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ANALYSIS

How to compare companies on relevant dimensions of sustainability

Damjan Krajnc, Peter Glavič*

Department of Chemistry and Chemical Engineering, University of Maribor, Smetanova 17, SI-2000 Maribor, Slovenia

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Abstract

Dozens of frameworks of sustainability assessment that focus on the performance of companies have been suggested by now. They propose using numerous sustainability indicators, which are generally measured in very different units. While it is important to assess sustainability with several indicators, it may sometimes be difficult to make comparisons among companies based on a large number of performance measurements.

This paper presents a model for designing a composite sustainable development index that depicts performance of companies along all the three dimensions of sustainability—economic, environmental, and societal. In the first part of the paper, the procedure of calculating the index that would enable comparisons of companies in specific sector regarding sustainability performance is presented. However, the emphasis of the paper is on the second part, where the effectiveness of the proposed model is illustrated with a case study in which two companies from specific sector are compared regarding their sustainability performance.

Keywords: Sustainable development; Sustainability assessment; Composite index; Sustainability indicators

1. Introduction

Since the Brundtland report has been published (WCED, 1987), the concept of sustainable development (SD) has become a leading goal of policy makers and scientific researchers. Many definitions of sustainability are based upon the "triple bottom line" concept, covering the three aspects, which are environmental performance, societal responsibility and economic contribution.

Nowadays, many companies recognize and monitor these three parallel aspects using sustainability

Abbreviations: AHP, Analytic Hierarchy Process; AIChE, American Institute of Chemical Engineers; CWRT, Center for Waste Reduction Technologies; EMAS, Eco-management and Auditing Scheme; GRI, Global Reporting Initiative; IChemE, Institution of Chemical Engineers; ISO, International Organization for Standardization; R&D, Research and Development; S.D., Standard deviation; SD, Sustainable development; UP, Unit of Production (mass of oil equivalents); USD, United States Dollar; WBCSD, World Business Council for Sustainable Development; WCED, World Commission on Environment and Development.

* Corresponding author. Tel.: +386 2 229 44 51; fax: +386 2 252 77 74.
E-mail address: glavic@uni-mb.si (P. Glavič).

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indicators, which provide information on how the company contributes to sustainable development (Azapagic and Perdan, 2000). Indicators translate sustainability issues into quantifiable measures with the ultimate aim of helping address the key sustainability concerns (Azapagic, 2004).

Sustainability reporting has evolved swiftly from an ambitious concept to a widely adopted practice. To date, more than 3000 corporate environmental, social or sustainability reports have been published on voluntary basis (GRI, 2002a). Sustainability reports are emerging as a new trend in corporate reporting, integrating financial, environmental, and social performance of the company into one report.

Dozens of frameworks of sustainability assessment that focus on the performance of companies have been suggested by now. Important developments for the issue of sustainability reporting were the foundation of the World Business Council for Sustainable Development (WBCSD, 1997), the Global Reporting Initiative (GRI, 2002b) and the development of standards for environmental management systems, such as the ISO and EMAS standards (OECD, 2002). One of significant studies on sustainability metrics was sponsored by the Center for Waste Reduction Technologies (CWRT) of AIChE (2004) for evaluating process alternatives. The Institution of Chemical Engineers (IChemE, 2002) published a set of sustainability indicators to measure the sustainability within the process industry. Veleva and Ellenbecker (2001) discussed the indicators of sustainable production, suggesting a methodology of core and supplemental indicators for measuring progress of companies towards sustainable development. Azapagic (2004) developed a framework for sustainability indicators for performance assessment of mining and minerals industry, which is compatible with the general indicators proposed by Global Reporting Initiative. Krajnc and Glavič (2003) collected and developed a standardized set of sustainability indicators for companies covering all main aspects of SD. To enable comparisons among companies, they used ISO 31 (1993) as a guide to terms used in names and symbols for (physical) quantities.

The above-mentioned frameworks suggest using numerous sustainability indicators, which are generally measured in very different units. While it is important to assess sustainability with several indicators, it may sometimes be difficult to make business decisions and comparisons among companies based on a large number of performance measurements. To help decision makers in this respect, it may be useful to use composite sustainable development index, linking many sustainability issues and so reducing the number of decision-making criteria that need to be considered.

However, a complex problem still consist of the aggregation of different indicators into a properly constructed index, which would enable quick and efficient assessment of sustainability of company as well as benchmarking of companies within a particular sector. In recent years, international research has focused on the development of composite indices mostly for cross-national comparisons of economic, societal, environmental and/or sustainable progress of nations in a quantitative fashion (Krajnc and Glavič, 2005). Despite the indices developed, there is still no useful method for integrated sustainability assessment on the company level available. Although the common principle to aggregate indicators for assessment of the company has gained acceptance, it has also become evident that methods for the aggregation of indicators are either not sufficiently well established yet, or are under development, or are not available with respect to all the sustainability aspects (Statistics Finland, 2003).

This paper proposes a mathematical model for the determination of the composite sustainability index that will enable comparisons of companies in specific sector regarding sustainability performance. In the first part of the paper, the procedure of calculating the index will be presented. In the second part, the applicability of the proposed model will be illustrated by a case study. In our previous paper (Krajnc and Glavič, 2005), the calculation and interpretation of the composite sustainable development index were illustrated only for sustainability assessment of one case company. The intention of this paper was to examine if the model proposed here is feasible and applicable not only for assessment of one individual company but also for the assessment and comparison of two or more companies.

