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Survey on the Environmental Efficiency Assessment Methods and Indicators

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Abstract

At present, environmental perfomance is a major factor for companies not only due to the environmental regulations but also the environmental awareness of consumers. How to measure and indicate environmental performance is therefore a key question. In the MMEA (Measurement, Monitoring and Environmental Assessment) research programme, the term Environmental Effciency (EE) was adopted to describe the environmental performance of production processes and companies. In MMEA, EE is understood as a broad concept and to include practically the same components than sustainability, i.e. environmental, technical, economic and social aspects, but to be synonymous to the concept of environmental performance. What is understood by environmental efficiency varies in the literature, however, and even though the term is used in some context, it has seldom been been explicitly defined. Moreover, there are different methods to assess EE. Life cycle analysis (LCA) is most commonly used as a basis for assessing the environmental performance of industries and companies. Other methods include material flow analysis, data envelopment analysis, as well as cost-benefit analysis and other equivalent methods that combine economic aspects with environmental aspects. Hazard and risk analysis provide complementing and specific information on the (potential) hazards to workers and other human recipients and/or the environment. Since the methods vary, also the measures, i.e. indicators, of environmental performance as well as sustainability vary and include different indicator sets and indexes related to a specific environmental consequence (e.g. climate change), resource use (e.g. water footprint), eco-efficiency measures, LCA impact catergories, and composite sustainability indexes which aim to aggregate all sustainability factors into a single figure. In addition, certificates and ecolabels are used to inform on the environmental performance/efficiency. In practice, depending on the industry, a certain environmental factor, such as energy use, material use, or emissions, generally drives the environmental performance. What is to be measured in monitoring and assessing of EE should therefore be defined case-by-case.

Helsinki, September 2011

Abbreviations

AHP analytical hierarchy process
BAT best available technology
CBA cost benefit analysis
CDP Carbon Disclosure Project
CDLI Carbon Disclosure Leadership Index
CDPI Carbon Performance Leadership Index
CEA cost effectiveness analysis
CED cumulative energy demand
CEI Chemical Exposure Index
CERA cumulative energy requirements analysis
CF carbon footprint
CPLI Carbon Performance Leadership Index
DEA data envelopment analysis
DfE design for environment
DJSI Dow Jones Sustainability Index
DMU decision making unit
DST decision support tool
ECI Environmental Condition Indicator
EE environmental efficiency
EEA environmental efficiency assessment
EMAS eco-management and auditing scheme
EMS environmental management system
EPC energy performance certificate
EPD environmental product declaration
EPI Environmental Performance Index
ESI Environmental Sustainability Index
FEI Fire and Explosion Index
FETI Fire, Explosion and Toxicity Index
FMEA Failure Modes & Effects Analysis
FTA Fault Tree Analysis
FU functional unit
GHG green house gas
GP green productivity
GRI global reporting initiative
GWP global warming potential
HA hazard assessment/analysis
HAZOP Hazard And Operability Method
HI hazard index

HQ hazard quotient

ICSD Composite Sustainable Development Index

IED Industrial Emissions Directive

ILCD International Reference Life Cycle Data System

IFAL instantaneous fractional annual loss

IPPC integrated pollution prevention and control

ISO International Organisation for Standardisation

LCA life cycle analysis

LCC life cycle costing

LCCA life cycle cost analysis

LCIA life cycle impact assessment

LEED Leadership in Energy and Environmental Design

MCA multi-criteria analysis

MFA material flow analysis

MEPI Measuring Environmental Performance of Industry

MIPS material input per unit of service

MMEA Measurement, Monitoring and Environmental Assessment

MORT Management Oversight and Risk Tree

MSEE management systems for environmental efficiency

NAMEA national accounting matrix including environmental accounts

NGO non-governmental organization

OECD Organisation for Economic Cooperation and Development

PHA process hazard analysis

POC point of compliance

RA risk assessment/analysis

RCA root-cause analysis

ROE return on environment

SAM sustainability asset management

SFA substance flow analysis

SETAC Society of Environmental Toxicology and Chemistry

SWeHI safety weighted hazard index

TMR total material requirement

UNEP United Nations Environment Programme

USEPA United States Environmental Protection Agency

WBCSD World Business Council for Sustainable Development

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1 Introduction

1.1 The concept of Environmental Efficiency (EE)

Environmental efficiency (EE) is a term that has been used in various contexts, but it has seldom been explicitly defined, however. The European Ecodesign Directive (EU 2009b) and the national act (Laki 1009/2010) issued pursuant to it define environmental performance of a product ”the results of the manufacturer’s management of the environmental aspects of the product, as reflected in its technical documentation file”. The requirements for evidence and documentation of the targets and indicators of environmental performance are further set in the recent Government decree on the requirements for the ecological design of products (VnA 2010). In all these provisions, the term ’environmental performance’ is used instead of ’environmental efficiency’ to describe the Finnish equivalent ’ympäristötehokkuus’. Based on this, these terms can be considered synonyms. From the operational viewpoint, what is specifically meant by EE seems to vary depending on the context and industrial field (Table 1).

In this study, environmental efficiency is understood as a broad concept and measures to improve it would therefore include all end-of-pipe solutions, pollution prevention processes and other activities to protect and conserve the environment and society[1] on site and off site by

- minimizing the use of energy and raw materials and natural resources, enhancing energy efficiency and material efficiency (by means of process optimization, among others);
- favoring renewable energy sources and raw materials with the lowest adverse environmental impacts:
- minimizing harmful emissions to air, water and soil;
- minimizing wastes to be disposed of and maximizing their reuse and recycling;
- retaining or restoring the quality of the environment, e.g. by managing accidental releases, and rehabilitating contaminated sites;
- considering the environmental impacts along the whole life-cycle; and
- taking into account that the activities to protect the environment do not entail excessive costs (profitability aspects).

The above definition is almost synonymous to the term sustainability, the major difference being that the temporal aspect is not emphasized. Environmental efficiency assessment (EEA) is considered a process to assess the environmental efficiency including

- determination of the scope and goal of EEA,
- data collection and processing,
- environmental impact assessment, and
- characterization/interpretation of EE.

In practice, the key element of EE can vary depending on the industrial activity or product to be assessed and therefore, the measures of EE, i.e. EE indicators, can case-specifically vary. Thus, no unambiguous EE indicator set exist even though several generic indicators are used that imply specific environmental impacts, such as carbon footprint and water footprint.

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[1] including any activities to minimize adverse effects to human welfare arising from harmful chemicals, noise, smell or vibration, with welfare covering also social aspects (when relevant).

Table 1. *Example of the factors included in the concept of environmental efficiency (EE, 'ympäristötehokkuus') by some Finnish companies, industries and organizations.*

Organization/ industry/ company	Description	EE factors considered	Source
The Federation of Finnish Technology Industries (Teknologiateollisuus ry)	Central organization for technology industries[a]	minimization of emissions (focus), energy efficiency (focus), material efficiency	http://www.teknologiateollisuus.fi > palvelut > Ymparistolinjaus
Nordic ecolabel	Authority granting environmental labels for products, all industries	material efficiency (including maximization of the use of renewable natural resources), energy efficiency, increasing the recyclability of products	Pohjoismainen ympäristömerkintä 2000
Lahti Science and Business Park	Environmental technology park, all industries	energy efficiency, material efficiency, longer life time and better recyclability of goods and services	Lahti Science and Business Park 2010
Construction industry	Building	energy efficiency as indicated by the LEED certificate[b]	several references, e.g. http://www.fi.issworld.com > Palvelumme > Monipalvelu > Ympäristötehokas kiinteistö
SKANSKA	Service provider in construction field	responsible construction, exceeding of regulatory requirements,energy efficiency, material efficiency (e.g. minimization of waste and use of clean water), avoidance of harmful materials	Mettälä 2010
RAISIO	Manufacturer of processed food	net energy loss (energy efficiency)	Laurinen 2010
The Federation of the Brewing and Soft Drinks Industry (Panimoliitto)	Central organization for brewing and soft drinks Industry	Components of the environmental balance: use of water, energy, raw materials, packing materials; waste water and air emissions; wastes (reused, recycled, disposed)	http://www.sinebrychoff.fi > Yhtiö > Ympäristö > Panimoliiton ympäristötase
Metsä Botnia	Forest industry company	compliance with environmental management system, minimization of emissions	Metsä-Botnia 2008
Wärtsilä	Supplier of power solutions for the marine and energy markets	reduction of emissions, compliance with regulations considering cost efficiency, effectiveness, life time and reliability of environmental solutions, minimization of interruptions due to such installations, use of sustainable solutions	http://www.wartsila.com > services & support > Environmental efficiency
Finavia	Service company that maintains airports and the air navigation system	energy efficiency, minimization of emissions (including noise) and fuel consumption, required infrastructure	http://www.finavia.fi > Media > Tiedotearkisto > Tiedotteet vuodelta 2009

[a] *covers the following industries: electronics and electricity, metals refining, manufacturing of machinery and metal products, information tehnology*

[b] *for the description of the LEED certificate see chapter 4.5.8*

1.2 Approaches to Environmental Efficiency Assessment (EEA)

EEA includes several competing methods that produce different results for differing purposes. At the same time, the assessment procedures are still in progress.

At present, there are two main approaches to assess EE that are applied globally and in Finland. In the production (or services) oriented approach, the EEA is conducted for optimizing a certain process in a production plant or the performance of the whole plant. This pollution prevention approach corresponds to the so-called integrated assessment involved in the environmental permit process that is enacted in the Industrial Emissions Directive[2]. In this process, the on-line measurement and monitoring of emissions and controlling the state of the surrounding environment are typically needed. Hence, in production/services oriented approach EEA relies on site-specific monitoring and measurement data.

The alternative approach focuses on the whole product chain using life cycle thinking, i.e. it is based on life cycle analysis (LCA). In this approach, the aim is to evaluate the environmental performance of products and services by considering the environmental effects associated with all stages of the life cycle and aggregating these to an estimate of the total impact. The environmental information used in the LCA approach typically involves more generic annual data on emissions and other environmental load (e.g. land use). Currently LCA only covers global and regional environmental aspects and hence, excludes local impacts that play an important role in the production/services oriented approach. Since the production/services oriented and the LCA-based approaches rely on different data of differing scale and elaborateness there is clearly a need to interconnect these approaches within a management system to produce EE information that is associated with the actual on site and the related off site product/service chains, such as off site production of energy used in the process. In practice, the integration of the two main approaches for EEA and establishing a management system for environmental efficiency (MSEE) is a challenging task. Owing to the diversity of the input data and required output, such MSEE must be able to both use and produce information that has various forms and varying accuracy.

The major challenge in EEA is to integrate the generic data on the environmental impacts of products/production generally used in LCA, and site-specific monitoring and measurement, as well as process data, generated by companies, various research institutes and environmental administration. While the companies focus on producing data on their process for use in their process control, automation and reporting to authorities, public parties produce site-specific and regional data for registers and for monitoring the overall quality of the environment. In order to utilize this information in company-specific EEA, the information needs to be traceable to the emissions of a specific industrial plant. The data used in EEA should also be comprehensive and valid, and it should depict the environmental impacts truthfully. Therefore, efficient utilization of EEA results, e.g. in developing and modifying processes or products and in business planning necessitates the existence of a system to verify the data involved. Moreover, optimization and focusing the future EEA activities requires that the key EE indicators, i.e. the indicators that represent the most significant environmental impacts arising from the process/products/services during the whole life cycle, are defined case-by-case.

Internationally, the practices and methods for assessing the performance, sustainability or eco-efficiency of industrial activities are being intensively developed. Here, particularly the R&D work of LCA techniques, BAT (best available technology/techniques) criteria, and various decision support tools[3] (DST) is relevant from the

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[2] European Commission enacted the IED in July 2010. IED covers the regulations previously included in the Integrated Pollution Prevention and Control (IPPC) directive.

[3] DSTs are tools that support informed decision-making by presenting information in an integrated, interactive manner.

viewpoint of EEA and needs to be considered when developing company- or industry-specific EEA practices. The DSTs developed for assessing the environmental performance of companies, production units or other entities are based on different decision theories and analysis methods, such as data envelopment analysis (DEA). While DEA and many other case-specific DSTs may originally have been designed rather for optimizing the profitability, similar techniques could be applied in EEA.

1.3 Aim of this study

This study comprised a survey on the available methods to conduct EEA and indicators to measure EE. The study belongs to the Work Package (WP) 2 entitled ”Management systems for environmental efficiency” of the Monitoring, Measurement and Environmental Efficiency Assessment (MMEA) research programme[4]. The results would provide the basis for conducting company-specific or process-specific EEAs for the specific companies participating in WP2. Therefore, the focus of the survey was on indicators used at the company level and site level. Thus, various European and country level indicators, such as the sustainability indicators used in the European statistics (Eurostat[5]); indicators to describe the state of European Environment and used by the European Environment Agency[6]; key environmental indicators provided by the OECD (OECD 2008); and equivalent sustainability indicators developed in different institutes and countries, e.g. in the International Institute for Sustainable Development (IISD[7]), in the United Nations Department of Economic and Social Affairs, Division for Sustainable Development[8], and in the Finnish Environment Institute (SYKE) Finland[9], are not presented here. Moreover, the focus is on the environmental dimension of EE. The methods to account for social factors, such as employment, equity, economic welfare, human rights and ethics are therefore not studied. Some of these factors are in fact merely important at the society level rather than at the company level.

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[4] See http://www.cleen.fi/research/index.php/MMEA

[5] Available at: http://epp.eurostat.ec.europa.eu/portal/page/portal/sdi/indicators

[6] Available at: http://www.eea.europa.eu/data-and-maps/indicators/#c7=all&c5=&c0=10

[7] http://www.iisd.org/

[8] http://www.un.org/esa/dsd/index.shtml

[9] http://www.ymparisto.fi/default.asp?node=15131&lan=en

2 Sustainability elements

2.1 General definitions of sustainability

Environmental sustainability refers to the long-term maintenance of valued environmental resources in an evolving human context (Esty et al. 2005). It is a characteristic of dynamic systems that maintain themselves over time and therefore, not a fixed endpoint that can be defined. Consequently, in sustainable development the world should be understood as a spatially and temporally connected system[10]. This means understanding that, for example air pollution from USA affects the air quality in Asia and that the present industrial activities cause environmental issues in the future.

Several definitions have been presented to describe the principle of sustainable development, the most frequently quoted being the one presented in the Brundtland Report (Bruntland 1987). According to this report sustainable development is ”development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:

- the concept of *needs*, in particular the essential needs of the world’s poor, to which overriding priority should be given; and
- the idea of *limitations* imposed by the state of technology and social organization on the environment’s ability to meet present and future needs.”

More operational principles of sustainability were presented by the former Chief Economist for the World Bank, Herman E. Daly. These principles are known as Daly’s rules and they define the condition of ecological sustainability:

- renewable resources such as fish, soil, and groundwater must be used no faster than the rate at which they regenerate;
- nonrenewable resources such as minerals and fossil fuels must be used no faster than renewable substitutes for them can be put into place; and
- pollution and wastes must be emitted no faster than natural systems can absorb them, recycle them, or render them harmless (Smith 2010).

Due to the multidisciplinary character (see chapter 2.2), dynamics and varying spatial and temporal dimensions, there is no absolute or universal measure of sustainability. Sustainability should also be understood as a relative concept implying the mutual differences in the overall performance among companies or processes.

2.2 Dimensions of sustainability

Sustainability is an integrated concept, which combines three separate dimensions: environmental, social and economic aspects.

Environmental dimension is characterized by terms that describe environmental performance, the aim being minimization of the use of hazardous or toxic substances, resources and energy (Glavič and Lukman 2007). Sometimes ”ecological principles” are linked to environmental principles in order to understand the relationships between natural ecosystems because similar relationships are being documented and developed in the industrial environment. Industrial symbiosis seems to be the most common of such relationships. Collaboration and the synergistic possibilities offered by geographic proximity are the key factors of industrial symbiosis (Salmi 2007).

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[10] IISD (International Institute for Sustainable Development). What is sustainable development? Available at http://www.iisd.org/sd/.

Economic dimension refers to more efficient use of materials and energy in order to provide profitability and the creation of added value (Glavič and Lukman 2007). Eco-efficiency is presumably the most well-known indicator to indicate economic value in relation to environmental development. According to the definition of the World Business Council for Sustainable Development (WBCSD) eco-efficiency is ”the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life cycle, to a level at least in line with the earth’s estimated carrying capacity” (WBCSD 2000a). In monitoring the environmental performance of industries, the European Commission understands eco-efficiency as the ratio of economic profit to environmental pressures, which can be measured as polluting emissions or resource use (CEC 2002). Hence, eco-efficiency is based on the concept of ‘‘doing more with less’’and it is described by the ratio of economy to the environment or vice versa.

