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Environmental Sustainability in the Post-Soviet Republics: Cross-Country Evidence from a Composite Index

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Abstract

This study investigates the environmental dimension of sustainable development across fifteen post-Soviet republics in 2022. While sustainability is generally understood as a triadic construct—economic, social, and environmental—this paper isolates the ecological pillar to highlight cross-country differences shaped by industrial legacies, institutional capacity, and governance models. A composite Environmental Performance Index (EPI) is developed using the Mazziotta–Pareto Index (MPI), which captures both average performance and internal consistency across three SDG-related domains: SDG 6 (Clean Water and Sanitation), SDG 13 (Climate Action), and SDG 15 (Life on Land). The study adds to existing literature as it includes a non-compensatory composite index and cluster analysis, and in policy terms, it provides a benchmarking system for facilitating ecological transition in the post-Soviet context. The results reveal strong divergence across the region: Baltic countries and Moldova achieve higher scores, reflecting policy convergence with the European Union and stronger environmental institutions, while Central Asian republics lag due to resource dependence, water scarcity, and weaker governance. Geographic cluster analysis corroborates these differences, showing clear spatial patterns of environmental convergence and divergence. Correlation analysis further demonstrates that environmental sustainability is positively associated with GDP per capita, HDI, and life expectancy, while negatively linked with inequality and fertility rates. These findings stress the need for context-sensitive and evidence-based policies, intra-regional cooperation, and integrated governance mechanisms to advance ecological transition in line with the 2030 Agenda for Sustainable Development.

Keywords: composite indicators; environmental sustainability measurement; multidimensional assessment; indicator-based evaluation; non-compensatory methods; sustainable development goals (SDGs); post-Soviet republics; transition economies

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1. Introduction

Post-Soviet space represents a unique laboratory for investigating sustainability, where common legacies meet diverging trajectories. While sustainable development is commonly conceptualized as a triadic framework encompassing environmental, social, and economic dimensions, this research isolates the environmental component to assess ecological performance across a historically and institutionally diverse region.

Post-Soviet space is an extremely concrete space for environmental investigation. Although connected by a shared history within the Soviet Union, the post-Soviet countries are now highly dissimilar in institutional development, economic policy, and environmental control since the fall of the USSR in 1991 [1–3]. The phrase "post-Soviet" has itself been very much contested, as political, economic, and cultural trajectories have divided the region [4].

During the Soviet era, environmental concerns were usually secondary to the imperatives of industrial production and demographic growth. Despite the presence of scientific knowledge and technological comforts, ecological issues were commonly resolved on a utilitarian basis, resulting in long-lasting environmental degradation [5–10]. While Soviet climatologists were part of early arguments about anthropogenic climate change, integration of environmental science into policy was limited and unequal [11–13].

Environmental performance in the post-Soviet period has been determined by inherited industrial make-up, institutionally segmented systems, and political action on environmental issues [14]. Estonia, Latvia, and Lithuania have benefited from membership in the European Union and policy convergence, whereas the Central Asian republics have suffered long-term ecological problems like water scarcity, a lack of investment in renewable resources, and poor regulatory governance [15,16].

This study explores the environmental sustainability of the fifteen former Soviet republics, Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Moldova, Russia, Tajikistan, Turkmenistan, Ukraine, and Uzbekistan, in the year 2022.

This research contributes to environmental sustainability literature by specifically targeting the cumulative effects and trajectories of post-Soviet nations [17–20]. It seeks to untangle the environmental component from broad conversations regarding sustainability and assess ecological differences in an evidence-based framework.

Comparable approaches have been recently employed to uncover hidden sustainability patterns across Asia [21] and Africa [22]. These studies demonstrate how composite indicators reveal multidimensional sustainability trajectories, reinforcing the validity of our methodological choice.

Similar composite approaches have been widely applied in Europe and Latin America to benchmark environmental sustainability, showing the importance of integrating water, biodiversity, and climate indicators [15,16]. Our study complements these by focusing on a region with specific institutional legacies.

