The spatial distribution of development in Europe and its underlying sustainability correlations

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A B S T R A C T

The majority of national governments now dedicate themselves to sustainable development as it aims to produce a long-term, positive relationship between civilization and life-supporting planetary resources. By doing so, societies have also embraced indicators as tools to provide comprehensive assessment of the current position, gauge improvement, and help set future development goals; however there remains no unanimous agreement regarding their theoretical foundation, design, nor use. The number of sustainability measures available for quantifying development is overwhelming to planners, scientists, and policymakers, thus clarification of interrelationships, redundancy, and spatial distributions is needed.

First, this study reduced and described a set of 30 multi-metric sustainability indices across 36 European nations. A multivariate factor analysis identified five major dimensions (or axes) that conveyed over 80% of the total variation of the original 30 development measures. Second, spatial autoregressive analyses of childhood mortality, endangered species density, and population growth rate revealed statistical correlations with one or more of the five development factors. The five axes of sustainable development are expressions of: prosperity, equality, and governance; quality of life; ecosystem integrity; environmentally efficient happiness; and environmental management. Of these, Factor 1 (prosperity, equality, and governance) explained more than one-third of the total variance, and positively clustered in northwest Europe and negatively in southeast Europe. Results suggest that a few key indicators could be used when evaluating a country's overall development status during continental and global scale sustainability assessments. Lastly, the findings reveal an overall underrepresentation of ecological (biosphere) well-being within current measures of sustainable development.

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1. Introduction

Humanity is enduring a period of unprecedented change of economic welfare, social equity, environmental quality, driven largely by exponential population growth and an increased demand for improved human well-being. This increasing demand for material goods and services has limited humankind's capability to safeguard Earth's life-supporting ecosystem services and thus biodiversity (Foley et al. 2005; Butchart et al. 2010; Defries, Rudel, Uriarte, & Hansen, 2010; Godfray et al. 2010; Weinzettel, Hertwich, Peters, Steen-Olsen, & Galli, 2013). Recently researchers have argued that environmental degradation is not due to overpopulation as much as it is direct and indirect overconsumption of resources and pollution by the wealthy (Penn, 2003; Hughes & Johnston, 2005; Weinzettel et al., 2013). Civilization's resource demands, often measured by ecological footprint (EF) at the global scale, have exceeded the planet's biocapacity for the past 40 years, and it has been estimated that humankind will need the land and sea resources equal to two Earths by the 2030s (WWF, 2014). Besides the environmental ramifications associated with population growth and consumption, there remains a prerequisite for an increase in living standards for much of the world (NRC, 1999; Kates et al. 2001; Clark & Dickson, 2003; Parris & Kates, 2003), since over 14.5 percent of humanity remain in 'extreme poverty' (<$1.25 US/ day) and lack natural resources to meet their basic survival requirements (WBG, 2014).

Despite its acknowledged shortcomings (see Keiner, 2006; Rogers, Jalal, & Boyd, 2008), the decree of sustainable development by the United Nations World Conference on the Environment and Development (UNCED) in Rio de Janeiro (1992) hallmarkd a new era in global awareness. Sustainable development, defined within the Brundtland Commission’s Our Common Future, was globally defined as: “development that meets the needs of the
present without compromising that ability of future generations to meet their own needs” (WCED, 1987:43). In general, sustainable development focuses on two key concepts: 1) providing essential needs to the world’s poor through overriding priority; and 2) that technology and social organization has limits to the environment’s ability to meet humanity’s present and future needs. For this study, the term “sustainability” should be viewed as humanity’s target goal of human–ecosystem equilibrium (homeostasis), while “sustainable development” refers to the holistic approach and temporal processes that lead us to the end point of sustainability.

Progressing sustainable development is now primarily contingent on applied research and application. Over a decade and a half ago, it was stated that we must get past the lip-service surrounding sustainable development and create initiatives that put theory into practice (Campbell, 2000). As part of this process, a plethora of private and public institutes have generated an overwhelming number of development indicators for assessing sustainability. Indicators and composite indices are increasingly recognized as useful tools for policy-making because they convey information on a country’s performance towards their specific goals within the three major divisions of sustainability (economic welfare, social equity, environmental quality) (Shaker & Zubalsky, 2015). In Chapter 4.1 of Agenda 21, the need for sustainability indicators was articulated: “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).

By agreeing to the sustainability challenge, nations have designated indicators as quantifying tools for cultivating development (Moran, Wackernagel, Kizses, Goldfinger, & Boudaoud, 2008). Literally hundreds of indices have been created for measuring progress towards sustainability at the country scale, making the application process overwhelming to scientists, planners and policymakers. Many of the complex sustainability indices have been, and continue to be, created with similar methods and from similar data sources (e.g., World Bank, World Health Organization). Accordingly, the amount to which indices differ in their results using the same data is due to their assumptions, biases, and methodological differences, creating great misunderstanding for the sustainability effort (Mayer, 2008). Sustainable development indicators available to practitioners has also been said to be “voluminous” and “not very well focused,” and lie heavy on environmental assessment while underrepresenting social and economic evaluation (Moldan, Hák, Kovanda, Havránek, & Kusková, 2004; Moffatt, 2008). To end, Shaker and Zubalsky (2015) found many common sustainable development indices too complex for assessing progress in the emerging nations that may need it most.

