Assessment of sustainability using a synthetic index

Luisa Marti, Rosa Puertas*

Grupo de Economía Internacional, Universidad Politécnica de Valencia, Camino de Vera s/n, Valencia 46022, Spain

ARTICLEINFO

Keywords:
Sustainable society index
Cross-efficiency
Cluster analysis
Synthetic indices

ABSTRACT

The Sustainable Society Index measures the three fundamental pillars of sustainability (the economy, the environment, and development) for154 countries around the world. It assigns the same weighting to all the indicators, without any aggregation of the pillars. This study proposes the use of cross-efficiency in order to overcome these shortcomings and obtain a more accurate sustainability index that allows countries to be ranked in terms of their environmental situation as well as their economic and social development. First, cluster analysis is used to classify the countries into homogeneous groups, according to their environmental position. Then, two sustainability indices are produced to measure environmental as well as economic and social aspects. The results show that few countries have managed to improve all facets of sustainability, and at times economic development is associated with both social progress and environmental deterioration, which diminishes the end result.

1. Introduction

At the beginning, the sustainability was associated only with the depletion of natural resources. Today, however, it incorporates both environmental and economic aspects, as well as all that is aimed at rectifying the deficiencies created by social inequalities. These three pillars are essential to ensuring the sustainability of society, and the economy must be addressed within their limits. Fuchs (2006) provides a detailed analysis of the dimensions of the sustainability of the information society. He argues that indicators such as the Ecological Footprint, the Pilot Environmental Sustainability Index and The Living Planet Index, among others, focus exclusively on the most ecological dimension of sustainability, where human action puts pressure on the environment and modifies it, overlooking the economic, political, cultural and social aspects.

At the same time, changes in well-being, sometimes associated with the level of sustainability achieved, is one of the issues that has been attracting most attention in recent years. Composite indices are a good tool for measuring utility and are used in both the academic and political field. Such indices are formed by aggregating very diverse components that can reflect the trends affecting a territory (Reig, 2010). Both public and private organizations have developed indicators that facilitate an assessment of progress towards sustainability (Environmental Performance Index, Legatum Prosperity Index, Sustainable Economic Development Assessment, Social Progress Index, and Sustainable Society Index, among others). Furthermore, recent studies have demonstrated their usefulness in decision-making processes. (Rogers et al., 2008; King et al., 2014; Phillips, 2015; Shaker, 2015, 2018). However, there is still a lack of consensus on the assessment of sustainability in the abundant literature. These discrepancies relate to the characteristics that define sustainability, as well as the way of aggregating the indicators used to measure it (Phillis et al., 2010; Wu et al., 2018).

The Sustainable Society Index (SSI) proposed by Van de Kerk and Manuel (2008) addresses many of the shortcomings identified, as it provides not only a broader definition of sustainability but also a greater degree of transparency in terms of how it is produced. It has been used to analyse the evolution of sustainability levels over time since 2006, confirming a notable overall improvement in terms of public debt, savings and employment (Gallego-Alvarez et al., 2015). Recently it has been used in a number of papers to analyse the sustainability of specific areas of the world, such as the Czech Republic and Poland (Bluszcz, 2016), the EU as a whole (Stratan et al., 2018), and Malaysia (Igrahim et al., 2019), among others. The SSI is one of the most comprehensive indices, covering the three dimensions (social, environmental, and economic) and evaluating more than 150 countries (Van de Kerk and Manuel, 2012).

In the first edition of the SSI (2006) Van de Kerk and Manuel (2008) proposed a global index presenting different ways of aggregating the three dimensions that define it. They concluded that the choice of weights did not substantially affect the results. However, the recommendations of the *Joint Research Centre of the European Commission* indicate that the negative relationship between the Human Well-being (HW) and Environmental Well-being (EW) dimensions prevents the aggregation (arithmetic or geometric) of the pillars into a single index. Therefore, in subsequent publications of the SSI, the authors have limited themselves to providing a ranking by pillar, omitting the step of aggregating the pillars, and advising that simply adding them together could reveal a country's level of sustainability,[1] an issue often criticized as eclecticism.

Therefore, the research gap is focused on the lack of consensus regarding the most appropriate objective/subjective methods for determining the weights that could enable the aggregation of the individual dimensions that make up the indices. According to Barron and Barrett (1996) the different methods used, and their standardization, provide different weights in the same environment. In addition, Melkonyan and Safra (2015) claim that the fact that results obtained vary depending on the technique used greatly complicates decisionmaking.

The research carried out has been motivated by the need to fill these gaps and to provide more literature on the subject; as such the aim of this paper is twofold. First, a simplified measurement of sustainability based on two pillars is proposed, thereby providing a more aggregated view of the situation. Second, the construction of synthetic indices using efficiency models is proposed, avoiding the arbitrary weighting of the indicators and components that make up the SSI pillars. All this is carried out in a setting of homogeneous groups of countries, achieved through cluster analysis. This homogeneity is necessary for the proper application of the cross efficiency (CE) method. The data used for the analysis are those published in the latest release of the SSI, 2016.

The main idea is to assess the environmental dimension and a combined economic and social dimension. The decision to aggregate these two pillars was based on the close relationship between the two; in a country with a certain level of wealth, the associated human conditions are usually at a similar level of development. To this end, for each group resulting from the cluster analysis, the study proposes the construction of two synthetic indices calculated using the multipliers provided by the cross-efficiency (CE) method:

- DEA-SSI EW, which includes the SSI indicators related to the environment.
- DEA-SSI EcHW, which includes both the economic and human indicators from the SSI, since there is a positive correlation between the two and they follow the same trend.

Specifically, the research questions are: How many homogeneous groups of countries can be established based on EW dimension?; Does the original SSI EW index rank the same or similarly to countries as the synthetic DEA-SSI EW index?; and Are there countries with significant disparities between DEA-SSI EW and DEA-SSI EcHW?.

This approach contributes a quantitative and qualitative improvement to the original SSI index, reducing the dimensions and circumventing one of the main weaknesses of the index; the arbitrary aggregation of indicators and categories using geometric means that assign the same weighting to each one. According to Wu et al. (2018), this is not Pareto-optimal, making it difficult to use the index as a guide for decision-making. The use of efficiency techniques to construct synthetic indices that facilitate the ranking of alternatives has been the subject of numerous studies focusing on a range of different areas of the economy (Hollingsworth and Wildman, 2002; Hollingsworth, 2008; Ho et al., 2010).

The rest of the paper is organized as follows. Section 3 describes the SSI as well as its evolution since 2006. Section 4 explains the methodology used to produce the synthetic indices. Section 5 details the main results. Finally, Section 5 summarizes the conclusions drawn from the research.

2. Sustainability assessment: Sustainable Society Index

The assessment of sustainability is a complex issue, the aim of which is to provide appropriate information to improve the decision-making process, selecting and measuring the various activities that contribute to sustainable development (Scrase and Sheate, 2002). In recent years, a number of calculation systems have been developed, focusing on the three dimensions of sustainable development (Labuschagne et al., 2005). Authors such as Kumar et al. (2009), and more recently Wątróbski et al. (2018) and Ziemba (2018), have offered a broad overview of the range of indices developed in this field to date. Said authors recognize the potential of these indices for guiding public policies tailored to individual scenarios, as well as for categorizing countries in environmental, economic and social terms.

Generally speaking, the indices are constructed in two phases. First, the individual indicators that identify the different aspects of sustainable development are determined. The second phase entails establishing the way of combining the indicators to provide an overall assessment of the country, city or activity under analysis (Table 1).

