where extreme heat days are defined as those with a maximum daily temperature exceeding 35°C. Table 1 summarizes the selected variables at both local and national levels.

The selected variables exhibit a high degree of comparability between FUA and national levels, as they rely on consistent exposure-based concepts and harmonized definitions. As for the value of PM2.5 air pollution, river flooding, and coastal flooding indicators, their national-level measures are built as coherent aggregations of lower territorial units, ensuring methodological continuity with urban-scale indicators. Variables related to wildfire and heat stress capture the same underlying climate-related risks to human populations,

Table 1. Variables included in the applied composite index according to territorial level

Classification	Functional Urban Area	Country
Negative Impact	Mean population exposure to PM2.5 air pollution	Mean population exposure to PM2.5 air pollution
	Share of built-up area exposed to river flooding (50-year return period)	Aggregation of the TL2 level share of built-up area exposed to river flooding (50-year return period)
	Share of built-up area exposed to coastal flooding (50-year return period)	Aggregation of the TL2 level share of built-up area exposed to coastal flooding (50-year return period)
	Share of the population exposed to at least one forest fire	Percentage of population exposed to wildfire
	Days of strong heat stress (UTCI > 32°C)	Percentage of population exposure to hot days (maximum daily temperature exceeds 35°C)

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although they are expressed through slightly different formulations. Therefore, these choices ensure that these indicators represent comparable dimensions of environmental vulnerability and allow for a consistent interpretation of results across territorial scales.

2.7. Country and period selection

The reduced version of the DEPI is computed annually from 2001 to 2020 for ten countries and their corresponding FUAs. This twenty-year period allows for an assessment of the evolution of environmental performance at national and FUA levels, providing insight into which territorial scale exhibits better environmental management over time. Data from the recent period were not available. The OECD countries selected for the final database were chosen to represent diverse regional contexts, with two countries from each continent. Specifically, the database includes Australia and New Zealand for Oceania, the United States (US) and Canada for North America, Mexico and Colombia for South America, Japan and South Korea for Asia, and Belgium and Sweden for Europe.

2.8. Final database processing and DEPI calculation

We select the variables of interest, focusing on those with a negative impact as well as the relevant periods, countries, and their respective FUAs from each of the previously mentioned datasets. These observations are then merged to create a unified database.

The merged database (including all FUA values) contains 37.25% zero entries, corresponding to 19,856 out of 53,300 rows. However, the distribution of zero values is highly uneven across variables and territorial levels, with important statistical implications for the analysis. Zero values are predominantly associated with share-based indicators, which measure exposure to hazards that may be absent or negligible in certain territories. For example, the share of the population exposed to at least one wildfire accounts for 28.71% of all zero observations at both the FUA and national levels, whereas heat-related variables display relatively few zero values (3.35% for days of strong heat stress at the FUA level and 0.26% for exposure to hot days at the national level). Flood-related indicators are particularly affected. Indeed, the share of built-up areas exposed to flooding alone accounts for 13,436 zero observations, representing 67.66% of all zero entries.

Zero values are overwhelmingly concentrated at the FUA level, which accounts for 99.20% of all zeros in the dataset (19,698 observations). This concentration reflects the finer spatial granularity of FUAs, where the non-occurrence of specific risks is more frequent and often structurally determined by geographic or land-use characteristics. From a temporal perspective, this pattern substantially limits the informative content of several variables. Specifically, 771 FUA-variable pairs record a value of zero for every year between 2001 and 2020. It indicates either the structural absence of the risk or the absence of any detectable variation over time. In addition, 49 pairs exhibit only a single non-zero observation over the entire period. Thus, they are unsuitable for robust trend analysis. To sum up, these two groups comprise 16,351 observations and account for 82.34% of all zero entries in the final FUA dataset. These characteristics imply that treating all zero values as standard numerical inputs would introduce distortions in both temporal and cross-sectional comparisons. Indeed, it can appear when indicators are aggregated into a composite index. To address this issue, variables that are conceptually irrelevant for a given territory (e.g., coastal flooding in inland areas) are coded as "NA" rather than zero. This distinction is crucial as zeros are interpreted as meaningful values denoting the absence of observed exposure, whereas "NA" refers to structural non-applicability. Using "NA" values ensures the computation of 100 baseline sub-indices and their aggregation via a geometric mean to derive the DEPI for each year. As a result, the index construction relies exclusively on relevant and varying information, preventing structurally null variables from artificially depressing composite scores. As a result, the DEPI reflects more accurately meaningful differences in environmental exposure and dynamics across territories and over time. The database used for DEPI computation is structured in a long format,

where each row represents an observation corresponding to a specific location, year, and variable. The included variables are as follows:

- 'LOCATION' informs us about the 3-character country code of each location. It contains 10 unique country codes associated with selected countries.
- 'GEO' provides granular information about FUAs' OECD code and replicates the 3-character country code for country-level observations. This dataset includes 533 unique values and, thus, 523 different FUAs across 10 countries.
- 'TIME' accounts for the year the observation occurred. It ranges from 2001 to 2020.
- 'VAR' includes a variable code for each result under consideration, representing the seven variable codes included in this application. Three of them have the same codes for country and FUA level, and four differ but still convey similar information.
- 'VALUE' carries values associated with each triple GEO-TIME-VAR ranked from 0.008 to 366.

First, we add two columns to this database to calculate the DEPI. One contains the first no-missing value of matching GEO–VAR pairs as the initial value on which 100 indices are calculated. The second is the result of thebase 100 computations. A low baseline value can make the overall result highly sensitive to subsequent increases. However, we argue that when a territory achieves such a low value, maintaining it should be a policy objective. When the indicator reflects a natural phenomenon, such as hot days, the index captures the increase in environmental risk faced by the population relative to the baseline observed in the sample. We then grouped the observations by geolocation and year to calculate the geometric mean for every variable per year and geolocation, obtaining the yearly DEPIs for every FUA and country. Finally, all FUA results by country are averaged to get a unique value for the FUA level per year. The DEPI values ranged from 34.52 (Japan at the country level in 2007) to 295.60 (New Zealand at the country level in 2017) (see Table 2). The mean and median of DEPI values are approximately 102.15 and 100.00, respectively. In summary, half of the results indicate a net reduction in harmful environmental impacts, while the other half suggest an increase. The bottom quartile of the results exhibits a decrease of at least 12.05% from the baseline level. In contrast, only a quarter of the results show a deterioration exceeding 14.23% of their initial environmental performance, primarily compared to their 2001 baseline. Table 2 presents the descriptive statistics discussed above.

