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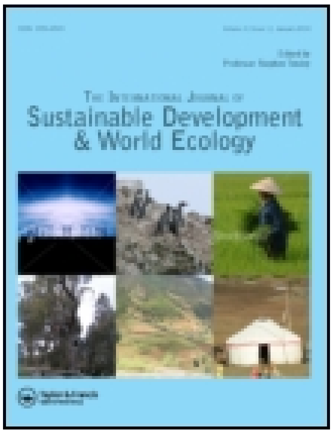




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Nearly all societies have now committed themselves to sustainable development by integrating some form of environmental quality, social equity, and economic welfare into their day-to-day activities. As such, there remains a strong political desire for the comprehensive assessment of conditions that evaluate the current status, measure progress, and help set future development goals. Indicators have been nominated as universal tools for progressing sustainable development across scales; however, there remains no consensus regarding the best approach to their design or use. While several studies have investigated the associations between indicators of sustainable development, few have directly addressed the question of how multiple measures can be used simultaneously to assess sustainability regionally. Building upon previous studies, this paper presents a quantitative and spatial assessment of 25 multi-metric indices across 36 European nations. The goals of this research were (1) to increase understanding of indicator complexity and (2) provide an applied example of their simultaneous use for regional assessment. Global Moran's *I*-test and Pearson's correlation coefficient ($r$) analysis were used to test spatial autocorrelation and multicollinearity, respectively. From the 25 composite indices, an overall rank was also provided for each country. Lastly, Ward's cluster analysis was used to create country bundles of similarity. Our findings revealed that environmental performance index, global information networking institute coefficient, and happy planet index were numerically and spatially random. Cluster analysis revealed a four-bundle solution, while Norway, Switzerland, and Sweden ranked highest. This approach shows promise for systematically describing, visualizing, and monitoring sustainable development at the continental scale.

**Keywords:** cluster analysis; environmental performance index; European Union; Gini coefficient; happy planet index; measuring sustainability; multi-metric index; sustainable development



## 1. Introduction

Despite its complexities, the adaption of sustainable development by the United Nations World Conference on the Environment and Development (UNCED) in Rio de Janeiro (UN 1992) marked a new era in global awareness. Sustainable development, defined by the Brundtland Report, is the equitable use of Earth's resources that meets civilization's present needs without compromising the ability of future generations to meet their own needs (WCED 1987). Nearly all societies throughout the world have now committed themselves to sustainable development by integrating some form of environmental quality, social equity, and economic welfare into their day-to-day activities. As such, there is strong political desire at all scales for the comprehensive assessment of environmental, social, and economic conditions for evaluating the current status, measuring progress, and setting future development goals.

Numerous studies have shown that humanity's current practices exceed the natural limits of Earth (WCED 1987; UNEP 2005; WWF 2012). Besides the environmental ramifications of anthropogenic behaviors, major global challenges remain between social groups and coupled human-ecological systems (Kates et al. 2001; Clark & Dickson 2003). In example, close to a billion people live in extreme economic poverty (e.g., less than US$1 a day) and lack access to essential natural resources to meet basic needs (WB 2008). Unfortunately, due to its all-encompassing goals and theoretical vagueness, sustainability has been found to be very difficult to measure. With over 300 working definitions of sustainability and sustainable development (Dobson 1996), and some definitions contradicting each other (Goodland & Daly 1996), some feel that achieving a sustainable destination is more remote than ever (Jickling 2000). Despite its shortcomings, a sustainability concept is still a seemingly rational guide to create a long-term, positive relationship between humankind and the planet; however, murky and conflicting goals hamper our ability to determine whether this relationship has been or will be achieved (Mayer et al. 2004).

The current challenges of sustainable development now lie in its operationalization (Keiner 2006). Efforts must be made for the implementation of initiatives that do not merely pay lip-service to the words but actively do justice to its original roots (e.g., sustainable yield) (Campbell 2000). As part of this process, numerous researchers and governmental organizations have developed many indicators for measuring sustainability. Indicators and composite indices are

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increasingly recognized as useful tools for policymaking because they convey information on a country's performance toward their specific goals within the three major aspects of sustainability (environmental quality, social equity, and economic welfare). In Chapter 40.4 of Agenda 21, the need for 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). The main benefit of an indicator is its ability to summarize complex information of our dynamic world into a manageable amount of meaningful information. Although it has been more than two decades since Agenda 21 first called for sustainable development indicators, there remains no consensus regarding the best approach to their design or use.

There exist no ideal planning instruments for achieving sustainability neither on regional nor local scale (Keiner 2006). Recently, policymakers have started to encourage scientists to improve models and develop new techniques for integration of quantitative and qualitative analysis for local and regional sustainable development planning (Grosskuth 2007). To be successful at planning at any scale, appropriate methods, procedures, and instructions are required (Keiner 2006). Specifically, the proper choice of indicators is essential for monitoring progress toward sustainable spatial development (Bossel 1999; Prescott-Allen 2001); however, understanding their strengths, weaknesses, scale-dependencies, data needs, etc., when employing them is even more important (Parris & Kates 2003; Morse & Fraser 2005; Ness et al. 2007). To further elucidate indicator complexity, and to provide an applied example of their combined use, this study examines 25 composite indices of sustainability across 36 European nations.

While several studies have investigated the relationships between indicators of sustainable development, few have directly addressed the question of how multiple measures can be used simultaneously to help operationalize sustainability. Building upon previous studies that examine the interplay between amalgamated indicators of sustainability (e.g., Moffatt 2008), we investigate a number of multi-metric measures for a majority of the countries in Europe. Specifically, we ask to what degree a group of indices are interrelated, and can they collectively be useful for analyzing sustainability regionally. To address this question, we test two null hypotheses: (1) no significant relationships exist between 25 composite sustainability indices; and (2) multivariate statistics do not provide the means to evaluate sustainable development geographically. By explicitly describing quantitative and spatial patterns between measures of sustainability, this research aims to improve understanding of complex coupled human–environmental relationships. This study also attempts to provide global management agencies, sustainability scientists, and policymakers tools for systematically describing, visualizing, and monitoring sustainable development at the continental and global scales.