In the construction of any index, there is inevitably a degree of subjectivity involved in the process, ranging from the selection of the data, to its standardization and the weighting phase. Specifically, in the 1990s, the need for an aggregate estimation of the performance of the economy and sustainability prompted the emergence of numerous indices, such as the Human Development Index (1990), Sustainable Progress Index (1994), Ecological Footprint (1996), Genuine Savings Indicator (1999), Barometer of Sustainability (1995) and Environmental Pressure Indicators (1999), among others. These are indices that give the same weighting to all the aspects that comprise them, with the overall index calculating by summing the individual aspects.

In recent decades, the growing concern about establishing an internationally accepted sustainable development index has led to a succession of indices aimed at filling this gap, such as Total Material Requirement (2001), Compass of Sustainability (2005), Environmental Sustainability Index (2002) and Environmental Performance Index (2002). Nevertheless, they have been of very limited use in decisionmaking due to the fact that issues inherent to the measurement, weighting and indicator selection have not been appropriately addressed at all levels. This latent problem thus calls for a solution in order to avoid the associated subjectivity.

The research carried out seeks to achieve a more objective aggregation of the sustainability indicators that make up the SSI, an index chosen due to its coverage of the three aspects of sustainability (environmental, economic and social). The SSI was developed by the Sustainable Society Foundation, based on the definition of sustainability provided in the Brundtland report (WCED, 1987). The aim of the index is to quantify sustainability levels, revealing the aspects in which countries are most deficient. Starting in 2006 and published every two years, the index evaluates the sustainability achieved by 154 countries, specifying results for the three basic pillars: environmental, economic and social. The *Joint Research Centre of the European Commission* rates it as a sound tool, both statistically and conceptually, for measuring the various aspects that define sustainability. It also serves as a reference in the study of the progress made by the countries analysed (Saisana and Philippas, 2012).

It was created under the concept that society is sustainable if three objectives are achieved: meeting the demands of current generations, not compromising the ability of future generations to meet their own needs, and allowing every human being the opportunity to develop in freedom and harmony with their environment (Phélan, 2018). It is constructed from 21 indicators, grouped into 7 categories that make up the three dimensions of sustainability (Table 2).

The three dimensions of the SSI correspond to the fundamental pillars of sustainable development. The social dimension (HW) consists in ensuring intergenerational equity; that is, meeting individuals' basic

Table 1
Some sustainable indices: weighting and aggregation.

Sustainable indices	Weighting	Aggregation
City development index	Principal Component Analysis	Weighted average
Environment performance index		Weighted average
General indicator of sciences and Technology		Principal Component Analysis
Success software process improvement		-
Sustainability performance index	Equal weights	T. area x unit product/area per cap.
Living planets		Geometric mean
Ecological Footprint		Summation
G Score method		Summation
Compass index of sustainability		Average
Environmental sustainability index		Arithmetic average
Human development index		Arithmetic average
Composite sustainability development index Composite	Analytic Hierarchy Process	Weighted average
sustainability performance index		Weighted average
Living cycle index		Geometric mean Weighted
Environment quality index		sum
Nation innovation capacity	Multiple Regression	Regression analysis

Source: Own elaboration.

Table 2
Composition of the Sustainable Society Index (SSI).

Dimensions	Categories	Indicators
Human well-being (HW)	Basic needs	Sufficient food Sufficient to drink Safe sanitation
	Personal Development & Health	Education Healthy life Gender equality
	Well-balanced Society	Income distribution Population growth Good governance
Environmental well-being (EW)	Natural Resources	Biodiversity Renewable water resources Consumption
	Climate & Energy	Energy use Energy saving Greenhouse Gases Renewable Energy
Economic well-being (EcW)	Transition	Organic Farming Genuine Saving
	Economy	Gross Domestic Product Employment Public Debt

Source: Van de Kerk and Manuel (2014).

needs in the present and the future. The environmental dimension (EW) is based on the obligation to maintain and ensure the continuity of ecological resources, limiting their consumption and reducing waste/ pollution. Lastly, the economic dimension (EcW) is focused on ensuring an optimal combination of economic development and the conservation of natural resources.

Both the first and the second dimensions (HW and EW) are considered goals; while there is a strong negative correlation between the two, it makes no sense to achieve one without the other. On the contrary, EcW is not an end in itself, but rather a condition enabling improvements to the other two (Kaivo-oja et al., 2014). The indicators that define each category are evaluated on a scale of 1 to 10, with 10 being the goal for all countries to achieve. The categories and dimensions are calculated using the geometric mean of their components, assigning the same weight to all the indicators or, as the case may be, to the categories. In order to offer an understanding of the evolution of SSI dimensions, Table 3 presents the statistical characterization from 2006 to 2016.

Over the 10 years, the greatest progress has been made in EcW (0.33), however, not all countries have moved in the same direction: the drop in the minimum value of the EcW has widened the gap between the most and least advanced countries in terms of economic well-being (0.43). Similarly, the analysis of HW shows that, although the maximum values have remained steady (0.05), notable progress has been made at the per capita level (0.33). This dimension includes aspects such as food, safety, education, gender equality, and income distribution, among others.

Today, EW is the pillar where government agencies are primarily targeting their combined efforts, giving rise to political measures aimed at safeguarding the environment. Nevertheless, and although many countries have stated their commitment to taking the necessary measures to prevent the drastic consequences of climate change, EW is the aspect that has registered only slight improvement, and at the per capita level the efforts made have even decreased (−0.13). This is a pillar that entails significant expenditure by public institutions, while the returns are slow to emerge and it is sometimes difficult to quantify the benefits, such as energy savings, biodiversity, the installation of renewable water resources, and the elimination of greenhouse gases, among others.

The database covers a wide range of countries with diverse characteristics, registering extreme values for one of the pillars that make up the SSI. In particular, Luxembourg's scores in economic and human terms are close to the top, but it lags far behind in terms of the environment, even tailing countries such as Togo and Sierra Leone. It is interesting to analyse countries' situations according to their income classification, as established by the World Bank: high, upper-middle, lower-middle, and low income (Table 4).

Countries classified as high income have made major efforts to address environmental issues, neglecting economic and human issues, while those classified as lower-middle income and low income have made important advances on economic and human issues, overlooking environmental issues (Table 3). Natural wealth is usually accompanied by scarce economic and social resources. Thus, for example, in 2016 Togo reached the highest level in EW, while remaining far behind the other countries in the rest of the pillars.

Another interesting aspect is the progress that the countries have made between 2006 and 2016, primarily observed in EcW (GDP, employment, public debt, savings, etc.). The gap between the high income and low income countries has narrowed by just over one point, mainly because of the progress made by the latter.

The SSI does not treat aspects related to the governance and sustainability of assets as isolated indicators, as proposed by Marques et al. (2015) in their study of the level of sustainability of water services. However, Brattebø et al. (2013) believe that both are implicit in the three pillars of sustainability and the extent to which they are achieved will depend on the levels reached in the economic, social and environmental dimensions.

Table 3
Descriptive statistics of the SSI 2006–2016.

	Human well-being (HW)						
	2006	2008	2010	2012	2014	2016	Progress score 2006–2016
Maximum	8.95	8.94	8.91	8.95	8.98	9.00	0.05
Average per country	6.16	6.21	6.26	6.33	6.39	6.45	0.29
Average per person	6.08	6.12	6.21	6.26	6.33	6.41	0.33
Minimum	3.05	2.96	2.95	3.03	3.09	3.12	0.07
Max-Min	5.90	5.98	5.96	5.92	5.89	5.88	−0.02
	Environmental well-being (EW)						
	2006	2008	2010	2012	2014	2016	Progress score 2006–2016
Maximum	8.01	8.22	8.23	8.18	8.00	8.13	0.12
Average per country	4.89	4.84	4.92	5.00	4.99	5.02	0.13
Average per person	4.89	4.78	4.77	4.69	4.64	4.76	−0.13
Minimum	1.45	1.54	1.48	1.58	1.54	1.52	0.07
Max-Min	6.56	6.66	6.75	6.60	6.46	6.61	0.05
	Economic well-being (EcW)						
	2006	2008	2010	2012	2014	2016	Progress score 2006–2016
Maximum	8.10	8.30	8.43	8.46	8.54	8.43	0.33
Average per country	4.17	4.45	4.46	4.44	4.44	4.41	0.24
Average per person	4.19	4.42	4.50	4.51	4.59	4.60	0.41
Minimum	1.38	1.38	1.40	1.69	1.45	1.28	−0.10
Max-Min	6.72	6.92	7.03	6.77	7.09	7.15	0.43

Source: Own elaboration. Database Sustainable Society Index.

