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Review

An overview of sustainability assessment methodologies

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ABSTRACT

Sustainability indicators and composite index are increasingly recognised as a useful tool for policy making and public communication in conveying information on countries and corporate performance in fields such as environment, economy, society, or technological improvement. By visualizing phenomena and highlighting trends, sustainability indicators simplify, quantify, analyse and communicate otherwise complex and complicated information.

There are number of initiatives working on indicators and frameworks for sustainable development (SD). This article provides an overview various sustainability indices applied in policy practice. The paper also compiles the information related to sustainability indices formulation strategy, scaling, normalisation, weighting and aggregation methodology.

Contents

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1. Introduction

The concept of sustainable development (SD) has become an important objective of policy makers in the industry. The Brundtland report defines the sustainable development as development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs (WCED, 1987). There are number of frameworks of sustainability assessment that evaluate the performance of companies. The World Business Council for Sustainable Development (WBCSD, 1997), the Global Reporting Initiative (GRI, 2002a,b) and development of standards (OECD, 2002a,b) were the foundation for sustainability reporting. Azapagic (2004) developed a framework for sustainability indicators for the mining and minerals industry, which is also compatible to GRI. Krajnc and Glavic (2005) collected and developed a standardised set of sustainability indicators for companies covering all main aspects of sustainable development.

Indicators and composite indicators are increasingly recognised as a useful tool for policy making and public communication in conveying information on countries' performance in fields such as environment, economy, society, or technological development.

'Indicators arise from values (we measure what we care about), and they create values (we care about what we measure)' (Meadows, 1998). The main feature of indicators is their ability to summarise, focus and condense the enormous complexity of our dynamic environment to a manageable amount of meaningful information (Godfrey and Todd, 2001). By visualizing phenomena and highlighting trends, indicators simplify, quantify, analyse and communicate otherwise complex and complicated information (Warhurst, 2002).

There is a widely recognised need for individuals, organisations and societies to find models, metrics and tools for articulating the extent to which, and the ways in which, current activities are unsustainable. This need arises on multiple layers ranging from supra-national (e.g. the negotiation of protocols for environmental protection), national (e.g. via some version of "greening" GDP) and sub-national levels (e.g. in regional development forums) (Ramachandran, 2000).

In an effort to introduce and define sustainability science, Kates et al. (2001) provide seven core questions for research. Two of them are particularly connected to the issue of assessing sustainability:

- "How can today's operational systems for monitoring and reporting on environmental and social conditions be integrated or extended to provide more useful guidance for efforts to navigate a transition toward sustainability?
- How can today's relatively independent activities of research planning, monitoring, assessment, and decision support be better integrated into systems for adaptive management and societal learning?"

According to Kates et al. (2001), the purpose of sustainability assessment is to provide decision-makers with an evaluation of global to local integrated nature–society systems in short- and long-term perspectives in order to assist them to determine which actions should or should not be taken in an attempt to make society sustainable.

The need for an integral systematic approach to indicators definition and measurement is recognised (Bossel, 1999) in order to give well-structured methodologies, easy to reproduce and to assure that all important aspects are included in the measurement. However, before developing the methodology and the indicators what is needed is the clear definition of the policy goals towards sustainability. This appears to be even more difficult since in most cases the development of indicators has started while there are still arguments over what constitutes sustainable development.

2. Sustainable development indicators

Warhurst (2002) considers measuring of sustainable development as a two-step approach. Firstly, the progress made in a number of selected individual fields is measured by SDIs and secondly, the overall progress made towards sustainable development is assessed by a combination of these individual fields with regard to their interlinking.

According to Lancker and Nijkamp (2000), 'a given indicator does not say anything about sustainability, unless a reference value such as thresholds is given to it'.

Summarizing from Lundin (2003) and Berke and Manta (1999) SDIs can be used to:

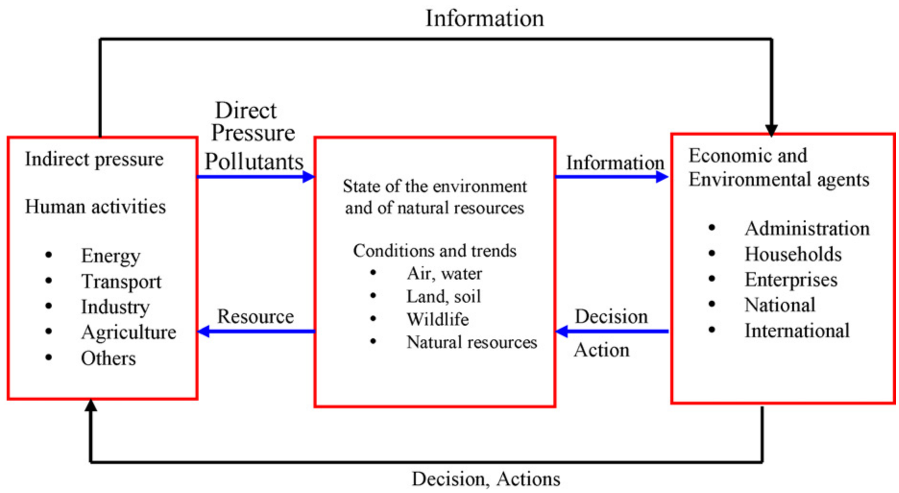

Fig. 1 – The pressure-state-response framework. ***Source*****: OECD (1998).**

- Anticipate and assess conditions and trends.
- Provide early warning information to prevent economic, social and environmental damage.
- Formulate strategies and communicate ideas.
- Support decision-making.

When developing a framework and selecting SDIs, two distinctive main approaches can be distinguished (Lundin, 2003):

- The 'top-down' approach, which means that experts and researchers define the framework and the set of the SDIs.
- The 'bottom-up' approach that features the participation of different stakeholders in the design of the framework and the SDI selection process.

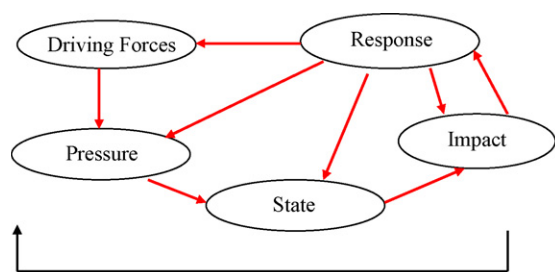

Fig. 2 – The DPSIR framework for reporting on environmental issues. ***Source*****: Smeets and Weterings, 1999.**

To tackle the problem of insufficient physical relations between society and nature, Holmberg and Karlsson (1992) introduced the concept of socio-ecological indicators (SEIs). The Pressure State Response (PSR) framework is based on the following concept of causality: human activities exert 'pressures' on the environment and change its quality and the quantity of natural resources (the 'state'). Society responds to these changes through environmental, general economic and sectored policies (the 'societal response'). The latter forms a feedback loop to pressures through human activities (OECD, 1998). Fig. 1 illustrates this PSR-framework of OECD.

The Driving Force Pressure State Impact Response (DPSIR) model is an extension of the PSR framework and has been adopted by the European Environmental Agency (EEA) and the

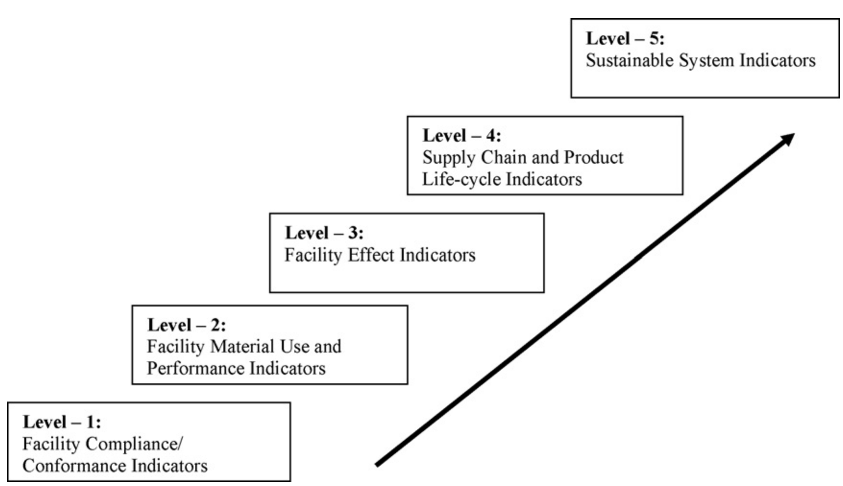

Fig. 3 – Lowell center for sustainable production indicator framework.

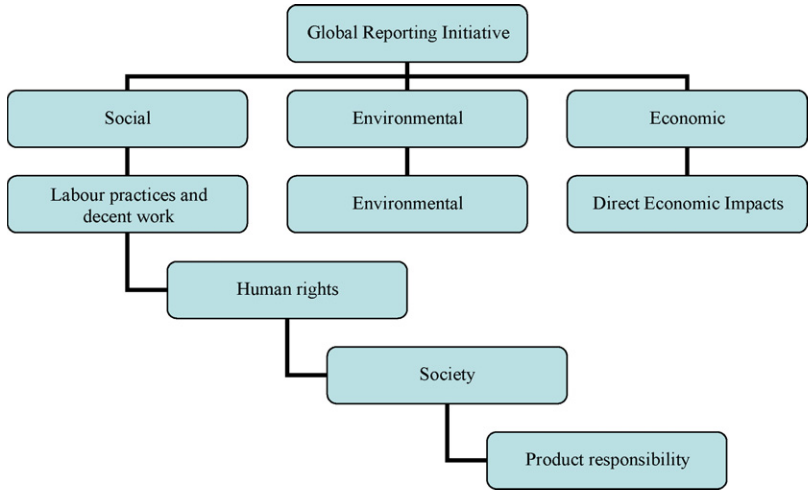

Fig. 4 – The hierarchical structure of the global reporting initiative (GRI) framework (*Source*: GRI, 2002a).

European Statistical Office in 1997. Fig. 2 visualises those five aspects and their connections.

Starting from the call for sustainable development indicators in Agenda 21, the UN Commission on Sustainable Development (CSD) published a list of about 140 indicators, which cover social, economic, environmental and institutional aspects of sustainable development (CSD, 2001).

In order to simultaneously evaluate both the environmental and social components of sustainable development, the barometer of sustainability has been developed (Prescott-Allen, 1995). It consists of two components, namely ecosystem well-being and human well-being that both have to be improved for achieving sustainable development. The ecological footprint (Wackernagel and Rees, 1996) measures the total land area that is required to maintain the food, water, energy and waste-disposal demands per person, per product or per city.

The eco-efficiency framework of the WBCSD attempts to measure progress towards economic and environmentally sustainability using indicators that are relevant and meaningful for business (WBCSD, 1999).