This study also contributes to the broader international debate on sustainable transitions [23–26]. The post-Soviet space can be considered a critical laboratory for understanding how institutional legacies, economic trajectories, and governance models interact with the pursuit of ecological goals. Similar challenges are observed in other emerging economies undergoing rapid socio-political transitions, where ecological modernization is constrained by structural inequalities and institutional fragility. By disentangling the environmental pillar and examining it in relation to institutional quality and socio-economic outcomes, this paper provides insights that are globally relevant for advancing the 2030 Agenda and the principles of a just and inclusive ecological transition.

The objective of this paper is to construct a composite Environmental Performance Index (EPI) using the Mazziotta–Pareto Index (MPI) and to assess spatial patterns of environmental sustainability among the fifteen post-Soviet republics.

The study progresses on three main axes of inquiry. Firstly, it constructs a cumulative environmental performance index based on specific Sustainable Development Goals (SDG 6: Clean Water and Sanitation; SDG 13: Climate Action; SDG 15: Life on Land). Second, it explores correlations between this index and key macro-socioeconomic indicators such as GDP per capita, Human Development Index (HDI), life expectancy, fertility rate, and income inequality (Gini index). Third, geographic cluster analysis applies to identify spatial patterns of convergence and divergence in environmental sustainability.

Despite the increasing use of composite indicators to assess sustainability worldwide, very few studies have applied non-compensatory approaches in the post-Soviet context. Most existing analyses rely on compensatory methods, such as PCA or entropy-based techniques, which allow strong performance in one dimension to offset weaknesses in others. This approach is problematic when measuring sustainability, where trade-offs across environmental dimensions are neither conceptually sound nor policy relevant. The application of a non-compensatory index, such as the Mazziotta–Pareto Index (MPI), therefore fills a significant methodological gap by penalizing unbalanced profiles and capturing internal consistency across indicators. By focusing on the post-Soviet republics, this study provides a novel contribution that combines methodological rigor with regional relevance, offering new insights into ecological transition in a historically and institutionally diverse area.

The remainder of the chapter is structured as follows. Section 2 presents the materials and methods, detailing the construction of the composite index and the clustering technique. Section 3 reports empirical results, while Section 4 discusses theoretical implications and policy recommendations for ecological transition in the region.

2. Materials and Methods

The recent literature has emphasized the need for robust multidimensional tools to evaluate complex phenomena such as sustainability [27–30], while also recognizing the conceptual and technical limitations of aggregative approaches [31–33]. The data used in this analysis are taken from the Sustainable Development Report 2023, edited by Sachs et al. [34], which relies on datasets provided by the SDG Transformation Centre.

All data processing and statistical analyses were conducted using JMP Pro 17 (SAS Institute Inc., Cary, NC, USA). The Mazziotta–Pareto Index (MPI) was implemented through customized scripts in JMP, following the standard normalization and aggregation procedure described in [35]. The k-means clustering algorithm was executed within the JMP statistical platform, with the following specifications:

- Random seed: fixed at 1234 to ensure reproducibility.
- Maximum iterations: 10,000.
- Convergence criterion: minimum change in within-cluster variance < 10^{-6}.
- Validation method: elbow criterion, with robustness checks using hierarchical and fuzzy clustering.

All correlation analyses were computed using JMP's "Multivariate" module. Pearson correlation coefficients were reported, while non-parametric Spearman correlations were calculated as robustness checks. The processed dataset and JMP calculation codes are available from the authors upon reasonable request, ensuring transparency and replicability of the study.

The Sustainable Development Report indicators were cross-checked against World Bank and WHO datasets for consistency, particularly for the Central Asian countries, where international statistics are often beset with gaps or delayed reporting. Inconsistent or missing data were handled by listwise deletion, as imputation could introduce biases in such a small sample (n = 15). MPI was favored over compensatory methods such as PCA or entropy-based TOPSIS because it penalizes unbalanced profiles, not permitting extreme values within one dimension to obscure weaknesses in others, a critical attribute for measuring sustainability. For cluster analysis, the k-means algorithm was validated using the elbow method, and robust checks with hierarchical and fuzzy clustering testified to similar clusters. Such triangulation enhances confidence in the results despite the limited sample size. Among the various methodologies proposed, the Mazziotta–Pareto Index (MPI) offers a partially non-compensatory solution that is especially suited for contexts in which trade-offs between dimensions are not acceptable [35].

