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## SURVEY

## Categorising tools for sustainability assessment

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## ABSTRACT

The aim of this paper is to provide a categorisation of sustainability assessment tools within the broader objective of lifting the understanding of sustainability assessment from the environmental-focused realm to a wider interpretation of sustainability. The suggested framework is based on three main categories: indicators/indices, product-related assessment, and integrated assessment tools. There is furthermore the overarching category of monetary valuation tools that can be used as a part of many of the tools listed in the three categories. The tools are also divided by their spatial focus and the level of nature–society system integration. Discussion focuses on if and how the tools fulfil the objectives from the more current understanding of sustainability assessment.

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### 1. Introduction

Sustainable development has been incorporated into many levels of society in recent years. The standard definition provided by the Brundtland Commission “to make development sustainable — to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987) is a starting point for most who set out to define the concept. The U.S. National Research Council (1999) argues that there are three important components of sustainable development: what is to be sustained, what is to be developed, and the intergenerational component. They identify three areas to be sustained, namely,

nature, life-support systems and community. The group furthermore brings out the three ideas to be developed: people, society and economy. Lastly, the intergenerational component is critical because specific sustainability goals must explicitly express the time-horizon for which the goals are to be achieved.<sup>2</sup> Emerging from this structural backbone is the field of sustainability science. Kasemir et al. (2003) describe this research area as combining work in the area of environmental science with work in economic, social and development studies to better understand the complex dynamic interactions between environmental, social and economic issues.

But for the transition to sustainability, goals must be assessed. This has posed important challenges to the scientific community in providing efficient but reliable tools. As a response to these challenges, sustainability assessment has become a rapidly developing area. The numbers of tools that claim that they can be used for assessing sustainability have

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<sup>2</sup> For more detailed discussion see Kates et al. (2005).

grown; simultaneously many of the tools have developed, providing better application guidelines, data and case study experiences. Sustainability assessment has increasingly become associated with the family of impact assessment tools consisting of e.g. Environmental Impact Assessment and Strategic Environmental Assessment (Devuyst, 2000; Pope et al., 2004), or EU Sustainability Impact Assessment. Devuyst et al. (2001) define sustainability assessment as "...a tool that can help decision-makers and policy-makers decide which actions they should or should not take in an attempt to make society more sustainable." 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?"

These two questions stress the need for the extension and integration of environmental and social assessment, monitoring and planning that should be particularly stressed in connection with sustainability assessment. Our suggestion, based on Kates et al. (2001), is that 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.*

But to which degree does the present sustainable assessment toolbox fulfil these broader objectives?

How do they manage to integrate nature–society systems, and are they able to sufficiently address local to global dimensions and short-term and long-term perspectives?

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## 2. Aims, materials and contents

Based on an inventory of different tools for assessing sustainability, the aim of this paper is to contribute to the overview and discussion on sustainability assessment tools. The ambition of the inventory is to provide a general understanding of existing approaches and to evaluate to which degree they are able to incorporate the different dimensions of sustainability described in the introduction. The inventory is based on a literature review from a wide-array of sources. The material used consisted not only of literature describing each of the tools, but also material related to the specific application of each of the assessment approaches. The ambition has been to cover the tools that most frequently appear in the literature, and as far as possible, cover the variety of the broad field that can be viewed as sustainability assessment. The inventory is not exhaustive; the tools covered are by no means all the tools that exist for sustainability assessment, but we claim that the most significant ones found in the literature today are represented.

Neither has there been made any attempt to quantify the importance of various tools by the number of studies or publications for each tool.

The article presents a categorisation of sustainability assessment tools with a presentation of each group of tools and its area of applicability. This categorisation is based on their approaches and focus areas. First, the general framework is presented. The article then delves deeper into each tool category and presents a short description of each tool group and application examples. The article concludes with a short discussion of the categorisation framework and the findings of the inventory.

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## 3. Framework for sustainability assessment tools

Earlier overviews of assessment methods/tools/indicators have demonstrated that approaches can be categorised based on numerous factors or dimensions (Baumann and Cowell, 1999; Moberg, 1999; Wrisberg et al., 2002; Finnveden et al., 2003; Finnveden and Moberg, 2005; Kates et al., 2005). We considered the following factors in our inventory:

- Temporal characteristics, i.e. if the tool evaluates past development (ex-post or descriptive), or if it is used for predicting future outcomes (ex-ante or change-oriented) such as a policy change or an improvement in a production process.
- The focus (coverage areas), for example, if their focus is at the product level, or on a proposed change in policy.
- Integration of nature–society systems i.e. to what extent the tool fuses environmental, social and/or economic aspects.

The sustainability assessment tool framework is developed on the basis of our inventory (see Fig. 1) 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.

### 3.1. Indicators and indices

The first umbrella of sustainability assessment tools consists of indicators and indices. Indicators are simple measures, most often quantitative that represent a state of economic, social and/or environmental development in a defined region—often the national level. When indicators are aggregated in some manner, the resulting measure is an index. Harger and Meyer (1996) suggest that indicators should contain the following characteristics: simplicity, (a wide) scope, are quantifiable, allow trends to be determined, tools that are sensitive to change, and allow timely identification of trends. Indicators and indices, which are continuously measured and calculated,