The LCSP framework primarily focuses on the environmental, health and safety aspects of sustainable production. The framework suggests five levels in the development

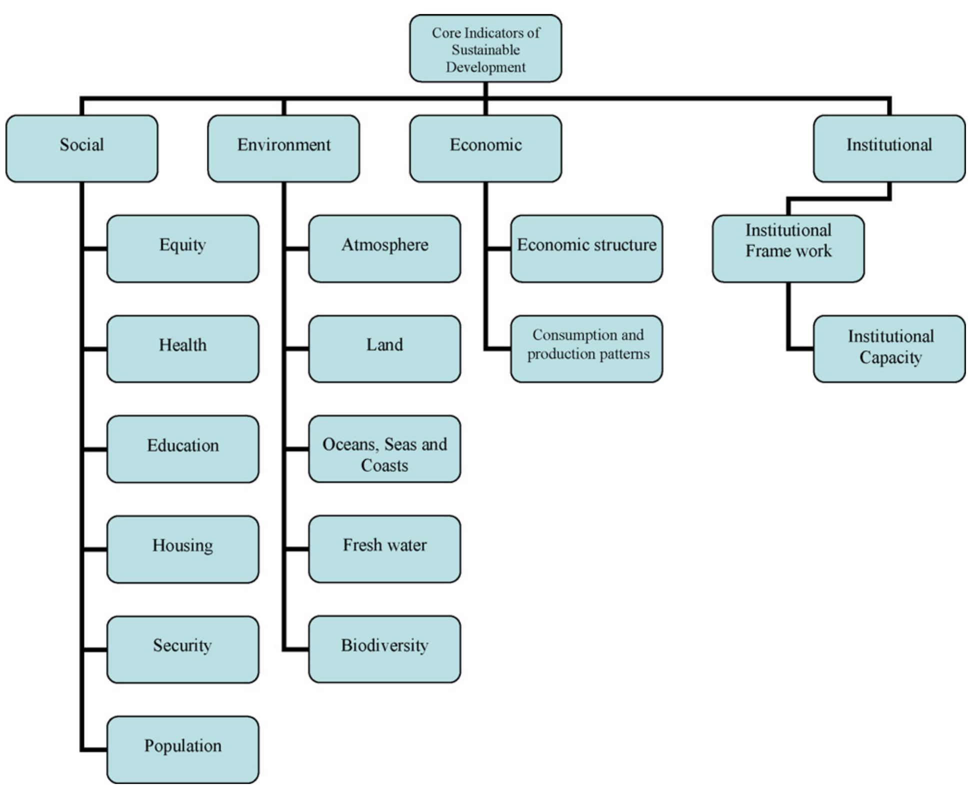

Fig. 5 – The United Nations Commission for Sustainable Development (UNCSD) Theme Indicator Framework.

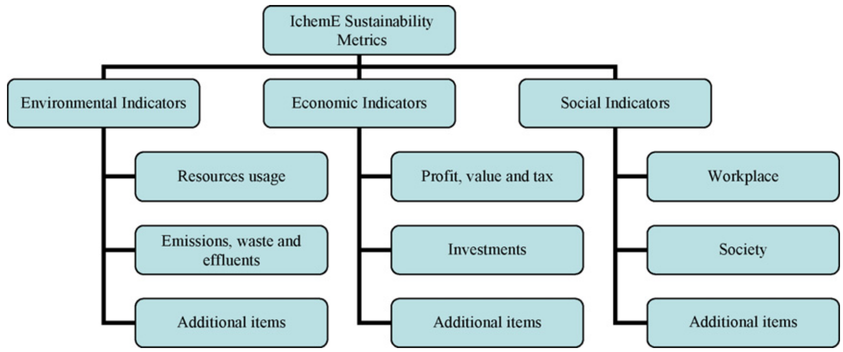

Fig. 6 – The Institute of Chemical Engineers (IChemE) Sustainability Metrics.

process moving toward sophisticated indicators of sustainable production as illustrated in Fig. 3.

To ensure optimised and effective steps towards sustainability, the progress and shortcomings need to be monitored and measured. Measurement systems (metrics) for SD are an area, where a lot of research and practical work has been conducted. The metrics should not be mixed with the tools and concepts, as they do not provide direct help to the actual work towards SD, but define the framework and operate as metrics and feedback loops for the process.

In 1997, the United Nations Environment Programme (UNEP) together with the United States nongovernmental organisation, Coalition for Environmentally Responsible Economics (CERES) launched the GRI with the goal of ''enhancing the quality, rigour and utility of sustainability reporting''.

Reporting is therefore the strong focal point of the guidelines. The GRI uses a hierarchical framework in three focus areas, namely social, economic, and environmental (Fig. 4).

The United Nations Commission on Sustainable Development (CSD) constructed a sustainability indicator framework for the evaluation of governmental progress towards sustainable development goals. A hierarchical framework groups indicators into 38 sub-themes and 15 main themes, that are divided between the four aspects of sustainable development (Fig. 5).

The Institution of Chemical Engineers (IChemE) published a set of sustainability indicators in 2002 to measure the sustainability of operations within the process industry (Fig. 6).

The Wuppertal Institute proposed indicators for the four dimensions of sustainable development, as defined by the United Nations CSD, together with interlinkage indicators between these dimensions (Fig. 7).

For the past two decades, there have been many local, regional, state/provincial, national and international efforts to find useful sustainability indicators. The UN Commission on Sustainable Development (UNCSD) from its working list of 134 indicators derived a core set of 58 indicators for all countries to use.

3. Classification and evaluation of sustainability assessment methodologies

There are two distinct methodologies that can be found for Sustainability Assessment. Mainstream economists use

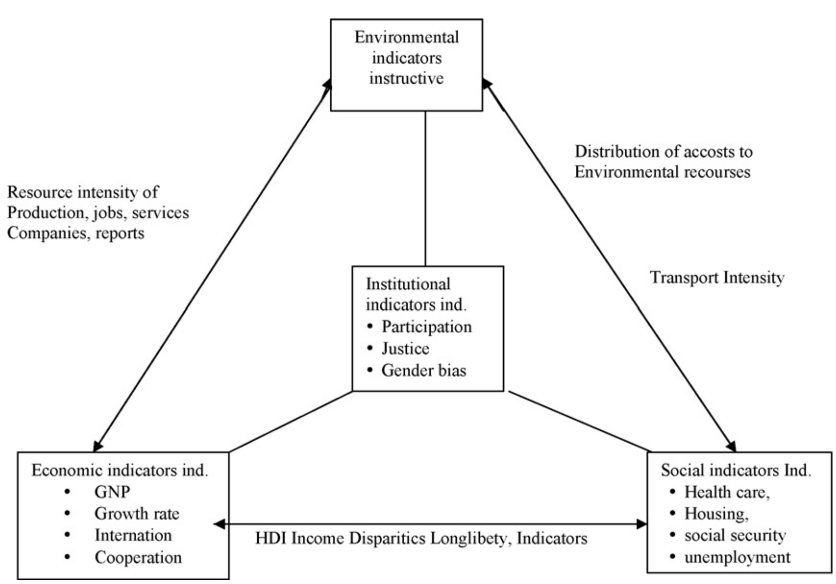

Fig. 7 – The Wuppertal Sustainable Development Indicator Framework.

monetary aggregation method, whereas scientists and researchers in other disciplines prefer to use physical indicators. Economic approaches include greening the GDP, resource accounting based on their functions, sustainable growth modelling, and defining weak and strong sustainability conditions. Mainstream economists assume sustainable growth to be a part of sustainable development of the economy.

In neo-classical models, natural environment is valued for its functions and economic welfare is measured in terms of the level of consumption. Therefore, sustainable growth models from this paradigm seek to find a non-declining per capita consumption path over an infinite time horizon through optimal use of resources and technology including discounted benefits from environmental functions and non-renewable natural resources. Substitution possibility between different types of capital is assumed in different forms.

The Hicks/Lindahl requirement for sustainable income is non-declining value of the aggregate capital stock (per capita produced capital and per capita natural capital) over time. *Weak sustainability condition* assumes perfect substitutability between produced and natural capital and *strong sustainability condition* assumes no substitutability. The assumption of secular improvement in factor productivity can ensure sustainability in neo-classical growth models.

In the Solow-Hartwick framework, sustainable growth path is different from the optimal growth path, which means that sustainability can be achieved at the cost of efficiency. Some recent models from the neo-classical paradigm have explored direct relationship between technological progress and sustainability. Endogenous growth models make the nature of technological progress explicit. The evolutionary modellers use inductive reasoning instead of trying to find the steady state. They are particularly concerned about fostering technical and institutional changes to reach sustainability.

The theme of ecological economics model is socio-economic and ecological co-evolution. Neo-Ricardian models of sustainability seek 'continual maintenance and joint renewal of economic and ecological structures (Pezzey, 1992).

For natural resource accounting, some economists use conventional capital theory that acknowledges the possibility of conversion of natural resource capital to other forms of capital. Some researchers used the depreciated values of natural resource stocks from the decreased values of the marketed commodities produced by the resource stocks to estimate resource depletion. Unit rent approach attempts to estimate the portion of income from resource liquidation that needs to be set aside as capital investment "in order to create a perpetual stream of income that would sustain the same level of true income, both during the life of the resource as well as after the resource had been exhausted."

Mainstream economists prefer monetary valuation simply because it represents the scarcity value of resources. Spangenberg (2005) considers 'the restriction of economic thinking' to monetary valuation of the functions of different types of capital 'a serious limitation for the analytical capacity of the discipline'. Citing criticisms about the assumption of strong substitutability between different types of capital in economic models, Spangenberg (2005) concluded that 'from a scientific point of view, there cannot be such a thing as one comprehensive measure or index of sustainability'.

Ness et al. (2007) developed a holistic framework for sustainability assessment tool which is shown in Fig. 8. It consists of three umbrellas or general categorisation areas; these areas are (1) indicators and indices, which are further broken down into non-integrated and integrated, (2) product-related assessment tools with the focus on the material and/or energy flows of a product or service from a life cycle perspective, and (3) integrated assessment, which are a collection of tools usually focused on policy change or project implementation. There is also the overarching category at the bottom of the figure used when non-market values are needed in the three categories. The tools are arranged on a time continuum based on if they look back in time (retrospective) or if they are forward looking (prospective, forecasting) tools.

The classification and evaluation of indicators can be done based on the following general dimensions of measurement:

- What aspect of the sustainability does the indicator measure?
- What are the techniques/methods employed for construction of index like quantitative/qualitative, subjective/objective, cardinal/ordinal, unidimensional/multidimensional.
- Does the indicator compare the sustainability measure (a) across space ('cross-section') or time ('time-series') and (b) in an absolute or relative manner?
- Does the indicator measure sustainability in terms of input ('means') or output ('ends')?
- Clarity and simplicity in its content, purpose, method, comparative application and focus.
- Data availability for the various indicators across time and space.
- Flexibility in the indicator for allowing change, purpose, method and comparative application.