3. RESULTS AND DISCUSSION

3.1. Country level

Most countries exhibit greater variability in DEPI scores at the national level than at the FUA level (Figure 1). Despite some fluctuations and short-term improvements, the general trend in DEPI is upward. Environmental conditions have worsened at both national and local levels in many countries since 2015. To sum up, we observe that environmental management appears more effective nationally than at the FUA level in Australia, Canada, Colombia, Japan, Mexico, and Sweden. However, results are more ambiguous for Belgium, South Korea, and the United States. In the United States, national and FUA-level trends intersected several times before 2012, after which the national level consistently outperformed the FUA level. New Zealand is the only country where the national level underperforms the FUA level almost every year, with 2008 being the sole exception. At the national level, Canada, Japan, and Mexico exhibit the greatest reductions in harmful environmental outcomes within that sample. Among FUAs, Belgium demonstrates the best overall perfor-

Table 2. Descriptive statistics for the global DEPI results

Minimum	Q1	Median	Mean	Q3	Maximum
34.52	87.95	100.00	102.15	114.23	295.60

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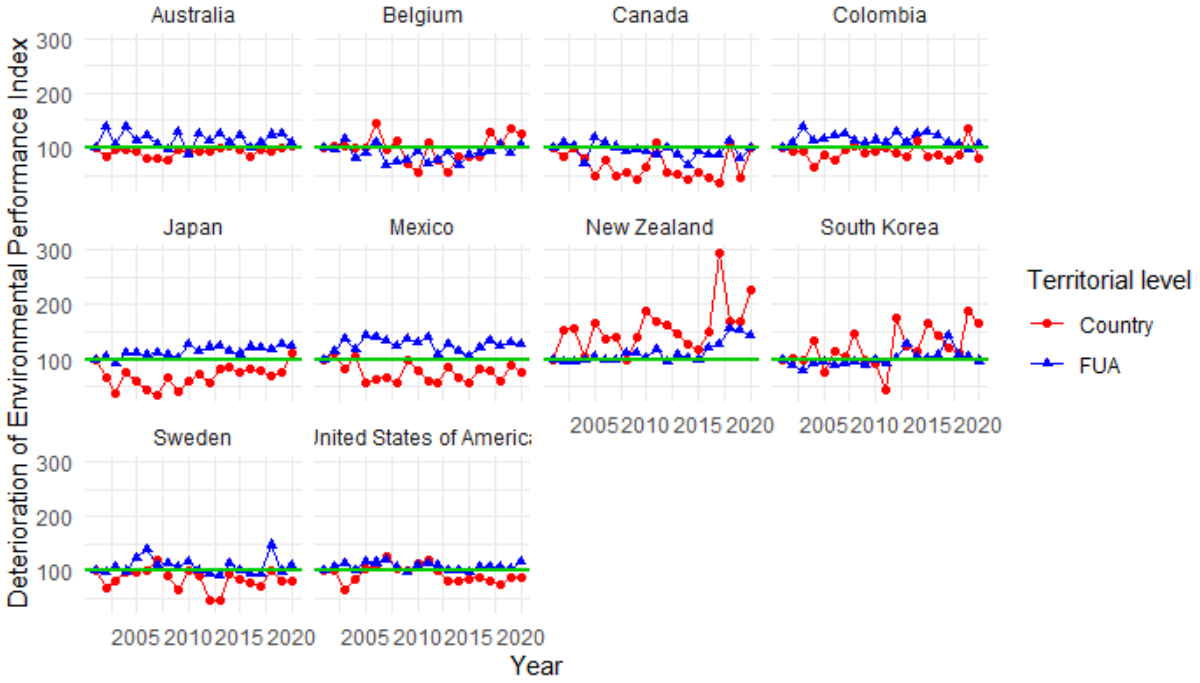
Table 3. Continent-level paired t-test

Continent	Territorial level	Sample size	t-value	p-value	95% confidence interval	Mean difference
Asia (Japan – South Korea)	National (country)	19	–6.584	2.657×10^{-6}	[–68.504; –35.455]	–51.980
Asia (Japan – South Korea)	Local (FUA)	19	5.092	6.466×10^{-6}	[7.711; 18.472]	13.091
Europe (Belgium – Sweden)	National (country)	19	2.274	0.034	[1.018; 24.507]	12.763
Europe (Belgium – Sweden)	Local (FUA)	19	–5.044	7.204×10^{-5}	[–26.716; –11.046]	–18.881
North America (Canada – USA)	National (country)	19	–4.125	0.0005	[–42.432; –13.870]	–28.151
North America (Canada – USA)	Local (FUA)	19	–5.125	6.014×10^{-5}	[–18.273; –7.676]	–12.975
Oceania(Australia – New Zealand)	National (country)	19	–6.483	3.268×10^{-6}	[–83.575; –42.782]	–63.179
Oceania (Australia – New Zealand)	Local (FUA)	19	0.582	0.566	[–7.773; 13.772]	2.999
South America (Columbia – Mexico)	National (country)	19	2.745	0.012	[3.422; 25.373]	14.397
South America (Columbia – Mexico)	Local (FUA)	19	–3.083	0.006	[–18.749; –3.587]	–11.168

mance. Additionally, in Canada, South Korea, Sweden, and urban areas in the United States, DEPI trends closely follow their baseline values. Similar patterns are observed in Australia and Colombia. Meanwhile, Japan and Mexico display an inverse relationship, with DEPI scores increasing at the FUA level while decreasing at the national level. These countries were selected to assess the environmental performance of nations across different continents within the OECD. These findings indicate that variations in results are just as pronounced between countries on the same continent as they are between countries on various continents. Paired *t*-tests were analyzed for all computed DEPI at each continent and for both levels to investigate this aspect[3]. All tests confirmed that differences between countries within the same continent were not statistically significant, except one[4]. Results are presented in Table 3.