## 2. Measuring sustainable development

'A concerted effort to enhance habitability of our planet is unlikely to succeed unless we know "where we are" and "where we want to go"' (Thomas 1972). Since the industrial revolution of the eighteenth and nineteenth centuries, due to increasing anthropogenic stressors, there has been a greater push to monitor the environment in which we live (Harris & Browning 2005). By the early 1970s, environmental indicators were starting to gain popularity. In the United States, through the formation of the President's Council on Environmental Quality, indicators were in demand to measure progress toward environmental goals and pollution control targets (Rogers et al. 1997). The foundations of indicator development can be linked back to the works of Herbert Inhaber's (1976) *Environmental Indices* and Wayne Ott's (1978) *Environmental Indices: Theory and Practice*. After a lull in indicator research through the early 1980s, a renaissance occurred after their applicability became apparent at the UNCED meeting and Agenda 21 (Rogers et al. 1997).

An indicator is a single value from a single measure of quantity, whereas an index is the combination or aggregation of more than one single indicator or single value (Ott 1978). According to Rogers et al. (2008), the World Bank describes an indicator as 'a performance measure that aggregates information into a usable form'. It is important to note that indicators are formed by observed or estimated data (OECD 2002) and likely contain a degree of error. Indicators are quantitative measures and only generic definitions of quality are used, making it very difficult to make accurate decisions at the margins (Rogers et al. 2008). Additionally, it has been recognized that nonmathematicians have frequently driven the development and use of indices (Young et al. 2009); therefore, a majority of sustainability measures remain conceptually and analytically simple. However, this should be seen as a positive attribute for some sustainability indices as it makes them attractive at all levels of study, easy to employ, and allows their use and interpretation by nonexperts (Maclaren 1996). Ultimately, measures of sustainability are tools that add focus to unstructured policies and enable trust and consensus building between actors (Lyytimäki et al. 2013).

The environment in which we live is multidimensional – influenced by many different economic, social, and environmental phenomenon (Pezzoli 1997; Cabezas et al. 2003; Mayer et al. 2004). By accepting the sustainability challenge, countries have nominated indicators as measuring tools for addressing sustainable development (Moran et al. 2008). Sustainability indices have been generated specifically to help policymakers make their decisions (Mayer 2008). Sets of sustainability indicators, and manipulation of these measurements into indices, are increasingly used to make policy decisions (Oras 2005; Hezri & Dovers 2006). At the global scale of management, the United Nations professed that indicators need to be developed to provide solid bases for decision making at all levels of government and to contribute to a self-regulating process that balances the needs of each pillar (social, economic, and environment) of sustainability (UN 1992).

However, the three pillars metaphor does not fully capture the crucial tasks of synergistically improving the needs of all spheres during sustainability-oriented decision making (Hansmann et al. 2012).

In the large and growing sustainable development literature, there are two dominant views on indicators: weak measures and strong measures (Moffatt 2008). With strong sustainability, measures assume that some ecological functions and resources cannot be substituted with technological or other man-made replacements. The strong measures are based on the assumption that maintaining the planet's ecology is vital, and economic and social activities have to remain well within the ecological means (Moffatt 2008). With weak sustainability, measures assume that there can be universal substitution. The weak measures are based from the long-standing tradition of neoclassical economics (see Pearce & Atkinson 1993; Pearce & Barbier 2000).

Hundreds of different indices have been suggested and more are under development by a growing number of institutions (see Tschirley 1997), and over 140 different indicators have been proposed for the Organization for Economic Co-operation and Development (OECD) countries (Moffatt 2008). However, it has been stated that the results are 'voluminous' and 'not very well focused' (Rogers et al. 2008). The UN Department of Economic and Social Affairs – Division for Sustainable Development – finalized a list of 96 indicators, including a subset of 50 core indicators, in their report *Indicators of Sustainable Development: Guidelines and Methodologies* (UN 2007) to be used as a reference for countries. Unfortunately, many of the sustainability indices are created with similar methods and from similar data sources (e.g., United Nations, World Bank). According to Mayer (2008), 'the degree to which these indices differ in their results using the same data is due to their assumptions, biases, and methodological disparities, creating confusion for sustainability efforts'. Finally, it has also been recognized that current sustainability indicators lie heavy on environmental needs while skimping on the social and economic (Moldan et al. 2004; Moffatt 2008). The forthcoming multivariate research aims to improve understanding of indicator use during sustainability related investigations. By explicitly describing quantitative dependencies between indices, and then concurrently using them to measure and map sustainable development, a greater understanding of regional relationships can be had.

## 3. Data and methods

### *3.1. Study area*

We have focused our empirical analysis of sustainable development indicators across 36 European sovereign states or dependent territories (Figure 1). Several

