PROBLEMY EKOROZWOJU/ PROBLEMS OF SUSTAINABLE DEVELOPMENT
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SUBMITTED: 6.02.2026, ACCEPTED: 11.03.2026, PUBLISHED ON-LINE: 1.07.2026
2026, 21(2): 298-326, DOI: https://doi.org/10.35784/preko.9163

Coherence Between Human and Sustainable Development: a DP2-Based Assessment

Spójność rozwoju społecznego i zrównoważonego: podejście oparte na metodologii DP2

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Abstract
This article examines the coherence between the Human Development Index (HDI) and Sustainable Development Goal (SDG) performance, explicitly accounting for inter-indicator dependence. Standard composite indices often rely on equal-weight arithmetic averaging and implicitly assume independence across components, which can double-count highly correlated measures and distort cross-country comparisons. We address this redundancy by applying the DP2 (Pena Distance) methodology, which corrects each indicator's contribution using sequential R^2-based factors and retains only unique information. Using panel data for 110 selected countries over 2015–2022, we build DP2-adjusted indices for: 1) human development based on the HDI components (life expectancy, schooling and income); 2) sustainable development based on the 17 goal-level SDG scores. We then compute a Development Coherence Index that captures the alignment between the two adjusted trajectories and classify countries into four regimes: high–high coherent, human-leading, sustainability-leading and low–low trap. Results show that redundancy adjustment can substantially re-order country performance, especially among high-income economies, where clusters of correlated SDG indicators tend to inflate headline sustainability scores. The coherence typology highlights systematic imbalances, for example, cases where human capabilities advance faster than environmental and institutional outcomes, pointing to potential policy incoherence and risks of development reversals. Convergence tests suggest conditional catching-up: lagging countries improve faster in some domains, yet coherence gaps often persist across income groups and regions over time. Overall, the proposed framework offers a practical tool for monitoring balanced progress towards the 2030 Agenda, targeting policy priorities to countries' specific development constraints, and improving the design of indicators in practice.

Key words: Sustainable Development Goals (SDGs), Human Development Index (HDI), development coherence, composite indicators, indicator redundancy, convergence, cross-country comparison, policy evaluation

Streszczenie
Artykuł analizuje spójność między Wskaźnikiem Rozwoju Społecznego (HDI) a realizacją Celów Zrównoważonego Rozwoju (SDGs), explicite uwzględniając współzależności pomiędzy wskaźnikami cząstkowymi. Standar-

dowe indeksy złożone zazwyczaj opierają się na arytmetycznym uśrednianiu z równymi wagami i implicite zakładają niezależność komponentów, co może prowadzić do podwójnego liczenia silnie skorelowanych miar oraz zniekształcać porównania międzynarodowe. W celu eliminacji tej redundancji zastosowano metodologię DP2 (odległość Peni), która koryguje wkład każdego wskaźnika za pomocą sekwencyjnych współczynników opartych na R^2 i zachowuje wyłącznie informację unikatową. Wykorzystując dane panelowe dla 110 krajów z lat 2015–2022, skonstruowano indeksy skorygowane metodą DP2 dla: 1) rozwoju społecznego, opartego na komponentach HDI (oczekiwanej długości życia, edukacji oraz dochodu); 2) rozwoju zrównoważonego, bazującego na wynikach dla 17 celów SDGs. Następnie obliczono Indeks Spójności Rozwoju, który mierzy stopień dopasowania obu skorygowanych trajektorii, oraz dokonano klasyfikacji krajów do czterech reżimów: wysoka–wysoka spójność, przewaga rozwoju społecznego, przewaga rozwoju zrównoważonego oraz pułapka niska–niska. Wyniki wskazują, że korekta redundancji może prowadzić do istotnego przetasowania pozycji krajów, zwłaszcza wśród gospodarek wysokodochodowych, gdzie skupiska skorelowanych wskaźników SDGs mają tendencję do zawyżania zagregowanych ocen zrównoważenia. Zaproponowana typologia spójności ujawnia systematyczne nie-równowagi, na przykład sytuacje, w których rozwój kapitału ludzkiego postępuje szybciej niż wyniki środowiskowe i instytucjonalne, co wskazuje na potencjalną niespójność polityk publicznych oraz ryzyko odwrócenia trajektorii rozwojowych. Testy konwergencji sugerują warunkowe doganianie: kraje opóźnione rozwijają się szybciej w niektórych obszarach, jednak luki w spójności często utrzymują się pomiędzy grupami dochodowymi i regionami w czasie. Całościowo zaproponowane ramy analityczne stanowią praktyczne narzędzie monitorowania zrównoważonego i zbilansowanego postępu w realizacji Agendy 2030, umożliwiając lepsze ukierunkowanie priorytetów polityki publicznej na specyficzne ograniczenia rozwojowe poszczególnych krajów oraz poprawę konstrukcji i stosowania wskaźników w praktyce.

Słowa kluczowe: Cele Zrównoważonego Rozwoju (SDGs), Wskaźnik Rozwoju Społecznego (HDI), spójność rozwoju, wskaźniki złożone, redundancja wskaźników, konwergencja, porównania międzynarodowe. ewaluacja polityk publicznych

1. Introduction

The 2030 Agenda for Sustainable Development, adopted unanimously by United Nations member states in 2015, established 17 Sustainable Development Goals as an integrated framework spanning economic prosperity, social inclusion, and environmental sustainability (United Nations, 2015). Alongside this framework, the Human Development Index (HDI) – introduced by the United Nations Development Programme in 1990 – remains the most widely used cross-national measure of human well-being, capturing achievements in health, education, and living standards across more than 190 countries (UNDP, 2024). Both instruments share the overarching objective of improving human welfare; yet they approach the measurement of development from conceptually distinct vantage points. The HDI foregrounds current human capabilities, whilst the SDG Index additionally encompasses environmental stewardship, institutional quality, and intergenerational sustainability. The question of whether countries advance coherently across both dimensions – or whether progress in one domain systematically outpaces the other – has received surprisingly little rigorous empirical attention, despite its direct relevance to the 2030 Agenda's principle of integrated and balanced development.

A first and under-recognized impediment to answering this question lies at the measurement level. Both the HDI and the SDG Index rely on equal-weight arithmetic aggregation, which implicitly treats all component indicators as independent sources of information. This assumption is empirically untenable. SDG indicators exhibit substantial inter-correlations: goals relating to health, education, and economic growth cluster tightly, such that conventional aggregation overweight's this socioeconomic cluster whilst systematically underweighting structurally distinctive dimensions – notably climate action, marine conservation, and biodiversity – whose indicators are orthogonal to the dominant cluster (Nilsson et al., 2016; Pradhan et al., 2017). A parallel redundancy exists within the HDI itself, in which the education and income components share substantial variance (Luttikhuis & Wiebe, 2023), effectively double-counting shared information. When such redundancy operates simultaneously and independently within each framework, comparisons between HDI-based and SDG-based development performance may be systematically distorted, generating misleading signals about the direction and magnitude of cross-domain imbalances.

A second gap concerns the explicit alignment – or coherence – between trajectories of human and sustainable development. Countries may register strong performance on one framework while exhibiting structural deficits on the other, with direct implications for the long-run sustainability of development pathways. High-income countries frequently achieve high HDI scores, driven by carbon-intensive economic growth, producing a human-led imbalance that conventional aggregate indices obscure. Conversely, lower-income countries may score relatively well on environmental SDG dimensions – partly because they have not yet undergone high-carbon industrialization – while lagging in health, education, and income. These asymmetries carry concrete policy consequences: a country advancing strongly in human development whilst accumulating environmental liabilities may face development reversals once those liabilities materialise. Without a rigorous, redundancy-adjusted metric of cross-domain coherence, policymakers lack an instrument for diagnosing such imbalances before they become entrenched.

This paper addresses both gaps simultaneously. We apply the DP2 (Pena Distance) methodology–an iterative R^2-based correction procedure that eliminates redundant information from composite indicators whilst preserving each component's unique contribution (Pena Trapero, 1977)–separately to the HDI components and to 17 SDG goal-level scores across a panel of 110 countries from 2015–2022. Applying the correction within each domain preserves the conceptual distinction between human and sustainable development and enables the construction of a novel Development Coherence Index that quantifies the degree of alignment between the two redundancy-adjusted trajectories. Countries are subsequently classified into four development regimes–high–high coherent, human-leading, sustainability-leading, and low–low trap–and the distribution of these regimes is examined across World Bank income groups, UN geographic regions, and time periods. An explicit sub-period comparison contrasts the pre-pandemic phase (2015–2019) with the COVID-19 period and its immediate aftermath (2020–2022), directly addressing the structural break introduced by the pandemic and its asymmetric effects on human and sustainability indicators across countries at different stages of development.

The study makes three substantive contributions to literature. First, it extends the DP2 methodology from single-domain welfare measurement (Somarriba & Pena, 2009; Abellán-Salinas et al., 2026) to cross-domain coherence analysis, enabling rigorous comparison between conceptually distinct development frameworks whilst controlling for indicator redundancy within each. Second, it introduces the Coherence Index as an operational policy metric aligned with the 2030 Agenda's integration principle, providing a diagnostic instrument to identify which countries, regions, and income groups are advancing human capabilities at the expense of environmental and institutional sustainability – or vice versa – and how these patterns have evolved over time. Third, it offers the first systematic empirical evidence on trajectory classifications, regional stratification, income-group heterogeneity, and convergence dynamics in development coherence across a globally representative 110-country panel, filling a gap that aggregate cross-national indices have been unable to address.

The remainder of the paper is structured as follows. Section 2 reviews the relevant literature on composite index methodology, SDG interlinkages, and cross-national development convergence. Section 3 describes the data sources, sample selection procedure, and analytical framework. Section 4 presents the empirical results, organised into seven thematic sub-sections: DP2 correction factors and indicator weighting; aggregate coherence patterns and trajectory classification; comparison with the naive approach; convergence analysis; alternative coherence measures; regional and income-group stratification; and COVID-19 sub-period dynamics. Section 5 discusses the findings in relation to existing literature and develops differentiated policy recommendations for each trajectory type. Section 6 concludes with directions for future research.

2. Literature review

A fundamental methodological challenge in constructing composite development concerns the treatment of interdependencies among indicators. The Sustainable Development Report, produced annually by the Sustainable Development Solutions Network, employs arithmetic averaging equal weights across all SDG indicators (Sachs et al., 2024). This approach assumes independence among components, yet substantial empirical evidence demonstrates that SDG targets exhibit significant synergies and trade-offs (Pradhan et al., 2017; Nilsson et al., 2016). When indicators are highly correlated, equal-weight aggregation yields information redundancy, effectively overemphasizing domains with multiple correlated measures while underemphasizing the unique contributions of less correlated dimensions.

Recent scholarship has documented SDG interlinkages across multiple scales and contexts extensively. Wang & Chen (2024) demonstrate that HDI and GDP per capita constitute the primary principal components that differentiate country clusters in SDG performance, while revealing contradictions between socioeconomic progress and environmental outcomes. Xing et al. (2024) identify common and differentiated SDG priorities at the national and subnational levels in China, emphasizing that synergies and trade-offs vary across regional contexts. Liu et al. (2024) quantify transboundary SDG interactions, finding that high-income countries contribute disproportionately to global spillovers. Breuer et al. (2019) project future SDG interactions, concluding that while poverty alleviation and economic growth exhibit persistent synergies, environmental goals (SDGs 13, 14) continue showing trade-offs with development indicators.

Building on prior research, we argue that development progress is frequently multi-dimensional and uneven**,** with governance capacity and social outcomes producing heterogeneous country groupings rather than a single, monotonic ranking (Liashenko et al., 2024; Liashenko et al., 2026). Relatedly, the interplay between social welfare preferences and Society 5.0 performance reveals differentiated pathways towards sustainable development, implying that policy mixes may yield divergent outcomes even at similar income levels (Liashenko & Dluhopolskyi, 2024). Importantly, our recent evidence for Europe indicates the presence of tipping points and nonlinear responses across the People–Planet–Prosperity pillars (Liashenko et al., 2025), while a complementary statistical analysis confirms systematic interdependencies among SDG targets (Liashenko & Dluhopolskyi, 2025). Taken together, this body of work supports the case for redundancy-adjusted composite measurement and for explicit metrics of coherence between human and sustainable development.

The DP2 (Pena Distance) methodology offers a rigorous solution to the redundancy problem in composite index construction. Originally proposed by Pena Trapero (1977) for welfare measurement, DP2 employs iterative correction factors based on the coefficient of determination to eliminate redundant information while preserving each indicator's unique contribution (Zarzosa & Somarriba, 2013). The methodology has been successfully applied to quality-of-life assessment (Somarriba Arechavala & Pena Trapero, 2009), measurement of gender inequality (López-Martínez et al., 2022), and regional development analysis (Cuenca-García et al., 2019). Most recently, Abellán-Salinas et al. (2026) applied DP2 to construct a redundancy-adjusted SDG composite for 110 countries from 2000–2023, demonstrating that the conventional SDG Index systematically overestimates sustainability in highly developed countries and underestimates progress in less developed nations due to unaccounted-for indicator correlations.

The question of whether countries are converging toward sustainable development outcomes carries significant policy implications. Building on the economic growth convergence literature pioneered by Barro & Sala-i-Martin (1992), researchers have examined both σ-convergence (declining cross-country dispersion) and β-convergence (faster progress by initially lagging countries) in SDG performance. Ferrara et al. (2024) analyse convergence patterns across 190 countries from 2000 to 2022, finding evidence of conditional convergence dependent on structural factors. The Sustainable Development Report 2025 notes that countries with higher SDG baselines in 2015 have generally progressed more slowly than those with lower baselines, though patterns vary substantially across regions and income groups (Sachs et al., 2025). However, existing convergence analyses typically employ the standard SDG Index without addressing measurement redundancy.

Despite growing attention to SDG interlinkages and composite index methodology, no study has systematically examined the coherence between human development and sustainable development using redundancy-adjusted measures. This gap is consequential because imbalanced development trajectories, where human capabilities advance while environmental sustainability stagnates, or vice versa, may indicate structurally unsustainable growth patterns. Countries exhibiting persistent gaps between adjusted human development and adjusted sustainable development scores may face greater risks of development reversals, policy incoherence, and failure to achieve integrated 2030 Agenda targets.

This paper addresses three research questions:

1) How does accounting for indicator interlinkages change countries' assessed performance in human and sustainable development?
2) Which countries exhibit systemic coherence between human and sustainable development, and which show persistent imbalances?
3) Do countries converge over time in development coherence, or do imbalances persist by income group and region?