Note: The green horizontal line for y = 100 represents normalization to base 100. On the one hand, when a country or FUA point is above this point, its environmental performance deteriorates compared with its reference level. On the other hand, when they are below, their performance improves. This means that they are reducing their harmful effects on the environment compared with their reference level. We need to subtract 100 from the result to read the percentage variation.

Figure 1. Evolution of DEPI for each country over the period (2001–2020)

3 Paired *t*-tests were computed with the null hypothesis that true mean difference between local and national indexes is equal to 0.

4 The only exception exists between Australia and New Zealand at the FUA level.

Overall, no clear continental effect would systematically explain the observed DEPI results. Given the large number of FUAs considered for each country, their evolution appears smoother than the national-level DEPI (Figure 1). Extreme values at the FUA level are mitigated by the geometric mean used in computation and by aggregation through an arithmetic mean. Three main environmental hazards strongly influence DEPI trends: heat exposure, flood risk, and wildfires. Hot days have a major impact in South Korea, Belgium, and Canada. Flood risk plays a key role in Japan, Colombia, Belgium, Sweden, and Mexico. Wildfire exposure is especially relevant in Australia, Canada, New Zealand, and the United States. These hazards often cause sharp year-on-year fluctuations, especially during extreme climate events. DEPI is highly sensitive to sudden changes in specific variables. For example, hot day exposure in South Korea jumped from 0.03% to 76.7%. In Belgium, coastal flood risk rose by over 200%. Such shifts can significantly affect DEPI, even if other variables stay stable.

3.2. Evolution of DEPIs at different territorial levels

In all countries but Belgium, paired *t*-tests confirm a statistically significant difference between national and local DEPI levels, suggesting territorial variation in environmental management. Table 4 summarizes the mains statistics of each test and Figure 2 presents DEPIs for each territorial level on a single chart, illustrating twenty different results.

3.3. Local vs. national

Finally, we use a geometric mean to calculate the DEPIs for all countries and FUAs. On average, en-

Table 4. Country-level paired t-test

Country	Sample size	t-value	p-value	95% confidence interval	Mean difference
Australia	19	6.544	$2{,}883\times10^{-6}$	[14.794; 28.707]	21.750
Belgium	19	–1.725	0.100	[–20.069; 1.932]	–9.068
Canada	19	5.044	7.192×10^{-5}	[16.135; 39.017]	27.576
Colombia	19	5.188	5.233×10^{-5}	[13.767; 32.388]	23.078
Japan	19	10.792	1.521×10^{-9}	[36.195; 53.612]	44.904
Mexico	19	9.350	1.534×10^{-8}	[37.755; 59.532]	48.644
New Zealand	19	–5.023	7.543×10^{-5}	[–62.938; –25.917]	–44.428
South Korea	19	–2.591	0.017	[–36.455; –3.880]	–20.167
Sweden	19	6.352	4.286×10^{-6}	[15.137; 30.015]	22.576
The United States of America	19	4.022	0.0007	[5.947; 18.852]	12.399

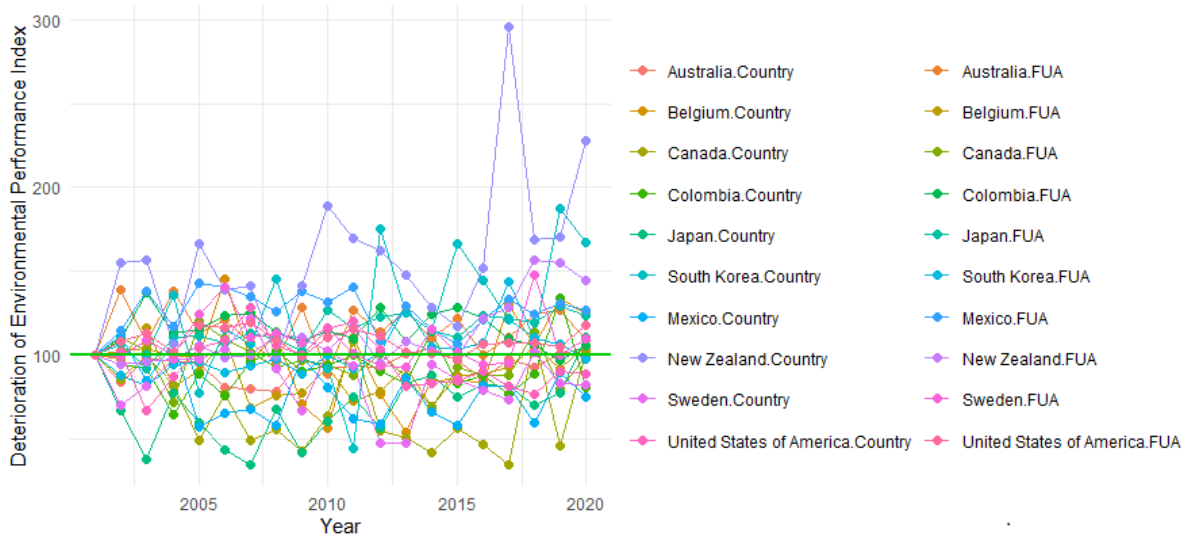


Figure 2. DEPI by territorial level (2001–2020)