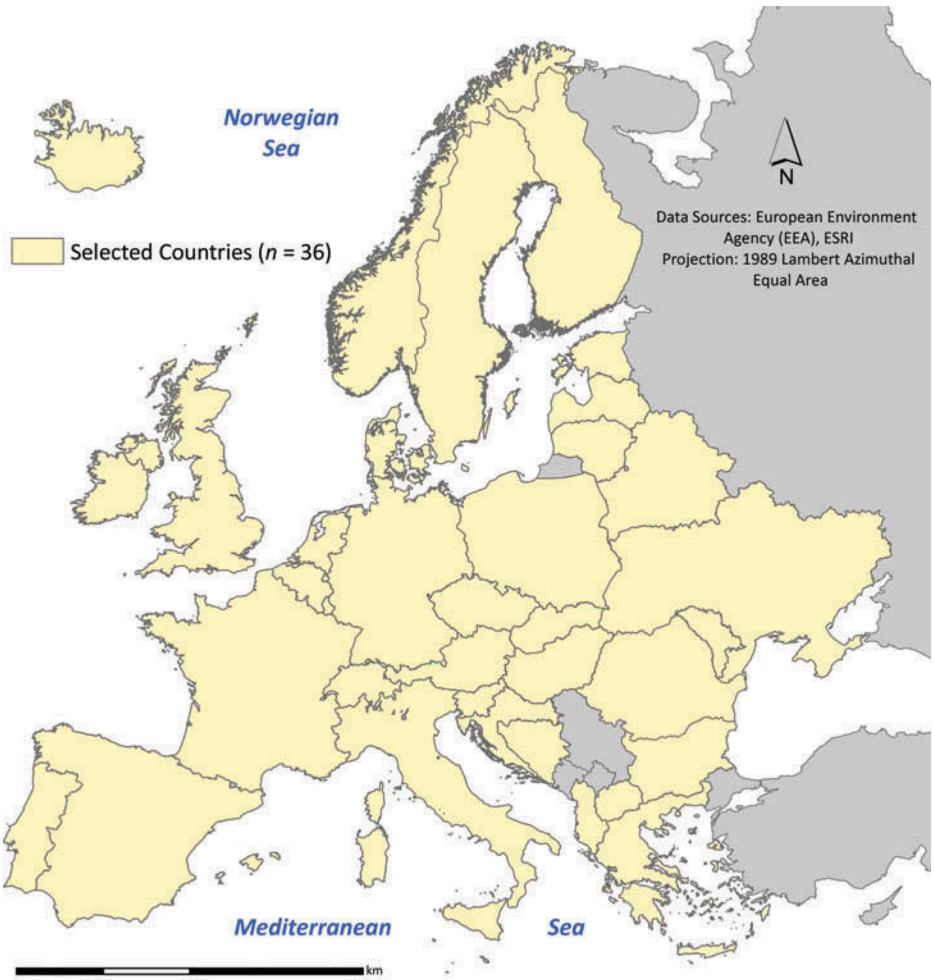


Figure 1. Location map of 36 European sovereign states or dependent territories utilized in this study.

characteristics of this region make it an ideal site for this study. By agreement Europe is one of the world's seven continents, and it is arguably the birthplace of urbanization and Western culture. Europe, the second smallest continent by surface area, is separated from Asia by the watershed divides of the Caucasus and Ural Mountains, the Ural River, the Caspian and Black Seas, and the waters connecting the Black and Aegean Seas (Ostergren & Le Bossé 2011). Comprising roughly 6.8% of Earth's terrestrial area, Europe has the greatest country and population densities of all continents. Although a few countries are in population decline, roughly 11% (2010) of humanity can still be found in Europe, where four out of five European citizens live in urban areas (EC 2006). Total population within the study area is over 500 million (2012). Culturally, Europe has historically included a diversity of religions, languages, beliefs, and traditions unique to its borders. The 36 countries were selected from the approximately 50 that comprise the continent of Europe. Countries were included in our study if they were evaluated within 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 are almost entirely contiguous, although minus the Russian territory between Lithuania and Poland, and the space making up Serbia, Montenegro, and Kosovo. Specific to the study area, the included territories cover about 5.7 million km$^2$ in area. Lastly, European nations can be credited with starting the sustainable development paradigm, and it can be argued that European Union members continue to lead the effort.

### 3.2. *Selected measures of sustainability*

As addressed earlier, a plethora of single index and composite indices exist for measuring sustainability. In the Moldan et al. (2004) and Moffatt (2008) papers, both put forth sustainability studies of the G7 nations using 11 and 13 indices, respectively. These preceding analyses, for the richest seven nations, updated knowledge for policy-makers and global managers; however, they provide limited information useful to regional planners or investigators. The forthcoming inquiry builds off the Moldan et al. (2004) and Moffatt (2008) studies to include a total of 25 multi-metric indices (Table 1) for evaluating sustainability across most of the European Union and a few of its neighbors. The indices of this research focus on one, or a combination, of the three major aspects of sustainability (environmental quality, social equity, and economic welfare). The indices can be broadly grouped into two categories: non-Gallup World Poll and Gallup World Poll (www.gallup.com) associated measurements.

Table 1. Descriptive statistics and metadata for the 25 composite sustainability indices used in the forthcoming multivariate and geographic analyses (data are not transformed; $N = 36$).

| Abbreviation | Description | Indicator Range | Mean ± 1 SE | Global Moran's $I$ | Source (Year) |
|---|---|---|---|---|---|
| CAI | Community attachment index | 0–100 | 82.9 ± 1.1 | *** | GWP (2006) |
| CBI | Community basics index | 0–100 | 62.9 ± 1.8 | *** | GWP (2006) |
| CEI | Civic engagement index | 0–100 | 33 ± 2.1 | *** | GWP (2006) |
| CI | Corruption index | 0–100 | 63.2 ± 3.8 | *** | GWP (2006) |
| EF | Ecological footprint | 0.04–10.68 (gha/pers) | 5.4 ± 0.3 | *** | GFN (2006) |
| EI | Education index | 0–1 | 0.95 ± 0.01 | *** | UNESCO (2006) |
| EPI | Environmental performance index | 0–100 | 73.5 ± 1.4 | – | Yale (2012) |
| EWI | Ecosystem wellbeing index | 0–100 | 34.8 ± 1.5 | *** | Prescott-Allen (2001) |
| EXWI | Experiential wellbeing index | 0–100 | 69.5 ± 1.1 | *** | GWP (2006) |
| GDP | Gross domestic product (purchasing power parity) | 7083–91,388 | 25,316.8 ± 2515.1 | *** | WB (2007) |
| GINI | Global information networking Institute coefficient | 0–100 | 31.7 ± 0.7 | – | WB (2007) |
| HDI | Human development index | 0–1 | 0.85 ± 0.01 | *** | UNPD (2006) |
| HPI | Happy planet index | 0–100 | 41.4 ± 1.0 | – | NEF (2007) |
| HWI | Human wellbeing index | 0–100 | 66.1 ± 2.4 | *** | Prescott-Allen (2001) |
| LEI | Life expectancy index | 0–1 | 0.86 ± 0.01 | *** | UN (2007) |
| LOI | Law and order index | 0–100 | 73.8 ± 1.4 | *** | GWP (2006) |
| NII | National institutions index | 0–100 | 50.4 ± 2.6 | *** | GWP (2006) |
| OI | Optimism index | 0–100 | 36.5 ± 1.8 | *** | GWP (2006) |
| PEI | Positive experience index | 0–100 | 59.3 ± 2.9 | *** | GWP (2006) |
| PGI | Poverty gap index | 0–100 | 17.1 ± 2.3 | *** | WB (2007) |
| QLI | Quality of life index | 0–10 | 6.8 ± 0.2 | *** | EIU (2005) |
| SCSI | Social capital sub-index | −5 to +5 | 0.99 ± 0.28 | *** | Legatum (2012) |
| SSI | Sustainable society index | 1–10 | 5.5 ± 0.1 | *** | SSF (2008) |
| SWI | Social wellbeing index | 0–100 | 81.7 ± 1.3 | *** | GWP (2006) |
| TI | Thriving index | 0–100 | 37.5 ± 3.2 | *** | GWP (2006) |

Notes: – Denotes random spatial pattern, ***denotes <1% chance spatial pattern is random.
GWP, Gallup World Poll; UNESCO, UNESCO Institute for Statistics; UNDP, United Nations Development Programme; NEF, New Economics Foundation; GFN, Global Footprint Network; WB, World Bank; UN, United Nations Statistics Division; EIU, Economist Intelligence Unit; Legatum, Legatum Institute; SSF = Sustainable Society Foundation.