2. Mathematical model for computing the composite index

The proposed model reduces the number of indicators by aggregating them into a composite sustainable development index (I_{CSD}). The basic hierarchy of composing indicators into the I_{CSD} is shown in Fig. 1. The procedure of calculating the I_{CSD} is divided into several parts: selecting, grouping, weighting, judging, normalizing indicators, calculating sub-indices and combining them into the I_{CSD}. These procedural parts are presented in the following.

2.1. Selection of indicators

At first, the proper performance indicators are selected covering different aspects of sustainability. Azapagic (2003) advises that indicators should be quantitative whenever possible; however, for some aspects of sustainability, qualitative descriptions may be more appropriate (e.g. societal aspects). The first step in selection is to understand which elements of sustainable development should be considered. Each indicator selected should be tracked periodically and equipped with symbol and unit of measurement. It is desired that terms used in names and symbols of indicators follow ISO 31 (1993).

2.2. Grouping of selected indicators

Grouping is strongly connected to the selection of indicators. Selected indicators are grouped according to the main aspects of sustainability (economic, $j=1$, environmental, $j=2$, and societal group of indicators, $j=3$). These groups have been chosen because they reflect the most widely accepted approach to defining sustainability (GRI, 2002b).

Economic group of indicators concerns the impacts of the company on the economic well-being of its stakeholders and on economic systems at the local, national and global levels. They encompass all aspects of economic interactions, including the traditional measures used in financial accounting (GRI, 2002b). Environmental group of indicators cover impacts of the company on living and non-living natural systems, including ecosystems, land, air and water. Societal group of indicators reflects the attitude of the company to the treatment of its own employees, suppliers, contractors and customers, and also its impact on society at large (IChemE, 2002).

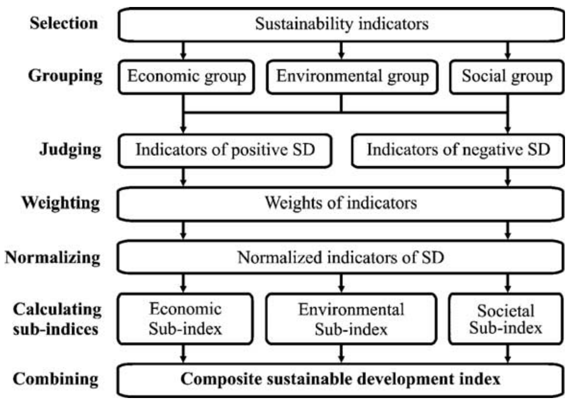

Fig. 1. Scheme for calculation of composite sustainable development index.

2.3. Judging the indicators

For each group j, indicators i of positive performance ($I^{+}_{A,ji}$) in the perspective of sustainability are considered (i.e. indicators whose increasing value has a positive impact to SD). Indicators of negative performance towards SD ($I^{-}_{A,ji}$) are also determined at this stage.

For example, increased value of air emissions per unit of production clearly has a negative impact (indicator is of type “less is better”) while increased operating profit is a value with a positive impact to the economic performance of the company (indicator is of type “more is better”).

2.4. Weighting the indicators

For the assessment of sustainability, a number of indicators exist, which are used to evaluate progress of organization towards sustainability. The individual importance of these indicators is very difficult to determine with sufficient accuracy (Afgan and Carvalho, 2004). To determine weights of indicators, the evaluators are often confronted with a lack of data. Therefore, the pair-wise comparison technique is used in the next procedural part of calculating the I_{CSD} in order to derive relative weights of each indicator practically.

The pair-wise comparison technique is based on the method developed by Saaty (1995) called the Analytic Hierarchy Process (AHP). Krajnc and Glavič (2005) described the procedural details of AHP along with an application on the case study of sustainability assessment. In the following, the method is briefly introduced only to highlight its applicability and suitability in the context of sustainability assessment.

Let us assume that N indicators of SD are being considered with the goal of quantifying relative weights of each indicator with respect to all the other indicators of group j. This is done by *pair-wise comparisons* between each pair of indicators. The comparisons are made by posing the question which of the two indicators i and k is more important with respect to the SD of the company, respectively. The intensity of preference is expressed on a factor scale from 1 to 9 (Hafeez et al., 2002). The value of 1 indicates equality between the two indicators while a preference of 9 indicates that one indicator is 9 times the importance of the one to which it is being compared. This scale is chosen because in this way comparisons are being made within a limited range where perception is sensitive enough to make a distinction.

These pair-wise comparisons result in a $(N\times N)$ positive reciprocal matrix A, where the diagonal $a_{ik}=1$ and reciprocal property $a_{ki}=(1/a_{ik})$, i, $k=1,\ldots,$ n assuming: if indicator i is 'p-times' the importance of indicator k, then, necessarily, indicator k is '$1/p$-times' the importance of indicator i. A quick way to find the normalized weight of each indicator is normalizing each column in matrix A (dividing an indicator relative weight by the sum of relative weights in column), and then averaging the values across the rows; this average column is the normalized weight vector $\boldsymbol{W}$ containing weights (W_{ji}) of sustainability indicators selected. In this paper, an application of pair-wise comparisons will be demonstrated in Table 9.

2.5. Normalizing the indicators

The main difficulty of aggregating indicators into the I_{CSD} is the fact that indicators may be expressed in different units. A suitable normalization procedure could use Eqs. (1) and (2):

$$I^{+}_{\mathrm{N},ijt}=\frac{I^{+}_{\mathrm{A},ijt}-I^{+}_{\mathrm{min},jt}}{I^{+}_{\mathrm{max},jt}-I^{+}_{\mathrm{min},jt}} \tag{1}$$

$$I^{-}_{\mathrm{N},ijt}=1-\frac{I^{-}_{\mathrm{A},ijt}-I^{-}_{\mathrm{min},jt}}{I^{-}_{\mathrm{max},jt}-I^{-}_{\mathrm{min},jt}} \tag{2}$$

where $I^{+}_{\mathrm{N},ijt}$ is the normalized indicator i of type "more is better" for group of indicators j for time (year) t and $I^{-}_{\mathrm{N},ijt}$ is the normalized indicator i of type "less is better" for group of indicators j for the same time (year) t.