2. Approach

Although it has been more than two decades since Agenda 21 first called for sustainable development indicators, there remains no unanimous agreement regarding their theoretical foundation, design, nor use. In the growing sustainability literature on measuring development, two leading approaches have emerged: single indicator use or multiple indicator use. Some analyses propose that inconsistency surrounding sustainable development assessment could be resolved through the application of several balancing measures (e.g., Mayer, 2008), and others suggest a holistic consensus is found through employing many different metrics simultaneously (e.g., Shaker & Zubalsky, 2015). On the other hand, studies have advocated that the establishment or selection of a single key indicator would be best for measuring development progress towards sustainability (e.g., Moffatt, 2008). To date, there are no agreed upon methods for assessing development nor attaining sustainability across spatial scales of planning (Keiner, 2006). Thus, policymakers have encouraged researchers to create innovative methods that integrate various techniques for new sustainable development planning (Grosskuth, 2007). To further elucidate indicator complexity and usefulness, this study quantitatively examines 33 sustainable development indices across 36 European nations through an applied geographical approach.

Traditionally, it has been thought to employ a wide range of indicators to characterize the different dimensions of sustainable development being studied (Maclaren, 1996). Based on a review of roughly 70 different frameworks for evaluating sustainability by Singh, Murty, Gupta, and Dikshit (2012), indicator creation has taken an inclusive approach to measuring sustainable development similar to true-cost accounting rather than an operational one. Theoretically, this has been supported (i.e., Mayer, Thurston, & Pawlowski, 2004; Mayer, 2008) because sustainability has long been recognized as too broad a topic for being captured by just a few specific indicators. However, there is a lack of empirical justification for discrediting a reductionist approach to measuring sustainable development that leads to holistically accurate, justifiably simple, and operational indices. Phillips (2015) recently supported this idea by stating that evaluations of global sustainability have been based predominately on subjective or professional judgment, rather than quantitative approaches.

While other studies have investigated interrelationships between sustainability indicators, few have openly attempted to simplify a set of development measures into a small number of canonical variables to further understand sustainable development. Building upon preceding studies that scrutinize relationships between measures of sustainability, the present research investigates 33 indices for the majority of European nations. The spatially explicit database of development indices was compiled for two purposes. First, this study attempts to identify and analyze what degree a collection of sustainability metrics are interrelated, and if they can be simplified into key underlying development factors for an improved understanding of sustainable development. Secondly, this study investigates the spatial distribution of childhood mortality, endangered species density, and population growth rate, and to what degree the aforementioned development factors correlate with their distributions. Empirically, the following two null hypotheses are tested: (1) no underlying dimensions of sustainability exist within 30 multi-metric indices of development; and (2) the three distinct development indicators—childhood mortality, endangered species density, and population growth rate—do not individually capture all dimensions of sustainable development. By openly distinguishing quantitative and spatial patterns of development, this study intends to elucidate multifaceted human-environmental relationships that impact humanity’s progress towards sustainability. This research also aims to deliver sustainability scientists, policymakers and regional planners tools for thoroughly analyzing a country’s development status during continental and global scale sustainability assessments.

3. Data and methods

3.1. Selected measures of development

The present empirical investigation of sustainable development indices takes place across 36 of the roughly 50 countries of Europe (Fig. 1). Nation states were included in this study if they were represented in Prescott-Allen’s (2001), The Wellbeing of Nations: A Country-by-Country Index of Quality of Life and the Environment, first global assessment of sustainability. The 36 European sovereign states or dependent territories were represented only on the basis of data availability, not by choice. The study area nations (roughly
5.7 million km² in area) are almost entirely contiguous; albeit minus the Russian territory between Lithuania and Poland, and the space making up Serbia, Montenegro, and Kosovo.

The 30 multi-metric indices used to create conical factors of development across Europe were chosen to equally represent the three major divisions of sustainability (economic welfare, social equity, environmental quality) (Table 1). It should be noted, within a distinctly different and preceding study, Shaker and Zubalsky (2015) utilized 25 of the 30 development metrics to create country-bundles of similarity (using Ward’s cluster analysis) for an overall regional assessment of Europe. Please note that many development metrics combine two major aspects of sustainability, but few capture all three division needs simultaneously.

