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A TOPSIS extension framework for re-conceptualizing sustainability measurement

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Abstract

Purpose – The purpose of this paper is to propose a sustainability measurement and scoring system for assessing the efforts of organizations at meeting sustainability targets. Using technique for order preference by similarity to ideal solution (TOPSIS) as the basic framework, the proposed method incorporates all three sustainability dimensions – economic, environmental and social – to establish a threshold below which an organization is considered to have failed a sustainability test. In Addition, an introduction of a time-independent threshold enables a clearer comparison of performance of organizations over time. The proposed method includes plots for visualizing the sustainability performance of organizations under review.

Design/methodology/approach – The proposed method first assigns target values to a hypothetical organization. TOPSIS is then used to generate composite scores in which the score of the hypothetical organization is set as the threshold below which organizations are deemed to have failed a sustainability test. Using the square of the closeness coefficient of TOPSIS, the final composite score is decomposed into three components to reflect the contribution of the three dimensions of sustainability to serve as a guide to determining which dimension to focus on for improvement. A relative comparison score is then proposed to track the performance of organizations over time.

Findings – The proposed method with its ability to set a threshold is able to determine organizations that have passed a sustainability test from those that have failed. The tracking of organizational performance over time also serves to highlight progress being made by organizations to meet an agreed sustainability target. Results from the application of the proposed method for evaluating sustainability of banks under the three dimensions of sustainability highlight its practical applicability. The proposed method can also be applied to a wide range of comparison problems including make-or-by decisions and award selection.

Practical implications – As most industries and organizations become conscious of the pressure to adopt sustainable practices, the proposed measuring system would help identify those that are meeting sustainability targets as well as to track their progress over time.

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Originality/value – Most sustainability measurement indicators rarely have thresholds to determine whether an organization has met or failed to meet a sustainability test other than ranking them from top to bottom. The proposed method provides a threshold as well as a procedure for tracking the sustainability performance of organizations over time.

Keywords Decision making, TOPSIS, Multi-criteria decision making, Threshold, Sustainability measurement

Paper type Research paper

1. Introduction

Sustainability seeks to ensure that resources available today are not used in ways that deprive the economic, environmental and social benefits of future generations (Pitelis, 2013; Walker *et al.*, 2014). To this end, many researchers and practitioners advocate for a measuring system that tracks sustainability progress over time since "what gets measured, gets done" (Schwarz *et al.*, 2002; Loucks, 1997).

In view of this, a lot of efforts have gone into developing indicators for measuring, predicting and ranking sustainability performance of organizations (Singh *et al.*, 2009; Labuschagne *et al.*, 2005). Such indicators provide a way to combine and condense the many complex criteria for assessing sustainability of a dynamic environment into a composite score that provides meaningful information for judgment (Godfrey and Todd, 2001). Indicators such as the Environmental Performance Index, Natural Resource Management Index and The Human Footprint, measure environmental and social sustainability. A number of sustainability indices focus on all three sustainability dimensions. The Global Reporting Initiative, Genuine Progress Index, the Global 100 index and the Dow Jones Sustainability Index (DJSI) determine the most sustainable companies with respect to economic, environmental and social dimensions. The DJSI in particular has attracted interests from a number of companies who in their attempt to improve stakeholder perceptions of their company's sustainability performance, proudly display their annual DJSI index scores and rankings on their websites for being among the top 10 percent leading sustainability-driven companies in the world (Fowler and Hope, 2007; Cerin and Dobers, 2001).

Over the years however, many authors have questioned the applicability of these sustainability indices. Lancker and Nijkamp (2000), states that "a given indicator does not say anything about sustainability, unless a reference value such as a threshold is set for it." Their argument stems from the fact that it is baseless to determine who ranks first if all of the organizations evaluated have a poor sustainability performance in relation to a minimum acceptable standard. An organization ranked high (or low) among competing organizations cannot necessarily be considered as having passed (or failed) sustainability test unless a base value or threshold exists to establish that. Arrow *et al.* (2012) also posits that sustainability is demonstrated when the measured performance is maintained or improved over time. In order words, a threshold or minimum acceptable level is a prerequisite for sustainability measurement. The apparent lack of a base value for a judgment on sustainability in almost all sustainable indices is a common flaw that needs to be addressed. For example, the well-known DJSI index ranks companies without reference to a base value. This paper therefore takes the position of Lancker and Nijkamp (2000), and proposes a technique that allows for the establishment of a threshold for sustainability measurement.

Böhringer and Jochem (2007), and Singh *et al.* (2009), also analyzed a number of sustainability indices with respect to consistency and meaningfulness and concludes that most indices fail to satisfy fundamental scientific requirements making them meaningless and on most occasions leading to ineffective policy directives. They argue that scientific rules on normalization, weighting, measurement units and aggregation of indicators toward composite indices are typically not taken into account in most composite indices. Additionally, indices based on weighted mean methods are particularly meaningless when for some criteria, more is better and for others, less is better. The proposed sustainability technique relies on results from technique for order preference by similarity to ideal solution (TOPSIS) which is a multi-criteria decision-making (MCDM) method that adheres to the scientific requirements of normalization, weighting and aggregation enumerated by Singh *et al.* (2009).

Another contribution of the paper is the decomposition of the final composite score. By taking the square of the closeness coefficient which is the decision-making criteria point for the TOPSIS method, the final composite performance score is decomposed into three components to reflect the contribution of the economic, environmental and social dimensions of sustainability.