3.1. *Guidelines for construction of Indices*

First of all number and nature of the components that will make up part of the composite index need to be determined based on theory, empirical analysis, pragmatism or intuitive appeal, or some combination thereof. Both bivariate and multivariate statistical techniques are employed where selection is based on empirical analysis. Whereas bivariate analysis measures the strength of the association between all pairs of variables, multi-variate analysis assesses the overall power of any collection of variables to measure any other variable. Bivariate analyses traditionally employ correlation matrices in selection. Most notable of the multivariate techniques employed in composite indexing are discriminant, principal component and factor analyses. The purposes of these analytical techniques are to determine the number of latent variables underlying the data, to condense the data and to define the content and meaning of the factors or latent variables accounting for the variation in the data. Equally dependent on purpose is the distinction between variables focused on ends as opposed to means. Other important selection criteria include validity, reliability, comparability, simplicity, and data availability. Selection requires a balance between simplification and complication. Despite claims that value-judgements and

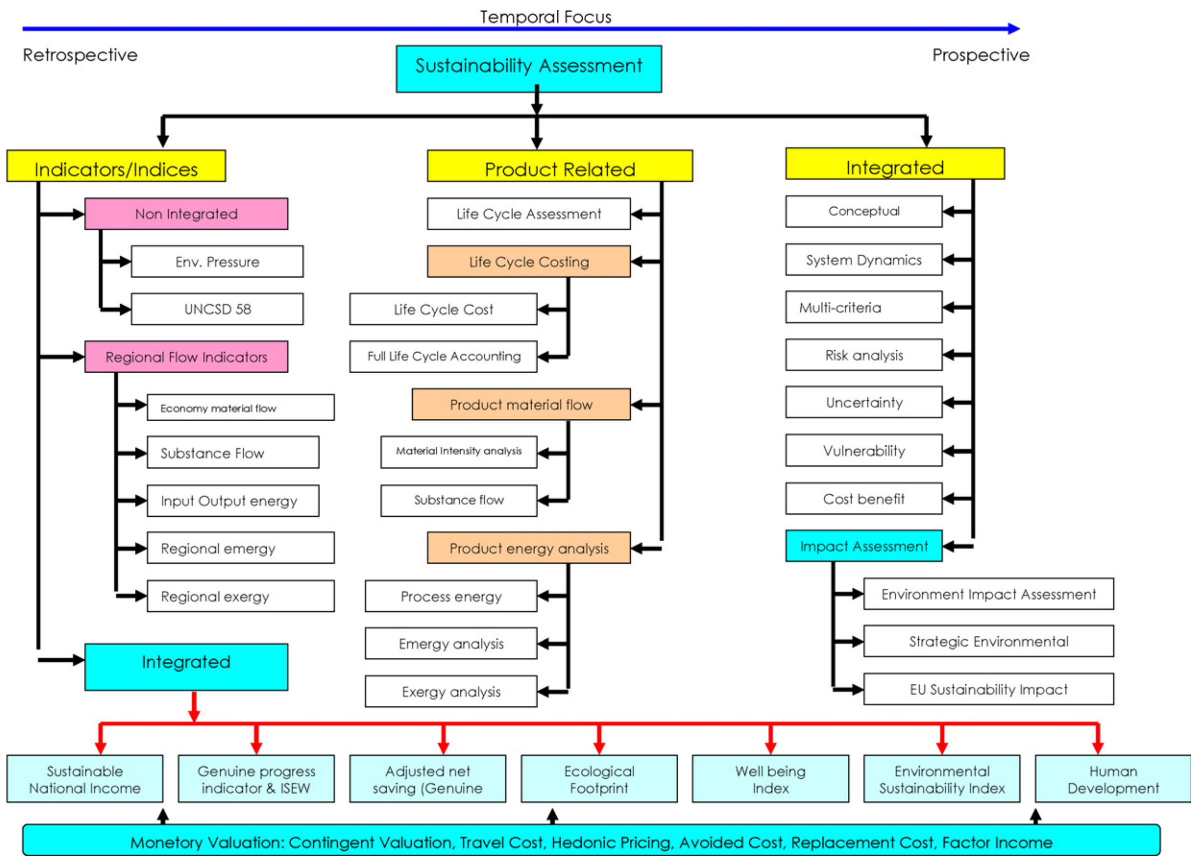

Fig. 8 – Framework of Sustainability Assessment Tools. *Source*: Barry Ness, Evelin Urbel-Piirsalua, Stefan Anderberg and Lennart Olssona, 2007.

cultural issues should be avoided as far as possible in selection, composite indexing remains an inherently value-laden and subjective exercise. Based on the goal, the components will have to be selected whether it is of universal significance or for local conditions.

Scaling for composite indexing purposes can be performed in one of four ways. Firstly, there is the option of not scaling variables. This is an especially viable option where variables are already scaled. In the *second* instance, the use of standard scores (z and t values) is also popular in composite indexing. Raw scores are first adjusted for directionality by multiplying each with either +1 or −1. Standardisation then involves transforming raw scores on each indicator into standard scores, e.g. z = (actual score − mean)/standard deviation. Standard scores can be further adjusted if calculations yield awkward values. Options include the multiplication of all scores by 10 to obtain more visually manageable scores, adding the proportionate share of each component in the composite index to each component score, rounding each score to eliminate decimals, and adding 100 to each score to obtain better-indexed scores. *Thirdly*, there is the option of transforming variables into ordinal response scales. This may be done either during the survey itself or at a later stage using available data. Finally, there is the conventional linear scaling transformation (LST) method. Variables are scaled from 0 to 100 with the aid of this technique. This requires points of reference relative to which indicators can be scaled. A minimum and a maximum value are usually identified for each of the variables.

Ebert and Welsch (2004) identified four generic classes of scales that can be applied to variables: interval-scale non-comparability (INC), interval-scale full comparability (IFC), ratio-scale non-comparability (RNC), and ratio-scale full comparability (RFC).

Table 1 provides an overview of which functional forms for the aggregation of variables are viable depending on their scales (and the desired mathematical properties).

Table 1 provides minimal methodological requirements to be met by any meaningful SD index. However, as will be laid out in the following section, indices applied in practice typically violate these qualifying conditions: whereas the aggregation of variables measured in ratio-scale without being comparable would call for a geometric mean, indices are often based on a (misleading) arithmetic mean.

One also needs to decide on the weighting system and method employed in aggregating component scores into one

Table 1 – Aggregation rules for variables by Ebert and Welsch

	Non-comparability	Full comparability
Interval scale	Dictatorial ordering	Arithmetic mean
Ratio scale	Geometric mean	Any homothetic function

composite index. In addition to the implicit weights introduced during scaling, explicit weights may be introduced during aggregation. The first option, though, is not to employ explicit weights. Here component and index scores are simply averages of the corresponding variable and component scores. Multivariate techniques present an empirical and relatively more objective option for weight selection. In the case of principal component analysis, components are weighted with the proportion of variance in the original set of variables explained by the first principal component of that particular component.

After weights have been assigned to each component index and the component scores weighted accordingly, these scores are aggregated into a composite score. The aggregation of indices tends to be of either an additive or a functional nature. Ideally, composite indices should remain relatively simple in terms of their construction and interpretation. The choice of method employed in weighting and aggregation is ultimately dependent on the nature and scope of the particular study.

Composite indices also need to be validated. Only through continued validation and adjustment resulting from constructive debate can indices be improved. During validation adjustments are effected in selection, scaling, weighting and aggregation in order to improve the quality of the final estimates. Validation is normally performed by using either item analysis or external validation.

The safe use of the composite requires proper evidence that the composite will provide reliable results. If the user simply does not know, or is not sure about the testing and certification of the composite, then composite's quality is low. A notational system called NUSAP (an acronym for five categories: Numeral, Unit, Spread, Assessment, Pedigree) can be used to characterise the quality of quantitative information based in large part on the experience of research work in the matured natural sciences (Funtowicz and Ravetz, 1990). One category of NUSAP, the pedigree, is an evaluative description of the procedure used to build the composite indicator.

4. Composite Indicators for Sustainability

The construction of (composite) indicators involves making choices. This introduces issues of uncertainty such as selection of data, imprecision of the data, data imputation methods, data normalisation, weighting schemes, weights' values and aggregation methods.

Composite indicators are an innovative approach to evaluating sustainable development (defined as non-declining welfare over the long-term). Computing aggregate values is a common method used for constructing indices. An index can be either simple or weighted depending on its purpose. Indices are very useful in focusing attention and, often simplify the problem (Atkinson et al., 1997). Such an approach allows for the evaluation of a multitude of aspects, which can then be deciphered into a single comparable index.

It is frequently argued that composite indicators are too subjective, due to the assumptions in estimating the measurement error in data, mechanism for including or excluding indicators in the index, transformation and/or trimming of indicators, normalisation scheme, choice of imputation algorithm, choice of weights and choice of aggregation system. A combination of uncertainty and sensitivity analysis can help to gauge the robustness of the composite indicator, to increase its transparency and to frame policy discussions. Sensitivity analysis is the study of how output variation in models such as a composite indicator can be apportioned, qualitatively or quantitatively, to different sources of variation in the assumptions.

Composite indicators are based on *sub-indicators that have no common meaningful unit of measurement* and there is *no obvious way of weighting these sub-indicators*.

Deciding on the phenomenon to be measured and whether it would benefit from the use of composite indicators.

Selection of sub-indicators. A clear idea is needed of which sub-indicators are relevant to the phenomenon to be measured.

Assessing the quality of the data. There needs to be high quality data for all the sub-indicators, otherwise the analyst has to decide whether to drop the data or find ways of constructing the missing data points. In case of data gaps, alternative methods could be applied, e.g. mean substitution, correlation results, time series, and assess how the selection of the method can affect the final result.

Assessing the relationships between the sub-indicators. Methods such as Principal Components Analysis can provide insight into the relationships between the sub-indicators. It can be considered as prerequisite for the preliminary analysis of the sub-indicators.

Normalising and weighting of the indicators. Many methods for normalising and weighting the sub-indicators are reported in the literature. The selection of the appropriate methods depends on the data and the analyst.

Testing for robustness and sensitivity. Inevitably changes in the weighting system and the choice of sub-indicators will affect the results the composite indicator shows. However, it is important to test the degree of sensitivity of the country rankings to avoid basing policy messages on rankings which are highly sensitive to small changes in the construction of the composite indicator. The values of the composite indicator should be displayed in the form of confidence bounds.