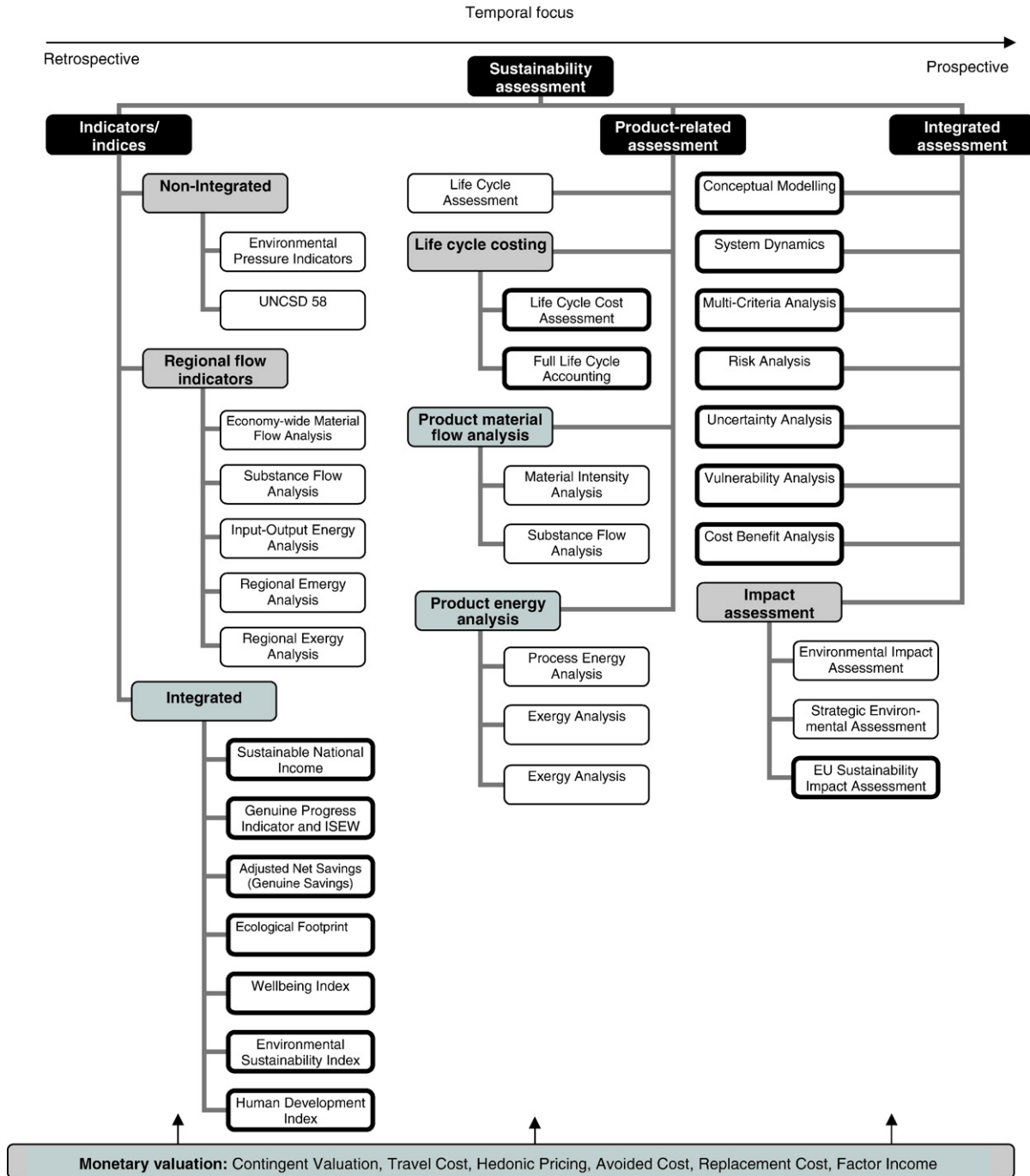


Fig. 1– Framework for sustainability assessment tools. The proposed assessment tool framework is based on the temporal focus of the tool along with the object of focus of the tool. The arrow on the top of the framework shows the temporal focus, which is either retrospective (indicators/indices), prospective (integrated assessment) or both (product-related assessment). The object of focus of the tools is either spatial, referring to a proposed change in policy (indicators/indices and integrated assessment), or at the product level (product-related assessment). The *monetary valuation* tools on the bottom are used when monetary valuations are needed in the above tools. Thick lines around the boxes mean that these tools are capable of integrating nature–society systems into single evaluation.

allow for the tracking of longer-term sustainability trends from a retrospective point of view. Understanding these trends allows making short-term projections and relevant decisions for the future. The tools in the category of indicators and indices are either *non-integrated*, meaning they do not integrate nature–society parameters, or *integrated*, meaning the tools aggregate the different dimensions. There is also a subcategory of non-integrated tools that focuses specifically on regional flow indicators.

### 3.1.1. Non-integrated indicators

An example of non-integrated indicators is Environmental Pressure Indicators (EPIs) developed by Statistical Office of the European Communities (Eurostat). One of Eurostat's missions is to provide comparable and comprehensible data for EU countries and regions, collected and prepared in close collaboration with member state statistical offices. The EPI set consists of 60 indicators, six in each of the ten policy fields under the Fifth Environmental Action Programme (Lammers and Gilbert, 1999). It is also possible to aggregate the six indicators in each policy field into an index, which in total makes up ten environmental pressure indices. The intention with these indicators, which consist of for example forest damage, fishing pressure, tourism intensity, waste landfilled, is to provide a common and comprehensive set of indicators for EU member states to evaluate and measure environmental sustainability. These indicators permit a comparison of the environmental situation in different EU member countries, and an evaluation of trends in member states and in the EU as a whole. Currently there are EPI reports available from years 1999 and 2001 (European Commission and Eurostat, 1999, 2001).

Another example is the set of 58 national indicators used by the United Nations Commission on Sustainable Development (UNCSD). The UNCSD was created to carry out the priorities of the United Nations Conference on Environment and Development in Rio de Janeiro, Brazil in 1992. In order to arrive at “a broader, more complete picture of societal development” these indicators extend further than just the common economic indicators, to include, social, environmental and institutional monitoring mechanisms (UNCSD, 2001). The indicators are not integrated or aggregated in any manner. Examples of the UNCSD indicators include water quality levels for the environmental category, national education levels, and population growth rates as social determinants, GNP per capita for the economic sphere, and the number of ratified global agreements in the category of institutional sustainability (UNCSD, 2001). National reports and country profiles using these indicators have been submitted by many member countries since 1994 (United Nations, 2002).

### 3.1.2. Regional flow indicators

Analysis of material and energy flows allows an overview of the structure of resource flows and identification of inefficiencies within a system. Such studies may be used both for reconstructing historical flows and emissions and for forecasting and decision support. Material Flow Analysis (MFA) analyses the physical metabolism of society in order to support dematerialisation and reduction of losses to the environment connected to the extensive

societal resources (Kleijn, 2001). MFA studies have been performed in many countries and the numbers of regional MFA studies have increased during the last decades. Overviews and analysis of various studies up to the 1990s are presented by e.g. Fischer-Kowalski and Hüttler (1998) and Anderberg et al. (2000). Regional flow indicators are also non-integrated as they only focus on physical flows, thus environmental aspects.

Economy-wide MFA developed by Eurostat is the most standardised tool for MFA for regions. It is mainly used at the national level with the possibility of being applied at other spatial levels. The studies of World Resources Institute on total material flows in industrialised economies (Adriaanse et al., 1997; Matthews et al., 2000) were important for standardising regional material flow analysis. Eurostat created guidelines for conducting a MFA for an economy (Eurostat, 2001). The results of flow analyses are most often in the form of detailed flow diagrams, but there are several indicators that are built on this kind of analysis. The Eurostat guide divides such material flow indicators into three categories—input, output and consumption indicators. Each category includes indicators of different levels depending on whether they cover domestic, foreign and/or hidden flows. Hidden flows are materials that do not enter into economic systems, for example excavation, non-saleable extraction, soil erosion, etc. (Matthews et al., 2000). Material input indicators show the material inflows into the economy through local production and consumption. Material output indicators measure all material outflows back to the environment in terms of wastes and emissions either during or after production and consumption process. Material consumption indicators measure the total of all materials used in an economy.