In that way, the possibility of incorporating different kinds of quantities, with different units of measurement (i.e. physical, economic, etc.) is offered. One of the advantages of the proposed normalization of indicators is the clear compatibility of different indicators, since all indicators are normalized.

2.6. Calculating the sub-indices

The calculation of the I_{CSD} is a step-by-step procedure of grouping various basic indicators into the sustainability sub-index ($I_{\mathrm{S},\,j}$) for each group of sustainability indicators j. Sub-indices can be derived as shown in Eq. (3).

$$I_{\mathrm{S},jt}=\sum_{jit}^{n}W_{jt}\,I^{+}_{\mathrm{N},jit}+\sum_{jit}^{n}W_{ji}\,I^{-}_{\mathrm{N},jit} \tag{3}$$

$$\sum_{ji}^{n}W_{ji}=1,\;W_{ji}\geq 0$$

where $I_{\mathrm{S},\,jt}$ is the sustainability sub-index for a group of indicators j in time (year) t. W_{ji} is the weight of indicator i for the group of sustainability indicators j and reflects the importance of this indicator in the sustainability assessment of the company.

2.7. Combining the sub-indices into the I_{CSD}

Finally, the sustainability sub-indices are combined into the composite sustainable development index, I_{CSD} (Eq. (4)).

$$I_{\mathrm{CSD},t}=\sum_{jt}^{n}W_{j}\cdot I_{\mathrm{S},jt} \tag{4}$$

where W_j denotes the factor representing a priori weight given to the group j of SD indicators. These weights should reflect priorities in the opinion of the decision makers. In the final calculation of the I_{CSD}, an approach that uses estimated weights can be considered. These weights reflect the importance given to the economic, environmental, and societal performance of the company.

3. An illustrative case study

Considering the availability of reliable data, we have selected two companies (Royal Dutch/Shell Group and BP) to evaluate and compare their performance. To track the sustainability successfulness, the proposed model was applied to the case companies and I_{CSD} with its sustainability sub-indices was delivered for the time period 2000–2003.

BP is the holding company of one of the largest petroleum and petrochemicals groups, providing its customers with fuel for transportation, energy for heat and light, retail services and petrochemicals products for everyday items. Their main activities comprise exploration and production of crude oil and natural gas, refining, marketing, supply and transportation, and the manufacture and marketing of petrochemicals.

Similarly, the companies that comprise the Royal Dutch/Shell Group are engaged in exploration and production of gas, oil and power, chemicals, and in other segments of industry. The Group is also one of the leading companies in energy and petrochemicals. They deliver a wide range of energy solutions and petrochemicals to customers. These include transporting and trading oil and gas, marketing natural gas, producing and selling fuel for ships and planes, generating electricity and providing energy efficiency advices.

The input data used in the case study have been obtained from annual sustainability reports (BP, 2003; Shell, 2003) which have both been prepared in accordance with the 2002 Global Reporting Initiative (GRI, 2002b). They comprise a GRI Content Index, i.e. a cross-referenced table that identifies the location of specified information to allow users to clearly understand the degree to which the reporting organization has covered the content in the GRI Guidelines.

The selection of the case companies was also based on the quality of their sustainability reports. In 2004, the first global index, the Accountability Rating®, has been launched (AccountAbility, 2004) to evaluate how well the 100 largest world companies account for their impacts on society and the environment. In this survey, BP was rated as the most accountable company measuring impacts on society and the environment. Royal Dutch/Shell Group also ranked prominently on the list (among the top 10) by demonstrating their commitment to corporate accountability practices.

The companies selected have been assessed and compared regarding sustainability using economic, environmental and societal sub-indices, which were composed of a number of individual indicators. The aim was to determine which company had better performance in the selected years 2000–2003 in terms of sustainability.

3.1. Calculation of the composite sustainable development index for the case companies

In the case study, a set of sustainability indicators has been *selected*. Tables 1–3 list performance indicators of the case companies. The time frequency of their tracking and calculating was the calendar year. Each indicator was equipped with its symbol and unit of measurement. ISO 31 was used as a guide to terms

Table 1
Economic indicators of the case companies from years 2000 to 2003

Indicator	Symbol	Unit	Royal Dutch/Shell Group				BP			
			2000	2001	2002	2003	2000	2001	2002	2003
Massic[a] cash flow after taxation	C_A	USD/t	71	55	49	64	63	39	39	58
Fraction of R&D expenditure in gross profit	$f_{R\&D}$	%	1.3	1.4	1.7	1.7	1.7	1.5	1.7	1.2
Massic[a] exploration cost	c_{expl}	USD/t	4.59	4.88	5.44	7.59	3.71	2.82	3.68	3.02
Environmental and safety fines and penalties cost	$c_{env.\ fines}$	MUSD	3	1	1	17	7	12	28	7

[a] Expressed relatively to unit of production (mass of oil equivalents).