Societal dimension is characterized by terms such as Social Responsibility, Health and Safety, and ‘‘Polluter pays’’ principle (Glavič and Lukman 2007). Social responsibility refers to safe, respectful, liberal, equitable and equal human development, contributing to humanity and the environment. The term ”Health and safety” usually refers to the working environment and includes responsibilities and standards. According to the ”Polluter pays” principle those causing pollution should pay the costs of any consequences (e.g. Glossary of Environment Statistics 1997). Thus, the polluter pays for environmental damage in the form of a clean-up or taxation. In practice, this principle is usually overlooked, however. Societal dimension also covers reporting to the stakeholders in order to share the progress, results and planning with the general public. Here, the Global Reporting Initiative (GRI)[11] has the leading role since it provides all organizations a framework for reporting on their performance.

In practice, there are several challenges for attaining sustainability, which can pertain to all its components (Table 2). Technical aspects such as availability of equipment, quality control, customer and supplier satisfaction, labour’s productivity, delivery compliance and development of new products, as well as organizational governance, for example investment and strategic planning, process management and technological parameters, leadership and expenditure on R&D, can all create additional challenges (Singh 2008).

Table 2. *Sustainability challenges, example from a typical steel industry (modified from Singh 2008).*

Sustainability categories	**Sustainability Challenges**
Economic	Financial robustness, Cost Competitiveness, Cost of product, Stock price, Exports, Value added (% of revenue), Operating cost, Return on capital employed, Revenue growth, cost of capital, Turnover, Profitability, Investment on new products and processes, Return on capital employed
Environment	Energy use and efficiency, Resource efficiency, Waste management and recycling, Land requirements, Biodiversity, Air pollution, Eco-design, Effluent quality, Use of ozone depleting substances, Hazardous waste management
Social	Stakeholder engagement and accountability, Quality of life, Expenditure on community development, Health and safety aspects of employees, Public perceptions, Code of conduct and ethics, Education, Health and infrastructure, Value creating partnership. Human rights issues, Job opportunities, Labour practices and management relations, Freedom of association, Customer health and safety

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[11] www.globalreporting.org; the environmental indicators considered in this system are presented in chapter 4.1.4

2.3 Hierarchical structure of sustainability

Various terms are used in the context of sustainability and these terms can be structured hierarchically. Firstly, the three dimensions, i.e. Environmental/Ecological, Economic and Societal Principles, are the fundamental elements that serve as a basis for a framework of sustainability (Glavič and Lukman 2007). Thus, these principles can be called the ”Three Dimensions” or ”Pillars of Sustainability” and they lie at the lowest level of the hierarchy (Figure 1). Glavič and Lukman (2007) added *sustainability policy* as a fourth dimension when defining sustainability terms. They defined ”Sustainability policy” as a set of ideas or an action plan agreed officially by a group of people, a business organization, a government or a political party.

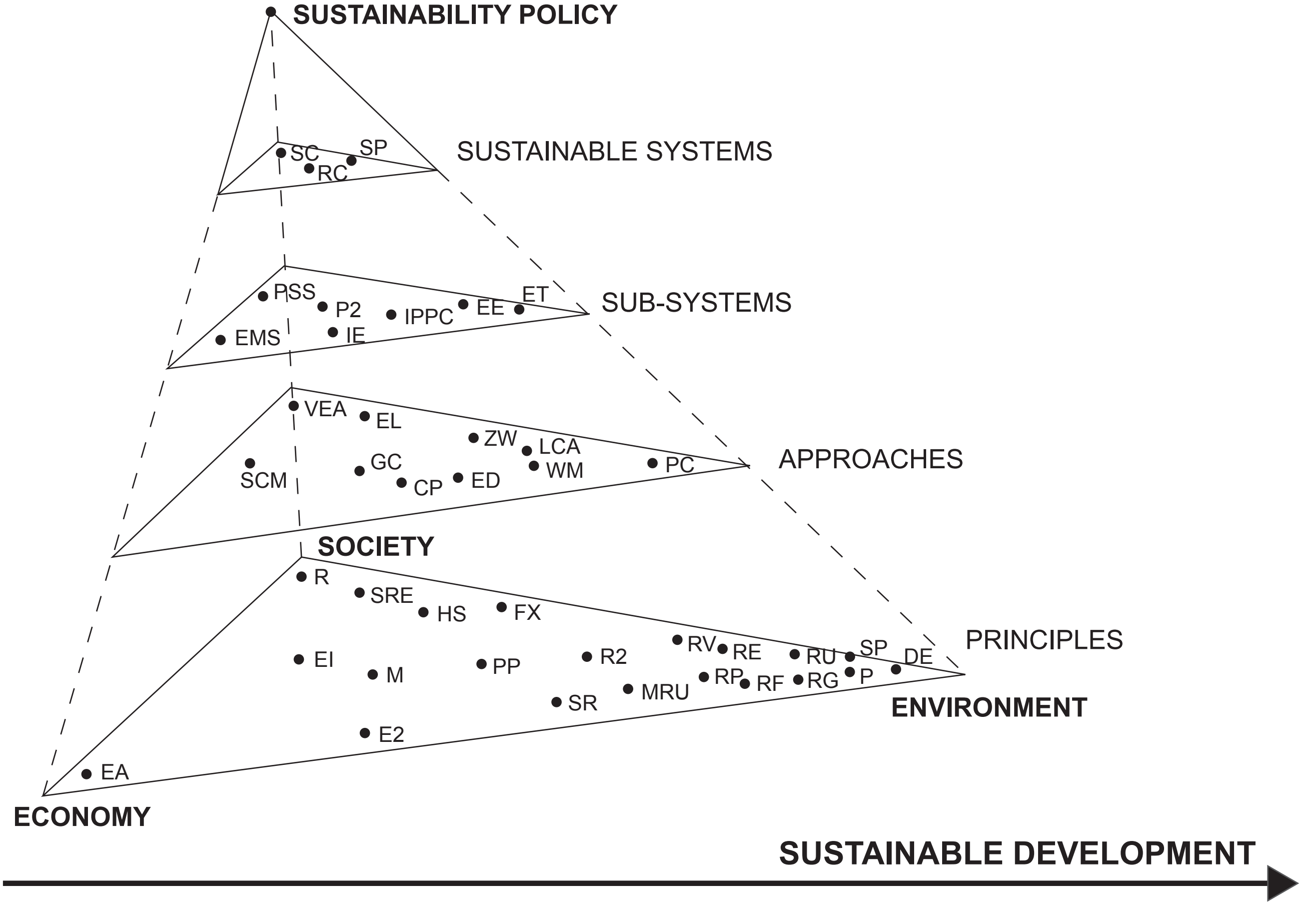

Figure 1. *Classification of sustainability oriented terms (Glavič and Lukman 2007).*

Environmental principles: R2 = renewable resources, RF = remanufacturing, MRU = minimization of resource usage, SR = source reduction, RE = recycling, RU = reuse; RP = repair, RG = regeneration, RV = recovery, P = purification, DE = degradation; Ecological principles: M = mutualism;

Economic principles: EA = environmental accounting, E2 = eco- efficiency, FX = factor X, EI = ethical investment;

Societal principles: HS, health and safety, SRE = social responsibility, PP, = polluter pays, R = reporting to the stakeholders;

Environmental approaches: PC = pollution control, CP = cleaner production, ED = eco-design, GC = green chemistry, LCA = life cycle analysis, WM = waste minimization, ZW = zero waste;

Economic and societal approaches: EL = environmental legalization, VEA = voluntary environmental agreement, SCM = supply chain management;

Environmental sub-systems: EE = environmental engineering, ET = environmental technology, IPPC = integrated pollution prevention and control, IE = industrial ecology, P2 = pollution prevention;

Economic and societal sub-systems: EMS = environmental management system, PSS = product service system;

Sustainability systems: RC = responsible care, SP = sustainable production, SC = sustainable consumption.

Sustainability policy is important on institutional, corporate, as well as on regional, state, and alliance level and can thus be locally, nationally or internationally oriented and address issues such as sustainable development, climate change, air, water, waste, and health, among others. At the European level, the European Commission has presented Declaration on Guiding Principles for Sustainable Development (CEC 2005).

At the next levels of the hierarchy, above the three principles, lie the Environmental Approaches (= Tactics) and Environmental Sub-systems (= Strategies). The broader term embracing all principles, approaches and sub-systems is known as Sustainable System.

Although sustainability requires consideration of all the three principles, i.e. environmental, economic and social, the environmental dimension is the major element as to EEA. The following chapters therefore focus on discussing the environmental/ecological principles of sustainability in more detail.

2.3.1 Sustainable systems

Sustainable systems include the highest level of activities required in order to make progress towards sustainable development (Glavič and Lukman 2007). The achievement of such objectives requires a change in thinking patterns and lifestyles. The level of sustainable systems encompasses the terms of sustainable production, responsible care and sustainable consumption.

Sustainable production means creating goods by using processes and systems that are non-polluting; conserve energy and natural resources in economically viable, safe and healthy ways for employees, communities, and consumers; and are socially and creatively rewarding for all stakeholders in the short and long time perspective.

Responsible care is the chemical industry's global voluntary performance guidance system, which shares a common commitment to advancing the safe and secure management of chemical products and processes[12]. The term involves environmental management systems as well as product service systems and it encompasses employees, transportation and process safety, releases into the environment, distribution incidents, and eco-efficiency, among other things. 'Responsible care' system also requires that the companies openly communicate their environmental performance to the public. Practices of implementation may vary between countries, and legislation does not determine them. Therefore, 'Responsible care' enables companies to go above and beyond regulatory requirements.

Sustainable consumption is about finding workable solutions to social and environmental imbalances through more responsible behavior by everyone. In particular, sustainable consumption is linked to production and distribution, use and disposal of products and services, and provides the means to rethink personal life cycles. The aim is to ensure that the basic needs of the entire global community are met, excess consumption of materials and energy is reduced and environmental damage is avoided or reduced. The term embraces industrial ecology and product service systems.

2.3.2 Environmental sub-systems (strategies)

Various strategies exist which aim to prevent environmental degradation. These include the strategy of integrated pollution prevention and control; industrial ecology; and environmental management systems (Glavič and Lukman 2007).

Integrated pollution prevention and control (IPPC) is a system that applies an integrated environmental approach to the regulation of certain industrial activities[13].This means that emissions to air, water and land, plus a range of other envi-

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[12] http://www.responsiblecare-us.com

[13] http://www.ymparisto.fi > Yritykset ja yhteisöt > Ekotehokkuus > Yhdennetty päästöjen ja vaikutusten hallinta teollisessa toiminnassa - IPPC

ronmental effects, are considered together and through a single permitting process. IPPC means that regulators must set permit conditions in order to achieve a high level of protection for the environment as a whole. The industries and agricultural activities requiring the permit were listed in the IPPC Directive of the European Commission from 1996. The permit conditions set by the authorities should be based on the BAT principle, which balances the costs to the operator against the benefits to the environment. The best available techniques for different industries are defined in reference documents (BREFs) produced by the European IPPC Bureau.

The IPPC Directive was superseded by the Industrial Emissions Directive (IED) in 2010. The IED recasted altogether seven existing directives related to industrial emissions, thereby integrating them into a single clear and coherent legislative instrument (EU 2010). IED entered into force on 6 January 2011. It applies strict limits on air pollution and sets rules designed to prevent, or where that is not practicable to reduce, emissions into air, water and land and to prevent the generation of waste.

The IED also

- improves and clarifies the concept of BAT to create a more coherent application of the IPPC system and requires decisions allowing permit conditions outside the scope of BAT to be justified and documented;
- tightens current minimum emission limit values of pollutants such as nitrogen oxides, sulphur dioxide and dust in some sectors;
- introduces minimum standards with regard to the inspection and review of permit conditions and compliance reporting;
- provides incentives for eco-innovation and support for the creation of lead markets;
- extends the scope of the IPPC Directive to cover additional installations and clarifies its scope for certain sectors (e.g, waste treatment); and
- requires Member States to adopt general binding rules on the basis of BATs, without prescribing the use of any technique or specific technology. Member States must also ensure that these rules are kept up to date in light of future developments in the BATs. (Herbert Smith 2010)

Member States can, under certain circumstances, deviate from the BAT standard for certain technical reasons or local circumstances, as long as a high overall standard of environmental protection is maintained and it can be shown that the costs associated with the rules would be disproportionate relative to their environmental benefits. (EU 2010)

Industrial ecology is closely related to industrial ecosystems, in which the consumption of energy, raw materials, water and other resources is optimized. In ecology, an ecosystem consists of various complex environs and sub-systems. The most important issue is the interrelationships between environs. Therefore, an industrial ecosystem represents a group of enterprises that utilize each other’s materials and by-products so that waste materials are reduced to an absolute minimum.

Environmental management system (EMS) can be defined as ”a continual cycle of planning, implementing, reviewing and improving the actions that an organization takes to meet its environmental obligations” (e.g. Stapleton et al. 1996). EMS comprises a set of management tools and principles designed to guide the allocation of resources, assignment of responsibilities and evaluation of practices, procedures and processes. EMS also helps to consider any environmental concerns industries, companies, or government agencies need to integrate into their daily business or management practices. EMS ensures that environmental issues are systematically identified, controlled, and monitored. It provides a mechanism for responding to changing environmental conditions and requirements, reporting on environmental performance, and reinforcing continual improvement. Product oriented environmen-

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[14] http://www.iema.net/ems/emas

tal management system (POEM) is a specific type of EMS that focuses particularly on product development and (re)design (Goedkoop and Spriensma 2001).

Some standards have been developed to unify the EMS practices, the most common of these being the European ISO 14000 standards. In addition, the European Union (EU) has a voluntary instrument known as eco-management and auditing scheme (EMAS)[14], whose rules and verification practices are enacted in a separate regulation (EU 2009a). EMAS is the instrument within EU that acknowledges organizations, which improve their environmental performance on a continuous basis. EMAS was originally designed for enterprises within industrial/manufacturing sectors. In 2001 the Regulation of the European Parliament proposed to broaden the system to cover all organizations having environmental impacts, including public ones (EC 2001).

The ISO 14000 series is a family of environmental management standards developed by the International Organization for Standardisation (ISO)[15]. The ISO 14000 standards are designed to provide an internationally recognized framework for environmental management, measurement, evaluation and auditing. They do not prescribe environmental performance targets, but instead provide organizations with the tools to assess and control the environmental impact of their activities, products or services. The standards address the following principles: environmental auditing, environmental labeling and declarations, environmental performance evaluation, as well as the environmental management and LCA approaches.

2.3.3 Approaches

Approaches (tactics) contain a group of principles related to the same topic, building a more complex system (Glavič and Lukman 2007). Approaches are semantically broader than principles and they are organized within environmental, economic and societal dimensions. Strictly one-dimensional approaches do not exist, as in the case of principles, since approaches are connected to all other dimensions of sustainable development.

The term **environmental approach** is a concept-oriented term that encompasses pollution control, cleaner production, green chemistry, eco-design, LCA, waste minimization, and zero waste. All the terms incorporate the elementary principles and activities, showing how to apply specific practices in order to contribute to improved industrial performance.

The concept **’cleaner production’** was first introduced by United Nations Environment Programme (UNEP) in Paris in 1989. Since then the definition has been expanded by adding the sustainable development aspect. Glavič and Lukman (2007) consequently proposed the following definition: cleaner production is ”a systematically organized approach to production activities, which has positive effects on the environment”. These activities include resource use minimization, improved eco-efficiency and source reduction, in order to improve the environmental protection and to reduce risks to living organisms. Van Berkel (2007) emphasizes that eco-efficiency and cleaner production are complementary concepts, with the former focusing on the strategic side of business (‘value creation’) and the latter on the operational side of business (‘production’). According to this definition, cleaner production and eco-efficiency (see also chapter 3.3) would be interchangeable terms. Cleaner production can be applied to processes used in any industrial sector and to products themselves (cleaner products). Cleaner production is generally understood to also cover services. However, Glavič and Lukman (2007) exclude services, because they define production as output, such as units generated in a factory, or the process of growing or manufacturing goods or materials, whereas service refers to conducting maintenance, supply, repair, installation, distribution, and other related work, or a system that provides something that the public needs, a business whose work involves doing something for consumers.