Substance Flow Analysis (SFA) focuses on regional flows of certain chemical and/or chemical compounds and the related losses to the environment. The ultimate goal for SFA is to reduce the load of a particular substance. SFA is performed regionally or nationally to identify problem areas. SFA results can be useful for environmental planning and management at various levels. Lindqvist and von Malmborg (2004) have conducted a study of cadmium flows in Swedish municipalities exemplifying how SFA could be used in the decision-making process.

Energy analysis focuses on all the energy flows in an economy. It is based on the first law of thermodynamics, which states that energy is constant and cannot be created nor destroyed, but it can only be converted into different types of energy (Hovelius, 1997). A national or regional energy analysis is often carried out using Input–Output Energy Analysis based on Leontief's economic input–output matrix, which analyses the trade between different industries in the economy. In the case of energy analysis, trade volumes are replaced with energy flows between industries (Hovelius, 1997; Finnveden and Moberg, 2005).

Energy analysis can also be carried out by using different types of energy measures, such as exergy and emergy. Both these forms of analyses are more advanced since they consider both the quality and the quantity of energy (Rosen and Dincer, 2001; Herendeen, 2004). The exergy of a system is the maximal amount of mechanical work that can be extracted (Wall, 1977). An exergy analysis gives an overview

of the effectiveness of resource utilisation and show where losses occur, and where technological improvements can be made to increase energy efficiency. There are examples of Regional Exergy Analyses for Sweden (Wall, 1997), Japan (Wall, 1990), and the United States (Ayres et al., 2003). Odum (1996) has created a methodology for Regional Exergy Analysis where all resources and goods are expressed in common units (solar *emjoules*) measuring the solar energy that was needed for producing them (Doherty et al., 2002).

### 3.1.3. Integrated indicators and indices

There are numerous attempts to move beyond the non-integrated and combine different nature–society dimensions in one indicator or index. The first four indices in the framework are attempts to develop alternatives to the national accounting indices such as Gross Domestic Product (GDP) and Net National Product (NNP), which are frequently used as measures of overall human welfare. GDP and NNP often provide decision-makers with the erroneous signals as to true sustainability—leaving out critical factors like income distribution, public safety, resource over-utilisation and other negative externalities that are not incorporated into these common measures (Gerlagh et al., 2002). Due to the shortcomings of GDP not taking environmental considerations into account, or as an adequate quality of life indicator, a variety of alternative measurement tools have been devised. Each provides a somewhat different measurement of sustainable development. A detailed description of many of these indicators along with assessment results can also be found in Hanley et al. (1999).

Sustainable National Income (SNI) is an index developed for the Netherlands (Huetting et al., 1993). The tool attempts to move beyond strict economic output parameters to determine well-being by incorporating sustainable resource utilisation measurements into national income accounting. SNI does not directly include social factors in calculations. The index is a comparison of national income that is estimated to be sustainable to that of conventional national income accounting practices. The gap between the two numbers describes the dependence of the country on natural resource use that exceeds sustainable utilisation (Gerlagh et al., 2002).

The Index of Sustainable Economic Welfare (ISEW) (Daly and Cobb, 1989) and the General Progress Indicator (GPI), developed by the non-profit organisation Redefining Progress in the mid-1990s (Cobb et al., 1995), span the economic, social and environmental dimensions. Both these tools, which are closely related, adjust national accounting practices to encompass a broader set of welfare determinants, which include deductions for military spending, environmental degradation and depreciation in natural capital. Calculations have been performed for a number of countries.

Adjusted Net Savings, also called Genuine Savings (Hamilton et al., 1997), is another alternative measurement mechanism to determine sustainability at the national level. This indicator is associated most with the World Bank. The Adjusted Net Saving rate encompasses resource depletion and environmental degradation, and has also been extended to include technological change, human resources, exhaustible resource exports, resource discoveries and critical natural capital. Most emphasis is placed on the economic and environmental components, but the tool also includes invest-

ments in education. A positive indicator value reflects a positive transition toward sustainability, whereas a negative indicator value represents the opposite. It thus has the advantage of giving a country a clear signal in terms of its direction of development (Everett and Wilks, 1999).

The Ecological Footprint (Wackernagel and Rees, 1996) is an accounting tool that estimates the resource consumption and waste assimilation requirements of a given population or economy in terms of a corresponding land area. Calculating the Ecological Footprint is a multi-stage process. The average person's annual consumption level of food, housing, transport, consumer goods and services is estimated. Next, the land area needed for the production and environmental impact of each of the consumption items is calculated, and finally all the areas needed are summed. The result is a per capita land area for the annual consumption of goods and services (Wackernagel and Rees, 1996). The Ecological Footprint has been applied to numerous countries and regions. It has mainly been used for gauging sustainability at the national level, but changes at city or urban-region level, and aggregated indices have also been evaluated (Venetoulis et al., 2004).

The Wellbeing Index (Prescott-Allen, 2001) was used in an evaluation for the World Summit for Sustainable Development in Johannesburg 2002 and included 180 countries. The Wellbeing Index consists of two indices, the Human Wellbeing Index (HWI) and Ecosystem Wellbeing Index (EWI), which are aggregated from more than 60 different indicators. HWI includes population and health parameters, wealth indicators, indicators on knowledge, culture, community and equity issues, while EWI aggregates land, water and air dimensions, biodiversity issues and resource use indicators. The two indices are given equal strength when they are combined into an illustrative tool called the Barometer of Sustainability.

The Environmental Sustainability Index (ESI) is developed to measure “overall progress toward environmental sustainability” (Centre for International Earth Science Information Network, 2002). It consists of 68 indicators of five different categories: the state of environmental systems (air, water, soil, ecosystems, etc.), reducing stresses on environmental systems, reducing human vulnerability to environmental change, social and institutional capacity to cope with environmental challenges, and the ability to comply with international standards and agreements (Centre for International Earth Science Information Network, 2002). Even though this index focuses mainly on environmental sustainability, it also includes some social and institutional issues. The aim of ESI is to make comparisons between countries possible and to assist environmental decision-making.

The Human Development Index (HDI) is used by the United Nations Development Programme (UNDP) for evaluating social and economic progress in different countries. It consists of three general parameters: longevity, knowledge, and standard of living (UNDP, 2004). Longevity is measured by life expectancy at birth; knowledge is measured by a combination of the adult literacy rate and the combined primary, secondary, and tertiary gross enrolment ratio. Finally the standard of living is measured by GDP per capita. The HDI has been calculated for UN member countries with sufficient data and a handful of other non-member countries since 1975. Since the index underwent a significant reform in 1999, historical comparisons have become difficult (Lind, 2004).