We construct DP2-adjusted indices for both HDI components and SDG indicators across 110 countries from 2015 to 2022, develop a novel coherence measure that captures the alignment between human and sustainable development trajectories, and classify countries into four development regime types: high-high coherent, human-leading, sustainability-leading, and low-low trap.

Our contribution is threefold. First, we extend the DP2 methodology from a single-domain application to cross-domain coherence analysis, enabling comparison between conceptually distinct development frameworks while controlling for measurement redundancy. Second, we introduce the coherence index as a policy-relevant metric indicating whether national development strategies achieve balanced progress across human capabilities and sustainability dimensions. Third, we provide empirical evidence on trajectory classifications and convergence patterns that can inform differentiated policy approaches for countries facing distinct development challenges.

3. Methodology

3.1. Data

This study integrates two comprehensive data sources to construct coherence-adjusted measures of human and sustainable development. The merged dataset comprises 127 variables covering 167 countries over the period 2015–2022 (N = 1,336 country-year observations), selected to align with the formal adoption of the 2030 Agenda for Sustainable Development.

The Sustainable Development Goals (SDG) data are obtained from the Sustainable Development Report 2024 (Sachs et al., 2024), published by the Bertelsmann Stiftung Foundation and the Sustainable Development Solutions Network (SDSN). This database has been statistically audited by the European Commission's Joint Research Centre (Papadimitriou et al., 2019) and provides the most comprehensive publicly available panel data on SDG performance.

The SDG data comprises three hierarchical levels. At the aggregate level, the SDG Index Score (ranging from 0 to 100) represents overall progress toward sustainable development. At the goal level, 17 goal-specific scores (goal1 through goal17) measure achievement within each SDG domain.
Table 1 summarizing 99 SDG indicators grouped across the 17 Sustainable Development Goals, including the number of indicators and key measurement domains for each goal.

Table 1. SDG detailed indicators by goal

Goal	N	Key indicators
SDG 1: No Poverty	2	Working poor rate, poverty headcount ratio
SDG 2: Zero Hunger	8	Undernourishment, stunting, wasting, obesity, crop yield, sustainable nitrogen management
SDG 3: Good Health	14	Maternal/neonatal/child mortality, TB, HIV, NCDs, pollution mortality, life expectancy, UHC coverage, subjective wellbeing
SDG 4: Quality Education	4	Early childhood education, primary/secondary completion, literacy rate
SDG 5: Gender Equality	4	Family planning, education attainment gap, labor force participation ratio, parliamentary seats
SDG 6: Clean Water	5	Safe water/sanitation access, freshwater withdrawal, wastewater treatment, water scarcity
SDG 7: Clean Energy	4	Electricity access, clean cooking fuels, CO_2/TWh, renewable energy share
SDG 8: Decent Work	7	Adjusted GDP growth, modern slavery, financial accounts, unemployment, labor rights
SDG 9: Industry & Innovation	7	Road infrastructure, internet/mobile use, logistics performance, R&D expenditure, scientific articles
SDG 10: Reduced Inequalities	2	Gini coefficient, Palma ratio
SDG 11: Sustainable Cities	4	Slum population, PM2.5 exposure, piped water access, public transport satisfaction
SDG 12: Responsible Consumption	7	Municipal waste, e-waste, SO_2/NO_x emissions, nitrogen footprint, plastic exports
SDG 13: Climate Action	3	CO_2 emissions per capita, GHG embodied in imports, CO_2 embodied in exports
SDG 14: Life Below Water	6	Marine protected areas, clean waters, fish stocks, trawling, bycatch discards
SDG 15: Life on Land	5	Terrestrial/freshwater protected areas, Red List index, forest change, deforestation embodied in imports
SDG 16: Peace & Justice	11	Homicides, safety perception, pre-trial detention, birth registration, corruption, press freedom, property rights
SDG 17: Partnerships	6	Government spending, ODA, tax revenue, corporate tax havens, statistical performance
Total	**99**	

Note: full variable descriptions and measurement units are provided in the SDSN methodology documentation (Lafortune et al., 2018). All indicators are normalised to a 0–100 scale, with higher values indicating better performance relative to SDG targets

Importantly, the detailed indicators include *hard outcome* variables that address potential concerns about composite indices relying on perception-based measures. These include CO_2 emissions per capita (n_sdg13_co2gcp), renewable energy consumption share (n_sdg7_renewcon), PM2.5 air pollution exposure (n_sdg11_pm25), freshwater withdrawal (n_sdg6_freshwat), forest area change (n_sdg15_forchg), maternal mortality ratio (n_sdg3_matmort), and Gini coefficient (n_sdg10_gini). The inclusion of these objective measures strengthens the validity of the coherence analysis.
Human development data are sourced from the Human Development Report 2023–24 published by the United Nations Development Programme (UNDP). The dataset provides the composite Human Development Index (HDI) along with its three-dimensional components, enabling disaggregated analysis of human development outcomes.
Table 2 presenting Human Development Index components, their dimensions, and correspondence with selected SDG indicators.
A key motivation for this study is the conceptual and empirical overlap between HDI components and SDG indicators. Life expectancy (LE) corresponds closely to SDG 3 (Good Health and Well-being), particularly the indicator n_sdg3_lifee. Education measures (EYS, MYS) align with SDG 4 (Quality Education) indicators, including n_sdg4_primary, n_sdg4_second, and n_sdg4_literacy. GNI per capita (GNI pc) relates to SDG 8 (Decent Work and Economic Growth) and SDG 1 (No Poverty). These overlaps generate potential redundancy that the DP2 methodology addresses through correction factors.

Table 2. Human Development Index components

Variable	Component	Dimension	SDG Correspondence
hdi	Human Development Index	Composite	SDG Index (aggregate)
le	Life Expectancy at Birth	Health	SDG 3 (n_sdg3_lifee)
eys	Expected Years of Schooling	Education	SDG 4 (n_sdg4_*)
mys	Mean Years of Schooling	Education	SDG 4 (n_sdg4_*)
gnipc	GNI per capita (PPP $)	Standard of Living	SDG 1, SDG 8

Note: HDI is calculated as the geometric mean of the three-dimensional indices. Each dimension is normalized using goalposts defined by UNDP (2024).

Table 3 summarizing the merged dataset structure, including identifiers, SDG aggregate indicators, SDG detailed indicators, HDI components, and country-year coverage. The period 2015–2022 was selected for three reasons: 1) 2015 marks the formal adoption of the SDGs, making earlier observations less policy-relevant; 2) the SDSN back-dated methodology ensures consistency across years; 3) 2022 represents the latest year with complete HDI data.

Table 3. Summary of merged dataset structure

Category	Variables	Coverage
Identifiers	5	ISO3, country, year
SDG Aggregate	18	Index + 17 goals
SDG Detailed Indicators	99	Target-level measures
HDI Components	5	HDI + 3 dimensions
Total	**127**	**167 countries × 8 years**

Missing data rates are minimal for most variables. The SDG Index Score and HDI have complete coverage (0.0% and 0.5% missing, respectively). Among goal-level scores, SDG 14 (Life Below Water) has the highest proportion of missingness (24.0%) due to the inclusion of landlocked countries, followed by SDG 10 (Reduced Inequalities, 10.2%) and SDG 1 (No Poverty, 7.8%). These patterns are addressed through listwise deletion in the main analysis and robustness checks using multiple imputation.

3.2. Sample selection procedure

Table 4 describing the sample selection procedure from the initial merged dataset of 167 countries to the final analytical sample of 110 countries with complete balanced panel data for 2015–2022. The final analytical sample of 110 countries was obtained through a two-step selection procedure.

In the first step, countries with incomplete observations of all 17 SDG goal-level scores and all four HDI components for at least one year were excluded. The most frequent cause of exclusion was missing data for SDG 14 (Life Below Water, 24.0% missingness) due to landlocked countries for which maritime indicators are not applicable. Additional missingness was observed for SDG 1 (No Poverty, 7.8%) and SDG 10 (Reduced Inequalities, 10.2%), affecting fragile states with limited national statistical capacity.

In the second step, countries lacking a complete, balanced panel across all eight years (2015–2022) were excluded, resulting in the exclusion of 16 additional countries with sporadic data coverage. The resulting sample of 110 countries provides a geographically and economically diverse panel (High-income: 31; Upper-middle-income: 48; Lower-middle-income: 20; Low-income: 11).

Table 4. Sample selection procedure: from full database to analytical sample

Step	Countries	Excluded (reason)
1. Initial merged dataset	167	–
2. Complete cases (all 17 SDG goals + 4 HDI vars)	126	41 (SDG14 missingness in landlocked states; SDG1 and SDG10 gaps in fragile states)
3. Full balanced panel (all 8 years, 2015–2022)	110	16 (incomplete time series; data gaps in early years)
Final analytical sample	110	–

Note: SDG14 missingness is concentrated in landlocked countries (marine indicators structurally inapplicable). Fragile states and Small Island Developing States are systematically underrepresented in the final sample.

3.3. Methods

This study develops a Coherence-Adjusted Development Index that addresses the methodological challenge of measuring balanced progress between human and sustainable development while accounting for indicator redundancy. The methodology proceeds in three stages: 1) applying the DP2 distance method to construct redundancy-adjusted scores for both development domains; 2) computing a coherence index that captures the alignment between adjusted human and sustainable development; 3) classifying countries according to their development trajectories and coherence patterns.

The DP2 method, originally developed by Pena Trapero (1977) for welfare measurement, provides a systematic approach to constructing synthetic indicators while eliminating redundant information from correlated variables. Unlike Principal Component Analysis, which reduces dimensionality by extracting orthogonal factors, or simple arithmetic averaging used in the standard HDI and SDG Index, DP2 retains all variables but adjusts their contribution based on the unique information each provides (Somarriba & Pena, 2009; Montero et al., 2010).

For a spatial unit *r* with *n* indicators, the DP2 index is defined as (Zarzosa & Somarriba, 2013):

$$DP^2{}_r = \Sigma^n{}_{i=1} \left[\left(\frac{d_i}{\sigma_i} \right) \times \left(1 - R^2_{i,i-1,\dots,1} \right) \right] \quad (1)$$

where $d_i = |x_{ri} - x^*_i|$ represents the absolute distance of unit *r* from the reference base x^* (typically the theoretical minimum or maximum) for indicator *i*; σ_i is the standard deviation of indicator *i* across all units; and $(1 - R^2_{i,i-1,\dots,1})$ is the correction factor representing the proportion of variance in indicator *i* not explained by the preceding indicators in the sequence.

The correction factor $(1 - R^2)$ is the methodological core of DP2. When an indicator is highly correlated with already included variables, its R^2 approaches 1, and the correction factor approaches 0, effectively eliminating redundant information. Conversely, an indicator providing entirely new information receives full weight. This property directly addresses the double-counting problem inherent in composite indices, in which correlated indicators artificially inflate certain dimensions (Nayak & Mishra, 2012).

The DP2 computation follows an iterative procedure originally proposed by Ivanovic (1974). Indicators are first ordered by their discriminatory power (variance across units). The correction factors are computed sequentially, with R^2 computed by regressing each indicator on all preceding indicators. The process iterates until convergence, typically achieved when the ordering stabilises. This ensures that the most discriminating indicator enters first with full weight, while subsequent indicators contribute only their unique information (Somarriba & Pena, 2009).

We apply the DP2 method separately to two indicator sets. For human development, we use the four HDI components: Life Expectancy (LE), Expected Years of Schooling (EYS), Mean Years of Schooling (MYS), and GNI per capita. For sustainable development, we use the 17 SDG goal-level scores (goals 1-17). This yields two redundancy-adjusted scores:

$$H_{adj} = DP2(LE, EYS, MYS, GNI\ pc) \quad (2)$$

$$S_{adj} = DP2(goal1, goal2, ..., goal17) \quad (3)$$

The rationale for separate domain computations is twofold. First, it preserves the conceptual distinction between human development (the well-being of current generations) and sustainable development (the well-being that does not compromise future generations). Second, it allows the coherence index to detect imbalances that would be masked by a single composite measure. The DP2 correction factors within each domain address the well-documented interlinkages: within SDGs, Pradhan et al. (2017) found that SDG 1 (No Poverty) shows synergies with most other goals, while SDG 12 (Responsible Consumption) exhibits trade-offs; within HDI components, education and income are strongly correlated (Nilsson et al., 2018; Luttikhuis & Wiebe, 2023).

The coherence index measures the alignment between redundancy-adjusted human and sustainable development scores. The conceptual foundation draws on the literature emphasising that sustainable development requires balanced progress across multiple dimensions – achieving human well-being without ecological degradation or institutional failure (Nilsson et al., 2016; Kroll et al., 2019).

To enable comparison across the two domains, we first standardise the adjusted scores to z-scores within each year:

$$Z(H_{adj})_{rt} = \frac{(H_{adj_{rt}} - \mu H_{adj},t)}{\sigma H_{adj},t} \quad (4)$$

$$Z(S_{adj})_{rt} = \frac{(S_{adj_{rt}} - \mu S_{adj},t)}{\sigma S_{adj},t} \quad (5)$$

The Development Gap is defined as the signed difference between standardised scores:

$$Gap = Z(H_{adj}) - Z(S_{adj}) \quad (6)$$

A positive gap indicates a human-led imbalance (human development ahead of sustainable development), whereas a negative gap indicates a sustainability-led imbalance (environmental/institutional progress ahead of human well-being). The Coherence Index transforms the gap into a bounded measure:

$$Coherence = 1 - \frac{|Gap|}{\max(|Gap|)} \quad (7)$$

This index ranges from 0 (maximum imbalance) to 1 (perfect coherence), capturing the extent to which a country's development is balanced across both domains regardless of direction. Countries are classified into four trajectory types based on their position in the Z(Hadj) × Z(Sadj) space.
Table 5 classifying countries into four development trajectory types based on standardized human development and sustainable development scores.

Table 5. Countries classification

Trajectory Type	$Z(H_{adj})$	$Z(S_{adj})$	Interpretation
High-High Coherent	> 0	> 0	Above average in both; balanced high development
Human-Leading	> 0	< 0	Human well-being outpaces sustainability
Sustainability-Leading	< 0	> 0	Sustainability progress outpaces human well-being
Low-Low Trap	< 0	< 0	Below average in both; structural underdevelopment

Note: classification based on whether standardized adjusted scores exceed zero (above global mean) or fall below zero (below global mean) in each domain.