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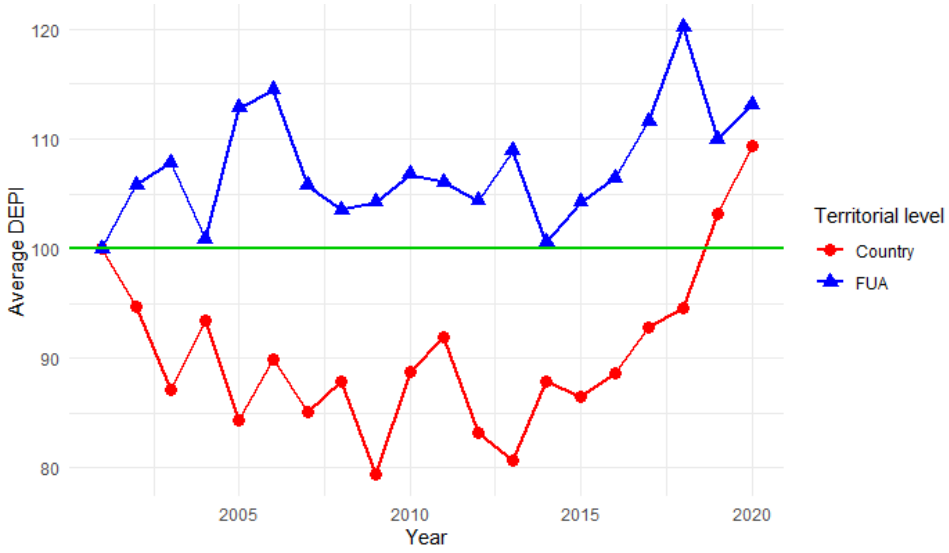

Figure 3. Overall average DEPI by territorial level (2001–2020)

vironmental management is consistently better at the national level than at the city level each year (Figure 3). Ideally, environmental policies should be implemented at all levels to mitigate the impacts of climate change. However, local-level policies would greatly benefit from improved implementation, as their performance has deteriorated over time.

Across all countries analyzed, DEPI values reveal that environmental performance has generally deteriorated, with national and local scales exhibiting significantly different trends. While the specific drivers and volatility vary, the most frequent contributors to degradation are particularly related to heat, flooding, and wildfire risks. Thus, it could help identify vulnerable areas and potential opportunities for improvement. Moreover, these findings underscore the importance of local policies and the need for adapted local governance that reflects specific environmental pressures.

3.4. Robustness tests: Alternatives versions of the DEPI

Robustness is assessed through two approaches. First, we compare the original results with three alternatives versions of the applied index. We recognize that modifying input variables or applying different weights could alter the overall results. Therefore, we first calculated an alternative DEPI, excluding coastal and river flooding risks, as they were the primary sources of extreme values. Overall, the results and trends remain consistent with the original findings (Figure 4). Environmental performance tends to be stronger nationally throughout the observed period, although some variations are year-dependent. Australia, Canada, Colombia, Japan, Mexico, and Sweden continue to perform better at the national and city levels, indicating greater environmental deterioration in urban areas. In contrast, the territorial level with the best-managed environment fluctuates over time in Belgium and the United States. New Zealand and South Korea were excluded from direct comparisons with other countries. In the alternative DEPI, New Zealand exhibits a relatively stable trend at the national level, as only one variable was considered (the mean population exposed to PM2.5). South Korea's results remain ambiguous, generally staying close to the baseline except for two outliers at each level. To sum up, this alternative version reinforces confidence in the initial results. National-level performance in air quality and climate hazard management consistently surpasses that of urban areas.

Secondly, DEPI is computed with arbitrary weight in the geometric mean for each dimension accounted for. Thus, a weighted version is computed because public authorities typically exert greater control over air pollution than over climate hazards. The air pollution dimension outweighs climate risks (flood, heat, and wildfire) in that version (Figure 5). Mean population exposure to PM2.5 is therefore assigned double weight in the composite index. Trends

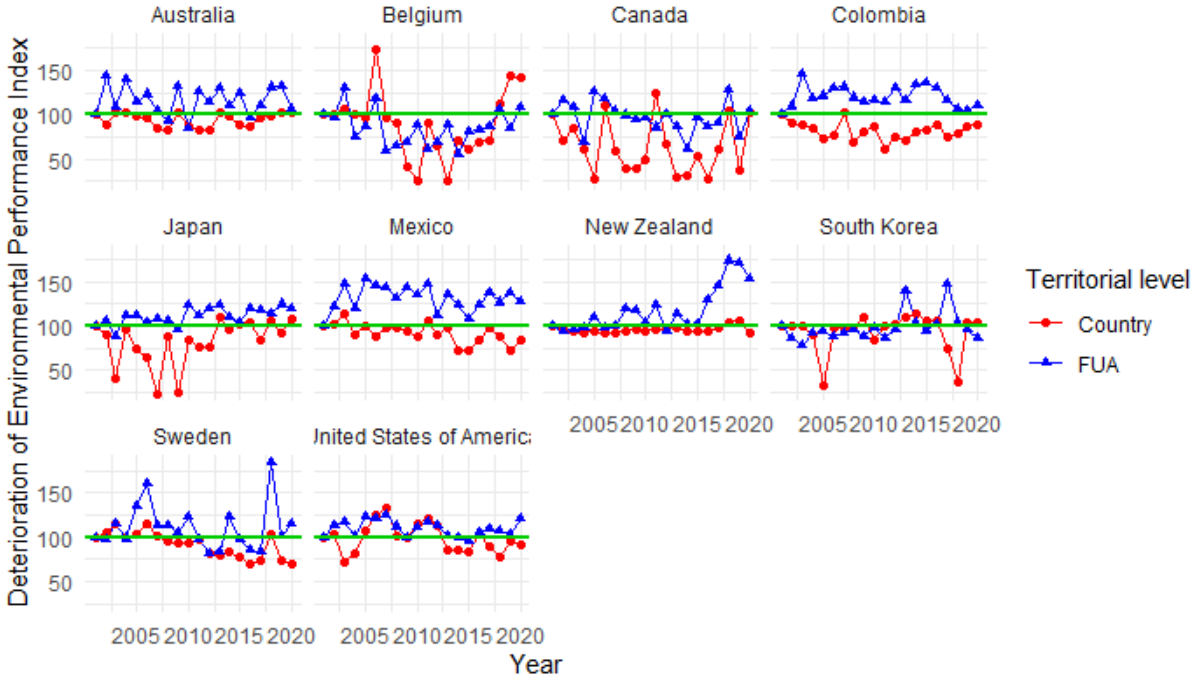

Figure 4. Alternative DEPIs by territorial level (2001–2020)

at both territorial levels and across all countries remain consistent with the unweighted results. However, weighted DEPI values present a narrower range, from 39.14 (Canada, national level, 2017) to 236.96 (New Zealand, national level, 2017) (see Table 5).