The various methods of aggregation are multiple linear regression models, principal components analysis, and factor analysis, cronbach alpha, neutralization of correlation effect, efficiency frontier, distance to targets, experts opinion (budget allocation), public opinion, and analytic hierarchy process (Nardo et al., 2005).

The various methods for calculating the composite indicators are shown in Table 2.

Recent initiatives include the development of aggregate indices, headline indicators, goal-oriented-indicators, and green accounting systems. Some of the early composite indices include Measure of Economic Welfare (MEW) by Nordhaus and Tobin (1973), Index of Social Progress (ISP) by Estes (1974), Physical Quality of Life Index (PQLI) by Morris (1979), and Economic Aspects of Welfare (EAW) by Zolotas (1981), Brekke (1997).

Indices developed in the 1990s to measure the aggregate performance of the economy or the sustainability include Human Development Index (HDI) by the UNDP (1990), Sustainable Progress Index (SPI) by Krotscheck and Narodoslawsky (1994), Ecological Footprint by Wackernagel and Rees

Table 2 – Methods for calculating composite indicators (CIs) (OECD, 2002a,b)

Method	Equation
1. Sum of country rankings	$CI_c^t = \sum_{i=1}^{N} \text{Rank}_{ic}^t$
2. Number of indicators above the mean minus the number below the mean	$CI_c^t = \sum_{i=1}^{N} \text{sgn}\left[\frac{x_{ic}^t}{x_{EUi}^t} - (1+p)\right]$
3. Ratio or percentage differences from the mean	$CI_c^t = \frac{\sum_{i=1}^{N} w_i y_{ic}^t}{\sum_{i=1}^{N} w_i}, \quad \text{where} y_{ic}^t = \frac{x_{ic}^t}{x_{EUi}^t}$
4. Percentage of annual differences over consecutive years	$CI_c^t = \frac{\sum_{i=1}^{N} w_i y_{ic}^t}{\sum_{i=1}^{N} w_i}, \quad \text{where} y_{ic}^t = \frac{x_{ic}^t - x_{EUt}^t}{x_{ic}^t}$
5. Standardized values	$CI_c^t = \frac{\sum_{i=1}^{N} w_i y_{ic}^t}{\sum_{i=1}^{N} w_i}, \quad \text{where} y_{ic}^t = \frac{x_{ic}^t - x_{EUt}^t}{\sigma_{EUi}^t}$
6. Re-scaled values	$CI_c^t = \frac{\sum_{i=1}^{N} w_i y_{ic}^t}{\sum_{i=1}^{N} w_i}, \quad \text{where} y_{ic}^t = \frac{x_{ic}^t - \min(x_i^t)}{\text{range}(x_i^t)}$

Note: x_{ic}^t is the value of indicator *i* for country c at time *t*. w_i is the weight given to indicator *i* in the composite index. In Method 2, p = an arbitrarily chosen threshold above and below the mean.

(1996), Material Input Per Service Unit (MIPS) by Schmidt-Bleek (1994), Index for Sustainable Economic Welfare (ISEW) by Daly and Cobb (1989) and Cobb (1989), Genuine Progress Indicator (GPI) by Cobb et al. (1995), Genuine Savings Indicator (GSI) by Hamilton (1999), Barometer of Sustainability by IUCN-IDRC (1995), and Environmental Pressure Indicators (EPI) by EU (1999).

The Consultative Group on Sustainable Development Indicators (CGSDI) at IISD as part of their effort to create 'an internationally accepted sustainable development index' produced the Dashboard of Sustainability, a performance evaluation tool, in 2001. More recently developed indices include Total Material Requirement by EEA (2001), Eco-efficiency Indices by WBCSD (1999), the Compass of Sustainability by At Kisson (2005), Environmental Sustainability Index (ESI) and Environmental Performance Index (EPI) by, WEF (2002).

Most of these indices are not used by policy-makers due to measurement, weighting and indicator selection problems. However, some of them are popular among different stakeholders. HDI, Ecological Footprint, ISEW, GPI and EPI have been computed by researchers for a number of countries under different assumptions due to the variation in data quality and availability.

In 1998 John Elkingtom, chairman of Sustainability, institutionalized the concept of the triple bottom line. Canada's National Round Table on the Environment and the Economy (NRTEE) conducted one of the earliest studies on the development of sustainability metrics.

5. Overview of Sustainability Indices

The brief description of various indices and ratings are described below.

5.1. *Innovation, Knowledge and Technology Indices*

5.1.1. *Summary Innovation Index*

The Summary Innovation Index (SII) is part of the innovation scoreboard, which depicts achievements and trends, highlights strengths and weaknesses of Member States' performances, and examines European convergence in innovation (European Commission, 2001a). The innovation scoreboard analyses 17 indicators studied between 1995/1997 and 1999/2000 in four areas: (a) human resources; (b) knowledge creation; (c) transmission and application of new knowledge; (d) innovation finance, output and markets. The SII for a given country is equal to the number of indicators that are more than 20% above the EU overall mean, minus the number of indicators that are more than 20% below. The SII is adjusted for differences in the number of available indicators for each country. The index can vary between +10 (all indicators are above average) to −10 (all indicators are below average).

5.1.2. *Investment in the knowledge-based economy*

This composite indicator, built by DG RTD, aims to summarize various indicators of national investment in highly qualified human resources in science, technology, research and education, so as to measure a country's capacity to create knowledge. The composite indicator combines seven indicators related to the number of researchers, the number of new doctors in science and technology (annual influx), domestic expenditure on R&D, expenditure on information technologies and imports of high-tech products. All sub-indicators are measured per capita to neutralize the effect of the size of the countries.

5.1.3. *Performance in the knowledge-based economy*

The second index related to the knowledge-based economy aims to measure a country's performance in converting the new knowledge into economic and technological progress to increase both a country's competitiveness and the well being of its citizens. The index combines six indicators: the number of EPO and USPTO patents, the number of publications, production of high-tech exports, the employment in the high-tech production and GDP per capita.

5.1.4. *Innovation Index*

The *Innovation Index* consists of three core components that combine between three and five underlying variables, mostly derived from OECD databases. The first core component (*generation of new knowledge*) aggregates variables such as basic research as a percentage of GDP and non-business researchers as a share of the labour force. The second core component (*industry/science linkages*) looks at public/private links through data relating to R&D, the scientific content of patents, and publications. In the third component (*industrial innovation*), data on business research, patents and the introduction of new products and processes are used to measure private sector innovative performance.

5.1.5. *National innovation capacity*

The central objective of the index is to create a quantitative benchmark of national innovative capacity, which highlights the resource commitments and policy choices that most affect innovative output in the long run (Porter and Stern, 1999). Eight sub-indicators are selected: personnel employed in R&D, expenditures on R&D, openness to International Trade and Investment, strength of protection for intellectual property, share of GDP spent on secondary and tertiary education, GDP Per Capita, percentage of R&D Funded by Private Industry and percentage of R&D Performed by Universities.

5.1.6. *Information and communication technologies*

The index aims at providing an overall picture of a country's situation regarding development and application of information and communication technologies (Fagerberg, 2001). Five simple indicators (number of mobile telephones, number of Internet users, etc.) are used as components for the development of the composite indicator.

5.1.7. *Technology Achievement Index*

The Technology Achievement Index (TAI) is designed to capture the performance of countries in creating and diffusing technology and in building a human skill base (United Nations, 2001). The index uses data from 8 indicators grouped in four dimensions:

- Technology creation as measured by the number of patents granted to residents per capita and by receipts of royalties and license fees from abroad per capita.
- Diffusion of recent innovations, as measured by the number of Internet hosts per capita and the share of high- and medium-technology exports in total goods exports.
- Diffusion of old innovations, as measured by telephones (mainline and cellular) per capita and electricity consumption per capita.
- Human skills, as measured by mean years of schooling in the population aged 15 and above and the gross tertiary science enrolment ratio.

5.1.8. *General Indicator of Science and Technology*

The National Institute of Science and Technology Policy of Japan (NISTEP) created the General Indicator of Science and Technology (GIST) with a view to grasp major trends in Japan's Science and Technology activities and make possible comprehensive international comparisons and time-series analysis (NISTEP, 1995). NISTEP starts with 13 indicators, five of which are classified as ''input'' and eight as ''output''. The cluster of inputs includes: ''R&D expenditure'', ''R&D scientists/engineers'', ''Bachelor's of Science degrees conferred'', ''Bachelor's of Engineering degrees conferred'', and ''technology imports''. As output are considered: ''scientific papers'', ''scientific paper citations'', ''domestic patents'', ''external patents'', ''patent citations'', ''product output'', ''high-tech product output'' and ''technology exports''.

5.1.9. *Success of software process improvement*

The index aims at combining the conditions (e.g., organisation and funding of improvement efforts) that can explain the successes and failures of software process improvement efforts (Emam et al., 1998). A set of 14 variables is considered as having a significant impact on the software process improvement.

5.2. *Development Indices*

5.2.1. *Human Development Index*

The Human Development Index (HDI) of the United Nations is a summary measure of human development in three basic dimensions: a long and healthy life, knowledge and GDP per capita (United Nations, 1990). The three base components of the HDI are: (a) life expectancy at birth, (b) adult literacy rate (with two-thirds weight) and the combined primary, secondary and tertiary gross enrolment ratio (with one-third weight) and (c) GDP per capita (PPP US$). The indices are formulated based on minimum and maximum values (goal posts) for each indicator and performance in each dimension is expressed as a value between 0 and 1.

5.2.2. *Index of sustainable and economic welfare*

The index of sustainable and economic welfare (ISEW) is one of the most advanced attempts to create an indicator of economic welfare, developed by the Centre for Environmental Strategy (CES) and the New Economics Foundation (NEF). The main objective is to measure the portion of economic activity that delivers welfare to people. It aims further to replace GDP as an indicator of progress, because GDP is likely to lead in the wrong direction given that it does not distinguish between activities that improve or directly damage the quality of life (CES, 2000). The set of 20 sub-indicators includes seven economic activities that deliver welfare to people, such as adjusted consumer expenditure, services from domestic labour, from consumer durables, from streets and highways, public expenditure on health and education, net capital growth and net change in international position. On the other hand, the 13 indicators that ''reduce'' the welfare are: consumer durables (difference between expenditure and value of services), defensive private expenditures on health and education, costs of commuting, of personal pollution control, of automobile accidents, of water pollution, of air pollution, of noise pollution, loss of natural habitats, loss of farmlands, depletion of non-renewable resources, costs of climate change and costs of ozone depletion (Guenno and Tizzi, 1998).