Table 2
Environmental indicators of the case companies from years 2000 to 2003

Indicator	Symbol	Unit	Royal Dutch/Shell Group				BP			
			2000	2001	2002	2003	2000	2001	2002	2003
Mass flow rate of oil products total production[a]	q_{prod}	kt/d	499.05	511.05	540.25	532.74	442.02	466.44	480.08	491.95
Mass ratio of CO_2 emissions to UP[b]	ζ_{CO_2}	kg/t	505.07	509.29	507.13	545.12	474.78	431.13	437.71	437.17
Mass ratio of CH_4 emissions to UP	ζ_{CH_4}	kg/t	2.18	1.69	1.22	1.20	2.05	2.00	1.54	1.34
Mass ratio of SO_2 emissions to UP	ζ_{SO_2}	kg/t	1.52	1.47	1.37	1.50	1.45	1.32	0.97	0.84
Mass ratio of NO_x emissions to UP	ζ_{NO_x}	kg/t	1.11	1.14	1.08	1.13	1.50	1.56	1.38	1.23
Mass ratio of hazardous waste to UP	$\zeta_{\text{wst, hazard}}$	kg/t	2.20	2.39	2.56	2.85	1.00	1.42	1.72	1.33
Mass ratio of spills to UP	ζ_{spills}	kg/t	0.05	0.10	0.04	0.03	0.05	0.02	0.02	0.02

[a] Expressed in mass of oil equivalents.
[b] UP = unit of production (expressed in mass of oil equivalents).

used in names and symbols for (physical) quantities (ISO, 1993).

The sustainability performance indicators have been *grouped* under three sections covering the economic (4 indicators), environmental (6 indicators), and societal (4 indicators) dimensions of sustainability. This grouping was based on the conventional model of sustainable development (GRI, 2002b).

At the *judging* stage, indicators of positive/negative performance in the perspective of sustainability (i.e. indicators whose increasing value has a positive/negative impact to SD of the case companies) have been considered for each group as shown in Table 4.

To determine the *weights* (importance) of the indicators selected, pair-wise comparisons of indicators according to their impact on overall sustainability assessment of the companies have been performed. A group of 7 experts was put together to serve as the assessment team in order to determine relative weights of indicators. Each group member was asked to estimate a preference factor of each indicator relative to another indicator following the scale from 1 to 9. The value of 1 indicated equality between the two indicators while for example a preference of 7 indicated that one indicator is 7 times the importance of the one to which it is being compared.

The results of the assessment procedure are summarized in Table 5. Based on this pair-wise comparison, average factors of preference have been calculated. Finally, the relative weights of indicators in each group have been estimated following the model of AHP. The calculated weights are shown in Table 6 for economic, in Table 7 for environmental, and in Table 8 for societal group of indicators.

From the relative weights values, it is clear that some indicators are rated much lower than the others. In the economic group of indicators, an indicator of exploration cost was found to be the most important, while indicator of cash flow after taxation was the least preferred (Table 6). In environmental group (Table 7), the highest importance has been assigned to the

Table 3
Societal indicators of the case companies from years 2000 to 2003

Indicator	Symbol	Unit	Royal Dutch/Shell Group				BP			
			2000	2001	2002	2003	2000	2001	2002	2003
Number of employees	N_{employ}	1000	90	91	116	119	107	110	115	104
Fraction of societal and community investment in gross profit	$f_{\text{soc and com}}$	%	0.28	0.32	0.34	0.30	0.32	0.37	0.39	0.25
Number fraction of fatalities per employee	$X_{\text{fatalities}}$	%	5.56	3.30	6.90	4.20	9.33	4.54	2.60	4.82
Fatality Accident Rate for employees and contractors[a]	R_{ac}	1/Mh	8.20	5.20	6.30	5.40	5.00	3.20	2.50	3.80
Recordable Injury Frequency (RIF) for employees and contractors[b]	v_{injury}	1/Mh	3.20	2.90	2.60	2.30	6.30	4.75	3.85	3.05

[a] Number of fatalities per million hours (Mh) worked.
[b] Number of injuries per million hours (Mh) worked.

Table 4
Judging the indicators according to the indication of positive or negative performance of the case companies

Group of sustainability indicators	Indicators of positive performance, $I^{+}_{N,ijt}$	Indicators of negative performance, $I^{-}_{N,ijt}$
Economic	C_A, $f_{R\&D}$	c_{expl}, $c_{env.fines}$
Environmental	/	ζ_{CO_2}, ζ_{CH_4}, ζ_{SO_2}, ζ_{NO_x}, $\zeta_{wst,\ hazard}$, ζ_{spills}
Societal	$f_{soc\ and\ com}$	$X_{fatalities}$, R_{ac}, v_{injury}

indicator of spills, followed by indicators of hazardous waste, SO_2 emissions and NO_x emissions. The lowest weights have been estimated for indicators of CH_4 and CO_2 emissions. In the societal group, the highest importance was assigned to the indicator of recordable injury frequency for employees and contractors, while indicator of fraction of societal and community investment achieved the lowest weight (Table 8).

The pair-wise comparison approach offers maximum insight, particularly in terms of assessing consistency of the experts' judgment. In this context, this technique is ideal for determining a set of sustainability indicators (e.g. deciding which indicators may be excluded from the set).

The variance of standard deviation reflects the range of estimations of experts with respect to the importance of indicators. A zero standard deviation implies complete agreement among the experts. The higher is the standard deviation, the more differing are opinions of experts. Judgments about importance

Table 5
Estimation of preferences for sustainability indicators of the case companies