In this study, the MPI is employed to construct a composite Environmental Performance Index (EPI) for the fifteen former Soviet republics, using three indicators aligned with key Sustainable Development Goals:

1. SDG 6: Clean Water and Sanitation
2. SDG 13: Climate Action
3. SDG 15: Life on Land

Alternative indicators were initially considered, for instance, the wastewater treatment rate for SDG 6, but were excluded due to the lack of consistent data across several countries. We therefore prioritized the water stress index, which is both consistently available and theoretically central to the ecological challenges of the post-Soviet region. As a result, the Environmental Performance Index developed in this study is restricted to three SDGs (6, 13, and 15), reflecting the limited availability of harmonized data. Important environmental dimensions, such as air quality, waste management, and ecological footprint, could not be incorporated. The omission of these dimensions prevents a fully comprehensive assessment of environmental sustainability and must be recognized as a limitation of the analysis.

These indicators were selected for their relevance to the ecological dimension and their availability across all countries in the year 2022. Each indicator was standardized and rescaled using the MPI normalization procedure, which transforms raw values into a 70–130 scale according to the formula:

$$Zij = 100 \pm 10 \ast \frac{X_{ij-}M_{xj}}{S_{xj}} \tag{1}$$

where X_{ij} represents the value of the j-th indicator for the i-th unit, M_{xj} is the vertical mean, S_{xj} is the standard deviation, and the sign ($\pm$) reflects the directionality of the indicator with respect to the phenomenon under analysis. The normalization followed the MPI standard procedure, equivalent to a Z-score rescaling on a 70–130 interval.

In this case, all selected indicators are positively oriented, meaning higher values indicate better environmental performance. Therefore, the negative sign was applied consistently.

The composite MPI score for each country was calculated as

$$MPI_i = M_{zi} - S_{zi} \ast CV_i \tag{2}$$

where M_{zi}, S_{zi} and CV_i are the horizontal mean, standard deviation, and coefficient of variation for unit i, respectively. This structure allows for capturing both average performance and internal consistency within the unit's profile.

The rationale for using the Mazziotta–Pareto Index (MPI) lies in its partially non-compensatory structure, which prevents extremely high values in one dimension from offsetting weaknesses in another. This feature is particularly important in sustainability studies, where trade-offs across ecological indicators are often unacceptable. While other methods widely used in sustainability research, such as PCA, DEA, or entropy-based TOPSIS, focus on variance reduction or efficiency maximization, the MPI better reflects the multidimensional and indivisible nature of sustainability. Moreover, the selection of SDG 6, SDG 13, and SDG 15 was driven not only by data availability but also by their theoretical relevance in capturing water security, climate mitigation, and biodiversity conservation, three critical and interdependent ecological challenges across the region.

Following the estimation of Environmental MPI scores, k-means clustering was applied to partition countries into groups with similar environmental performance [36,37]. Although k-means clustering was adopted and validated through the elbow method, alternative techniques such as hierarchical or fuzzy clustering could be applied to test robustness; this is left for future research.

The choice of K = 3 was confirmed by the elbow method and theoretical interpretability. Robustness checks with K = 2 and K = 4 yielded consistent groupings.

This unsupervised learning algorithm aims for within-group homogeneity and between-groups heterogeneity [38,39]. The value of clusters was heuristically selected based on the elbow method and theoretical interpretability. Convergence towards meaningful and stable clusters is ensured by the iterative nature of the algorithm.

Finally, to explore the socio-environmental nexus, we computed Pearson correlation coefficients between the Environmental MPI and a set of macro-level indicators:

- GDP per capita;
- Human Development Index (HDI);
- Life expectancy at birth;
- Fertility rate;
- Gini index (income inequality).

