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A mega-index for the Americas and its underlying sustainable development correlations

ABSTRACT

Indicators and their composite indices have been embraced as development tools for guiding humanity toward a sustainable destination. In response, public and private organizations have generated hundreds of these metrics, making their application overwhelming to policymakers, planners, and scientists. Past reviews have revealed that a majority of common development indices have theoretical or quantitative shortcomings, supporting that there is no consensus regarding their theoretical basis, design, use, thresholds-of-effect, or validation. In response, this study was designed around four guiding research questions: (*i*) What are the underlying development themes within a collection of established sustainability indices, and what distinguishes winning locations from losing ones? (*ii*) Are the three major divisions of sustainability (economic growth, social equity, environmental integrity) equally represented by current sustainable development measuring initiatives? (*iii*) Could just a few common and freely available indicators capture all present dimensions of sustainable development? (*iv*) Would a new sustainable development mega-index research paradigm improve humanity's ability to assess progress toward sustainability? Those questions were investigated using data from 30 mostly contiguous Western Hemisphere nations and three amassing methodological objectives. First, 31 known indices were reduced into underlying dimensions (factors) of sustainable development. Next, those factors were combined (aggregated) into the first mega-index of sustainable development (MISD). Finally, 11 common development indicators were explored regarding collinearity and explanatory power of the sustainable development dimensions and MISD. Seven latent dimensions (sub-metrics) captured over 85% of the variation of the original 31 indices, with socioeconomic themes dwarfing environmental ones. The factors conveyed: (F1) socioeconomic well-being synergies; (F2) economic freedom and democracy; (F3) environmentally efficient happiness; (F4) ecosystem well-being; (F5) peace to economic vulnerability tradeoff; (F6) natural resources protection; and (F7) environmental stewardship and risk resilience. MISD is the geometric mean of the seven sub-metrics, which were directed toward sustainability, and rescaled (normalized) 0 (worst case) to 100 (best case). Geographically, this study ranked Belize best overall, followed by Guyana, Panama, Uruguay, and Canada; Barbados ranked worst, preceded by Haiti, Trinidad and Tobago, Mexico, and Cuba. Winning countries were characterized by low population density, increased forestland, decreased urban, and larger country area. Child mortality and population growth rate remained negative predictors of socioeconomic conditions; however per-capita CO_2 sacrificed ecological integrity for improved human well-being. Mega-index creation will serve as an important scientific stepping-stone for improving accuracy and simplifying valuations of sustainable development, thus others should follow.

Keywords

Composite index; Factor analysis; Geometric mean; Mega-index; Sustainability assessment; Sustainable development planning; Sustainability indicators

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HIGHLIGHTS

- 31 sustainability indices were reduced into seven orthogonal axes of development.
- The first mega-index of sustainable development created using seven sub-metrics.
- Ecological well-being was found less than half as important as socioeconomic.
- Regressions between sub-metrics, mega-index, and 11 key indicators were made.
- Percent urban correlated negatively with three environmentally defined sub-metrics.

1. Introduction

We live in a time of unprecedented global change. *Environmentally*: Atmospheric greenhouse gasses continue to increase resulting in the warmest decade in Earth's recorded history (Seneviratne et al., 2014). Increased temperatures melt glaciers, ice sheets, and expand oceans, which exacerbate sea level rise and displace populations in coastal and island regions (Dutton et al., 2015). Further, the increased ocean temperatures have made global weather patterns less predictable and natural disasters more severe (Webster et al., 2005). Tropical rainforests continued to be exploited despite their known ecological services (Rands et al., 2010), ocean ecosystems are collapsing due to over harvesting (Worm et al., 2006), and eradication of our life-supporting ecosystems continues (Butchart et al., 2010). *Socially*: Inequalities remain regarding access to health care, freedom of expression, education, clean water, sanitation, technology, birth control, gender and religious equality (Griggs, 2013). Terrorism and fear have reached unmatched levels, resulting in significant reinvestments in military and defense, and accepting war as the status quo for solving social and political problems (Lum et al., 2006; Harcourt, 2008). Forced from their home nations, refugee populations are often neither welcomed nor treated equally in their new locations (Bauder, 2016). *Economically*: The world's richest countries continue to separate themselves from the poorest ones. Wealthy nations increasingly invest in their developing counterparts through progress loans, from sources such as the World Bank (Shaker and Sirodoev, 2016). In search of low-cost employment and lax environmental laws, globalization continues to move manufacturing from once-industrialized nations to developing nations (Krugman and Venables, 1995). *Governmentally*: Little legislative follow-through, corruption, decision-maker self-interests, and shortsighted policies keep trust in government and social capital low in many countries (Keele, 2007; Lyytimäki et al., 2013). These global problems are propelled and exacerbated by population growth and an increased demand for material well-being (Weinzettel et al., 2013), which have both been projected to have an indefinite future (Gerland et al., 2014).

"Sustainable development" remains the agreed upon and unifying approach to combat the negative impacts associated with global change. As defined by the Brundtland Commission's *Our Common Future*, sustainable development is: "development that meets the needs of the present without compromising that ability of future generations to meet their own needs" (WCED, 1987:43). Although a uniting concept, it is impossible to know how to prioritize development strategies without assessing where we have been or our current position. During the 1992 Rio de Janeiro Earth Summit the need for indicators was solidified: "indicators of sustainable development need to be developed to provide solid bases for decision making at all levels and to contribute to a self-regulatory sustainability of integrated environment and development systems" (UN, 1992:346). In response, by the end of the 20th century, hundreds of indicators had been created and structured into several comprehensive lists. For example, the Compendium of Sustainable Development Indicator Initiates organized more than 500 such measurements (Parris and Kates, 2003). During this sustainability assessment renaissance, efforts were also made to focus initiatives into core sets of sustainable development metrics. In 2007, the United Nations report, *Indicators of Sustainable Development: Guidelines and Methodologies* provided a core set of 50 indicators drawn from a group of 96 (UN, 2007). At roughly the same time, the *Official List of Millennium Development Goals Indicators* established 60 indicators that addressed its needs (UNSD, 2008). Efforts continue to refine an indicator set for the European Union's Sustainable Development Strategy, which currently has more than 100 indicators across ten themes for its countries (Eurostat, 2015). There are 247 indicators across 12 topic areas currently inventoried for the Organization for Economic Co-operation and Development (OECD) member countries (OECD, 2017). More globally inclusive, a preliminary list of 231 indicators was endorsed to meet humanity's needs for 169 targets across the 17 Sustainable Development Goals (Sachs et al., 2016).

Public and private organizations have generated an overwhelming number of indicators and composite indices for assessing progress toward sustainability, making their application mind-boggling to policymakers, planners, and scientists (Rogers et al., 2008; Shaker, 2015). Past reviews have revealed that a majority of common development indices have theoretical or quantitative shortcomings causing great misunderstanding for the sustainability effort (Böhringer and Jochem, 2007; Wilson et al., 2007; Mayer, 2008; Singh et al., 2012). Therefore, elucidating the strengths, weaknesses, scale-dependencies, data needs, construction, interrelationships, redundancy, and validation of these indices and the indicators on which they are based is essential for improving sustainable development monitoring programs (Parris and Kates, 2003; Morse and Fraser, 2005; Ness et al., 2007). In an inductive study of 30 common sustainable development indices, Shaker (2015) found that socioeconomic measures overpowered ecological (biosphere) measures two-to-one. Recognizing that many sustainable development indices are environmentally weak, researchers have begun to supplement socioeconomic indices with indicators of environmental condition (i.e., Bravo, 2014); however, work remains to adequately capture and include biogeophysical complexities (Moldan et al., 2012).

Non-mathematicians have frequently driven the creation and use of indices (Shaker and Zubalsky, 2015). This may accomplish the goal of making development metrics conceptually simple and understandable (see Maclaren, 1996), yet at the cost of calculation and accuracy errors. According to Böhringer and Jochem (2007), common sustainable development indices often fail to employ appropriate scientific requirements (i.e., geometric mean), or inaccurately conduct the three fundamental steps (normalization, weighting, aggregation), misinforming users (i.e., planners, policymakers) during their application. Therefore, no consensus has been reached regarding sustainable development index design, theoretical basis, use, thresholds-of-effect, or validation (Parris & Kates, 2003; Keiner, 2006; Rogers et al., 2008). In response, policymakers have encouraged researchers to improve existing models and develop new techniques for optimizing local and regional sustainable development planning (Grosskurth, 2007). This sentiment was supported internationally at the 2012 Rio +20 Earth Summit, which focused on clear and practical measures for implementing sustainable development across spatial and temporal scales (UNCSD, 2012).

In response to the aforementioned issues with sustainable development indices, and current needs of sustainable development planning, this study was designed around four guiding research questions: (*i*) What are the underlying development themes within a collection of established sustainability indices, and what distinguishes winning locations from losing ones? (*ii*) Are the three major divisions of sustainability (economic growth, social equity, environmental integrity) equally represented by current sustainable development measuring initiatives? (*iii*) Could just a few common and freely available indicators capture all present dimensions of sustainable development? (*iv*) Would a new sustainable development mega-index research paradigm improve humanity's ability to assess progress toward sustainability? In the forthcoming paper, those questions were investigated using data from 30 mostly contiguous Western Hemisphere nations and three amassing methodological objectives. First, 31 known indices were reduced into underlying dimensions (factors) of sustainable development. Next, those factors (sub-metrics) were combined (aggregated) into the first mega-index of sustainable development (MISD). Finally, 11 common development indicators were explored regarding collinearity and explanatory power of the latent sustainable development dimensions and mega-index.