3. Methodology for the construction of a synthetic index: DEA andcluster analysis

Using partial indicators to construct an index presents a major problem: determining the most appropriate way to aggregate the indicators. This issue can be solved by creating a synthetic indicator. Currently, there is no single accepted method for doing so; some of the most commonly-used methods include principal component analysis, multiple-criteria decision analysis, system dynamics approach, distance principal component, systems thinking and analytic hierarchy process, and the Bayesian network model (Jiang et al., 2018). All of these have certain limitations that prevent a consensus from being reached.

This study proposes the use of the data envelopment analysis (DEA) method as a tool for aggregating SSI indicators, avoiding any prior aggregation of the categories that comprise the index. It is a powerful tool applicable to multidimensional studies, and is not affected by

Table 4
Evolution of SSI by income.

subjectivity associated with the allocation of weights (Martínez-Roget, 2005). Such applications date back to the early 90s and feature prominently in the literature (Hashimoto and Ishikawa, 1993; Hashimoto and Kodama, 1997; Zhu, 2001; Storrie and Bjurek, 2000; Murias et al., 2006; Martínez et al., 2009; Martín et al., 2017).

At the beginning, DEA was proposed by Charnes et al. (1978) as an instrument for estimating the technical efficiency of a set of productive units with multiple inputs and outputs. By solving a linear programming model, the efficiency levels of each observation are obtained, as shown in Eq. (1).

$$\max_{u,v \geq 0} h = \frac{\sum_{r=1}^{s} u_r * y_{r0}}{\sum_{i=1}^{m} v_i * x_{i0}} \quad (1)$$

$$\frac{\sum_{r=1}^{s} u_r * y_{rj}}{\sum_{i=1}^{m} v_i * x_{ij}} \leq 1$$

s. t.

u , $v_{r\,i} \geq 0$ where: x_{ij}: amounts of inputs i (i = 1, 2, …, m) used by the jth country. x_{i0}: amounts of inputs i used by the country analysed.

y_{rj}: amounts of outputs r (r = 1, 2, …, s) produced by the jth country. y_{r0}: amounts of outputs r produced by the country analysed. u_r: output weightings. v_i: input weightings.

Bearing in mind that the measure of efficiency takes values between 0 and 1, it is interpreted as follows:

- If h_0 = 1, the DMU is efficient in relation to the others and, therefore, will be located on the production frontier.
- If h_0 < 1, another DMU is more efficient than the one under analysis.

DEA is an objective tool because it does not need the allocation of weights and does not require all units to assign the equal importance to the same partial indicator. The DEA methodology makes it possible to differentiate between efficient and inefficient observations, but it does provide a ranking of the efficient observations. Thus, the use of the cross-efficiency (CE) method is needed to achieve a complete ranking of all the efficient observations. Other techniques such as super-efficiency have been used to obtain rankings in different spheres of the economy, however, its accuracy depends on the development of the analysis under constant returns to scale.

CE was originally proposed by Sexton et al. (1986), and later validated by Doyle and Green (1994), in order to overcome the main limitations of DEA. As highlighted by Angulo-Meza and Lins (2002), these limitations include not only the inability to distinguish between efficient units but also the fact that an inappropriate weighting scheme can distort the results. CE is used to assess the performance of each country, computed using the input and output weights that are optimal for the other countries. The resulting CE matrix contains information on the efficiency of a country relative to the others. This allows the researcher to rank all the observations that have an efficiency score of 1. Each element is calculated by means of the following expression:

$$E_{kj} = \frac{\sum_{r=1}^{s} u_{rk}\, y_{rj}}{\sum_{i=1}^{m} v_{ik}\, x_{ij}} \quad j = 1\ldots,n;\ k = 1, \ldots,n \qquad (2)$$

where u_{rk} y v_{ik} are the optimal multipliers obtained by DEA for the corresponding country, with the original efficiency scores on the diagonal. Thus, the value of E_{kj} is obtained by evaluating country j using the optimum weights for country k.[2]

DEA is based on two fundamental hypotheses. First, all the DMUs in the sample are functionally similar; that is, they all have the same type and number of inputs and outputs. Second, the set of DMUs has to be homogeneous; in other words, directly comparable. If both hypotheses hold true, the difference in the scores for the relative performance of DMUs in the sample is thought to reflect the differences in their efficiency at converting inputs into outputs (Samoilenko and Osei-Bryson, 2010). However, the presence of heterogeneity may undermine the scores registered by the countries.

The literature includes studies that recommend the combination of cluster analysis (CA) with DEA in order to ensure these assumptions are met (Hirschberg and Lye, 2001; Meimand et al., 2002; Shin and Sohn, 2004; Lemos et al., 2005; Marroquin et al., 2008; Sharma and Yu, 2009). They all conclude that the groupings obtained through CA improve DEA results when applied on homogeneous DMUs.

CA is a multivariate method that provides clusters of observations according to their inherent characteristics. Its application to a set of DMUs enables the researcher to obtain subgroups characterized by high internal (within-cluster) homogeneity and high external (betweencluster) heterogeneity. The observations in one cluster share many characteristics in common, and are very different from those of another cluster, since this method minimizes within-cluster variability and maximizes between-cluster variability. CA involves the following stages:

1. Selection of variables
2. Selection of the measure of association, which may be a distance (forexample, Euclidean distance) or a similarity (for example, coefficient of correlation. The groups formed will contain similar individuals, such that the distance between them is reduced or they show strong similarity, depending on the measure chosen.
3. Selection of the clustering technique, choosing between hierarchicalor non-hierarchical methods depending on whether homogeneous groups are constructed by joining or separating existing clusters, or conversely, by exchanging observations between different clusters.

	Human well-being (HW)						
	2006	2008	2010	2012	2014	2016	Progress score 2006–2016
High income	7.84	7.80	7.82	7.91	7.95	8.02	0.18
Upper middle income	6.10	6.12	6.22	6.28	6.35	6.43	0.32
Lower middle income	5.65	5.76	5.88	5.94	6.02	6.12	0.47
Low income	4.02	4.13	4.25	4.32	4.41	4.49	0.47
GAP (High – Low income)	3.82	3.67	3.57	3.59	3.55	3.53	−0.29
	Environmental well-being (EW)						
	2006	2008	2010	2012	2014	2016	Progress score 2006–2016
High income	2.80	2.84	3.00	3.16	3.28	3.40	0.60
Upper middle income	4.35	4.21	4.16	4.11	4.00	4.05	−0.30
Lower middle income	5.87	5.68	5.58	5.33	5.27	5.44	−0.43
Low income	7.34	7.34	7.42	7.45	7.26	7.28	−0.06
GAP (High – Low income)	−4.54	−4.50	−4.42	−4.29	−3.98	−3.88	0.67
	Economic well-being (EcW)						
	2006	2008	2010	2012	2014	2016	Progress score 2006–2016
High income	5.41	5.33	4.92	4.64	4.78	4.88	−0.53
Upper middle income	4.81	5.07	5.12	5.13	5.30	5.18	0.38
Lower middle income	3.31	3.67	3.98	4.10	4.11	4.21	0.89
Low income	2.87	3.14	3.32	3.42	3.41	3.39	0.52
GAP (High – Low income)	2.54	2.19	1.60	1.22	1.37	1.49	−1.05

Source: Own elaboration. Database Sustainable Society Index.