TOPSIS is an ideal method for evaluating alternatives simultaneously on the basis of cost (or less is better) criteria and benefit (or more is better) criteria (Singh and Benyoucef, 2011). First proposed by Hwang and Yoon (1981), TOPSIS is based on a distance to an ideal point using two hypothetically created ideal alternatives (or solutions) known as the positive ideal and the negative ideal alternatives. In furtherance to this idea, an alternative under evaluation must be closer to the positive ideal alternative and farther away from the negative ideal alternative to merit a higher rank (Triantaphyllou, 2000). The TOPSIS method is chosen over other MCDM methods since, aside its numerous advantages it has the fewest rank reversals compared to the other MCDM methods. TOPSIS also possesses many desirable features compared to other MCDM techniques and has wide acceptance and applications in industry and academia (Shih *et al.*, 2007). In particular, it is able to accommodate interactions between different criteria (Govindan *et al.*, 2013). Numerous studies on evaluation, selection and ranking have applied TOPSIS, its several variants and its fuzzy TOPSIS extension (for cases of uncertain information) in the MCDM literature. For papers on the application of TOPSIS see Shih *et al.* (2007).

A number of works have applied the TOPSIS technique to sustainability concepts but in different perspectives compared to what is considered in this paper. Kannan *et al.* (2014) used fuzzy TOPSIS, whiles Büyüközkan and Çifçi (2012) used a variety of MCDM tools including fuzzy TOPSIS to select green or environmentally friendly suppliers under generally accepted green supply chain management practices. Awasthi *et al.* (2011) used fuzzy TOPSIS technique to evaluate sustainable transportation systems under uncertain information. Govindan *et al.* (2013) and Wittstruck and Teuteberg (2012) used a fuzzy TOPSIS and fuzzy-AHP-TOPSIS approach, respectively, to evaluate the supplier selection issue in supply chain management based on the three sustainability dimensions of economic, social and environmental factors. Similar work can be found in Wibowo and Deng (2013) who evaluated the sustainability of semiconductor companies under economic, environmental, social and product dimensions using inter-valued-based intuitionistic fuzzy TOPSIS. Kucukvar *et al.* (2014) also ranked the life cycle sustainability performance of pavement types under the three sustainability dimensions. In a similar manner, Demirtas (2013) determined the best renewable energy technology for sustainable energy planning using a number of MCDM techniques including fuzzy TOPSIS.

In our analysis of related literature, only the approaches by Govindan *et al.* (2013), Kucukvar *et al.* (2014), Wibowo and Deng (2013) and Wittstruck and Teuteberg (2012) are similar to the method proposed in this paper largely in terms of the sustainability dimensions used and the application of TOPSIS for ranking. However, the approach used in this paper besides serving as a ranking tool, is also more general in scope and considers the general problem of determining sustainability as envisaged by Lancker and Nijkamp (2000) and Arrow *et al.* (2012) by generating a threshold for sustainability determination and measurement. In addition, the proposed method allows for the tracking of the contribution from the three dimensions of sustainability in the final composite index score.

The rest of the paper is organized as follows. First the TOPSIS model is presented, followed by a modified model that decomposes the final composite score into three components – one each for the three dimensions of sustainability. Next, a threshold for measuring sustainability is presented along with a numerical example accompanied by plots to demonstrate the applicability of the proposed method. Finally, a measure for determining a time-independent threshold for clearer comparison of performance over time is proposed and demonstrated on a time series plot. Conclusions and future research directions are then proffered.

2. TOPSIS method for performance ranking

This section presents the theoretical background for the TOPSIS method, first introduced by Hwang and Yoon (1981). In Section 3, the TOPSIS method is extended for the case where a performance criteria can be grouped into three components to track the contribution of each sustainability criterion in the final composite performance index score.

Formally, for a set $A=\{A^k | k=1, 2, \ldots, n\}$ of n alternatives evaluated under a set $C=\{c_j | j=1, 2, \ldots, m\}$ of m criteria with associated relative weights $W=\{w_j | j=1,2, \ldots, m, \quad \sum_{j=1}^{m} w_j = 1\}$, a decision matrix with elements x_j^k for $k=1,2,\ldots,n$ and $j=1, 2, \ldots, m$ in the form of Table I can be generated.

An element x_j^k is the rating for alternative k under criterion j, and w_j is the importance weight assigned to criterion j. Using information from the decision matrix, ranking of the alternatives are generated through the following steps.

Step 1: transforming criteria dimensions into non-dimensional criteria.

The first step of the TOPSIS method is the construction of a normalized decision matrix R of elements r_j^k which is a transformation of x_j^k from Table I into non-dimensional criteria to allow for comparisons across criteria. Where r_j^k is computed as:

$$r_j^k = \frac{x_j^k}{\sqrt{\sum_{k=1}^{n} \left(x_j^k\right)^2}}, \quad \text{for } k=1,2, \ldots, n \text{ and } j=1,2, \ldots, m \tag{1}$$

	Criteria			
Alternatives	c_1	c_2	$\cdots$	c_m
A_1	x_1^1	x_2^1	$\cdots$	x_m^1
A_2	x_1^2	x_2^2	$\cdots$	x_m^2
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
A_n	x_1^n	x_2^n	$\cdots$	x_m^n
Weight (W)	w_1	w_2	$\cdots$	w_m

Table I. Decision matrix

Step 2: forming the weighted normalized decision matrix (v_j^k)
The next step after normalization is to account for the importance of each criterion in the decision matrix. This is done by multiplying the weight w_j with the normalized element r_j^k to obtain the weighted normalized matrix element v_j^k:

$$v_j^k = w_j r_j^k, \quad \text{for } k = 1, 2, \ldots, n \text{ and } j = 1, 2, \ldots, m \tag{2}$$