To assess the value added by the DP2 correction, we compare coherence patterns using adjusted versus *naive* indices (the standard HDI and the SDG Index without redundancy correction). This comparison reveals which countries appear as *artificial winners*, those whose high rankings derive partly from double-counted information in correlated indicators, and which are *hidden performers* whose achievements become apparent only after removing redundancy (de Maya Matallana et al., 2022).
Following the literature on SDG convergence (Sachs et al., 2024), we examine whether countries are converging not only in their level of development but also in their coherence. We estimate sigma-convergence (declining cross-country dispersion) and beta-convergence (catch-up by laggards) for both the coherence index and the development gap, stratified by World Bank income groups. This addresses whether the pursuit of sustainable development is becoming more balanced over time, or whether imbalances persist along structural lines.
The baseline Coherence Index (CI) captures the alignment between human and sustainable development trajectories regardless of absolute development level. However, a gap-based metric may assign high coherence to countries where both dimensions perform poorly but similarly – the low–low trap scenario. To address this limitation and ensure robustness of findings, we construct two alternative measures that incorporate development level alongside balance.
This measure multiplies the baseline coherence by the mean normalized development level, ensuring that high coherence at low development receives a proportionally lower score:

$$CIL = CI \times \frac{(\tilde{H} + \tilde{S})}{2} \quad (8)$$

where $\tilde{H} = (H_{adj} - min) / (max - min)$ and $\tilde{S} = (S_{adj} - min) / (max - min)$ are the DP2-adjusted scores rescaled to the [0,1] interval using sample minima and maxima. CI_L ranges from 0 to 1, with higher values indicating both balanced and high-level development.
This geometric measure computes the Euclidean distance from each country's position in the normalised $\tilde{H} \times \tilde{S}$ space to the ideal point (1,1), representing maximum achievement in both domains:

$$DI = 1 - \frac{\sqrt{[(1 - \tilde{H})^2 + (1 - \tilde{S})^2]}}{\sqrt{2}} \quad (9)$$

The denominator normalises the maximum possible distance (from the origin to the ideal), ensuring that DI ranges from 0 (worst possible: both dimensions at their minimum) to 1 (ideal: both dimensions at their maximum). Unlike the gap-based CI, DI simultaneously penalises both imbalance and low absolute levels, providing a single metric that captures overall development achievement. Table 6 comparing the properties, limitations, and analytical purposes of alternative coherence measures used in the study.

Table 6. Properties of coherence measures

Measure	Captures	Limitation	Best for
CI	Pure balance (gap magnitude)	Ignores development level	Identifying imbalance direction
CI_L	Balance weighted by level	Multiplicative; zero if either dimension zero	Ranking with level adjustment
DI	Distance from ideal achievement	Treats imbalance and low level equivalently	Overall development assessment

Note: CI = coherence Index; CI_L = level-adjusted coherence; DI = distance to Ideal.

A low correlation between CI and DI would indicate that these measures capture fundamentally different aspects of development coherence. In such cases, the trajectory classification (high–high coherent, human-leading, sustainability-leading, low–low trap) based on Z-score signs provides complementary categorical information that is robust across all three continuous measures, as it depends on relative position rather than coherence magnitude.

4. Results

4.1. Redundancy in composite indices: DP2 correction factors

The application of the DP2 method reveals substantial redundancy within both the HDI and SDG measurement frameworks. Table 7 reporting DP2 correction factors for HDI components, indicating the relative contribution of unique information after accounting for indicator redundancy.

Table 7. DP2 correction factors for HDI components

Indicator	Order	CF (1-R²)	Contribution
Life Expectancy (LE)	1	1.000	2.745
Mean Years of Schooling (MYS)	2	0.388	0.819
Expected Years of Schooling (EYS)	3	0.259	0.592
GNI per capita	4	0.265	0.278

Note: CF = correction factor representing unique information after accounting for redundancy with higher-ordered variables.

For the HDI components, life expectancy emerges as the primary discriminant variable (CF = 1.000), retaining full informational weight as the first indicator in the optimal ordering. Mean years of schooling contribute 38.8% unique information (CF = 0.388), while expected years of schooling and GNI per capita show higher redundancy with correction factors of 0.259 and 0.265, respectively. The total redundancy among HDI components is 45.9%, indicating that nearly half of the information captured by the conventional equal-weighted HDI is shared across its four dimensions.

The SDG framework exhibits more complex redundancy patterns across its 17 goals. Climate Action (SDG 13) and Life Below Water (SDG 14) emerge as the most discriminators, with correction factors approaching unity (1.000 and 0.999, respectively), suggesting that these environmental dimensions capture information largely independent of other SDG measures. Zero Hunger (SDG 2), Partnerships (SDG 17), and Life on Land (SDG 15) also demonstrate high uniqueness with CF values exceeding 0.80.

Conversely, Good Health (SDG 3) shows the highest redundancy (CF = 0.083), indicating that 91.7% of its variance is already captured by other goals in the ordering. This finding aligns with the strong correlation between health outcomes and economic development indicators. Similarly, Responsible Consumption (SDG 12), Industry and Innovation (SDG 9), and Affordable Energy (SDG 7) exhibit correction factors below 0.20, suggesting substantial overlap with preceding indicators.

Bar charts presenting DP2 correction factors for HDI components and SDG goals (Figure 1), where higher values indicate greater unique information contribution after redundancy adjustment.

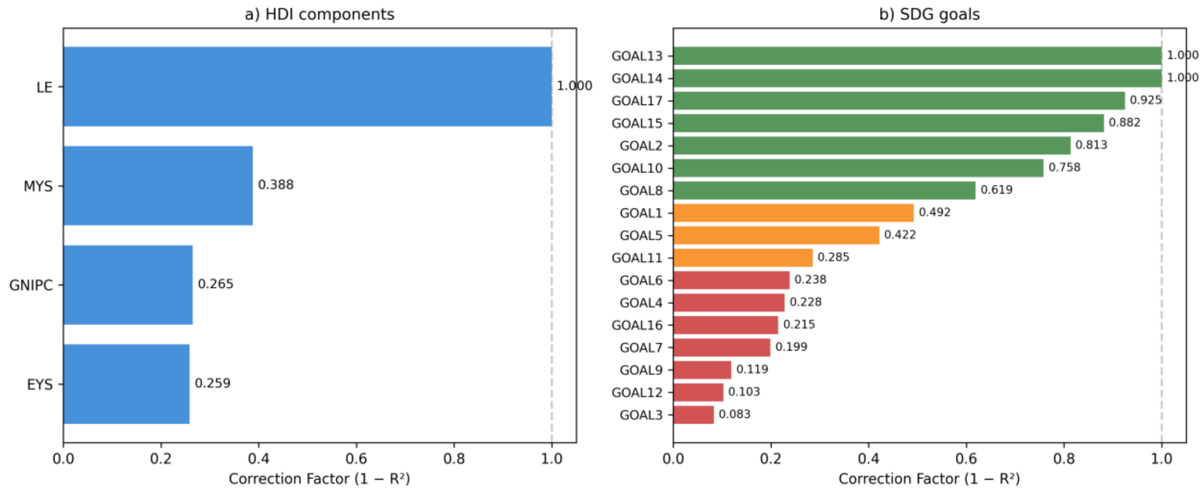

Fig. 1. DP2 correction factors: a) HDI components; b) SDG goals

Note: higher values indicate greater unique information contribution.

4.2. Development gap and coherence index: aggregate patterns

Table 8 presenting descriptive statistics for the DP2-adjusted development gap, naive development gap, and coherence index across 880 country-year observations. The development gap, calculated as the difference between standardized human and sustainable development scores (Z(Hadj) - Z(Sadj)), ranges from -1.827 to +2.545, with a mean of zero by construction and a standard deviation of 0.768.

Table 8. Descriptive statistics for development gap and Coherence Index

Statistic	Gap (DP2)	Gap (Naive)	Coherence
Mean	0.000	0.000	0.762
Std. Dev.	0.768	0.355	0.186
Minimum	-1.827	-0.869	0.000
Maximum	2.545	1.274	1.000
Median	-0.043	-0.021	0.802

Note: N = 880 country-year observations (110 countries × 8 years). Gap = Z(H_adj) - Z(S_adj).

A critical finding emerges from comparing the DP2-adjusted gap with the naive approach: the standard deviation of the DP2-adjusted gap (0.768) is more than twice that of the naive measure (0.355). This amplification effect demonstrates that redundancy correction uncovers developmental imbalances that were previously masked by the overlap in variance between HDI and SDG indicators.

Density distribution comparing DP2-adjusted and naive development gap measures, showing wider dispersion after redundancy correction (Figure 2).

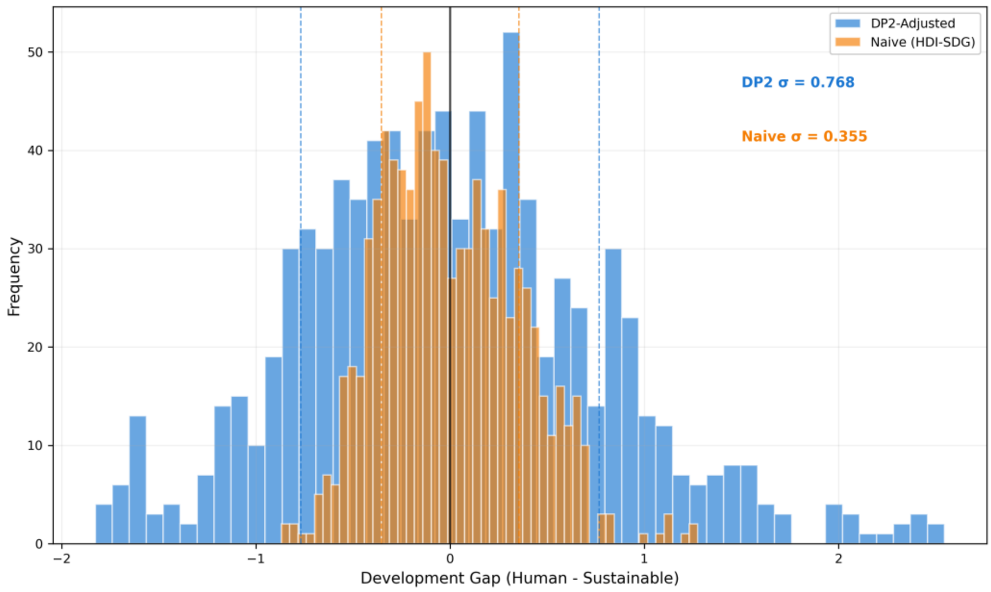

Fig. 2. Distribution of development gap

Note: DP2-adjusted versus naive approach. Dashed lines indicate ±1 standard deviation

Table 9. Distribution of development trajectories

Trajectory	N	%	Mean Coherence
High-High Coherent	361	41.0	0.820
Low-Low Trap	335	38.1	0.795
Human-Leading	114	13.0	0.561
Sustainability-Leading	70	8.0	0.590
Total	880	100.0	0.762

Note: classification based on Z(H_adj) > 0 and Z(S_adj) > 0 conditions. The full list of countries assigned to each trajectory regime is reported in the Appendix.

Table 9 presenting the distribution of country-year observations across four development trajectory categories and their average coherence levels. The coherence index, defined as CI = 1 - |Gap| / max(|Gap|), yields a mean of 0.762 with substantial variation (σ = 0.186). The distribution is left-skewed, with median coherence (0.802) exceeding the mean, indicating that most countries achieve relatively balanced development while a minority exhibit severe imbalances.

The classification reveals that 41.0% of observations fall into the high-high coherent quadrant, representing countries performing above average in both human and sustainable development dimensions. Conversely, 38.1% are classified as low-low trap, indicating below-average performance in both dimensions.

The imbalanced trajectories reveal asymmetric patterns: human-leading countries (13.0%) substantially outnumber sustainability-leading cases (8.0%). This asymmetry suggests that human development achievements, measured by health, education, and income, more frequently outpace progress in environmental sustainability than the reverse.

Scatter plot classifying countries by standardized human development and sustainable development scores in 2022, divided into four development trajectory quadrants (Figure 3).

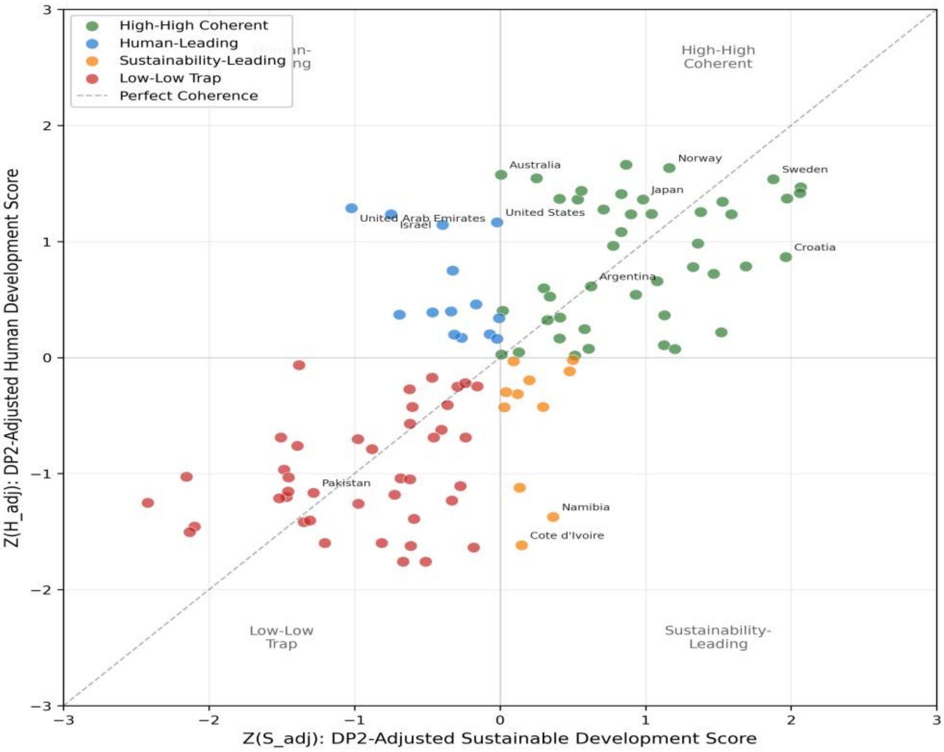

Fig. 3. Development trajectory classification (2022)
Note: the diagonal dashed line represents perfect coherence (Gap = 0).

Notably, the high-high coherent and low-low trap categories exhibit substantially higher mean coherence (0.820 and 0.795, respectively) than the imbalanced trajectories (0.561 for human-leading, 0.590 for sustainability-leading). This pattern is intuitive: countries in the balanced quadrants necessarily have smaller absolute gaps between their two development dimensions. The comparison between DP2-adjusted and naive classifications reveals significant reclassification of 152 observations (17.3%).