2. Data description

National-level development indices have reached such saturation that it is now imperative to critically evaluate their use for assessing progress toward sustainability. To maximize geographical variability, 30 nation-states across North, Central and South America, along with the Caribbean (hereafter: the Americas) were assessed in this study (Fig. 1). These countries capture a majority of the Western Hemisphere, are a microcosm of the global system, and represent an optimal study region for testing sustainable development hypotheses because: (*i*) the area encompasses over 140 degrees of latitude; (*ii*) two G7 countries (Canada, USA) are included; (*iii*) two of the thirteen Organization of the Petroleum Exporting Countries (OPEC) are included (Ecuador, Venezuela); (*iv*) four of the 35 member countries from the OECD are represented (Canada, Chile, Mexico, USA); (*v*) a high degree of human diversity and physical geography is captured; (*vi*) the 30 countries are mostly contiguous from North to South America, making an ideal but seldom represented macroscale regional development study; (*vii*) varying levels of human and ecological well-being, along with different access to natural resources, are represented; and (*viii*) many developing countries with limited regional sustainable development assessment inclusion (i.e., Haiti) are embraced herein.

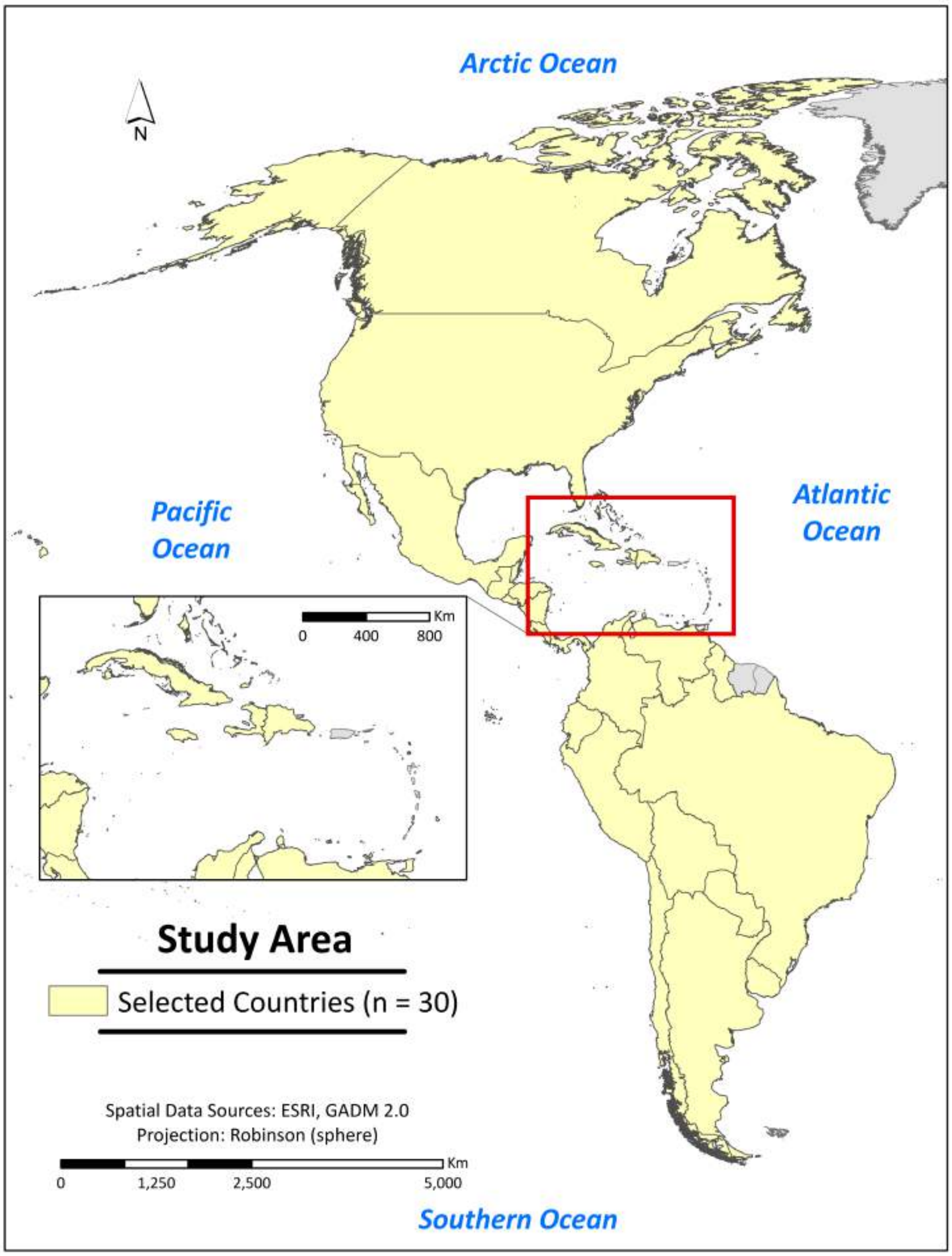

Fig. 1 Study area map of the 30 selected American countries utilized in this research.

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This paper employed 31 composite indices designed for evaluating and guiding progress toward sustainability across 30 chosen American countries (Table 1). For nomenclature clarification, this paper adopted the term *indicator* as a single value from a single attribute measure, whereas an *index* is an aggregation of more than one single indicator (Ott, 1978). When selecting development indices, effort was used to equally represent the three major spheres of sustainability (economic growth, social equity, environmental integrity); however, while many indices capture two pillars, few capture all three. Additionally, effort was used to assemble a dataset for a comparable time period (circa 2014), but was constrained to available indices published from 2001 to 2016. Given the objectives of this paper, all American countries and 32 composite indices were originally considered for use in the research. However, due to lack of data across the initially selected countries, an approach was adopted to optimize a regional development assessment and reduce spurious statistical findings. For both an index and country, a minimum threshold of 50% complete was used as criteria for their inclusion in this study. Using the aforementioned selection criteria, the where-to-be-born index (EIU, 2013) and roughly one-third of the original nations (mostly island) were eliminated from this study.

Table 1
Descriptive statistics and metadata for the 31 composite sustainable development indices used in the forthcoming statistical analyses (data are not transformed; *N* = 30).

Abbreviation	Description	Potential Index Range	Percent (%) Originally Complete	Mean ± SE Modeled Nulls	Reference
CDI	Child Development Index	(Best) 0 - 100	87	7.69 ± 0.95	SCF (2008)
CHI	Child Health Indicator	0 - 100 (Best)	100	89.65 ± 1.90	CIESIN (2013)
CPI	Corruption Perception Index	0 - 100 (Best)	93	42.63 ± 3.08	TI (2016)
DI	Democracy Index	0 - 10 (Best)	83	6.43 ± 0.22	EIU (2016)
EF	Ecological Footprint	(Best) 0.04 - 10.68 gha/pers	87	2.74 ± 0.31	GFN (2011)
ECVI	Economic Vulnerability Index	(Best) 0 - 100	93	30.43 ± 1.38	Feindouno & Goujon (2016)
EDUI	Education Index	0 - 1 (Best)	100	0.65 ± 0.02	UNDP (2013a)
EPI	Environmental Performance index	0 - 100 (Best)	97	72.38 ± 1.53	YCELP (2012)
ESI	Environmental Stress Index	(Best) 0 - 100	100	56.13 ± 1.97	Prescott-Allen (2001)
ESUI	Environmental Sustainability Index	0 - 100 (Best)	83	53.17 ± 1.54	YCELP (2005)
EVI	Environmental Vulnerability Index	(Best) 174 - 436	100	299.67 ± 8.48	SOPAC (2005)
EWI	Ecosystem Well-being Index	0 - 100 (Best)	100	43.87 ± 1.97	Prescott-Allen (2001)
GDP	Gross Domestic Product (Purchasing Power Parity)	7,083 - 91,388 (Best)	100	11,043.45 ± 2,199.03	WB (2011)
GINI	Global Information Networking Institute Coefficient	(Best) 0 - 100	100	47.61 ± 1.15	WB (2014)
GPI	Global Peace Index	(Best) 1.11 - 3.00	83	2.04 ± 0.06	IEP (2013)
HDI	Human Development Index	0 - 1 (Best)	100	0.73 ± 0.02	UNDP (2014)
HAPI	Happy Planet Index	0 - 100 (Best)	87	51.96 ± 1.39	NEF (2012)
HWI	Human Well-Being Index	0 - 100 (Best)	100	46.80 ± 2.39	Prescott-Allen (2001)
HSDI	Human Sustainable Development Index	0 - 1 (Best)	100	0.76 ± 0.01	IGBP (2010)
IEF	Index of Economic Freedom	0 - 100 (Best)	97	58.77 ± 2.92	HF (2015)
KEI	Knowledge Economy Index	0 - 10 (Best)	80	5.12 ± 0.29	WB (2008)
LEI	Life Expectancy Index	0 - 100 (Best)	100	60.67 ± 2.11	UNDP (2013b)
NRPI	Natural Resource Protection Indicator	0 - 100 (Best)	100	65.43 ± 5.74	CIESIN (2013)
ND-GAIN	Notre Dame Global Adaptation Initiative Index	0 - 100 (Best)	100	53.54 ± 1.58	ND-GAIN (2015)
PGI	Poverty Gap Index	(Best) 0.02 - 52.8	57	3.66 ± 0.95	UNSD (2011)
PROS	Legatum Prosperity Index	0 - 100 (Best)	80	61.12 ± 0.99	Legatum (2013)
SDGI	Sustainable Development Goal Index	0 - 100 (Best)	80	59.90 ± 1.41	Sachs et al. (2016)
SPI	Social Progress Index	0 - 100 (Best)	77	69.12 ± 1.21	Porter (2015)
SSI	Sustainable Society Index	1 - 10 (Best)	83	5.14 ± 0.12	SSF (2012)
WGI	World Giving Index	0 - 100 (Best)	77	59.81 ± 5.95	CAF (2013)
WRI	World Risk Index	(Best) 0.08 - 36.72	93	8.22 ± 0.85	Birkmann & Welle (2016)