4. Validation of the results

From all the hierarchical algorithms available, Ward's method was chosen for this study. It is an agglomerative hierarchical clustering method that enables a measurement of the loss of information that occurs when DMUs are integrated into clusters, through the total sum of the squared deviations between each DMU and the average of the cluster of which it is part. The method seeks to combine clusters such that the combination of those clusters yields the smallest increase in the sum of the squared deviations. This method is very commonly used because it offers all the advantages of the average method and has more discriminatory power when determining the clustering levels. According to Kuiper and Fisher (1975) this is a powerful classification technique; in their research they demonstrated that Ward's Method is more powerful than other methods (minimum, maximum, average and centroid) when it comes to obtaining the optimal classification. They demonstrated that it has all the advantages of the mean method and is more discriminating in the determination of clustering levels, specifically it facilitates the formation of more compact clusters of similar size and minimizes the loss of information in the clustering organization process. Recently, Bracke et al. (2019) proposed to combine DEA and CA, using the Ward method, in order to establish groups of similar characteristics and determine their efficiency based on multiple inputs/ outputs.

Subsequently, the study of the 2016 SSI was carried out by forming homogeneous groupings of countries according to the EW dimension, applying CA in order to ensure robust results in the subsequent application of CE (Abbot and Doucouliagos, 2003; Gómez and Mancebón, 2005; Torrico et al., 2007; De la Torre et al., 2015). The two pillars EcW and HW are intrinsically more closely related, however, EW is independent of the country's economic and social development. This has influenced the choice of this dimension as a criterion for the application of the cluster. In addition, clustering based on the EW pillar will yield enlightening results on sustainability levels in different countries.

4. Results and discussion

The cluster analysis was carried out on 154 countries based on the seven indicators of the EW dimension (Table 1), yielding four groups of countries according to their degree of involvement in the different aspects of this pillar.[3] Table 5 shows the mean values of each indicator for its corresponding cluster.

Cluster 1 is made up of 71 countries, mainly from the African continent (52.11%), followed by Asia (19.71%) and South America (16.9%). Compared to the rest of the clusters, this group registers the highest mean scores for each indicator, with the exception of Biodiversity and Energy Savings, indicating that these countries with predominantly emerging economies have a lot of potential in terms of environmental resources.

Table 5
Mean values of environmental indicators by clusters.

Indicator	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Biodiversity	6.3	4.7	6.5	7.0
Renewable Water Resources	9.3	1.8	9.0	8.8
Consumption	6.3	6.2	4.6	2.9
Energy Use	8.7	5.2	6.0	1.6
Energy Savings	3.4	5.0	5.8	6.2
Greenhouse Gases	9.1	4.7	5.3	2.0
Renewable Energy	5.6	1.5	1.6	2.0
Num observations (DMUs)	71	18	40	25

Source: Own elaboration.

Cluster 2 contains a total of 18 countries, divided between Asian (72.2%) and African countries, though the share of the latter is much smaller. With respect to the indicators, Consumption (6.2) stands out on average. This indicator is interpreted as a measure of the use and depletion of material resources. On the opposite side is Renewable Energy (1.5), revealing these countries' low level usage of renewable energy resources that can prevent fossil fuel depletion and gas emissions.

Next, Cluster 3 is mainly made up of European countries (65%), with the rest being divided between the different continents. These are countries characterized by their high degree of commitment to the sustainability of water resources (Renewable Water Resources, 9.0) though the same cannot be said for energy resources (Renewable Energy, 1.6). Lastly, Cluster 4 predominantly contains the countries with the highest incomes, notably European countries (60%), the USA and Japan. Once again, this group's commitment to the sustainability of water resources registers the highest value (Renewable Water Resources, 8.8). In addition, this is the group with the greatest involvement in caring for nature and energy savings (Biodiversity, 7.0; Energy Savings, 6.2), neglecting other aspects such as the use of energy (Energy Use, 1.6), needed to achieve economic development.

Two synthetic indices have been constructed from these homogeneous groups, which will enable a detailed analysis of each country. The first index is DEA-SSI EW, calculated with only the indicators comprising the EW dimension; and the second is DEA-SSI EcHW, in which both the EcW and HW pillars have been included.

These synthetic indices have been produced using the CE method,

Table 6
Definition of inputs and outputs for each indicator.

DEA-SSI EW		DEA-SSI EcHW	
Inputs (Natural Resources)	Outputs (Climate & Energy)	Inputs (HW)	Outputs (EcW)
Biodiversity Renewable water resources Consumption	Energy savings Greenhouse gases Renewable energy	Sufficient to drink Safe sanitation Education Healthy life Gender	Genuine savings GDP Employment Public debt
Energy use		Sufficient food equality Income distribution Population growth Good governance	Organic farming

which requires the definition of a hypothetical production function where outputs can be obtained from a series of inputs. As established in the methodology, and since the objective is not to measure efficiency but rather to construct indices that produce a ranking of observations, the decision of which variables to use as inputs and which as outputs is an arbitrary choice of the researcher and, at times, does not have a substantial influence on the conclusions drawn (Falagario et al., 2012; Puertas and Martí, 2019). The inputs and outputs used to construct the indices are defined in Table 6.

The DEA-SSI EW produces a ranking with the seven environmental indicators, taking the three that comprise the category "Natural Resources" as inputs, and the four components of "Climate & Energy" as outputs. In the case of DEA-SSI EcHW, the inputs correspond to the HW dimension and outputs to the EcW. To construct both of these indices, the indicators identified as inputs had to be transformed into "values to be improved", by subtracting the value corresponding to each of the observations from the maximum value of the indicator, as established by the methodology used (Martí et al., 2017).

Table 7 compares the ranking of countries obtained by the proposed DEA-SSI EW index with the ranking from the original SSI EW index, showing the differences between the two. This clustering criterion can lead to countries with significant economic and social disparities being included in the same group, as is the case with Trinidad & Tobago, which belongs to the same cluster as Norway and Denmark.

Columns 2 and 3 of each cluster show the rankings produced by the synthetic index and the original index, respectively. Column 4 presents the differences between the two, determining the possible higher ranking of the top-positioned countries in the DEA-SSI EW. As can be seen in Table 6, these differences are mostly positive; that is, the original index assigns a lower ranking to the top-ranked countries under the proposed index. This is especially true in Clusters 1 and 2, where, respectively, Mozambique registers a difference of 12 points and Libya of 8. In Clusters 3 and 4, meanwhile, there is less divergence in the rankings produced by the two indices. Montenegro, South Africa, Japan, and Trinidad and Tobago have the same ranking and for several others, such as Croatia, Moldova, Venezuela, the Slovak Republic, Denmark and Sweden, the difference is not significant.

A similar analysis is then carried out with the economic and social dimension, first constructing the index from the original data of these two pillars combined[4]:

$$SSIEcHW = EcW + HW \quad (3)$$

Subsequently, using the CE technique (Eq. (2)), with the inputs and outputs previously defined in Table 6, the synthetic indicator DEA-SSI EcHW has been calculated, thus allowing a comparison of the two rankings of countries (Table 8).

According to the ranking in Table 8, there are many similarities between the DEA-SSI EcHW and SSI EcHW rankings for the top 10 countries in Cluster 2 and Cluster 4. According to the World Bank, most of these countries are upper-middle-income economies and high-income economies, where economic well-being is aligned with a concern for improving social aspects. Identical rankings are produced by the two indices for countries such as United Arab Emirates, Iran, Algeria, Egypt, Norway, Sweden and Germany, with the indices differing by only one point for Saudi Arabia, Kuwait, Qatar, and the Czech Republic. The rest of the differences are mostly positive, reflecting the better position assigned by the proposed synthetic index.