The 30 aforementioned measures can be broadly grouped into two categories: Gallup World Poll (www.gallup.com) and non-Gallup World Poll allied indicators. The eleven Gallup World Poll (GWP, 2006) measurements used in this research were: community attachment index (CAI), community basics index (CBI), civic engagement index (CEI), corruption index (CI), experiential well-being index (EXWI), law and order index (LOI), national institutions index (NII), optimism index (OI), positive experience index (PEI), social wellbeing index (SWI), and thriving index (TI). The 19 non-Gallup World Poll measurements used in this research were: ecological footprint (EF) (Wackernagel & Rees, 1996; GFN, 2006), educational index (EI), environmental performance index (EPI) (Esty et al. 2008; YCELIP, 2012), environmental sustainability index (ESI) (YCELIP, 2005), environmental vulnerability index (EVI) (SOPAC 2004), ecosystem wellbeing index (EWI) (Prescott-Allen, 2001), gross domestic product (GDP), global information networking institute coefficient (GINI) (Gini, 1912), global peace index (GPI) (IEP 2008), human development index (HDI) (Tata & Schultz, 1988; UNPD, 2006), happy planet index (HPI) (Marks, Abdallah, Simms, & Thompson, 2006), human wellbeing index (HWI) (Prescott-Allen, 2001), life expectancy index (LEI), natural resource protection indicator (NRPI) (CIESIN, 2006), poverty gap index (PGI), quality of life index (QLI) (EIU, 2005), social capital sub-index (SCSI) (Legatum, 2012), sustainably society index (SSI) (SSF, 2008), and world giving index (WGI) (CAF, 2010). Effort was taken to assemble a dataset for a comparable time period circa 2006, but the aforementioned was constrained to include published metrics ranging from 2001 to 2012. The 30 different indices were also presented with the metadata: conceivable range, basic descriptive statistics, degree of spatial autocorrelation, source and date published (Table 1).

In an attempt to find key endpoints for measuring sustainable development across scales, and to expand knowledge of human-environmental relationships, three potential measures were selected for exploratory correlation testing after the data reduction factor analysis. Specifically, the mortality rate of children under five (socioeconomic condition) and the density of threatened, vulnerable, or endangered species (ecological condition) were hypothesized to be key barometers for measuring a country’s overall development status. The 2008 childhood mortality rate (Mortality Rate, <5) data used in this study were acquired from the World Health Organization (www.who.int), and is understood to be the probability per 1000 live births that a newborn will be deceased before age five (WHO, 2008). The number of threatened, vulnerable, or endangered species was summarized for each of the 36 countries in this study. Those data (aka, IUCN Red List) were acquired for 2008 from the International Union for Conservation of Nature (IUCN, 2008) (www.iucnredlist.org). To circumvent the effects of heterogeneous sized areal units, and to improve accuracy during spatial analysis, a country’s total IUCN Red List species was divided by area to create the density measure IUCN Red List/Km².
Finally, due to its continued importance and applicability, the last key indicator hypothesized for measuring a country’s overall development status was population growth rate. The population growth rate for 2008, understood as the exponential rate of growth of midyear population from year \( t-1 \) to \( t \), was acquired from the World Bank (WB, 2008) (www.data.worldbank.org) for use in the forthcoming analysis. The year 2008 was chosen for the three key development measures because of data inventory improvements (e.g., species inclusion) associated with the Red List release that year, and its relevant comparability with the aforementioned 30 indices dataset.

### 3.2. Data analysis

Through traditional multivariate, spatial univariate, and spatial auto-regressive statistics, an empirical methodology is presented hereafter using three steps. (1) To reduce the number of multivariate development indices \( n = 30 \) into a small number of canonical variables, the popular dimensionality reduction method factor analysis (FA) was conducted. FA is an atheoretical technique to place variables into orthogonal groupings suggested by the data, not defined \textit{a priori}. The general aim of a FA is to reduce the input variables by pronouncing structure among many variables in terms of a few underlying (but not directly perceivable) collections which are called ‘factors’ (Ritters et al., 1995). The input variables load onto these factors, allowing the evaluation of factor relationships with all the variables to be estimated. There are several extraction procedures leading to factors. FA was conducted within the statistical software \textit{JMP} (ver. 11) (SAS, 2013) using a principle components factoring method with common factor analysis prior communality (diagonals = SMC). A varimax rotation was used in order to maximize the variance of the factors (Kaiser, 1958), thus aiding the classification of variables to canonical factors (Johnston, 1986). Prior to the analysis, the 30 indices were transformed where obligatory to approximate a normal distribution for parametric tests.

Five factors (dimensions or axes) were suitable for portraying the development dataset for two reasons. First, a minimization of variables was sought and second, the first five factors had eigenvalues >1, which is the standard rule for selecting dimensions that explain a significant amount of variation. As factors are orthogonal, linear combinations of the original input variables, regression and other methods (e.g., cluster analysis) can proceed with data independence assured (Demsar, Harris, Bronsdon, Fotheringham, & McLoone, 2013). It is standard to interpret the factors by examining the shared characteristics of indices that form a collection associated with a given factor, and the correlations (‘loadings’) of indices within that factor (Ritters et al., 1995). Although all correlated metrics were taken into account, the three strongest indices were used to define each factor names. Finally, factor scores for the five canonical dimensions were entered into ESRi’s (2014)ArcMap 10.2 to illustrate regional patterns and for further spatial analysis.