Estimated indicator	Relative to indicator	Factors of preference assessed by participants							Average factor	S.D. of factors
		1	2	3	4	5	6	7		
Economic indicators										
$f_{R\&D}$	C_A	9	3	3	9	7	7	1/9	5	3.43
c_{expl}	C_A	5	1/3	1/7	7	7	9	1/9	4	3.82
$c_{env.\ fines}$	C_A	1/3	1	1/3	1/7	1	3	2	1	1.04
c_{expl}	$f_{R\&D}$	1	1	1/5	7	1	5	1/7	2	2.69
$c_{env.\ fines}$	$f_{R\&D}$	1/5	1/4	1	1/5	1/5	1	5	1	1.75
$c_{env.\ fines}$	c_{expl}	1/7	1/2	1	5	1/5	1/3	1/3	1	1.76
Environmental indicators										
ζ_{CH_4}	ζ_{CO_2}	1/3	1/4	2	1/7	1/5	3	1	1	1.11
ζ_{SO_2}	ζ_{CO_2}	3	3	2	7	1/5	3	3	3	2.03
ζ_{NO_x}	ζ_{CO_2}	3	1/3	2	1/7	1/3	3	1	1	1.26
$\zeta_{wst,\ hazard}$	ζ_{CO_2}	1	8	5	7	1	5	1	4	3.00
ζ_{spills}	ζ_{CO_2}	1	5	7	7	7	7	3	5	2.43
ζ_{SO_2}	ζ_{CH_4}	1	4	1	7	1	3	2	3	2.21
ζ_{NO_x}	ζ_{CH_4}	1	3	1	7	1	3	4	3	2.19
$\zeta_{wst,\ hazard}$	ζ_{CH_4}	3	9	3	7	5	5	5	5	2.14
ζ_{spills}	ζ_{CH_4}	3	5	2	7	7	7	1/9	4	2.79
ζ_{NO_x}	ζ_{SO_2}	1/3	4	1	1/7	1	3	2	2	1.43
$\zeta_{wst,\ hazard}$	ζ_{SO_2}	1	7	2	7	3	5	4	4	2.34
ζ_{spills}	ζ_{SO_2}	1	3	3	7	7	7	3	4	2.51
$\zeta_{wst,\ hazard}$	ζ_{NO_x}	3	4	5	7	3	5	4	4	1.40
ζ_{spills}	ζ_{NO_x}	3	4	5	7	7	7	5	5	1.62
ζ_{spills}	$\zeta_{wst,\ hazard}$	1	1	3	7	5	3	5	4	2.23
Societal indicators										
$X_{fatalities}$	$f_{soc\ and\ com}$	9	5	3	7	5	1	9	6	2.99
R_{ac}	$f_{soc\ and\ com}$	9	5	1/3	7	2	1	1/7	3	3.53
v_{injury}	$f_{soc\ and\ com}$	9	5	1/3	7	2	1	1/7	3	3.53
R_{ac}	$X_{fatalities}$	1	1	1	1	1	1	1	1	0.00
v_{injury}	$X_{fatalities}$	5	1/5	5	1/7	1/3	1	6	3	2.66
v_{injury}	R_{ac}	5	1/5	5	1/7	1/3	1	6	3	2.66

Table 6
Normalized values of economic indicators (not normalized) of the case companies

I	Indicator	Symbol	Weight, W_{1i}	Royal Dutch/Shell Group				BP			
				2000	2001	2002	2003	2000	2001	2002	2003
1	Massic cash flow after taxation	C_A	0.120	1.00	0.53	0.34	0.80	0.75	0.00	0.01	0.62
2	Fraction of R&D expenditure in gross profit	$f_{R\&D}$	0.281	0.14	0.47	0.87	0.97	1.00	0.60	0.99	0.00
3	Massic exploration cost	c_{expl}	0.363	0.63	0.57	0.45	0.00	0.81	1.00	0.82	0.96
4	Environmental and safety fines and penalties cost	$c_{env.\ fines}$	0.236	0.94	1.00	1.00	0.42	0.80	0.59	0.00	0.79
		Total	1.000								

of indicators are quite varied as shown by the high values of the standard deviation. High standard deviation implies lack of consensus among the evaluators. However, the AHP provides a measure called the consistency ratio (R_c) to check the consistency of judgments. In this case study, a consistency ratio of 0.1 was considered as the acceptable upper limit. The consistency ratio has not exceeded upper limit in any group of indicators. If the consistency ratio was greater than 0.1 then it would be necessary to re-evaluate judgments in pair-wise comparison matrix until the ratio was finally less than 0,1.

The sustainability reports of the case companies do not measure all sustainability indicators using common units and their absolute values are very different. For this reason, the next step of sustainability assessment involved *normalization* of indicators using Eqs. (1) and (2). In that way, the indicators became dimensionless and bounded between the values 0 and 1. Normalized results are presented in Tables 6–8 for economic, environmental and societal group of indicators, respectively.

To *calculate sustainability sub-indices* in time t (t (years)=2000,..., 2003) for economic, environmental and societal group of indicators, the normalized value of each indicator was multiplied by its calculated weight using Eq. (3).

The last step of the model represents combining of derived sustainability sub-indices $I_{S,\ 1t}$, $I_{S,\ 2t}$, $I_{S,\ 3t}$ into the *composite sustainable development index* (I_{CSD}) for each time (year) t using Eq. (4). In the final calculation of the I_{CSD}, each sustainability sub-index has been multiplied by its weight, which reflected the importance given to the economic, environmental, and societal group of SD indicators of the case company.

Weights attributed to each sub-index have also been calculated involving expert judgment (7 experts) using pair-wise comparison of sub-indices in AHP. The results in Table 9 indicate the highest importance of the environmental sub-index followed by the economic and societal sub-indices. The result is comparable for example with a survey of Tiwari et al. (1999) where environmental sustainability criteria of agricultural system achieved higher importance when compared to economic sustainability.