Another relevant aspect is the study of the possible relationship between the environmental and socio-economic dimension according to DEA-SSI EW and DEA-SSI EcHW. Table 9 shows, for each cluster, the top 10 countries according to the environmental ranking, compared to their position in the socio-economic ranking.

In all the clusters there is a wide disparity between the two

Source: Own elaboration.

[4] See Wu et al. (2018).

Table 7

Comparison between DEA-SSI EW and SSI EW rankings for the top 10 countries from the synthetic indicator.

CLUSTER 1 (71 countries)				CLUSTER 2 (18 countries)			
Countries	Ranking DEA-SSI EW	Ranking SSI EW	Dif	Countries	Ranking DEA-SSI EW	Ranking SSI EW	Dif
Burundi	1	1	0	Yemen	1	6	5
Central African Rep	2	4	2	Sudan	2	2	0
Togo	3	2	−1	Egypt	3	5	2
Mozambique	4	16	12	Libya	4	12	8
Guinea	5	10	5	Syria	5	4	−1
Rwanda	6	7	1	Jordan	6	9	3
Lesotho	7	3	−4	Pakistan	7	1	−6
Gambia	8	9	1	Kuwait	8	13	5
Zambia	9	11	2	Tunisia	9	3	−6
Uganda	10	5	−5	U. A. Emirates	10	16	6
CLUSTER 3 (40 countries)				CLUSTER 4 (25 countries)			
Countries	Ranking DEA-SSI EW	Ranking SSI EW	Dif	Countries	Ranking DEA-SSI EW	Ranking SSI EW	Dif
Montenegro	1	1	0	Denmark	1	2	1
Korea, North	2	4	2	Norway	2	6	4
Croatia	3	2	−1	South Africa	3	3	0
Uzbekistan	4	8	4	Sweden	4	5	1
Serbia	5	7	2	Austria	5	1	−4
Romania	6	3	−3	Luxembourg	6	10	4
Moldova	7	6	−1	Japan	7	7	0
Venezuela	8	9	1	France	8	4	−4
Slovak Rep	9	10	1	Trinidad Tobago	9	9	0
Macedonia	10	5	−5	Netherlands	10	8	−2

Note: Dif is calculated using the difference between SSI EW and DEA-SSI EW. Source: Own elaboration.

Table 8
Comparison between DEA-SSI EcHW and SSI EcHW rankings for the top 10 countries from the synthetic indicator.

CLUSTER 1 (71 countries)				CLUSTER 2 (18 countries)			
Countries	Ranking DEA-SSI EcHW	Ranking SSI EcHW	Dif	Countries	Ranking DEA-SSI EcHW	Ranking SSI EcHW	Dif
Thailand	1	3	2	U. A. Emirates	1	1	0
Azerbaijan	2	2	0	Saudi Arabia	2	3	1
Panama	3	8	5	Kuwait	3	2	−1
Costa Rica	4	11	7	Israel	4	4	0
Philippines	5	9	4	Iran	5	5	0
Peru	6	6	0	Algeria	6	6	0
Nepal	7	18	11	Turkmenistan	7	9	2
Indonesia	8	10	2	Libya	8	15	7
Ecuador	9	12	3	Qatar	9	8	−1
Uruguay	10	1	−9	Egypt	10	10	0
CLUSTER 3 (40 countries)				CLUSTER 4 (25 countries)			
Countries	Ranking DEA-SSI EcHW	Ranking SSI EcHW	Dif	Countries	Ranking DEA-SSI EcHW	Ranking SSI EcHW	Dif
Switzerland	1	1	0	Norway	1	1	0
Slovenia	2	7	5	Sweden	2	2	0
Belarus	3	21	18	Denmark	3	5	2
United Kingdom	4	12	8	Korea, South	4	10	6
Poland	5	3	−2	Czech Rep	5	4	−1
Hungary	6	9	3	Taiwan	6	12	6
Romania	7	4	−3	Germany	7	7	0
Portugal	8	17	9	Iceland	8	15	7
Latvia	9	5	−4	Australia	9	6	−3
Lithuania	10	2	−8	Estonia	10	3	−7

Note: Dif is the difference between SSI EcHW and DEA-SSI EcHW. Source: Own elaboration.

dimensions; for example, Togo, Yemen, Uzbekistan and South Africa occupy some of the top positions of the DEA-SSI EW ranking but the bottom positions for DEA-SSI EcHW, thus demonstrating the high environmental level achieved and a substantial neglect of socio-economic aspects. However, there are exceptions in Europe, such as Romania, Denmark, Norway and Sweden, which have shown strong involvement in all aspects of sustainability, thus achieving an overall balance, as reflected in the results of both synthetic indices.[4]

Generalizing this analysis for all the observations for each cluster, it is possible to identify which countries present the same level of

.

Table 9
DEA-SSI EW versus DEA-SSI EcHW for the top 10 countries in the environmental ranking.

CLUSTER 1 (71 countries)			CLUSTER 2 (18 countries)		
Countries	Ranking DEA-SSI EW	Ranking DEA-SSI EcHW	Countries	Ranking DEA-SSI EW	Ranking DEA-SSI EcHW
Burundi	1	51	Yemen	1	18
Central African Rep	2	55	Sudan	2	16
Togo	3	69	Egypt	3	10
Mozambique	4	68	Libya	4	8
Guinea	5	56	Syria	5	11
Rwanda	6	26	Jordan	6	14
Lesotho	7	52	Pakistan	7	13
Gambia	8	59	Kuwait	8	3
Zambia	9	58	Tunisia	9	12
Uganda	10	32	U. A. Emirates	10	1
CLUSTER 3 (40 countries)			CLUSTER 4 (25 countries)		
Countries	Ranking DEA-SSI EW	Ranking DEA-SSI EcHW	Countries	Ranking DEA-SSI EW	Ranking DEA-SSI EcHW
Montenegro	1	32	Denmark	1	3
Korea, North	2	19	Norway	2	1
Croatia	3	25	South Africa	3	25
Uzbekistan	4	37	Sweden	4	2
Serbia	5	34	Austria	5	13
Romania	6	7	Luxembourg	6	19
Moldova	7	24	Japan	7	16
Venezuela	8	29	France	8	22
Slovak Rep	9	16	Trinidad Tobago	9	24
Macedonia	10	35	Netherlands	10	14

Source: Own elaboration.

Table 10
Ranking of countries with the greatest similarity between the DEA-SSI EW and DEA-SSI EcHW indices.

Countries	Ranking DEA-SSI EW	Ranking DEA-SSI EcHW
CLUSTER 1 (7%)		
Burkina Faso	24	25
Tanzania	27	27
Zimbabwe	44	46
Albania	57	57
Kyrgyz Rep	64	66
CLUSTER 2 (11%)		
Countries	Ranking DEA-SSI EW	Ranking DEA-SSI EcHW
Iraq	17	17
Oman	12	15
CLUSTER 3 (12.5%)		
Countries	Ranking DEA-SSI EW	Ranking DEA-SSI EcHW
Ireland	22	22
Italy	23	21
Lebanon	39	40
Mongolia	38	39
Romania	6	7
CLUSTER 4 (32%)		
Countries	Ranking DEA-SSI EW	Ranking DEA-SSI EcHW
Belgium	14	15
Canada	21	20
Denmark	1	3
Finland	11	12
Kazakhstan	17	17
Norway	2	1
Sweden	4	2
United States	18	21

Source: Own elaboration.

environmental and socio-economic commitment. Thus, Table 10 shows the countries that are ranked almost identically by the DEA-SSI EW and the DEA-SSI EcHW.