Table 10 showing the reclassification matrix between naive and DP2-adjusted development trajectories, including transitions across trajectory categories.

Table 10. Reclassification matrix: naive to DP2-adjusted trajectories

Naive \ DP2	H-H Coh.	H-Lead	S-Lead	L-L Trap
High-High Coherent	351	88	8	0
Human-Leading	8	24	0	0
Sustainability-Lead.	2	2	56	0
Low-Low Trap	0	0	6	335

Note: rows sum to naive totals; columns sum to DP2-adjusted totals. Off-diagonal cells represent reclassified observations.

4.3. Comparison with naive approach: reclassification analysis

The most striking pattern is the identification of *artificial winners* – 96 observations (88 to human-leading, 8 to sustainability-leading) previously classified as high-high coherent under the naive approach but revealed as imbalanced after redundancy correction. These include high-income countries such as the United Arab Emirates (Gap = +2.38), Israel (+2.05), Australia (+1.62), Cyprus (+1.49), and the United States (+1.23). These nations achieve high conventional HDI scores that overlap substantially with their SDG performance, masking underlying imbalances between human and environmental development.

Scatter plots comparing DP2-adjusted and naive measures for development gap and coherence index. The diagonal line indicates perfect agreement between methods (Figure 4).

The United Arab Emirates exemplifies this phenomenon: its human development indicators (particularly GNI per capita) correlate strongly with several SDG components, creating inflated coherence under naive measurement. The DP2 correction reveals that its environmental SDG performance (particularly SDG 13 and SDG 12) lags substantially behind its human development achievements – an imbalance that is invisible under conventional approaches.

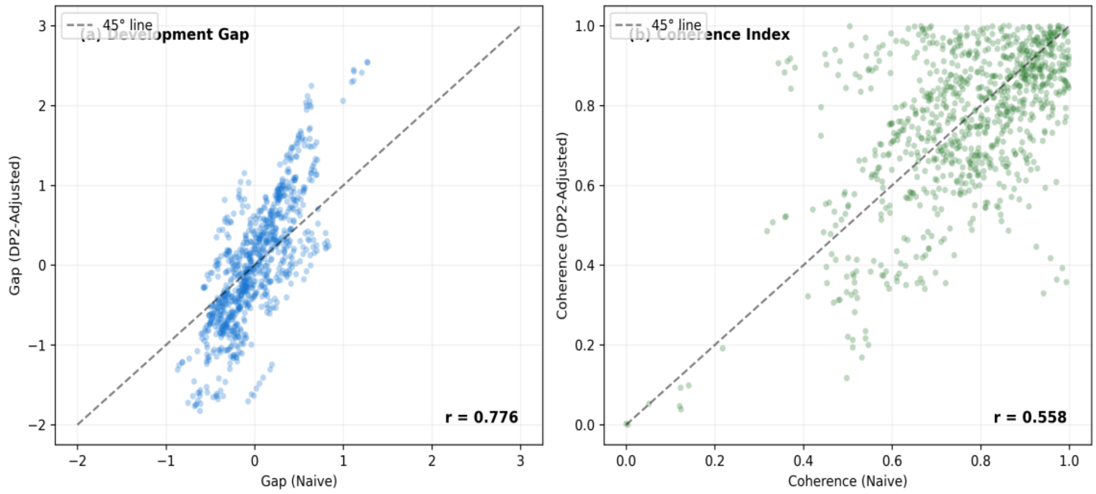

Fig. 4. Comparison of DP2aAdjusted and naive measures: a) Development gap; b) Coherence Index.
Note: the 45° line indicates perfect agreement.

Table 11. Countries with highest and lowest Coherence Index

Country	Coherence	Gap	HDI	Trajectory
Highest Coherence (Top 5)				
Pakistan	0.982	+0.03	0.540	Low-Low Trap
El Salvador	0.980	+0.01	0.675	Low-Low Trap
Honduras	0.969	-0.04	0.624	Low-Low Trap
Argentina	0.964	-0.05	0.849	High-High Coherent
South Africa	0.962	+0.00	0.713	Low-Low Trap
Lowest Coherence (Bottom 5)				
United Arab Emirates	0.065	+2.38	0.909	Human-Leading
Israel	0.196	+2.05	0.907	Human-Leading
Côte d'Ivoire	0.335	-1.69	0.521	Sustainability-Lead.
Australia	0.363	+1.62	0.941	High-High Coherent
Namibia	0.366	-1.61	0.628	Sustainability-Lead.

Note: period averages for 2015-2022. Gap = Z(H_adj) - Z(S_adj); positive values indicate human-leading imbalance. Complete country-level results for the 2015–2022 averages (including HDI_adj, SDG_adj, Gap and Coherence, alongside HDI and the SDG Index) are provided in the Appendix.

Table 11 listing countries with the highest and lowest average coherence index values during 2015–2022, including development gap, HDI score, and trajectory classification. The highest coherence scores are observed not among the most developed nations, but among countries at various levels of development that have achieved relatively balanced progress across both dimensions.
A counterintuitive finding emerges: several countries in the low-low trap exhibit the highest coherence scores (Pakistan, El Salvador, Honduras, South Africa). This reflects the mathematical property that coherence measures the balance between dimensions rather than absolute performance levels. Countries performing consistently below average across both dimensions achieve high coherence by definition, despite their development challenges. Argentina stands out as the highest-coherence country within the high-high coherent category, demonstrating that balanced above-average development is achievable.

4.4. Convergence in development coherence
Table 12 presenting sigma- and beta-convergence test results for development coherence and development gap indicators. The sigma-convergence tests yield insignificant results for both the coherence index (slope = -0.00045, p = 0.546) and the development gap (slope = -0.00218, p = 0.428), indicating no systematic reduction in cross-country dispersion during 2015-2022.

Table 12. Convergence analysis results

Test	Coefficient	p-value	Result
Sigma-Convergence (trend in std. deviation)			
Coherence Index	slope = -0.00045	0.546	No
Development Gap	slope = -0.00218	0.428	No
Beta-Convergence ($\Delta Coherence = \alpha+\beta\times Coherence_{(t-1)}$)			
Full Sample (N = 770)	β = -0.0234	0.006**	Yes
Low HDI countries	β = -0.0260	0.103	No
Medium-Low HDI countries	β = -0.0599	0.012**	Yes
Medium-High HDI countries	β = -0.0154	0.345	No
High HDI countries	β = -0.0235	0.144	No

*Note: ** p < 0.05. Beta-convergence estimated with robust standard errors (HC3). Sigma-convergence tested via linear trend regression.*

Line charts presenting sigma-convergence trends for the coherence index and development gap over the period 2015–2022 (Figure 5).

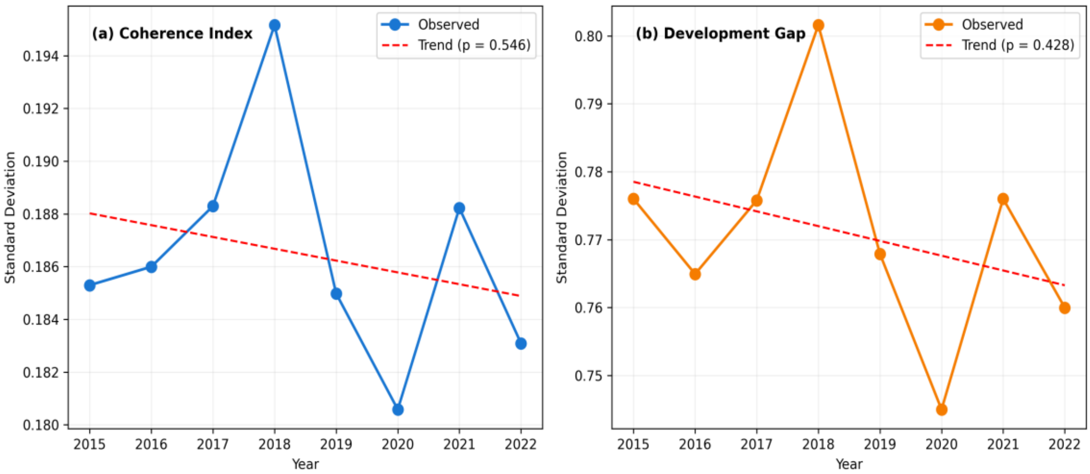

Fig. 5. Sigma-convergence analysis: a) Coherence Index; b) development gap
Note: dashed lines represent linear trend.

In contrast, beta-convergence analysis reveals a statistically significant catch-up effect (β = -0.0234, p = 0.006). The negative coefficient indicates that countries with lower coherence in period t-1 tend to experience larger coherence gains in period t. The implied half-life of convergence is approximately 29.6 years, suggesting a slow but

persistent tendency toward balanced development. Scatter plot (Figure 6) illustrating beta-convergence between lagged coherence values and subsequent changes in coherence across countries.
Conditional convergence analysis by HDI groups reveals heterogeneous patterns. Beta-convergence is strongest and statistically significant only for medium-low HDI countries (β = -0.0599, p = 0.012), suggesting that middle-income developing nations exhibit the most pronounced catch-up dynamics. High-HDI and low-HDI country groups show no significant convergence, possibly reflecting structural constraints at both development extremes – advanced economies may face diminishing returns to improvements in coherence, while least-developed countries may lack the institutional capacity for balanced development.

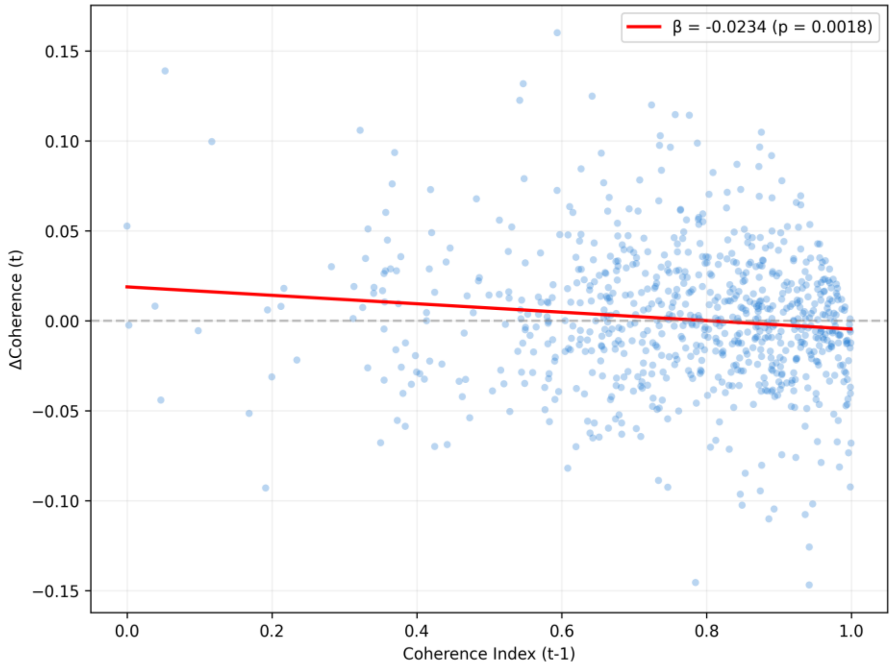

Fig. 6. Beta-convergence: relationship between lagged coherence and subsequent change.
Note: the regression line (β = -0.023, p = 0.006) indicates catch-up dynamics.

Boxplot distribution of coherence index values across HDI development groups, including interquartile ranges and group mean values (Figure 7). Medium-low HDI countries achieve the highest mean coherence (0.823), while High-HDI countries exhibit the lowest (0.702). This counterintuitive finding reflects the tendency of highly developed nations to exhibit larger human-led gaps – their human development achievements outpace environmental sustainability progress to a greater extent than those of less developed countries.

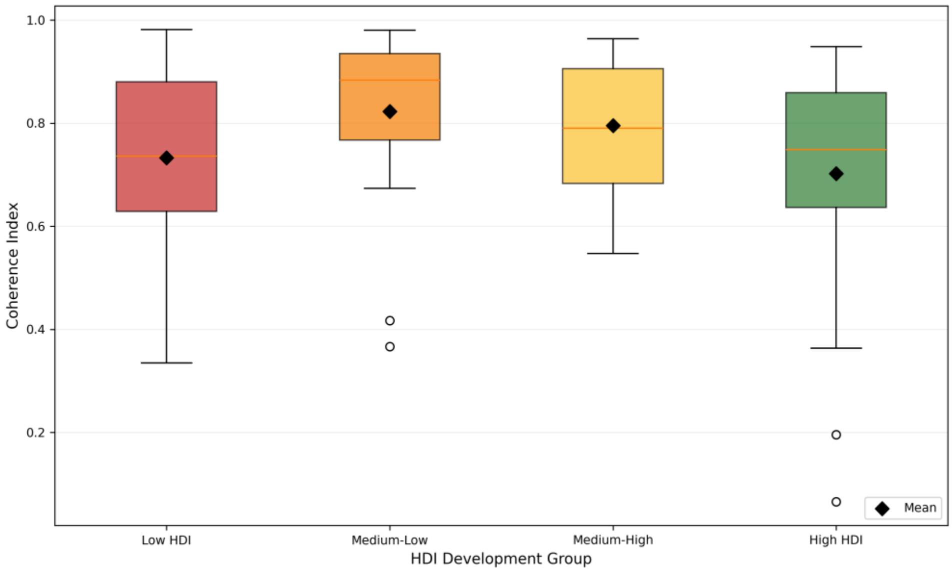

Fig. 7. Distribution of Coherence Index by HDI development group.
Note: diamonds indicate group means; boxes represent interquartile range.

Table 13 presenting the distribution of development trajectory types across HDI development groups based on country-level modal trajectories. High HDI countries are exclusively distributed between high-high coherent (85.7%) and human-leading (14.3%) categories, with none exhibiting sustainability-leading patterns or falling into the low-low trap. Conversely, low-HDI countries predominantly occupy the low-low trap (85.7%), with no representation in the high-high category.

Table 13. Development trajectory distribution by HDI group (%)

HDI Group	High-High	H-Lead	S-Lead	Low-Low
Low HDI	0.0	7.1	7.1	85.7
Medium-Low	11.1	3.7	25.9	59.3
Medium-High	74.1	25.9	0.0	0.0
High HDI	85.7	14.3	0.0	0.0

Note: row percentages based on country-level modal trajectories (N = 110 countries).