3.2. Analysis of the results

Four economic, six environmental and four societal indicators were aggregated into sustainability sub-

Table 7
Normalized values of environmental indicators (not normalized) of the case companies

I	Indicator	Symbol	Weight, W_{2i}	Royal Dutch/Shell Group				BP			
				2000	2001	2002	2003	2000	2001	2002	2003
1	Mass ratio of CO_2 emissions to UP	ζ_{CO_2}	0.061	0.00	0.51	0.98	1.00	0.14	0.19	0.66	0.86
2	Mass ratio of CH_4 emissions to UP	ζ_{CH_4}	0.055	0.00	0.08	0.22	0.03	0.10	0.30	0.82	1.00
3	Mass ratio of SO_2 emissions to UP	ζ_{SO_2}	0.110	0.94	0.87	1.00	0.89	0.13	0.00	0.38	0.70
4	Mass ratio of NO_x emissions to UP	ζ_{NO_x}	0.103	0.35	0.25	0.16	0.00	1.00	0.77	0.61	0.82
5	Mass ratio of hazardous waste to UP	$\zeta_{wst,\ hazard}$	0.263	0.53	0.00	0.74	0.78	0.54	0.99	1.00	0.98
6	Mass ratio of spills to UP	ζ_{spills}	0.407	0.42	0.30	0.00	0.08	1.00	0.75	0.61	0.49
		Total	1.000								

Table 8
Normalized values of societal indicators (not normalized) of the case companies

I	Indicator	Symbol	Weight, W_{3i}	Royal Dutch/Shell Group				BP			
				2000	2001	2002	2003	2000	2001	2002	2003
1	Fraction of societal and community investment in gross profit	$f_{\text{soc and com}}$	0.0692	0.16	0.45	0.59	0.33	0.51	0.85	1.00	0.00
2	Number fraction of fatalities per employee	$X_{\text{fatalities}}$	0.2744	0.56	0.90	0.36	0.76	0.00	0.71	1.00	0.67
3	Fatality Accident Rate for employees and contractors	R_{ac}	0.2410	0.00	0.53	0.33	0.49	0.56	0.88	1.00	0.77
4	Recordable Injury Frequency (RIF) for employees and contractors	v_{injury}	0.4154	0.78	0.85	0.93	1.00	0.00	0.39	0.61	0.81
		Total	1.000								

indices for the case companies and finally aggregated into the I_{CSD} as presented in Table 10. The variation of sustainability sub-indices and the I_{CSD} for the case companies over a time interval of years 2000–2003 is graphically presented in Fig. 2.

The results of the case study enable easy interpretation of SD for the case companies. The I_{CSD} highlights the progress towards sustainability achieved: the company scores high in the I_{CSD} in the certain year if the composition of its individual sustainability sub-indices I_{ECN}, I_{ENV}, and I_{SOC} is high relative to the other years and other companies included in evaluation. The higher is the value of the I_{CSD} the greater is the improvement of the company towards sustainability. The same is true for sustainability sub-indices. For any given year, the I_{CSD} and sub-indices reveal the performance of the company in that year compared to the other years and companies, respectively. Relatively high I_{CSD} score can also be interpreted as a measure of the relative likelihood that a company will be able to achieve and sustain favorable sustainable conditions several years into the future.

Through the sub-indices calculated, the economic and financial development, as well as the environmental and societal performance of the case companies have been evaluated in the case study. Within each sub-index, wide variations in performance of the case companies are evident in the period 2000–2003. The *economic sub-index* of BP has been decreasing in the period 2000–2002 in contrast to the sub-index of Royal Dutch/Shell Group (Fig. 2a). However, in 2003 the BP slightly improved its performance and scored higher than the competing company. Here, it should be pointed out that economic development has affected, but not determined the I_{CSD} results. That is very important since nowadays a great emphasis has been put on the economic assessment and less on the societal and environmental one. *Environmental performance* of the BP has been increasing thoroughly from 2000 as seen in Fig. 2b. Thus, it has excelled Royal Dutch/Shell Group in environmental performance, in 2003 by 92 %. However, in *societal performance*, the Royal Dutch/Shell Group scored higher as compared to the BP in the whole time period with exception of 2002 (Fig. 2c).

Following the I_{CSD} of the case companies for the time interval 2000–2003, it shows how the company is progressing over the time in comparison with the other companies evaluated. If the index is higher in year $N+1$ than it was in year N, the performance of the

Table 9
Pair-wise comparison matrix for evaluation of estimated weights of sustainability sub-indices

Sub-index	I_{ECN}	I_{ENV}	I_{SOC}	
Economic Sub-index, I_{ECN}	1	1/2	2	
Environmental Sub-index, I_{ENV}	2	1	1	
Societal Sub-index, I_{SOC}	1/2	1	1	
$\sum$	3.50	2.50	4.00	Weights
Economic Sub-index, I_{ECN}	0.286	0.200	0.500	0.329
Environmental Sub-index, I_{ENV}	0.571	0.400	0.250	0.407
Societal Sub-index, I_{SOC}	0.143	0.400	0.250	0.264

Table 10
The I_{CSD} and sustainability sub-indices for economic (I_{ECN}), environmental (I_{ENV}), and societal (I_{SOC}) group of indicators

Index	Royal Dutch/Shell Group				BP			
	2000	2001	2002	2003	2000	2001	2002	2003
I_{ECN}	0.609	0.637	0.683	0.467	0.856	0.673	0.579	0.607
I_{ENV}	0.427	0.211	0.547	0.470	0.554	0.712	0.790	0.904
I_{SOC}	0.518	0.765	0.640	0.784	0.152	0.604	0.818	0.700
I_{CSD}	0.511	0.497	0.616	0.552	0.547	0.671	0.728	0.753