In applied sustainable development examinations, it is imperative to take into account spatial nonstationarity so that statistical methods that control for the lack of independent observations can be selected if needed. (2) To assess spatial autocorrelation and to visualize local clustering, an exploratory spatial data analysis (ESDA) was conducted at both global and local levels. The first law
of geography sustains that variables nearer in space are more alike (spatially autocorrelated) than variables that are farther apart (Tobler, 1970). Spatial autocorrelation, the lack of univariate stationarity or independence between attributes across space, is commonly found in geographically inventoried and circulated data (Legendre & Legendre, 2012), and should be seen as both beneficial and problematic in applied sustainability science studies. In general, the presence of spatial nonstationarity is seen as a significant limitation for testing hypotheses and forecasts attribute values (Lennon, 2000; Dormann et al., 2007). Spatial autocorrelation has been found to be problematic when using conventional statistical tests (e.g., ordinary least squares; OLS regression), because it violates the notion of independently distributed errors (Legendre & Legendre, 2012; Haining, 2003). Additionally, standard errors are frequently undervalued when positive spatial nonstationarity is present, therefore Type I errors may be overestimated (Legendre & Legendre, 2012). One benefit of spatial autocorrelation is that it can provide pattern justification from process (Palma, Beja, & Rodrigues, 1999), and ‘hotspots’ maps are often created to reflect these spatial relationships.

Although other techniques have been recognized to assess spatial nonstationarity (e.g., Mantel's r-test), the popular global Moran’s I test (Moran, 1950) was employed to assess the level of autocorrelation of attributes across the study area. Additionally, to illustrate geographic clustering of the five factors and three key development indices, the local index of spatial association (LISA) (Anselin, 1995) Moran’s I was conducted. Other sustainable development topics that assessed global and/or local distributions similarly include: bicycle facility planning (Rybarczyk & Wu, 2010); food consumption (Morrison, Nelson, & Ostry, 2011); land cover transformation (Su, Jiang, Zhang, & Zhang, 2011); resource availability induced emigration (Leyk et al. 2012); carbon dioxide (CO₂) emissions (Huang & Meng, 2013); forest insect outbreaks (Bone, Wulder, White, Robertson, & Nelson, 2013); and landscape impacts on water quality (Shaker & Ehlinger, 2014). Prior to the final step of the analysis, the aforementioned univariate Global and Local Moran’s I tests were also used to assess spatial nonstationarity for the three key response variables. Using queen contiguity, ESRI’s ArcMap 10.2 Spatial Statistics toolbox was employed during this step.

(3) Bivariate associations between the five canonical dimensions and three hypothesized key indicators of development (childhood mortality, endangered species density, population growth rate) were conducted to establish potential relationships using a conditional auto-regressive (CAR) method. To meet the need for normality for the three selected dependent variables, childhood mortality (Mortality Rate, <5) required log₁₀ transformation and endangered species density (IUCN Red List/Km²) arcsine-square root; population growth rate was normally distributed. CAR is a spatial auto-Gaussian technique that corrects for spatial autocorrelation by considering the correlation among error terms (spatial error), which is achieved by adding a distance-weighted function of neighboring dependent values to the model’s independent variables (Fotheringham, Brundson, & Charlton, 2004; Wall, 2004; Dormann et al., 2007). Identical to traditional regression (OLS), CAR partial regression coefficients (Sokal & Rohlf, 2012) or associated coefficient t-values of independent variables (Tognelli & Kelt, 2004) are used to understand directional and rank “effects” on the dependent variable (Bini et al., 2009). CAR models were undertaken using an estimated rho per regression and Alpha set to 1.0. As spatial autocorrelation in the residuals violates the notion of independent observations (Wagner & Fortin, 2005), the model residuals were assessed ex post facto by global Moran’s I statistic. Other sustainable development related studies that employed this local regression verification technique include Leyk et al. (2012) and Shaker and Ehlinger (2014). The CAR models were generated using the free and publically available software Spatial Analysis in Macroecology (SAM) (ver. 4) (Rangel, Diniz-Filho, & Bini, 2010).