5.2.3. *Relative intensity of regional problems in the Community (by the EC)*

Back in 1984 the European Commission (EC) constructed a synthetic index measuring the ''relative intensity of regional problems in the Community'' (Commission of the European Communities, 1984). The objective of the Index is to assist the Community regional policy to focus on strengthening the economic performance of regions experiencing delayed development. The Commission, with a view to measure the relative intensity of the regional problems at Community level in a global and synthetic way, uses three sub-indicators: GDP per employed in ECU, GDP per head in PPS, and unemployment rate.

5.3. Market- and Economy-based Indices

5.3.1. Internal Market Index

The objective of the Internal Market Index is to measure whether the "real world" benefits, that the Internal Market Strategy attempts to bring to the citizens and companies, are effectively delivered (European Commission, 2001b). Nineteen variables are synthesized in the Index, including growth in per-capita income, long-term unemployment, price dispersion, growth in intra-EU trade, prices of utilities services, availability of venture capital, energy intensity and greenhouse gas emissions.

5.3.2. Business Climate Indicator

To improve the understanding of the business cycle in the European area as a whole DG ECFIN has formulated a composite indicator based on business surveys designed to deliver a clear and early assessment of the cyclical situation within the area (European Commission, 2000). The five sub-indicators are related to the responses of national business surveys and available only from 1985 onwards: production trends in recent past, order books, export order books, stocks and production expectations. Each series therefore varies by construction between −100 (indicating that all firms have reported a deterioration) and +100 (all firms have noted an improvement).

5.3.3. European Labour Market Performance

The objective of the composite index is to monitor labour market performance using many of the Basic Performance Indicators that are used in the benchmarking process according to the Amsterdam Treaty (Storrie and Bjurek, 1999). For illustration purposes, three measures of unemployment from the Commission's Basic Performance Indicators are benchmarked. The three single indicators are: the unemployment rate, the long-term unemployment rate and the youth unemployment ratio.

5.3.4. Composite Leading Indicators

The OECD Composite Leading Indicators (CLIs) are based on individually selected leading indicators for each country and are calculated for 22 Member States (Nilsson, 2000). They aim at providing a cyclical business indicator with better forecasting and tracking qualities than any of its individual components. The OECD CLI's are based on individually selected leading indicators for each country (OECD, 2002a,b).

5.3.5. Genuine Savings (GSs)

Pearce and Atkinson (1993) put forward an index which is based on the Hicksian income concept. The genuine savings (GS) are thus an indicator of weak SD. The societal capital stock consists of produced capital, human capital (knowledge, skills, etc.) as well as natural capital (resources, etc.). As in the ISEW all values are monetarized, such that aggregation is again achieved by simply adding up.

5.3.6. Economic Sentiment Indicator

The Economic Sentiment Indicator of the European Commission (EC ESI) combines business tendency surveys into a single cyclical composite or confidence indicator, with a view to reduce the risk of false signals and to provide a cyclical indicator with better forecasting and tracking qualities than any of its individual components (Nilsson, 2000). A standard set of four components is used, mainly based on qualitative data from business or consumer tendency surveys. The EC ESI combines the following component series: (a) industrial confidence indicator; (b) construction confidence indicator; (c) consumer confidence indicator; (d) share price index.

5.3.7. Green Net National Product (EDP) and SEEA

The Green Net National Product or likewise the Environmentally Adjusted Net Domestic Product (EDP) has been developed within the scope of SEEA (System of Integrated Environmental and Economic Accounting—UNEP, 2000 and UN, 2003). Following inter alia Hanley (2000) three different versions of the EDP can be distinguished: (i) the EDPI which subtracts depreciations of natural resources caused by their extraction from the net national income (NNI), (ii) the EDPII, which subtracts from the NNI the costs necessary to reach the same state of the environment at the end of the period as existed at the beginning of the period, and (iii) the EDPIII, which subtracts the costs of environmental pressure and destruction (calculated by willingness-to-pay methods). Again aggregation takes place by simply adding up the monetarized values.

5.4. Eco-system-based Indices

5.4.1. Sustainability Performance Index

The SPI is based on an operationalized form of the principle of sustainability. It uses only process data known at an early stage of planning and data of natural concentrations of substances (not on their presumable impact which is usually not known). The core of the SPI evaluation is the calculation of the area needed to embed a process completely into the biosphere (Narodoslawsky and Krotscheck, 2004). This comprises the area required for production of raw material, process energy and provided installations as well as the area required for the staff and for the accumulation of products and by-products within the available area (Lundin, 2003).

5.4.2. Eco-Index Methodology

The eco-index methodology developed by Best Foot Forward (Chambers et al., 2000) utilizes a 'component' or bottom-up approach to perform EF analysis. It is compatible with the 'compound' top-down approach which uses international trade statistics as a starting point. In the eco-index methodology full life cycle impact data is used to derive EF conversion factors wherever possible for key component. The ecological footprint (as measured using global average yields) is normalised by the application of equivalence factors.

5.4.3. Living Planet Index

The global biodiversity indicator Living Planet Index was developed by WWF (1998). It measures trends in over 2000 populations of more than 1100 species of vertebrates in terrestric, freshwater, and seawater ecosystems. The LPI provides a sub-index for the three spheres: for every species within a sphere, the ratio between its populations in pairs of consecutive years is calculated. The geometric mean of these quotients of different species multiplied with the index value of the former year then delivers the biodiversity index for the respective sphere (1970 serves as a base-year with the index value for 1970 scaled to unity). The geometric mean of these indices is the LPI.

5.4.4. Ecological Footprint (EF)

The ecological footprint (EF) (Wackernagel and Rees, 1997) is based on the quantitative land and water requirements to sustain a (national) living standard into infinity thereby assuming certain efficiency improvements. The ratio of required resources to available resources is interpreted as a measure of ecological sustainability: ratios exceeding one are seen as unsustainable, i.e. contemporary living standards would violate the principles of sustainable development. Calculation of the EF is based on data from national consumption statistics. Thus, the EF primarily relies on normalisation (as any consumption is converted in land use). Weighting is rather implicit in the conversion parameter and aggregation is done by adding up all land and water requirements. There are several approaches similar to the EF, e.g. the MIPS (Material-Input-Per-Service) concept (Schmidt-Bleek, 1994), Gassner and Narodoslawsky, 2004) or the Ecoindex^{TM} (Chambers and Lewis, 2001).

5.5. *Composite Sustainability Performance Indices for Industries*

5.5.1. Composite sustainable development index

Krajnc and Glavic (2005) collected and developed a standardized set of sustainability indicators for companies covering all main aspects of sustainable development. A composite sustainable development index (I_{CSD}) in order to track integrated information on economic, environmental, and social performance of the company with time. Normalised indicators were associated into three sustainability sub-indices and finally composed into an overall indicator of a company performance. This was applied by determining the impact of individual indicator to the overall sustainability of a company using the concept of analytic hierarchy process.

5.5.2. Composite Sustainability Performance Index

The composite sustainability performance index (CSPI) is an attempt to develop a measure of corporate citizenship and to critically evaluate how well a company stands up to its policies and commitments regarding sustainable development. This model enables industry to identify the key sustainability performance indicators and provides framework for aggregating the various indicators into the CSPI (Singh et al., 2007). The calculation of CSPI is a step-by-step procedure of grouping various basic indicators into the sustainability sub-index for each group of sustainability indicators. Sub-indices then subsequently derived in the form of aggregated index. Weights are derived using AHP methodology. Liberator scoring and Z score method were employed for aggregation of indicators. The model has been evaluated based on the real-time application for a steel industry. CSPI with its sub-indices for each dimensions of sustainability were evaluated for the time period of 4 years.

5.5.3. ITT Flygt Sustainability Index

ITT Flygt Sustainability Index suggests a method for measurement of corporate contribution to sustainable development, looking at how well a company stands up to its policies and commitments regarding sustainable development. This index is developed and calculated for ITT Flygt AB over a 3 years period (2002–2004). The index structure is based on scientific literature and interviews with ITT Flygt and four other engineering companies. The purpose of the index is to support corporate sustainability-management. The index is calculated by aggregating some 40 sustainability-indicators. These indicators are individual to each company and are designed to measure the significant sustainability aspects of the company (Pohl, 2006).

5.5.4. G Score method

"G score" that consists of five categories, namely general environmental management (GEM), input, process, output, and outcome. *G* score is a proxy measure of corporate environmental performance based on voluntary environment, health, and safety (EHS) report and is calculated by aggregating the points of the above five-categories (Jung et al., 2001).

5.6. *Investment, Ratings and Asset Management Indices*

5.6.1. Sustainable Asset management (SAM) Zurich, Switzerland (www.sam-group.com)

This serves as an in-house department for the investment company Sustainable Performance Group (founded by Swiss Re, Volkart Brothers Group and SAM), but also assesses companies for external clients such as Credit Suisse Eco-Efficiency Fund. Their approach is to 'invest worldwide in companies which have committed themselves to sustainability: in companies which, successfully integrate their economic, ecological and social interests into the way they conduct their business, are able to recognise opportunities and risks early and thus create for themselves long-term, sustainable competitive advantages, and achieve above-average profitability. The assessment involves looking at a company's 'sustainability chances' (its strategic chances; product; corporate sustainability), and its 'sustainability risks' (stakeholder exposure; environmental management; resource efficiency; strategic risks; sustainability costs). In total, more than 100 criteria are used for the rating. Together with the Dow Jones indices, SAM recently launched a series of sustainability indices. The global index contains 225 components, selected from the Dow Jones global index of 2000 blue chip companies.

5.6.2. Dow Jones sustainability group indices (DJSGI), US (www.sustainability-index.com)

The DJSGI and the SAM Sustainability Group created the first collection of global sustainability indices in September 1999.

The DJSGI allows for the benchmarking of the performance of investments in sustainability companies and funds. It tracks the performance of the top 10% of the companies in the Dow Jones global index that lead the field in sustainability. The criteria by which the sustainability companies are identified and ranked are based on five 'sustainability' principles (Dow Jones/SAM 2007):

- technology: innovative technology and organisation that uses financial, natural and social resources efficiently, effectively and economically;
- governance: high standards of corporate governance including management responsibility, organisational capability, corporate culture and stakeholder relations;
- shareholders: demands should be met by sound financial return, long-term economic growth, long-term productivity increases, sharpened global competitiveness and contributions to intellectual capital;
- industry: lead an industry shift towards sustainability by demonstrating commitment and publishing superior performance;
- society: encourage lasting social well-being by appropriate and timely responses to social change, evolving demographics, migratory flows, shifting cultural patterns and the need for continuing education.

The criteria facilitate a financial quantification of sustainability performance by focusing on a company's pursuit of sustainability opportunities, and reduction and avoidance of sustainability risks and costs. Each company's sustainability performance is given a score, and the companies are ranked according to their score.