The non-Gallup World Poll measurements included in this study were ecological footprint (EF) (Wackernagel & Rees 1996; GFN 2006), educational index (EI) (UNESCO 2006), environmental performance index (EPI) (Esty et al. 2008; Yale 2012), ecosystem wellbeing index (EWI) (Prescott-Allen 2001), gross domestic product (GDP), global information networking institute (GINI) coefficient (Gini 1912), human development index (HDI) (Tata & Schultz 1988; UNPD 2006), happy planet index (HPI) (Marks et al. 2006; NEF 2007), human wellbeing index (HWI) (Prescott-Allen 2001), life expectancy index (LEI), poverty gap index (PGI) (WB 2007), quality of life index (QLI) (EIU 2005), social capital sub-index (SCSI) (Legatum 2012), and sustainable society index (SSI) (SSF 2008). The Gallup World Poll (GWP 2006) measurements included in this study were community attachment index (CAI), community basics index (CBI), civic engagement index (CEI), corruption index (CI), experiential wellbeing 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 25 different indices were also presented by the metadata: conceived range, basic descriptive statistics, source and date published (Table 1). Effort was taken to assemble data at a comparable time period circa 2006, but the forthcoming analyses were constrained to include circulated data sets ranging from 2001 to 2012. Some European sovereign states or dependent territories were excluded from this analysis (e.g., Kosovo) due to lack of available data, not by choice.

### *3.3. Data analysis*

Through traditional and spatial statistics, a method is presented hereafter to (1) assess relationships between composite indices of sustainability and (2) simultaneously use those measures to create country bundles of similarity for regional assessment. Specifically, exploratory spatial data analysis, correlation coefficient (*r*) analysis, and cluster analysis were employed to test our hypotheses. To meet the assumptions of normality for variables required during parametric tests, two types of transformation were used: arcsine square root (proportion data) and log (length/score data).

In sustainability-related investigations, it is essential to take into account spatial autocorrelation. The first law of geography states that things that are near are more similar (spatially autocorrelated) than things that are farther apart (Tobler 1970). Spatial autocorrelation, the lack of independence between pairs of observation at given distances in time and space, is commonly found in geographically collected and distributed data (Legendre & Legendre 1998). Spatial autocorrelation has been found to be problematic when using classical statistical tests (e.g., ANOVA) because it violates the assumption of independently distributed errors (Legendre & Legendre 1998; Haining 2003). Further, standard errors are usually undervalued when positive autocorrelation is present and Type *I* errors may be strongly exaggerated (Legendre & Legendre 1998). In most cases, the presence of spatial autocorrelation is seen as a significant shortcoming for hypothesis testing and prediction (Lennon 2000; Dormann et al. 2007). Although many investigations still fail to acknowledge or account for spatial autocorrelation, this may prevent an in-depth interpretation of almost all sustainability studies over space. Although other methods have been identified to assess spatial autocorrelation (e.g., Mantel's *r*-test), for this study we applied the common and frequently used global Moran's *I*-test. Spatial autocorrelation index scores vary from each other; however, positive scores indicate similar values are spatially clustered and negative scores indicate unlike values are spatially clustered (Wong & Lee 2005). Spatial clustering of each sustainability indicator was determined using queen contiguity. ESRI's (2013) ArcMap 10.1 Spatial Statistics toolbox was implemented during this step of the analysis.

We used Pearson's correlation coefficient (*r*) to analyze relationships between the 25 selected sustainability indices for all 36 countries in the study region. We used correlation coefficient as a descriptive measure of the relative strengths of relationships. Like other correlation statistics, Pearson's statistic ranges from +1 to −1. For interpretation, correlation statistics can be classified into very positive (+1.0 to +0.75), positive (<+0.75 to +0.5), neutral (<+0.5 to <−0.5), negative (>−0.5 to −0.75), or very negative (>−0.75 to −1.0). The statistical software JMP version 10 (SAS 2012) was employed during this step in the analysis.

To identify and bundle similar patterns of sustainability across the European sovereign states or dependent territories ($n$ = 36), Ward's (1963) minimum variance method of hierarchical clustering was performed in JMP version 10 (SAS 2012). Cluster analysis is an atheoretical technique to place entities into groups or clusters suggested by the data, not defined *a priori*, such that entities in a given cluster tend to be similar to each other in some sense, and entities in different clusters tend to be dissimilar (Aldenderfer & Blashfield 1984). Cluster analysis can also be used for summarizing data rather than finding 'natural' or 'real' groups; this use of clustering is sometimes called dissection (Everitt 1980). Many popular procedures (e.g., k-means) of cluster analysis exist, but a review by Milligan (1981) suggests that the clustering technique with best overall performance is either average linkage or Ward's (1963) minimum variance method. In this study, each country begins as its own cluster, then, step by step, those clusters are joined into a hierarchical dendrogram that result in the minimum increase in the error sum of squares. This process organizes entities so that one cluster may be entirely contained within another cluster, but no other kind of overlap between clusters is allowed.

Although some statistics (e.g., Mojena's stopping rule #1) have been used to help in this process, there remains no universal way to determine the optimal number of clusters. For this study, the number of cluster bundles was determined heuristically by examining the Cubic Clustering Criterion (CCC) change at each stage of the cluster-joining process (see SAS 1983). The dendrogram created, a tree-like diagram illustrating the rescaled distance at which clusters are combined, permitted visual examination of bundled countries. To ensure statistically significant separation between clustered bundles *ex post facto*, Wilks' lambda test was employed using SYSTAT 13. Wilks' lambda is frequently used to test differences between the means of identified groups for a combination of dependent variables selected for a discriminant model (Klecka 1980). Because Wilks' lambda is a kind of inverse measure, significance levels near zero denote high discrimination between groups. Generally, if the Wilks' lambda significance level is less than 0.05, then this represents sufficient discriminatory power. To aid in deciphering sustainability, and to addend the cluster analysis, a cumulative rank from the 25 indices was calculated for each country. Finally, the major hierarchical clusters were entered into ESRI's (2013) ArcMap 10.1 for spatial assessment and to illustrate regional patterns.