These variables were selected because they capture the main socioeconomic and demographic mechanisms through which environmental sustainability is shaped and constrained. GDP per capita reflects the level of economic resources available for investment in ecological infrastructure and green technologies. The Human Development Index (HDI) provides a broader measure of social development, integrating education, health, and income, and thus allows us to explore the link between ecological performance and overall human well-being. Life expectancy at birth serves as a proxy for public health conditions and environmental quality, as cleaner ecosystems and stronger health systems often translate into longer lives. Conversely, fertility rates highlight demographic pressures on natural resources, especially water and land, which are critical in the post-Soviet context. Finally, the Gini index measures income inequality, which is increasingly recognized as a determinant of collective action and institutional capacity for ecological transition: higher inequality tends to undermine long-term investments in sustainability. Together, these indicators provide a balanced framework to analyze how environmental performance interacts with economic, social, and demographic structures.

This allowed us to investigate the extent to which environmental performance is associated with broader patterns of development, demography, and equity.

3. Results

The distribution of the Environmental MPI for the fifteen former Soviet republics in 2022 reveals heterogeneity in ecological sustainability outcomes (Table 1).

Table 1. Environmental Performance Index (MPI) scores and SDG-related component indicators for the 15 post-Soviet republics.

Country	SDG 6 Clean Water and Sanitation	SDG 13 Climate Action	SDG 15 Life on Land	Environment MPI
Armenia	65.6	91.9	61.9	69.475
Azerbaijan	66.3	82.7	65.7	70.266
Belarus	83.3	68.6	94.3	80.041
Estonia	84.1	61.5	96.1	76.736
Georgia	80.3	91	69.3	78.732
Kazakhstan	72.4	57.1	62.5	63.059

Table 1. *Cont.*

Country	SDG 6 Clean Water and Sanitation	SDG 13 Climate Action	SDG 15 Life on Land	Environment MPI
Kyrgyz Republic	66.4	94.8	70.9	74.355
Latvia	89.2	71.7	97.8	84.182
Lithuania	78.8	58.4	95.3	73.091
Moldova	70.4	90.6	89.3	81.901
Russian Federation	75.1	69.9	66.1	70.077
Tajikistan	59.5	97.2	61	66.287
Turkmenistan	57.3	59.3	63.8	59.949
Ukraine	76.1	85.8	79.6	80.200
Uzbekistan	58.8	92.8	64.7	67.522

These are consistent with regional observations in Central and Eastern Europe, where EU convergence has played a key role in driving environmental performance [16]. Resource-based economies of Central Asia trend following sub-Saharan Africa, where ecological transition is undermined by extractive dependency as well as by population pressure [22]. The best-performing countries are Moldova (81.90), Belarus (80.04), and Ukraine (80.20), while Turkmenistan (59.95) and Tajikistan (66.29) register the lowest scores. Kyrgyzstan and Tajikistan achieve very high results in SDG 13 (Climate Action), largely due to hydropower dependence and low industrial intensity. Yet, their overall performance remains weak because the Mazziotta–Pareto Index (MPI) is designed as a partially non-compensatory composite indicator. In other words, strong results in one dimension cannot offset poor outcomes in others. The penalty term, derived from the variability of standardized indicators, reduces the final score of countries with unbalanced profiles. Thus, nations excelling in climate performance but lagging in water management (SDG 6) and biodiversity protection (SDG 15) receive low overall MPI values. This feature makes the MPI particularly suitable for sustainability assessment, where trade-offs across ecological dimensions are methodologically inappropriate and substantively unacceptable.

The indicator breakdown highlights further contrasts. In SDG 6 (Clean Water and Sanitation), Latvia (89.2) and Estonia (84.1) achieve the best results, while Turkmenistan (57.3) and Uzbekistan (58.8) lag. For SDG 13 (Climate Action), Tajikistan (97.2) and the Kyrgyz Republic (94.8) obtain the highest values, though this does not translate into stronger composite scores. In SDG 15 (Life on Land), Estonia (96.1) and Lithuania (95.3) lead, whereas Russia (66.1) records weaker outcomes.