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[15] http://www.iso14000-iso14001-environmental-management.com/index.htm

Green chemistry, also known as sustainable chemistry, is the design of chemical products and processes that eliminate or reduce the use and generation of hazardous substances (Marteel et al. 2003). Moreover, green chemistry relies on a set of 12 rules that contain five principles: waste minimization, renewable resources, eco-efficiency, degradation of the environment, and health and safety. The overall objective is to design and modify chemical reactions to be clean and sustainable, while maintaining the current standard of living. Equivalently, **green engineering** comprises 12 principles and is an analogous term to green chemistry. Green engineering requires minimal depletion of natural resources instead of providing the use of renewable resources, however (Anastas and Zimmerman 2003). In addition to material safety and efficiency issues, life cycle thinking and assessments are highlighted along with creation of solutions beyond current or dominant technologies to achieve sustainability. The need of active engagement of communities and stakeholders in the development of engineering solutions is also important (Abraham and Nguyen 2003).

The 12 principles of green engineering include the following (Anastas and Zimmerman 2003):

- designers need to strive to ensure that all material and energy inputs and outputs are as inherently nonhazardous as possible
- it is better to prevent waste than to treat or clean up waste after it is formed
- separation and purification operations should be designed to minimize energy consumption and materials use
- products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency
- products, processes, and systems should be "output pulled" rather than "input pushed" through the use of energy and materials
- embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition
- targeted durability, not immortality, should be a design goal
- design for unnecessary capacity or capability (e.g., "one size fits all") solutions should be considered a design flaw
- material diversity in multicomponent products should be minimized to promote disassembly and value retention
- design of products, processes, and systems must include integration and interconnectivity with available energy and materials flows
- products, processes, and systems should be designed for performance in a commercial "afterlife"
- material and energy inputs should be renewable rather than depleting

Terms ’**eco-design**’[16] and ’**design for environment**’ (DfE) are understood as product development processes that take into account the complete life cycle of a product and consider environmental aspects at all stages of a process, and strive for products, which make the lowest possible environmental impact, i.e. improve the environmental performance, throughout the product’s life cycle (e.g. EU 2009b). The term eco-design encompasses eco-efficiency, health and safety, remanufacturing, recycling, source reduction, and waste minimization and it is linked with LCA (Glavič and Lukman 2007). The inclusion of environmental dimensions in product design and services also contributes to product innovations. European Union has issued a separate directive which sets the principles of eco-design requirements for energy-

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[16] Term ”ecoconscious design” is also used as a synonym.

[17] Energy-related product is ”any good that has an impact on energy consumption during use which is placed on the market and/or put into service, and includes parts intended to be incorporated into energy-related products… placed on the market and/or put into service as individual parts for end-users and of which the environmental performance can be assessed independently” (EU 2009)

using products[17] (EU 2009b). Products that comply with the ecodesign requirements in accordance to the Directive should bear the ‘CE’ marking and associated information. The United States Environmental Protection Agency’s (USEPA) Design for the Environment partnership program[18] is an equivalent approach to eco-design. It allows manufacturers of household and commercial products to put a DfE label on those products that meet the criteria set for protecting human and environmental health.

The principles of ecolabels are presented in more detail in chapter 4.5.7.

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[18] http://www.epa.gov/dfe/

3 Methods to assess sustainability and environmental efficiency

3.1 Life cycle assessment (LCA)

3.1.1 Principles

Life cycle thinking (LCT) identifies possible improvements to goods and services in order to reach lower environmental impacts and reduce the use of resources across all life cycle stages. Life cycle assessment (LCA) is a structured and globally standardized (ISO 14040/44) methodology based on life cycle thinking. This means that instead of assessing environmental impacts only for the main process the whole product chain is considered from extraction of raw materials to end-of-life treatment and final disposal of a product ('cradle to grave'- approach) (ISO 2006). The more restricted 'cradle to gate'- approach that involves extraction of raw materials, manufacturing, transportation, and energy purchase is the most popular way to conduct LCAs among industries, however. LCA is currently perhaps the most common method used for the quantitative environmental evaluation of products (goods and services).

LCA consists of four phases: 1) definition of goal and scope, 2) inventory analysis, 3) impact assessment, and 4) interpretation (Figure 2).

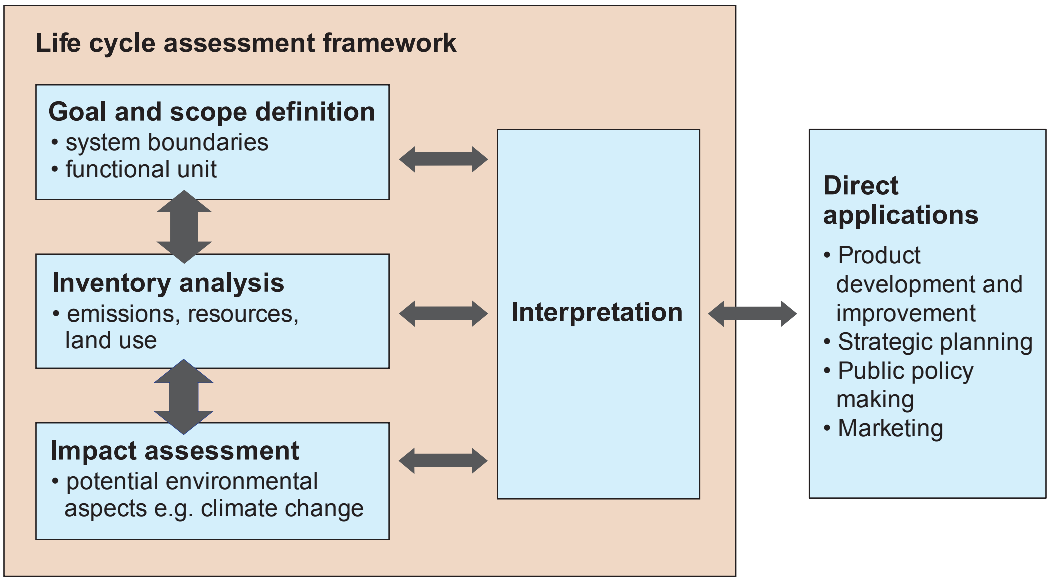

Figure 2. *Life cycle assessment framework and its utilization.*

The merit of LCA is that environmental performances of different products can be calculated on an equal basis. This also enables a comparison between products due to the definition of a similar functional unit (FU). FU is a quantified performance of a product system which is used as a reference unit, for example tons of product produced; its definition is a crucial step of LCA. LCA helps to avoid resolving one environmental problem while creating others elsewhere by taking a comprehensive approach in one consistent framework through:

- considering the entire life cycle of a product from the extraction of resources, through production, use, and recycling, up to the disposal of waste;
- quantifying resources consumed as well as emissions into air, water and soil that can be attributed to the product;

- providing indicators of the product's contribution to a wide range of environmental problems such as climate change, toxic pressures, and resource depletion.

The EU Commission provides very comprehensive guidelines for LCAs[19]. In addition, the European Platform on Life-Cycle Assessment has published the International Reference Life Cycle Data System (ILCD) handbook[20] to help policy-makers and businesses assess the environmental impact of products. The handbook was developed by the Institute for Environment and Sustainability in the European Commission Joint Research Centre (JRC), in co-operation with the Directorate-General for the Environment (DG Environment) of the EU Commission and it consists of five parts: 1) review, 2) life cycle inventory, 3) life cycle impact assessment, 4) general guidance for life cycle assessment, and 5) documentation, nomenclature and terminology. The main goal of the ILCD handbook is to ensure quality and consistency of life cycle data, methods and assessments. The main target audience is LCA practitioners, data providers, and reviewers.

Many life cycle based instruments have been derived based on LCA methodology, such as environmental management tools, indicators and indexes (Figure 3). The various indicators used to present LCA results (e.g. ecolabels, carbon footprint) are described in chapter 4.5.

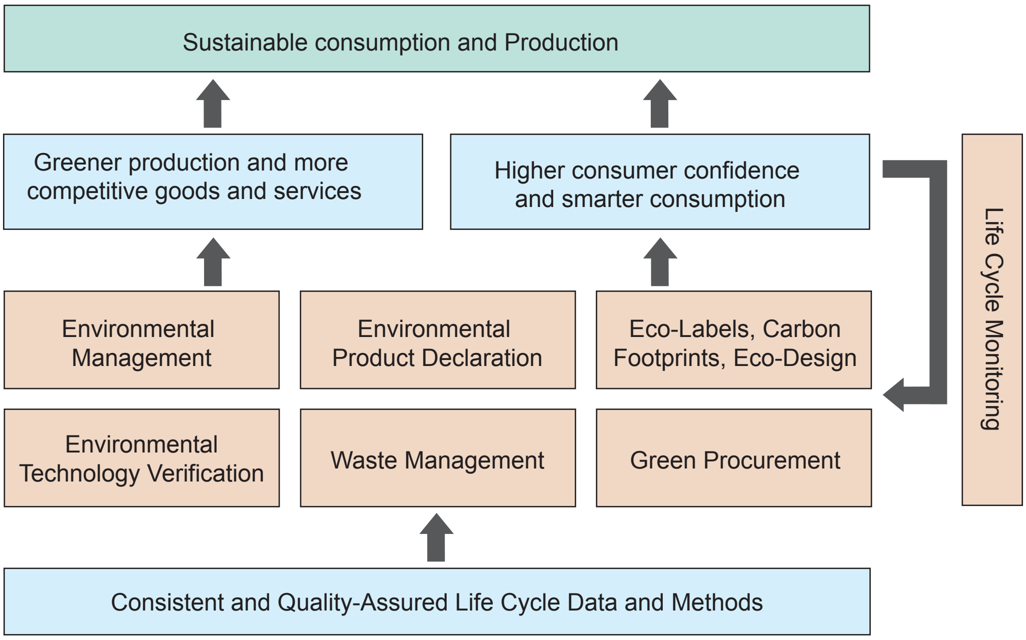

Figure 3. *Life-cycle-based instruments supporting sustainable production and consumption*[21].

The environmental data produced by LCA-type analysis can be combined with economic data in order to assess the eco-efficiency and life cycle costs of products, production, systems or services (see chapter 3.3 and 3.4). The economic data can refer to price of a product versus the costs of production or value added. LCA also complements other environmental assessments, such as site-specific environmental risk assessments (chapter 3.6.1).

[19] http://lct.jrc.ec.europa.eu/assessment/assessment/projects#d
[20] http://lct.jrc.ec.europa.eu/assessment/assessment/projects#d
[21] lct.jrc.ec.europa.eu/pdf-directory/European%20Platform-090310-last.pdf

3.1.2 Life Cycle Impact Assessment – LCIA

In LCA, the impact assessment is a work step where the data from the inventory step is broaden to imply actual environmental consequences. Life cycle impact assessment (LCIA) is essentially based either on problem-oriented methods (mid points) or damage-oriented methods (end points). In the former approaches, flows are classified into environmental themes to which they contribute. Most LCA studies cover the following themes: greenhouse effect (or climate change), natural resource depletion, stratospheric ozone depletion, acidification, photochemical ozone creation, eutrophication, human toxicity and aquatic toxicity. Thus, problem-oriented methods aim at simplifying the complexity of hundreds of flows into a few environmental areas of interest. The EDIP (Environmental Development of Industrial Products) and CML[22] 2000 methods are examples of problem-oriented methods. The damage-oriented methods also start by classifying a system's flows into various environmental themes, but they model each environmental theme's damage to human health, ecosystem health or damage to resources. For example, acidification may cause damage to ecosystems, but also to buildings and other structures. Eco-indicator 99 is an example of LCIA procedure that applies the damage-oriented approach. In Eco-indicator 99, each damage category includes several adverse effects which arise from the use of fossil fuels and mineral resources, change in habitats and presence of harmful substances (Goedkoop and Spriensma 2001). At present, the Eco-indicator 99 methodology and the CML method are integrated in the ReCiPe method[23].

Alternative LCIA methods and tools further include BEES (Building for Environmental and Economic Sustainability) for building products, developed by the National Institute of Standards and Technology (NIST) of the U.S. Department of Commerce; Ecological Scarcity by the Swiss Federal Office for the Environment (FOEN) for Integrated Product Policy; EPS (Environmental Priority Strategy in product design); Impact 2002 and 2002+ (Risk and Impact modeling at the University of Michigan); JEPIX (Japan Environmental Policy Index); LIME (Japan Environmental Management Association for Industry) by the LCA Society of Japan (JLCA); ReCiPe, developed by the Dutch National Institute of Public Health and the Environment (RIVM), CML, PRe Consultants, Radboud Universiteit Nijmegen and CE Delft; TRACI (The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts) by USEPA; USEtox, UNEP-SETAC characterization modelling of human and ecotoxic impacts; and furthermore, ecosystem damage potential (EDP) (Frischknecht et al. 2007, Koskela et al. 2010, LCA Links 2011). The bases of these methods have been described, for example in the SETAC summary comparison report[24].

LCIA includes characterization, normalization and weighting of the environmental factors identified in the inventory stage. In characterization, the harmfulness of emission or resource extraction are expressed as a relation to a reference substance within a given impact category, for example global warming potential or acidification potential. Hence, the characterized quantity is generally expressed in equivalents of the reference substance, such as CO_2-equivalents in the case of green-house gases. Normalization gives the contribution of a unit of contaminant or resource use to the total current load or pressure in a region, e.g. in Finland, per year. Weighting expresses the relationship between the current pollutant emission/resource consumption and the corresponding critical emission/resource consumption which have been issued as emission/consumption targets.

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[22] CML is the abbreviation of the Institute of Environmental Sciences (developer of the method) at the Leiden University

[23] http://www.lcia-recipe.net/

[24] http://lcinitiative.unep.fr/sites/lcinit/ > Publications > Summary of Life Cycle Impact Assessment Methods…

3.1.3 Limitations of LCA methodology

The strength of LCA is that it is a consistent tool which quantifies all possible environmental burdens in relation to a functional unit (holistic approach). Its weakness is that results have a low spatial and temporal resolution, and that social and economic aspects are very difficult to connect to environmental impacts (Udo de Haes et al. 2004). LCA-type analysis is a quantitative method based on a fixed scenario with fixed inputs (e.g. material flows) and outputs (e.g. emissions) and therefore, it disregards any intrinsic uncertainties and barriers to arriving at the scenario. For this reason, LCA-based methods to assess sustainability have been criticized for not being resilient (e.g. Udo de Haes et al. 2004, Korhonen and Saeger 2008, Huppes 2009). The time aspects are often critical; LCA should consider environmental impacts on the longest possible timeframe (De Benedetto and Klemes 2009).

Furthermore, impact assessment is both a critical and controversial work stage in LCA since it includes the process of weighting different environmental consequences. Weighting always involves some subjectivity making the results non-generalizable. Single scores resulting from LCA that lack the necessary transparency are unsuitable for public comparisons, marketing and eco-labelling and should therefore merely be used for internal purposes (Goedkoop and Spriensma 2001).

In real life, the socio-economic, cultural and physical dynamics affect the selection of technologies, instead of fixed technology relations. Such dynamics is created, for example by changing policies and institutional development as a result of technology development, research and changes in public opinion, among other things. These changes cannot be predicted, but should be accepted as such. According to Huppes (2009), in practice the assessment of sustainability of technologies calls for connecting macro and micro level aspects and different time spans. This means integration with the technology driven information with the information on the socio-economic and cultural aspects. To accomplish this goal, we also need more transdisciplinary and specialized knowledge on the sustainability effects of technologies and how to influence them.

The development work among LCA researchers has been intensive during the last years. Many methodological problems have been solved but still many development needs remain both in inventory analysis and in impact assessment. New tools or methods are needed, e.g. for consequential LCA which aims to assess consequences of a certain decision, several impact categories (e.g. resource depletion, ecotoxicity, land use) and weighting (Finnveden et al. 2000). Furthermore, there might be additional methodological problems to be clarified such as, the concepts of normalization and weighting while determining factors for the LCIA (Frischknecht et al. 2007).