Notes: CAF = Charities Aid Foundation, CIESIN = Center for International Earth Science Information Network, EIU = Economist Intelligence Unit, GFN = Global Footprint Network, HF = Heritage Foundation, IEP = Institute for Economics & Peace, IGBP = International Geosphere-Biosphere Programme, Legatum = Legatum Institute, NEF = New Economics Foundation, ND-GAIN = Notre Dame Global Adaptation Initiative, SCF = Save the Children Fund, SOPAC = South Pacific Applied Geoscience Commission, SSF = Sustainable Society Foundation, TI = Transparency International, UNSD = United Nations Statistics Division, UNDP =United Nations Development Programme, WB = World Bank, YCELP = Yale Center for Environmental Law & Policy.

A multiple imputation procedure was used to eliminate all null values within the remaining 31 sustainable development indices across the 30 American countries (n = 30). The multiple imputation method: used all 31 indices for estimation; employed a linear multiple regression model; used a sequence that estimated indices with fewest null values first; and ultimately provided five estimated values for each null in the dataset (Appendix S1). Although other computer programs were trialed, the multiple imputation procedure ultimately chosen came from the statistical software SPSS (ver. 21, IBM, 2012). From the five estimated imputations, the median value was selected to replace each null score, completing the dataset for the forthcoming statistical analyses (Data S1). Lastly, each sustainable development metric was provided with its metadata: potential index range, intended directionality, percent of dataset originally complete for the study area, basic descriptive statistics, and references (Table 1).

The 31 sustainable development indices used in this study were as follows: child development index (CDI; SCF, 2008), child heath indicator (CHI; CIESIN, 2013), corruption perception index (CPI; TI, 2016), democracy index (DI; EIU, 2016), ecological footprint index (EF; Wackernagel and Rees, 1996; GFN, 2011), economic vulnerability index (ECVI; Feindouno and Goujon, 2016), education index (EDUI; UNDP, 2013a), environmental performance index (EPI; YCELP, 2012), environmental stress index (ESI; Prescott-Allen, 2001), environmental sustainability index (ESUI; YCELP, 2005), environmental vulnerability index (EVI; SOPAC, 2005), ecosystem well-being index (EWI; Prescott-Allen, 2001), gross domestic product (GDP; WB, 2011), global information networking institute coefficient (GINI; Gini, 1912; WB, 2014), global peace index (GPI; IEP, 2013), human development index (HDI; UNDP, 2014), happy planet index (HAPI; NEF, 2012), human well-being index (HWI; Prescott-Allen, 2001), human sustainable development index (HSDI; IGBP, 2010), index of economic freedom (IEF; HF, 2015), knowledge economy index (KEI; WB, 2008), life expectancy index (LEI; UNDP, 2013b), natural resource protection indicator (NRPI; CIESIN, 2013), Notre Dame global adaptation initiative index (ND-GAIN; ND-GAIN, 2015), poverty gap index (PGI; UNSD, 2011), Legatum prosperity index (PROS; Legatum, 2013), sustainable development goal index (SDGI; Sachs et al., 2016), social progress index (SPI; Porter, 2015), sustainable society index (SSI; SSF, 2012), world giving index (WGI; CAF, 2013), and world risk index (WRI; Birkmann and Welle, 2016).

3. Methods

3.1. Revealing sustainable development dimensions

A factor analysis (FA) was used to identify the hidden sustainable development dimensions of the original 31 indices across the 30 American nations. A derivative of principle components analysis (PCA), FA is a powerful statistical procedure that reduces input variables into a smaller number of latent unique "factors" by pronouncing sets of correlated variables (Tabchnick and Fidell, 2006; Johnson and Wichern, 2007). FA uses the overall data structure and correlated variable sets to create orthogonal groupings (axes). The input variables load onto the orthogonal axes (factors), which allow every index to be contrasted based on its correlation coefficient within each factor. FA was conducted within the statistical software JMP (ver. 13, SAS, 2016) using a principle components factoring method and prior communality (diagonals = 1). Prior to the FA, guided by Shapiro-Wilk normality test, the 31 indices were transformed where pertinent to approximate Gaussian distributions. Since FA was conducted on the correlation matrix, the 31 indices were standardized so that each had a variance of one. To aid in pronouncing the input indices to canonical factors, a varimax rotation was used to maximize the variance of the orthogonal axes (Tabchnick and Fidell, 2006; Johnson and Wichern, 2007). Using Kaiser's rule (Kaiser, 1960), eigenvalues greater than 1.0 were considered significant at separating the factors (sustainable development dimensions) for this study. Because factors are orthogonal linear combinations of the original input variables, future parametric tests can be confident of their data independence (Demšar et al., 2013).

The FA revealed seven statistically independent sustainable development dimensions (eigenvalue >1). Remaining factors with eigenvalues less than one were deemed statistically trivial and omitted. The latent canonical factors (e.g., underlying sustainable development dimensions) were discovered via each index's loadings on the seven orthogonal axes. The closer the coefficient was to either −1 or 1 conveyed that it had a stronger correlation to that sustainable development dimension. Each original sustainable development index was ultimately assigned to the factor with which it was most strongly correlated. It is important to note that the initial directionality of factor loadings and their corresponding scores are atheoretical from statistical software, thus requiring latent dimensions to be evaluated and manually directed toward sustainability (Floridi et al., 2011; Bolcárová and Kološta, 2015). A factor is often subjectively named by the shared characteristics of its strongest correlated variables within the statistical grouping. Although all indices on the orthogonal axis were taken into account, the three strongest loading metrics were used to name each sustainable development dimension. This practice has been accepted for interpreting and naming factor axes in earlier multivariate research related to sustainable development (see Gabriel et al., 2009; Shaker et al., 2015). Note that if two indices have the same correlation score but load oppositely on a factor axis, then the side with greater statistical weight (more metrics) should govern its overall thematic interpretation. Finally, for geographical assessment, factor scores of the seven latent sustainable development dimensions were illustrated using ESRI's (2016) ArcMap 10.4.

3.2. Calculation: mega-index of sustainable development

To help answer this study's guiding research questions, an aggregate (composite) index of the seven sustainable development dimensions was created. Each of the original 31 indices were considered useful for guiding progress toward sustainability, yet next to impossible to determine their comparative importance in doing so. Thus, it was deemed appropriate and necessary to reduce the 31 indices into a smaller number of latent sustainable development dimensions for multi-metric index construction. Thereby, all current sustainable development assessment themes were included in this first mega-index of sustainable development (MISD). To guide mega-index creation, a theoretical approach was chosen that: supports strong sustainability (Neumayer, 2003) for living within Earth's planetary boundaries (Rockström et al., 2009); requires resilience to cope with climate change ills (Brown et al., 2016; Cutter, 2016), and uses sustainable development planning strategies for managing coupled human-natural systems (Liu et al., 2007; Carpenter et al., 2009). Therefore, the applied definitions of "sustainability" and "sustainable development" by Shaker (2015) guided this work: "'sustainability' should be viewed as humanity's target goal of human-ecosystem equilibrium (homeostasis), while 'sustainable development' is the holistic approach and temporal processes that lead humanity to its end goal of sustainability" (305). Typical to sustainable development indices, the goals of all three sustainability spheres (economic growth, social equity, environmental integrity) have yet to be reached simultaneously, thus weighting and directional conflicts occur. All underlying dimensions were equally valued despite changing amounts of variance explained, as magnitude of statistical redundancy did not justify higher weighting for this study. Lastly, it was adopted that when sub-metric conflict occurred, the directionality that improved global life-supporting ecosystems was chosen (Shaker and Sirodoev, 2016).