Step 3: determining the positive ideal (A^+) and negative ideal (A^-) solution.
In step 3, a hypothetical positive and negative ideal solutions meant to be a yardstick for comparison are generated. For an alternative to rank high, it must be closer to the positive ideal solution A^+ and farther away from the negative ideal solution A^-. Let J^+, and J^-, respectively be the set of positive (more is better) and negative (less is better) criteria, Then the ideal solutions are computed using information from matrix R as:

$$A^+ = \{v_1^+, \ldots, v_m^+\}, \quad \text{where } v_j^+ = \left\{ \left(max_k \; v_j^k | j \in J^+ \right), \left(min_k \; v_j^k | j \in J^- \right) \right\} \tag{3}$$

$$A^- = \{v_1^-, \ldots, v_m^-\}, \quad \text{where } v_j^- = \left\{ \left(min_k \; v_j^k | j \in J^+ \right), \left(max_k \; v_j^k | j \in J^- \right) \right\} \tag{4}$$

Step 4: computing separation measures based on Euclidean distance.
In this step, separation measures or distances from the positive ideal solution, denoted S^{k^+} and, also from the negative ideal solution, denoted S^{k^-} for each alternative are computed. These separation measures are computed using the m-dimensional Euclidean distance:

$$S^{k^+} = \sqrt{\sum_{j=1}^{m} \left(v_j^+ - v_j^k \right)^2}, \quad \text{for } k = 1, 2, 3, \ldots, n \tag{5}$$

$$S^{k} = \sqrt{\sum_{j=1}^{m} \left(v_j^- - v_j^k \right)^2}, \quad \text{for } k = 1, 2, 3, \ldots, n \tag{6}$$

Step 5: calculating the closeness coefficient (C^k) to the ideal solution.
Whiles S^{k^+} shows how close an alternative is to the ideal solution, S^{k^-} is the opposite and shows how far the same alternative is from the negative ideal solution. Between k alternatives, a dilemma is created as to which of the two separation measures to use. This dilemma is resolved by using the so-called relative closeness coefficient as expressed in the following equation:

$$C^k = \frac{S^{k^-}}{S^{k^+} + S^{k^-}} \quad 0 \leqslant C^k \leqslant 1 \tag{7a}$$

Among competing alternatives, the relative closeness coefficient C^k allows for ranking the alternatives based on S^{k^-} by taking into account the presence of S^{k^+}. Therefore, the alternative with the highest C^k emerges the best. In other words, alternatives can be ranked from best to worst in descending order of C^k. When the focus is on S^{k^+} (i.e. the distance to the positive ideal solution), the best alternative can be obtained by selecting the one with the smallest value from the expression in the following equation:

$$\frac{S^{k^+}}{S^{k^+}+S^{k^-}} = 1-C^k \tag{7b}$$

Then, in a similar manner, the alternatives can be ranked from best to worst in ascending order using values from Equation (7b).

3. Decomposition of the TOPSIS closeness coefficient

According to Pitelis (2013), sustainability is often seen to be the pursuit of the "triple bottom line" – environmental, social and economic goals that seek to ensure that resources available today are not used in ways that deprive future generations of their benefits. Furthermore, authors such as Govindan *et al.* (2013) and Wittstruck and Teuteberg (2012) have proposed methods for selecting competing organizations under all three dimensions of sustainability. However, while the final composite score which is the decision-making criterion is a representation of the performance of an organization in all three dimensions, it is not possible to construe the exact contribution of the economic, social and environmental criteria in the final composite score. The ability to decompose the final composite score into the three dimensions will be very helpful in directing the effort of an organization as to which of the three dimensions to improve to boost its sustainability score. This paper uses the square of the closeness coefficient as the final decision criterion to decompose the final composite score into three components reflecting the contributions of the three sustainability dimensions.

Formally, let the importance weight for criterion j under factor i be w_{i_j} and the normalized element in matrix R for criterion j under dimension i for alternative k be $r^k_{i_j}$. Then, Equation (2) becomes $v^k_{i_j} = w_{i_j} r^k_{i_j}$, for $i = 1, 2, 3, \ldots, p$, $j = 1, 2, \ldots, m_i$ and $k = 1, 2, \ldots, n$. The expression $v^k_{i_j}$ now becomes the weighted normalized value of criterion j under factor i for alternative k.

For any alternative k, the criteria could be decomposed into i dimensions by squaring Equation (5) which leads to the following equation:

$$\left(S^{k^-}\right)^2 = \sum_{i=1}^{p} \sum_{i_j=1}^{m_i} \left(v^-_{i_j} - v^k_{i_j}\right)^2 \tag{8}$$

$$v^-_{i_j} = \left\{ \left(min_k \; v^k_{i_j} | j \in J_i^+ \right), \left(max_k \; v^k_{i_j} | j \in J_i^- \right) \right\}$$

$$\left(S^{k^-}\right)^2 = \sum_{1_j=1}^{m_1} \left(v^-_{1_j} - v^k_{1_j}\right)^2 + \sum_{2_j=1}^{m_2} \left(v^-_{2_j} - v^k_{2_j}\right)^2 + \ldots + \sum_{p_j=1}^{m_p} \left(v^-_{p_j} - v^k_{p_j}\right)^2,$$

$k = 1, 2, \ldots, n$ and $i = 1, 2, \ldots, p$.