Thirdly, the unweighted composite index is computed with different return period on built-up area flood risk. Global descriptive statistics are presented in Table 6. The DEPI range is smaller when using a 10-year return period (222.59) and larger with a 100-year return period (295.5), relative to the base-

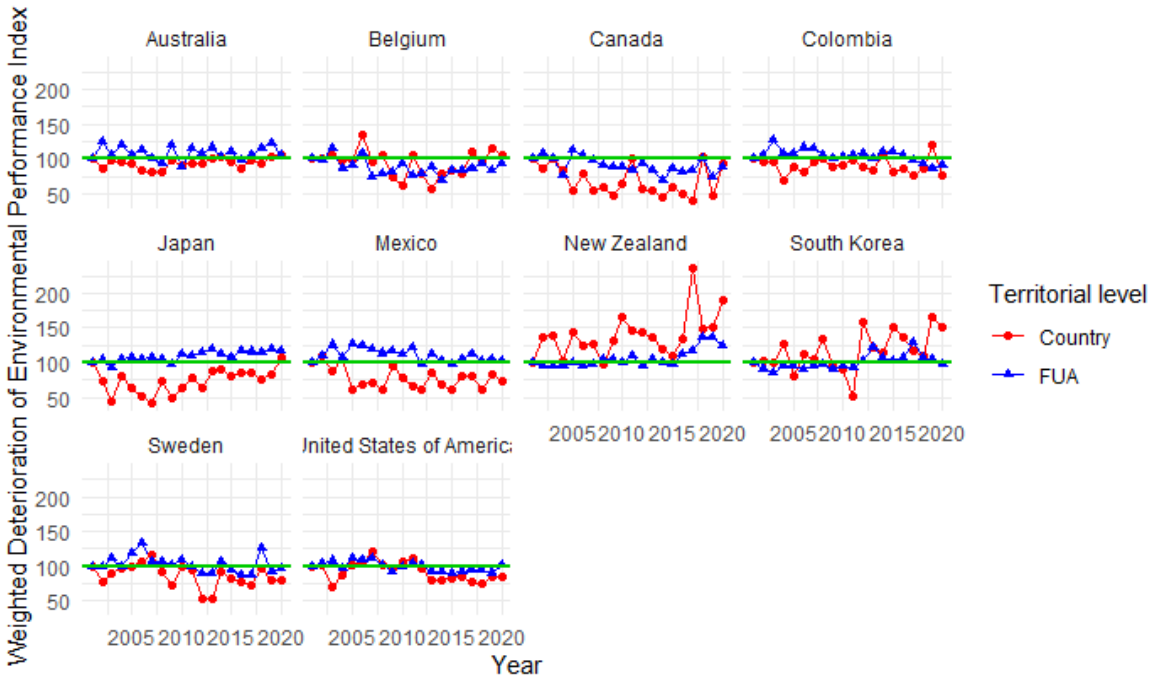

Figure 5. Weighted DEPI by territorial level and country (2001–2020)

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Table 5. Descriptive statistics for the unweighted and weighted DEPI results

DEPI	Minimum	Q1	Median	Mean	Q3	Maximum
Unweighted	34.52	87.95	100.00	102.15	114.23	295.60
Weighted	39.15	86.12	99.11	97.90	107.27	236.96

Table 6. Descriptive statistics for DEPI results with different return period on flood risk

Return period	Minimum	Q1	Median	Mean	Q3	Maximum
10-year	21.19	87.71	100.00	100.38	113.21	243.78
50-year	34.52	87.95	100.00	102.15	114.23	295.60
100-year	28.33	90.42	101.49	105.96	117.56	323.83

line specification. Despite this variation, the overall distribution remains similar to quarterly values that are broadly comparable across return periods.

From a graphical perspective, however, both alternative return periods produce less distinct environmental performance patterns (Figures 6 and 7). This effect is particularly pronounced with the 100-year return period, where values tend to flatten around the base-100 normalization (Figure 7). Accordingly, the 50-year return period remains the most appropriate choice for this analysis.

3.5. Theoretical and practical evaluation

The integrity of composite indices primarily depends on the rigorous scrutiny of their theoretical framework, underscoring the need for full transparency. Robustness is achieved when every decision can be explicitly traced back to the index's intended purpose (Greco et al., 2019; OECD, 2008). Accordingly, we present a multicriteria evaluation of the Deterioration of Environmental Performance Index. The evaluation method, outlined in Table 7, is based on the framework developed by Gadrey and Jany-Catrice (2016), which assesses an index's efficiency and methodological soundness as a measurement tool. There is no universally "correct" answer for each criterion; the overall evaluation depends on the intended goal and application of the indices. One notable area for improvement is the lack of public involvement in the development and use of the index, which significantly affects its perceived legitimacy. Additionally, the degree of consideration giv-