With the theoretical basis established for original indices included, sub-metric weighting, and directionality, MISD was calculated using the seven latent dimensions of development (sub-metrics), which were directed toward sustainability, rescaled (normalized) 0 to 100, and aggregated by their geometric mean. First, each factor was defined and directionally assessed to determine whether its corresponding indices loaded naturally toward sustainability. Based on this evaluation, three of the seven factors were reversed from their original loading structure; redirecting their corresponding sets of factor scores so that positive values represent good development. Next, the seven sustainability-directed latent dimensions were normalized using the 'distance from the best and worst performers' method (Kondyli, 2010) to create MISD sub-metrics. This common rescaling of each "dimension" positioned a country in relation to the study area's actual minimum and maximum values for that factor, normalizing its factor scores between 0 (worst case) and 100 (best case) using the following sub-index equation (I_{dim}):

$$I_{dim} = \frac{x - \min}{\max - \min} * 100$$

Where x is the observed directed factor score for a given country; maximum is the highest observed factor score across all study area countries; and minimum is the lowest observed factor score across all study area countries. The seven sustainable development sub-metrics were initially produced separately, and then combined (aggregated) by computing their geometric mean to create the first MISD:

$$\text{MISD} = \sqrt[7]{I_{dim} * \ I_{dim} * \ I_{dim} * \ I_{dim} * \ I_{dim} * \ I_{dim} * I_{dim}}$$

The geometric mean was chosen as it allowed the seven sustainable development sub-metrics to hold the same weight, and because it remains the most appropriate scientific aggregation technique for ratio-scale non-comparability sub-metrics (see Ebert and Welsch, 2004; Böhringer and Jochem, 2007). Finally, because the seven sub-metrics were rescaled 0 and 100, the same range bound the MISD; with greater values of MISD indicating better sustainable development conditions overall.

3.3. Evaluating common indicators

Improved data quality and open access to data sets has created an abundance of complex sustainable development indices for use in country-level assessments. As with this mega-index creation, a proliferation of "more indicators capture more development variation" neglects to make measuring initiatives inclusive. Besides capturing a majority of sustainable development variation, the best indices are easy to understand and rapidly computable across space and time. Most current sustainable development indices fail to accomplish this feat, often skipping over locations that need progress toward sustainability the most (Shaker and Zubalsky, 2015). In an effort to find holistic, rapid, and justifiable indicators for improving sustainable development assessments across space and time, and to elucidate tradeoffs made between winning locations and losing ones, 11 common indicators were selected for collinearity and exploratory correlation testing. Specifically, the indicators were: number of International Union for Conservation of Nature (IUCN, 2008) Red List species made into a density using country area (IUCN Red List/Km^2); World Health Organization's 2010 child mortality rate (Mortality Rate, <5) (WHO, 2010); World Bank's (WB, 2015) 2015 population growth rate, and metric tons of carbon dioxide per capita (Metric Tons Per-Capita CO_2); composition of land covers: percent forest circa 2011 (CIA, 2016), percent agriculture circa 2014 (WB, 2015), and percent urban circa 2010 (NGCC, 2015); and country geographical area (GADM, 2015), country's latitude (centroid), and its distance from the equator. Spatial analysis tools within ESRI's (2016) ArcMap 10.4 were used to create indicators not commonly found in referenced data sets (i.e., Population Density).

Using a two-step process, the following empirical method was used to help answer this study's guiding research questions. First, a two-tailed Pearson's product-moment correlation test was used to assess collinearity between the 11 common development indicators and MISD. Second, bivariate ordinary least squares (OLS) regression was used to assess explanatory power of the 11 selected indicators for characterizing the seven sustainable development sub-metrics and MISD. These bivariate statistics are two of the most common parametric tests for understanding inferential relationships. Pearson's correlation coefficient (r) and OLS's coefficient of determination (R^2) both range from 1 to −1, with values closer to 1 denoting stronger bivariate relationships; both tests have a P-value that accompany the coefficient indicating its level of statistical significance. Prior to running these inferential tests, the 11 common indicators were transformed where necessary to approximate Gaussian distributions. The Shapiro-Wilk normality test was used here, and also to assess OLS regression residuals *ex post facto*. JMP (ver. 13, SAS, 2016) was used for this step of the analysis.

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4. Results

4.1. Dimensions of sustainable development

The 31 original indices were reduced to seven sustainable development dimensions, which combined to explain over 85% of the variation in the original dataset (Table 2). The seven factors (sub-metrics) were named: (F1) socioeconomic well-being synergies; (F2) economic freedom and democracy; (F3) environmentally efficient happiness; (F4) ecosystem well-being; (F5) peace to economic vulnerability tradeoff; (F6) natural resources protection; and (F7) environmental stewardship and risk resilience. From the original reduction and sorting via FA, factors four, five, and seven were reversed so that sustainable development affirming indices loaded positively on their corresponding orthogonal axis. Details regarding final communality estimates and rotated factor loadings are found in the Supporting Information, Appendix S2.

Table 2
Loadings of 31 development indices across 7 hidden sustainability dimensions derived from factor analysis (varimax rotation method). Each index was assigned to the dimension (axis) with its strongest correlation. The three strongest indices are highlighted in bold type and were used to define the factor name.

	Positive correlations	Negative correlations	Explained variance (%)
Factor 1: Socioeconomic Well-being Synergies	HWI (0.75), **HDI (0.89)**, EDUI (0.86) EPI (0.73), LEI (0.84), GDP (0.56) CPI (0.59), CHI (0.86), ND-GAIN (0.74) **SDGI (0.91)**, KEI (0.60), HSDI (0.86)	PGI (-0.78), **CDI (-0.89)**, GINI (-0.64)	43.03
Factor 2: Economic Freedom & Democracy	PROS (0.48), **IEF (0.91)**, **DI (0.81)** **SPI (0.55)**	WGI (-0.55)	13.27
Factor 3: Environmentally Efficient Happiness	**HAPI (0.83), SSI (0.75)**	**EF (-0.72)**	10.05
Factor 4: Ecosystem Well-being	**EWI (0.93)**	**ESI (-0.93)**	6.13
Factor 5: Peace to Economic Vulnerability Tradeoff	**ECVI (0.58)**	**GPI (-0.81)**	5.55
Factor 6: Natural Resources Protection	**NRPI (0.86)**	--	3.95
Factor 7: Environmental Stewardship & Risk Resilience	**ESUL (0.60)**	**EVI (-0.70), WRI (-0.66)**	3.43

Technical notes: factoring method = principle components; prior communality = principle components (diagonals = 1).
For detailed factor loadings and communalities see Appendix S2.

Factor 1, often considered the most important dimension within FA, accounted for 43% of the variance and its indices were dominated by socioeconomic themes. Overall, the strongest sustainable development-affirming indices conveyed the importance of education, human life longevity, early childhood wellness, and affluence. Specifically, SDGI, HDI, EDUI, CHI, and HSDI had the strongest positive loadings (≥0.86) on this axis. The strongest sustainable development-refuting index was CDI (-0.89), which exposes neglect of childhood health and education. Unequal distribution of wealth was also revealed on the negative side of this axis by the loading of PGI (-0.78) and GINI (-0.64). Geographically, Canada ranked best on this socioeconomic dimension, followed by the United States, Cuba, and Argentina; Haiti ranked worst, preceded by Guatemala, Honduras, and Bolivia (Fig. 2).

Factor 2 (accounting for 13% of the variance) was also interpreted again as a socioeconomic factor, with indices showcasing the importance of democratic governance, economic opportunities for individuals, and strong social capital for reaching sustainability. This dimension was the second most directionally contested sub-metric. The strongest positive loading indices within this dimension were economic freedom (IEF) (0.91) and democracy (DI) (0.81), while trading off charity through the negative and marginally loading index WGI (-0.55). WGI was the only index that loaded negatively on this axis, and many stronger indices loaded on the positive side of this axis. Therefore, the original directionality of this sustainable development dimension was maintained. The stronger factor loadings of IEF and DI thus largely controlled this axis at the cost of marginally trading off WGI. Geographically, Canada ranked best on this socioeconomic dimension, followed by Chile, Costa Rica, and United States; Cuba ranked worst, preceded by Venezuela, Ecuador, and Argentina (Fig. 2).

Factors 3 and 4 accounted for 10% and 6% of the variance, respectively. Both axes measured different aspects of the environmental integrity sphere. Specifically, Factor 3 captured human-environmental relationships, with measures of environmentally efficient happiness (HAPI) and sustainable society (SSI) loading positively (0.83) and (0.75), respectively. Contrarily, the very popular index ecological footprint (EF) index, which measures humanity's lack of consumption efficiency in relation to Earth's biocapacity, loaded negatively (-0.72). Geographically, Costa Rica ranked best on this environmental dimension, followed by Antigua and Barbuda, El Salvador, and Guatemala; Trinidad and Tobago ranked worst, preceded by United States, Canada, and Haiti (Fig. 2). Factor 4 measured the quality of ecosystem integrity, without aspects of human behavior. After reversing polarity, Prescott-Allen's (2001) ecosystem well-being index (EWI) and ecosystem stress index (ESI) controlled this axis in opposing directions, with strongest positive (0.93) and negative (-0.93) loadings, respectively. Geographically, Guyana ranked best on this environmental dimension, followed by Belize, Peru, and Bolivia; Mexico ranked worst, preceded by the Bahamas, Chile, and Barbados (Fig. 2).