The relative closeness coefficient can then be expressed as shown in the following equation:

$$\left(C^k\right)^2 = \frac{\sum_{1_j=1}^{m_1}\left(v_{1_j}^- - v_{1_j}^k\right)^2 + \sum_{2_j=1}^{m_2}\left(v_{2_j}^- - v_{2_j}^k\right)^2 + \ldots + \sum_{p_j=1}^{m_p}\left(v_{p_j}^- - v_{p_j}^k\right)^2}{\left(S^{k^+} + S^{k^-}\right)^2} \quad (9)$$

Let $S_i^{k^-}$ and $S_i^{k^+}$ be the total distance from the negative ideal alternative and the positive ideal alternative for the set of criteria under factor i for alternative k, respectively. Then:

$$\left(S_i^{k^-}\right)^2 = \sum_{i_j=1}^{m_i}\left(v_{i_j}^- - v_{i_j}^k\right)^2$$

For $k = 1, 2, \ldots, n$, Equation (9) can be expressed succinctly as:

$$\left(C^k\right)^2 = \frac{\left(S_1^{k^-}\right)^2}{\left(S^{k^+} + S^{k^-}\right)^2} + \frac{\left(S_2^{k^-}\right)^2}{\left(S^{k^+} + S^{k^-}\right)^2} + \ldots + \frac{\left(S_p^{k^-}\right)^2}{\left(S^{k^+} + S^{k^-}\right)^2} \quad (10)$$

Let $(C_i^k)^2$ be the contribution to the overall composite value $(C^k)^2$ by the sub-criteria under dimension i. Then following Equation (7a), Equation (10) can be expressed in the form below:

$$\left(C^k\right)^2 = \left(C_1^k\right)^2 + \left(C_2^k\right)^2 + \ldots + \left(C_p^k\right)^2 \quad k = 1, 2, \ldots, n \quad (11)$$

For three dimensions as in the case of sustainability, the final composite score based on Equation (11) is $(C^k)^2 = (C_1^k)^2 + (C_2^k)^2 + (C_3^k)^2 \quad k = 1, 2, 3$.

Thus, the final composite value for an alternative k can be decomposed into p components, one for each dimension i. Note that like the original composite score C^k of Equation (7a), the square of C^k also lies between 0 and 1. When applied to sustainability measurement, the decomposed composite score helps in highlighting the contribution of the economic, social and environmental dimensions of sustainability to the composite score. It also can serve as a guide for organizations to determine which of the three dimensions should receive greater attention when seeking to improve its overall composite score.

4. Establishing a threshold for sustainability measurement

Lancker and Nijkamp (2000) argue that a threshold is needed to determine sustainability and that it is only when an entity falls below this threshold that it could be deemed to have failed a sustainability test. This is analogous to setting a standard value for all criteria which should be met by an alternative. More importantly, by identifying a sustainability threshold, the progress of the entities under evaluation could be properly monitored for the realization of an effective response policies. We begin the development of a sustainability threshold by setting minimum industry standard values for the list of criteria under study and assigning these values to a hypothetical alternative. In what follows, we add this hypothetical alternative, herein called the "industry standard" alternative to the original list of alternatives under study so that there are now $k+1$ alternatives where the industry standard alternative is the $(k+1)$th alternative. Then, if $(C^S)^2$ is the square of the closeness coefficient for the industry standard alternative, any alternative k satisfying the following equation can be adjudged to have passed the sustainability test:

$$\left(C^k\right)^2 \geqslant \left(C^S\right)^2 \tag{12}$$

In other words, $(C^S)^2$ can be regarded as a critical point (or a threshold) below which an alternative can be considered to have failed a sustainability test. Note that by assigning the standard values to a new alternative, all attributes of the TOPSIS method are maintained. In particular, the positive and negative ideal alternatives are determined as before. This way, competition among alternatives is assured as well as ensuring that a minimum standard sustainability level is attained. In line with the above explanation, Equation (12) can further be expressed as:

$$\left(C_1^k\right)^2 + \left(C_2^k\right)^2 + \ldots + \left(C_p^k\right)^2 \geqslant \left(C_1^s\right)^2 + \left(C_2^s\right)^2 + \ldots + \left(C_p^s\right)^2$$

For a particular dimension i, $(C_i^k)^2$could be compared to $(C_i^s)^2$ to observe the performance of alternative k under dimension i with regards to the industry standard (in relation to all i dimensions). Note however that result from such comparison under dimension i may not necessarily be the same as that obtained when the TOPSIS approach, is applied to data on only one dimension because, then there is no interaction effect among dimensions.

The next section presents a numerical example to illustrate the use of the threshold and the decomposition approach based on data found in corporate sustainability reports of major European banks and concludes with a proposed technique for generating a time-independent threshold for sustainability performance comparison over time.

5. Numerical example

This section applies the new proposed TOPSIS-based performance ranking procedure to assess the sustainability of banks under the trio criteria of economic, environmental and social factors as presented in Table II. The banking industry is under increasing pressure to pay more attention to environmental and social factors from both regulatory bodies and investors. This development has led to more banks increasing their socially responsible investment portfolio (Lee and Faff, 2009; Fowler and Hope, 2007) and also issuing comprehensive annual sustainability reports similar in scope to the traditional annual reports. Table II contains data that are generally found in the annual sustainability reports of the top 15 European banks. In all, 15 criteria, comprising of four for economic, seven for environmental and four for social dimensions of sustainability were selected for the numerical example. All the four criteria (C1, C2, C3 and C4) under the economic dimension are designated as benefits or "more is better" criteria. In addition criteria C5 and C6 under the environmental dimension are also considered as benefit criteria, whiles the remaining five (C7, C8, C9, C10 and C11) are considered as cost or "less is better" criteria. Similarly, criteria (C12, C13, C14 and C15) of the social dimension, are also classified as benefits with C15 a cost criterion.