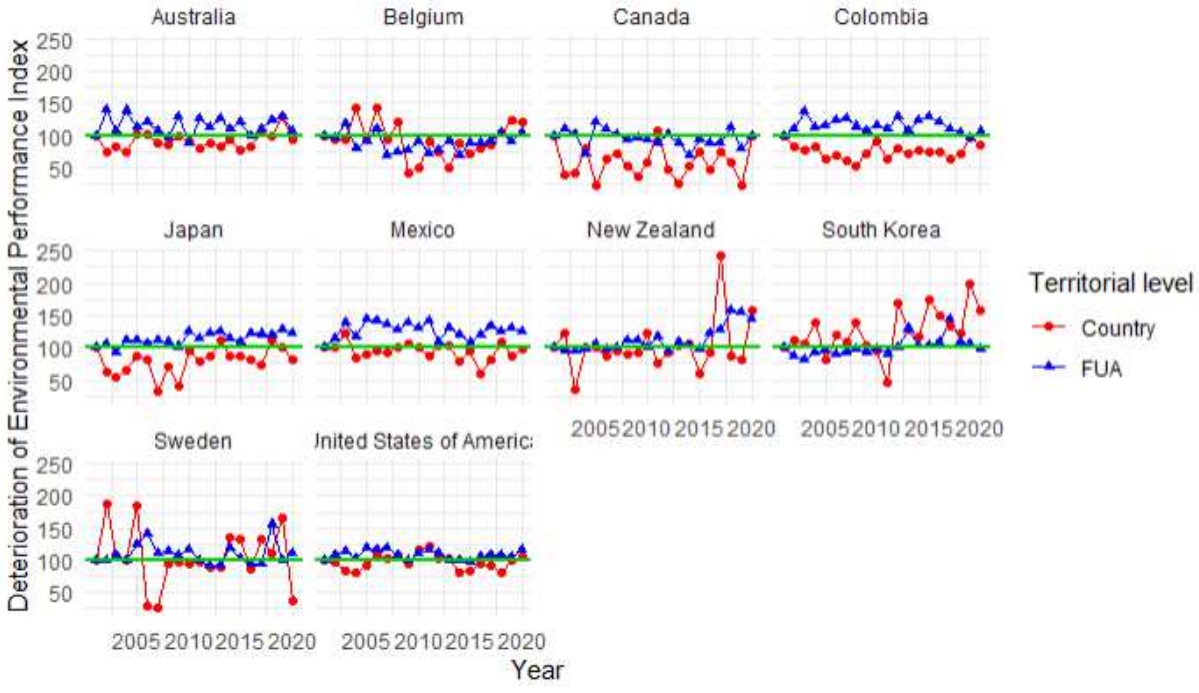

Figure 6. 10-years return period on flood risk's DEPI by territorial level and country (2001–2020)

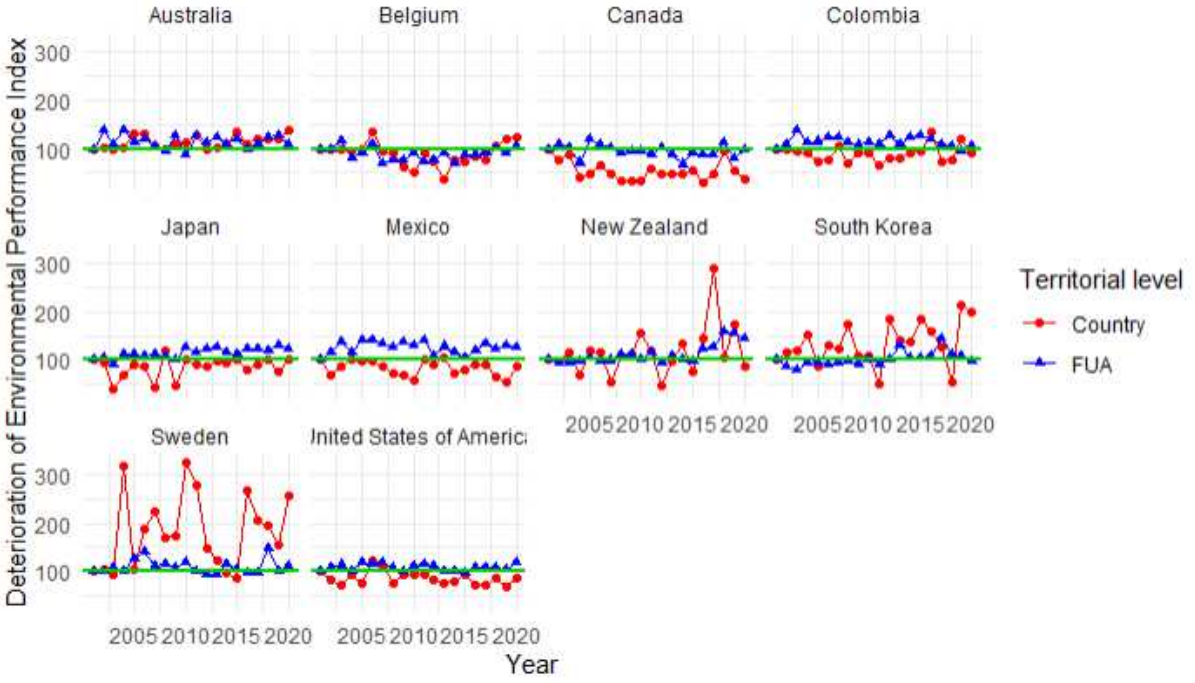

Figure 7. 100-years return period on flood risk's DEPI by territorial level and country (2001–2020)

en to irreversible environmental effects could be enhanced. However, using a geometric mean introduces an inherent trade-off between outcomes, which may not fully capture these effects. Similarly, while one could argue that aggregation should be weighted – since not all environmental outcomes hold equal importance in management decisions – both weighted and unweighted approaches can be valid if well justified. On the positive side, the DEPI index has a clearly defined objective: evaluating the environmental performance of government entities at various levels. The selection of outcomes was guided by relevant literature and remains flexible for further expansion. Moreover, the transparency of methodology and data processing is a key strength. The ability to compare results annually and track overall trends adds further value. Additionally, the indices allow for disaggregation by dimension, individual outcomes, and territorial levels, making them adaptable for specific assessments. DEPI incorporates only two dimensions, represented by five outcomes: four related to climate hazard management and one addressing air pollution management. The applied version is less comprehensive regarding complementarity and coverage of environmental outcomes that reflect territorial ecological performance. However, it maintains strong data integrity and international comparability due to its reliance on the OECD database.