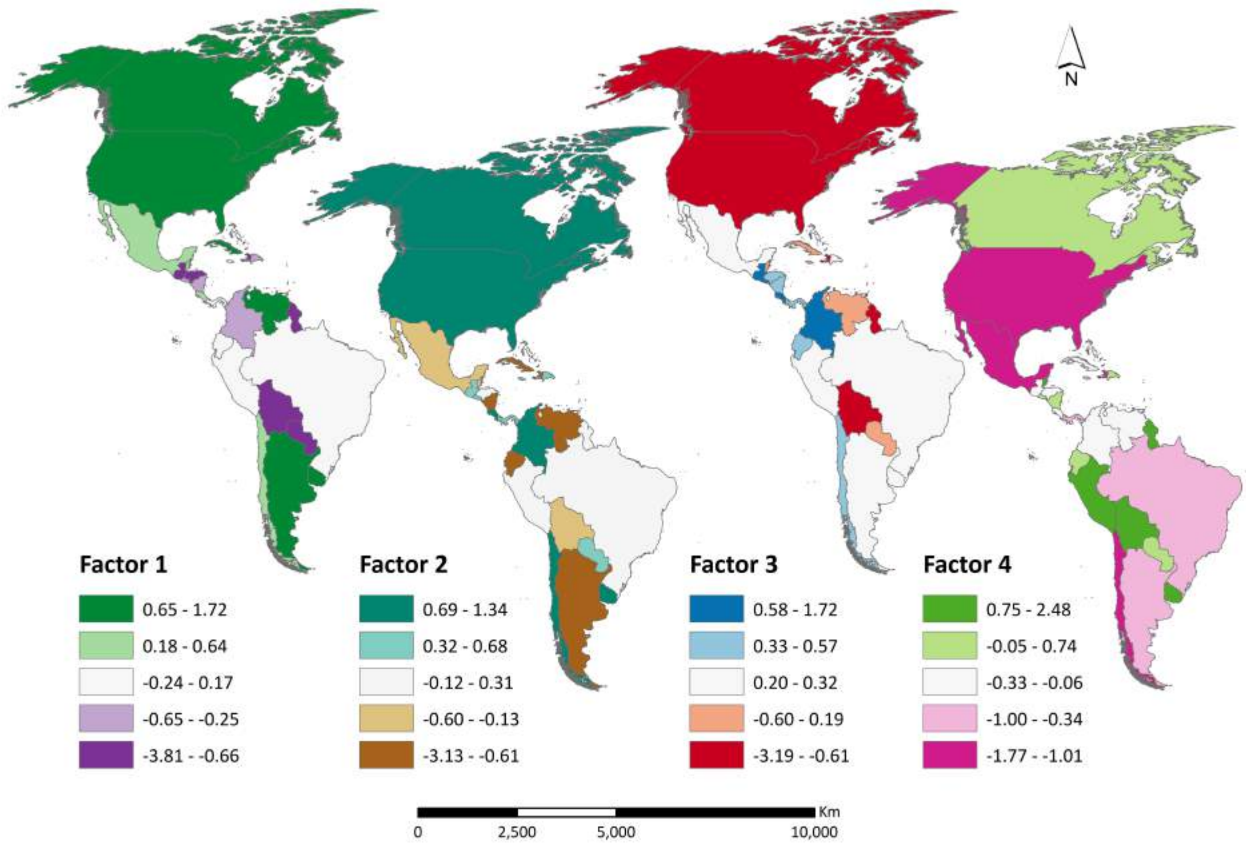

Fig. 2 Geographic patterning of factor scores for the first four hidden dimensions (eigenvalues >1) of sustainable development across the Americas. The Factors are F1, socioeconomic well-being synergies; F2, economic freedom and democracy; F3, environmentally efficient happiness; and F4, ecosystem well-being. Increased factor scores equate to improved dimension conditions. *Cartographic note*: Choropleth categories represent quantiles.

Factor 5 (accounting for 6% of the variance) was interpreted as socioeconomic in nature, with competing indices conveying the importance of a resilient economy, improved domestic safety and security, and decreased international conflicts for reaching sustainability. This dimension was the most directionally questioned sub-metric because both indices were counterbalanced with lowest value targets. After reversing the polarity, this axis positively loaded the weaker economic vulnerability index (ECVI) (0.58) and negatively loaded the much stronger global peace index (GPI) (-0.81). In doing so, the stronger factor loadings of GPI largely controlled this axis at the marginal cost of trading off ECVI. Geographically, the Bahamas ranked best on this socioeconomic dimension, followed by Canada, Cuba, and Haiti; Barbados ranked worst, preceded by the Mexico, Colombia, and Peru (Fig. 3).

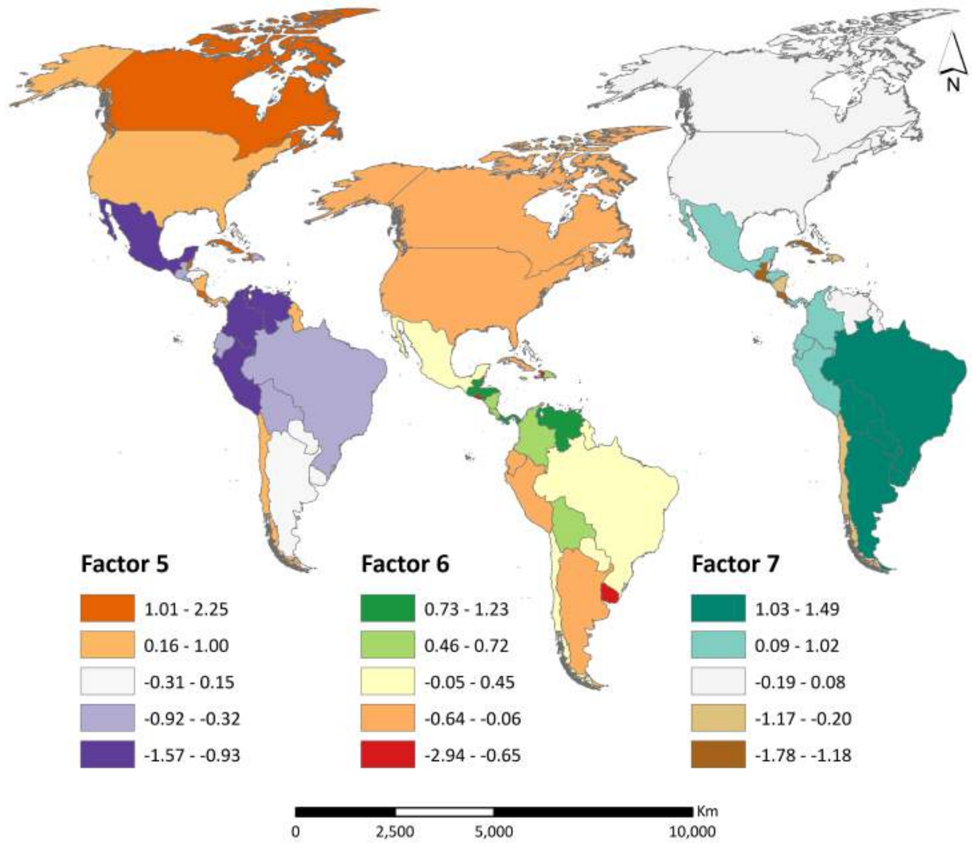

Fig. 3 Geographic patterning of factor scores for the last three hidden dimensions (eigenvalues >1) of sustainable development across the Americas. The Factors are F5, peace to economic vulnerability tradeoff; F6, natural resources protection; and F7, environmental stewardship and risk resilience. Increased factor scores equate to improved dimension conditions. *Cartographic note*: Choropleth categories represent quantiles.

Factors 6 and 7 accounted for 4% and 3% of the variance, respectively. Both axes measured different themes within the environmental integrity sphere, but were anthropocentric. Factor 6 was explained by one strongly correlated (0.86) index, natural resources protection index (NRPI), which contrasts countries by quality and quantity of biomes under protected environmental management (CIESIN, 2013). Geographically, Honduras ranked best on this environmental dimension, followed by Trinidad and Tobago, Panama, and Belize; Barbados ranked worst, preceded by the Haiti, Uruguay, and Saint Vincent and the Grenadines (Fig. 3). Factor 7 was explained by three indices, one positive and two negative, that expressed environmental management needs and risk prevention associated with human-induced hazards and natural disasters for reaching sustainability. After reversing polarity of this axis, environmental sustainability index (ESUI) loaded positively (0.60), while environmental vulnerability index (EVI) and world risk index (WRI) loaded negatively (-0.70) and (-0.66), respectively. Geographically, Brazil ranked best on this environmental dimension, followed by the Bahamas, Bolivia, and Uruguay; Jamaica ranked worst, preceded by the El Salvador, Costa Rica, and Guatemala (Fig. 3).

4.2. Americas' mega-index of sustainable development

Computing the geometric mean of the seven latent sub-metrics resulted in 30 observations of the mega-index of sustainable development (MISD), which covered most of the contiguous landmass of the Americas. The calculated values of MISD ranged from 15.4 to 69.6, while the mean (±SE) and median were 49.58 (±2.68) and 55.43, respectively. As commonplace to indices calculated using geometric mean, MISD's frequency distribution was notably left skewed (Fig. 4). Geographically, Belize ranked best overall on the mega-index of sustainable development followed by the Guyana, Panama, Uruguay, and Canada; Barbados ranked worst preceded by Haiti, Trinidad and Tobago, Mexico, and Cuba (Fig. 5).