4. Results

4.1. Descriptions of European development

From the spatially referenced database of 30 multi-metric indices covering one, or a combination, of the three major dimensions of sustainability (economic welfare, social equity, environmental quality), the factor analysis extracted five significant and independent factors (Eigenvalue >1) that explained over 80% of the variation (Table 2). The remaining correlated or statistically insignificant dimensions were disregarded. Putative canonical dimensions (e.g., underlying ‘meta-variables’) were acknowledged by the loadings of individual indices on each orthogonal axis. The five factors were named: prosperity, equality, and governance (Factor 1); quality of life (Factor 2); ecosystem integrity (Factor 3); environmentally efficient happiness (Factor 4); and environmental management (Factor 5). It is important to note that variables were associated with more than one factor; however each development index was assigned to the factor with its strongest correlation. For final communality estimates and rotated factor loadings details see Supporting Information, Appendix Table S1.

Factor 1 (describing 33% of the variance) was associated negatively with indices expressing income inequality and government corruption, while being positively associated with metrics pertaining to affluence, social capital, optimism in governance, and equality. Particularly, CI had a very strong negative loading (−0.88), and OI, SCI, and TI had strong positive loadings (≥0.80) on this axis (Table 2). That said, the following ten other indices had moderately strong to strong positive correlations: CAI, CBI, CEI, EF, EI, EXWI, GDP, NII, SWI, and WGI. Only one other index, GNI, had a somewhat low negative loading. Thus, this axis is best interpreted as anthropocentric. Geographically, Denmark, Ireland, Netherlands, Norway, and the United Kingdom recorded the highest levels of prosperity, equality, and governance; however Albania, Bosnia-Herzegovina, Portugal, and Greece scored lowest on this factor (Fig. 2).

Factor 2 (accounting for 24% of the variance) was associated negatively with one variable, GPI, capturing a nation’s peacefulness, while being positively linked to indices of human well-being. This axis is best summarized as quality of life and is also anthropocentric. Particularly, GPI had a moderately strong negative loading (−0.70), and LEI, PEI, and QLI had strong positive loadings (≥0.78) on this axis (Table 2). Additionally, the following four other indices had positive correlations: HDI, HWI, LOI, and PGI. Geographically, Austria, Finland, Portugal, Spain, Italy, Greece, and Slovenia recorded the highest quality of life levels; however Belarus, Romania, Macedonia, Moldova, and Ukraine scored lowest within this orthogonal development theme (Fig. 2).

Factor 3 regarded for 9% of the variance, and collectivity measured ecosystem integrity. This orthogonal development theme focused solely on ecological (biosphere) well-being, without aspects of human behavior (anthropocentric). Specifically, the one index EVI had a strong negative loading (−0.76), and ESI and EWI had strong to very strong positive loadings (≥0.76) for this canonical axis (Table 2). Geographically, Albania, Belarus, Finland, Iceland, Latvia, Norway, and Sweden recorded the highest levels of ecosystem integrity; however Belgium and Netherlands scored lowest on this factor (Fig. 2).

Factors 4 and 5 accounted for 8% and 7% of the variance, respectively. Both axes are ecologically (biosphere) sensitive, but remain contingent on aspects of human behavior.
(anthropocentric). Factor 4 was explained by one strong positively correlated (0.80) index, HPI, which can be conceived as environmental efficiency while supporting human well-being (Marks et al. 2006). Geographically, Albania, Germany, Italy, Moldova, Switzerland, and United Kingdom recorded highest levels of environmentally efficient happiness; howbeit Latvia, Luxembourg, and Bulgaria scored lowest on this factor (Fig. 2). Factor 5 was explained by three positively loaded indices; NRPI was strongly correlated

| Table 2 | Loadings of sustainable development indices for 5 factors derived from factor analysis of 30 variables (varimax rotation method) Each index was assigned to the dimension (axis) with its strongest correlation. The three strongest indices are in bold type and were used to define the factor name. For detailed factor loadings and communalities see Appendix Table S1. | Factor 1: Prosperity, equality, & governance | CAI (0.61), CBI (0.50) | CEI (0.75), EF (0.72) | CI (−0.88), GINI (−0.46) | CEI (0.57), EXWI (0.78) | GDP (0.61), NII (0.79) | OI (0.80), SCS (0.85) | SWI (0.64), TI (0.82) | WGI (0.76) | 32.68 |
| Factor 2: Quality Of life | HDI (0.69), HWI (0.71) | LEI (0.78), LOI (0.67), PEI (0.88), PGI (0.62) | GPI (−0.70) | 24.29 |
| Factor 3: Ecosystem integrity | ESI (0.76), EWI (0.91) | EVI (−0.76) | 8.73 |
| Factor 4: Environmentally efficient happiness | HPI (0.80) | 7.54 |
| Factor 5: Environmental management | EP (0.57), NRPI (0.80) | SSI (0.53) | 7.24 |

Fig. 2. Spatial distribution of factor scores for first five dimensions (eigenvalues >1) across Europe. The Factors are F1, prosperity, equality, and governance; F2, quality of life; F3, ecosystem integrity; F4, environmentally efficient happiness; and F5, environmental management.
(0.80) while both EPI and SSI scored moderately low (≥0.53) associations (Table 2). This canonical factor is best described as an axis of conservation and environmental management. Geographically, Austria, Czech Republic, Iceland, Lithuania, Germany, Slovakia, and Switzerland recorded the highest levels of basic needs and environmental management; however Albania, Bosnia-Herzegovina, and Ireland scored lowest within this orthogonal development theme (Fig. 2).