## 4. Results

### *4.1. Exploratory spatial data analysis*

Taking all 36 study area countries into account, Global Moran's *I* analysis revealed a high degree of spatial autocorrelation for most of the multi-metric indices of sustainability. In total, 22 of the 25 sustainability measures had spatial autocorrelation with less than 1% likelihood that the geographic pattern could be the result of random chance (Table 1). Measures of sustainability found spatially autocorrelated are useful for locating univariate themed 'hotspots'; however, they can hinder classical statistical tests (e.g., ANOVA) that assume independence. Only EPI, GINI, and HPI had spatial patterns that can be considered random. Although the presence of spatial autocorrelation has been considered a shortcoming in hypothesis testing and prediction (Dormann et al. 2007), spatially random and nonrandom variables were entered into the ensuing multivariate analyses.

### *4.2. Correlation coefficient analysis*

Pearson's correlation coefficients for one index with the other 24 ranged from −0.88 to +0.92 ($P < 0.01$). Focusing on sustainability measures with very positive (+1.0 to +0.75) or very negative (>−0.75 to −1.0) correlation coefficients, 17 indices had representation with at least three others (Table 2). With 11 scores recorded, EXWI and NII exhibited the highest degree of multicollinearity across the 25 sustainability indices. HWI, CBI, GDP, and SWI recorded 10 very positive correlation coefficients with the other indices. QLI, HDI, CAI, and LOI recorded nine very positive correlation coefficients with the other indices. The following eight sustainability measures had weak or neutral correlation coefficient scores: EI, GINI, EWI, HPI, LEI, SSI, PEI, and EPI. Throughout this step of the analysis, CI was the only measure that exhibited very negative correlations; it was found negatively correlated with TI, EXWI, OI, and NII.

Correlation among the indices can be expected since the themes they measure were selected to reflect some type of association with sustainability; as data inputs often overlap within the calculation of index measures. Because of this, statistics should be used cautiously to validate single metric choices and predictions in decision making. Current literature on sustainability and planning recognizes the shortcomings of indicator use in policy decisions but lacks evidence that there is a link connecting governance, ecological well-being, social well-being, and community sustainability as a whole (Hezri & Dovers 2006). Moreover, indicator data analyzed in isolation can suggest what is good for the environment is not necessarily good for humans and vice versa. However, through intrinsic values and mindful living, a sustainable way of life needs to enhance both personal and environmental well-being (Brown & Kasser 2005). Therefore, a selection of several indices for simultaneous use, rather than single endpoint measurements, would provide policymakers a more holistic view of conditions of sustainability.

### *4.3. Cluster analysis*

Cluster analysis empirically identified homogeneous country bundles in the data without a preexisting theoretical classification strategy or prearranged number of clusters. Visual examination of the dendrogram, depicting the hierarchical arrangement of the bundles, suggested a possible four-cluster 'cut' solution (Figure 2). To further evaluate the optimal number of bundles, the CCC was evaluated at each stage of the cluster-joining process. Although a CCC value of greater than two indicates the clustering outcome is robust (SAS 1983), all groupings greater than four had scores less than one. To inspect the optimal number of clusters, Wilks' lambda significance test revealed sufficient discriminatory power between the four bundles of similarity (Wilks' $-\lambda = 0.001$). Review of CCC values, along with visual inspection of the dendogram, application of Wilks' lambda, and the geographical meaningfulness of results, suggested a four-cluster solution.

To help illuminate country–country relationships within the dendrogram, cluster 1, cluster 2, cluster 3, and cluster 4 have accumulative ranks that range 1–10, 11–27, 19–33, and 23–36, respectively. The overall rank, from assessing all 25 indices, is provided for each country within Figure 2. Norway received the best overall ranking, followed by Switzerland and then Sweden. Bosnia–Herzegovina received the worst overall ranking preceded by Macedonia and then Ukraine.

The cluster analysis allowed each country to be grouped into four geographic bundles of similarity. Bundle sizes range from 6 to 10 countries; the first three clusters were represented equally with 10 nations and the fourth cluster with 6. Each of the 36 European sovereign

Table 2. Very positive or very negative Pearson's correlation coefficients for 25 composite sustainability indices.

| EXWI | NII | HWI | CBI | GDP | SWI |
|---|---|---|---|---|---|
| TI (0.87) | CI (−0.88) | GDP (0.91) | LOI (0.85) | QLI (0.92) | CAI (0.88) |
| SWI (0.87) | TI (0.85) | QLI (0.90) | GDP (0.82) | HWI (0.91) | EXWI (0.87) |
| OI (0.85) | EXWI (0.83) | SWI (0.86) | SWI (0.81) | HDI (0.84) | HWI (0.86) |
| NII (0.83) | LOI (0.82) | CAI (0.83) | NII (0.81) | CBI (0.82) | QLI (0.82) |
| CBI (0.80) | HDI (0.80) | EF (0.82) | QLI (0.80) | CAI (0.79) | CBI (0.81) |
| CAI (0.80) | GDP (0.78) | HDI (0.79) | EXWI (0.80) | SWI (0.79) | GDP (0.79) |
| CI (−0.79) | SWI (0.78) | PGI (0.79) | CAI (0.78) | LOI (0.78) | LOI (0.79) |
| HDI (0.78) | CAI (0.78) | SCSI (0.77) | HDI (0.77) | NII (0.78) | NII (0.78) |
| LOI (0.78) | QLI (0.77) | CBI (0.77) | HWI (0.77) | EF (0.75) | CEI (0.77) |
| CEI (0.76) | CEI (0.77) | EXWI (0.75) | TI (0.77) | PGI (0.75) | EF (0.75) |
| HWI (0.75) | OI (0.77) | | | | |