Table II. Criteria and criteria weights for the three dimensions of sustainability

Criteria	Symbol	Criteria weight	Dimension weight
Efficiency ratio	C1	0.11	
ROE	C2	0.12	Economic (0.38)
Capital adequacy ratio	C3	0.08	
% total assets in sustainable investment	C4	0.07	
% of electricity consumed from renewables	C5	0.04	
% of waste recycled	C6	0.03	
Total CO_2 emission per FTE (tons)	C7	0.09	
Total energy consumption (KWh per FTE)	C8	0.08	Environmental (0.30)
Water consumption per FTE (m^3/FTE)	C9	0.02	
Waste generated per FTE (kg)	C10	0.02	
Paper used per FTE (Kg)	C11	0.02	
% of net profit for community investment	C12	0.13	
% of females in senior position	C13	0.06	Social (0.32)
Training expense per FTE (in EUR)	C14	0.07	
Employee turnover	C15	0.06	

Column 4 of Table II shows the importance weight assigned to the three dimensions of sustainability. These weights closely match those assigned for the banking industry by DJSI. In the 2014 RobecoSam Sustainability Investing report, the DJSI assigned weights of 0.38, 0.24 and 0.38, respectively, to the economic, environmental and social factors for the banking industry. However, in a bid to place more emphasis on the environmental dimension, this paper assigns weights of 0.38, 0.30 and 0.32 to the economic, environmental and social factors, respectively. These weights are further apportioned among the sub-criteria for a particular sustainability dimension as shown in column 3 of Table II. It is advisable that weights are assigned first for the dimension of sustainability and then distributed among the criteria under a dimension to avoid a situation where more weight is assigned to a dimension with more criteria than one with fewer criteria.

Table III lists data on banks for the criteria listed in Table II. For the purposes of establishing a threshold, column 2 of Table III contains data considered in this paper to be the industry standard below or above which is considered undesirable for a "more is better" or "less is better" criteria, respectively. More than 80 percent of the data in Table III were compiled from actual sustainability reports of major European banks. However, not all banks had data for all three sustainability dimensions, particularly for social and environmental dimensions. As a result, and for the purposes of showing the new proposed method, those blanks were filled with imputed data derived from a comparison with similar banks of equal size. Therefore the names of the banks were removed in order to prevent any unjustified comparison among those banks.

Table IV shows the sustainability performance result for the selected banks and the industry standard alternative, grouped into economic, environmental and social dimensions. The industry standard alternative has a value of 0.2175 for the square of the relative closeness coefficient. According to Equation (12), this value becomes the threshold for the year 2013 below which an organization can be considered to have performed worse than the minimum expected standard and therefore failing the sustainability test. Therefore, only Banks D, A, C and E (in descending order of performance) passed the sustainability test in 2013. Similarly, Banks F and B failed the sustainability test. Bank D ranks first among the banks that passed the sustainability

Criteria	Industry standard	Bank A	Bank B	Bank C	Bank D	Bank E	Bank F	Bank G
C1	55	75.00	61.70	49.90	88.00	30.45	58.00	58.00
C2	4	5.20	2.70	5.42	6.70	2.82	4.20	4.20
C3	12	19.80	13.61	11.71	22.20	7.66	13.00	13.00
C4	15	5.69	20.56	33.00	24.11	22.32	33.50	33.50
C5	45	59.5	68.4	33.54	48.8	64.03	43	53
C6	50	21.90	68.92	55	55.6	63.8	58.2	39.3
C7	2.5	2.1	3.53	2.6	3.04	2.22	6.3	4.5
C8	12,000	4,653	12,013.90	7,070	12,241.51	11,397.78	13,900	7,600
C9	20	8	20.8	20	29.40	19.2	26	13
C10	180	94.5	205.5	86.3	213	165	250	92
C11	100	26	48	170	121	126	110	148
C12	0.07	0.03	0.08	0.09	0.10	0.09	0.08	0.06
C13	20	27.60	17.95	25.05	21.70	8.80	16.00	16.00
C14	1,000	1,603	450.58	606.15	800.64	1,969.58	1,350.41	989.52
C15	12	11.30	8.42	10.20	15.00	11.30	15.20	3.95

Note: Also included are the corresponding industry standard values

Table III. Sustainability data based on 15 criteria for seven European banks in 2013

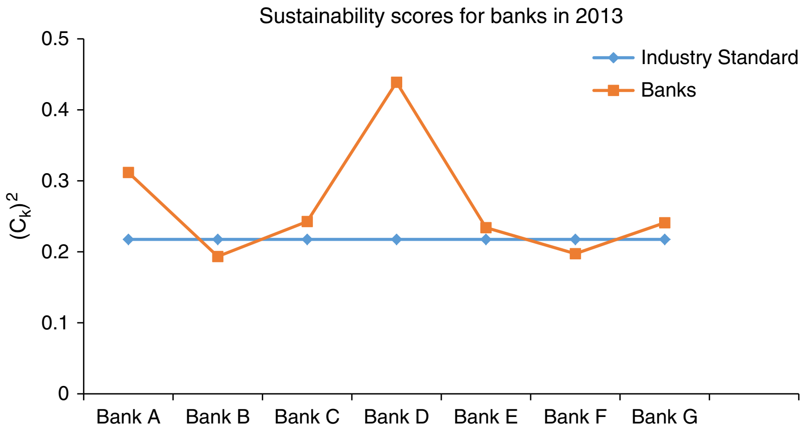
Alternative	Economic	$(C_i^k)^2$ Environmental	Social	$(C^k)^2$ Total	Ranking
Industry standard	0.0454	0.1036	0.0685	0.2175	6
Bank A	0.1142	0.1351	0.0624	0.3118	2
Bank B	0.0559	0.0661	0.0715	0.1934	8
Bank C	0.1087	0.1044	0.0296	0.2427	3
Bank D	0.2455	0.0595	0.1338	0.4389	1
Bank E	0.0156	0.0882	0.1303	0.2341	5
Bank F	0.0973	0.0053	0.0948	0.1974	7
Bank G	0.1126	0.0547	0.0737	0.2409	4

Table IV. Sustainability index report for seven European banks in 2013

test whiles Bank B comes last among the seven banks evaluated. The same conclusion could be arrived at using the ranking result in the last column of Table IV. Then, rank 6 for the industry standard becomes the threshold above which an organization fails the sustainability test. Figure 1 plots the $(C^k)^2$ values from Table IV, where the industry standard is the threshold. It can be seen from the plot that both Banks B and F came close to passing the sustainability test.