The quality and availability of data significantly influence the LCA results, and therefore the quality of LCA databases plays an important role in data collection. In general, the errors in LCA come from unreliable measurements, estimates and assumptions; bias in source data; temporal, geographical, and technological miscorrelation; and lack of knowledge about the system (Hoffmann et al. 1994, Weidema and Wesnæs 1996). These systematic errors are often case-specific. In addition, conventional LCAs in accordance with SETAC or ISO guidelines carry systematic truncation error (Lenzen 2001). This error is caused by the setting of system boundaries that leads to the omission of processes outside the set boundaries. According to Lenzen (2001), the problem of boundary selection for a production system can be dispensed with by complementing the analysis with input-output analysis covering all omissions. Input-output models are based on national monetary tables to which environmental interventios have been linked over ecomomic sectors. Generalized input-output analyses are *total factor multipliers*, which describe embodiments of production factors, such as labor, energy, resources, and pollutants per unit of final consumption of commodities. Integration of an input-output model with LCA results in a hybrid LCA method - a very promising methodology to alleviate data collection. The bases of the two models are different which increases uncertainties, however (Udo de Haes et al. 2004). Despite these uncertainties, studies have shown that the error related to the input-output analysis in hybrid analysis technique is often significantly lower than the truncation error of a typical LCA of processes (Lenzen 2001).

3.1.4 LCA in industries

LCA is variably adopted among industries. Nygren (2010) conducted a survey on the use of LCA based public information provided by 20 multinational companies from different sectors. Sustainability disclosures, environmental reports, environmental product declarations (EPDs), LCA case studies and research articles provided by the companies were analyzed qualitatively. The material was screened to find out the type of LCA applied, how the results were used, and the products and assessment tools, i.e. specific methods, software and databases, applied. The weighting method of environmental impact categories was also recorded.

The survey showed that the concept of product life cycle was well adopted in all of the 20 companies (Table 3). The use of the ISO 14040 standards as a guideline was also very common, which enhances the comparability of assessments and results. All companies had conducted some form of LCA at varying intensities although most companies did not disclose any information on the number of LCAs. However, there is a trend of an increasing use of LCA, especially in companies, in which customized and streamlined methods were developed. For external purposes most companies were using only one or a few extensive LCAs as references.

Table 3. *Results of a survey on the adoption of LCA at company level (modified from Nygren 2010).*

Assessed products	Country	Life cycle approaches reported
Chemicals	Germany	Integrated LCA and LCC, social LCA
Detergents	US	LCA, environmental risk assessment, socio-economic impact analysis
Pharmaceutical products	UK	LCA, streamlined LCA
Food and hygiene products	US	LCA, streamlined LCA, checklists
Bottled water	US	LCA, MFA
Electronic domestic appliances	Sweden	LCA, carbon footprint
Electronic appliances	Japan	Carbon footprinr (referred to as LCA), MFA
Electronic appliances	Japan	Streamlined "system integration" LCA (SI-LCA), carbon footprint
Printer	US	Streamlined LCA
LED lamps	Japan	LCA, carbon footprint, streamlined LCA, cumulative energy demand
Lumber, pulp and paper products, newspaper	Canada	LCA
Packages	Finland	LCA, carbon footprint
Carpets	US	LCA
Cars	Germany	LCA, integrated LCA and DfR (Design for Recycling) -model, carbon footprint
Tires and car accessories	Germany	LCA
Elevators	Finland	LCA, carbon footprint
Electricity (nuclear, wind, hydro, coal)	Sweden	LCA,environmental risk assessment, environmental impact assessment
Windturbine models	Denmark	LCA, EIA (Environmental Impacts Assessment)
Not specified (energy production, water purification, appliances etc.)	US	LCA, streamlined LCA, envirinmental risk assessment
Trains, metro system	Canada	LCA, LCC

Nygren (2010) concluded that LCA is the tool of choice for process development, and enhanced efficiency is the main motivator for adopting it. LCA can also be a useful tool for communicating complex phenomena and producing credible and comprehensive information for product declarations and other corporate communications. The evidence from Nygren's survey confirmed that companies rely on existing LCA resources such as software and databases in conducting LCA. This finding is also in line with the generally known problem that conducting LCA is a very time consuming process. By using pre-developed tools companies can attain fast results. It is however debatable whether the generic software and data are sensitive enough to the unique features of certain products and processes.

3.2 Material flow analysis

Material flow analysis (MFA) refers to the analysis of the materials of process chains comprising extraction or harvest, chemical transformation, manufacturing, consumption, recycling and disposal (Bringezu Stefan 2002, Moriguchi 2002). It can also be considered as a part of a full LCA. MFA is based on accounts in physical units, usually in terms of weight units, such as tons, quantifying the inputs and outputs of processes. The subjects of accounting are chemically defined substances, for example carbon or carbon dioxide, and natural or technical compounds or 'bulk' materials, such as coal and wood. MFA has often been used as a synonym for material flow accounting; in a strict meaning accounting is a more restricted concept since it represents only one (accounting) of several steps of the analysis. It also has a clear linkage to economic accounting. It is more often used at the level of national economies.

Two basic types of material flow-related analyses may be distinguished according to their primary focus (Table 4).

Table 4. *Types of material flow-related analysis and examples of environmental problems and scope considered in them (modified from Bringezu Stefan 2002, Moriguchi 2002). CFC = chlorofluorocarbons*

Type of MFA	Primary interest	Examples of environmental problems and the scope of MFA
Ia	Substances	heavy metals, nutrients, CFC, CO_2
Ib	Materials	wooden products, energy carriers, plastics, biomass
Ic	Products	batteries, cars, diapers
IIa	Companies	single plants, medium sized and large companies
IIb	Sectors	chemical industry, construction, production sectors
IIc	Regions	total or major throughput, mass flow balance, total material requirement

MFA focused on substances (Type Ia), i.e substance flow analysis (SFA), has been used to determine the main routes of specific chemicals to the environment; the processes associated with these emissions; the stocks and flows within the industrial system as well as the trans-media flows; chemical, physical, biological transformations; and the resulting concentrations in the environment. Results from these analyses are often used as inputs to further analyses for quantitatively assessing risks to certain endpoints. Spatiotemporal distribution is of concern in SFA.

In type Ib MFA, i.e. MFA focused on bulk materials, selected bulk material flows have been studied for various reasons. For example, extraction of natural resources in mining and quarrying has been studied to assess the geomorphic and hydrological changes due to urbanization. The flow of biomass from human production has been studied and compared with biomass production in natural ecosystems in order to evaluate the pressure on species diversity. The flows of metals, such as aluminium, timber products and construction aggregates, although rather harmless materials, may be linked with other flows that significantly burden the environment.

Type Ic MFA refers to MFA focused on products. When the environmental impacts of certain products and services is the primary interest, the approach is normally denoted LCA (see chapter 3.1) instead of MFA. All type I MFAs can conducted at the companies, sectors or regions level.

Accounting for the physical throughput of a company is becoming more and more common, at least for larger corporations. Company-specific MFAs (Type IIa MFA) concerning substances, materials or products have thus been applied for optimization within companies. However, the limited scope of company accounts calls for complementary analyses with a wider systems perspective, either through LCA-type analyses for infrastructures and main products or by analyses of higher aggregates of production and consumption.

When the primary interest is devoted to certain industrial sectors or fields of activity, sector-specific MFA (Type IIb) may be used to identify the most critical fluxes of substances, materials or products in terms of quality and/or quantity. For instance, different industrial sectors may be compared with regard to various inputs and outputs either from other sectors or from the environment.

A major field of MFA focuses on the analysis of the material requirements of cities, regions and national or supranational economies. The accounting in such a region-specific MFA (Type IIc) may be directed to specific substances and materials or to total material input, output and throughput. Total material requirement (TMR) is a common indicator to describe the results of a region-specific MFA. TMR is a measure of all of the material input required by a national economy. Since TMR is calculated from a life-cycle perspective, it includes both the direct use of resources and the indirect material flows associated with domestic extraction as well as those associated with the production of imported goods, the latter known as “hidden flows”. Since all the material inputs measured by TMR will sooner or later be transformed to material outputs, that is emissions and waste, TMR can also indicate potential future environmental pressures to the environment.

3.3 Measuring eco-efficiency

WBCSD has identified seven different elements of eco-efficiency, namely 1) reduction of material intensity 2) and energy intensity of goods and services; 3) reduction of toxic dispersion; 4) enhancement of material recyclability; 5) maximization of sustainable use of renewable resources; 6) extended product durability; and 7) increase in service intensity of goods and services (WBCSD 1996). Various methods have been proposed for the identification, evaluation and implementation of eco-efficiency approach. These can be broadly classed under the following three categories (USEPA 2001, van Berkel 2007):

1. **Engineering approach:** this traditional approach to eco-efficiency implementation is organised around engineering evaluations of production processes, generally referred to as “opportunity assessments”. Each opportunity assessment focuses on a particular aspect of the operation, either a set of unit operations or a specific waste or emission problem, and develops, and when found feasible, implements a set of opportunities by which the eco-efficiency of that aspect of the operation is improved.

2. **Management systems approach:** this approach has emerged since the creation of international environmental management systems standards, most notably ISO 14001, but also other industry specific codes such as Responsible Care. The idea is to embed the identification, evaluation and implementation of eco-efficiency opportunities in existing management systems. In doing so, the EMS is used to deliver environmental performance through eco-efficiency in preference of other environmental technologies, such as end-of-pipe treatment or remediation.

3. **Quality management approach:** this approach aims to make eco-efficiency a guiding ethos for the entire organization rather than something the environmental or engineering department does, as is often the case with EMS and the engineering approach. Quality management approach builds upon total quality management and total productivity management models, and essentially adds eco-efficiency as a new attribute for the quality the organisation sets out to deliver.

Two basic choices must be made in defining practical eco-efficiency: which variable (environmental or economic) is in the denominator and which is in the numerator; and whether to specify environmental impact or improvement and value created or cost. Distinguishing between the two situations, the general one of value creation and the specific one of environmental improvement efforts, and leaving the numerator-denominator choice to the user results in four basic types of eco-efficiency: environmental intensity and environmental productivity in the realm of value creation; and environmental improvement cost and environmental cost-effectiveness in the realm of environmental improvement measures. (Huppes and Ishikawa 2005).

Example of using eco-efficiency analysis.

Garcilaso et al. (2006) used eco-efficiency analysis to demonstrate how the conversion from conventional treatment to ultrafiltration may reduce total treatment costs in a typical wastewater treatment plant for an automobile manufacturer. Environmental impact was estimated using LCA reporting results as eco-indicator points. By detecting the highest economic and environmental cost within the process, this method helped focus on the particular part of the process that can be optimized or changed with the greatest impact. In addition, it was possible to identify the most eco-efficient process among all the alternatives.

3.4 Cost benefit analysis (CBA), cost effectiveness analysis (CEA) and life cycle cost (LCC) analysis

Cost benefit analysis (CBA) is a process that aims to estimate and describe the total monetary value of the overall benefits and costs of projects or some actions in order to find out their profitability. In CBA, both the costs and benefits are thus measured in equivalent units, i.e. in terms of money. In addition, the change of the value in time should be considered when conducting CBA. Besides discounting the value to the future, it should be taken into account that the equivalent money could be invested so that it produces interest and consequently, the money today can in fact be more valuable in the future.

Cost effectiveness analysis (CEA) can be used for several purposes, i.e. to inform a specific decision-maker or to provide general information on different costs and (health) benefits of different technologies or strategies in order to facilitate debate on resource allocation priorities. It has been applied at least for assessing the costs and effectiveness of possible interventions in order to select the mix that maximizes health for a given set of resource constraints (Edejer et al. 2003).

According to Blanchard and Fabrycky (1998) life-cycle cost refers to ”all costs associated with the system as applied to the defined life cycle”. Life cycle costing (LCC) is the procedure to assess these costs, i.e. an economic analysis to assess the total cost of acquisition, ownership and disposal of a product (IEC 2004). Life cycle cost analysis (LCCA) provides information that is important in the decision-making concerning product design, development, use and disposal. LCCA includes six basic processes: 1) problems definition, 2) cost elements definition, 3) system modeling, 4) data collection, 5) cost profile development, and 6) evaluation (Kawauchi and Rausand 1999). The evaluation stage comprises a sensitivity analysis, uncertainty analysis and identification of cost drivers. Product suppliers can optimize their designs by evaluating alternatives and by performing trade-off studies and evaluate various operating, maintenance and disposal strategies to optimize life cycle cost. Life cycle costing can also be effectively applied to evaluate the costs associated with a specific activity, for example, the effects of different maintenance concepts/approaches, to cover a specific part of a product, or to cover only selected phase or phases of a product's life cycle.

The main limitation of CBA, CEA and LCCA is that not all benefits are easily measurable in money (e.g. some social benefits), some people can even find measuring some factors, e.g. human life, quality of the environment, in monetary value inappropriate or even unethical. Moreover, the monetary value of a benefit can vary depending on the recipient, i.e. an individual person can find the monetary value of a benefit such as the improved quality of the living environment differently than a company who is in charge for limiting its emissions. Therefore, monetization of some factors can involve subjectivity.

3.5 Data envelopment analysis

Data envelopment analysis (DEA) is a method that can be used to assess the efficiency of a manufacturer, service provider, production unit or any other decision making unit (DMU). By DEA, DMUs are directly compared against other DMUs or a combination of other DMUs. The idea of DEA is to find the "best", i.e. the most efficient DMU. In practice, the best DMU is the one with the lowest ratio of input to the desired output. For conducting DEA, the information of the inputs (e.g. volume of raw materials, amount of energy consumed) and outputs (e.g. number of products) of several peer DMUs are collected, including the DMU whose efficiency is to be evaluated. The identified best DMU is usually virtual, i.e. based on virtual inputs and/or outputs defined on the basis of the combination of real DMUs with factual inputs and outputs. The inputs and outputs used in DEA can be in different units, meaning that no preceding normalization or tradeoff between them is needed to conduct the analysis. (Zhou et al. 2008).

DEA has been used in many applications, such as manufacturing, benchmarking and management evaluation. It has been accepted as a major frontier technique for benchmarking energy sectors in many countries (Jamasb and Pollitt 2001, Abbott 2005). Main advantage of DEA is that it can handle multiple input and multiple output models and it does not require any prior assumptions on their functional relationships (Seiford and Thrall 1990). It is therefore a nonparametric approach.

Modeling environmental performance (environmental performance measurement) has been a popular application area of DEA in energy and environmental studies (Zhou et al. 2008 and references therein). Recently the potential of DEA in energy efficiency study has also been widely investigated by researchers.

Examples

1) Using DEA to study the productive efficiency and innovation activity.

Diaz-Balteiro et al. (2006) analyzed the relationship between productive efficiency and innovation activity in Spain's wood-based industry. The methodology included two levels of analysis. First, DEA was applied with several inputs and outputs associated to economic and financial data. In a second stage, a logistic regression model explored the relationship between the property of efficiency and innovation activity indicators. This approach was used to analyze a set of enterprises in the following sectors: lumber and wood products, pulp and paper and wood furniture. Results did not show the existence of significant links between enterprise's efficiency and innovation activities.

2) Using DEA to assess EE and company performance: comparison of pollution prevention vs. end-of-pipe approach.

Sarkis and Cordeiro (2001) used DEA to evaluate EE and to calculate efficiency scores for 482 companies included in the USEPA's toxic releases inventory (TRI) database. The efficiency scores were further related to companies' financial performance, measured as return of sales (ROS). The efficiency score E_{ks} for any DMU (= company) was calculated using the following formula:

$$E_{ks} = \frac{\sum_y O_{sy} v_{ky}}{\sum_x I_{sx} u_{kx}}$$

where 's' denotes for a single company; 'O_{sy}' is the value of output 'y' for that company; 'O_{sx}' is the value of input 'x' of that company; 'k' is a test company (i.e. the best DMU which is often virtual); 'v_{ky}' is the weight assigned to company 'k' for output 'y'; and 'u_{kx}' is the weight assigned to company 'k' for input 'x'. Sarkis and Cordeiro conducted a basic DEA, where the efficiency value of the DMU 'k' was maximized by selecting the optimal weights for input (x) and output (y) measures. The efficiencies were then scaled so that the maximum efficiency received the value of 1. The inputs included total sales and assets, number of employees, total wastes released, and total wastes generated. The ratio of the wastes generated in the year 1991 to the corresponding figure in 1992 was used as one output to imply pollution prevention measures. The end-of-pipe output measures were described by the ratio of the wastes generated in 1992 to the total releases during the same year. The total releases covered emissions to different environmental compartments and treatment facilities, as well as transfers, recycling, energy recovery and other treatment, and releases unrelated to production (e.g. releases from remedial measures). The TRI data that included the information on the releases and wastes were merged with the companies' financial data. Multiple regression analysis showed that both the pollution prevention and end-of-pipe efficiencies as measures of EE correlated negatively with ROS, the negative relationship being more significant in the former case.