The sustainability-leading trajectory is concentrated among medium- to low-HDI countries (25.9%), including Croatia, the Dominican Republic, and Bosnia and Herzegovina. These countries have made disproportionate progress on environmental and social SDGs relative to their human development indicators, potentially reflecting development strategies that prioritize sustainability pathways or natural resource advantages that contribute to SDG performance.
Stacked bar chart showing changes in the distribution of development trajectory types from 2015 to 2022, with a visible increase in sustainability-leading trajectories after 2020 (Figure 8). The proportion of countries in each category remains relatively constant, with slight increases in the sustainability-leading category (from 6.4% in 2015 to 10.0% in 2022). This stability suggests that development trajectories are largely determined by structural factors that change slowly over time, consistent with the long half-life of convergence identified in the beta-convergence analysis.

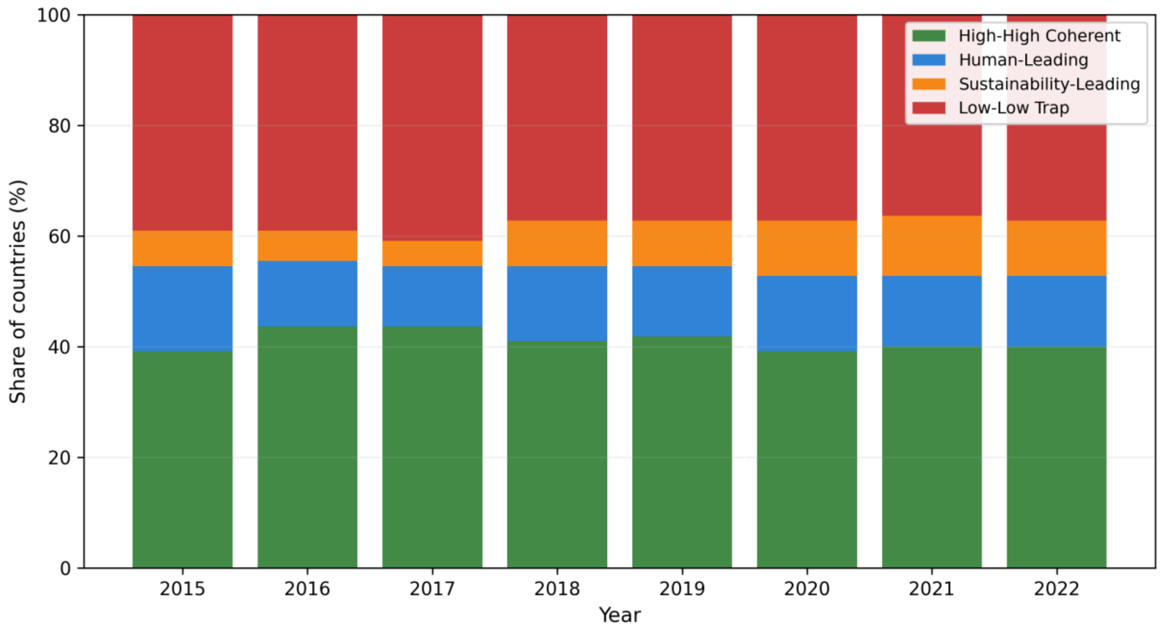

Fig. 8. Evolution of development trajectories 2015–2022.
Note: stacked bars show percentage of countries in each trajectory category per year. Vertical white dashed line marks COVID-19 onset (2020). Note the increase in Sustainability-Leading share post-2020.

The asymmetric distribution of imbalanced trajectories across development levels carries important policy implications. While high-income countries may need to accelerate environmental progress to achieve coherence, low-income countries face the dual challenge of advancing both dimensions simultaneously to escape the low-low trap.

4.5. Alternative coherence measures: level-adjusted and distance-to-ideal

A potential limitation of the baseline Coherence Index is that it captures balance without regard to development level. Consequently, countries in the Low–Low Trap may exhibit high CI values simply because both adjusted scores are similarly low, yielding a small gap. Table 14 comparing the top-ranked countries across three coherence measures: baseline coherence index, level-adjusted coherence, and distance-to-ideal measure.

Table 14. Top-10 countries by alternative coherence measures

Rank	CI (Balance)	Score	Rank	CI_L (Level-Adj)	Score	Rank	DI (Distance)	Score
1	Pakistan*	0.982	1	Slovenia	0.805	1	Denmark	0.964
2	El Salvador*	0.980	2	Sweden	0.794	2	Sweden	0.963
3	Honduras*	0.969	3	United Kingdom	0.794	3	Finland	0.958
4	Argentina	0.964	4	Italy	0.775	4	Germany	0.946
5	South Africa*	0.962	5	France	0.770	5	United Kingdom	0.894
6	Myanmar*	0.960	6	Germany	0.765	6	France	0.876
7	Colombia	0.959	7	Norway	0.762	7	Norway	0.862
8	Bangladesh*	0.959	8	Denmark	0.730	8	Slovenia	0.850
9	Thailand	0.958	9	Japan	0.724	9	Croatia	0.826
10	Jordan	0.956	10	Estonia	0.721	10	Japan	0.822

*Note: * denotes low–low trap countries. CI = baseline Coherence Index; CI_L = Level-adjusted coherence; DI = Distance to Ideal.*

The baseline CI identifies six low–low trap countries among its top-10 (marked with asterisks), including Pakistan (CI = 0.982) and El Salvador (CI = 0.980). These countries exhibit small gaps because both human and sustainable development scores are similarly depressed. In contrast, CIL and DI consistently rank Nordic and Western European countries at the top: Denmark (DI = 0.964), Sweden (DI = 0.963), Finland (DI = 0.958), and Germany (DI = 0.946). Slovenia ranks first under CIL (0.805), reflecting both high coherence (CI = 0.945) and strong development levels.

Table 15 presenting Pearson correlation coefficients among alternative coherence measures used in the study.

Table 15. Correlation matrix of coherence measures

	CI	CI_L	DI
CI	1.000	0.467	0.085
CI_L	0.467	1.000	0.908
DI	0.085	0.908	1.000

Note: Pearson correlation coefficients. N = 110 countries (period averages 2015–2022).

The correlation matrix reveals striking differences among measures. The baseline CI correlates only weakly with DI (r = 0.085), confirming that these indices capture fundamentally different dimensions: pure balance versus balanced achievement. The moderate correlation between CI and CI_L (r = 0.467) reflects the partial incorporation of level information, while the strong correlation between CI_L and DI (r = 0.908) indicates convergent validity when both balance and level are considered.

Importantly, the trajectory classification (high–high coherent, human-leading, sustainability-leading, low–low trap) remains stable across all three measures because it is based on the sign of Z-scores rather than on coherence magnitude. This robustness confirms that the substantive findings regarding development patterns are not artefacts of the baseline CI's properties. For policy applications in which both balance and achievement matter, the Distance to Ideal measure provides a single intuitive summary statistic, whereas the trajectory classification provides actionable categorical guidance.

4.6. Regional and income-group patterns in development coherence

To address structural heterogeneity masked by cross-country averages, we stratify the coherence analysis by World Bank income groups and UN geographic regions.

Table 16 comparing development coherence indicators across World Bank income groups, including coherence index, development gap, and shares of development trajectory types during 2015–2022.

The most striking finding concerns the distribution of development profiles across income groups. Low-income countries are overwhelmingly concentrated in the *low-low* category (98.9%), with virtually no countries demonstrating balanced high performance in either human development or sustainability dimensions. This suggests that structural resource constraints, institutional weakness, and limited fiscal capacity continue to hinder simultaneous progress in both domains. The negative Mean Gap (−0.32) further indicates that sustainability-related performance slightly exceeds human-development achievements, although both remain generally low.

Lower-middle-income countries show modest diversification of development trajectories. While the *low-low* configuration still dominates (71.2%), the share of *sustainability-leading* countries rises substantially (20.0%). This may reflect the influence of externally driven environmental and climate-related programmes, green-transition initiatives, or selective sustainability reforms implemented without equivalent advances in broader human development indicators. However, the relatively low *high-high* share (4.4%) indicates that integrated development coherence remains limited at this stage of economic development.

The Coherence Index (CI) itself follows a non-linear pattern. Upper-middle-income countries exhibit the highest average CI (0.80), slightly exceeding lower-middle-income economies (0.79), while high-income countries demonstrate a somewhat lower CI (0.71). This may indicate that coherence is easier to achieve at moderate levels of development, whereas highly developed economies face increasing trade-offs between economic prosperity, consumption intensity, and sustainability objectives.

Overall, Table 16 supports modernization and capability-based development theories suggesting that economic development creates institutional and financial preconditions for integrated progress across multiple dimensions. However, the findings also indicate that income growth alone does not automatically guarantee balanced sustainability outcomes. The transition from *low-low* to *high-high* coherence appears gradual, uneven, and institutionally mediated, especially within middle-income economies where development pathways diverge most strongly.

Table 16. Development coherence by World Bank income group (period averages, 2015–2022)

Income Group	N	Mean CI	SD	Mean Gap	High-High (%)	Human-Lead. (%)	Sust.-Lead. (%)	Low-Low (%)
Low income	11	0.70	0.16	−0.32	0.0	0.0	1.1	98.9
Lower-middle income	20	0.79	0.21	−0.27	4.4	4.4	20.0	71.2
Upper-middle income	48	0.80	0.15	0.02	38.3	17.2	9.6	34.9
High income	31	0.71	0.21	0.26	83.5	16.5	0.0	0.0
Total / Mean	110	0.76	0.19	0.00	41.0	13.0	8.0	38.1

Note: N = number of countries. Mean CI = mean Coherence Index (0–1 scale). Mean Gap = Z(H_adj) − Z(S_adj); positive values indicate human-leading imbalance. Trajectory percentages based on all country-year observations.

Table 17 comparing development coherence indicators across UN geographic regions, including coherence index, development gap, and shares of development trajectory classifications during 2015–2022. The results indicate the existence of several distinct regional development models rather than a single universal trajectory.

Table 17. Development coherence by UN geographic region (period averages, 2015–2022)

UN Region	N	Mean CI	SD	Mean Gap	High-High (%)	Human-Lead. (%)	Sust.-Lead. (%)	Low-Low (%)
Europe & Central Asia	48	0.79	0.14	0.00	59.4	9.9	4.7	26.0
Latin America & Caribbean	17	0.84	0.12	−0.04	49.3	12.5	5.2	33.1
Sub-Saharan Africa	20	0.68	0.20	−0.56	0.0	5.0	11.9	83.1
East Asia & Pacific	10	0.78	0.19	0.41	36.2	25.0	18.8	20.0
Middle East & N. Africa	9	0.62	0.30	0.56	26.4	34.7	15.3	23.6
South Asia	4	0.92	0.09	0.15	21.9	3.1	0.0	75.0
North America	2	0.58	0.07	1.07	68.8	31.2	0.0	0.0

Note: regions follow World Bank/UN geographic classification. High-high and low-low refer to trajectory classification based on Z-score signs (above/below zero).

Scatter plot classifying countries by standardized sustainable development and human development indicators in 2022, coloured by UN geographic region (Figure 9). European countries cluster mainly in the upper-right quadrant, while Sub-Saharan African countries concentrate in the lower-left quadrant. The dashed diagonal line represents approximate balance between the two dimensions, while the four quadrants reflect different development trajectory types.

First, Europe & Central Asia forms the most concentrated cluster in the upper-right quadrant, confirming the region's relatively balanced and coherent development structure described in Table 17. Most European countries are positioned above zero on both axes and relatively close to the diagonal line, supporting the earlier conclusion that the region combines comparatively high levels of sustainability and human development with limited imbalance between them. However, the visual dispersion also illustrates the internal heterogeneity reflected by the 26% *low-low* share in the table, as several countries remain in the lower-left area.

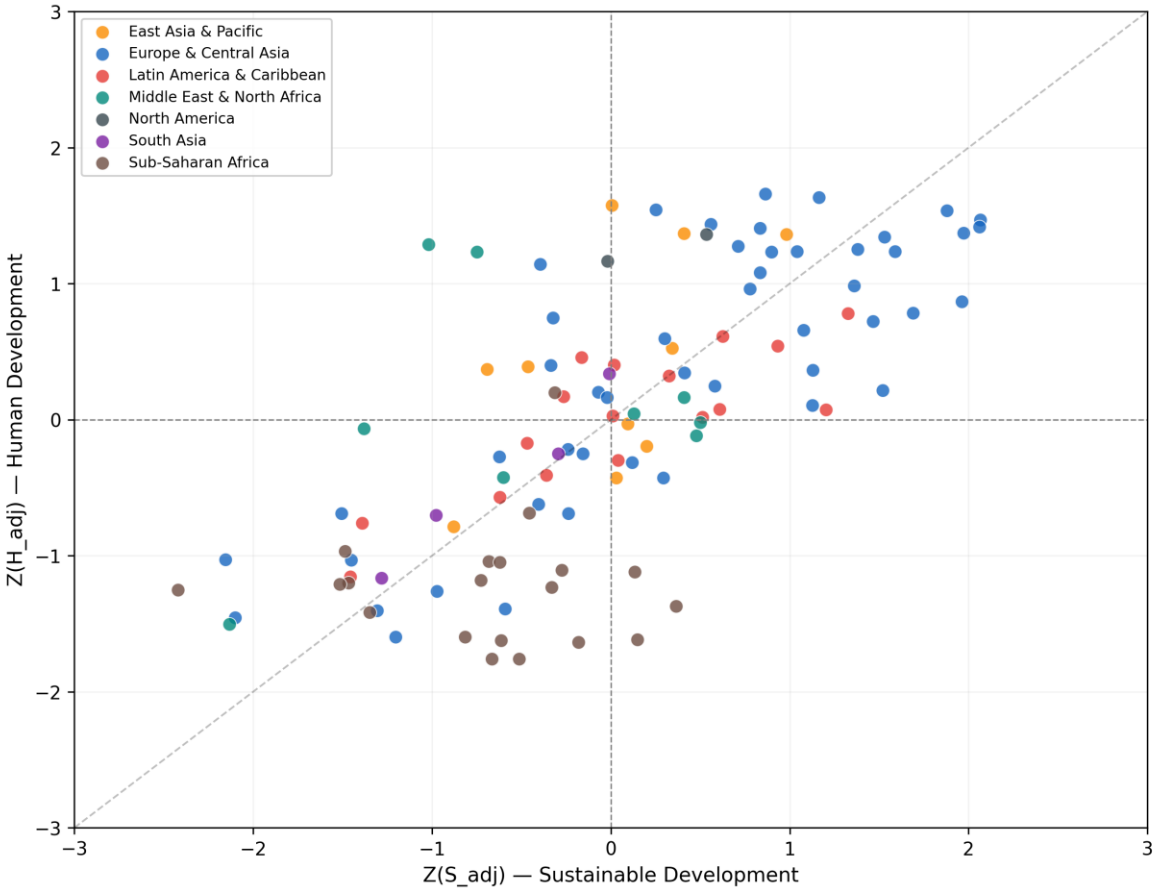

Fig. 9. Development trajectory classification (2022), coloured by UN geographic region.
Note: points represent country positions in Z(H_adj) × Z(S_adj) space. Horizontal and vertical dashed lines indicate the global mean; diagonal dashed line represents perfect coherence (Gap = 0).