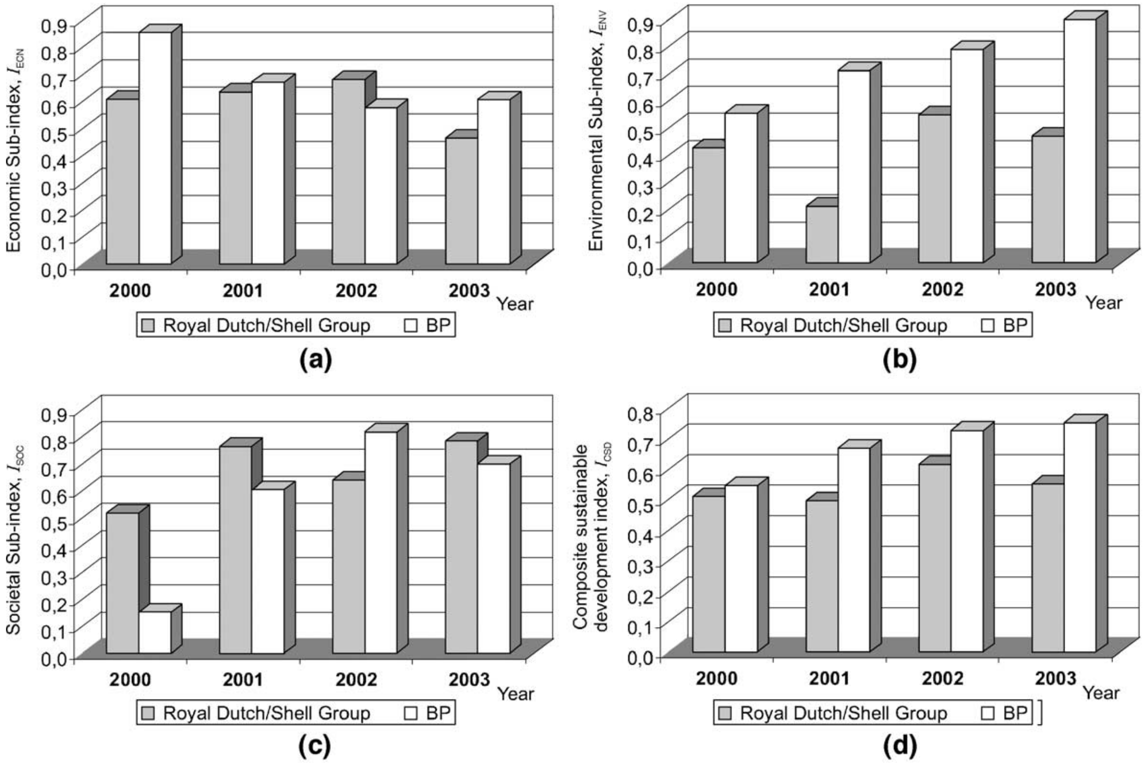

Fig. 2. Variation of sustainability sub-indices and the I_{CSD} of the case companies over a time interval of years 2000–2003: (a) economic sub-index, (b) environmental sub-index, (c) societal sub-index and (d) composite sustainable development index.

company has improved over that period. In such a way, decision makers can better understand the sustainability status of their companies.

It is evident from the results of the case study that the I_{CSD} differs for the companies evaluated in the selected time period. Comparing Royal Dutch/Shell Group and BP, I_{CSD} reveals better results for BP. It can be seen that the I_{CSD} for Royal Dutch/Shell Group is comparatively lower than for the BP for all the time period measured (Fig. 2d). In 2003, the I_{CSD} of BP has been higher by 36%. This fits well with the measurements of Dow Jones Sustainability Indices which recognized the BP as sustainability leader within the industry group "Oil, Gas and Coal Companies" in 2003 on a global basis (DJSI, 2003). However, the Royal Dutch/Shell Group was among the best companies, too.

One could argue that I_{CSD} fails to demonstrate the sustainability of the company in the view of individual sustainability indicators. Because of that, the I_{CSD} was visualized by the presentation technique of the amoeba indicator (Ten Brink et al., 1991). AMOEBA, in the Dutch language, stands for 'general method of ecosystem description and assessment'. In our case study, an attempt was made to use this method for quantitative and graphical description of the I_{CSD}.

To compare sustainability performance of both case companies in the year 2003, normalized values of all indicators have been visualized as can be seen in Fig. 3. For each indicator, the distance from the center point of the circle to the point on the line has been determined representing a normalized value of the indicator specified. The amoeba-like indicator was finally obtained by connecting these points.

The larger amoeba, the more sustainable is the company and vice versa. The probability of sustainable development becomes larger the closer the normalized value of indicator is to the point 1. Curves express quantitative discrepancies between the two benchmarking companies. For the year 2003, BP