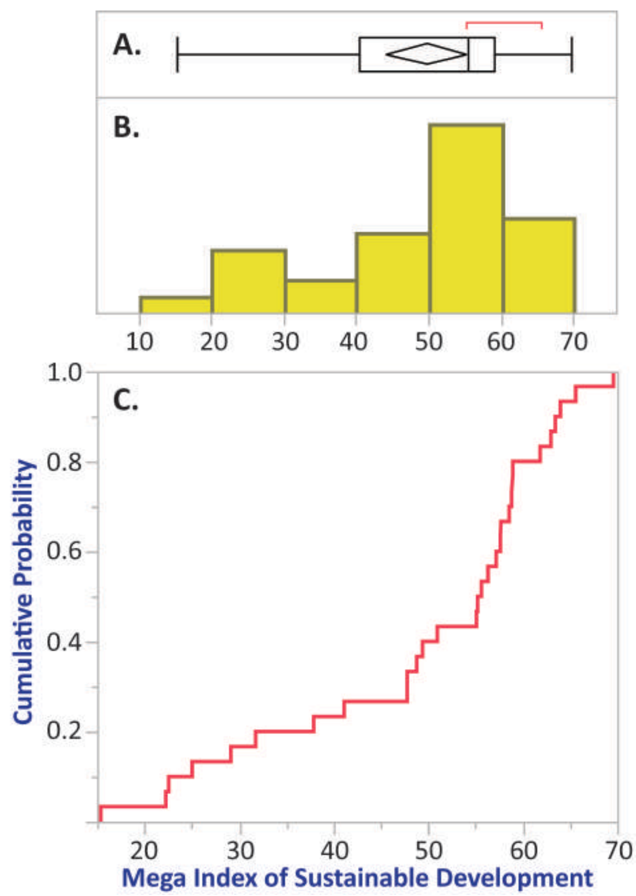

Fig. 4 Distribution of Americas' mega-index of sustainable development (MISD): box plot illustrating quartiles (whiskers are ±1.5 * interquartile range), confidence diamond for mean value, and *shortest half* bracket (A); frequency histogram (B); and cumulative distribution function plot (C).

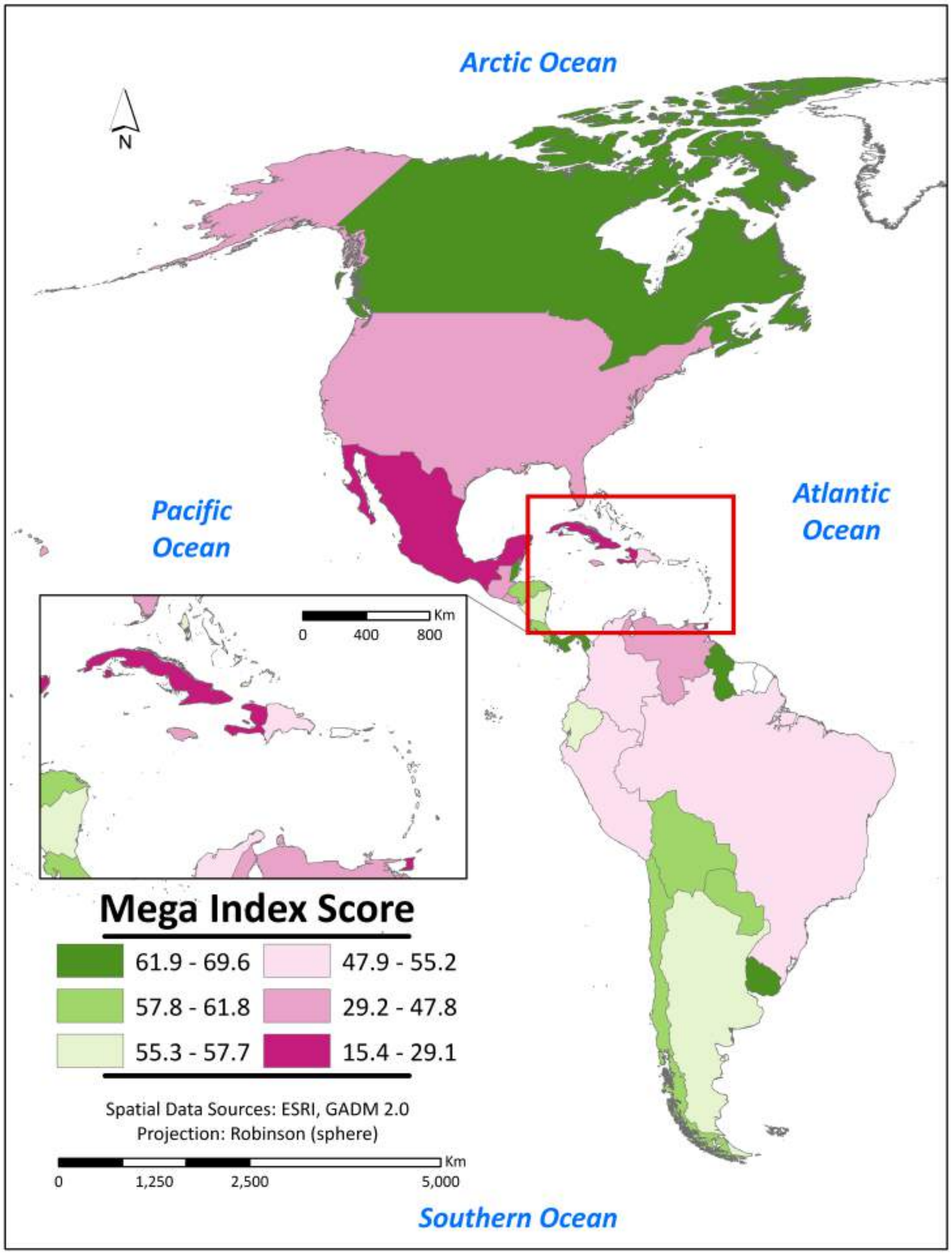

Fig. 5 Map illustrating the relative spatial distribution of the mega-index of sustainable development (MISD) for the Americas. The MISD is the geometric mean of the seven latent sustainable development dimensions found (Table 2). Higher MISD scores equate to improved sustainable development conditions. *Cartographic note*: Choropleth categories represent quantiles.

4.3. Collinearity of common indicators

Pearson's correlation coefficients for one indicator with the other 11 metrics ranged from -0.84 to +0.59 with varying levels of statistical significance (Table 3). Focusing on the relationships at the 99% level, nine statistical associations were further interpreted here. Regarding the 11 common development indicators, population density exhibited the highest degree of collinearity with four correlations recorded at the aforementioned statistical significance level ($P < 0.01$). Population density was negatively associated with country geographic area and percent forest, while it was positively associated with endangered species density (IUCN Red List/Km^2) and percent urban. IUCN Red List/Km^2 logged two correlations at this significance level: the first reiterated the positive relationship with population density; the second was the strongest correlation recorded, and was negative with country area. Percent forest recorded two negative correlations at this level, the first with the aforementioned population density and second with percent agricultural land. Percent urban area recorded two positive correlations at this statistical significance, the first with aforementioned population density and the second with metric tons of carbon dioxide per capita (Metric Tons Per-Capita CO_2). Country geographic area and population density chronicled an expected negative correlation at this significance level. Regarding MISD, two indicators were correlated at the 99% level. MISD was positively associated with percent forest, yet negatively with population density.

Table 3
Pearson product-moment correlation coefficients (two-tailed) matrix of 11 key selected indicators and the mega-index of sustainable development (MISD) for the Americas.

Indicator	12	11	10	9	8	7	6	5	4	3	2	1
Description	Pop. Gro.	Pop. Den.	CO_2	Dist to E.	Latitude	Area	Urban	Agland	Forest	<5 yrs	RED	MEGA
(1) MEGA-Index	0.32	-0.71**	-0.24	-0.00	-0.27	0.31	-0.45*	-0.31	0.53**	-0.17	-0.28	1
(2) IUCN Red List/Sq. Km.	-0.28	0.59**	0.12	-0.09	0.16	-0.84**	0.32	-0.20	-0.34	-0.06	1	
(3) Mortality Rate, <5 yrs	0.38*	0.21	-0.42*	-0.35	-0.13	-0.15	-0.07	0.14	0.03	1		
(4) Percent Forest	0.31	-0.58**	0.02	-0.35	0.07	0.34	-0.35	-0.64**	1			
(5) Percent Agland	-0.08	0.28	-0.40*	0.23	-0.23	0.11	0.05	1				
(6) Percent Urban	-0.31	0.53**	0.58**	-0.03	0.05	-0.36*	1					
(7) Country Area	0.24	-0.71**	0.03	0.16	-0.15	1						
(8) Latitude (+90° to -90°)	-0.01	0.24	0.30	0.13	1							
(9) Dist. from Equator	-0.06	-0.15	0.22	1								
(10) Metric Tons Per-Capita CO_2	-0.40*	-0.04	1									
(11) Population Density	-0.14	1										
(12) Pop Growth Rate	1											

** Correlation is significant at the 0.01 level.
* Correlation is significant at the 0.05 level.

4.4. Regressions of development

Results of the OLS bivariate analysis were used to understand the explanatory power of the 11 common indicators, and to characterize the seven sustainable development sub-metrics and MISD (Table 4). The socioeconomic well-being synergies sub-metric (Factor 1) was best explained by childhood mortality (Mortality Rate, <5) ($R^2 = 0.82$, $P < 0.001$), with a negative association (std. coeff. = -0.91). Metric tons of carbon dioxide per capita (Metric Tons Per-Capita CO_2) and population growth rate were also significant predictors of this sub-index dimension. None of the selected indicators were statistically significant at explaining the sub-metric dimension capturing economic freedom and democracy (Factor 2). The environmentally efficient happiness sub-metric (Factor 3) was best explained by metric tons of carbon dioxide per capita (Metric Tons Per-Capita CO_2) ($R^2 = 0.45$, $P < 0.001$), which was negatively associated (std. coeff. = -0.67). Also, percent urban area was marginally important at predicting this sub-index dimension. The sub-metric capturing ecosystem well-being (Factor 4) was best explained by population density ($R^2 = 0.17$, $P = 0.025$), and was negatively associated (std. coeff. = -0.41). Metric tons of carbon dioxide per capita (Metric Tons Per-Capita CO_2), percent urban, and percent forest were also significant predictors of this sub-index dimension.