### 3.2. Product-related assessment

The second umbrella consists of product-related tools that focus on flows in connection with production and consumption of goods and services. Built on a similar flow perspective, they are closely related to the regional flow indicators of the previous category (Anderberg et al., 2000). But the tools in this category focus on evaluating different flows in relation to various products or services instead of regions. They evaluate resource use and environmental impacts along the production chain or through the life cycle of a product (from cradle to grave). The aims of identifying particular risks and inefficiencies to support decision-making are similar to the regional flow indicators, but in this case in connection with design of products and production systems. These tools do not integrate nature–society systems as they are mainly focusing on environmental aspects. However, life cycle costing tools may integrate environmental and economic dimensions. Product-related tools allow both retrospective and prospective assessments that support decision-making.

#### 3.2.1. Life cycle assessment

The most established and well-developed tool in this category is Life Cycle Assessment (LCA). LCA has been used in varying forms over the past 35 years to evaluate the environmental impacts of a product or a service throughout its life cycle. It is an approach that analyses real and potential pressure that a product has on the environment during raw material acquisition, production process, use, and disposal of the product (Lindfors, 1995). The International Standards Organisation (ISO) has established guidelines and principles for LCA that have been further interpreted and developed by many (Ciambrone, 1997; Hauschild and Wenzel, 2000; Ross and Evans, 2002; Jolliet et al., 2004). LCA results provide information for decisions regarding product development and ecodesign, production system improvements, and product choice at the consumer level. Life Cycle Assessment has been performed for the pulp and paper industry (Ekvall, 1999; Ross and Evans, 2002; Lopes et al., 2003), the waste and energy field (Lunghi et al., 2004; Finnveden et al., 2005; Moberg et al., 2005), as well as a multitude of other product and service areas.

#### 3.2.2. Life cycle costing

Life cycle costing (LCC) is an economic approach that sums up “total costs of a product, process or activity discounted over its lifetime” (Gluch and Baumann, 2004). In principle LCC is not associated with environmental costs, but costs in general. A traditional LCC is an investment calculation that is used to rank different investment alternatives to help decide on the best alternative. There are many different tools for life cycle costing analysis, but only two of them include environmental costs — Life Cycle Cost Assessment and Full Cost Environmental Accounting. For additional information on life cycle costing tools, see Gluch and Baumann (2004).

#### 3.2.3. Product material flow analysis

Analysis of material and substance flows is also used for product systems. The Wuppertal Institute for Climate, Environment and Energy has developed a product Material Intensity Analysis based on the Material Input per unit of

Service (MIPS) index (expressed in weight) (Spangenberg et al., 1999). This analysis considers all the material flows connected to a particular product or a service including the so called *ecological rucksack*. The ecological rucksack consists of all the materials required for the complete production process minus the actual weight of the product and represents the actual material intensity of a given product. The MIPS concept has been the starting point for the strategic discussions on the Factor 4 and Factor 10 goals.

Substance Flow Analysis (SFA) is performed through life cycle stages in order to discover where the inflows and outflows of substances occur. The analysis enables the identification of the source of the environmental impact, and thusly where corresponding reduction of the environmental burden can be directed. SFA could be used for analysing a product life cycle but it is often used for analysing industries (Antikainen et al., 2004).

#### 3.2.4. Product energy analysis

Product energy analysis measures the energy that is required to manufacture a product or a service (Herendeen, 2004). It includes both direct and indirect energy flows. Indirect energy is the energy that is used for producing inputs, for example, energy that is used to produce metal for the car industry. An example of tools for analysing product or service energy requirements is Process Energy Analysis (Hovelius, 1997). It focuses on different processes and levels in the product life cycle and sums up the flows of energy use through each of the production process stages. Life cycle-based Exergy and Emery Analysis also occur. Emery Analysis has been used for analysing production processes of a single product (Hovelius, 1997) as well as whole industries (Doherty et al., 2002), while Exergy Analysis has been used for analysing energy systems such as heating or electricity production (Nilsson, 1997; Brown and Ulgiati, 2002).

### 3.3. Integrated assessment

Tools under the third umbrella are integrated assessment tools; they are used for supporting decisions related to a policy or a project in a specific region. Project related tools are used for local scale assessments, whereas the policy related focus on local to global scale assessments. In the context of sustainability assessment, integrated assessment tools have an ex-ante focus and often are carried out in the form of scenarios. Many of these integrated assessment tools are based on systems analysis approaches and integrate nature and society aspects. Integrated assessment consists of the wide-array of tools for managing complex issues (Gough et al., 1998). There are many examples of integrated assessments of major environmental problems, but also established tools such as Multi-Criteria Analysis, Risk Analysis, Vulnerability Analysis and Cost Benefit Analysis that do not necessarily pertain directly to only sustainability issues, but can be extended to a variety of other problem areas across disciplinary thresholds.

#### 3.3.1. Conceptual modelling and systems dynamics

Although the terms may have slightly different connotations, Conceptual Modelling is often referred to as conceptual

modelling, mental modelling or soft-systems modelling (see Checkland, 1981). Conceptual Modelling analyses qualitative (causal) relationships and often makes use of stock and flow diagrams, flow charts, or causal loop diagrams. Conceptual Modelling can be used for visualising and detecting where changes in a given system can be made for increasing sustainability or as the initial conceptualisation mechanism in a larger computer modelling approach. Systems Dynamics refers to “the building of computer models of complex problem situations and then experimenting with and studying the behaviour of these models over time” (Caulfield and Maj, 2001). Examples of models related to sustainability assessment include IIASA’s air pollution model (RAINS), the IMAGE model created to analyse social, biosphere, and climate system dynamics, and the Wonderland model designed to illustrate economic–environmental interactions.

### 3.3.2. Multi-criteria analysis

Multi-Criteria Analysis (MCA) is used for assessments in situations when there are competing evaluation criteria. MCA identifies, in general, goals or objectives and then seeks to spot the trade-offs between them; the ultimate goal is to identify the optimal policy. This approach has the advantage of incorporating both qualitative and quantitative data into the process (Wrisberg et al., 2002). MCA has been used for example for choosing the best alternative for flood control policies for the Netherlands (Brouwer and van Ek, 2004), and in the design energy and environmental policy (Greening and Bernow, 2004).

### 3.3.3. Risk analysis and uncertainty analysis

Risk is defined as “the possibility that certain losses or damages occur as the result of a particular event or series of events” (Rotmans, 1998). Risk Analysis is the assessment of these potential damages. The process begins with identification of the risk, and moves on to a qualitative and/or quantitative assessment of the risk—leading to certain management decisions regarding the minimisation of that risk. The final stage of the Risk Analysis includes communication with stakeholders concerning the assessment and the corresponding decisions involved with minimising the risk (Vose, 2000). Since risk is closely related to uncertainty, risk analysis cannot be separated from uncertainty analysis (Rotmans, 1998). There are two types of uncertainties: stochastic uncertainty refers to natural variability of the system, fundamental uncertainty is the inability to predict due to lack of knowledge about the system (Kann and Weyant, 2000; Vose, 2000). Uncertainty and Risk Analysis involve both types of uncertainty. They estimate the probability of events and predicting the events using the knowledge that is available. These aspects of natural variability and lack of knowledge are also the reason why societal and environmental risk analyses are forms of sustainability assessments.