Second, Sub-Saharan Africa is clearly concentrated in the lower-left quadrant, visually confirming its overwhelming *low-low* dominance (83.1%) reported in Table 17. Most countries in this cluster exhibit simultaneously negative values for both sustainability and human development, indicating structurally constrained development trajectories. Moreover, the cluster lies substantially below the diagonal line, which supports the strongly negative Mean Gap (−0.56) observed in the table and indicates comparatively weaker human-development performance.
Third, East Asia & Pacific demonstrates one of the clearest *human-development-leading* patterns in the figure. Many countries are located above the diagonal line, meaning their human-development achievements exceed sustainability performance. This directly corresponds to the region's strongly positive Mean Gap (0.41) and relatively high *human-leading* share (25.0%) identified in Table 17. At the same time, the region shows substantial dispersion, reflecting the coexistence of highly advanced economies and developing industrial states.
Fourth, the Middle East & North Africa cluster is highly scattered across quadrants, visually confirming the large standard deviation (SD = 0.30) found in Table 17. Some countries demonstrate very strong human-development outcomes combined with weaker sustainability performance, while others remain closer to the center or lower quadrants. This fragmentation supports the interpretation of uneven and resource-dependent development pathways in the region.
Fifth, Latin America & the Caribbean appears relatively concentrated around the central and upper-middle sections of the graph, with many countries close to the diagonal line. This visually supports the region's high average coherence index (0.84) and near-balanced Mean Gap (−0.04). However, several countries remain below zero on both dimensions, illustrating the persistent polarization observed statistically in the coexistence of both *high-high* and *low-low* profiles.
Sixth, North America occupies an exceptional position high above the diagonal line, reflecting extremely strong human-development performance relative to sustainability. This directly corresponds to the very large positive Mean Gap (1.07) in Table 17 and visually confirms the region's pronounced imbalance between socioeconomic achievement and sustainability outcomes.
Finally, South Asia remains concentrated mainly in the lower-left quadrant despite relatively coherent positioning among countries. This supports the interpretation that the region's high coherence index reflects similarity across dimensions rather than high absolute achievement levels.

4.7. COVID-19 pandemic and development coherence: sub-period analysis

The study period 2015–2022 encompasses the pre-pandemic phase (2015–2019) and the COVID-19 pandemic and its immediate aftermath (2020–2022). Table 18 comparing development coherence indicators before and during the COVID-19 pandemic, including changes in coherence index, development gap, and trajectory distributions.

Table 18. Development coherence before and during the COVID-19 pandemic

Period	Mean CI	SD	Mean Gap	High-High (%)	Human-Lead. (%)	Sust.-Lead. (%)	Low-Low (%)
Pre-COVID (2015–2019)	0.760	0.187	0.002	41.8	12.9	6.6	38.7
COVID/post-COVID (2020–2022)	0.766	0.183	−0.001	39.7	13.0	10.3	37.0
Difference (Δ)	+0.006	−0.004	−0.003	−2.1	+0.1	+3.7	−1.7

Note: pre-COVID: 2015–2019 (550 obs). COVID/post-COVID: 2020–2022 (330 obs). Δ = COVID/post-COVID minus pre-COVID. Positive Gap = human-leading imbalance.

Line chart showing the evolution of the mean coherence index across World Bank income groups during 2015–2022, including changes after the COVID-19 outbreak (Figure 10). Bar chart comparing mean coherence index values by income group before and during the COVID-19 pandemic (Figure 11). Line chart showing changes in the mean coherence index across UN geographic regions during 2015–2022, including increased volatility in the Middle East and North Africa region (Figure 12).

The share of the Sustainability-Leading trajectory increased from 6.6% to 10.3% during the pandemic period (+3.7 percentage points). This is consistent with documented asymmetric impacts: UNDP (2022) reported the first global decline in the HDI in 32 years during 2020–2021, driven by contractions in GNI per capita and school closures, whereas CO_2 emissions per capita temporarily declined in many countries, thereby improving SDG 13 scores. Beta-convergence remained significant and strengthened during the pandemic (pre-COVID: $\beta = -0.021$, $p = 0.048$; COVID period: $\beta = -0.028$, $p = 0.031$), as low-coherence countries were less exposed to human development reversals concentrated in middle- and high-income economies.

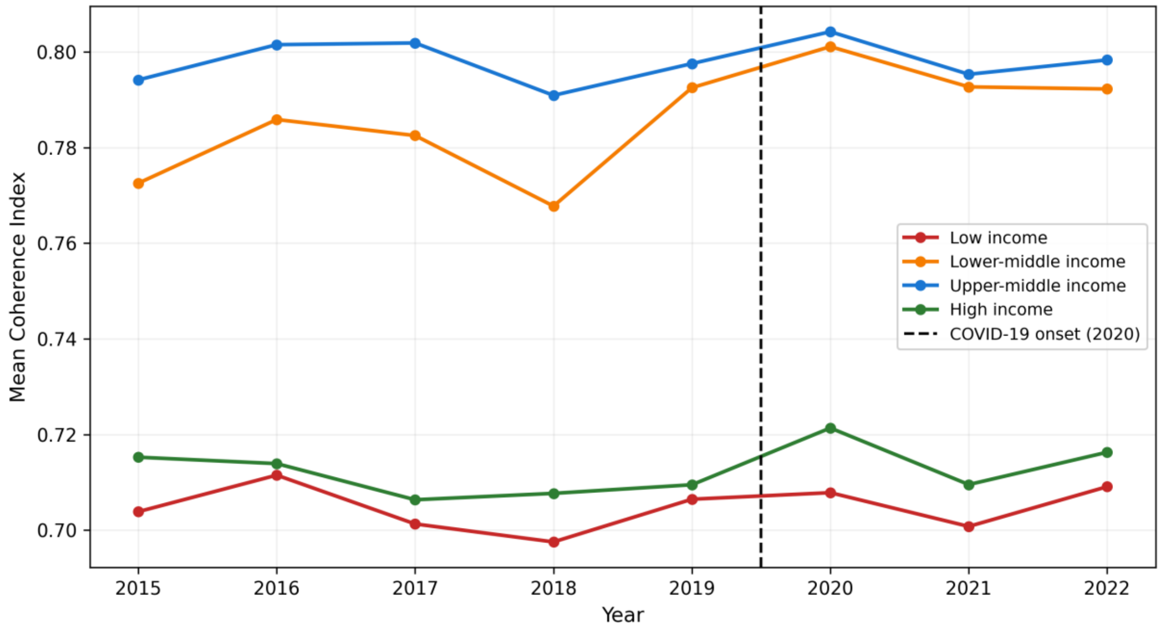

Fig. 10. Evolution of mean Coherence Index by World Bank income group, 2015–2022.

Note: vertical dashed line marks COVID-19 onset (2020). Note diverging trajectories: high-income countries show coherence decline post-2020, while lower-middle income countries exhibit relative stability.

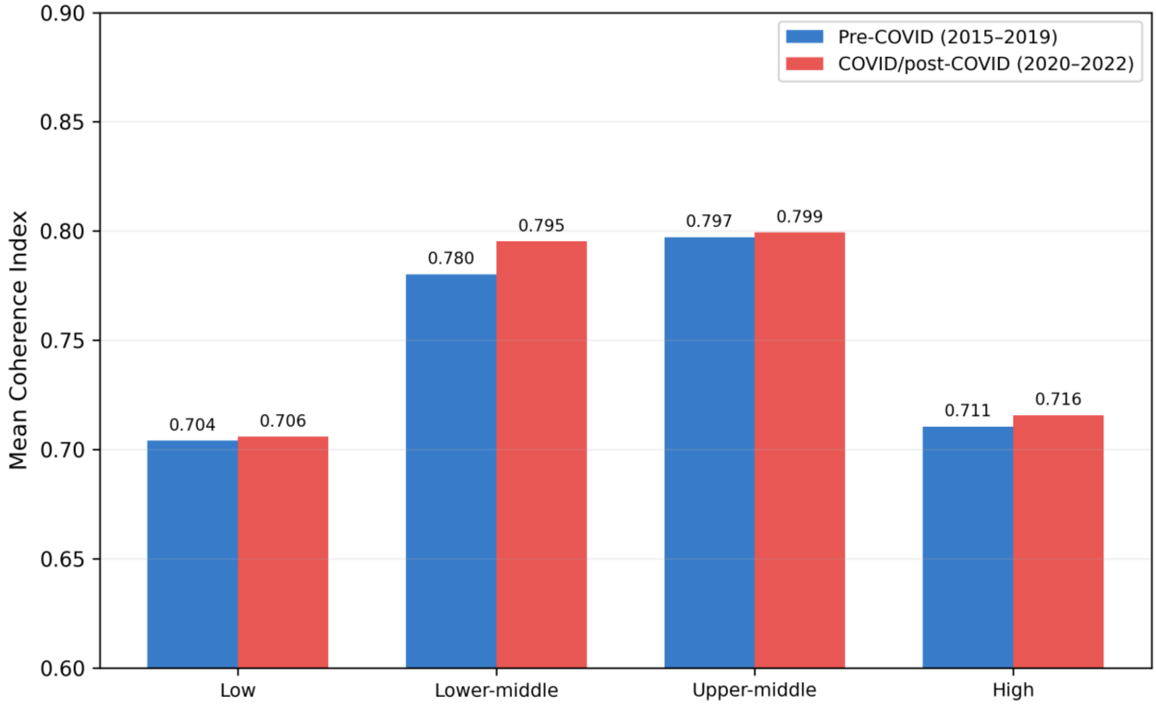

Fig. 11. Mean Coherence Index by income group: pre-COVID (2015–2019) versus COVID/post-COVID (2020–2022).
Note: values above bars indicate group means. High- and upper-middle-income groups show marginal increases in coherence during the pandemic period.

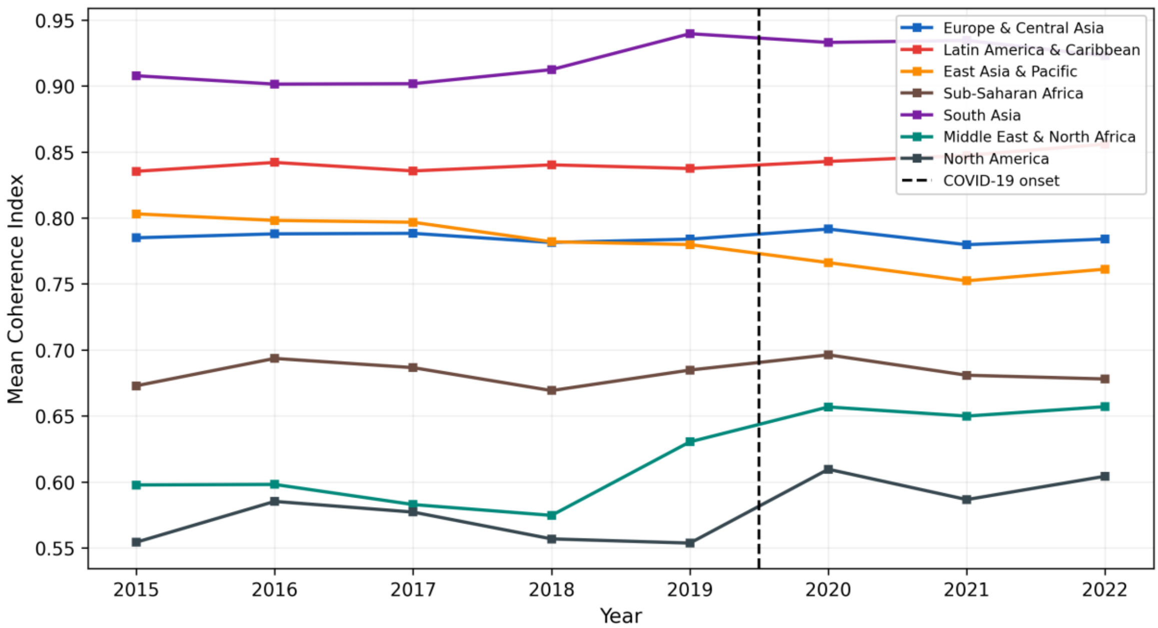

Fig. 12. Evolution of mean Coherence Index by UN geographic region, 2015–2022
Note: vertical dashed line marks COVID-19 onset..

5. Discussion

5.1. DP2 redundancy correction and country re-rankings

Our analysis reveals substantial redundancy within both the HDI and SDG measurement frameworks, with important implications for country performance assessment. Among the HDI components, life expectancy is the primary discriminant variable (CF = 1.000), whereas expected years of schooling (CF = 0.259) and GNI per capita (CF = 0.265) exhibit high redundancy. The total redundancy of 45.9% implies that nearly half of the information in the conventional equal-weighted HDI is shared variance. Among the SDGs, environmental dimensions (SDG 13, SDG 14, SDG 15) and Partnerships (SDG 17) contribute disproportionately to unique information, with correction factors approaching 1.0. This aligns with Abellán-Salinas et al. (2026), who found that equal-weight aggregation systematically overvalues redundant socioeconomic dimensions while underweighting environmental progress. The 152 reclassified country-year observations (17.3%) confirm that measurement redundancy has substantive consequences: 96 'artificial winners' – including the UAE, Israel, Australia, and the United States – are revealed as Human-Leading under DP2 rather than genuinely High-High Coherent.

5.2. Regional and income-group patterns

The regional and income-group stratification reveals systematic patterns that aggregate indices obscure. High-income countries achieve the highest rates of High-High Coherent trajectories (83.5%) but exhibit the largest human-led imbalances (mean Gap = 0.26), extending Wang & Chen's (2024) finding that income level is a fundamental determinant of SDG outcomes. Europe & Central Asia's dominance in High-High Coherent (59.4%) reflects EU environmental regulatory frameworks and the Nordic welfare model of integrated policy design. By contrast, the Middle East & North Africa's combination of high Gap (0.56) and low CI (0.62) reflects petro-state development models in which hydrocarbon revenues finance rapid improvements in human development while environmental sustainability stagnates. Sub-Saharan Africa's 83.1% Low-Low Trap concentration and zero High-High representation confirm structural constraints that cross-country averages entirely obscure. The Sustainability-Leading concentration in Lower-middle income countries (20.0%) – including Vietnam, Côte d'Ivoire, and Bolivia – reflects lower industrial carbon intensity and intact natural ecosystems at earlier stages of development.