Table 4
Bivariate ordinary least squares (OLS) regressions between the seven sustainable development sub-metrics, the mega-index of sustainable development (MISD), and eleven selected indicators.

	Factor 1 (Socioeconomic Well-being)			Factor 2 (Econ. Freedom & Democracy)			Factor 3 (Env. Efficient Happiness)			Factor 4 (Ecosystem Well-being)		
Indicator	R-square	*P*	Std. Beta	R-square	*P*	Std. Beta	R-square	*P*	Std. Beta	R-square	*P*	Std. Beta
IUCN Red List/Sq. Km.		--			--			--			--	
Mortality Rate, <5 yrs	0.82	****	-0.91		--			--			--	
Percent Forest		--			--			--		0.10	*	0.32
Percent Agland		--			--			--			--	
Percent Urban		--			--		0.12	*	-0.35	0.11	*	-0.33
Country Area		--			--			--			--	
Latitude (+90° to -90°)		--			--			--			--	
Dist. from Equator		--			--			--			--	
Metric Tons Per-Capita CO_2	0.18	**	0.43		--		0.45	****	-0.67	0.12	*	-0.35
Population Density		--			--			--		0.17	**	-0.41
Pop Growth Rate	0.18	**	-0.42		--			--			--	

	Factor 5 (Peace to Econ. Vulnerability)			Factor 6 (Nat. Resources Protection)			Factor 7 (Env. Steward. & Low Risk)			Mega-Index: Geometric Mean (Sustainable Development)		
Indicator	R-square	*P*	Std. Beta	R-square	*P*	Std. Beta	R-square	*P*	Std. Beta	R-square	*P*	Std. Beta
IUCN Red List/Sq. Km.		--		0.22	***	-0.47		--			--	
Mortality Rate, <5 yrs		--			--			--			--	
Percent Forest		--		0.54	****	0.74		--		0.28	***	0.53
Percent Agland		--		0.13	**	-0.36		--		0.10	*	-0.31
Percent Urban		--			--		0.13	**	-0.37	0.20	**	-0.45
Country Area		--			--		0.21	**	0.45	0.10	*	0.31
Latitude (+90° to -90°)		--			--		0.19	**	-0.43		--	
Dist. from Equator	0.13	**	0.36		--			--			--	
Metric Tons Per-Capita CO_2		--			--			--			--	
Population Density		--			--		0.37	****	-0.60	0.50	****	-0.71
Pop Growth Rate		--		0.12	*	0.35		--			--	

Levels of significance: *$P < 0.10$; **$P < 0.05$; ***$P < 0.01$; ****$P < 0.001$; -- no relation observed.
Dist. from Equator, Country Area, Population Density, Mortality Rate (<5 yrs. of age) transformed using: Log(x+1); IUCN Red List/Sq. Km., Metric Tons Per-Capita CO_2, Percent Urban transformed using: Arcsine(Square Root(x/100)); Percent Agland, Percent Forest, Latitude, Pop. Growth Rate exhibited Gaussian distributions.

The peace to economic vulnerability tradeoff sub-metric (Factor 5) was best explained by the indicator distance from the equator ($R^2 = 0.13$, $P = 0.049$), which was positively associated (std. coeff. = 0.36). The natural resources protection sub-metric (Factor 6) was best explained by percent forest ($R^2 = 0.54$, $P < 0.001$), also positively associated (std. coeff. = 0.74). Endangered species density (IUCN Red List/Km^2), percent agricultural land, and population growth rate (marginally) were also significant predictors of this sub-index dimension. The sub-metric capturing environmental stewardship and risk resilience (Factor 7) was best explained by population density ($R^2 = 0.37$, $P < 0.001$), which was negatively associated (std. coeff. = -0.60).

Country area, latitude, and percent urban were also significant predictors of this sub-index dimension. The multi-metric index, MISD, was best explained by population density (R^2 = 0.50, P < 0.001), with a negative association (std. coeff. = -0.71). Percent forest, percent urban, country geographic area (marginally), and percent agriculture (marginally) were also significant predictors of MISD. Lastly, the *ex post facto* Shapiro-Wilk test disclosed near Gaussians distributions of residuals for the statistically significant bivariate regressions.

5. Discussion

5.1. Balancing sustainability assessments

Evaluations of national-level well-being are maturing, as four and a half decades has passed since Nordhaus and Tobin's (1971) seminal work. Based on this study, the three pillars or spheres of sustainability (economic growth, social equity, environmental integrity) are not equally represented by current national-level measuring initiatives. Seven hidden dimensions of sustainable development were identified, and socioeconomic themed factors captured over twice the amount of variation as environmental. Next, the factor scores of the seven dimensions were mapped to differentiate "winning" locations from "losing" locations across the Americas. Concerning socioeconomic conditions, Canada collectively ranked best across Factors 1, 2, and 5 (total variation = 61.85%). Therefore, Canada may serve as an example for those nations looking for ways to improve their socioeconomic progress toward sustainability. Concerning environmental conditions, no country emerged as a single best example across Factors 3, 4, 6, and 7 (total variation = 23.56%). Consequently, American countries can look to the highest-ranking nations within the environmental themed dimensions for ideas on how to improve relationships with their biogeophysical environment and life-supporting ecosystems. Overall, winning countries were characterized by low population density, increased forestland, decreased urban, and larger country area.

Despite a few research groups focusing their national-level indices on the environmental pillar of sustainability, the results of this study suggest that the natural environment continues to be undervalued. Since the concept of sustainable development emerged from humanity's capacity for self-reflection, it is not surprising that it is anthropocentric, as basic human needs are not yet universally met. Short-term gains through neoclassical economics are also easy to understand, as benefits come through competition, which matches our evolutionary programing of "survival of the fittest" (Penn, 2003; Wilson and Wilson, 2007; Mesoudi, 2011). Moldan et al. (2012) brought attention to these topics with their reiteration of Maslow's (1968) work, which stated that an individual's basic needs (survival, physiological, safety, esteem, love) must be met before they act altruistically. Agreeing to this theory, sustainability scientists have continually prioritized human well-being at the cost of consuming biogeophysical resources and life-supporting ecosystems (see Kates et al., 2001; Griggs et al., 2013). The results of this study capture this tradeoff with per-capita CO_2 sacrificing ecological integrity for improved human well-being. Since humanity's long-term survival is contingent on environmental sustainability it should be equally valued during sustainable development assessments. Consider this thought experiment: Which could humanity live without in the future, a non-polluted atmosphere or improved material well-being? On the surface, the answer is simple, yet an unequal distribution of wealth has existed across humanity for millennia. The developed world has historically polluted the atmosphere and indirectly continues to do so through the globalized economy and its disposable income, thus the developing world is certainly deserving of greater material well-being. This example exposes the difficulties in trying to understand and justify tradeoffs among indicators of development across space and time. Therefore, important ethical, applied, and policy research remains for implementing and monitoring consumption, pollution, and other population-related limits to avoid reaching "thresholds" (Dearing et al., 2014) or surpassing "tipping points" (Phillips, 2015) of Earth's life-supporting biogeophysical systems. It is without question that many people will suffer greatly if Earth's natural systems are left to determine its optimal human carrying capacity.

5.2. Simplifying sustainability assessments

As previously argued, to reliably measure progress toward sustainability across spatial and temporal scales, simplified sustainable development indices are needed. Although sustainability scientists, regional planners, and policymakers find a wide set of indicators useful, practitioners and the general public often use a set of 10 to 15 key indicators to assess their most pertinent development needs (Dahl, 2012). Building on previous research, this study first reduced a set of 31 multi-metric sustainability indices into seven major dimensions. In doing so, the results revealed a high degree of redundancy across those measuring initiatives, suggesting that just a few indices could capture all sustainable development dimensions during national-scale assessments. This study also tested 11 common and freely available indicators to see whether they could empirically explain all hidden dimensions of sustainable development. The findings suggest that there is no "silver bullet" indicator within the set of 11 for explaining progress toward sustainability; however, the findings reveal that common indicators could be used to represent most of the sustainable development dimensions. Specifically, child mortality and population growth rate remain negative predictors of socioeconomic conditions. These metrics, along with common income and education indicators, make judging progress toward socioeconomic sustainability across spatial and temporal scales easier than judging progress toward environmental sustainability.