| QLI | HDI | CAI | LOI | TI | SCSI |
|---|---|---|---|---|---|
| GDP (0.91) | GDP (0.84) | SWI (0.88) | CBI (0.85) | OI (0.88) | HWI (0.77) |
| HWI (0.90) | NII (0.80) | HWI (0.83) | NII (0.82) | EXWI (0.87) | TI (0.77) |
| SWI (0.82) | HWI (0.79) | EXWI (0.80) | QLI (0.80) | NII (0.85) | HDI (0.76) |
| CBI (0.80) | EXWI (0.78) | GDP (0.79) | GDP (0.78) | CI (−0.79) | EF (0.76) |
| LOI (0.80) | QLI (0.77) | QLI (0.79) | EXWI (0.78) | SCSI (0.77) | CAI (0.75) |
| CAI (0.79) | CBI (0.77) | NII (0.78) | SWI (0.77) | CBI (0.77) | |
| PGI (0.79) | LOI (0.76) | CBI (0.78) | CAI (0.76) | LOI (0.75) | |
| HDI (0.77) | SCSI (0.76) | LOI (0.76) | HDI (0.76) | | |
| NII (0.77) | CEI (0.75) | SCSI (0.75) | TI (0.75) | | |

| OI | CI | EF | CEI | PGI | EI |
|---|---|---|---|---|---|
| TI (0.88) | TI (−0.79) | HWI (0.82) | NII (0.77) | HWI (0.79) | – |
| EXWI (0.85) | EXWI (−0.79) | SCSI (0.76) | SWI (0.77) | QLI (0.79) | |
| CI (−0.78) | OI (−0.78) | GDP (0.75) | EXWI (0.76) | GDP (0.75) | |
| NII (0.77) | NII (−0.75) | SWI (0.75) | HDI (0.75) | | |

| GINI | EWI | HPI | LEI | SSI | PEI/EPI |
|---|---|---|---|---|---|
| – | – | – | – | – | – |

states or dependent territories was placed via cluster analysis into one of the four clusters. The four geographic bundles are contiguous with the exception of cluster 4. Cluster 1 nations are focused mostly within Scandinavia and the northwest region of Central Europe. Cluster 2 countries consist largely inside the Mediterranean basin and southwest Europe. Cluster 3 nations are located predominantly in Eastern Europe and along the east coast of the Baltic Sea. Cluster 4 countries are found in Eastern Europe, but dissected into two groups by cluster 3. One of the subgroups of cluster 4 is arranged within the former communist states in the north, and the other smaller subgroup within the Balkan Peninsula. Mapping analysis provided a visual narrative of the four homogeneous bundles across Europe (Figure 3). Global Moran's *I* analysis of the four-country bundles revealed a less than 1% chance that the geographic pattern could be the result of random chance. The dendrogram with accompanying country rank, and map of geographic bundles provided clues about Europe's sustainability by subregion.

## 5. Discussion

### *5.1. No single measure of sustainability*

Over the past two decades, numerous studies have linked indices with sustainability or sustainable development. Some studies suggest that discrepancy of sustainability indices could be remedied through the use of several complementary measures (e.g., Mayer 2008). Others suggest the establishment of a single key indicator or index would be useful for making development sustainable (e.g., Moffatt 2008). Our study emphasized that numerical and spatial relationships could be both a hindrance and benefit. Although *EPI, GINI coefficient*, and *HPI* emerged to be numerically and spatially independent, it is clear that there is no best single measure for capturing all three major aspects of sustainability (environmental quality, social equity, and economic welfare) simultaneously. Indeed, when we think about the virtuality of national boundaries, characterizing a country only according to a single metric turns out to be a paradox when it comes to the sustainability approach (Türe 2013). Since EPI's main foci are environmental