5.6.3. *Bovespa Corporate Sustainability Index*

The Bovespa Corporate Sustainability Index (Índice de Sustentabilidade Empresarial—ISE) is the index tracking the economic, financial, corporate governance, environmental and social performance of leading companies listed in the São Paulo Stock Exchange. It is based on the triple bottom line (TBL) concept, which evaluates the economic-financial, social, and environmental elements in an integrated manner. The economic-financial, social, and environmental dimensions were divided into four groups of criteria: policies (commitment indicators); management (indicating plans, programs, goals, and monitoring); performance; and legal compliance (with environmental and consumer regulation, among others).

5.6.4. *Benchmarking US petroleum refineries, the Environmental Defence Fund (EDF), US NGO*

Ranking environmental performance of 166 oil refineries. Publicly available data on toxic waste generation and pollutant release was normalised by refinery capacity to adjust for size (Ditz and Ranganathan, 1997).

5.6.5. *ECCO-CHECK Index, Environmental Risk Rating Ltd., Surrey, UK*

Described as a fully commercial index of corporate environmental performance in Europe, with the aim of providing definitive information about a company's potential liability under key elements of site-specific UK legislation.

5.6.6. *Investor Responsibility Research Centre (IRRC), Washington, DC, US (www.irrc.org)*

It produces a corporate environmental profile directory consisting of a series 60 of indicators of emissions (total weight of corporate toxic release inventory emissions), volume of oil spill, volume of chemical spill, hazardous waste (number of superfund national priority list sites), compliance (punitive fines for environmental non-compliance), environmental litigation (number of disclosed environmental litigation incidents) normalised by considering 'environmental risk per unit revenue', enabling comparisons of companies of different sizes.

5.6.7. *Council on Economic Priorities (CEP), New York, US (www.cepnyc.org)*

CEP is a public service research organisation, providing reports that rates companies' environmental performance. Ethical factors, such as charitable giving, community outreach, family benefits and workplace issues are also assessed. Thirteen areas of corporate environmental performance are evaluated: releases, policy, packaging, office recycling, raw materials/waste, toxic reduction, community impact, energy conservation, natural resources, accidents, superfund sites, compliance and environmental technologies.

5.6.8. *Oeko Sar Fund, Bank Sarasin and Cie, Basel, Switzerland (www.sarasin.ch)*

The bank assesses environmental performance for its own environmental fund (DEM 64 million). The assessment system was developed by environmental consultant Ellipson Ltd. in Basel and is the same as the system used by Norwegian UNI Storebrand (also designed by Ellipson). The categories used for environmental and social ratings are Policy/strategy, Production/provision of service, Products/services, Environmental management systems, Customers/suppliers, Employee relations, Public relations and Shareholders/investors.

Companies are divided into three groups according to the potential environmental impact: high (e.g. an energy producer), medium and low (service sector companies). To be included in the fund, the company must attain a certain level of rating depending on the impact group. In addition, negative criteria are used, avoiding any company that drives more than 5% from the defence industry, nuclear power and nuclear power plant construction, gene technology, chlorine industry, agrochemical and automobile industries. Assessment is based on CERs, annual reports and other material from the companies, management interviews, a newspaper article database, information from environmental pressure groups such as Greenpeace, and a questionnaire.

5.6.9. *Storebrand Scudder Environmental Value Fund, Oslo, Norway (www.storebrand.no)*

The Storebrand Scudder environmental investment fund was set up in 1996 by the Norwegian insurers, UNI Storebrand. It uses a proprietary sustainability index to assess business environmental performance. The index is calculated from environmental indicators of: global warming, ozone depletion, material efficiency, toxic release, energy intensity, water use, environmental liabilities, and environmental management quality. Storebrand uses the index to measure the 'environmental dividend'—the difference between the fund's environmental performance and the market on average. Although termed a sustainability index it only focuses on environmental performance, and does not include social issues.

5.6.10. *Innovest strategic value advisors (www.innovestgroup.com)*

This is based in the United States and uses a proprietary investment model 'Eco Value 21' to evaluate both the environmental risk and opportunity profiles of companies and determine the implications for investors. This analysis of the upside potential is a unique facet of the rating. It too can provide a fund rating as well as a customized portfolio analysis on both US and Canadian stocks.

5.6.11. *OEKOM Environment Rating*

In 1993 oekom research AG, an international supplier of environmental research studies based in Munich, established an Environmental-Rating, which has since been continuously improved. Since 1994 oekom has used this method to analyse and assess over 400 companies quoted on various stock markets worldwide. The research process of an Environmental-Rating is divided into three steps. First, the relevant ecological and industry-specific assessment criteria have to be defined; for example, with the automobile industry oekom has applied the following criteria divided into three separate rating areas:

Environmental management

- Environmental goals/environmental managers
- Environmental management systems/environmental audits/environmental programmes/ecological balance sheet
- Environmental standards used in overseas operations
- Partnerships/training and personnel/environmental office management
- Suppliers/transport and logistics

Products and services

- Reduction of emissions and resource use
- Development of efficient engines and alternative drive systems
- Durability
- Re-usability/suitability for recycling
- Take-back of products and recycling capacities
- Avoidance of toxic substances
- Use of environmentally compatible materials

Environmental benchmarks

Analysis of the following information in relation to turnover, output or number of employees:

- Energy and water consumption
- Air pollution, e.g. CO_2, NOX, SOX, dust
- Water pollution
- Quantity of waste and its composition, e.g. proportion of recyclable raw
- Materials, proportion of hazardous waste

Each rating area is given a grade on a scale from A+ to D− based on the ecological activities within the area:

- A+. The company's environmental activities are especially progressive within the industry.
- D−. The company focuses on complying with environmental regulation but shows little or no further environmental commitment.
- The three rating areas are weighted according to the specific industry after which the separate grades are brought together to form the overall rating.

5.6.12. *Jupiter Income Trust Funds (subsidiary of Jupiter Tyndall Group PLC), UK (www.jupiteronline.co.uk)*

This is a fund management service, with eight UK unit trusts, and 11 investment trusts especially created to pursue environmental and financial objectives. They use very substantial investment criteria to assess companies and avoid companies that derive more than 1% from oppressive regimes, or armaments, nuclear or tobacco industries.

5.6.13. *FTSE Good Index*

The FTSE4Good Index Series has been designed to measure the performance of companies that meet globally recognised corporate responsibility standards, and to facilitate investment in those companies. The FTSE4Good selection criteria have been designed to reflect a broad consensus on what constitutes good corporate responsibility practice globally. Using a widespread market consultation process, the criteria are regularly revised to ensure that they continue to reflect standards of responsible business practice, and developments in socially responsible investment as they evolve.

5.7. *Product-based Sustainability Index*

5.7.1. *Life Cycle Index*

Life cycle index (LInX) is an indexing system that incorporates the life cycle attributes of process and products in decision-making. Its purpose is to aid the selection and design of processes and products. LInX is comprised of environment, cost, technology, and socio-political factors. For environmental index—one where all the targets have to be met separately (fixed) and one where trade-offs between different impacts are allowed (flexible). The flexible model offers more freedom in reaching the target, but does this at the cost of increased need for preference information collection and modeling. In practice, both the fixed and the flexible models can be included in the index development so that for certain impacts, targets would be given separately, whereas the rest of the impacts would be aggregated and the target for them would be given in terms of the aggregated impact (Khan et al., 2004).

5.7.2. *Ford of Europe's Product Sustainability Index*

Ford of Europe's Product Sustainability Index (PSI) is a sustainability management tool directly used by engineering, i.e. not by sustainability or life cycle experts. PSI is looking at eight indicators reflecting environmental (Life Cycle Global Warming Potential, Life Cycle Air Quality Potential, Sustainable Materials, Restricted Substances, Drive-by-Exterior-

Noise), social (Mobility Capability, Safety) and economic (Life Cycle Cost of Ownership) vehicle attributes.

5.8. Sustainability Indices for Cities

5.8.1. Urban Sustainability Index

The urban sustainability index (USI) developed by Zhang (2002) based on 22 individual indicators in the context of urban China. These indicators were chosen from a sustainability indicator database (with 387 indicators) through three rounds of extensive consultation of experts using the pre-coded questionnaires. Total urban sustainability score is based on three components of the urban sustainability scores and each of the three components is based on a number of individual indicators. All the inputs into the urban sustainability have been weighted, based on the analytical hierarchy process (AHP) method and experts consultation. Overall urban sustainability consists of three dimensions: the dimension of urban status, the dimension of urban coordination and the dimension of urban potential. These dimensions capture the three key points of urban sustainability: the urban development capacity, urban coordination capacity and urban development potential. The score of USI is the weighted sum of scores of the three components of the urban sustainability index. The score of each of the three components of the urban sustainability index is the weighted sum of scores of the relevant subcomponents of the urban sustainability. Theoretically, the score on the urban sustainability index varies from 0 to 1.

5.8.2. Sustainability Index for Taipei

This study was carried out for Taipei city. After considering the characteristics of Taipei, Taiwan, discussions with experts, scholars and government departments and an exhaustive literature review, this study selected 51 sustainability indicators corresponding to the socio-economic characteristic of Taipei city. Indicators are classified into economic, social, environmental and institutional dimensions. Furthermore, statistical data is adopted to identify the trend of SD from 1994 to 2004. Moreover, the sustainability index is calculated for the four dimensions and for Taipei as a whole. This study applies standard deviation as the basic method for calculating the sustainability index. It standardizes indicator values so that each standardized value falls between 0 and 1. Study applies the equal weight method for initial integration and analysing overall sustainability trend.

5.8.3. City Development Index

The City Development Index (CDI) suggested by the United Nations Centre for Human Settlements (HABITAT) consists of five sub-indices: (i) an infrastructure index, which builds on four (equally weighted) indicators as percentages of households which are connected to clean water, canalization, electricity and a phone network (without mobiles), (ii) a twofold (equally weighted) waste index, which is composed of the percentage of untreated sewage in total wastewater and the percentage of disposal of solid waste in total solid wastes.

5.8.4. Compass Index of Sustainability

The compass index of sustainability developed for Orlando, Florida by AtKisson Inc. They used a simple averaging method for indicators clustered in four categories—Nature (N), Economy (E), Society (S) and Well Being (W) corresponding to the four points on a compass. Indicators were scaled on a 0–100 performance scale. Scales were set by normative judgments. Each indicator has equal weight (Atkinson et al., 1997).

5.8.5. The Sustainability Cities Index

Forum for the future chose three baskets of indicators against which to rank the cities of Britain:

- The Environmental Impact of the city—the impact of the city on the wider environment in terms of resource use and pollution.
- The Quality of Life for residents—what the city is like to live in for all its citizens.
- Future Proofing—how well the city is preparing itself for a sustainable future.