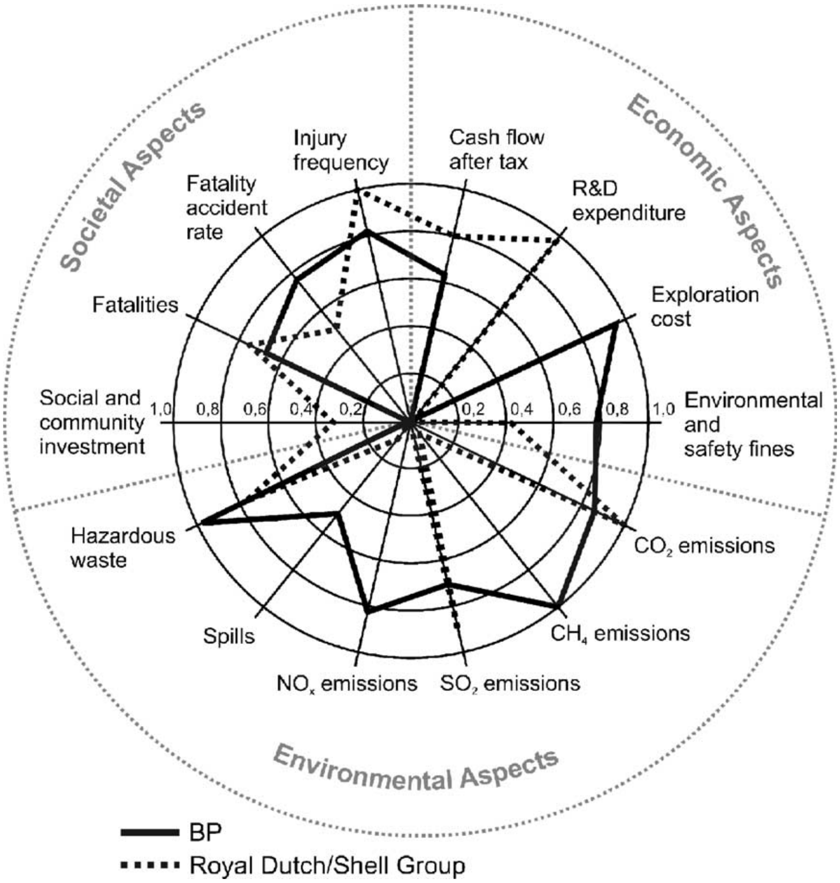

Fig. 3. Representation of the I_{CSD} of the case companies for year 2003 using normalized values of indicators.

scored higher for example in CH_4 emissions while it achieved lower scores in R&D expenditure (in opposition to the Royal Dutch/Shell Group which scored higher in R&D expenditure and lower in CH_4 emissions). By such comparisons of curves for both companies, decision makers get information of aspects in which companies approach sustainability and in which ones they do not.

4. Conclusions

There are basically three different target groups whose attitudes towards clarity of sustainability assessment differ: scientists, decision makers and individuals (Braat, 1991). Scientists are interested primarily in statistically useable and possibly not aggregated data, while decision makers require aggregated data, as well as relating data to goals and criteria. Individual users (the public) prefer aggregation of data to one value (i.e. an index).

This paper presents a designing of a composite sustainable development index (I_{CSD}) that depicts performance of companies along all the three aspects of sustainability—economic, environmental, and societal in order to provide a good guidance for decision-making. It discusses how sustainability indicators can be associated into sustainability sub-indices and finally into an overall indicator of a company performance.

The purpose of the I_{CSD} is to give both a simplified and quantified expression for a more complex composition of several indicators. It can be used to inform decision makers and individuals of trends in development of the company. However, it may also be included in a more targeted context, such as reflecting the status of a company regarding sustainability, providing information to critical decision processes, or possibly forming the basis for a company to head in a certain direction. The I_{CSD} helps to highlight opportunities for improvement and to respond to emerging issues and pressures. It provides early warning information and tracks sustainability development of the company. The decision makers can easily interpret the I_{CSD} and its corresponding sub-indices, rather than trying to find a trend in many separate indicators of SD. If included in the annual sustainability report, the I_{CSD} can also be used to present the progress of the company to the various parties interested in SD of the company.

An important feature of the I_{CSD} is the possibility of comparing and ranking companies in specific sector in terms of SD as shown in our case study. Therefore, the I_{CSD} could offer consistent and flexible benchmarking for private and institutional investors. It could be used as criteria by which companies could be identified and ranked according to their sustainability performance. The index could support investors to invest in companies committed to the concept of corporate sustainability. The model proposed in this paper could help in developing standards for external benchmarking and to monitor progress of companies in time.

The possible disadvantage of the model may be the way in which the weights of indicators are determined. One could argue that the weights used reflect hierarchies and/or priorities according to the opinion of the evaluator and may therefore suffer from a high degree of subjectivity. However, in the case of a different opinion on the importance of an indicator, it is not needed to reformulate the proposed model, but only re-evaluate the weights. The second possible weakness of the model could be a selection of indicators. In the case study, the indicators have been selected considering the availability of reliable data. Since different indicators in the index for different companies would prevent decision makers from making comparisons between companies in the same sector, it is required to determine how and who will select the indicators. The authors suggest the Global reporting Initiative (GRI) as the basis of the I_{CSD}, although no company currently reports on all the GRI indicators and no guidance is provided on how to choose between the indicators.

However, the results of the model proposed here showed it was feasible and could be easily applied to compare companies regarding sustainable development. While no measure of such a complex phenomenon is perfect, the I_{CSD} can be useful in benchmarking the sustainability performance of the companies in the selected sector. The combination of better assessment methods and rising stakeholder demands for wider reporting on sustainability is likely to continue this movement towards a new generation of integrated sustainability assessments. As the credibility of aggregation methodologies is of crucial importance for the quality of sustainability metrics, the I_{CSD} model can be one of the tools that help to make sustainability more assessable.

Nomenclature

Symbols

I_{CSD} Composite Sustainable Development Index
I_A^+ indicator whose increasing value has positive impact in the perspective of sustainability
I_A^- indicator whose increasing value has negative impact in the perspective of sustainability
I_{ECN} economic sustainability sub-index
I_{ENV} environmental sustainability sub-index
I_N^+ normalized indicator whose increasing value has positive impact on the sustainability
I_N^- normalized indicator whose increasing value has negative impact on the sustainability
I_{min}^+ indicator of positive performance with minimum value of all companies compared
I_{min}^- indicator of negative performance with minimum value of all companies compared
I_{max}^+ indicator of positive performance with maximum value of all companies compared
I_{max}^- indicator of negative performance with maximum value of all companies compared
I_S sustainability sub-index
I_{SOC} societal sustainability sub-index
W a priori weight of indicator

Indices
i sustainable development indicator
j group of sustainable development indicators
t time in years
other indices are explained in Tables 6–8.

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