3.6 Hazard assessment and risk assessment

Hazard assessment/analysis (HA) is a procedure that is used particularly in engineering, e.g. in the field of chemical process safety. Safety assessment/analysis is often used as a synonym to hazard assessment/analysis in the case of process safety issues focused on occupational health.

In hazard assessment, the possible adverse effects of an agent or situation to which an organism, system or (sub)population, such as employees and surrounding biota, could be exposed are identified (based on WHO 2004). The process includes hazard identification and hazard characterization, where the latter term refers to the description of the inherent property of an agent or situation having the potential to cause adverse effects. Characterization should also include a dose–response assessment and its uncertainties.

Risk assessment/analysis (RA)[25] is a term generally used beside hazard assessment/analysis. Risk comprises the following elements: 1) hazard, 2) the consequences of that hazard (e.g. environmental, economic), and 3) the frequency with which the hazard occurs or is expected to occur. The difference to HA is that in RA,

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[25] The terminology somewhat varies. Nowadays risk analysis is generally understood as a wider concept than risk assessment and to cover both the determination of risks and planning of risk management actions.

exposure assessment is a distinct additional work step. Moreover, determination of the probability of hazards is an essential element of RA. It is also worth noting that safety is considered something that can be controlled, while risk must be addressed. Unless safety is a concern, risk can generally be addressed over time rather than immediately.

Determination of exposure is the fundamental component that distinguishes LCA based methodologies from risk/hazard assessment since LCA does not consider actual exposure, which is the determinant in the formation of hazards. LCA focuses on quantifying emissions, but it does not consider the fact that the actual impacts of those emissions depend on the time, place and means of release into the environment. Furthermore, probability is another disjunctive factor since unlike in LCA, in risk assessment uncertainty is explicitly considered. At the same time, the perspective to the adverse impacts of industrial activities to human health and the environment is more constrained in hazard/risk assessment/analysis compared to LCA. RA and process HA only look at the (eco)toxicity or other direct detrimental effects of chemicals to human life, ecosystems and/or the quality of the environment, whereas LCA also relates the emissions to broader impacts such as climate change and acidification, to name a few. A complete LCA considers toxicity as one factor, and can utilize the results of RA, i.e. the information on dose-effect assessment. Above all, LCA is a cradle-to-grave approach which considers all inputs and outputs of a process whereas RA focuses on certain elements. For example in the case of industrial production, LCA would look at all the raw materials and natural resources used in the process, and all the products and emissions generated. LCA would also consider the environmental impacts associated with the use and disposal of the final product. HA or RA, on the other hand would only look at the emissions of the production process and the consequent potential hazards to the relevant receptors.

3.6.1 Environmental risk assessment

In environmental sciences, HA and RA are typically used to assess the adverse impacts to living organisms (humans, animals, plants) that arise from the toxicity of chemicals, and the deterioration of groundwater quality. In its simplest form RA includes the comparison of concentrations of harmful chemicals in environmental medium (e.g. soil, groundwater) or exposure medium (e.g. food items) against the corresponding reference values which indicate the highest concentration in that medium which is expected to be safe to the respective receptor, such as human being or a certain animal species. A more detailed RA aims to determine the relationship between the concentration in the environment and the potential adverse effects in the receptor and the probability of the occurrence of the latter. In the case of industrial emissions, the hazards of which can appear in the future, RA generally requires using some models or experiments to predict the distribution and transport of chemicals in the different environmental media involved and their concentration in a specific point of compliance (POC[26]). In addition, a more detailed RA requires using some tools to determine receptors’ exposure, such as exposure models and bioassays. (e.g. Sorvari 2010)

3.6.2 Process hazard analysis (PHA)

Process hazard analysis (PHA) is a specific type of hazard analysis that focuses on safety issues of production activities. The consequences studied in PHA generally include worker safety, public safety, environmental impact, and economic loss (Sutton 2003). Generally, PHAs do not consider environmental issues directly, but they can help the environmental experts to understand how releases may occur and how such releases can be mitigated. Several methods exist for carrying out PHA such

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[26] POC is the pre-defined location in the environment, where the concentration of the substance has to meet the set reference value, e.g. water works in the case of groundwater pollution.

as, Hazard And Operability Method (HAZOP), what-if method, checklists, Failure Modes & Effects Analysis (FMEA) and Fault Tree Analysis (FTA) (Neogy et al. 1996, Sutton 2003). From these fault trees is probably the most common means of quantifying risk in process industries. According to Khan et al. (2001), the substantial economic inputs, high-quality technical expertise, and time required by HAZOP, FMEA and FTA limit their use in practice.

Hazard and Operability (HAZOP) analysis operates on the principle that a group of experts with different backgrounds working together on a project can interact in a creative fashion and identify more problems than when working separately and combining their results (Neogy et al. 1996). HAZOP Analysis was originally developed for a new design or technology, but it is applicable to almost all phases of a process's lifetime. The HAZOP study focuses on specific process sections or operating steps (known as ”study nodes”) which are examined for potentially hazardous deviations using a set of established guide, such as ”No”, ”Less”, ”More”, ”Part Of”, ”AsWell As”, ”Reverse” and ”Other Than”. Compared to other hazard evaluation techniques, HAZOP is more oriented towards a multi-disciplinary team approach.

The what-if analysis technique is a flexible, creative examination of a process or operation for potential hazards. It is the least structured of the creative PHA techniques. This method is often used for Conceptual PHAs, where very little detail is available concerning the process or the equipment because the plant is still being designed. In such a case what-if analysis allows to quickly focus on the most critical issues. Its use requires a team of experienced analysts capable of identifying incident scenarios. Members of the hazard evaluation team are encouraged to ask What-If questions or discuss specific issues that concern them. The analysis usually focuses on a particular type of consequence such as environmental contamination, or worker and public safety. (Neogy et al. 1996, Sutton 2003)

A checklist analysis is an experience based approach in which a list of specific items is used to identify known types of hazards, potential accident situations, or design deficiencies (Neogy et al. 1996). Checklists are often used in the evaluation of new processes to identify and eliminate hazards that have been recognized in the previous operation of similar systems.

FMEA is a technique for determining the ways in which equipment items and their internal components can fail, and the possible consequences of such failures on the overall system reliability and safety (Sutton 2003). Traditionally, the FMEA method has been used in the aerospace and nuclear power industries, and to a lesser degree in the process industries since single equipment failures do not usually have catastrophic results.

A Fault Tree is a logic diagram that shows the combination of events that have to take place before an accident can occur (Sutton 2003). Fault Trees are normally used to analyze systems rather than to creatively identify hazards. The Fault Tree method differs from most other PHA techniques in that it is often more suitable to be used by a single individual rather than a team.

Root-cause analysis (RCA) differs from most PHA methods in that it is a retrospective method which can help to identify what and how an event occurred, and why it happened. The basic reason for investigating and reporting the causes of occurrences is to enable the identification of corrective actions adequate to prevent recurrence and thereby protect the health and safety of the public, the workers, and the environment (DOE 1992). The most common root cause analysis methods are: Events and Causal Factor Analysis, Change Analysis, Barrier Analysis, Management Oversight and Risk Tree (MORT) Analysis, Human Performance Evaluation and Kepner-Tregoe Problem Solving and Decision Making.

Events and Causal Factor Analysis identifies the time sequence of a series of tasks and/or actions and the surrounding conditions leading to an occurrence. The results are presented in an Events and Causal Factor chart that describes the relationships of the events and causal factors. Change Analysis is a systematic process that is generally used for a single occurrence and focuses on elements that have changed. It is used when the problem is obscure. MORT identifies specific factors relating to an occurrence and identifies the management factors that permitted these factors to exist. Identification of inadequacies in barriers/controls, specific barrier and support functions, and management functions is part of MORT. Human Performance Evaluation identifies the factors influencing task performance. The focus is on operability, work environment, and management factors. Lastly, the Kepner-Tregoe method provides a systematic framework for gathering, organizing, and evaluating information and it applies to all phases of the occurrence investigation process. Its root cause phase is similar to change analysis. (DOE 1992)

In practice, most PHAs use a semi-quantitative approach such as risk matrices (see example in Table 12). A full quantitative analysis is generally impractical because it takes too long, and much of the basic data is either missing or of low quality.

Barrier analysis is an integral part of PHA. The aim of barrier analysis is to identify and evaluate barriers that provide control over the hazards (Neogy et al. 1996). These barriers can be physical, procedural or administrative or originating from human action.

Hazard and barrier analysis has important applications both as a proactive aid in safe work planning and in systematic after-the-fact investigations of incidents and accidents to characterize the safety/risk significance of operating events (Neogy et al. 1996). Hazard and Barrier Analysis is adaptable to simple risk analysis, which enhances its usefulness. Risk-based hazard and barrier analysis provides a measure of risk associated with individual operations and a measure of risk reduction associated with the implementation of individual barriers. Furthermore, it allows judging the relative importance of hazards and barriers.

4 Indicators and measures of sustainability and environmental efficiency

At present, corporate sustainability and environmental performance reporting is an important issue for companies who want to show their environmental consciousness to their clients, authorities and general public. Reliable and comparable reporting assumes using accepted and established measures and metrics, that means indicators. Through indicators, companies can also find opportunities for innovation, identify potential resource constraints, avoid costly business interruptions and make strategic choices in areas from R&D to marketing (Wackernagel 2008). With information on ecological pressures generated by their operations, companies can choose the best designs for products and facilities. Using a common unit, businesses are also able to establish benchmarks, set quantitative targets, and evaluate alternatives for future activities.

There are different approaches for environmental performance measurement, namely production, auditing, ecological, accounting, economic and quality (James 1994, ref. in Berghout et al. 2001). These approaches have different drivers, focus and metrics (Table 5). Furthermore, due to the diversity of environmental issues, organisational variables, such as organization's size and management style, national circumstances and individual corporate strategies, performance measurement activities vary in different countries and industries. As a consequence, several indicators to describe sustainability, eco-efficiency and environmental performance of production, products, systems and services have been established.

Table 5. *Frameworks for environmental performance measurement (Berghout et al. 2001).*

Approach	Orientation	Drivers	Measurement focus	Metrics
Production	Engineering	Efficiency	Mass/energy balance	Efficiency Resource use
Regulatory	Legal	Compliance	Management systems Risk Non-compliance	Emissions/waste Risk
Ecological	Scientific	Impacts	Impact assessment Life cycle assessment	Emissions/waste Impacts Resource use
Accounting	Reporting	Cost Accountability	Liabilities	Emissions/waste Monetary
Economic	Welfare	Internalising externalities	Environmental valuation	Monetary
Quallity	Management	Pollution prevention	Emissions/waste generation	Emissions/waste

OECD defines an environmental indicator as a ”a parameter, or a value derived from parameters, which points to, provides information about, describes the state of a phenomenon/environment/area, with a significance extending beyond that directly associated with a parameter value” (OECD 2002). Thus, an indicator should provide meaningful information about the aspect it ought to describe. If an aspect is complex, such as sustainability, more than one indicator may be needed. The various indicators can, however, be aggregated to produce a single index, i.e. a composite sustainable development index (ICSD) if desired. Environmental Sustainability Index (ESI), Dow Jones Sustainability Index (DJSI) and indexes by the Global Reporting Initiative (GRI) are examples of ICSDs. In addition, there are various environmental performance indicators and indicators implying specific environmental consequences, such as climate change.

According to Ethridge (1998) Indicators describing environmental performance can be divided into the following groups according to their metrics:

- **lagging indicators** are end-of-process measures such as amount of pollutants emitted or discharged;
- **leading indicators** are in-process measures of performance, i.e. they measure the implementation of practices or measures which are expected to lead to improved environmental performance, such as percent of facilities conducting self audits;
- **environmental condition indicators** (ECI) measure the direct effect of an activity on the environment, such as concentrations in air, water, groundwater and soil, changes in the size of a population of a particular species in a given area.

Each type of indicator has its own strengths and weaknesses, and different target audiences and many companies use a mixture of indicators (Ethridge 1998). Besides using indicators, environmental progress can be assessed by benchmarking against other companies or average industry performance; evaluating progress against codes of management practices developed by some trade associations; measuring progress against principles, goals, or corporate management system standards; and determining indices which describe progress from year to year.

ISO has established a list of prerequisites that an indicator should fulfill in order to be useful and relevant to measuring environmental performance. These include the following features (ISO 1999):

- relevant to the environmental policy and the important environmental aspects;
- appropriate to the management activities, operations or the environment;
- useful to and representative of the environmental performance criteria;
- understandable to internal and external stakeholders;
- easily obtainable, measurable and informative;
- adequate in relation to data quality and quantity; and
- responsive to changes in environmental performance.

The data presented by indicators can be direct, relative or indexed. Any aggregation and weighting operations of separate indicators must be done and explained carefully to maintain verifiability, consistency, comparability and understandability (ISO 1999). The standard including the above prerequisites (ISO 14031:1999) supports the ISO standard for environmental management systems (ISO 14001:2004) (see chapter 2.3.2).

The results of LCAs can also be considered environmental indicators for example in companies' environmental reporting. There are two types of indicators within the LCA methodology, namely midpoint and endpoint indicators. Midpoint indicators are the indicator results of different impact categories. They depict potential environmental impacts of certain impact categories, e.g. climate change, acidification, eutrofication etc. Midpoint indicators can still be aggregated to endpoint indicators, which represent impacts to Human health, ecosystem quality and resources. At present, carbon footprint, belonging to the impact category 'Climate Change', is the most frequently used LCA-based indicator (see chapter 4.5.3) .

The various indicators available are used at different levels, that is, at the international, national, regional, enterprise, process or product level. In this report, the focus is on the indicators which are relevant from companies' viewpoint. The following chapters aim to present some of the known and most commonly used indicator and index systems and it is therefore not a comprehensive overview. Any identified systems developed in Finland are specifically highlighted.

4.1 Sustainability indexes

According to the definition by OECD, an index is "a set of aggregated or weighted parameters or indicators” (OECD 2002). Several composite sustainability indexes have been developed for measuring the sustainability performance of industries or companies. An index can be either simple or weighted depending on its purpose. According to Atkinson et al. (1997), indexes are very useful in focusing attention and, often in simplifying the problem. Indexes are based on the aggregation of the different factors of sustainability thereby enabling the simultaneous evaluation of multiple of aspects. The limitations of composite indexes, however, arise from the subjectivity involved in their determination (Singh 2008). Composite indexes are of a cardinal nature, but remain ordinal in so far as the difference in index values cannot be interpreted meaningfully. In the case of weighted indexes, the methods used in weighting and aggregating the weights and indicators/parameters can significantly affect the results (e.g. Pöyhönen and Hämäläinen 2001, Koffler et al. 2008).

In the case of enterprises, and particularly manufacturing companies and facilities the social dimension is seldom included in the assessment of sustainability (Schneider 2008). Corporate reports often stress governance aspects and environmental practices, but tend to overlook the role of the employees or workforce. This oversight may be due to measurement difficulties since the social aspects of corporate responsibility include difficult-to-measure factors such as attention to human rights and gender diversity, and interactions with local communities. At the same time, studies show that investments in human and social capital can deliver important benefits such as increased productivity, more innovation, and reduced costs. There is therefore a need for more quantitative work in measuring social aspects to increase the comprehensiveness and reliability of corporate sustainability reporting. UNEP/SETAC Life Cycle Initiative has recently published guidelines for social LCA of products to facilitate the consideration of social aspects (Andrews et al. 2009).

4.1.1 Environmental Sustainability Index (ESI)

The Environmental Sustainability Index (ESI) was a composite index published from 1999 to 2005 that considered 21 factors of environmental sustainability covering natural resource endowments, past and present pollution levels, environmental management efforts, contributions to protection of the global commons, and a society's capacity to improve its environmental performance over time (Esty et al. 2005). Although the monitoring and reporting of ESI focused on countries, 'country' was understood as a loose concept and to refer to any administrative or economic entity. ESI only measures the management of environmental resources and stresses and therefore does not track sustainability in the overarching concept which includes economic and social aspects. ESI should therefore be coupled with some economic and social sustainability indices.