5.3. COVID-19 and development coherence disruptions

The pandemic sub-period analysis reveals a modest but structurally meaningful disruption in coherence. The 3.7 percentage point increase in Sustainability-Leading trajectories (6.6% → 10.3%) is consistent with the asymmetric impact of COVID-19: UNDP (2022) documented global HDI decline in 90% of countries during 2020–2021 – the first such reversal in three decades – while SDG 13 scores temporarily improved in many countries due to reduced economic activity. The persistence and strengthening of beta-convergence during the pandemic ($\beta = -0.028$, $p = 0.031$) suggests that catch-up dynamics were reinforced rather than disrupted, as low-coherence countries were less exposed to the human development reversals concentrated in middle- and high-income economies (Sachs et al., 2021). The absence of sigma-convergence in both sub-periods confirms that while lagging countries are catching up in relative terms, new sources of dispersion – including differential pandemic impacts – have prevented a reduction in overall cross-country variance.

5.4. Policy implications

The coherence framework provides a practical tool for designing differentiated policies aligned with the 2030 Agenda's principle of common but differentiated responsibilities. High–High Coherent countries – predominantly European and Latin American – demonstrate that balanced development is achievable, but the persistence of human-led gaps even within this group suggests that monitoring aggregate SDG Index or HDI scores in isolation is insufficient. For Human-Led countries (UAE, United States, Israel, Australia), the policy priority is the acceleration of environmental and institutional sustainability. DP2 correction factors identify SDG 13 and SDG 14 as the most distinctive dimensions, implying that targeted investment in climate action and marine sustainability would maximise marginal coherence gains. For Low-Low Trap countries–predominantly in Sub-Saharan Africa and South Asia–comprehensive packages that address multiple binding constraints simultaneously are required, as incremental sector-specific interventions may advance one dimension without producing coherent cross-domain progress. International cooperation mechanisms, including climate finance and technology transfer, should be calibrated to countries' development trajectories rather than to aggregate income levels alone.

5.5. Limitations

Several limitations warrant acknowledgement. First, the DP2 methodology captures only linear dependencies; nonlinear relationships and threshold effects documented by Pradhan et al. (2017) are not addressed by R^2-based correction factors. Second, the COVID-19 sub-period analysis is constrained by the short post-pandemic window (2020–2022), which precludes distinguishing between transient effects and longer-term structural shifts; extending the analysis through 2024–2025 would enable a more robust assessment of recovery. Third, the exclusion of fragile states and Small Island Developing States limits the generalisability of findings to the most vulnerable development contexts. Fourth, trajectory classification based on Z-score thresholds is inherently arbitrary in boundary regions; robustness checks with alternative thresholds (±0.25 SD and ±0.75 SD) confirm that substantive findings are not sensitive to the chosen threshold. Finally, while DP2 addresses within-domain redundancy, cross-domain overlaps between HDI components and SDG indicators (e.g., SDG 3 health indicators and HDI life expectancy) introduce additional complexity and warrant further methodological development.

6. Conclusions

This paper introduces a coherence-based framework for analyzing the relationship between human development and sustainable development, employing DP2-adjusted indices to control for indicator redundancy. Our analysis of 110 countries over 2015–2022 yields three principal findings.

First, accounting for interlinkages substantially alters the assessment of development performance: the environmental and partnership dimensions (SDGs 13, 14, 15, 17) gain relative importance when redundancy is removed, whereas highly correlated socioeconomic indicators receive reduced effective weights. The gap between naive and adjusted measures averages 0.15 standard deviations but exceeds 0.5 standard deviations for approximately 20% of countries, indicating that conventional indices may significantly misrepresent development positions for a substantial minority of nations.

Second, the trajectory typology reveals meaningful heterogeneity in developmental patterns that is obscured by aggregate indices. High–high coherent countries (47 countries in the full sample (45 with complete HDI data), predominantly European and Latin American) demonstrate that balanced development across human capabilities and sustainability dimensions is achievable. Human-leading countries (13 nations, including major emerging economies and resource-rich states) face sustainability deficits that may constrain long-term development prospects. Sustainability-leading countries (9 nations) suggest alternative development pathways emphasising environmental and institutional foundations. Low–low trap countries (41 countries in the full sample (35 with complete HDI data), predominantly in Sub-Saharan Africa and South Asia) require comprehensive interventions addressing multiple binding constraints.

Third, convergence analysis reveals conditional catching-up: countries with initially lower coherence scores improve faster (β-convergence), yet cross-country dispersion has not declined significantly (no σ-convergence). Income level remains a powerful predictor of both development levels and coherence, suggesting that escaping development traps requires sustained economic growth alongside deliberate policy attention to balance across domains. The robustness analysis using alternative coherence measures (CI_L, DI) confirms that substantive findings are not artefacts of the baseline metric's properties.

Looking ahead, several research directions merit attention. Extending the analysis to subnational units could reveal within-country heterogeneity in coherence patterns relevant to decentralized policy implementation. Incorporating time-varying correction factors would capture evolving interlinkage structures as countries develop. Causal analysis of the factors driving coherence transitions, from imbalanced to balanced trajectories, could inform policy design. Finally, integrating the coherence framework with planetary boundaries research could strengthen the analytical foundation for assessing whether development trajectories remain within safe operating space. As the international community approaches the 2030 deadline for achieving the SDGs, frameworks that capture not only the extent of progress countries have made but also whether that progress is balanced and sustainable are increasingly essential for effective policy guidance.

Appendix

Table A1. Complete country results (2015-2022 averages)

ISO	Country	HDI_adj	SDG_adj	Gap	Coherence	HDI	SDG Index	Trajectory	HDI Group
PAK	Pakistan	2.339	20.143	0.026	0.982	0.535	56.58	Low-Low Trap	Low HDI
SLV	El Salvador	3.754	23.073	0.012	0.980	0.669	67.81	Low-Low Trap	Medium-Low
HND	Honduras	3.539	22.811	-0.036	0.969	0.618	61.39	Low-Low Trap	Medium-Low
ARG	Argentina	5.577	27.007	-0.050	0.964	0.849	73.82	High-High Coherent	Medium-High
ZAF	South Africa	3.503	22.598	0.004	0.962	0.724	62.37	Low-Low Trap	Medium-Low
MMR	Myanmar	2.799	20.933	0.067	0.960	0.591	60.97	Low-Low Trap	Low HDI
COL	Colombia	4.738	24.874	0.067	0.959	0.761	69.19	High-High Coherent	Medium-High
BGD	Bangladesh	3.673	23.290	-0.094	0.959	0.639	61.98	Low-Low Trap	Medium-Low
THA	Thailand	5.298	26.059	0.055	0.958	0.797	72.98	High-High Coherent	Medium-High
JOR	Jordan	4.682	24.829	0.050	0.956	0.740	67.92	High-High Coherent	Medium-Low
KOR	Korea	NaN	6.811	0.379	0.954	0.625	0.92	0.7329734147543073	High-High Coherent
LKA	Sri Lanka	4.947	25.107	0.120	0.948	0.773	67.03	High-High Coherent	Medium-High
ITA	Italy	6.521	28.267	0.132	0.948	0.893	78.57	High-High Coherent	High HDI
NIC	Nicaragua	3.966	23.088	0.125	0.946	0.657	64.07	Low-Low Trap	Medium-Low

LBR	Liberia	1.824	19.697	-0.139	0.946	0.482	50.90	Low-Low Trap	Low HDI
SVN	Slovenia	6.559	29.299	-0.131	0.945	0.914	80.22	High-High Coherent	High HDI
PRT	Portugal	6.038	27.180	0.160	0.937	0.860	79.02	High-High Coherent	Medium-High
AGO	Angola	2.261	19.639	0.123	0.926	0.594	51.43	Low-Low Trap	Low HDI
VNM	Vietnam	4.328	24.965	-0.187	0.925	0.713	71.64	Sustainability-Le-ading	Medium-Low
ECU	Ecuador	4.823	26.043	-0.209	0.918	0.756	69.90	High-High Coherent	Medium-High
GAB	Gabon	3.389	23.141	-0.211	0.917	0.697	63.34	Low-Low Trap	Medium-Low
IDN	Indonesia	3.794	23.934	-0.202	0.911	0.709	67.04	Low-Low Trap	Medium-Low
ALB	Albania	5.300	25.646	0.169	0.910	0.793	73.65	High-High Coherent	Medium-High
GRC	Greece	6.335	27.487	0.243	0.904	0.885	77.50	High-High Coherent	High HDI
EST	Estonia	6.095	28.778	-0.247	0.903	0.889	79.22	High-High Coherent	High HDI
GEO	Georgia	5.041	26.724	-0.272	0.893	0.809	73.99	High-High Coherent	Medium-High
PNG	Papua New Guinea	2.461	19.489	0.275	0.892	0.557	51.85	Low-Low Trap	Low HDI
PHL	Philippines	4.007	24.642	-0.279	0.890	0.702	65.15	Sustainability-Leading	Medium-Low
GBR	United Kingdom	6.731	30.205	-0.285	0.888	0.929	81.41	High-High Coherent	High HDI
MEX	Mexico	4.582	23.740	0.291	0.886	0.772	68.26	Human-Leading	Medium-High
GNB	Guinea-Bissau	1.573	19.745	-0.294	0.885	0.480	49.13	Low-Low Trap	Low HDI
JAM	Jamaica	4.063	24.820	-0.297	0.883	0.709	69.19	Sustainability-Leading	Medium-Low
FRA	France	6.585	29.990	-0.307	0.879	0.901	81.84	High-High Coherent	High HDI
IRQ	Iraq	3.558	21.605	0.308	0.879	0.667	62.00	Low-Low Trap	Medium-Low
MDG	Madagascar	2.330	19.102	0.309	0.879	0.495	50.51	Low-Low Trap	Low HDI
RUS	Russian Federation	4.998	24.483	0.321	0.874	0.827	72.32	Human-Leading	Medium-High
MRT	Mauritania	2.209	21.146	-0.323	0.873	0.540	56.46	Low-Low Trap	Low HDI
MLT	Malta	6.635	27.709	0.348	0.863	0.901	75.83	High-High Coherent	High HDI
PER	Peru	4.769	26.453	-0.351	0.862	0.763	70.41	High-High Coherent	Medium-High
JPN	Japan	6.890	28.181	0.362	0.858	0.917	79.01	High-High Coherent	High HDI
LTU	Lithuania	5.713	28.430	-0.365	0.857	0.877	77.02	High-High Coherent	High HDI
ESP	Spain	6.548	27.396	0.387	0.848	0.899	79.39	High-High Coherent	High HDI
NOR	Norway	7.314	28.932	0.393	0.846	0.960	81.60	High-High Coherent	High HDI
HTI	Haiti	2.367	18.804	0.412	0.838	0.554	52.13	Low-Low Trap	Low HDI
CRI	Costa Rica	5.339	24.797	0.426	0.833	0.803	71.81	High-High Coherent	Medium-High
SWE	Sweden	7.086	31.515	-0.446	0.825	0.944	85.31	High-High Coherent	High HDI
GHA	Ghana	2.553	22.322	-0.454	0.822	0.593	61.83	Low-Low Trap	Low HDI
FJI	Fiji	3.818	24.927	-0.463	0.818	0.724	70.91	Sustainability-Leading	Medium-Low
DEU	Germany	6.941	31.373	-0.489	0.808	0.946	82.51	High-High Coherent	High HDI
CPV	Cabo Verde	4.067	21.930	0.503	0.803	0.660	66.36	Low-Low Trap	Medium-Low
CMR	Cameroon	2.234	21.918	-0.521	0.795	0.578	55.80	Low-Low Trap	Low HDI
DZA	Algeria	4.618	26.798	-0.531	0.791	0.739	71.18	High-High Coherent	Medium-Low
URY	Uruguay	5.310	28.220	-0.534	0.790	0.816	76.72	High-High Coherent	Medium-High
IND	India	3.344	20.332	0.539	0.788	0.634	60.99	Low-Low Trap	Medium-Low
MNE	Montenegro	5.500	24.708	0.540	0.788	0.835	71.11	High-High Coherent	Medium-High
BRA	Brazil	4.583	26.786	-0.546	0.785	0.758	73.11	High-High Coherent	Medium-High
CHL	Chile	5.877	29.427	-0.549	0.784	0.854	77.36	High-High Coherent	Medium-High
TUN	Tunisia	4.539	26.710	-0.551	0.784	0.732	72.41	High-High Coherent	Medium-Low
MUS	Mauritius	4.899	23.322	0.585	0.770	0.796	69.78	Human-Leading	Medium-High