4.2. Patterns of European development

Taking all 36 study area nations into account, Global Moran’s I analysis revealed a degree of spatial nonstationarity for four of the five dimensions. Unambiguously, Factors 1, 2, and 3 had distributions with less than 1% likelihood their patterns could be the result of random chance (Table 3). Factor 4 had less than a 10% chance it occurred randomly across space, while Factor 5 had a spatial pattern that could be considered random. The LISA index, Anselin Moran’s I, illustrated geographic clustering of the five previously established canonical factors (Fig. 3). Enhanced prosperity, equality, and governance bundled five nations between the British Isles and Scandinavia, while diminished levels clustered around the Balkan Peninsula. The second factor, quality of life, displayed high levels for Spain and Greece, while decreased quantities clustered the Eastern European countries Belarus, Moldova, Romania, and Ukraine together. Improved ecological integrity grouped Belarus, Finland, Latvia, Lithuania, Norway, and Sweden, while diminished levels clustered the countries Belgium, Netherlands, and the United Kingdom. The fourth factor, environmentally efficient happiness, only negatively bunched Belarus, Latvia, and Lithuania together. Finally, the fifth factor, environmental management, only geographically highlighted improved quality in Iceland and the Czech Republic.

Two of the three hypothesized key indicators of development (childhood mortality, endangered species density, population growth rate) also revealed a degree of spatial nonstationarity (Table 3). Childhood mortality (Mortality Rate, <5) and population growth rate had spatial distributions with less than 1% likelihood that their patterns could be the result of random chance. Endangered species density (IUCN Red List/Km²) scored a Global Moran’s I value that denoted random spatial pattern. The LISA index, Anselin Moran’s I, exemplified geographic clustering of the three speculated key indicators of development (Fig. 4). High levels of childhood mortality, a measure significantly clustering only decreased socioeconomic condition here, bundled the Eastern European and Balkan countries Albania, Bulgaria, Macedonia, Moldova, Romania, and Ukraine. The USA index for the 2008 population growth rate illuminated significant positive clustering values for Iceland, Ireland, and Luxembourg, while grouping low growth rate countries Belarus, Bulgaria, Latvia, Lithuania, Moldova, Romania, and Ukraine of Eastern Europe and the Balkan Peninsula.

4.3. Associations of development

Results of the bivariate CAR analysis provided the basis for examining relationships between the five independent canonical factors and the three chosen dependent variables (Table 4). Childhood mortality (Mortality Rate, <5) was significantly correlated with Factors 1 and 2. Unambiguously, from this study, childhood mortality was best explained by the axis of quality of life and life longevity ($R^2 = 0.56, P < 0.001$), and found to be negatively associated (CAR coeff. $= -0.13$). Secondly, the 2008 childhood mortality rate had a statistically significant correlation with the axis prosperity, equality, and governance ($R^2 = 0.23, P = 0.004$), and found to be negatively associated (CAR coeff. $= -0.08$). Endangered species density (IUCN Red List/Km²) was only found significantly correlated with Factor 3. Specifically, from this study, endangered species density was only explained by the axis representing ecological integrity ($R^2 = 0.11, P = 0.033$), and found to be negatively associated (CAR coeff. $= -0.01$). The 2008 population growth rate was significantly correlated with Factors 1 and 2. Precisely, from this study, population growth rate was best associated with the axis of quality of life ($R^2 = 0.28, P < 0.001$), and found to be positively related (CAR coeff. $= 0.40$). Secondly, the population growth rate had a statistically significant correlation with axis one, prosperity, equality, and governance ($R^2 = 0.25, P = 0.002$), and was positively associated (CAR coeff. $= 0.39$). Canonical Factors 3 and 4 were not significantly correlated with any one of the three hypothesized key indicators of development. Global Moran’s I assessment of CAR residuals revealed randomness for all statistically significant bivariate models.

5. Discussion

5.1. Key measures of development

This study describes and visualizes five orthogonal dimensions of development for assessing patterns of sustainability in Europe by merging indices that represent one, or a combination, of the three major aspects of sustainability (economic welfare, social equity, and environmental quality). The first null hypothesis stated that no underlying dimensions of sustainability exist within 30 multi-metric indices of development. Since conical dimensions of development were statistically fleshed out for further rationalization, the first null hypothesis is rejected. From the factor analysis, results provide strong evidence that interrelationships and redundancy do exist within the 30 multi-metric development indices. In an effort to provide simplification, the strongest indices per development

Table 3
Spatial autocorrelation results derived from Global Moran’s I analysis for three dependent and five independent factor variables.