### 3.3.4. Vulnerability analysis

Vulnerability Analysis evaluates the vulnerability of coupled human–environment systems with the aim to determine how sensitive and resilient systems are to changes, and how capable systems are to cope with changes (Turner et al., 2003). If the analysis determines a human or environmental system

to be vulnerable then a risk analysis can be performed. Vulnerability Analysis has recently often been carried out in the context of climate change (Kelly, 2000; Dixon et al., 2003; O’Brien et al., 2004) and shown that some societies and ecosystems are definitely more vulnerable to climate change effects than others.

### 3.3.5. Cost benefit analysis

Cost Benefit Analysis (CBA) is an applied welfare economics tool with roots reaching back to the early 20th century (Johansson, 1996). It is used for evaluating public or private investment proposals by weighing the costs of the project against the expected benefits. In the realm of sustainability assessment, CBA can be an effective tool for weighing the social costs and benefits of different alternatives in connection with e.g. energy and transports (Wrisberg et al., 2002). It is this aspect of measuring expected benefits, or placing monetary units on the benefits that is often problematic with CBA (Moberg, 1999).

### 3.3.6. Impact assessment

Impact assessment is a small group of forecasting tools used for improving the basis for policymaking and project approval process. They are all based on methodologies that attempt to incorporate concerns from diverse stakeholder groups into the assessment process.

Environmental Impact Assessment (EIA) has been used since 1960s for evaluating potential environmental impacts of large development projects with the aim to reduce the negative effects (Sadler, 1999). In the EU, a directive that made EIA compulsory for proposed public and private projects (e.g. construction projects) that are likely to have environmental impacts was introduced in 1985 (EU Commission, 1985; 1997). EIA has also been introduced in the legislation in many other countries (Petts, 1999). Due to such legal requirements, there are strict guidelines for the EIA process in the EU and other countries (Walker and Johnston, 1999).

Evolving from EIA in the 1990s, Strategic Environmental Assessment (SEA) is a tool for evaluating potential environmental impacts of strategic decisions (Partidario, 1999). There are two major differences between SEA and EIA. SEA has to be carried out earlier than EIA, and it is performed for conditions that involve less information, higher uncertainty and less concreteness, which is often the case with political decisions; whereas EIA is performed in concrete conditions of a particular project. Despite these differences many of the principles and procedures are similar in both processes (Partidario, 1999). In both EIA and SEA, involvement of the public is part of the process, and diverse interests should be able to have a voice in connection with the recommendations.

More recently, the EU has introduced the more comprehensive tool of Sustainability Impact Assessment (SIA). The intention is to move from the sectoral and often fragmented assessments to an integrated assessment covering environmental, economic and social parameters. The goal of this new tool is to better be able to identify “the likely positive and negative impacts of proposed policy actions, enabling informed political judgments to be made about the proposal and identify trade-offs in achieving competing objectives” (see EU Commission, 2002). Sustainability Impact Assessment was

first applied in early 2003 and is now used for all major Commission initiatives. An analysis of the first SIAs carried out by Wilkinson et al. (2004) concluded among other things that none of the assessments had followed the Commission guidelines completely. This study also revealed that the range of assessed impacts was limited, and that most attention was still placed on economic aspects and not on environmental or social. Further guideline development and revisions are expected in the near future.

### 3.4. Monetary valuation

Monetary valuation is also often referred to as shadow pricing or non-market valuation. This group consists of tools that are not sustainability assessment techniques themselves, but rather an important set of tools that can be used to assist other tools when monetary values are needed for goods and services not found in the marketplace. Tools, for example, Cost-Benefit Analysis, Genuine Savings, and Life Cycle Cost Assessment require such values to be used. With monetary valuation there are different ways to assign values. There is for example the Contingent Valuation method (previously called the Survey Method), which uses surveys to estimate people's willingness-to-pay for certain nature's goods and services. The Travel Cost method uses the price paid for travelling as a basis of its monetary value (Johansson, 1996), and the Hedonic Pricing method that focuses mainly on property markets through analysing prices influenced by its surrounding, which can be either positive (near beach or park) or negative (close to highway, airport or industrial area) (Pearce et al., 1994). There also are additional techniques for monetary valuation including Factor Income, Avoided Cost and Replacement Cost that can be used (see Pearce et al., 1994).

## 4. Discussion and conclusions

This paper has presented a framework for the classification of common sustainability assessment tools with the objective of contributing to the overview and discussion of sustainability assessment tools. The suggested framework is primarily based on a combination of the temporal dimensions of the tool and the object of focus for the tool and consists of three major categories: indicators/indices, product-related assessment, and integrated assessment tools. Monetary valuation tools can be used as a part of numerous tools listed in the three categories.

### 4.1. Do the tools fulfil the objectives?

To what degree does the assessment tools presented fulfil the expanded objectives for sustainability assessment? The suggested redefinition of sustainability assessment was based on three important elements. The first element is the *integration of nature and society*, or if the tools are capable of integrating nature–society systems? The second element in the definition focuses on the *spatial aspects* of an assessment: is the tool capable of assessing different scales or spatial levels? The final element concerns the *temporal aspects*: are the tools able to address both the short- to long-term perspectives?

Some tools may be integrated within their specific assessment dimensions, but according to our view only seventeen tools (marked with the dark, thick border in Fig. 1) are capable of integrating nature–society facets, representing only a minority of approaches that exist today.<sup>3</sup> There is still a strong focus on environmental parameters, particularly among the product-related assessment tools, where, with the exception of LCC, the tools largely disregard social and/or economic aspects. Even though tools in some categories have made a transition to more integrated approaches (see Section 3.1.3), these are not commonly used.

Efforts have been made through combining two or more different tools to extend the focus of analysis (Wrisberg et al., 2002). Examples of this tendency are the simultaneous analysis of a product or service function using Life Cycle Assessment (environmental impact tool), Life Cycle Costing (economic tool) and/or the Social Life Cycle Assessment (Klöpffer, 2003; Dreyer et al., 2005). A shortcoming of such an approach is that the overall results of the study are not presently integrated in any manner.