These index categories were selected to reflect the sustainability of each city in a fair and balanced way considering 13 indicators.

5.8.6. Ecosistema Urbano Performance Index

Ecosistema Urbano is a project started in 1994 that has developed a well-established system of 20 environmental indicators and tests it since 10 years on the 103 main Italian municipalities. The project evaluates the resources quality and the management and environmental protection. Indicators are used to evaluate the sustainability of these cities and how much the economic activities and modern lifestyles affect environmental resources and how good are the actions implemented as an answer to this pressure. It allows to organise cities environmental data in order to identify a sustainability evaluation criteria and an environmental performance benchmarking.

5.8.7. Sustainable Seattle: developing Indicators of Sustainable Community

Confronted with the health problems of the city, community leaders from different areas of Seattle city agreed to the idea of citizens choosing their own ways of measuring long-term community well being. Based on a consultative process, a set of 40 indicators has been proposed for 1998 covering various issues like environment, population and resources, economy, youth and education, health and community.

5.9. Environmental Indices for Policies, Nations and Regions

5.9.1. Environment Sustainability Index

The 2002 environmental sustainability index (ESI) is a measure of the overall progress towards environmental sustainability developed for 142 countries. The ESI is based upon a set of 68 basic indicators. These are then aggregated to construct 21 core indicators. The Environmental Sustainability Index value for each economy is simply the average value for the 21 factors. For every variable in our data set we created a normalised range and scaled values from 0 (low sustainability) to 100 (high sustainability) (WEF, 2002).

5.9.2. *Environment Quality Index*

The main environmental factors are selected and defined on the basis of the multiattribute-utility theory and a numerical evaluation carried out by applying the Analytic Hierarchy Process (AHP) methodology (Saaty, 1980). A weighted sum of all environmental factors forms the so-called environmental quality index (EQI), which gives an estimate of the overall environmental impact of each alternative (Bisset, 1988). Each environmental factor is interpreted as a linear utility function, which assumes values in the range 0–10. The utility functions are given the weights according to the importance of each environmental factor, and the weighted sum is the environmental quality index for which a maximum is sought.

5.9.3. *Concern about environmental problems*

The index proposed by Parker aims to measure the concern of the public on certain environmental problems (Parker, 1991). Eleven indicators are considered, four related to air problems (nitrogen oxides, sulphur dioxide, carbon dioxide and particulates), two indicators associated with water problems (bathing and fertilizers) and five landscape-related indicators (population change, new dwellings, tourism, traffic and waste).

5.9.4. *Index of Environmental Friendliness*

The model for the Index of Environmental Friendliness is a general model for the aggregation of direct and indirect pressure data to problem indices and further to an overall Index of Environmental Friendliness. The scope of the model is designed to cover the key environmental problems of greenhouse effect, ozone depletion, acidification, eutrophication, ecotoxicological effect, resource depletion, photo-oxidation, biodiversity, radiation and noise (Puolamaa et al., 1996).

5.9.5. *Environmental Policy Performance Indicator (by Adriaanse A., the Netherlands)*

The composite indicator aims to monitor the trend in the total environmental pressure in the Netherlands and indicate whether the environmental policy is heading in the right direction or not (Adriaanse, 1993). Six theme indicators (composed of several simple indicators) are combined, including: (a) change of climate, (b) acidification, (c) eutrophication, (d) dispersion of toxic substances, (e) disposal of solid waste, and (f) odour and noise disturbance.

5.9.6. *Environmental Performance Index*

Complementary to the ESI which focuses on the environmental dimension of sustainability, ‘‘the EPI addresses the need for a gauge of policy performance in reducing environmental stresses on human health and promoting ecosystem vitality and sound natural resource management. The EPI focuses on current on-the-ground outcomes across a core set of environmental issues tracked through six policy categories for which all governments are being held accountable’’ (Esty et al., 2006). All variables are normalised in a scale from 0 to 100. The maximum value of 100 is linked to the target, the minimum value of 0 characterises the worst competitor in the field. Weights are drawn from statistical mechanisms or by consulting experts. Finally, the six policy categories are aggregated to the ESI taking the weighted sum.

5.9.7. *Environmental Vulnerability Index*

The environmental vulnerability index (EVI) compromises 32 indicators of hazards, 8 indicators of resistance, and 10 indicators that measure damage (SOPAC, 2005). The EVI scale for normalisation ranges between a value of 1 (indicating high resilience/low vulnerability) and 7 (indicating low resilience/high vulnerability). The 50 indicators are given equal weights and then aggregated by an arithmetic mean (EVI, 2005).

5.9.8. *Two ‘‘synthetic environmental indices’’*

In the review paper of Isla M., two composite indicators (one structural and one functional) are developed aiming to assist the local municipalities of Barcelona to monitor and evaluate their environmental performance (Isla, 1997). Twenty-two sub-indicators for environment are combined into two synthetic indices, a structural and a functional one.

5.10. *Environment Indices for Industries*

5.10.1. *Eco-Points*

A number of eco-points schemes have been developed, Eco-points scores within Eco-Scan are based on a ‘distance to target’ methodology. The underlying premise is that there is a correlation between the seriousness of an effect and the distance between the current level and the target level to achieve sustainability. They are similar in that they cover all life cycle stages—production, distribution, use and end-of-life. For each stage, the user selects the appropriate materials, processes, usage, and transportation details from the options which are provided in the software. The package then calculates an ‘‘eco-score’’ for each of these elements, based on a number of points for a given quantity or usage. Three separate databases, viz Eco-indicator 95, Idemat 96, Eco-indicator 97 of eco-points are provided with the Eco-Scan package, allowing users to select which they consider most appropriate to use (Pre Consultants, 2004).

5.10.2. *Eco-compass*

The eco-compass has been developed by Dow Chemical to provide a simple, visual summary of LCA data (Fussler and James, 1996). It is based on the indicators of eco-efficiency developed by the World Business Council for Sustainable Development (WBCSD), with some minor amendments (DeSimone and Popoff, 1997). The eco-compass has six ‘poles’ or dimensions:

- energy intensity
- mass intensity
- health and environmental potential risk
- resource conservation
- extent of re-valorization (re-use, re-manufacturing and re-cycling)
- service extension.

5.10.3. *Eco-indicator 99*

The Eco-indicator 99 is a state of the art, damage oriented impact assessment method for materials and processes,

Table 3 – Summary table of the sustainability indices

	Name	Number of sub-indicators	Scaling/normalisation	Weighting	Aggregation
1	Summary innovation, index	17	[+10 −10] mean subtraction	Equal weights	Number of indicators that are more than 20% above the European average minus the number of indicators which are more than 20% below and division by the total number of available indicators for each country
2	Internal Market Index	19	Percentage annual differences	PCA	Synthesis of variables using PCA
3	Business climate indicator	5	−100 to 100	PCA and FA	PCA applied to define weights. One principal component adopted as the composite indicator
4	Investment in the knowledge-based economy	7	Mean subtraction and division by the standard deviation	Choice of weights is up to the user	Weighted average
5	Performance in the knowledge-based economy	7	Mean subtraction and division by the standard deviation	Choice of weights is up to the user	Weighted average
6	Relative intensity of regional problems in the community	3	Mean subtraction and division by the standard deviation	Empirical weights are determined considering the degree of correlation between two sub-indicators	Neutralising the effect of correlation
7	Economic sentiment indicator	4	Dividing the month-to-month changes with the average month-to-month change	Equal weights	Summation
8	Composite leading indicators	Number varies across Member States	Mean subtraction and division by the mean of the absolute differences from the mean	Smoothing via ‘‘Months for cyclical dominance moving average’’	Arithmetic average of the normalised indicators
9	Information and communication technologies	5	Country rankings for each indicator		Sum of rankings
10	Environmental sustainability index	68	Mean subtraction and division by the standard deviation	Equal weights	Arithmetic average of the normalised indicators
11	Human development index	3	[0, 1], using minimum and maximum value for each indicator as goal post	Equal	Arithmetic average of the scaled indicators
12	Technology achievement index	8 (grouped in 4 sub-indices)	[0, 1] using minimum and maximum value for each indicator as goal post	Equal	Arithmetic average of the 4 sub-indices
13	Overall health system attainment	5	[0, 100]	Weights based on survey of preferences of informed individuals	Summation
14	Two ‘‘Synthetic environmental indices’’	22	Indicators are combined into 2 synthetic indices a structural and a functional one	Equal	Arithmetic average of the indicators
15	National innovation capacity	8	The logarithmic values of the sub-indicators are considered	Multiple regression model	Regression analysis employed
16	General Indicator of Science and Technology	13	FA/PCA was applied to define weights	PCA	PCA (primary principal component of each set)
17	Success of software process improvement	14	Subjective scale	PCA	–

18	European labour market performance	3	[0, 100] efficiency frontier (objective method)	Weight based on value judgement	–
19	Eco-indicator 99	3	Division by a reference value for each indicator	Weighting scheme is selected by a panel of experts	–
20	Concern about environmental problems	11	Dividing the value in each year by the value for the year for which each indicator is first available	Weights derived from public opinion polls	Sum of normalised weights multiplied by the corresponding normalised indicators
21	National Health Care systems performance	6	No standardisation	'Budget allocation' survey of 1000 people across the UK defined the weights for the indicators	Weighted average
22	Index of sustainable and economic welfare	20	Sub-indicators are expressed in monetary terms.	Equal. Allow the user to change the weightings and assumptions used in the index	Arithmetic average of the indicators
23	Index of environmental friendliness	11	Normalisation of problem indices by dividing the sectoral problem index by the value of the national problem index.	Subjective weights for the normalised problem indices are determined from experts by means of the Analytic Hierarchy Process.	Weighted sum
24	Environmental policy performance indicator	6 theme indicators (composed of several simple indicators)	Division by the corresponding (a) sustainability levels, and (b) policy targets	Equal	Sum of the six theme indicators
25	Living planet index	2000 populations of more than 11,000 species	Ratio to current and previous year	Equal weights	Geometric mean
26	Ecological footprint	6	Area	Equal	Summation
27	City development index	5	Distance from mean	PCA/experts	Weighted average
28	Environment performance index	Six policy categories	[0, 100]	PCA/experts	Weighted average
29	Environment vulnerability index	50	Aim = 1, worst = 7	Equal	Average
30	Well being index	87	[0, 100]	Subjective	Weighted average
31	Composite sustainability performance index	Five categories; 59 indicators	Distance from mean divided by standard deviation	AHP	Weighted average
32	Composite sustainable development index	Three categories; 38 indicators	Distance from maximum and minimum	AHP	Weighted average
33	Ford of Europe's product sustainability index	8	Life Cycle Impact assessment	–	–
34	Genuine savings index	3 capitals	Monetized	Equal	Summation
35	Sustainability performance index	5	Area	Equal	Total area per unit product divided by area per capita
36	Compass index of sustainability	Four categories of indicators	[0, 100] normative judgement	Equal	Average
37	ITT Flygt sustainability index	40	[+10, −100]	Company opinion	Summation
38	Environment quality index	Based on multi-attribute utility theory	[0, 10], linear utility function	AHP	Weighted sum
39	Life cycle index	4 categories; 21 indicators	Linear and non linear functions	AHP	Geometric mean
40	G score	5 categories	Subjective	Equal	Summation
41	Index of sustainable society	5 categories; 22 indicators	Mathematical formula for each indicator	Equal	Summation

which has been developed by a large team of experts from 1997 to 1999 (Pré Consultants, 2000). The composite index, which is calculated via as a user-friendly tool, aims to assist designers and product managers to improve products. The Eco-indicator 99 addresses three damage categories (endpoints): (a) human health, (b) ecosystem quality and (c) resources, minerals and fossil fuels. Damages to human health are expressed as DALY (Disability Adjusted Life Years). Models have been developed for respiratory and carcinogenic effects, the effects of climate change, ozone layer depletion and ionising radiation. Damages to Ecosystem Quality are expressed as the percentage of species that have disappeared in a certain area due to the environmental load. Resource extraction is related to the quality of the remaining mineral and fossil resources.