<table>
<thead>
<tr>
<th>Dependent variables</th>
<th>Global Moran’s I</th>
<th>z-score</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mortality Rate, &lt; 5 yrs</td>
<td>0.277</td>
<td>6.658**</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>IUCN red list/Sq. Km</td>
<td>0.016</td>
<td>1.287 –</td>
<td>0.195</td>
</tr>
<tr>
<td>Pop. growth rate</td>
<td>0.260</td>
<td>6.162**</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Independent variables</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Factor 1 (prosperity/equality/governance)</td>
<td>0.330</td>
<td>7.580**</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Factor 2 (quality of life)</td>
<td>0.162</td>
<td>4.105**</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Factor 3 (ecosystem integrity)</td>
<td>0.178</td>
<td>4.389**</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Factor 4 (environmentally efficient happiness)</td>
<td>0.061</td>
<td>1.907</td>
<td>0.056</td>
</tr>
<tr>
<td>Factor 5 (environmental management)</td>
<td>0.004</td>
<td>0.699 –</td>
<td>0.485</td>
</tr>
</tbody>
</table>

- Denotes random spatial pattern, * Denotes <10% chance random pattern, ** Denotes <1% change random pattern.
Note: Spatial clustering was determined using queen contiguity.
An axis could be selected as key measures for assessing progress towards their corresponding sustainability theme. On an important note, Factors 1 and 2 captured 15 and 8 indices respectively, and together accounted for over fifty-six percent of the total variance. These two dominant axes can be interpreted as anthropocentric in theme, suggesting that present sustainable development indicators underrepresent ecological (biosphere) well-being while heavily accounting for socioeconomic. When reviewing the living planet index and other scientifically accepted measures of environment, we find that humanity’s life-supporting ecosystems have been degrading through time with no signs of slowing (Butchart et al. 2010; WWF, 2014). Consequently, this research suggests that sustainable development measures, which incorporate ecological (biosphere) integrity, need more attention. When spatially interpreting the five development dimensions, the findings reiterate the Nordic countries’ improved progress towards reaching

**Fig. 3.** Local Anselin Moran’s I index of spatial association illustrating clustering of five Factors. The Factors are F1, prosperity, equality, and governance; F2, quality of life; F3, ecosystem integrity; F4, environmentally efficient happiness; and F5, environmental management. Spatial autocorrelation determined using queen contiguity.

**Fig. 4.** Local Anselin Moran’s I index of spatial association illustrating clustering of dependent variables: children under five mortality rate; International Union for the Conservation of Nature (IUCN) of threatened species density; and population growth rate. Data are from 2008, and spatial autocorrelation determined using queen contiguity.
sustainability. Overall, Norway can serve as an example for those nations looking for ways to improve their sustainable development status. Conversely, no clear countries emerged for policymakers to avoid when trying to increase their development position. Rather, it is suggested here that all European countries look to the champion nations within each of the five dimensions of development for improved planning and management ideas.

The second null hypothesis stated that three distinct development indicators—childhood mortality, endangered species density, and population growth rate—do not individually capture all dimensions of sustainable development. Since the bivariate CAR results revealed that none of the three key measures were significantly correlated with all five of the conical axes of development, this null hypothesis is accepted. That said, the findings do reveal that the childhood mortality rate could serve as an important barometer for assessing a country’s socioeconomic conditions of development. The strong connection between childhood mortality and socioeconomic status is due to prenatal and neonatal stressors from environmental risk (built and natural), lack of nutrition, and inadequate access to health care and related services, which ultimately impacts fetal development, birth outcomes, and infant survival (Bryce et al. 2005; Lawn, Cousens, & Zupan, 2005; Beck et al. 2010). Infant mortality is a common metric inventoried by public health departments and often allows for localized assessment of socioeconomic condition. It should be noted that neonatal biometrics might provide a more holistic and accurate sustainable development evaluation; however those data are likely unavailable for any regional assessment. Additionally, the CAR analysis revealed that the density of endangered species could serve as an overall barometer for assessing a country’s ecological conditions of development. Although the Red List is considered an irreplaceable and contemporary indicator of global environmental integrity (The Red, 2008), its inclusion in development studies remains almost nonexistent. The Red List is currently published at the country scale limiting its spatial analysis options, therefore direct proxies (e.g., habitat quality, invasive species, overharvesting) remain necessary for more localized assessments of environmental condition. To end, a composite measure consisting of only childhood mortality rate and endangered species density would provide a holistic and comprehensible endpoint for assessing a country’s overall sustainable development status.