The spatial coverage is more flexible in connection with various tools. Although the national level is the most common focus, the tools in the first umbrella can be used at a variety of spatial levels. This means that specific environmental impacts can be calculated for a region within a country, or national level indicators can be aggregated to detect international or global impacts. Integrated sustainability assessments can be performed on human impacts on local ecosystems all the way up to dynamic global climate models. The category of impact assessment can also be modified to reflect the spatial focus required. Impact assessments focus on a proposed change in policy or expected impacts from a project. The first two tools, EIA and SEA, are tools that are used most from local or regional impacts from the project proposal; global impacts are often not part of the scope of the assessment. The tool of EU Sustainability Impact Assessment though has the intentions to move beyond impacts at the EU's spatial boundaries and assess impacts of EU policy decisions on other nations as well as more localised impacts. It may, for example, address how a decrease in EU economic agricultural support will affect not only producers in member countries, but also farmers in other countries? However, the overall effectiveness of the tool has not been determined and is not the issue here.

A group of tools that is different concerning spatial aspects are the product-related assessment tools. This group generally does not focus on the spatial attributes of a particular product. In the case of life cycle assessment, the tool is considered a *global tool* giving it the weakness of low spatial resolution (Udo de Haes et al., 2004). In other words, the impacts are tied only to the product function and not specifically to where the impacts occur, making it site-independent. Work is underway though to make the tool more site-specific through the development of site-dependent characterisation factors (c.f. Finnveden and Nilsson, 2005).

<sup>3</sup> The number of tools with thick borders in our framework (Fig. 1) represents a minority of tools, but it does not appear that way in the framework. This is due to some of the individual non-integrated boxes actually containing up to 60 indicators each (e.g. Environmental Pressure Indicators and UNCSO 58).



The temporal aspect stressed in connection with the tool framework was if the tools look forward or backward. We do not argue that retrospective tools cannot be used for assessing future sustainability patterns, but they may not be optimal for gauging longer-term sustainability since they have been developed for analysing the past. Forecasting tools are more favourable to our interpretation of sustainability assessment. These tools were designed to for example to help reveal impacts, benefits, risks, vulnerabilities, etc. resulting from some system change at a variety of temporal scales. Unlike the more verifiable retrospective tools though, forecasting tools have the disadvantage that they are more subjective in nature—often making it more difficult for decision-makers to accept their credibility.

#### 4.2. Other differences among the tools

There are important differences among the tools concerning their establishment and frequency of use. For many of the tools, e.g. LCA, CBA, EIA and MFA, there are relatively well established guidelines available for tool practitioners, whereas newer tools such as the EU Sustainability Impact Assessment represent an area where guideline establishment is still in early developmental stages. The same can be said for data availability for use with many of the tools. Although it can be argued that input data is generally a weak link with all of the assessment mechanisms, tools like LCA have developed data sets in a number of areas. As the area of sustainability assessment matures, it is expected that some of the tools presented in the framework will be utilised significantly less or disappear; other tools will experience an increased standardisation and usage, while other completely new tools will emerge.

Interpretations of sustainability are also important in which assessment approach will be used. In some cases assessment tool practitioners and decision-makers have a choice to use a tool, or specific assessment results that most closely reflect their political viewpoint and their broader interpretation of sustainability. Simply speaking, how one defines sustainability largely determines how one goes about assessing it. For example, is an assessment done from a weak sustainability perspective, implying that manufactured capital can be substituted for natural capital, or from a strong sustainability perspective, where the stock of natural capital must be preserved and is not substitutable? Examples of a weak sustainability assessment tools under the rubric of integrated indicators are ISEW and Adjusted Net Savings, with the Ecological Footprint as an example of a stronger measure of sustainability (Hanley et al., 1999). The differing interpretations can have implications for decision-making processes.

#### 4.3. Final remarks

There is a contradiction with the future development of sustainability assessment tools. On the one hand there is the demand for approaches that have more specific assessment performance, meaning among other things are more case- and site-specific. At the same time there exists the demand for tools that are broader in order to be accessible to a wide user group for differing case circumstances. There is also the need

for more *standardised* tools that give more transparent results. Can future assessment tool development meet the challenges of allowing for better assessment tool guidelines and data availability and for succinct analyses on a more diverse range of assessment situations? Like the many facets of the concept of sustainability itself, proper tool development can only happen when all parameters are considered simultaneously.

## REFERENCES

- Adriaanse, A., Bringezu, S., Hamond, A., Moriguchi, Y., Rodenburg, E., Rogich, D., Schütz, H., 1997. Resource Flows: The Material Base of Industrial Economies. World Resources Institute, Washington.
- Anderberg, S., Prieler, S., Olendrzynski, K., de Bruyn, S., 2000. Old Sins — Industrial Metabolism, Heavy Metal Pollution and Environmental Transition in Central Europe. UN University Press, Tokyo.
- Antikainen, R., Haapanen, R., Rekolainen, S., 2004. Flows of nitrogen and phosphorus in Finland — the forest industry and use of wood fuels. *Journal of Cleaner Production* 12, 919–934.
- Ayres, R.U., Ayres, L.W., Warr, B., 2003. Exergy, power and work in the US economy, 1900–1998. *Energy* 28 (3), 219–273.
- Baumann, H., Cowell, S.J., 1999. An evaluative framework for conceptual and analytical approaches used in environmental management. *Greener Management International* 26, 109–123.
- Brouwer, R., van Ek, R., 2004. Integrated ecological, economic and social impact assessment of alternative flood control policies in the Netherlands. *Ecological Economics* 50 (1–2), 1–21.
- Brown, M.T., Ulgiati, S., 2002. Emergy evaluations and environmental loading of electricity production systems. *Journal of Cleaner Production* 10, 321–334.
- Caulfield, C.W., Maj, S.P., 2001. A case for Systems Thinking and System Dynamics. *Systems, Man and Cybernetics*.
- Centre for International Earth Science Information Network (2002). 2002 Environmental Sustainability Index, Global Leaders for Tomorrow World Economic Forum Yale Center for Environmental Law and Policy. Main report.
- Checkland, P., 1981. *Systems Thinking, Systems Practice*. John Wiley & Sons, Chichester.
- Ciambrone, D.F., 1997. *Environmental Life Cycle Analysis*. Lewis Publishers, Boca Raton.
- Cobb, C., Halstead, E., Rowe, J., 1995. *The Genuine Progress Indicator — Summary of Data and Methodology*. Redefining Progress, Washington DC.
- Daly, H.E., Cobb, J.B., 1989. *For the Common Good*. Beacon Press, Boston.
- Devuyst, D., 2000. Linking impact assessment and sustainable development at the local level: the introduction of sustainability assessment systems. *Sustainable Development* 8, 67–78.
- Devuyst, D., Hens, L., Lannoy, W.d., 2001. How Green is the City? Sustainability Assessment and the Management of Urban Environments. Columbia University Press, New York.
- Dixon, R., Smith, J., Guill, S., 2003. Life on the edge: vulnerability and adaptation of African ecosystems to global climate change. *Mitigation and Adaptation Strategies for Global Change* 8 (2), 93–113.
- Doherty, S.J., Nilsson, P.O., Odum, H.T., 2002. Emergy Evaluation of Forest Production and Industries in Sweden. Department of Bioenergy, Swedish University of Agricultural Sciences, Uppsala.
- Dreyer, L.C., Hauschild, M., Schierbeck, J., 2005. A framework for social life cycle impact assessment. *International Journal of Life Cycle Assessment* 11 (2), 88–97.
- Ekvall, T., 1999. Key methodological issues for life cycle inventory analysis of paper recycling. *Journal of Cleaner Production* 7, 281–294.