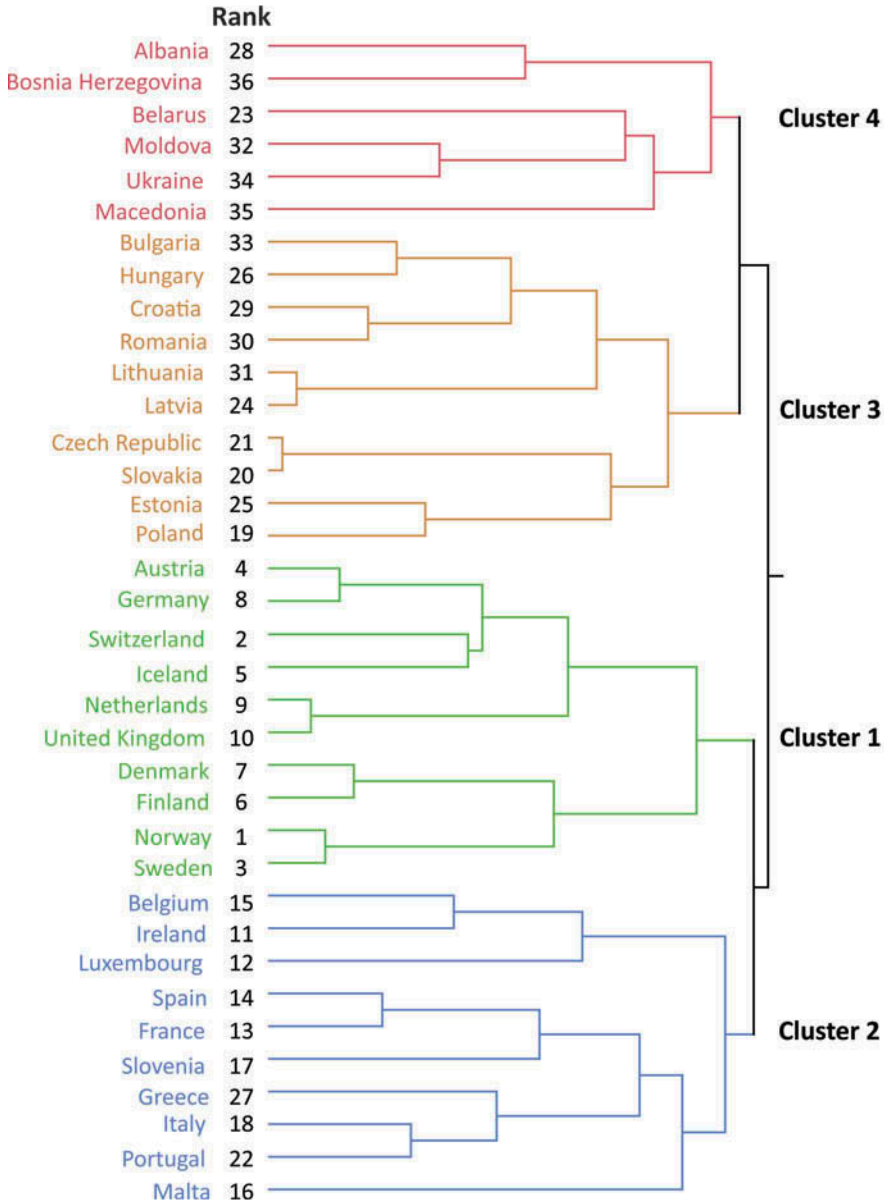


Figure 2. Hierarchical cluster dendrogram (Ward's method) illustrating 36 European sovereign states or dependent territories.

The linkage points between country bundles are shown at increasing levels of dissimilarity; entities closer together are more similar than ones that are farther apart. The overall ranks from the 25 indices accompany each country.

health and ecosystem vitality (Yale 2012), it fails to capture the social and economic needs of sustainability. GINI measures the inequality of income distribution of a nation's residents, which can be argued to capture the economic and social aspects of sustainability. However, GINI fails to capture our life-supporting ecosystem needs or any aspect of environmental quality. HPI, introduced in 2006, was designed to challenge nonholistic indices (e.g., GDP) by capturing multiple themes of sustainable development simultaneously. Each country's HPI score is a function of its average subjective life satisfaction, life expectancy at birth, and EF per capita; HPI can best be conceived as an index of environmental efficiency while supporting human well-being (Marks et al. 2006). Although HPI is the most inclusive sustainability index within this study, it can be criticized for incorporating subjective 'happiness' indicators and using the locally biased and environmentally limited (i.e., only carbon biocapacity) measure EF. Since some degree of significant correlation (spatial and/or numerical) was recorded for the other 22 sustainability indices, we can reject our first null hypothesis. As there is no causal order in space as there is in time, there is likely no minimum set of transferable metrics for quantifying sustainability. Thus, as in this study, a group of measurements along with multivariate methods should be considered when using indicators to evaluate sustainability regionally.

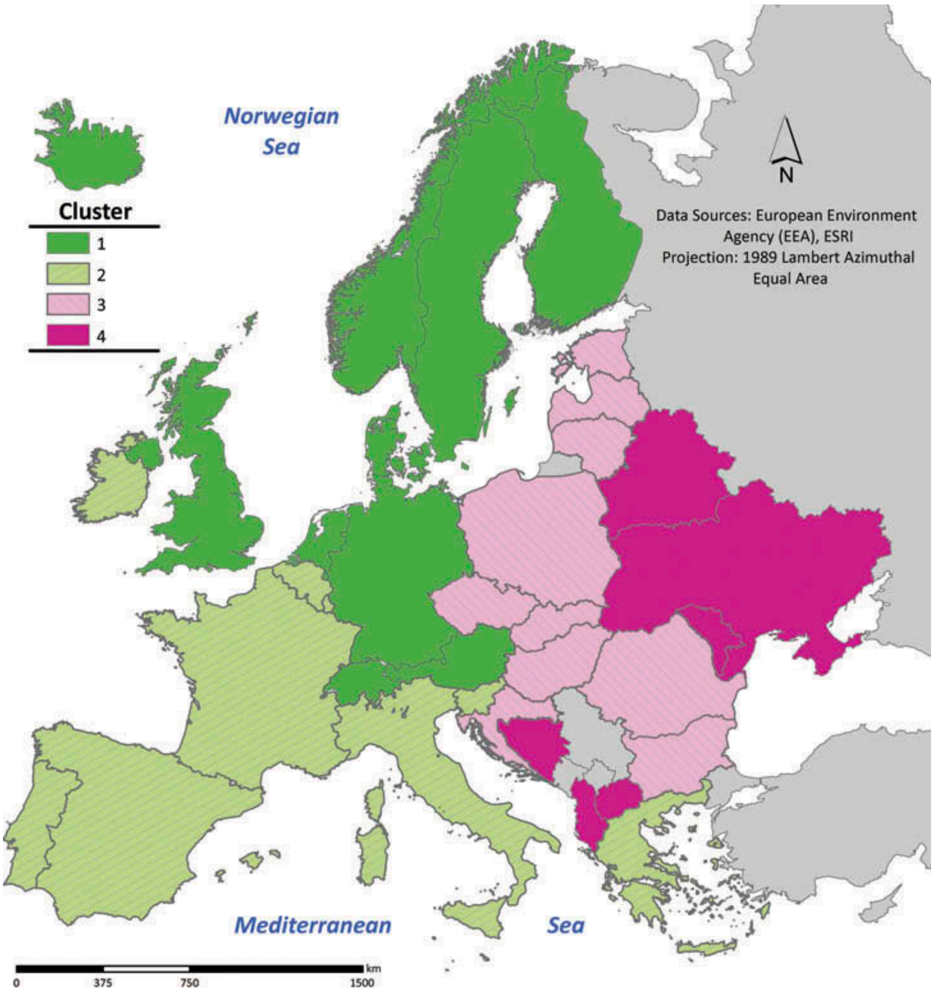


Figure 3. Map illustrating the four major geographic bundles from cluster analysis (Ward's method).

### *5.2. Operationalization of sustainability*

The second null hypothesis stated that multivariate statistics do not provide the means to evaluate sustainable development geographically. Since Ward's (1963) hierarchical clustering analysis provided results that could be spatially interpreted, we can reject the second hypothesis. The four clusters likely reflect deeper attributes of culture, politics, environment, and economics within regions of Europe. Our findings confirm an improved level of sustainability across the developed nations of Western Europe. Specifically, the countries within cluster one may hold the key to making a sustainable society. However, it is likely that these nation states are natural resource rich, have low population needs, and stable and equitable governments. Furthermore, many successful countries have exploited ecological integrity in the past to gain their present status, and developing countries are in the process of using natural resources to improve their levels of well-being (Rands et al. 2010). On the other hand, the countries within cluster four, and the Balkan nations too unstable to evaluate, may provide policymakers insight on what to avoid when trying to make progress toward sustainability. It is important here to point out that the countries needing the most improvement may be flying under the management radar as they lack the resources or attention to be assessed and compared. Although recent research has exposed possible injustice in measuring sustainability (e.g., Fredericks 2012), work remains for ensuring inclusion and objectivity in future regional indicator assessments.