Metabolization of healthy and intact biogeophysical systems to meet human needs and improve material well-being has weakened humanity's life-support systems, making the need for sustainable development planning critical (Alberti, 2008; Pickett et al., 2011; Forman and Wu, 2016). Increases in percent urban, per-capita CO_2, and population density were consistently and negatively related to environmental conditions; conversely, increased forest composition was repeatedly linked to improved environmental integrity. Increased endangered species density was also negatively related to environmental well-being, but this indicator is not easily disaggregated from the national scale. The correlations between environmental sustainability dimensions and land cover percentages reiterates an important finding because land cover data sets have global coverage, are freely available, and can be easily added to existing indices at any spatial scale. Landscape ecology metrics, which capture configuration can be calculated from land cover data, provide detailed information useful for sustainable landscape design, ecological restoration, land-use zoning, and sustainable development planning (Turner and Gardner, 2015; Shaker, 2018). A fertile area of research remains for incorporating landscape ecology metrics into existing sustainable development indicator inventories, which would bolster the currently limited measures of environmental sustainability and help meet future biosphere policy goals.

5.3. Future index considerations

This study has limitations, as do others in the literature, that require future considerations. Along with the modest sample size of this study, there were unavoidable subjective choices made using expert opinion and supported by scholarly literature. Regarding creation of the mega-index of sustainable development (MISD), Factors 2 and 5 provided some directional difficulties due to one marginal loading index on each axis. A potential solution would have been to remove the outliers, but all indices were previously vetted by the scientific community and thus deemed appropriate to remain within this study. The directional anomalies were more likely due to this study's sample size, and data sets with more attributes than cases should be avoided where possible. Since factor analysis (FA) is based on the correlation matrix of the input metrics, Tabchnick and Fidell (2006) found that statistical relationships usually need a large sample size ($n > 300$) before they stabilize well. To avoid future computational anomalies, index creation using FA at the national-scale should include all 195+ world countries. It would also be ideal to have index and indicator data for all study area nations without the need to impute estimated values, as well as data for the same time period. Data availability issues such as these will remain troublesome unless simple indices are created and adopted for measuring progress toward sustainability.

Future sustainable development measuring initiatives should also remain mindful of matters pertaining to stakeholder inclusion, robustness analysis, spatial autocorrelation, thresholds-of-effect, trade-offs, and feedback mechanisms. Although few examples exist at the national-scale, incorporating stakeholder knowledge into index creation (i.e., selection of input indicators, directionality, weighting, validation) remains a fertile area for future research. Indeed, it would lead to future questions of who the appropriate stakeholders are for deciding the fate of sustainable development, and the appropriate mixed-methods needed to avoid potential injustices that could arise when attempting to manage coupled and shared-resource systems. It is at the nexus of quantitative and qualitative methods that abundant advances remain for assessing sustainable development across spatial and temporal scales. Multi-criteria decision analysis (MCDA), combined with spatial analysis tools (see Malczewski, 2006), and stakeholder opinion, should be considered a future approach to justify initial indicator selection, sub-metric directionality, and weighting. In doing so, critical attention to stakeholder inclusion and cross-referenced findings through pair-wise comparison would be required. For this study, a robustness analysis, commonly the arithmetic mean of all possible combinations of normalization, weighting, and aggregation, was not used because it was presumed to violate the same aggregation requirements for ratio-scale non-comparability sub-metrics established by Ebert and Welsch (2004). Lastly, thresholds-of-effect are still scarce within the literature on measuring sustainable development. Although there are exceptions (i.e., ecological footprint), most indices presume their best case reference location is at a sustainable condition and moving directionally toward it is sufficient. These metrics are good for ranking actors and prioritizing resources; however they provide little thresholds-of-effect information, which is useful for establishing proximity to target goals and benchmark initiatives.

Akin to indices needing recalculation using geometric mean, spatial autocorrelation should be considered when evaluating sustainable development across regions. Spatial autocorrelation is the lack of numerical independence of an attribute over space (Tobler, 1970), is commonly found in geographically inventoried data, and violates error independence required by parametric tests (Dormann et al., 2007). For this study, local regression methods that correct for errors associated with spatial autocorrelation (i.e., conditional autoregression; CAR) were considered; however they were deemed inappropriate due to centroid location issues caused by nations with distant islands, island states, and non-contiguous nations. Potential solutions include modifying shape geometry (e.g., removing islands) or using the capital or most prominent city of a country for spatial reference. With more than half of humanity living in cities, and megaregions largely controlled by their most influential cities, it is hypothesized that the connectivity (both virtual and physical) of these urban centers will foster solutions to sustainable development challenges locally, regionally, and globally. Additionally, akin to "smart cities" improving efficiency for urban dwellers, sustainable urbanization will continue to progress by combining Internet 2.0 technology, smartphone applications, and rapid-time sustainable development indices. This method will allow for instantaneous data collection and quick information dissemination, fueling practical behavior changes through solutions-based sustainability science. As humanity moves from "smart citizens" to "smart cities" to "smart regions," the rate of progress toward sustainability should minimally match that of technology implementation. However, much more research is required to understand humanity's temporal and spatial patterns of development and their impacts on advancement toward sustainability.

6. Conclusions

Sustainable development measuring initiatives have reached such volume that perhaps a sustainable development index revolution is now warranted. As with all rapidly growing academic and professional topics, theoretical and applied research can become so focused on improving accuracy of current practices that they often lose sight of practical application. In this regard, measuring progress toward sustainability now resembles true cost accounting rather than rapidly employable tools useful for the developed and developing world alike. Although access to and quality of data continues to improve, the need remains for indicators that are accurate, easy to understand, and usable across spatial and temporal scales. Therefore, a time for disciplinary self-reflection is warranted for sustainability indicators. A constructive sustainable development index revolution would allow sustainability scientists to streamline complex indices into simple, meaningful tools for operationalizing development planning and policymaking. Dismissing such a research paradigm based on past sustainability failures (i.e., Easter Island, Biosphere 2), would only obstruct sustainable development monitoring programs and prevent future refinement. Indeed, the study presented herein is not immune to subjectivity concerning index inclusion criteria and sub-metrics descriptions, directionality, and weighting. These limitations reflect the current status of sustainability assessment as a whole, thus future research into best practices is warranted. To the antagonists, humanity's ability to reach sustainability is akin to our ability to create a perpetual motion machine and equally futile. However, to reject future studies like this one because they have limitations, or because sustainability seems impossible to reach, would be to abandon any hope for society's long-term survival altogether.

A study of 30 Western Hemisphere nations was presented around four research questions and three amassing methodological objectives. Its overall goal was to create the first mega-index of sustainable development (MISD), with the aim to improve humanity's ability to calculate progress toward sustainability through an inductive approach. In doing so, 31 known indices were reduced into seven underlying dimensions of sustainable development, then normalized 0 to 100, and aggregated by their geometric mean. The seven orthogonal axes (latent dimensions) were subjectively articulated as: (1) socioeconomic well-being synergies; (2) economic freedom and democracy; (3) environmentally efficient happiness; (4) ecosystem well-being; (5) peace to economic vulnerability tradeoff; (6) natural resources protection; and (7) environmental stewardship and risk resilience. Overall, this study found that the underlying socioeconomic themes of sustainability dwarfed environmental themes, signifying a greater need for more simple, accurate, and scaleless (spatial and temporal) biogeophysical indicators. Using Pearson's correlation and bivariate ordinary least squares (OLS) regression, 11 common development indicators were then explored regarding collinearity and explanatory power of the sustainable development dimensions and MISD. In sum, winning countries were characterized by low population density, increased forestland, decreased urban, and larger country area. The presented evidence is sufficient to suggest that just a few common and freely available indicators could eventually capture all present dimensions of sustainable development. However, it would be incorrect to assume the 11 common and freely available indicators chosen for this study are all-encompassing; others indicators that easily cross spatial and temporal scales should also be investigated. In conclusion, it is believed that mega-index creation will serve as an important scientific stepping-stone for improving accuracy and simplifying valuations of sustainable development, thus others should follow.

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LIST OF APPENDICES

Appendix S1: Multiple imputation details for missing data method, modeling technique, and imputation sequence for the 18 sustainable development indices with null values estimated.

Appendix S2: Detailed factor loadings and final communality estimates resulting from the rotated factor analysis of the 31 included sustainable development multi-metric indices.

Appendix S3: Pearson product-moment correlation coefficients (two-tailed) matrix for seven sub-metric Factor scores and their composite mega-index of sustainable development. Figure includes histograms, bivariate scatter plots, fit lines, r-values, and p-values for significant relationships.

Data S1: Two databases in comma separated values (CSV) format for the 30 study area countries: (i) raw indicator and null values for the 31 indicators; and (ii) imputed indicator values, factor scores, re-directed factor scores, 11 key indicators, and mega-index values.