- EU Commission, 1985. Council directive of 27 June 1985 on the assessment of the effects of certain public and private projects on the environment. Official Journal L 175, 40–48.
- EU Commission, 1997. Council Directive 97/11/EC of 3 March 1997 amending Directive 85/337/EEC on the assessment of the effects of certain public and private projects on the environment. Official Journal L073, 5.
- EU Commission, 2002. Communication from the commission on impact assessment. Brussels, Commission of the European Communities. COM(2002) 276 final.
- European Commission and Eurostat, 1999. Towards environmental pressure indicators for the EU. Brussels. First edition 1999.
- European Commission and Eurostat, 2001. Towards environmental pressure indicators for the EU. Brussels. Second edition 2001.
- Eurostat, 2001. Economy-wide Material Flow Accounts and Derived Indicators. A Methodological Guide. Statistical Office of the European Union, Luxembourg.
- Everett, G., Wilks, A., 1999. The World Bank's Genuine Savings Indicator: A Useful Measure of Sustainability? Bretton Wood Project, London.
- Finnveden, G., Moberg, Å., 2005. Environmental systems analysis — an overview. *Journal of Cleaner Production* 13 (12), 1165–1173.
- Finnveden, G., Nilsson, M., 2005. Site-dependent life-cycle impact assessment in Sweden. *International Journal of Life Cycle Assessment* 10 (4), 235–239.
- Finnveden, G., Nilsson, M., Johansson, J., Persson, Å., Moberg, Å., Carlsson, T., 2003. Strategic environmental assessment methodologies — applications within the energy sector. *Environmental Impact Assessment Review* 23, 91–123.
- Finnveden, G., Johansson, J., Lind, P., Moberg, Å., 2005. Life cycle assessment of energy from solid waste—part 1: general methodology and results. *Journal of Cleaner Production* 13 (3), 213–229.
- Fischer-Kowalski, M., Hüttler, W., 1998. Society's metabolism. The intellectual history of material flow analysis, part II, 1970–1998. *Journal of Industrial Ecology* 2 (4), 107–136.
- Gerlagh, R., Dellink, R., Hofkes, M., Verbruggen, H., 2002. A measure of sustainable national income for the Netherlands. *Ecological Economics* 41, 157–174.
- Gluch, P., Baumann, H., 2004. The life cycle costing (LCC) approach: a conceptual discussion of its usefulness for environmental decision-making. *Building and Environment* 39, 571–580.
- Gough, C., Castells, N., Funtowicz, S., 1998. Integrated assessment: an emerging methodology for complex issues. *Environmental Modeling and Assessment* 3, 19–29.
- Greening, L.A., Bernow, S., 2004. Design of coordinated energy and environmental policies: use of multi-criteria decision-making. *Energy Policy* 32 (6), 721–735.
- Hamilton, K., Atkinson, G., Pearce, D., 1997. Genuine Savings as an Indicator of Sustainability. CSERGE Working Paper GEC 97-03.
- Hanley, N., Moffatt, I., Faichney, R., Wilson, M., 1999. Measuring sustainability: a time series of alternative indicators for Scotland. *Ecological Economics* 28, 55–73.
- Harger, J.R.E., Meyer, F.M., 1996. Definition of indicators for environmentally sustainable development. *Chemosphere* 33 (9), 1749–1775.
- Hauschild, M., Wenzel, H., 2000. Life cycle assessment – environmental assessment of products. In: Jørgensen, S.E. (Ed.), *A Systems Approach to the Environmental Analysis of Pollution Minimization*. Lewis Publishers, Boca Raton, pp. 155–189.
- Herendeen, R., 2004. Energy analysis and emergy analysis — a comparison. *Ecological Modelling* 178, 227–237.
- Hovelius, K., 1997. Energy-, Exergy- and Emergy Analysis of Biomass Production. Report, vol. 222. Swedish University of Agricultural Sciences, Uppsala.
- Huetting, R., Bosch, P., de Boer, B., 1993. Methodology for the calculation of sustainable national income. *Environmental Accounting. A review of the current debate*. A. Markandya and R. Costanza, United Nations Environment Programme.
- Johansson, P.-O., 1996. *Cost-benefit Analysis of Environmental Change*. Cambridge University Press, Cambridge.
- Joliet, O., Müller-Wenk, R., Bare, J., Brent, A., Goedkoop, M., Heijungs, R., Itsubo, N., Pena, C., Pennington, D.W., Potting, J., et al., 2004. The LCIA midpoint-damage framework of the UNEP/SETAC life cycle initiative. *International Journal of Life Cycle Assessment* 9 (6), 394–404.
- Kann, A., Weyant, J.P., 2000. Approaches for performing uncertainty analysis in large-scale energy/economic policy models. *Environmental Modeling and Assessment* 5, 29–46.
- Kasemir, B., Jaeger, C.C., Jäger, J., 2003. Citizen participation in sustainability assessment. In: Kasemir, B., Jäger, J., Jaeger, C.C., Gardner, M.T. (Eds.), *Public Participation in Sustainability Science*. Cambridge University Press, Cambridge, pp. 3–36.
- Kates, R.W., Clark, W.C., Corell, R., Hall, M.J., Jaeger, C.C., Lowe, I., McCarthy, J.J., Schellnhuber, H.J., Bolin, B., Dickson, N.M., et al., 2001. Sustainability science. *Science* 292, 641–642.
- Kates, R.W., Parris, T., Leiserowitz, A., 2005. What is sustainable development? Goals, indicators, values and practice. *Environment* 47, 8–21.
- Kelly, P.M., 2000. Theory and practice in assessing vulnerability to climate change and facilitating adaptation. *Climatic Change* 47 (4), 325–352.
- Kleijn, R., 2001. Adding it all up. The sense and non-sense of bulk-MFA. *Journal of Industrial Ecology* 4 (2), 7–8.
- Klöppfer, W., 2003. Life-cycle based methods for sustainable development (editorial). *International Journal of Life Cycle Assessment* 8 (3), 157–159.
- Lammers, P.E.M., Gilbert, A.J., 1999. Towards Environmental Pressure Indicators for the EU: Indicator Definition. EUROSTAT, Brussels.
- Lind, N., 2004. Values reflected in the human development index. *Social Indicators Research* 66, 283–293.
- Lindfors, L.-G., 1995. Nordic Guideline on Life-Cycle Assessment. Nord 20.
- Lindqvist, A., von Malmborg, F., 2004. What can we learn from local flow analyses? The review of cadmium flows in Swedish municipalities. *Journal of Cleaner Production* 12, 909–918.
- Lopes, E., Dias, A., Arroja, L., Capela, I., Pereira, F., 2003. Application of life cycle assessment to the Portuguese pulp and paper industry. *Journal of Cleaner Production* 11, 51–53.
- Lunghi, P., Bove, R., Desideri, U., 2004. Life-cycle-assessment of fuel-cells-based landfill gas energy conversion technologies. *Journal of Power Sources* 131 (1–2), 120–126.
- Matthews, E., Bringezu, S., Fischer-Kowalski, M., Huetler, W., Kleijn, R., Moriguchi, Y., Ottke, C., Rodenburg, E., Rogich, D., Schandl, H., et al., 2000. The Weight of Nations. Material outflows from industrial economies. World Resource Institute, Washington.
- Moberg, Å., 1999. *Environmental Systems Analysis Tools: Differences and Similarities*. Institution for Systems Ecology. Stockholm University, Stockholm, p. 83.
- Moberg, Å., Finnveden, G., Johansson, J., Lind, P., 2005. Life cycle assessment of energy from solid waste—part 2: landfilling compared to other treatment methods. *Journal of Cleaner Production* 13 (3), 231–240.
- Nilsson, D., 1997. Energy, exergy and emergy analysis of using straw as fuel in district heating plants. *Biomass and Bioenergy* 13 (1/2), 63–73.
- O'Brien, K., Sygna, L., Haugen, J.E., 2004. Vulnerable or resilient? A multi-scale assessment of climate impacts and vulnerability in Norway. *Climatic Change* 64 (1–2), 193–225.
- Odum, H.T., 1996. *Environmental Accounting. EMERGY and Environmental Decision Making*. John Wiley & Sons, Toronto.
- Partidario, M.R., 1999. Strategic environmental assessment — principles and potential. In: Petts, J. (Ed.), *Handbook of Environmental Impact Assessment*. Vol 1 Environmental