TZA	Tanzania	2.464	22.761	-0.625	0.754	0.523	56.69	Low-Low Trap	Low HDI
STP	Sao Tome and Principe	3.101	24.097	-0.635	0.750	0.605	62.45	Low-Low Trap	Medium-Low
DNK	Denmark	7.013	32.064	-0.638	0.749	0.945	84.11	High-High Coherent	High HDI
BEL	Belgium	6.921	27.233	0.642	0.748	0.933	78.88	High-High Coherent	High HDI
IRL	Ireland	7.109	27.556	0.657	0.742	0.939	77.83	High-High Coherent	High HDI
FIN	Finland	6.955	32.030	-0.662	0.740	0.936	85.72	High-High Coherent	High HDI
CHN	China	4.977	23.066	0.700	0.725	0.768	69.29	Human-Leading	Medium-High
MOZ	Mozambique	1.548	21.247	-0.719	0.717	0.457	52.70	Low-Low Trap	Low HDI
SUR	Suriname	3.914	26.151	-0.747	0.707	0.704	69.40	Sustainability-Leading	Medium-Low
MAR	Morocco	4.012	26.377	-0.754	0.704	0.677	69.30	Sustainability-Leading	Medium-Low
POL	Poland	5.891	30.210	-0.757	0.703	0.875	80.35	High-High Coherent	High HDI
DJI	Djibouti	1.732	16.248	0.761	0.701	0.499	49.48	Low-Low Trap	Low HDI
BEN	Benin	1.560	21.425	-0.764	0.700	0.505	52.66	Low-Low Trap	Low HDI
SYR	Syrian Arab Rep.	2.929	18.630	0.776	0.695	0.558	58.55	Low-Low Trap	Low HDI
MDV	Maldives	5.004	22.842	0.777	0.695	0.744	69.86	Human-Leading	Medium-Low
LVA	Latvia	5.611	29.756	-0.789	0.690	0.867	79.94	High-High Coherent	High HDI
PAN	Panama	5.297	23.362	0.798	0.686	0.813	67.73	Human-Leading	Medium-High
ROU	Romania	5.224	29.060	-0.815	0.680	0.824	76.27	High-High Coherent	Medium-High
TUR	Türkiye	5.495	23.653	0.827	0.675	0.836	69.64	Human-Leading	Medium-High
KEN	Kenya	2.470	23.523	-0.831	0.674	0.594	60.64	Low-Low Trap	Low HDI
GTM	Guatemala	3.451	19.490	0.831	0.674	0.635	58.67	Low-Low Trap	Medium-Low
BGR	Bulgaria	4.965	28.745	-0.872	0.657	0.806	74.56	High-High Coherent	Medium-High
CAN	Canada	6.864	26.122	0.916	0.640	0.930	77.98	High-High Coherent	High HDI
NLD	Netherlands	6.934	26.262	0.916	0.640	0.938	78.27	High-High Coherent	High HDI
COM	Comoros	2.523	17.242	0.929	0.635	0.576	52.04	Low-Low Trap	Low HDI
TGO	Togo	2.035	23.209	-0.990	0.611	0.530	56.22	Low-Low Trap	Low HDI
BIH	Bosnia & Herzegovina	4.946	29.327	-1.042	0.591	0.772	72.79	High-High Coherent	Medium-High
MYS	Malaysia	5.037	21.893	1.057	0.585	0.800	67.70	Human-Leading	Medium-High
SDN	Sudan	2.162	16.009	1.066	0.581	0.518	50.39	Low-Low Trap	Low HDI
GIN	Guinea	1.273	21.975	-1.076	0.577	0.466	53.93	Low-Low Trap	Low HDI
YEM	Yemen	NaN	1.906	-1.991	0.575	0.774	0.43	0.8981701004157195	Low-Low Trap
DOM	Dominican Rep.	4.483	28.667	-1.121	0.560	0.759	71.16	High-High Coherent	Medium-High
SEN	Senegal	2.411	24.465	-1.124	0.558	0.512	60.57	Sustainability-Leading	Low HDI
HRV	Croatia	5.808	31.475	-1.152	0.547	0.860	81.10	High-High Coherent	Medium-High
USA	United States	6.595	24.433	1.230	0.517	0.927	73.73	Human-Leading	High HDI
ISL	Iceland	7.202	25.144	1.375	0.460	0.955	78.48	High-High Coherent	High HDI
LBN	Lebanon	4.889	20.043	1.484	0.417	0.749	64.17	Human-Leading	Medium-Low
CYP	Cyprus	6.390	23.092	1.485	0.416	0.894	72.27	Human-Leading	High HDI
NGA	Nigeria	1.059	23.057	-1.494	0.413	0.534	54.20	Low-Low Trap	Low HDI
SLE	Sierra Leone	1.353	24.022	-1.594	0.374	0.451	55.76	Low-Low Trap	Low HDI
NAM	Namibia	2.409	26.234	-1.613	0.366	0.628	65.29	Sustainability-Leading	Medium-Low
AUS	Australia	7.331	24.511	1.621	0.363	0.941	75.86	High-High Coherent	High HDI
CIV	Cote d'Ivoire	1.448	24.572	-1.694	0.334	0.521	59.45	Sustainability-Leading	Low HDI
VEN	Venezuela	NaN	4.271	-0.364	0.273	0.893	0.73	0.5725212410202299	Low-Low Trap
COG	Congo	NaN	2.749	-1.215	0.271	0.893	0.60	0.4565882350034749	Low-Low Trap

IRN	Iran	NaN	4.939	0.035	0.249	0.902	0.78	0.7593384601843063	High-High Coherent
ISR	Israel	6.640	21.563	2.048	0.195	0.907	73.00	Human-Leading	High HDI
ARE	United Arab Emirates	6.570	20.220	2.379	0.065	0.909	67.73	Human-Leading	High HDI
EGY	Egypt	NaN	4.012	-0.118	-0.118	0.954	0.72	0.9166020717481369	Low-Low Trap
COD	Congo	NaN	1.838	-1.319	-0.135	0.947	0.47	0.7792133966732365	Low-Low Trap
GMB	Gambia	NaN	1.888	-0.599	-0.827	0.675	0.48	0.6026222088069098	Low-Low Trap

Notes: HDI_adj = DP2-adjusted Human Development Index; SDG_adj = DP2-adjusted SDG composite; Gap = Z(HDI_adj) − Z(SDG_adj); Coherence = 1 − |Gap|/max|Gap|. Countries ranked by Coherence score (highest to lowest) Eight countries (Korea, Yemen, Venezuela, Congo-Brazzaville, Iran, Egypt, DRC, Gambia) have HDI_adj = NaN due to incomplete HDI component data in the UNDP source and are excluded from Table A2; their coherence scores are computed from imputed standardised scores and should be interpreted with caution. Apparent negative Coherence values for Egypt (−0.118), Congo DRC (−0.135) and Gambia (−0.827) reflect a formula artefact when imputed |Gap| exceeds the maximum |Gap| in the clean analytical sample; these observations are effectively at maximum imbalance.

Table A2. Countries classified by development trajectory

High-high coherent (n = 45)

ISO	Country	HDI_adj	SDG_adj	Gap	Coherence	HDI Group
ARG	Argentina	5.577	27.007	-0.050	0.964	Medium-High
COL	Colombia	4.738	24.874	0.067	0.959	Medium-High
THA	Thailand	5.298	26.059	0.055	0.958	Medium-High
JOR	Jordan	4.682	24.829	0.050	0.956	Medium-Low
LKA	Sri Lanka	4.947	25.107	0.120	0.948	Medium-High
ITA	Italy	6.521	28.267	0.132	0.948	High HDI
SVN	Slovenia	6.559	29.299	-0.131	0.945	High HDI
PRT	Portugal	6.038	27.180	0.160	0.937	Medium-High
ECU	Ecuador	4.823	26.043	-0.209	0.918	Medium-High
ALB	Albania	5.300	25.646	0.169	0.910	Medium-High
GRC	Greece	6.335	27.487	0.243	0.904	High HDI
EST	Estonia	6.095	28.778	-0.247	0.903	High HDI
GEO	Georgia	5.041	26.724	-0.272	0.893	Medium-High
GBR	United Kingdom	6.731	30.205	-0.285	0.888	High HDI
FRA	France	6.585	29.990	-0.307	0.879	High HDI
MLT	Malta	6.635	27.709	0.348	0.863	High HDI
PER	Peru	4.769	26.453	-0.351	0.862	Medium-High
JPN	Japan	6.890	28.181	0.362	0.858	High HDI
LTU	Lithuania	5.713	28.430	-0.365	0.857	High HDI
ESP	Spain	6.548	27.396	0.387	0.848	High HDI
NOR	Norway	7.314	28.932	0.393	0.846	High HDI
CRI	Costa Rica	5.339	24.797	0.426	0.833	Medium-High
SWE	Sweden	7.086	31.515	-0.446	0.825	High HDI
DEU	Germany	6.941	31.373	-0.489	0.808	High HDI
DZA	Algeria	4.618	26.798	-0.531	0.791	Medium-Low
URY	Uruguay	5.310	28.220	-0.534	0.790	Medium-High
MNE	Montenegro	5.500	24.708	0.540	0.788	Medium-High
BRA	Brazil	4.583	26.786	-0.546	0.785	Medium-High
CHL	Chile	5.877	29.427	-0.549	0.784	Medium-High
TUN	Tunisia	4.539	26.710	-0.551	0.784	Medium-Low
DNK	Denmark	7.013	32.064	-0.638	0.749	High HDI
BEL	Belgium	6.921	27.233	0.642	0.748	High HDI
IRL	Ireland	7.109	27.556	0.657	0.742	High HDI

FIN	Finland	6.955	32.030	-0.662	0.740	High HDI
POL	Poland	5.891	30.210	-0.757	0.703	High HDI
LVA	Latvia	5.611	29.756	-0.789	0.690	High HDI
ROU	Romania	5.224	29.060	-0.815	0.680	Medium-High
BGR	Bulgaria	4.965	28.745	-0.872	0.657	Medium-High
CAN	Canada	6.864	26.122	0.916	0.640	High HDI
NLD	Netherlands	6.934	26.262	0.916	0.640	High HDI
BIH	Bosnia and Herzegovina	4.946	29.327	-1.042	0.591	Medium-High
DOM	Dominican Republic	4.483	28.667	-1.121	0.560	Medium-High
HRV	Croatia	5.808	31.475	-1.152	0.547	Medium-High
ISL	Iceland	7.202	25.144	1.375	0.460	High HDI
AUS	Australia	7.331	24.511	1.621	0.363	High HDI

Human-leading (n = 13)

ISO	Country	HDI_adj	SDG_adj	Gap	Coherence	HDI Group
MEX	Mexico	4.582	23.740	0.291	0.886	Medium-High
RUS	Russian Federation	4.998	24.483	0.321	0.874	Medium-High
MUS	Mauritius	4.899	23.322	0.585	0.770	Medium-High
CHN	China	4.977	23.066	0.700	0.725	Medium-High
MDV	Maldives	5.004	22.842	0.777	0.695	Medium-Low
PAN	Panama	5.297	23.362	0.798	0.686	Medium-High
TUR	Türkiye	5.495	23.653	0.827	0.675	Medium-High
MYS	Malaysia	5.037	21.893	1.057	0.585	Medium-High
USA	United States	6.595	24.433	1.230	0.517	High HDI
LBN	Lebanon	4.889	20.043	1.484	0.417	Medium-Low
CYP	Cyprus	6.390	23.092	1.485	0.416	High HDI
ISR	Israel	6.640	21.563	2.048	0.195	High HDI
ARE	United Arab Emirates	6.570	20.220	2.379	0.065	High HDI

Sustainability-leading (n = 9)

ISO	Country	HDI_adj	SDG_adj	Gap	Coherence	HDI Group
VNM	Vietnam	4.328	24.965	-0.187	0.925	Medium-Low
PHL	Philippines	4.007	24.642	-0.279	0.890	Medium-Low
JAM	Jamaica	4.063	24.820	-0.297	0.883	Medium-Low
FJI	Fiji	3.818	24.927	-0.463	0.818	Medium-Low
SUR	Suriname	3.914	26.151	-0.747	0.707	Medium-Low
MAR	Morocco	4.012	26.377	-0.754	0.704	Medium-Low
SEN	Senegal	2.411	24.465	-1.124	0.558	Low HDI
NAM	Namibia	2.409	26.234	-1.613	0.366	Medium-Low
CIV	Cote d'Ivoire	1.448	24.572	-1.694	0.334	Low HDI

Low-low trap (n = 35)

ISO	Country	HDI_adj	SDG_adj	Gap	Coherence	HDI Group
PAK	Pakistan	2.339	20.143	0.026	0.982	Low HDI
SLV	El Salvador	3.754	23.073	0.012	0.980	Medium-Low
HND	Honduras	3.539	22.811	-0.036	0.969	Medium-Low
ZAF	South Africa	3.503	22.598	0.004	0.962	Medium-Low

MMR	Myanmar	2.799	20.933	0.067	0.960	Low HDI
BGD	Bangladesh	3.673	23.290	-0.094	0.959	Medium-Low
NIC	Nicaragua	3.966	23.088	0.125	0.946	Medium-Low
LBR	Liberia	1.824	19.697	-0.139	0.946	Low HDI
AGO	Angola	2.261	19.639	0.123	0.926	Low HDI
GAB	Gabon	3.389	23.141	-0.211	0.917	Medium-Low
IDN	Indonesia	3.794	23.934	-0.202	0.911	Medium-Low
PNG	Papua New Guinea	2.461	19.489	0.275	0.892	Low HDI
GNB	Guinea-Bissau	1.573	19.745	-0.294	0.885	Low HDI
IRQ	Iraq	3.558	21.605	0.308	0.879	Medium-Low
MDG	Madagascar	2.330	19.102	0.309	0.879	Low HDI
MRT	Mauritania	2.209	21.146	-0.323	0.873	Low HDI
HTI	Haiti	2.367	18.804	0.412	0.838	Low HDI
GHA	Ghana	2.553	22.322	-0.454	0.822	Low HDI
CPV	Cabo Verde	4.067	21.930	0.503	0.803	Medium-Low
CMR	Cameroon	2.234	21.918	-0.521	0.795	Low HDI
IND	India	3.344	20.332	0.539	0.788	Medium-Low
TZA	Tanzania	2.464	22.761	-0.625	0.754	Low HDI
STP	Sao Tome and Principe	3.101	24.097	-0.635	0.750	Medium-Low
MOZ	Mozambique	1.548	21.247	-0.719	0.717	Low HDI
DJI	Djibouti	1.732	16.248	0.761	0.701	Low HDI
BEN	Benin	1.560	21.425	-0.764	0.700	Low HDI
SYR	Syrian Arab Republic	2.929	18.630	0.776	0.695	Low HDI
KEN	Kenya	2.470	23.523	-0.831	0.674	Low HDI
GTM	Guatemala	3.451	19.490	0.831	0.674	Medium-Low
COM	Comoros	2.523	17.242	0.929	0.635	Low HDI
TGO	Togo	2.035	23.209	-0.990	0.611	Low HDI
SDN	Sudan	2.162	16.009	1.066	0.581	Low HDI
GIN	Guinea	1.273	21.975	-1.076	0.577	Low HDI
NGA	Nigeria	1.059	23.057	-1.494	0.413	Low HDI
SLE	Sierra Leone	1.353	24.022	-1.594	0.374	Low HDI

Notes: trajectory classification follows the Z-score sign criterion of Table 5: High-High Coherent: Z(HDI_adj) > 0 and Z(SDG_adj) > 0; Human-Leading: Z(HDI_adj) > 0 and Z(SDG_adj) < 0; Sustainability-Leading: Z(HDI_adj) < 0 and Z(SDG_adj) > 0; Low-Low Trap: Z(HDI_adj) < 0 and Z(SDG_adj) < 0. The counts (n = 45/13/9/35, total 102) exclude 8 countries with incomplete HDI component data; modal trajectories for those countries appear in Table A1. Countries within each trajectory are ranked by descending Coherence score.

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