Making progress toward sustainability is contingent on putting theory and scientific findings into applied practice. Most of the discussion on measuring sustainable development is contained within academic literature and any real progress is limited to conceptual and methodological designs; therefore, it rarely reaches the realm of policy and practice (Hezri & Dovers 2006). The process of moving sustainability policy forward has been slowed by lack of consensus provided by the few selected indices employed in decision making. Furthermore, indicators will not be selected for use in policymaking if they contradict a policymaker's own vision, prior literacy, or interests (Lyytimäki et al. 2013).

It is also important for policymakers to note that each index was originally developed for a specific purpose that vary and include scientific exploration of hypotheses;

organizing understanding of issues and their possible solutions; tracking policy performance through outcomes-based management; discriminating among alternative decisions; and informing general users (McCool & Stankey 2004; Freeman & Soete 2009). Use of indices across geographical boundaries allow policymakers a technique for providing services to populations and/or regions of need (Wong 2006), therefore maximizing the impact of their available resources. Ultimately, governing agencies need to select appropriate and reliable measuring techniques for addressing their specific sustainability goals and needs, while maintaining an iterative an adaptive process. To end, the research contained within this paper allows for a more stable and accurate method for assessing sustainability across geographical management units (countries in this analysis) that could be used in macroscale policymaking (i.e., European Union).

### *5.3. Limitations*

A primary limitation of this study is its reliance on data collected at different but broadly comparable time periods. Although currently unrealistic, it would be ideal to have all relevant data for a single time period or the aggregate of a long time series (Moffatt 2008). Although this study covers 36 countries across a continent, a fleshed out version including all global nations is warranted. Another common inadequacy of sustainability studies relates to data aggregated to the country scale. Although most relevant data are only collected at one spatial scale, it is likely that complex sustainability relationships change with the level of geography under study (Levin 1992; Cushman & McGarigal 2004). At present, such disaggregated methods and data are not readily available for a multiscale study.

Another limitation of this study pertains to the exploratory Ward's (1963) cluster analysis used for the creation of classification. When attempting to evaluate clustering methods, it is essential to realize that most techniques are biased toward finding clusters possessing certain characteristics related to size, shape, or dispersion. Methods based on the least-squares criterion, such as Ward's (1963) minimum variance method, tend to find clusters with roughly the same number of observations in each cluster (SAS 1983). A potential bias during the cluster analysis may have come with the four-cluster 'cut' solution. Due to a small sample size, the accepted CCC value of greater than two was not reached. This atheoretical approach fits the needs of this study, in which our aim was to allow country bundles to emerge without *a priori* assumptions. Within this study, we used formal procedures to limit bias and include a post hoc analysis to support the country bundles that emerged.

## 6. Conclusions

Humankind and other species are dependent upon Earth's life-supporting ecosystem services, which in turn depend upon on the practices of human society (Cairns 2007). In order to maintain, or optimistically enjoy increased, levels of environmental quality, social equity, and economic welfare, humanity must learn to live within the limitations of their biophysical environment. The discussion of limits may have led us to the margin of what traditional science provides; however, it has made humanity embrace sustainability as a rational guide to create a long-term, positive relationship between themselves and the Earth. Over the last two decades, the scientific community has come to realize that indicators are useful for measuring current aspects of sustainability, and increasingly they will be needed to help operationalize sustainable development. Results from past investigations have revealed that a majority of sustainability indicators have theoretical or quantitative shortcomings (Rogers et al. 2008), ultimately causing a lack of consensus on their design or use. That said, the following question remains to be understood: at what point does the metabolization and destruction of life-supporting ecosystems start to hinder humanity's social equity and economic welfare? Since little attention has been given to this question, and the majority of sustainability research employing historic data sets, the answer to this inquiry may soon point to a time in our past. Therefore, now is the time for operationalizing sustainability theory into practice by selecting measurable targets by policymakers.

While the processes of sustainable development are linked to environmental quality, social equity, and economic welfare, they are by no means homogeneous or uniform in terms of their explicit spatial patterns. Furthermore, as there is no causal order in space as there is in time, a holistic approach to indicator use should be considered when assessing sustainability regionally. In this study, we postulate that a set of composite indices can be employed collectively through cluster analysis to analyze sustainability regionally. When doing so, it is necessary to understand the nature of each indicator, and the interaction between measures, before trying to associate them to sustainability and prior to management strategies targeting any one indicator for guiding or limiting development.

Building upon previous studies, this paper provides empirical evidence of quantitative and spatial relationships for 25 composite indices of sustainability across 36 countries in Europe. Although previous studies have addressed statistical relationships between indicators of sustainable development, few have directly asked how a number of indices can be used concurrently for analyzing sustainability over space. Previous country-scale indicator studies (e.g., Moffatt 2008) used global economic leaders for their analysis of sustainable development. Unfortunately, these studies only allow for course prediction of the development processes underway and do not help decipher differences within geographic regions (e.g., European Union). As such, they can offer only crude conditions of sustainable development and a limited amount of information for global management agencies, sustainability scientists, and policymakers. This paper presents preliminary results of four geographic bundles of similarity, from 25 composite indices of sustainable development, using Ward's (1963) cluster analysis for 36 European nations. We hope that these results provide tools to further investigate sustainable development patterns useful to global management agencies, sustainability scientists, and policymakers. It is hoped that readers of this article will be inclined to develop an approach similar to the one outlined here in an effort to improve indicator applicability. Its outright rejection without provision of an alternative procedure that can be useful for regional assessment will only serve to slow the progress of future sophisticated sustainable development monitoring programs. Forthcoming studies should closely examine and establish relationships between country policies and management practices, with measures of sustainability. More research could also be pursued to develop local (disaggregated) indicators of sustainable development. Across local and regional scales, explicit explorations of the landscape mechanisms and policies impacting sustainability remain. In closing, information from studies like this one help to determine processes that need to be modified or maintained to ensure the longevity of global systems.

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