5.10.4. *Environment Assessment for Cleaner Production Technologies*

Fizal (2007) developed an environmental assessment method for cleaner production technologies enabling quantitative analysis of environmental impact. The method is based on material and energy flows and uses a set of profile indices, including raw material, energy, waste, product and packaging profiles that describe all material and energy flows related to the technology under investigation. The indices are used as a basis for determining an integrated index for overall environmental assessment of cleaner production technologies. The presented method can be employed to evaluate environmental nuisance of implemented, modernised and modified technological processes and products as well to perform comparative analyses of alternative technologies.

5.10.5. *COMPLIMENT—Environment Performance Index for Industries*

Hermann et al. (2007) developed an analytical tool, called COMPLIMENT, which can be used to provide detailed information on the overall environmental impact of a business. COMPLIMENT integrates parts of tools such as life cycle assessment, multi-criteria analysis and environmental performance indicators. The methodology is based on environmental performance indicators, expanding the scope of data collection towards a life cycle approach and including a weighting and aggregation step. The method starts with the selection of EPIs to be calculated while taking into account the goal and scope definition of an LCA, followed by data collection, analysis and conversion and subsequently the classification, characterisation and normalisation steps. Carrying out classification, characterisation and normalisation result in a set of output data in the form of impact categories, such as global warming, acidification potential, eutrophication potential, ozone precursors and human health. Three sets of weights based on local, regional and national perspectives were developed using AHP analysis. As a next step in applying COMPLIMENT, the weights per impact category) are multiplied by the normalised potential impacts per category. The resulting weighted impacts per category can then be added up to form an index of the normalised total potential environmental impact for each perspective.

5.11. *Energy-based Indices*

5.11.1. *Sustainability Assessment tool for Energy System*

Begic and Afghan (2007) performed multi-criteria sustainability assessment of various options of the energy power system. The rehabilitation of a 110 MW Thermal Power Unit is compared with other options, such as: a thermal power unit with a coal-fueled boiler with combustion in fluidized bed; combined cycle gas turbine plants; hydropower plant, power plants based on solar energy (photovoltaic [PV] systems); wind turbines; and biomass power plants. The assessment methodology comprise a system of stochastic models of uncertainty, enabling decision-makers to perform the assessment of various systems, as well as to obtain normalisation indexes by using non-numeric (ordinal), non-exact (interval) and non-complete information (NNN information).

Through the analysis of multi-criteria assessment of potential options, the decision-makers are able to evaluate options and select the optimal new power plant capacity.

5.11.2. *Energy Indicators for tracking Sustainability in Developed Countries*

In developed countries, the sustainability discussion is focused on environmental topics, while in developing countries the issues of poverty and equity are equally important. Consequently, for measuring sustainable development in a developing country, the inclusion of a poverty indicator in a set of lead indicators is essential Moreover human activities and most sustainability issues are closely related to energy use, the energy system is a sound framework for providing lead indicators for sustainable development. Common energy-economic models enable the estimation of future states of the energy system. Kemmler and Spreng (2007) developed energy-based indicators of poverty which is quite relevant for social issues. The three energy measures that are used for the comparison are primary, useful, and an access-adjusted useful energy (all per capita). Poverty measures available in the NSSO data are total household expenditure, education level of the head of the household, calorie intake, source of drinking water, sanitation, house condition, dwelling area size, dwelling construction type and land possession.

5.12. *Social and Quality of Life-based Indices*

5.12.1. *Gender Empowerment Measure*

Focusing on women's opportunities rather than their capabilities, the GEM captures gender inequality in three key areas:

- Political participation and decision-making power, as measured by women's and men's percentage shares of parliamentary seats.
- Economic participation and decision-making power, as measured by two indicators—women's and men's percentage shares of position s as legislators, senior official s and managers and women's and men's percentage shares of professional and technical positions.
- Power over economic resources, as measured by women's and men's estimated earned income (PPP US$).

Gender Empowerment Measure (GEM) and Gender-related Development Index (GMI) are also calculated as arithmetic means of three components. The components of each Index were first scaled to lie between 0 and 1 before computation (UNDP, 1996).

5.12.2. *Physical Quality of Life Index*

Morris (1979) also used the arithmetic mean to compute the physical quality of life Index (PQLI) from three indices—life expectancy index, infant mortality index and adult literacy rate. Ram (1982) applied principal component analysis and recomputed the PQLI.

5.12.3. *Well-being Assessment (Well-Being Index—WI)*

The well-being assessment by Prescott-Allen (2001) is based on the assumption that a healthy environment is necessary for healthy humans. Accordingly, the Well-Being Index (WI) is the arithmetic mean of a Human Well-being Index (HWI) and an Ecosystem Well-Being Index (EWI). The indices HWI and EWI in turn consist of five sub-indices. The HWI comprises a Health and Population, Welfare, Knowledge, Culture and Society, as well as an Equity Index. The EWI comprises indices for land, water, air, species and genes as well as for resources deployment. The five dimensions of the HWI are based on 36 indicators, those of the EWI on 51 indicators. The aggregation of these dimensions is conducted by a weighted arithmetic mean of further sub-indices or variables which are normalised again by a proximity-to-target approach using targets of related indicators.

5.12.4. *National Health Care systems performance*

The composite index aims to measure the performance of all 120 Health Authorities in England, Scotland and Wales with a view to reveal whether there is (a) variation in health care standards across the country, (b) gulf in the health of town and city dwellers, and (c) an important impact of poverty on the health service (King's Fund, 2001). Six sub-indicators were selected which cover various aspects of the performance of the National Health Care System: deaths from cancer, deaths from heart disease, total number of people on hospital waiting lists, percentage of people on waiting lists waiting over 12 months, number of hip operations and deaths from 'avoidable' diseases (e.g. TB, asthma, etc.).

5.12.5. *Overall Health System Attainment*

The World Health Organisation has developed a composite index that summarizes the performance of health systems in 191 countries, in terms of both the overall level of goal achievement and the distribution of that achievement, giving equal weight to these two aspects (WHO, 2000). Five components make up the index: overall good health, distribution of good health, overall responsiveness, distribution of responsiveness and fairness in financial contributions. Good health is measured by disability-adjusted life expectancy and the distribution of good health by an equality of child survival index.

5.12.6. *Index for sustainable society*

The recently developed Index for a sustainable society, the SSI, integrates for the sustainability and quality of life. The SSI shows at a glance the level of sustainability of a country, what is going well and where improvements are urgently required.

The framework of the Index for a Sustainable Society consists of five categories, each built up from several indicators:

- Personal Development (Healthy Life, Sufficient Food, Sufficient to Drink, Safe Sanitation, Education Opportunities and Gender Equality).
- Clean Environment (Air Quality, Surface Water Quality and Land Quality).
- Well-balanced Society (Good Governance, Unemployment, Population Growth, Income Distribution and Public Debt).
- Sustainable Use of Resources (Waste Recycling, Use of Renewable Water Resources and Consumption of Renewable Energy).
- Sustainable World (Forest Area, Preservation of Biodiversity, Emission of Greenhouse Gases, Ecological Footprint and International Cooperation).

The details of various indexes, viz. scaling, normalisation, weighting and aggregation are summarized in Table 3.

6. Conclusion

This paper covers an overview of various sustainability indices which are practically implemented to measure sustainable development. Attempts have been made to compile the information about how the index were formulated using the three central steps, viz.—normalisation, weighting, aggregation. It has been found that normalisation and weighting of indicators – which in general are associated with subjective judgments – reveal a high degree of arbitrariness without mentioning or systematically assessing critical assumptions. As to aggregation, there are scientific rules which guarantee consistency and meaningfulness of composite indices.

Indices and rating systems are subject to subjectivity despite the relative objectivity of the methods employed in assessing the sustainability. The multi-dimensionality of composite indices and rating systems represent one of their main advantages. Indices represent aggregate measures of a combination of complex development phenomena. Composite indices generally combine measures of ends and means. In respect of method and technique, composite indexing is relatively complex.

Although there are various international efforts on measuring sustainability, only few of them have an integral approach taking into account environmental, economic and social aspects. In most cases the focus is on one of the three aspects. Although, it could be argued that they could serve supplementary to each other, sustainability is more than an aggregation of the important issues, it is also about their interlinkages and the dynamics developed in a system. This point will be missing if tried to use them supplementary and it is one of the most difficult parts to capture and reflect in measurements.

Composite indicators may send misleading, non-robust policy messages if they are poorly constructed or misinterpreted. Sensitivity analysis certainly can help in testing the index for robustness. Sometimes, the simple picture depicted by index may invite spontaneous conclusions on policies. Sub-indicators should be selected meticulously. Choice of model, weighting mechanism and treatment of missing value also play a predominant role while construction of framework. Sometimes index increases the quantity of data needed because data are required for all the sub-indicators and for a statistically significant analysis. There are two critical issues, viz. correlation among indicators and compensability between indicators must be taken into consideration. A composite constructed on the basis of underlying indicators with high internal correlation will give a very robust CI, whose values and ranking are moderately affected by changes in the selection of weights, the normalisation method and other steps involved in the analysis.

Indicators of sustainable development should be selected and negotiated by the appropriate communities of interest. Thus, composite indicator must be constructed within a coherent framework. This would ensure that the specific parameters involved in the evaluation process could change through time according to the interests of the particular stakeholders involved in the construction of the indicator.

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