The $(C^k)^2$ result in Table IV for the individual dimensions of sustainability can also be informative. It can be seen that compared to the industry standard alternative, Bank F did better than the industry standard under the economic and social dimensions, but poorly to the industry standard under the environmental dimension. Similar conclusion can be drawn for Bank B which had the worst performance among the seven banks. Therefore, a little focus on the environmental practices of Banks F and B could see them passing the sustainability test.

Table V and Figure 2 depict results based on data from Table AI on the criteria listed in Table II for the year 2012, where Bank A, E, F and G failed the sustainability test. Note that, the threshold value $(C^s)^2$ from Figure 2 is different from that of Figure 1. However, one cannot necessarily conclude that the threshold was lowered in 2013

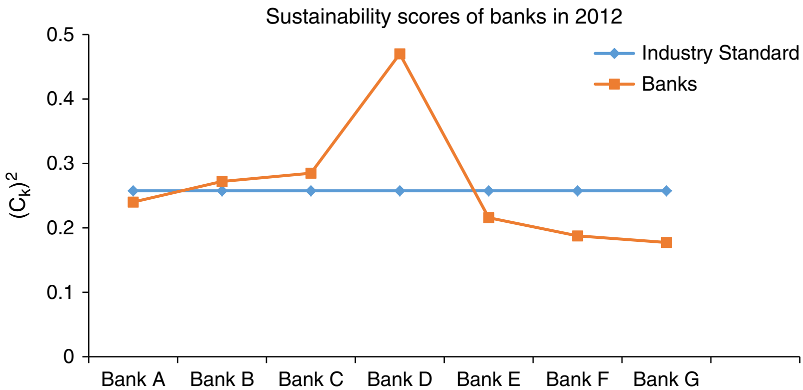


Notes: The industry standard line is the threshold below which a bank is considered to have failed the sustainability test. The vertical-axis is the square of the relative closeness coefficient of TOPSIS

Figure 1. Sustainability test plot of seven European banks in 2013

Table V. Sustainability Index report for seven banks in 2012

Alternative	Economic	$(C_i^k)^2$ Environmental	Social	$(C^k)^2$ Total	Ranking
Industry standard	0.0610	0.1206	0.0759	0.2575	4
Bank A	0.1092	0.1281	0.0028	0.2400	5
Bank B	0.0879	0.1086	0.0756	0.2721	3
Bank C	0.0773	0.1131	0.0946	0.2849	2
Bank D	0.2308	0.0675	0.1719	0.4701	1
Bank E	0.0430	0.0942	0.0785	0.2157	6
Bank F	0.0937	0.0073	0.0866	0.1875	7
Bank G	0.1022	0.0565	0.0187	0.1773	8



Notes: The industry standard line is the threshold below which a bank is considered to have failed the sustainability test. The vertical-axis is the square of the relative closeness coefficient of TOPSIS

Figure 2. Sustainability test plot of seven European banks in 2012

compared to 2012. This is occurring since TOPSIS can be considered to be an endogenous model, in that the positive ideal and negative ideal solutions are not fixed values but are derived using data from the same alternatives being evaluated. Therefore, it is not unusual for the $(\boldsymbol{C^s})^2$ value of year 2013 to be different from that of 2012. In other words, a lower threshold for 2013 does not necessarily translate to an opportunity of passing the sustainability test. Intuitively, by being endogenous, the TOPSIS method allows for resetting of the threshold to reflect developments within the industry. Note that when all the alternatives fail to match the industry standard values, the industry standard alternative will become the positive ideal solution and the $(\boldsymbol{C^k})^2$ for all the alternatives would be less than that of the industry standard. This will lead to all alternatives failing the sustainability test. The opposite is true when all the alternatives perform better under all criteria than the industry standard. The challenge of obtaining a common threshold for comparison irrespective of the period of evaluation is treated in the next sub-section.

5.1 Tracking the progress of an organization over time

According to Arrow *et al.* (2012), true sustainability is demonstrated when a measured performance is maintained or improved over time. Thus, organizations must strive to consistently improve or at least maintain their sustainability performance or rankings over time. In the increasingly competitive banking industry, for example, merely passing a sustainability test might not be enough to attract the sustainability conscious investor. The organization with a consistently improving sustainability record might stand to gain in attracting more investors. This section seeks to create a time series plot for easy visualization of sustainability performance over time. For easier interpretation of such a plot, a constant threshold is first sought.

Let $(C_t^k)^2$ and $(C_t^s)^2$, respectively, be the square of the relative closeness coefficient for alternative k and the industry standard alternative in time t, and define a new score – relative comparison score – R_t^k given in following equation for alternative k in time t:

$$R_t^k = \frac{\left(C_t^k\right)^2}{\left(C_t^s\right)^2} \tag{13}$$

Then, by Equation (13), the relative comparison score for the standard alternative is $R_t^s = 1$. More importantly, $R_t^s = 1$ irrespective of the time period. Being time independent, the symbol t can be dropped so that $R_t^s = R^s = 1$ for any period. Table VI shows the R_t^k values for the seven banks for the year 2008-2013 based on data from Table AI.