In 2006 ESI was superseded by the Environmental Performance Index, EPI (Esty et al. 2008). The EPI focuses on two environmental objectives, namely reducing environmental stresses to human health and promoting ecosystem vitality and sound natural resource management. The realization of these objectives is measured by 25 indicators which are weighted and aggregated: Environmental Burden of Disease, Adequate Sanitation, Drinking Water, Urban Particulates, Indoor Air Pollution, Local Ozone, Regional Ozone, Sulfur Dioxide Emissions, Water Quality Index, Water Stress, Conservation Risk Index, Effective Conservation, Critical Habitat Protection, Marine Protected Areas, Change in Growing Stock, Marine Trophic Index, Trawling Intensity, Irrigation Stress, Agricultural Subsidies, Intensive Cropland, Pesticide Regulation, Burned Area, Emissions Per Capita, CO_2 from Electricity Production, and Industrial Carbon Intensity. It is evident, that not all of the these indicators are suitable or relevant for company level sustainability analysis.

4.1.2 Product Sustainability Index (PSI)

Sustainability of a particular product can be measured by Product Sustainability Index (PSI). There is no international standard for measuring product sustainability, however, and therefore, variable approaches based on, e.g. ISO 14040 and work of the Society of Environmental Toxicology and Chemistry (SETAC) Europe on life cycle costing (Hunkeler et al. 2008), have been used for deriving PSIs. Several companies have actually developed their own PSIs, Wal Mart and Ford being probably the most known of these (see also chapter 4.6.3).

Product sustainability comprises an array of elements (Figure 4) each of which cover several sub-elements.

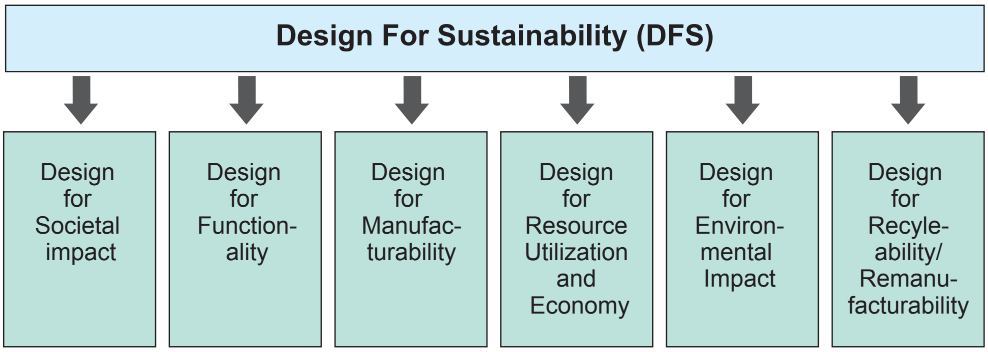

Figure 4. *The elements and sub-elements of product sustainability (modified from Jawahar et al. 2006).*

Jawahar et al. (2009) introduced a generic, three stage methodology for determining a PSI. The first work step includes identification of potential influencing factors by product developers, using national and international regulations as a basis. The focus should be in all sustainability components and in all four life cycle stages, i.e. pre-manufacturing, manufacturing, use and post-use, of the product. In step 2, a 3x4 matrix that represents all components of sustainability and all four life cycle stages is created. Each influencing factor is then scored or rated between the values 0 and 10. Examples of influencing factors in the Environment component include material extraction in the pre-manufacturing stage, energy consumption in the manufacturing stage, emissions and waste generated during product use, and recyclability in the post-use stage. The influencing factors can be further weighted. Non-quantifiable factors can be scored based on designers' experience and judgment. In the final work step, PSI is calculated using the following formula.

$$PSI_{(en\_pm)}=\{[\sum_{i=1}^{n} IF_{(en\_pm)i}]/(n*10)\}*100\%$$

where PSI($_{en\_pm}$) is the Product Sustainability Index for Environment component of pre-manufacturing stage, IF($_{en\_pm}$) is the Influencing Factor rated on a scale from 0 to 10 for the Environment component of pre-manufacturing stage, and n is the number of Influencing factors considered. PSIs for Environment component of each life cycle stage is similarly calculated. The final PSI for Environment component is the mean value of the PSIs of each life cycle stage, while the overall product sustainability index (PSI_{TLC}) is the sum of the PSIs of the different sustainability components, i.e. Environment, Economy, and Society.

4.1.3 Dow Jones Sustainability Indexes (DJSI)

Dow Jones Sustainability Index[27] (DJSI) measures companies' sustainability initiatives. It represents a cooperation of the Dow Jones Indexes[28] and SAM[29] (Sustainability Asset Management) and includes global and regional benchmarks, such as DJS World Index and DJS Europa Index. Recently, the DJS Nordic Index was also established. The Dow Jones family of indexes evaluates the performance of the world's sustainability leaders. The DJSI focuses on how a company recognizes the risks and opportunities arising from sustainability issues in its business strategy[30]. The trend is to reject companies that do not operate in a sustainable and ethical manner. The DJSI Indexes are the longest-running global sustainability benchmarks worldwide and have become the key reference point in sustainability investing for investors and companies.

To be incorporated in the Dow Jones Sustainability Index, companies are assessed and selected based on their long term economic, social and environmental asset management plans. The assessment methodology is based on the application of criteria to measure the opportunities and risks deriving from economic, environmental and social dimensions. These criteria consist of both general criteria applicable to all industries and specific criteria applicable to companies in 57 industry sectors accordant with the Industry Classification Benchmark (ICB)[31] . The criteria are derived following identification of global and industry challenges. (DJI 2010)

DJSI conducts regular reviews of the DJSI family and makes changes to the index composition, if needed. Consequently, the selection criteria evolve each year and companies must continue to make improvements to their long term SAM plans in order to remain on the Index. Once a company is selected as a member of any of the indexes in the DJSI family, it is continuously monitored for its corporate sustainability performance. This corporate sustainability monitoring is based on the company's code of conduct; corporate governance, risk and crisis management; customer relationship management; environmental management where issues include, for example ecological disasters and hazardous substances; supply chain management; external stakeholders, e.g. emerging countries; and labor practices, e.g. workplace accidents and occupational health and safety, remuneration, benefits, and flexible working schemes. (DJI 2010)

By the end of 2010, 600 companies were listed in the DJSI Europe list, including five Finnish companies (DJSI 2010a). At the same time, three additional Finnish companies were listed in the DJSI World index (DJSI 2010b).

4.1.4 Indicators by Global Reporting Initiative (GRI)

Global Reporting Initiative (GRI,)[32] is a network-based organization that has pioneered the development of the world's most widely used sustainability reporting framework and is committed to its continuous improvement and application worldwide. The GRI reporting framework sets out the principles and indicators that organizations can use to measure and report their economic, environmental, and social performance. The cornerstone of the framework is the Sustainability Reporting Guidelines. The first version of the Guidelines – the G3 Guidelines – was published in 2006 and they were updated in 2011. Other components of the framework include indicators for specific industry sectors, i.e. Sector Supplements, and National Annexes, which include unique country-level information.

GRI guidelines list a wide variety of indicators to be used in organizations' sustainability reporting. These include environmental performance indicators, which

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[27] http://www.sustainability-index.com/07_htmle/indexes/djsi.html
[28] http:/ /www.djindexes.com/
[29] http:/ /www.sam-group.com/htmle/main.cfm
[30] http://www.djindexes.com/sustainability/
[31] http:/ / www. icbenchmark. com/
[32] www.globalreporting.org

are the most relevant from the viewpoint of EEA (Table 6), economic performance indicators and social performance indicators. Core indicators are separated from additional indicators. The former are generally applicable indicators and they are assumed to be material for most organizations. An organization should report on all core indicators unless they are deemed not material on the basis of the Reporting Principles. Additional indicators may also be determined to be material.

Table 6. *Environmental performance indicators of the GRI guidelines (modified from GRI 2011). C = core indicator, A = additional indicator.*

Aspect	**Indicator**
Materials	EN1: Materials used by weight of volume (C) EN2: Percent of materials used that are recycled input materials (C)
Energy	EN3: Direct energy consumption by primary energy source (C) EN4: Indirect energy consumption by primary source (C) EN5: Energy saved due to conservation and efficiency improvements (A) EN6: Initiatives to provide energy-efficient or renewable energy-based products and services, and reductions in energy requirements as a result of these initiatives (A) EN7: Initiatives to reduce indirect energy consumption and recuctions achieved (A)
Water	EN8: Total water withdrawal by source (C) EN9: Water resources significantly affected by withdrawal of water (A) EN10: Percentage and total volume of water recycled and reused (A)
Biodiversity	EN11: Location and size of land owned, leased, managed in or adjacent to protected areas and areas of high biodiversity value outside protected areas (C) EN12: Description of significant impacts of activities, products, and services on biodiversity in protected areas and areas of high biodiversity value outside protected areas (C) EN13: Habitats protected or restored (A) EN14: Strategies, current actions, and future plans for managing impacts on bioversity (A) EN15: Number of IUCN Red List species and national conservation list species with habitats in areas affected by operations, by level of extinction risk (A)
Emissions, effluents, and waste	EN16: Total direct and indirect greenhouse gas emissions by weight (C) EN17: Other relevant indirect greenhouse gas emissions by weight (C) EN18: Initiatives to reduce greenhouse gas emissions and reductions achieved (A) EN19: Emissions of ozone-depleting substances by weight (C) EN20: NO, SO, and other significant air emissions by type and weight (C) EN21: Total water discharge by quallity and destination (C) EN22: Total weight of waste by type and disposal method (C) EN23: Total number and volume of significant spills (C) EN24: Weight of transported, imported, exported, or treated waste deemed hazardous under the terms of the Basel Convention Annex I, II, III, and VIII, and percentage of transported waste shipped internationally (A) EN25: Identity, size, protected status, and biodiversity value of water bodies and related habitats significantly affected by the reporting organization's discharges of water and runoff (A)
Products and services	EN26: Initiatives to mitigate environmental impacts of products and services, and extent of impact mitigation (C) EN27: Percentage of products sold and their packaging materials that are reclaimed by category (C)
Compliance	EN28: Monetary value of significant fines and total number of non-monetary sanctions for non-compliance with environmental laws and regulations (C)
Transport	EN29: Significant environmental impacts of transporting products and other goods and materials used for the organization's operations, and transporting members of the workforce (A)
Overall	EN30: Total environmental protection expenditures and investments by type (A)

The Aspects in the Environment Indicator set are structured to reflect the inputs, outputs, and modes of impact an organization poses on the environment. Energy, water, and materials represent three standard types of inputs used by most organizations. These inputs result in outputs of environmental significance, which are captured under the Aspect 'Emissions, Effluents, and Waste'. Biodiversity is also related to the concepts of inputs to the extent that it can be viewed as a natural resource. However, biodiversity is also directly impacted by outputs such as pollutants.

The Aspects 'Transport' and 'Products and Services' represent areas in which an organization can further impact the environment, but often indirectly through other parties, such as customers or suppliers of logistics services. 'Compliance' and 'Overall Aspects' are specific measures the organization takes to manage environmental performance.

Energy use plays very important role in industrial activities, both from the economic and from the environmental point of view. Indicators in the 'Energy' Aspect cover the five most important areas of energy use, including both direct and indirect energy. Direct energy covers forms of energy that enter the reporting company's operational boundaries. It can be consumed either by the organization within its boundaries, or it can be exported to another user. Direct energy can appear as either primary energy (e.g., natural gas for heating) or intermediate energy, which is produced by converting primary energy into other forms (e.g., electricity for lighting). It can be purchased, extracted (e.g., coal, natural gas, oil), harvested (e.g., biomass energy), collected (e.g., solar, wind), or brought into the organization's boundaries by other means. Indirect energy refers to the energy produced outside the organization's organizational boundary that is consumed to supply energy for the organization's intermediate energy needs. The most common example is fuel consumed outside the reporting organization's boundary in order to generate electricity to be used inside the boundary. For most organizations, electricity will be the only significant form of intermediate energy. For a small percentage of organizations, other intermediate energy products might also be important, such as steam or water provided from a district heating plant or chilled water plant, or refined fuels, such as synthetic fuels and biofuels.

Measurement of energy consumption is relevant to greenhouse gas emissions and climate change. The burning of fossil fuels to generate energy creates emissions of carbon dioxide (a greenhouse gas). Lowering of energy demand can be achieved through more efficient energy use (measured under EN5 and EN6) and replacing fossil fuel energy sources with renewable ones (measured under EN3 and EN4). In addition to lowering the direct consumption of energy, designing energy-efficient product and services (EN6) and reducing indirect energy consumption (EN7) (e.g., by preferring raw materials with low energy-intensity) are important strategies.

Indicators in the ‘Emissions, effluents, and waste’ aspect measure standard releases to the environment considered to be pollutants. These Indicators (EN20-EN23, EN24) comprise different types of polluting agents (e.g. air emissions, effluents, solid waste) that are typically recognized in regulatory frameworks. In addition, two types of indicators are related to emissions that are the subject of international conventions, i.e. greenhouse gases (EN16 and EN17) and ozone depleting substances (EN19). EN18 addresses the emissions reductions achieved and initiatives to reduce emissions.

The GRI criteria used to assess the sustainability should emulate as closely as possible the essence of the sustainable development concept. However, every indicator is not relevant to a specific industry. Therefore, it is essential to identify key indicators to be used in monitoring environmental performance.

4.1.5 Ethibel Sustainability Index

The Ethibel Sustainability Index[33] is a measure of sustainability that combines the social and economic profit of a company. The Ethibel Sustainability Index scheme consists of a checklist of "sustainable criteria" which describe the extent to which a company takes its social role seriously. The first element only includes a general description of the context of the enterprise which is not evaluated in determining the

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[33] http://www.ethibel.org/subs_e/4_index/main.html

Index. The remaining four criteria cover company's internal social policy, environmental policy, external social policy and ethical economic policy. Each of the four areas is given equal importance, i.e. the Index applies the same criteria and gives equal weights to company scores on social, environmental and economic criteria, regardless of the type of company or the sector. The subjects to be evaluated in the four areas are the following:

Internal Social Policy analysis

- The development of employment and the nature of contracts
- Training possibilities for employees
- Equal opportunity policy of the company and its effects on the number of women in higher positions, the attitude of the company towards employees of different cultures, etc.
- Wage structure
- Safety policy on the work floor
- Negotiating structures
- Participation of employees in company policy

Environmental Policy (Table 7)

- Examination of the internal organisation of a company and its production chains
- Existence of a comprehensive environmental care system and to the extent to which this is certified by external bodies
- Use of raw materials and energy, emissions and waste
- Environmental impact of the finished product

External Social Policy

- How does the company adhere to its responsibility vis a vis its environment?
- Attitude to human rights and its relation with developing countries and the specific results of these policies
- The extent to which the company is involved in technologies or practices which may be controversial and are in conflict with sustainable society in the widest sense of the term: involvement in the production and trade in arms, genetic manipulation and animal testing

Ethical Economic Policy.

- The innovative capacity of the company
- Existence of internal control procedures to deal with internal and external risks
- Existence of an effective quality care system
- Respect of the interests of customers, suppliers, shareholders, the authorities and other stakeholders

Different sectors and regions are facing different key issues and the concept of Corporate Social Responsibility changes over time. The Ethibel Sustainability Indices are therefore reviewed semesterly to ensure that the index composition accurately represents the companies in terms of sustainability.

4.1.6 FTSE4GOOD Sustainability Index

The FTSE4Good Sustainability Index Series covers four tradable and five benchmark indices, representing Global, European, US, Japan (benchmark only) and UK markets[34]. The TSE4Good Index series was intially designed to provide investors with a tool for evaluating and investing in companies with good track records of corporates' social responsibility and responsible invest. Nowadays, the indexes are

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[34] www.ftse.com

Table 7. *Subjects analysed related to Environmental Policy in order to determine the Ethibel Sustainability Index (modified from http://www.ethibel.org/subs_e/4_index/main.html).*

Subject	**Target of the assessment**	**Assessment criterion**	**Indicator**
Strategy	Principles	Environmental policy • degree of formalization • quality of the formal principles • degree of integration in company's activities	Comprehensiveness Scope Quality
	Public commitment	The degree of • dialogue with stakeholders • co-operation with environmental initiatives surpassing the company level • consideration of legal requirements	Memberships (stakeholder groups, co-operation platforms) Lobbying Infringements Anticipation of future legislation Quality and quantity of communication
	Environmental publications	The extent of informing public about the company's env. responsibility	Quality of publications
Management	Environmental management system (EMS)	Existence, quality and external certification	Comprehensiveness Completeness Application, e.g. number of certified plants
	Employees' involvement	Involvement in the development and implementation of company's env. policy	Handling of env. matters in training and communication Type of involvement (passive/active)
	Environmental responsibilities and instruments	Integration of env. responsibility in company's hierarchy	Position(s) of the person(s) with env. responsibilities and supportive staff
Production	Measures to reduce environmental impact – input	Efforts to reduce energy and raw material consumption	Measures against BAT criteria, generic status in the industry and achieved results
	Measures to reduce environmental impact – output	Efforts to reduce emissions to air, water and soil	Measures against BAT criteria, generic status in the industry and achieved results
	Measures to reduce environmental impact – waste	Efforts to minimize the amount and harmfulness of waste Use of environmentally friendly waste treatment methods	Measures against BAT criteria, generic status in the industry and achieved results
	Consideration of environmental issues through the supply chain	Efforts to reduce env. impact of supply chain	Conditions imposed to suppliers and subcontractors
Products	Overall environmental impact	Env. impact of products	Environmental impact during the whole life cycle
	Measures to reduce environmental impact	Efforts to reduce or avoid adverse env. impact of products considering the whole life cycle	Eco-design activities Research on the development of env. friendlier products Product stewardship management practices Instructions to customers

used by several stakeholders and for different purposes. For instance, the companies use them as a framework for responsible business management, a reputational badge in stakeholder communications and to gain access to ethical and socially responsible investors' funds. The environmental aspects considered in the FTSE-4GOOD indexes are focused on the climate change (Table 8).