Table 7. Evaluation of technical and political aspects of DEPI

Source: Gadrey and Jany-Catrice (2016), with author's elaborations.

Deterioration of Environmental Performance Index	
A. Construction mode	
Nature of the initiative	Research article
Accounting consistency	Non-monetary valuation, comparing each outcome with its initial value
Data integrity	Reliable statistics, OECD datasets
Possible expansion	Yes, open to new data and new dimensions enlargement
Theoretical and conventional framework	Environmental performance outcomes chosen via dedicated literature
B. Dimensions and components	
Complementariness	Data restriction, but the main quantitative environmental outcomes included (air pollution, climate hazard via heat, flood, and fire risks)
Objective or subjective measure	Objective measure
Number of dimensions	Two dimensions through five outcomes, relative simplicity
Choice and transparency of weighting	Unweighted geometric mean of base 100, complete transparency

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Table 7 (cont.). Evaluation of technical and political aspects of DEPI

C. Technical potential of the index for various uses	
Temporal continuity, regularity of the data used	Normalization through the first non-zero value of each outcome in the chosen period. Rather strong regularity of OECD data
International comparability of variables and data sources	Strong comparability, single data source (OECD datasets)
Synchronicity and diachronicity	Comparison can be made for a single year from a starting point, as well as for its evolution over time
Adjustability and disintegration	Strong, can be computed for any territorial level and declined for any outcome
Degree of consideration given to irreversible effects	Relatively weak via geometric means
D. Political perspectives	
Clear economic and/or social policy objective	Yes, evaluation of territorial environmental performances
Public decision-making tool	No, a research project without public involvement
Possible use	An indicator of the sustainability of the development strategies, with quantified measurements of environmental performance to fuel discussion
Acquired legitimacy (media coverage, influence in public debate, lifespan of the index)	No media coverage, unknown lifespan

CONCLUSION

This paper presents an innovative framework for calculating a new quantitative composite index. Its purpose is to evaluate environmental management across different territorial levels over time. The DEPI's annual evolution is examined for ten OECD countries and their respective urban areas over the period 2001–2020. Statistical analysis reveals that, in most cases, national-level environmental management outperforms urban areas. Specifically, all countries with non-ambiguous results exhibit lower DEPI scores (indicating better performance) than their corresponding urban areas, except for New Zealand. New Zealand is the only country in the sample that presents poorer results at the national level. The results for Belgium, South Korea, and the United States of America are inconclusive. These findings highlight the vulnerability of cities to climate-related risks. Environmental policies may be applied at all levels for better effectiveness in mitigating climate change impacts. However, there is a particular need to improve the implementation of local-level policies. Despite establishing ambitious climate plans and mitigation targets, FUAs' performance has deteriorated over time at a greater rate than the environmental performance of their respective countries[5]. For instance, coastal and river flood risks usually present greater tension at the city level than at the national level, as important cities are often located near water access areas. Thus, the DEPI results show that urban areas may be more sensitive to climate change threats than countries. However, the current results might reflect data coverage issues rather than true actual performance gaps. A sufficient degree of independence between the local and national levels of each country is assumed to compare the results. Endogeneity may exist if local performance is too constrained by national policy frameworks. A complementary study on each state's territorial organization would help further explain observed differences. Moreover, introducing additional differentiation thresholds at various levels for each outcome could provide a more comprehensive assessment of territorial environmental performance.

AUTHOR CONTRIBUTIONS

Conceptualization: Romain Gaté, Elise Callerisa.
Data curation: Elise Callerisa.
Formal analysis: Romain Gaté, Elise Callerisa.
Funding acquisition: Elise Callerisa.
Investigation: Romain Gaté, Elise Callerisa.

5 However, an example of an effective municipal intervention is Barcelona's "Superblocks" policy. By restricting through-traffic in selected neighborhoods to prioritize pedestrian zones and green spaces, the city reduced local PM2.5 concentrations by approximately 7% and achieved broader air quality improvements, with pollutant reductions ranging from 7% to as much as 93% (OECD, 2021).

Methodology: Elise Callerisa.
Project administration: Romain Gaté.
Resources: Romain Gaté.
Software: Elise Callerisa.
Supervision: Romain Gaté.
Validation: Romain Gaté.
Visualization: Elise Callerisa.
Writing – original draft: Elise Callerisa.
Writing – review & editing: Elise Callerisa, Romain Gaté.

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REFERENCES

1. Albert, J. S., Destouni, G., Duke-Sylvester, S. M., Magurran, A. E., Oberdorff, T., Reis, R. E., Winemiller, K. O., & Ripple, W. J. (2021). Scientists' warning to humanity on the freshwater biodiversity crisis. *Ambio, 50*(1), 85-94. https://doi.org/10.1007/s13280-020-01318-8

2. Aminzadeh, S. C. (2007). A moral imperative: The human rights implications of climate change. *Hastings International and Comparative Law Review, 30*(2), 231-265. Retrieved from https://scispace.com/pdf/a-moral-imperative-the-human-rights-implications-of-climate-2awam2ajor.pdf

3. Balme, R., & Ye, Q. (2014). Multilevel governance and the environment: Intergovernmental relations and innovation in environmental policy. *Environmental Policy and Governance, 24*(3), 147-154. https://doi.org/10.1002/eet.1635

4. Botta, E., & Koźluk, T. (2014). *Measuring environmental policy stringency in OECD countries: A composite index approach* (OECD Economics Department Working Papers No. 1177). Paris: OECD Publishing. https://doi.org/10.1787/5jxrjnc45gvg-en

5. Coalition for Urban Transitions. (2019). *Climate emergency, urban opportunity: How national government can secure economic prosperity and avert climate catastrophe by transforming cities*. Retrieved from https://urbantransitions.global/wp-content/uploads/2019/09/Climate-Emergency-Urban-Opportunity-report.pdf