	2008	2009	2010	2011	2012	2013
Bank A	0.9413	0.9082	1.0059	0.9521	0.9322	1.4334
Bank B	4.3716	1.6191	1.0643	1.0425	1.0566	0.8894
Bank C	1.1363	1.4775	1.2446	1.1786	1.1064	1.1158
Bank D	6.5629	1.6069	2.1069	1.8675	1.8258	2.0176
Bank E	1.1453	0.6133	0.5681	0.6566	0.8379	1.0762
Bank F	0.6482	0.7454	0.7650	0.7400	0.7283	0.9075
Bank G	0.6330	0.8240	0.7840	0.9548	0.6887	1.1077

Table VI. Values for relative comparison score R_t^k for seven banks from 2008 to 2013

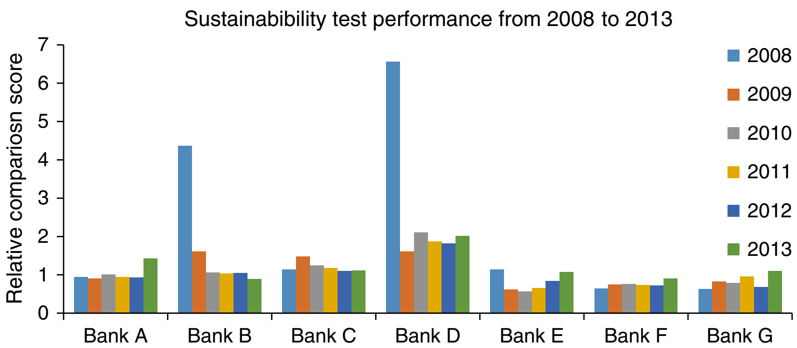
The R_t^k can be interpreted as the size of $(C_t^k)^2$ relative to the threshold values $(C_t^s)^2$ in period t. For example, $R_t^k = 2.0176$ for Bank D in 2013 implies Bank D's $(C_t^k)^2$ value is 2.0176 times that of the industry standard alternative. Similarly, $R_t^k - 1$ would measure how much alternative k outperforms or underperforms the industry standard alternative. Therefore, Bank D outperformed the industry standard alternative by approximately 102 percent while Bank B underperformed the industry standard alternative by 11 percent in 2013.

Figure 3 is a time series plot tracking the R_t^k values of organizations among their compatriots over time. By Arrow *et al.* (2012), a sustainable bank such as Banks C and D must have their bars at least higher than that of the industry standard alternative each period. The time series plot can help visualize quickly the improvement made by organizations over the past years. Among its competitors, a consistently sustainable bank should have a non-decreasing bar height above the value of 1 over time.

From Figure 3, it is clear that Bank D consistently outperformed the industry standard from 2008 to 2013. Bank F however, consistently underperformed the industry standard within the same time period. It is also clear the performance of Bank B has been going down since 2008.

6. Conclusion

To be effective in establishing sustainability among organizations require measurement systems that are able to establish a minimum threshold for sustainability determination and rank the competing organizations for award recognition. To date, many sustainability indices have been proposed and adopted in practice, yet the majority of these indices focus on merely ranking the organizations under study without first establishing if they meet the minimum requirement for sustainability. Using TOPSIS as the basic framework, this paper addresses the basic problem of sustainability determination and measurement by first establishing a threshold against which organizations could be compared. The proposed method establishes this threshold by assigning industry minimum standard values for each criterion to a hypothetical alternative whose overall relative closeness coefficient becomes the threshold for comparison. This way, organizations with relative closeness coefficient below that of the



Notes: That is, the ratio of the square of the relative closeness coefficient for banks to the square of the relative closeness coefficient of the industry standard alternative – from 2008 to 2013. The industry standard alternative has a relative comparison score value of 1 each period

Figure 3.
Time series plot of the relative comparison score of banks

industry standard alternative are deemed to have failed the sustainability test. We note that the same idea of threshold establishment can be applied to make or buy decisions of manufacturing companies when evaluating whether to manufacture in-house or outsource a particular parts. In that sense, the company would be set as the industry standard alternative to be evaluated against potential suppliers. A decision to manufacture in-house would be reached if all suppliers rank below the industry standard.

In addition, by using the square of the relative closeness coefficient of TOPSIS, the proposed method also allows for decomposing the contributions of the three dimensions of sustainability to the overall sustainability performance score. This allows for the tracking of the performance of an alternative (in comparison to that of the industry standard) under the economic, environmental and social dimensions so that organizations could identify and prioritize opportunities for improvement.

The practicality of the proposed method is illustrated with a numerical example using data most of which were collated from major European banks from 2008 to 2013. The proposed method also includes visualization plots for clearer presentation of results. In particular, a times series plot is presented for visualizing the performance of organizations against the industry standard over time in line with the sustainability definition by Arrow *et al.* (2012).

Future research could build upon the proposed method in the case of uncertainty in criteria weight determination using fuzzy TOPSIS. More so, the general idea of establishing industry standard values and assigning it to a hypothetical alternative for threshold determination could be implemented in other sustainability indices such as the DJSI.