Table 8. *Climate change criteria of the FTSE4Good Index.*

Subject	**High Operational Impact**	**Medium Operational Impact**	**Additional Product Impact**
Policy & Governance	• Board level or senior executive responsibility for climate change related issues • Public statement/policy identifying climate change as relevant to business activities and the need to address it as a key concern	• Board level or senior executive responsibility for climate change related issues • Public statement/ policy identifying climate change or energy consumption as relevant to business activities and the need to address it as a key concern	• Responsibility:No additional requirement • Public statement/policy should also include a commitment to reduce product related emissions or climate change impact
Management & Strategy	At least one of the following must be met (unless the company meets the performance requirements): • Long-term strategic goal of significant quantified reductions of operational GHG emissions or carbon intensity improvement for more than 5yrs • Short/medium-term management targets for quantified GHG operational emissions reduction for less than 5yrs	No requirements yet	No requirements yet
Disclosure	Public disclosure of the following: • Total operational CO_2 or GHG emissions • Sector metric where established as an industry norm, e.g. kg CO_2/t cement, or efficiency ratio	Public disclosure of one of the following: • Total operational CO_2 or GHG emissions • Sector metric where established as an industry norm, e.g. kg CO_2/t cement, or efficiency ratio	Public disclosure of product related emissions/efficiency; varies for different sectors: • Oil & Gas: end user emissions • Coal mining: end user emissions • Automobiles: fuel efficiency • Aerospace: fuel efficiency
Performance	At least one of the following must be met: • Minimum of 5% reduction in carbon intensity over the last two years • Demonstration of being in the top quartile of companies in its subsector for the previous two years (assessment using accepted carbon efficiency metrics) • A transformational initiative or a combination, providing they are quantified and significant	No requirements yet	Automobile and Aerospace companies must meet one of the following: • Emissions reductions: fuel efficiency improvements above average for subsector • Eco-efficiency metrics: above average fuel efficiency relative to subsector peers • A transformational initiative to reduce product emissions

4.1.7 Index of Environmental Friendliness

The Index of Environmental Friendliness is an index developed by the Statistics Finland. The methodology is based on a general model for the aggregation of direct and indirect environmental pressure data to problem indices and further to an overall Index (Puolamaa et al. 1996). These procedures are also included in the current national accounting matrix including environmental accounts (NAMEA) framework for environmental accounting developed by Statistics Netherlands. The fundamental idea of the NAMEA is to extend the conventional national accounting matrix with two additional accounts, i.e. the account for environmental problems like the greenhouse effect or the ozone layer depletion and for environmental substances, like carbon dioxide or sulfur dioxide (Schenau and Hoekstra 2006). Thus, the selected environmental themes are partly global environmental problems and partly national and local environmental problems. NAMEA generates consistent summary indicators for the environmental problems, which are considered most pressing at the political level. The environmental accounts are expressed in different physical units, such as tons, kilojoules or cubic−meters instead of monetary units.

The core assumption of the Index of Environmental Friendliness model is that environmental problems are the most feasible basis for a comprehensive assessment (Puolamaa et al. 1996). The model covers the key environmental problems of greenhouse effect, ozone depletion, acidification, eutrophication, ecotoxicological effect, resource depletion, photo-oxidation, biodiversity, radiation and noise. The aggregation of pressure data to indices reguires information on the impact pathways and pressures affecting the development of each environmental problem. In order to prevent overlaps in impact assessments of various concerns, the pressures are made commensurate with each other according to their primary impact potential. The work steps are equivalent to a complete LCA and therefore include normalization based on the national total pressures, weighting based on the valuation of environmental concerns and aggregation into the overall Index of Environmental Friendliness. Puolamaa et al. (1996) carried out the valuation excercise by asking eight stakeholders to assign weights using a pair-wise comparison method. The environmental pressures considered were: greenhouse effect, ozone depletion, loss of biodiversity, radioactivity, chemicalization, resources depletion, photo-oxidants, acidification of soil, acidification of waterbodies, eutrophication, and noise exposure. Based on stakeholders' valuation, greenhouse effect, ozone depletion, and loss of biodiversity received the highest scores whereas noise reduction followed by acidification of waterbodies received the lowest scores. Overall, the differences were quite marginal, however. As the model gathers both direct and total pressures of economic activities, the assessment of environmental pressures proceeds parallel with both of them. This also provides a more complete picture of environmental impacts associated with each economic activity and makes internal services and treatment operations comparable to those of purchased ones from the environmental point of view. The model provides information categories that can be used separately as such or together with relevant socio-economic data.

No information was available on whether and how widely the Index of Environmental Friendliness Index has been applied in the Finnish industry.

4.1.8 Minimal Manufacturing Index

'Minimal Manufacturing' refers to "manufacture of the highest performance products through minimal resource input and minimal energy use (in terms of manufacturing cost and environmental load), while maintaining minimal environmental load in the disposal stage” (Kita 2008). What is the standard or criterion of ”minimum” for a sustainable society is the key question. The environmental load decreases when the amount of resources, material and energy decreases. However, this frequently suppresses sound developments in industry and economy. The Minimal Manufacturing Index was developed in order to consider all these aspects in the assessment of sustainability.

Minimization of resource input is an objective that extends to the whole lifecycle of the product, i.e. from the design to the management of waste (Kita 2008). It therefore involves different space-time ranges. The aims and items of the “minimum” depend on the life cycle stages such as production, usage and disposal. Moreover, the environmental impacts in the different stages are affected and interact with each other. Therefore, in order to minimize the overall environmental load, an index is needed which can commonly describe ”quantities of state” for energy, resources, and products in those stages. Kita (2008) used exergy for this purpose.

In thermodynamics, exergy has been defined as a measure of the actual potential of a system to do work. Exergy is also considered as entropy-free energy in energetic, biological and other systems. It is generally expressed by the following equation:

$$Ex = (H-H_0) - T_0(S-S_0)$$

where Ex is exergy, H is enthalpy[35], S is entropy[36] and T is the absolute temperature. The subscript, ”0” stands for the environmental standard.

The Minimal Manufacturing Index is the combination of the Environmental Index (EI) which is equivalent to the exergy loss through the whole life cycle and Competitive Index (CI) which considers economic aspects (Figure 5). The competitive index (CI) is the ratio of customer value, i.e. the benefit to customer through the product's life cycle, to the supply price that covers producer's expenses and profits.

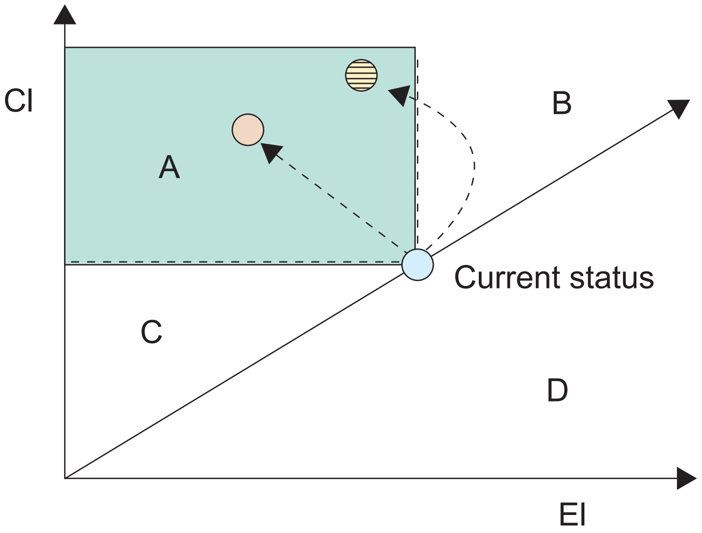

***Figure 5**. Determination of the Minimal Manufacturing Index on the basis of exergy and economic factors (modified from Kita 2008). Region A corresponds to the ideal direction while in region C EI is improved but competitiveness decreases. In region B competitiveness increases more than EI. Region D shows the unacceptable direction.*

4.2 Life Cycle INdeX (LInX)

Khan et al. (2004) developed a method for facilitating the LCA application in process and product evaluation and decision-making. This method, known as LInX (life cycle indexing system) is comprised of four major attributes: environment, cost, technology, and socio-political factors. These are described as 'a house' and 'a colony of houses' (Figure 6). Each attribute contains a number of basic parameters, the quantification of which is performed for the complete life cycle of a process or product to be evaluated. The environment colony comprises three houses: pollution, risk, and global warming. Resource depletion (RD) is the roof of the environment colony. Each house is futher divided into units and rooms, the latter representing the basic parameters to be measured. For example, the global warming (GW) house has four rooms (corresponding the basic parameters to be measured): greenhouse (GH), ozone depletion (OD), acidification (AP) and oxidation potentials (OP).

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[35] Enthalpy is a measure of the total energy of a thermodynamic system.

[36] Entropy expresses disorder or randomness; entropy of an isolated system always increases or remains constant.

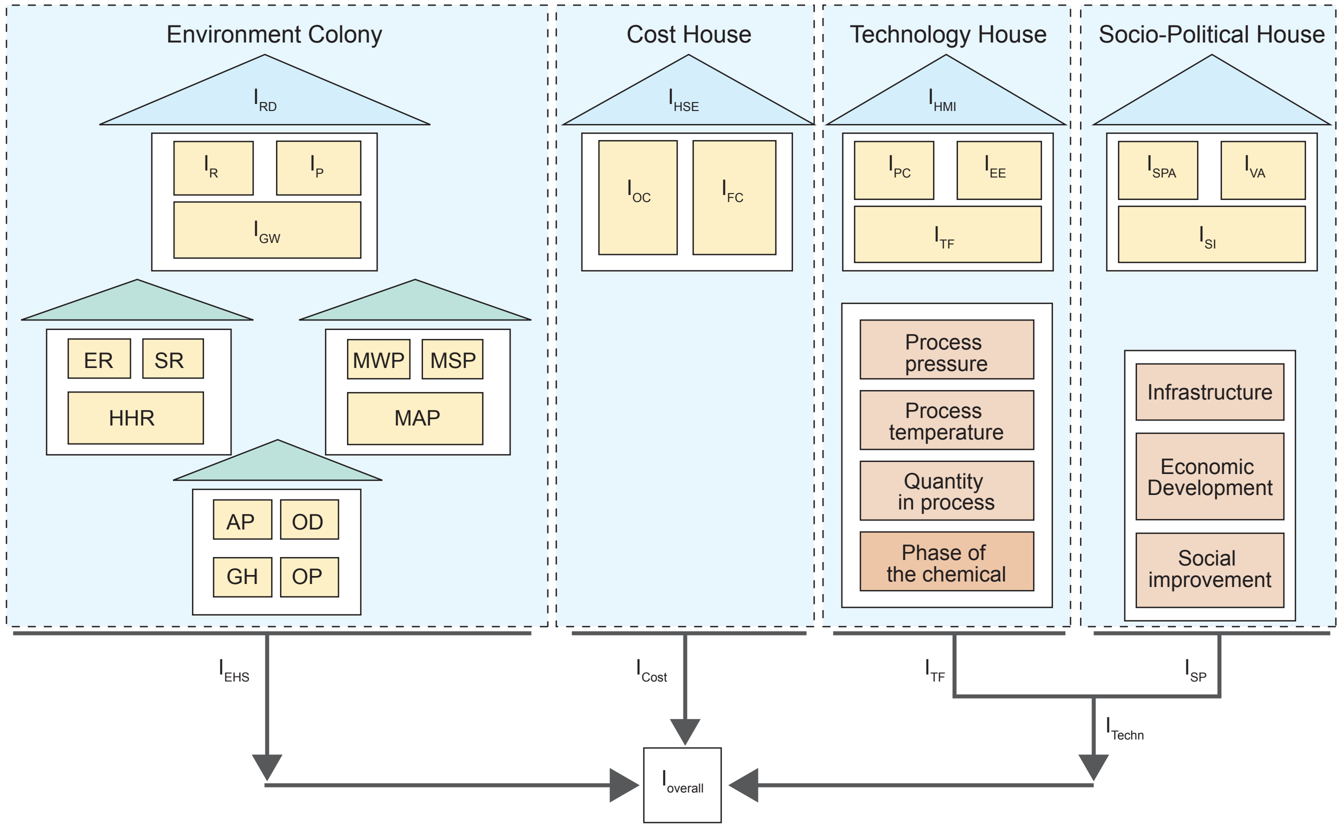

Figure 6. *The framework of LiNX (Khan et al. 2004). Letter 'I' refers to index. RD = resource depletion, GW = global warming, ER = ecological risk, SR = safety risk, HHR = human health risk, MWP = mass of water pollutant released, MSP = mass of solid waste disposed, MAP = mass of air pollutant released, AP = acidification, GH = greenhouse, OD = ozone depletion, OP = oxidation potentials, HSE = health, safety, and environment cost, OC = operation and maintenance cost, FC = fixed cost, HMI = human–machine interaction, PC = process conditions, EE = energy efficiency, TF = status of the technology, SPA = socio-political acceptance, VA = vulnerability of area, SI = social impacts. Combined indexes: EHS = environment, health and safety; TF = technical feasibility; SP = socio-political factors.*

The parameter values are further scaled from 1 to 10 and the scaled parameters are aggregated using the multi-criteria analysis (MCA) method known as analytical hierarchy process (AHP). Khan et al. (2004) determined the weights of each basic parameter and sub-index to be considered in the aggregation on the basis of an expert opinion survey. Demonstration of the use of LInX was conducted with three different power generation options, namely 1) a coal-fired power plant with three different emission control or boiler options, 2) a power plant using natural gas, and 3) a power plant using biomass. On the basis of the demonstration, the LInX system is environment sensitive, the overall index being most sensitive to the following four parameters: resource depletion (RD), greenhouse effect (GH), human health risk (HHR), and air pollutant mass (MAP). The overall index is also sensitive to the fixed cost (FC) parameter, but comparatively less sensitive to technical feasibility (TF) and human-machine interaction (HMI). As in any MCA method, such as AHP, the subjectivity in weighting and quantification of some parameter values causes uncertainty in the results. However, on the basis of the demonstration Khan et al. (2004) conclude that parameters involving subjective quantifications do not have pronounced impact on the indices and corresponding ranking in the LInX system. The system would therefore be useful as a rapid screening tool for LCA based decision-making.

4.3 Eco-efficiency indicators

The indicators of eco-efficiency originate from its definition, i.e. eco-efficiency is the ratio of economy to the environment or vice versa. Different parameters can be used to describe the factors 'economy' and 'environment', however.

Return on environment (ROE) shows economic returns on environmental burdens incurred from products. ROE is a measurable life cycle index intended to render LCAs more suitable for decision making. A further benefit that ROE provides is the guidance to a life cycle practitioner, or product development team, to assess if sufficient data has been collected, or if costs and impacts have been over or underestimated. It has advantages over specific ecoindicators, such as manufacturing energy or waste emissions, which are both product specific and subjective. ROE also serves as a systematic index for reporting improvements or as a relative environmental rating. (Hunkeler and Biswas 2000)

Green productivity (GP) **index** is the ratio of productivity to environmental impacts. Hur et al. 2004 developed two types of GP indicators to help understand the practical concept and executive approaches of GP, using environmental management tools such as LCA and total cost assessment (TCA). GP index is defined as the ratio of productivity of a system to its environmental impacts. This index is intended for estimating the GP performance of an existing product or process and comparing it with other equivalents. Specifically, the GP index is a measure of the GP performance of a product system throughout its entire life cycle. The “overall” GP index can be divided into a “direct” GP index and an “indirect” GP index which are intended to analyze the GP performances of direct production processes and indirect processes, respectively. For internal managerial decision, GP ratio is developed to select one alternative out of a list of contenders in order to improve the GP performance of an existing system.