The choropleth map (Figure 1) provides a visual representation of the Environmental MPI across the 15 republics of the former Soviet Union. Darker shades of green indicate higher ecological performance. Three geographic groups are evident:

- The Baltic States (Estonia, Latvia, Lithuania) with the highest MPI values.
- Eastern European and Transcaucasian countries (Moldova, Ukraine, Belarus, Armenia, Georgia, and Russia) with intermediate scores.
- The Central Asian republics (Kazakhstan, Uzbekistan, Turkmenistan, Tajikistan, and the Kyrgyz Republic) with the lowest performance.

The software's visualization tools allowed for a consistent representation of the results, ensuring that both numerical outputs and graphical evidence are fully reproducible. The combination of tabular data, descriptive statistics, and visual displays strengthens the robustness and transparency of the empirical findings. Finally, Table 2 presents the correlation matrix between the Environmental MPI and key socioeconomic and demographic indicators. Correlations are presented as descriptive associations; given the small sample size (*n* = 15) and non-normal distributions, no significance tests are reported. The index is positively associated with HDI (r = 0.450), life expectancy (r = 0.446), and GDP per capita (r = 0.433), while it is negatively correlated with fertility (r = –0.669) and income inequality measured by the Gini index (r = −0.370). Additional robustness checks using Spearman correlations confirmed the consistency of these results.

Figure 1. Geographic distribution of Environmental Performance Index (MPI) scores across 15 post-Soviet republics (2022). Darker shades of green indicate higher environmental performance. Darker green indicates higher ecological performance.

Table 2. Correlation matrix between Environmental Performance Index (MPI) and selected socioeconomic and demographic indicators in the 15 post-Soviet republics (2022).

	Gini Index	Fertility Rate, Total (Births Per Woman)	HDI	Life Expectancy at Birth, Total (Years)	GDP Per Capita (Current US$)	Environment MPI
Gini index	1	0.294	0.034	−0.133	0.287	−0.370
Fertility rate, total (births per woman)	0.294	1	−0.722	−0.513	−0.514	−0.669
HDI	0.034	−0.722	1	0.607	0.737	0.450
Life expectancy at birth, total (years)	−0.133	−0.513	0.607	1	0.723	0.446
GDP per capita (current US$)	0.287	−0.514	0.737	0.723	1	0.433
Environment MPI	−0.370	−0.669	0.450	0.446	0.433	1

The negative correlation with fertility rates underscores the population burden that plagues most Central Asian republics, given the fact that growth is high and puts pressure on already scarce water resources. Similarly, the negative correlation with inequality indicates that ecologically sustainable development depends on distributive justice. The above results are in accordance with worldwide evidence linking social cohesion with the capacity for implementing long-term environmental changes [15].

In addition, the positive association between the Environmental MPI and HDI (r = 0.450) and life expectancy (r = 0.446) suggests that environmental sustainability is not an isolated dimension but closely embedded in broader patterns of human development and public health. Countries with higher life expectancy and more developed welfare systems tend to perform better ecologically, reinforcing the argument that social investments and environmental protection are mutually reinforced. Similarly, the correlation with GDP Per Capita ($r = 0.433$), while moderate, points to the role of economic resources in enabling ecological transition through infrastructure investment and institutional capacity. Nevertheless, the magnitude of these coefficients also indicates that income alone does not guarantee ecological sustainability; rather, it must be accompanied by effective governance and balanced development strategies. The weak and inconsistent correlations involving the Gini index confirm that inequality exerts a negative influence on sustainability, but not uniformly across all cases, highlighting the complex interplay between distributional outcomes and ecological performance. Overall, the correlation matrix underscores the multidimensional nature of environmental sustainability, which depends simultaneously on demographic pressures, social equity, welfare achievements, and economic capacity.

4. Discussion

Spatial heterogeneity may also reflect institutional spillover effects, such as the EU environmental acquis influencing Baltic and Eastern partners. External factors such as EU financial and technical support, or migration-driven demographic changes, may also contribute to observed sustainability patterns. These aspects deserve more systematic investigation in future studies. Incorporating institutional quality measures (e.g., World Governance Indicators) supports the interpretation that stronger regulatory frameworks mediate environmental outcomes. A full spatial econometric model remains beyond the scope of this paper, but is indicated for future research.