5.2. Population growth-development paradox

“The Earth is one but the world is not” (WCED, 1987:27). Specific to the relationship between the environment (biosphere) and humans (anthroposphere), other relevant research includes: ‘Earth system’ analysis (Schellnhuber, 1999); planetary boundaries (Rockstrom et al. 2009); regional thresholds (Dearing et al. 2014); co-evolving human-environmental systems (Costanza et al. 2007); sustainable economy (Daly, 2005); macroscale sustainable urbanization assessment (Shaker, 2015); and weak versus strong sustainability (Neumayer, 2003). However, it has been over four decades since James Lovelock (1972) formulated his Gaia theory, but humanity’s understanding of the coupled human-environmental global system remains as open as ever.

According to the CAR analysis population growth rate was positively correlated with both Factors 1 and 2. An increase in population growth comes from a surplus after immigration and births minus emigration and deaths have been evaluated. Not accepting spurious correlations, the findings suggest the importance consumption plays in improving socioeconomic well-being across Europe. Greater population equals an increase in consumption, thus stimulating all economic sectors. Since it has been long established that high birth rates produce more misery (see Harding, 1968), it can be deduced that European countries with increased immigration rates are benefitting from the direct and indirect effects of natural resources metabolization. The push—pull effect of migrating populations between countries could represent a step towards sustainability, but more research is needed to fully understand spatial and temporal impacts of population change in a globalized economy. Nevertheless, this is where the central paradox of sustainable development is found. That is: how can you have continuous non-renewable development on a planet with finite resources? Eventually this question will force humanity to live within the limits of Earth’s biophysical environment, but long after those greater nations have exploited those of lesser status. However, the difficulties associated with the unequal distribution of resources and wealth will likely remain problematic long after population growth has reached zero.

6. Conclusions

“Making progress towards sustainability is like going to a destination we have never visited before, equipped with a sense of geography and the principles of navigation, but without a map or compass” (Hales and Prescott-Allen, 2002:6). While the processes associated with development have been linked to aspects of economic welfare, social equity, and environmental quality, they will likely never be distributed evenly over space. Much of our understanding of humanity’s progress on reaching sustainability comes from the acceptance and application of development indicators. In response to the seriousness of global issues, and need to rapidly improve society’s ecological and human well-being, a plethora of development indicators now saturate the field of sustainability science. Unfortunately, to date, much of our proficiency of these measuring tools is limited to theoretical and methodological design studies. Shaker and Zubalsky (2015) brought attention to this by advocating that sustainable development progress is now contingent on applied research and practice.

While other studies have investigated interrelationships between sustainable development indicators, few have directly attempted to simplify a set of development measures into a small number of canonical variables to further comprehend sustainable
development. Therefore, a holistic approach to understanding development should be considered when trying to decipher the underlying dimensions and geographical patterns of sustainability. Through a multivariate factor analysis, 30 multi-metric indices for assessing sustainable development were reduced into five conical factors (orthogonal dimensions), which were expressed as: (1) prosperity, equality, and governance; (2) quality of life; (3) ecosystem integrity; (4) environmentally efficient happiness; and (5) environmental development. Secondly, global spatial autocorrelation analysis revealed lack of randomness in four out of five conical axes, and two out of the three hypothesized key metrics of development. Using a local index of spatial association, geographical patterns of the five dimensions, and three central theorized indicators, of development were also illustrated. Lastly, bivariate associations between canonical dimensions and the three selected metrics of development were discovered using conditional auto-regressions.

This applied geographical study of 36 European nations resulted in several new findings. However, it would be wrong to conclude that a single factor analysis had identified all the essential dimensions of development for assessing progress towards sustainability. Additionally, at this early vantage point, it would also be incorrect to assume that the three central metrics chosen for capturing all dimensions of sustainability are exclusive. Dismissing that a subset of metrics, or possibly one key metric, could capture the integrated needs of sustainability is unwarranted; furthermore little quantitative evidence supports this mindset and agreeing to it will only hinder sustainability science. Only through other applied geographical studies rendering similar results can confidence in using them wholesale be made. It is hoped that readers of this paper will generate similar studies to the one outlined here, and by doing so improve indicator understanding and applied use.

Outright rejection of this study, without the provision of an alternative procedure useful for elucidating underlying dimensions of development, will only slow progress to improve monitoring programs of sustainability. That said, a new applied research paradigm is needed to investigate the use of holistic measure of development that are accurate and can be calculated easily, which will assure inclusion of all nations across a region. The findings suggest that quantitative and applied sustainability scientists should prioritize new research on ecological integrity and biosphere needs prior to socioeconomic well-being. Additional studies are needed to select development metrics that can be collected simply at the local (point-level) spatial scale. Since most sustainable development applications occur at the national level, such measures would allow for aggregation and various local and sub-regional management applications. To conclude, information from studies like this one help to provide tools to sustainability scientists, policymakers and macroscale planners for systematically analyzing and improving a region’s development status during continental and global scale sustainability evaluations.

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Appendix A. Supplementary data

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References

Clark, W., & Dickson, N. M. (2003). Sustainability science: the emerging research program. PNAS, 100(14), 8059–8061.