- Impact Assessment: Process, Methods and Potential. Blackwell Science, Oxford, pp. 60–73.
- Pearce, D., Turner, K.R., Bateman, I., 1994. Environmental Economics. Harvester Wheatsheaf, London.
- Petts, J., 1999. Handbook of Environmental Impact Assessment. Environmental Impact Assessment in Practice: Impact and Limitations. Blackwell Science, Oxford.
- Pope, J., Annandale, D., Morrison-Saunders, A., 2004. Conceptualising sustainability assessment. *Environmental Impact Assessment Review* 24, 595–616.
- Prescott-Allen, R., 2001. The Wellbeing of Nations. A Country-by-Country Index of Quality of Life and the Environment. Island Press, Washington.
- Rosen, M., Dincer, I., 2001. Exergy as the confluence of energy, environment and sustainable development. *Exergy International Journal* 1 (1), 3–13.
- Ross, S., Evans, D., 2002. Use of life cycle assessment in environmental management. *Environmental Management* 29 (1), 132–142.
- Rotmans, J., 1998. Methods for IA: the challenges and opportunities ahead. *Environmental Modeling and Assessment* 3, 155–179.
- Sadler, B., 1999. Framework for environmental sustainability assessment and assurance. In: Petts, J. (Ed.), *Handbook of Environmental Impact Assessment. Vol 1 Environmental Impact Assessment: Process, Methods and Potential*. Blackwell Science, Oxford, pp. 12–32.
- Spangenberg, J. H., Femia, A., Hinterberger, F. Schütz, H., 1999. Material Flow-based Indicators in Environmental Reporting. *Environmental Issues Series*, European Environment Agency. No 14: 58.
- Turner, B.L., Kaspersen, R., Matson, P.A., McCarthy, J.J., 2003. A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of the United States of America (PNAS)* 100 (14), 8074–8079.
- U.S. National Research Council, 1999. *Our Common Journey: a transition toward sustainability*. National Academy Press, Washington DC.
- Udo de Haes, H.A., Heijungs, R., Suh, S., Huppel, G., 2004. Three strategies to overcome the limitations of life-cycle assessment. *Journal of Industrial Ecology* 8 (3), 19–32.
- UNCSD, 2001. *Indicators of Sustainable Development: Guidelines and Methodologies*. United Nations, New York.
- UNDP, 2004. *Human Development Report. Cultural Liberty in Today's Diverse World*. United Nations Development Programme, New York.
- United Nations, 2002. *National Implementation of Agenda 21: A report*. New York, Department of Economic and Social Affairs, Division for Sustainable Development, National Information Analysis Unit, United Nations.
- Wackernagel, M., Rees, W.E., 1996. *Our Ecological Footprint. Reducing Human Impact on the Earth*. New Society Publishers, Gabriola Island.
- Walker, J., Johnston, J., 1999. *Guidelines for the Assessment of Indirect and Cumulative Impacts as well as Impact Interactions*. Office for Official Publications of the European Communities, Luxembourg.
- Wall, G., 1977. Exergy — A resource concept within resource accounting. Report, vol. 77-42. Göteborg, Institute of Theoretical Physics, p. 58.
- Wall, G., 1990. Exergy conversion in Japanese society. *Energy* 15 (5), 435–444.
- Wall, G., 1997. Exergy Use in the Swedish Society 1994. International Conference on Thermodynamic Analysis and Improvement of Energy Systems, TAIES'97, Beijing, China, Jun 10–13, 1997 Beijing World.
- WCED, 1987. *Our Common Future*. Oxford University Press, Oxford.
- Venetoulis, J., Chazan, D., Gaudet, C., 2004. *Ecological Footprint of Nations. Redefining Progress*.
- Wilkinson, D., Fergusson, M., Bowyer, C., Brown, J., Ladefoged, A., Monkhouse, C. Zdanowicz, A., 2004. *Sustainable Development in the European Commission's Integrated Impact Assessments for 2003*. London, Institute for European Environmental Policy.
- Vose, D., 2000. *Risk Analysis. A quantitative guide*. John Wiley & Sons, Chichester.
- Wrisberg, N., Udo de Haes, H.A., Triebswetter, U., Eder, P., Clift, R., 2002. *Analytical tools for an environmental design and management in a systems perspective. Eco-efficiency in Industry and Science*. Kluwer Academic Publishers, Dordrecht.