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Appendix

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
Weight	0.11	0.12	0.08	0.07	0.04	0.03	0.09	0.08	0.02	0.02	0.02	0.18	0.05	0.05	0.04
Industry standard	55	4	12	15	45	50	2.5	12,000	20	180	100	0.07	20	1,000	12
2013															
Bank A	75.00	5.20	19.80	5.69	59.5	21.90	2.1	4,653	8	94.5	26	0.03	27.60	1,603.00	11.30
Bank B	61.70	2.70	13.61	20.56	68.4	68.92	3.53	12,013.9	20.8	205.5	48	0.08	17.95	450.58	8.42
Bank C	49.90	5.42	11.71	33.00	33.54	55	2.6	7,070	20	86.3	170	0.04	25.05	606.15	10.20
Bank D	88.00	6.70	22.20	24.11	48.8	55.6	3.04	12,241.51	29.40	213	121	0.10	21.70	800.64	15.00
Bank E	30.45	2.82	7.66	22.32	64.03	63.8	2.22	11,397.78	19.2	165	126	0.09	8.80	1,969.58	11.30
Bank F	58.00	4.20	13.00	33.50	43	58.2	6.3	13,900	26	250	110	0.08	16.00	1,350.41	15.20
Bank G	58.00	4.20	13.00	33.50	53	39.3	4.5	7,600	13	92	148	0.06	16.00	989.52	3.95
2012															
Bank A	66.1	5.4	19	2.32	57.5	20.04	2.2	4,761	6.8	100.9	29	0.03	8.9	960	27.4
Bank B	59.3	4.32	14.52	17.04	65.8	70.43	3.07	11,180.56	21.5	209	52.4	0.06	38	820	29
Bank C	46	2.91	10.33	34	22.69	48	2.8	6,900	19.1	90.2	150	0.079	34	980	25.5
Bank D	106.6	5.14	18.9	11.38	42	54.2	3.44	12,151.11	31.14	230	122	0.11	21.5	1,290	21.5
Bank E	34.25	2.14	7.08	29.57	63.57	67.4	2.57	13,068.92	21	193	137.9	0.08	16	1,240	11.92
Bank F	59.6	3.3	12.8	32	40	63.2	7.2	14,200	29	280	120	0.075	13.33	1,550	16
Bank G	59.6	3.3	12.8	32	56.3	23.43	4.8	8,300	12.5	100	180	0.045	14.9	640	16
2011															
Bank A	64.9	7.6	17.5	1.98	55.5	22.38	2.2	4,906	7.9	101.6	29	0.02	7.9	1,010	25.8
Bank B	61.4	2.12	12.37	17.49	66.5	68.75	4.00	12,083.34	23.5	246.75	61.5	0.10	30.01	880	22.48
Bank C	45.7	7.12	10.02	40	17.9036	45	2.9	6,800	19.3	103.6	100	0.032	32.7	950	25.35
Bank D	80.7	9.1	17.2	11.12	45	54.2	3.32	12,459	30.1	242	122	0.11	20.93	1,380	20.9
Bank E	38.82	4.00	0.68	0.37	53.3	63	1.94	11,666	22	157	125.8	0.06	20	1,040	11
Bank F	62.1	3.8	14.5	28.6	38	64.8	7.6	14,000	26	280	120	0.07	13.5	1,350	16
Bank G	62.1	3.8	14.5	28.6	53.3	20	5.1	8,000	12.25	117	210	0.07	13.3	720	16

(*continued*)

Table AI. Sustainability data on 15 criteria for seven banks from 2008 to 2013

Table AI.

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
2010															
Bank A	64.5	8.6	16.3	1.73	58	24.38	2.4	4,988	9.4	108	18.9	0.02	6.2	1,140	24.6
Bank B	58.8	2.22	12.68	20.08	59.2	69.77	4.40	12,500.01	28	235	81	0.10	36.90	860	28.25
Bank C	44.1	11.8	8.8	35.82	17.11	43	3.5	7,000	21.7	110.5	170	0.018	35.69	1,120	25.59
Bank D	76.5	16.7	20.4	1.19	43	53.7	3.66	12,633	33.3	251	119	0.09	28	1,460	28
Bank E	10.63	0.10	5.12	23.57	48	60	1.5366	11,926.15	23.5	165	140	0.05	16	970	12
Bank F	52.2	4.6	13.8	24.6	34	65.6	8.2	14,346	38	290	11	0.06	30.23	1,250	15
Bank G	52.2	4.6	13.8	24.6	51.9	59.77	5.6	12,968.38	38	290	220	0.06	16.5	570	15
2009															
Bank A	64.6	7.3	14.1	1.80	59	18.12	2.7	5,283	7.7	113	33.7	0.03	7.65	1,060	23.2
Bank B	55.6	4.35	12.88	16.77	64.5	62.26	4.35	12,152.79	25.5	216.25	77.5	0.14	28.94	1,081	24.96
Bank C	41.7	13.9	8.6	34.21	13.35	45	4	7,100	21.8	128	200	0.01	22.35	1,070	18.43
Bank D	103	3.41	19.8	1.2	51	54.4	3.12	11,986	31.9	265	130	0.12	27.24	1,600	27.2
Bank E	45.59	2.20	4.32	1.90	45	58	2.46	12,030.04	25.2	170	145	0.055	22	1,120	12
Bank F	48.4	5.2	15.1	28.7	35	68.1	7.9	14,338	33	308	122	0.052	14.1	1,280	14.2
Bank G	48.4	5.2	15.1	28.7	45.63	21.32	5	14,388	33	308	238	0.05	16.2	810	14.2
2008															
Bank A	65.3	9.7	13	6.97	51.71	21.62	2.33	4,981.17	6.47	101.09	25.67	0.02	6.5	1,010	22.1
Bank B	54.84	5,456.00	12.77	14.53	68.30	66.03	4.45	12,119.75	25.75	251.50	74.75	0.095	36.90	1,015	28.25
Bank C	44.60	17.10	7.50	39.08	20.07	38.00	3.69	7,200.00	109.53	107.34	225.00	0.01	25.00	1,120	20.00
Bank D	753	2.22	15	0.83	48	54.6	3.40	13,061.98	31.1122	329.69	185.169	0.682	25	700	16.84
Bank E	40.16	2.89	9.72	23.47	46	52	1.95	12,328.48	27.2	156	148	0.038	19	1,210	10
Bank F	42.5	3.7	16	22.5	36.5	46.45	8.1	13,760	28	290	127	0.041	23.615	1,320	15.8
Bank G	42.5	3.7	16	22.5	43.54	22.54	5.4	14,080	28	290	240	0.025	15.5	740	15.3

Note: Also included are the corresponding industry standard values