In Cluster 4, 32% of the countries hold very similar positions in the rankings according to the two indices, showing their equity in all aspects of sustainability. In general, in all the groups analysed, it can be seen that these similarities are found in the countries in the fourth quartile of each group, reflecting their disregard for all environmental and socio-economic aspects.

In summary, comparing the two synthetic indices constructed, it can be concluded that Burundi, Yemen, Montenegro and Denmark all occupy the top position of their respective clusters according to the DEASSI EW, while for the DEA-SSI EcHw it is Thailand, the United Arab Emirates, Switzerland and Norway that are in the top positions (Tables 1A, 2A, 3A and 4A in the appendix). Lastly, the countries that can be considered the best out of the 154 in all areas of sustainability are Norway, Denmark and Sweden, which excel in the three dimensions included in the SSI, taking the top positions in both of the proposed synthetic indicators.

5. Conclusions

All the aspects relating to sustainability are becoming a cause of major concern in society. International organizations, under the urging of the governments of the major world powers, are adopting common measures to address the environmental, social and economic failings that reflect existing inequalities. It is essential to have access to tools that can be used to assess the situation of each country, thus providing an understanding of which aspects require greater efforts.

One of the most widely-used indices in this regard is the SSI, which is made up of three pillars assessing the basic aspects of sustainability in 154 countries, and which has been published every two years since 2006. Despite its extensive content, the current version of the SSI has been sharply criticized due to the use of geometric means to aggregate the indicators. This limits its use as a discriminatory tool in the decision-making process because it gives equal weight to all its components, overlooking the discriminatory power of its different dimensions. This methodology could be an alternative to the aggregation methods used by the OECD or the World Bank in the construction of their indices.

In order to overcome some of the shortcomings of the aforementioned index and gain a more accurate understanding of the situation, this study proposes not only an analysis of sustainability using environmentally homogeneous groups, but also a way of aggregating SSI indicators that avoids any kind of subjectivity. The resulting indices have enabled a more comprehensive analysis of countries' level of sustainability, facilitating extrapolations that can guide the adoption of public and private measures aimed at making progress towards greater economic, social and environmental development.

Two synthetic indices have been developed—one to analyse environmental issues and the other for socio-economic issues—for application to each cluster obtained using the CE method. They provide a simplified view of the situation, facilitating the identification of those aspects that require the implementation of more focused policies.

The results confirm the wide disparities around the world. Regardless of the cluster analysed, it can be seen that countries with great natural wealth—the top-ranked countries according to DEA-SSI EW—are in very precarious situations both socially and economically, as shown by DEA-SSI EcHW. Government measures adopted to date have not managed to promote sustainability in all its dimensions; for example, Togo, Yemen, Montenegro and South Africa occupy prominent positions in terms of environmental sustainability, but lag far behind other countries in terms of socio-economic aspects.

The great exception is countries such as Denmark, Norway and Sweden, which have managed to combine their efforts and have achieved an overall balance, holding the top positions in both of the proposed indices. These are countries with great natural wealth along with a good socio-economic situation, which has helped them to implement sustainable practices by raising public awareness about the importance and positive returns of such practices.

The economic development of countries usually involves social progress and environmental deterioration, which can diminish the end result. Public awareness-raising must be accompanied by policies that promote continuous improvement and that offer returns in the form of improved quality of life.

Appendix A. Appendix

The research carried out represents a novel contribution to the exacting task of assessing sustainability, allowing a comparative analysis of dimensions between comparable countries and adding aspects that greatly simplify the measurement and study of sustainability. It is an alternative tool for measuring sustainability, reducing biases in the difficult task of decision-making, as it entails similar countries that could provide models of behaviour patterns to follow. However, one of the limitations found is that it is not possible to create a single synthetic index that groups together the three dimensions of the SSI, due to the opposing nature of its components. Future research should analyse issues related to the standardization of indices, which could affect the results, as well as the effects relating to the omission of any of the indicators. It would even be worth evaluating which of the dimensions require greater effort and dedication in order to progressively raise the levels.

Recent publications

Puertas, R.; Martí, M. (2019). Sustainability in universities: DEAGreenmetric. Sustainability 11.

Puertas, R.; Calafat, C. Martí, M. (2019). Efficiency of innovation in textile companies: A non-parametric approximation. Bulletin of Economics Research.

Martí, ML; Puertas, R. (2019): Factors determining the trade costs of major European exporters. Maritime Economics & Logistics, 324-333. Martí, ML; Martín JC; Puertas, R. (2017). A DEA- Logistics Performance Index. Journal of Applied Economics XX (1), 169-192.

Declaration of Competing Interest

The research carried out has no conflict of interest with previous research or with other researchers.

Table 1A

Cluster 1. Ranking of countries.

Countries	DEA-SSI EW	DEA-SSI EcHW	Countries	DEA-SSI EW	DEA-SSI EcHW
Burundi	1	51	Dominican Rep	37	14
Central African Rep	2	55	Nigeria	38	29
Togo	3	69	Bangladesh	39	12
Mozambique	4	68	Mauritania	40	71
Guinea	5	56	Costa Rica	41	4
Rwanda	6	26	Myanmar	42	17
Lesotho	7	52	Honduras	43	21
Gambia	8	59	Zimbabwe	44	46
Zambia	9	58	Colombia	45	33
Uganda	10	32	Guyana	46	61
Kenya	11	48	El Salvador	47	43
Congo Dem Rep	12	60	Guatemala	48	20
Sierra Leone	13	42	Papua New Guinea	49	30
Haiti	14	36	Philippines	50	5
Liberia	15	62	Sri Lanka	51	31
Guinea-Bissau	16	65	Namibia	52	28
Cameroon	17	45	Vietnam	53	24
Ethiopia	18	40	Indonesia	54	8
Chad	19	47	Peru	55	6
Nepal	20	7	Tajikistan	56	35
Malawi	21	64	Albania	57	57
Madagascar	22	50	Georgia	58	16
Niger	23	39	Jamaica	59	53
Burkina Faso	24	25	Panama	60	3
Senegal	25	44	Ecuador	61	9
Cambodia	26	19	Morocco	62	41
Tanzania	27	27	India	63	34
Benin	28	22	Kyrgyz Rep	64	66

(*continued on next page*)

Table 1A (*continued*)

Countries	DEA-SSI EW	DEA-SSI EcHW	Countries	DEA-SSI EW	DEA-SSI EcHW
Congo	29	70	Uruguay	65	10
Mali	30	37	Gabon	66	63
Cote d'Ivoire	31	23	Botswana	67	18
Laos	32	54	Armenia	68	38
Angola	33	67	Mexico	69	15
Ghana	34	49	Azerbaijan	70	2
Paraguay	35	11	Thailand	71	1
Nicaragua	36	13			

Table 2A

Cluster 2. Ranking of countries.

Countries	DEA-SSI EW	DEA-SSI EcHW
Yemen	1	18
Sudan	2	16
Egypt	3	10
Libya	4	8
Syria	5	11
Jordan	6	14
Pakistan	7	13
Kuwait	8	3
Tunisia	9	12
United Arab Emirates	10	1
Israel	11	4
Oman	12	15
Saudi Arabia	13	2
Turkmenistan	14	7
Algeria	15	6
Qatar	16	9
Iraq	17	17
Iran	18	5

Table 3A

Cluster 3. Ranking of countries.