Beyond academic contribution, the Environmental MPI can be applied as a policy tool for benchmarking and monitoring progress towards the SDGs. Governments can use the index to identify weak dimensions (e.g., biodiversity or water management) and prioritize investment. Regional organizations such as the Eurasian Economic Union or the Eastern Partnership could also adopt this framework to promote evidence-based cooperation on cross-border ecological issues, such as water management or biodiversity corridors. The relatively high Environmental MPI scores of countries such as Moldova and Belarus derive from a balanced performance across water, climate, and biodiversity dimensions (SDG 6, 13, 15). This coherence suggests that institutional arrangements and policy configurations can generate favorable ecological outcomes even in transition economies. In these cases, centralized systems—despite democratic shortcomings—may have enabled more coordinated interventions, less exposed to distributive conflicts [40,41].

By contrast, the Central Asian republics register significantly lower MPI values, reflecting structural weaknesses. Their economies remain dependent on extractive industries, heavily exposed to water scarcity, and characterized by limited access to sustainable technologies. Development models centered on energy-intensive sectors exacerbate vulnerability and reduce fiscal capacity for ecological investment.

The indicator-specific results highlight important trends. For instance, very high climate scores in Kyrgyzstan and Tajikistan largely reflect hydropower reliance and low industrialization. However, the non-compensatory structure of the MPI prevents these advantages from masking poor water and biodiversity performance, underscoring that low emissions alone are insufficient without parallel investment in infrastructure, land use planning, and conservation. Similarly, the Baltic countries achieve outstanding values in SDG 15, reflecting effective biodiversity protection and sustainable land management, while Russia illustrates the difficulties of reconciling industrial output with ecosystem preservation.

These contrasts point to the central role of governance. Moldova's performance, despite a relatively modest GDP, illustrates how institutional coherence and regulatory capacity outweigh sheer economic resources. Conversely, Kazakhstan underperforms due to its extractive model and weak regulatory effectiveness.

Spatial heterogeneity is also shaped by broader institutional spillovers. EU membership and policy convergence appear to have strengthened environmental institutions in the Baltic States, while Central Asia lags due to weak governance and resource dependency. Incorporating institutional quality measures (e.g., World Governance Indicators) would enrich this interpretation; future research could further explore these relationships with spatial econometric models.

The cluster analysis supports the need for region-specific approaches. The Baltics stand out for their transition to service economies, strong environmental governance, and convergence with EU standards. Eastern European and Transcaucasian countries present intermediate outcomes shaped by mixed legacies and uneven institutional robustness. Central Asian republics remain the weakest performers, facing persistent structural and demographic challenges that constrain ecological transition.

Correlation analysis confirms that environmental sustainability is embedded in broader socio-institutional and demographic contexts. Positive associations with HDI, life expectancy, and GDP Per Capita indicate that stronger welfare systems and higher human development facilitate ecological outcomes. Negative correlations with fertility and inequality point to demographic pressure and social fragmentation as obstacles to sustainability, especially in Central Asia.

Taken together, these findings echo international evidence. They are consistent with the hidden regional development patterns identified in Asia and Africa by Shaker and Mackay [21,22], confirming the usefulness of composite non-compensatory indices in revealing sustainability trajectories not visible through single indicators [42,43]. Similar spatial divides have been documented in other world regions, such as the contrast between Andean and Southern Cone countries in Latin America [44] or between Northern and Sub-Saharan countries in Africa [22]. These findings suggest that institutional quality and regional integration are cross-cutting determinants of ecological transition. In this respect, our study addresses an important gap: despite the growing use of composite indicators for sustainability assessment, very few contributions have applied non-compensatory indices to regions undergoing deep institutional transitions. By adopting the Mazziotta–Pareto Index (MPI), our analysis demonstrates the added value of penalizing unbalanced profiles, which provides a more realistic picture of ecological sustainability in the post-Soviet space.

Ultimately, the post-Soviet experience highlights that ecological transition cannot be pursued in isolation but must be integrated into broader strategies that link environmental, social, and economic dimensions through effective institutions and inclusive governance.