6. Dasgupta, P. (2021). *The economics of biodiversity: The Dasgupta review*. London: HM Treasury. Retrieved from https://assets.publishing.service.gov.uk/media/602e92b2e90e07660f807b47/The_Economics_of_Biodiversity_The_Dasgupta_Review_Full_Report.pdf

7. Eisenack, K., & Roggero, M. (2022). Many roads to Paris: Explaining urban climate action in 885 European cities. *Global Environmental Change, 72,* Article 102439. https://doi.org/10.1016/j.gloenvcha.2021.102439

8. Gadrey, J., & Jany-Catrice, F. (2016). *Les nouveaux indicateurs de richesse [The new wealth indicators]* (4th ed.). La Découverte. (In French). Retrieved from https://www.editionsladecouverte.fr/les_nouveaux_indicateurs_de_richesse-9782707190635

9. Gong, W., & Lyu, H. (2017). *Sustainable city indexing: Towards the creation of an assessment framework for inclusive and sustainable urban-industrial development* (Issue Paper No. 2). United Nations Industrial Development Organization (UNIDO), BRIDGE for Cities. Retrieved from https://www.unido.org/sites/default/files/files/2018-02/BRIDGE%20for%20Cities_Issue%20Paper_2.pdf

10. Greco, S., Ishizaka, A., Tasiou, M., & Torrisi, G. (2019). On the methodological framework of composite indices: A review of the issues of weighting, aggregation, and robustness. *Social Indices Research, 141,* 61-94. https://doi.org/10.1007/s11205-017-1832-9

11. Hannah, L. (2008). Protected areas and climate change. *Annals of the New York Academy of Sciences, 1134*(1), 201-212. https://doi.org/10.1196/annals.1439.009

12. Larson, W., Liu, F., & Yezer, A. (2012). Energy footprint of the city: Effects of urban land use and transportation policies. *Journal of Urban Economics, 72*(2-3), 147-159. https://doi.org/10.1016/j.jue.2012.05.001

13. Liu, S., Fan, F., & Zhang, J. (2019). Are small cities more environmentally friendly? An empirical study from China. *International Journal of Environmental Research and Public Health, 16*(5). https://doi.org/10.3390/ijerph16050727

14. Martin, D., Tomida, M., & Meacham, B. (2016). Environmental impact of fire. *Fire Science Reviews, 5,* Article 5. https://doi.org/10.1186/s40038-016-0014-1

15. Matsumoto, T., Allain-Dupré, D., Crook, J., & Robert, A. (2019). *An integrated approach to the Paris climate agreement: The role of regions and cities* (Working Papers No. 2019/13). Paris: OECD

http://dx.doi.org/10.21511/ee.17(1).2026.09

Regional Development. https://doi.org/10.1787/96b5676d-en

16. NEC. (2019). *Net Environmental Contribution 1.0 Handbook. All Frameworks*. Retrieved from https://www.nec-initiative.com/files-methodologies/en/NEC_1_0_All_Frameworks_Methodology.pdf

17. OECD. (2008). *Handbook on constructing composite indices: Methodology and user guide*. Paris: OECD Publishing. Retrieved from https://www.oecd.org/content/dam/oecd/en/publications/reports/2008/08/handbook-on-constructing-composite-indicators-methodology-and-user-guide_g1gh9301/9789264043466-en.pdf

18. OECD. (2021). *Transport strategies for net-zero systems by design*. Paris: OECD Publishing. https://doi.org/10.1787/0a20f779-en

19. OECD. (2022). *The OECD Metropolitan Database*. OECD Database. Retrieved from https://data-explorer.oecd.org/?fs[0]=Topic%2C1%7CRegional%252C%20rural%20and%20urban%20development%23GEO%23%7CCities%20and%20functional%20urban%20areas%23GEO_URB%23&snb=28

20. OECD. (2023). *OECD Green Growth Indices*. OECD Database. Retrieved from https://data-explorer.oecd.org/vis?tm=Green%20Growth%20Indices&pg=0&snb=21&vw=tb&df[ds]=dsDisseminateFinalDMZ&df[id]=DSD_GG%40DF_GREEN_GROWTH&df[ag]=OECD.ENV.EPI&df[vs]=1.1&dq=AUS....&pd=2017%2C&to[TIME_PERIOD]=false

21. OECD. (n.d.). *OECD Climate and Environment regional statistic*. OECD Database. Retrieved June 13, 2023, from https://stats.oecd.org/wbos/fileview2.aspx?IDFile=113af38b-3c74-4aba-94e3-2752595654a4

22. Ribeiro, T. L. (2023). Institutional outcome at the subnational level – Climate commitment as a new measurement. *Earth System Governance, 16,* Article 100176. https://doi.org/10.1016/j.esg.2023.100176

23. Shi, L., Han, L., Yang, F., & Gao, L. (2019). The evolution of sustainable development theory: Types, goals, and research prospects. *Sustainability, 11*(24). https://doi.org/10.3390/su11247158

24. Von Uexkull, N., & Buhaug, H. (2021). Security implications of climate change: A decade of scientific progress. *Journal of Peace Research, 58*(1), 3-17. https://doi.org/10.1177/0022343320984210

25. Wang, H., Zhou, J., Tang, Y., Liu, Z., Kang, A., & Chen, B. (2021). Flood economic assessment of structural measure based on integrated flood risk management: A case study in Beijing. *Journal of Environmental Management, 280,* Article 111701. https://doi.org/10.1016/j.jenvman.2020.111701

26. Wolf, M. J., Emerson, J. W., Esty, D. C., Sherbinin, A. D., & Wendling, Z. A. (2022). *2022 Environmental Performance Index (EPI) results.* New Haven, CT: Yale Center for Environmental Law & Policy. Retrieved from https://bvearmb.do/handle/123456789/2828