Countries	DEA-SSI EW	DEA-SSI EcHW
Montenegro	1	32
Korea, North	2	19
Croatia	3	25
Uzbekistan	4	37
Serbia	5	34
Romania	6	7
Moldova	7	24
Venezuela	8	29
Slovak Rep	9	16
Macedonia	10	35
Hungary	11	6
Ukraine	12	27
Cuba	13	18
Bhutan	14	28
Brazil	15	33
Latvia	16	9
Switzerland	17	1
United Kingdom	18	4
Greece	19	30
Slovenia	20	2
Portugal	21	8
Ireland	22	22
Italy	23	21
Cyprus	24	36
Bolivia	25	31
Lithuania	26	10
Spain	27	13
Argentina	28	17
Malta	29	12
Mauritius	30	23
Bosnia-Herzeg.	31	38
Poland	32	5
Chile	33	11
Bulgaria	34	15
Belarus	35	3
Turkey	36	14
Malaysia	37	20
Mongolia	38	39
Lebanon	39	40
China	40	26

(*continued on next page*)

Table 3A (*continued*)

Table 4A

Cluster 4. Ranking of countries.

Countries	DEA-SSI EW	DEA-SSI EcHW
Denmark	1	3
Norway	2	1
South Africa	3	25
Sweden	4	2
Austria	5	13
Luxembourg	6	19
Japan	7	16
France	8	22
Trinidad Tobago	9	24
Netherlands	10	14
Finland	11	12
Iceland	12	8
Czech Rep	13	5
Belgium	14	15
Germany	15	7
Australia	16	9
Kazakhstan	17	17
United States	18	21
Russia	19	23
New Zealand	20	11
Canada	21	20
Taiwan	22	6
Singapore	23	18
Korea, South	24	4
Estonia	25	10

References

Abbot, M., Doucouliagos, C., 2003. The efficiency of Australian universities. A data envelopment analysis. Econ. Edu. Rev. 22, 89–97. https://doi.org/10.1016/S02727757(01)00068-1.

Angulo-Meza, L., Lins, M.P.E., 2002. Review of methods for increasing discrimination in data envelopment analysis. Ann. Oper. Res. 116, 225–242. https://doi.org/10.1023/A:1021340616758.

Barron, H.F., Barrett, B.E., 1996. Decision quality using ranked attribute weights. Manag. Sci. 42, 1515–1523. https://doi.org/10.1287/mnsc.42.11.1515.

Bluszcz, A., 2016. A comparative analysis of selected synthetic indicators of sustainability. Procedia Soc. Behav. Sci. 220, 40–50. https://doi.org/10.1016/j.sbspro.2016. 05.467.

Bracke, S., Radetzky, M., Rosebrock, C., Ulutas, B., 2019. Efficiency and effectivity of high precision grinding manufacturing process: an approach based on combined DEA and cluster analyses. Proc. CIRP 79, 292–297. https://doi.org/10.1016/j.procir.2019.02. 069.

Brattebø, H., Alegre, H., Cabrera, E., Marques, R., Hein, A., Cruz, C., 2013. A Master Framework for UWCS Sustainability. TRUST Project. http://www.trust-i.net/downloads/?iddesc=40.

Charnes, A., Cooper, W.W., Rhodes, E., 1978. Measuring the efficiency of decision making units. Eur. J. Oper. Res. 2, 429–444. https://doi.org/10.1016/0377-2217(78) 90138-8.

Coll-Serrano, V., Benitez, R., Bolós, V.J., 2018. Tutorial Data Envelopment Analysis With deaR. Version 1.0. Facultat d'Economia. Universitat de València.

De la Torre, E.M., Casani, F., Perez-Esparrells, C., 2015. ¿Existen diferentes tipologías de universidades en España? Una primera aproximación. (XXV Jornadas de Economía de la Educación).

Doyle, J.R., Green, R., 1994. Efficiency and cross-efficiency in data envelopment analysis: derivatives, meanings and uses. J. Oper. Res. Society 45, 567–578. https://doi.org/10.1057/jors.1994.84.

Falagario, M., Sciancalepore, F., Costantino, N., Pietroforte, R., 2012. Using a DEA-cross efficiency approach in public procurement tenders. Eur. J. Oper. Res. 218, 523–529. https://doi.org/10.1016/j.ejor.2011.10.031.

Fuchs, C., 2006. Sustainability and the information society in IFIP International Federation for Information. In: Berleur, T., Numinen, M.I., Impagliazzo, T. (Eds.), Social Informatics: An Information Society for All? In Remembrance of Rob Kling Springer, Boston, pp. 219–230.

Gallego-Alvarez, I., Galindo-Villardón, M.P., Rodríguez-Rosa, M., 2015. Evolution of sustainability indicator worldwide: a study from the economic perspective based on the X-STATICO method. Ecol. Indic. 58, 139–151. https://doi.org/10.1016/j.ecolind. 2015.05.025.

Gómez, J.M., Mancebón, M.J., 2005. Algunas reflexiones metodológicas sobre la evaluación de la eficiencia productiva de las instituciones de educación superior. Ekonomiaz 60, 140–167.

Hashimoto, A., Ishikawa, M., 1993. Using DEA to evaluate the state of society as measured by multiple social indicators. Socio-Econ. Plan. Sci. 27, 257–268. https://doi.org/10.1016/0038-0121(93)90019-F.

Hashimoto, A., Kodama, M., 1997. Has livability of Japan gotten better for 1956-1990? A DEA approach. Soc. Indic. Res. 40, 359–373. https://doi.org/10.1023/ A:1006804520184.

Hirschberg, J.G., Lye, J.N., 2001. Clustering in a Data Envelopment Analysis Using Bootstrapped Efficiency Scores. Department of Economics – Working Papers Series 800 The University of Melbourne.

Ho, W., Xu, X., Dey, P.K., 2010. Multi-criteria decision-making approaches for supplier evaluation and selection: a literature review. Eur. J. Oper. Res. 202, 16–24. https://doi.org/10.1016/j.ejor.2009.05.009.

Hollingsworth, B., 2008. The measurement of efficiency and productivity of health care delivery. Health Econ. 17, 1107–1128. http://doi https://doi.org/10.1002/hec.1391. Hollingsworth, B., Wildman, J., 2002. Efficiency and Cross Efficiency Measures: A Validation Using OECD Data. Centre for Health Program Evaluation (CHPE) (Working paper 132).

Igrahim, F.I., Bakar, A.A., Omar, D., 2019. Sustainable City indicators in Malaysia. In: Muthu, S.S. (Ed.), Development and Quantification of Sustainability Indicators. Springer Nature, Singapore.

Jiang, Q., Liu, Z., Liu, W., Li, T., 2018. A principal component analysis based three-dimensional sustainability assessment model to evaluate corporate sustainable performance. J. Clean. Prod. 20, 625–637. https://doi.org/10.1016/j.jclepro.2018.03.255.

Kaivo-oja, J., Panula-Ontto, J., Vehmas, J., Luukkanen, J., 2014. Relationships of the dimensions of sustainability as measured by the sustainable society index framework. Int. J. Sustain. Dev. World Ecol. 21, 39–45. https://doi.org/10.1080/13504509. 2013.860056.

King, M.F., Reno, V.F., Novo, E., 2014. The concept, dimensions and methods of assessment of human wellbeing within a socioecological context: a literature review. Soc. Indic. Res. 116, 681–698. https://doi.org/10.1007/s11205-013-0320-0.

Kuiper, F.K., Fisher, L., 1975. A Monte Carlo comparison of six clustering procedures. Biometrics 31, 777–783. https://doi https://doi.org/10.2307/2529565.

Kumar, R., Murty, H.R., Gupta, S.K., Dikshit, A.K., 2009. An overview of sustainability assessment methodologies. Ecol. Indic. 9, 189–212. https://doi.org/10.1016/j. ecolind.2008.05.011.

Labuschagne, C., Brent, A.C., van Erck, R.P.G., 2005. Assessing the sustainability performances of industries. J. Clean. Prod. 13, 373–385. https://doi.org/10.1016/j. jclepro.2003.10.007.