5. Conclusions

This study has highlighted substantial heterogeneity in environmental sustainability across the fifteen post-Soviet republics. The Baltic States and Moldova achieve comparatively higher MPI scores, reflecting EU integration, regulatory coherence, and effective governance, while Central Asian republics consistently lag due to dependence on extractive industries, weak institutions, and demographic pressures. Ukraine and Belarus occupy an intermediate position, showing potential for improvement through stronger governance frameworks.

The results confirm that environmental sustainability is closely embedded in broader socio-institutional and demographic contexts. Positive correlations with HDI, life expectancy, and GDP Per Capita, and negative associations with fertility and inequality demonstrate that ecological performance is not only the outcome of environmental policies but also of institutional quality and social equity. Methodologically, the application of the Mazziotta–Pareto Index (MPI) has proved effective in capturing multidimensional sustainability while penalizing internal imbalances, offering a non-compensatory approach well suited to transition economies.

Based on these findings, differentiated policy recommendations are needed:

- Baltic States (EU-convergence type): consolidate acquis Communautaire and further strengthen renewable energy and biodiversity strategies (SDG 13.2; SDG 15.1).
- Ukraine and Belarus (transition challenge type): invest in capacity building and transparent governance to enhance environmental policy effectiveness (SDG 16.6).
- Central Asia (resource-dependent type): adopt a water–energy–food nexus governance framework and strengthen cooperation on shared water resources, aligned with SDG 6.4 and SDG 6.5.
- Caucasus (institutionally vulnerable type): establish cross-border ecological compensation mechanisms and reinforce biodiversity cooperation (SDG 15.9).

Despite its contributions, the study is not without limitations. First, the Environmental MPI is restricted to three SDGs (6, 13, and 15) due to data availability, excluding important domains such as air quality, waste management, and ecological footprint. Second, the analysis is cross-sectional, relying only on data for 2022, which prevents the assessment of temporal dynamics or the evaluation of long-term policy effects. Third, although consistent indicators were available for all fifteen republics, data quality and comparability may still pose challenges, especially for countries such as Tajikistan and Turkmenistan, where international databases often provide less reliable or discontinuous information. For this reason, robust checks were performed, confirming that the overall rankings remain stable even when these cases are excluded.

Future research needs to pursue several complementary streams to expand and bolster the analysis of environmental sustainability in post-Soviet republics. First, a longitudinal methodology would allow temporal dynamics to be extracted and follow ecological performance trajectories as well as evaluate the long-term effect of policy interventions. Such a dynamic methodology would be necessary to distinguish the effects of cyclical shocks (e.g., financial crises, wars, pandemics) from structural changes involving institutional reform or international integration. Second, a wider range of indicators than the three SDGs utilized here would enable the use of longer and more multidimensional measurements. Including air pollution and quality measures, waste management, ecological footprint, use of renewable energy, and urban environmental policy would more accurately capture sustainability under the classical ecological challenges and emerging challenges associated with climate change and the green shift. Third, composite indicators would be merged with spatial econometric techniques to uncover cross-border spillover and interdependencies. This is particularly so for transnational issues such as common water basins (e.g., the Aral Sea, the Caspian Sea basin), migratory biodiversity corridors, and transboundary pollution, in which ecological responses in one country are largely determined by what neighboring countries do. Fourth, blending quantitative analyses with qualitative case studies would add depth to the meaning of statistical results by describing local specifics, institutional setups, cultural dimensions, and governance practices that affect environmental outcomes on the ground. Comparative field-based research would be able to demonstrate how identical structural constraints result in varying ecological paths depending on political leadership, regulatory ability, and social mobilization. Finally, building bridges between academic analysis and policy practice must be a priority: future studies could develop policy-oriented dashboards, simulation models, and scenario-based approaches for supporting decision-makers. Combined, these channels would not only make the methodological robustness of the results more solid but also raise their policy significance for policy design to serve more accurate and context-aware guidance for countries on the hard roads of ecological transformation.

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Abbreviations

The following abbreviations are used in this manuscript:

EPI	Environmental Performance Index
MPI	Mazziotta–Pareto Index
SDG	Sustainable Development Goals
HDI	Human Development Index
GDP	Gross Domestic Product
PCA	Principal Component Analysis
DEA	Data envelopment analysis

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