Lemos, C.A.A., Lima, M.P., Ebecken, N.F.F., 2005. DEA implementation and clustering analysis using the *K*-means algorithm. In: Zanisi, A., Brebbia, C.A., Ebeckens, N.F.F. (Eds.), Data Mining VI – Data Mining. Text Mining and Their Business Applications, WIT, Southampton, UK, pp. 321–329.

Marques, R.C., Ferreira da Cruz, N., Pires, J., 2015. Measuring the sustainability of urban water services. Environ. Sci. Pol. 54, 142–151. https://doi.org/10.1016/j.envsci. 2015.07.003.

Marroquin, M., Pena, M., Castro, C., Castro, J., Cabrera-Rios, M., 2008. Use of data envelopment analysis and clustering in multiple criteria optimization. Intell. Data Anal. 12, 89–101. https://doi.org/10.3233/IDA-2008-12106.

Martí, M.L., Martin, J.C., Puertas, R., 2017. A DEA-logistics performance index. J. Appl. Econ. XX 169–192. https://doi.org/10.1016/S1514-0326(17)30008-9.

Martín, J.C., Mendoza, C., Román, C., 2017. A DEA travel-tourism competitiveness index. Soc. Indic. Res. 130, 937–957. https://doi.org/10.1007/s11205-015-1211-3.

Martínez, F., Murias, P., De Miguel, J.C., 2009. Los principios del desarrollo sostenible en las políticas nacionales: Un análisis comparativo desde la perspectiva de los indicadores del milenio. Tribuna de Economía ICE 846, 155–173.

Martínez-Roget, F., 2005. El análisis envolvente de datos en la construcción de indicadores sintéticos. Una aplicación a las provincias españolas. Estud. Econ. Aplic. 23, 753–771.

Meimand, M., Cavana, R.Y., Laking, R., 2002. Using DEA and survival analysis for measuring performance of branches in New Zealand's Accident Compensation Corporation. J. Oper. Res. Soc. 53, 303–313. https://doi.org/10.1057/palgrave.jors. 2601291.

Melkonyan, T., Safra, Z., 2015. Intrinsic variability in group and individual decision making. Manag. Sci. 62, 2651–2667. https://doi.org/10.1287/mnsc.2015.2255.

Murias, P., Martínez, F., De Miguel, J.C., 2006. An economic wellbeing index for the Spanish Porvinces: a data envelopment analysis approach. Soc. Indic. Res. 77, 395–417. https://doi.org/10.1007/s11205-005-2613-4.

Phélan, M., 2018. Revisión y comparación metodológica de cinco Indices Alternativos de Desarrollo. Resultados para países de América Latina. Espacio Abierto 27, 21–45.

Phillips, J., 2015. A quantitative approach to determine and evaluate the indicated level and nature of global ecological sustainability. Area 47, 197–210. https://doi.org/10.1111/area.12174.

Phillis, Y.A., Kouikoglou, V.S., Manousiouthakis, V., 2010. A review of sustainability assessment models as system of systems. IEEE Syst. J. 4, 15–25. https://doi https://doi.org/10.1109/JSYST.2009.2039734.

Puertas, R., Martí, L., 2019. Sustainability in universities: DEA-Greenmetric. Sustainability 11, 3799. https://doi.org/10.3390/su11143766.

Reig, E., 2010. Análisis del potencial socioeconómico de municipios rurales con métodos no paramétricos: aplicación al caso de una zona Leader. (Working Paper BBVA).

Rogers, P., Jalal, K., Boyd, J., 2008. An Introduction to Sustainable Development. Glen Educational Foundation, Sterling, VA, USA.

Saisana, M., Philippas, D., 2012. Sustainable Society Index (SSI): taking societies' pulse along social, environmental and economic issues. Environ. Impact Assess. Rev. 32, 94–106. https://doi.org/10.2788/6330.

Samoilenko, S., Osei-Bryson, K.M., 2010. Determining sources of relative inefficiency in heterogeneous samples: methodology using cluster analysis, DEA and neural networks. Eur. J. Oper. Res. 206, 479–487. https://doi.org/10.1016/j.ejor.2010.02.017. Scrase, J.I., Sheate, W.R., 2002. Integration and integrated approaches to assessment: what do they mean for the environment? J. Environ. Policy Plan. 4, 275–294. https:// doi.org/10.1002/jepp.117.

Sexton, T.R., Silkman, R.H., Hogan, A.J., 1986. Data envelopment analysis: Critique and extensions. In: Silkman, R.H. (Ed.), Measuring Efficiency: An Assessment of Data Envelopment Analysis. JosseyBass, San Francisco, pp. 73–105.

Shaker, R.R., 2015. The spatial distribution of development in Europe and its underlying sustainability correlations. Appl. Geogr. 63, 304–314. https://doi.org/10.1016/j.apgeog.2015.07.009.

Shaker, R.R., 2018. A mega-index for the Americas and its underlying sustainable development correlations. Ecol. Indic. 89, 466–479. https://doi.org/10.1016/j.ecolind. 2018.01.050.

Sharma, M.J., Yu, S.J., 2009. Performance based stratification and clustering for benchmarking of container terminals. Expert Syst. Appl. 36, 5016–5022. https://doi.org/10.1016/j.eswa.2008.06.010.

Shin, H.W., Sohn, S.Y., 2004. Multi-attribute scoring method for mobilie telecommunication subscribers. Expert Syst. Appl. 26, 363–368. https://doi.org/10.1016/j.eswa.2003.09.013.

Storrie, D., Bjurek, H., 2000. Bechmarking European Labour Market Performance with Efficiency Frontier Techniques. CELMS Discussion paper. Universidad de Goteborg.

Stratan, A., Cautisanu, C., Hatmanu, M., Mihai, C., 2018. Environmental protection in the context of sustainable development. Comparative analysis across EU countries. USV Ann. Econ. Public Adm. 18, 45–57.

Torrico, A., Laza, T.G., Molina, J., Gómez, T., Caballero, R., 2007. Análisis de la eficiencia de las unidades productivas de una universidad. Rev. Elec. Com. Trab. ASEPUMA 8, 163–195.

Van de Kerk, G., Manuel, A., 2008. A comprehensive index for a sustainable society: the SSI - the Sustainable Society Index. Ecol. Econ. 66, 228–242. https://doi.org/10.1016/j.ecolecon.2008.01.029.

Van de Kerk, G., Manuel, A., 2012. Sustainable Society Index SSI-2012. Sustainable Society Foundation, The Netherlands.

Van de Kerk, G., Manuel, A., 2014. Sustainable Society Index SSI-2014. Sustainable Society Fundation, The Netherlands.

Wątróbski, J., Ziemba, E., Karczmarczyk, A., Jankowski, J., 2018. An index to measure the sustainable information society: the polish households case. Sustainability 10, 3223. https://doi.org/10.3390/su10093223.

WCED, 1987. Report of the World Commission on Environment and Development: Our Common Future. World Commission on Environment and Development.

Wu, S., Fu, Y., Shen, H., Liu, F., 2018. Using ranked weights and Shannon entropy to modify regional sustainable society index. Sust. Cities Soc. 41, 443–448. https://doi.org/10.1016/j.scs.2018.05.052.

Zhu, J., 2001. Multidimensional quality of life measure with an application to Fortune's best cities. Socio-Econ. Plan. Sci. 35, 263–284. https://doi.org/10.1016/S00380121(01)00009-X.

Ziemba, 2018. Synthetic indexes for a sustainable information society: measuring ICT adoption and sustainability in polish enterprises. LNBIP 311, 151–169. https://doi. org/10.1007/978-3-319-77721-4-9.