Several organizations, such as the United Nations Conference on Trade and Development (UNCTAD), WBCSD and the National Round Table on the Environment and Economy (NRTEE, Canada), have defined eco-efficiency indicators. The environmental impacts considered in the determination of the indicator values vary (Table 9).

Table 9. *Environmental impacts considered in the eco-efficiency indicators presented by three different organizations (based on Nerg 2008). CC = climate change, A = acidification, OD = ozone depletion, MC = material consumption, W = amount of waste (total), EC = energy consumption, WC = water consumption*

Organization	CC	A	OD	MC	W	EC	WC	Ref.
the United Nations Conference on Trade and Development (UNCTAD)	X		X		X	X	X	UNCTAD 2004
World Business Council for Sustainable Development (WBCSD)	X	X	X	X	X	X	X	WBCSD 2000b
the National Round Table on the Environment and Economy (NRTEE)					X	X	X	NRTEE 2001

As an example of tailored, company-specific eco-efficiency assessment, Baxter, a medical products and services company, developed an environmental financial statement system where it compared the environmental costs of its environmental program with the environmental program benefits in terms of income, savings and cost avoidance (Ethridge 1998). Savings come from the reduced use of hazardous material, decreased hazardous and non-hazardous waste disposal costs, energy conservation, and reductions in packaging cost. While income is generated by recycling. Waste reduction initiatives produce cost avoidance, i.e. savings, also in future years in which the waste remains eliminated from processes and packaging.

Respectively, conoco, oil and gas producing company and a subsidiary of DuPont, has adopted **an environmental cost-effectiveness index** which measures environmental costs for spill cleanup, remediation, waste disposal and water and air pollution control (Ethridge 1998). The index is expressed as cents per barrel of refined product. Environmental benefit can be assessed by comparing the index values in different years.

4.4 MEPI indicators

The EC fourth framework programme 'Environment and Climate' financed a study called 'Measuring Environmental Performance of Industry' (MEPI)[37]. The aim of this study was to develop measures for comparing the overall environmental performance of industrial companies (Berghout et al. 2001). As a result, the project defined quantitative indicators for the environmental performance of manufacturing in six industrial sectors: electricity generation, pulp and paper production, production of fertilizers, book and magazine printing, textile finishing and computer manufacture. The study focused on six EU countries: the UK, the Netherlands, Germany, Austria, Belgium and Italy. In addition, some data from the Finnish and Swedish pulp and paper industry were also included.

The MEPI approach separates *variables*, that is data on performance from *indicators*, i.e. normalised measures of performance (Berghout et al. 2001). The project identified a total of 60 variables covering the studied six industrial sectors. The indicator sets were developed from the variables, most of them being simple ratios of two variables. Indicators were divided into physical, eco-efficiency and impact indicators. Physical indicators measure mass, energy and waste flows through manufacturing processes and are reported as ratios of mass, energy or waste per unit of produced product (or service). Eco-efficiency indicators link physical data to data on business performance and thereby give a measure of the economic value associated with use of resources or pollution burdens. Impact indicators link physical data on inputs and emissions of a company to measurable impacts on human populations and the environment, such as contributions to climate change and acidification. For constructing the indicators, MEPI defined the following functional units:

- a standardised unit of production from a given sector;
- turnover: total sales for a given company (or site);
- employees: number of personnel employed by the company (or site);
- value added: total value of sales minus cost of materials; and
- profit: untaxed total value of sales minus cost of sales.

Comparison of different indicator sets across industrial sectors showed that some environmental issues, such as energy use, greenhouse gas emissions and water consumption, are generally applicable. Whereas some are specific to certain production processes, e.g. nuclear fuel discharges from nuclear power plants, or copper emissions from textile finishing. Therefore, MEPI defined generic and sector-specific indicators. Factor analysis was used to identify the indicators that explain most of the variability in the overall environmental performance between companies. The identified core indicators typically included both generic and sector-specific indicators. For the studied industrial sectors, following core indicators were identified: total waste; SO_2, NO_x, and CO_2 emissions to air; nitrogen, phosphorous, chemical oxygen demand (COD) emissions to water; total water input; and total energy input.

The MEPI study concluded that it is crucial to focus on the most relevant elements of corporate environmental performance. Normalization was identified a critical issue since there is frequently a mismatch between the most appropriate functional units and those for which data is available. (Berghout et al. 2001)

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[37] http://www.sussex.ac.uk/Units/spru/mepi/index.php

4.5 Indicators implying specific environmental consequences or resource use

Besides indicators that integrate different environmental, economic, and social aspects, there are several indicators that only imply specific environmental consequences or resource use. Such indicators include at least the ecological footprint/fingerprint, material input per unit of services (MIPS), carbon footprint, water footprint and different ecolabels.

4.5.1 Ecological footprint/fingerprint

Ecological footprint[38] is a resource management tool that measures how much land and water area a human population requires to produce the resources it consumes and to absorb its wastes under prevailing technology (Wackernagel 2008). The footprint calculates the biologically productive land and water an entity (an individual, a city, a firm, a country) needs to obtain resources and dispose of waste. The measurement of the footprint is based on the entity's use of energy, food, water, building material and other consumables. Measuring a company's (i.e. its activities) environmental demand on nature is based on translating the amount of resources used and wastes generated into units of biologically productive area, which is easy to understand and communicate to a broad set of stakeholders. The ecological footprint can be used to reveal when a company's products are ”footprint neutral”, i.e. when their use results in a net reduction in overall demands on the environment in offsetting pressures created by other activities. It is compatible with all scales of company operations, and provides both aggregated and detailed results by sector and products, facilities, and processes.

The ecological fingerprint depicts the relative impacts of the alternatives evaluated in each impact categories involved (Wall-Markowski et al. 2004) and is an indicator equivalent to ecological footprint. Figure 7 presents an example of ecological fingerprint assessment that involved six impact categories. The best alternative lies towards the center, meaning it has the least impact in that category. Conversely, the alternative that lies towards the outside of the fingerprint has the greatest environmental impact in that category.

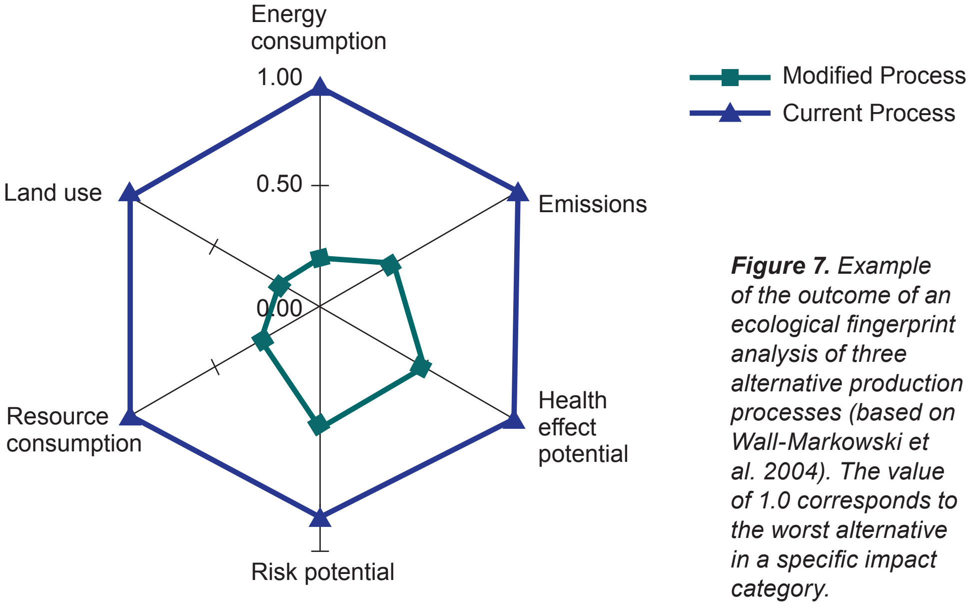

Figure 7. Example of the outcome of an ecological fingerprint analysis of three alternative production processes (based on Wall-Markowski et al. 2004). The value of 1.0 corresponds to the worst alternative in a specific impact category.

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[38] http://www.footprintnetwork.org/en/index.php/GFN/

4.5.2 Material input per unit of service (MIPS)

The concept of material input per unit of service (MIPS) was originally developed at the Wuppertal Institute, Germany in the 1990s. The MIPS concept can be used to measure eco-efficiency of a product or service and applied in all scales from a single product to complex systems. The calculation takes into account materials required to produce a product or service. The total material input (MI) is divided by the number of service units (S). For example in case of a passenger car, the number of service units is the total number of passenger kilometers during the whole life span of the vehicle. The lower the material input per kilometer, the more eco-efficient the vehicle is. The whole life-cycle of a product or service is measured when MIPS values are calculated (Ritthoff et al. 2003). This allows comparisons of resource consumption of different solutions to produce the same service. When a single product is examined, the MIPS calculations reveal the magnitude of overall resource use and help to focus efforts on the most significant phases to reduce environmental burden of the product.

The main limitation of MIPS as an EE indicator is that it only considers material flows. In many cases, other environmental aspects such as energy flows or emissions of harmful substances can be more important from the viewpoint of the overall environmental performance.

4.5.3 Climate change indicators

Several indicators exist which describe the climate change potential caused by industrial activities and are used as a measure of environmental performance. In addition, the Greenhouse Gas (GHG) Protocol sets the guidelines for calculating and reporting GHG emissions.

Carbon footprint (CF) – also known as carbon profile - describes the overall amount of carbon dioxide (CO_2) and other GHG emissions (e.g. methane, nitrous oxide etc.) associated with a product, along its supply-chain and sometimes covering use and end-of-life recovery and disposal. Sources of these emissions are various, for example electricity production in power plants, heating with fossil fuels, transport operations, and industrial and agricultural processes in general.[39] Analysis of a company's carbon footprint will quantify impacts and identify opportunities to move to less carbon-intensive products and processes. In manufacturing, profit margins built on carbon-dioxide emitting fossil fuels will become an increasing liability (Wackernagel 2008). The carbon footprint is quantified using measures such as the global warming potential (GWP). As defined by the Intergovernmental Panel on Climate Change (IPCC), GWP is an indicator that reflects the relative effect of a greenhouse gas in terms of climate change considering a fixed time period, such as 100 years (GWP100). The GWPs for different emissions can then be added together to give one single indicator that expresses the overall contribution to climate.

The carbon footprint is a sub-set of the data covered by a more complete LCA. Hence, carbon footprint is a measure of LCA with the analysis limited to emissions that have an effect on climate change. Suitable background data sources for the footprint are therefore those available in existing LCA databases. These databases contain the life cycle profiles of the goods and services that you purchase, as well as of many of the underlying materials, energy sources, transport and other services. The standards ISO/WD 14067-1 (ISO 2009a) and 14067-2 (ISO 2009b) provide guidelines for the quantification of carbon footprint of products and communication of the results.

Carbon Disclosure Leadership Index (CDLI) measures the performance of companies according to the Carbon Disclosure Project (CDP) annual scores, which have been published since 2003 (PriceWaterhouseCoopers 2009). The CDLI fam-

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[39] http://lca.jrc.ec.europa.eu/Carbon_footprint.pdf

ily includes global, European, UK and US indexes[40]. The CDLI scores companies based on information disclosed by them in the annual survey. In the methodology, the index components are ranked and weighted according to the criteria provided by CDP and the market capitalisation and liquidity screenings in line with standard equity indices. Company responses are scored based on the quality of their reporting to CDP. Companies with the top scores for disclosure qualify to be listed in the CDLI. In 2010, the **Carbon Performance Leadership Index (CPLI)** was introduced to complement the disclosure score and recognize top scoring companies that are taking positive measures on climate change mitigation[41]. The sections of the CDP methodology consequently cover the following aspects: 1) governance; 2) risks and opportunities; 3) strategy; 4) GHG accounting, energy and fuel use, and trading; and 5) communications (CDP 2010). The governance section aims to track the responsibilities, mechanisms of monitoring the progress and performance incentives related to climate change, while the risks and opportunities section finds out the processes of identifying risks and opportunities, their magnitude and potential financial and other implications, among other things. The strategy section tracks company's potential emission reduction targets and actions and whether policy makers are engaged with in this context. GHG accounting section collects data on the GHG emissions, the methodology to determine them, and participation in emission trading, as well as on fuel and energy use. Finally, the practices of reporting on climate change mitigation activities are described in the communications section. In addition to the core questions included in these sectors, supplementary sector-specific questions are directed to oil and gas industry, electric utilities industry and automotive industry. In 2010, altogether 33 companies were qualified for global CDLI and additional 15 for CPLI.

The **Greenhouse Gas (GHG) Protocol Initiative** is a partnership of businesses, non-governmental organizations (NGOs), governments, and others convened by the World Resources Institute (WRI), a U.S.-based environmental NGO, and the World Business Council for Sustainable Development (WBCSD), which is a Geneva-based coalition of 170 international companies (revised version of the Greenhouse Gas Protocol from 2004)[42]. It was launched in 1998 with the mission to develop internationally GHG accounting and reporting standards for business and to promote their broad adoption. At present, the GHG Protocol is the most widely used international accounting tool for government and business leaders to understand, quantify, and manage greenhouse gas emissions. The Intitiative comprises two standards: GHG Protocol Corporate Accounting and Reporting Standard and GHG Protocol Project Quantification Standard. The former includes guidance on setting the inventory boundaries, identifying and calculating GHG emissions, quality managing of the inventory, accounting for offsets or credits resulting from GHG reduction, reporting, verification of the results and setting GHG targets. The GHG Protocol also serves as a foundation for the development of international programs, company inventories and standards, such as ISO standards.

4.5.4 Energy efficiency indicators

According to Martin et al. (1994) energy efficiency indicator is "a measure of the quantity of energy required to perform a particular activity, such as the production of output". Energy efficiency is effectively the inverse of this ratio, but it aims to measure ‘how well’ the energy is used to produce output. The units of energy efficiency indicators vary depending on the level of data aggregation, i.e. the level of analysis (Table 10). Physical indicators using physical units are generally more suitable for use in a detailed sub-sectoral analysis whereas economic indicators described in monetary units are usually applied at the macro economic level (Stevenson et al. 2000).

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[40] http://markit.com > Products and Services > Indices > Markit Equity Indices > Markit Carbon Disclosure Leadership Indices

[41] https://www.cdproject.net/en-US/Results/Pages/leadership-index.aspx

[42] http://www.ghgprotocol.org/files/ghgp/public/ghg-protocol-revised.pdf

Physical indicators express specific energy consumption relative to a physical measurement of production, such as tonnes of product. Their advantage is that there is a direct relationship between the indicator and the technology. For example improvements in technologies will be indicated as savings in the specific energy consumption, and result in an indicator that assesses a lower specific energy requirement per ton of output. The disadvantages of physical units include the difficulties of aggregating physical energy efficiency indicator data since it is not possible to compare physical indicators defined in differing units without conversions. Moreover, indicators measured in different forms are incomparable. Lastly, the data requirement associated with the construction of physical energy efficiency indicators is generally more laborious, and is not necessarily easily interpreted. (Stevenson et al. 2000)

Value based indicators measure the energy efficiency in monetary units, i.e. as the quantity of energy consumed relative to the economic/monetary value of the activity generated, for example the quantity of energy consumed relative to the value added of a particular industry sector production. The key advantage of using monerary units is that indicators can be easily compared across industries despite dissimilar products. However, economic based energy efficiency indicators suffer from a number of limitations. Firstly, they do not consider structural changes either between economies, or within an economy. Secondly, they incorporate a range of non-energy efficiency related influences, such as pricing effects. Furthermore, not all all sectors of the economy are represented adequately in economic variables, such as the household and personal transportation sectors. Differences in aggregation and measurement techniques between economies can also limit the analysis which is a problem particularly in the case of multi-sector aggregated analysis. (Stevenson et al. 2000)

Table 10. *Definitions of aggregate energy efficiency indicators relevant at the industrial sector and company level (modified from Stevenson et al. 2000)*

Level of aggregation	**Indicators**
Industrial sector	*Economic:* Energy intensity within industrial sector measured as sector-specific energy consumption per unit of value added *Physical:* Energy consumption measured as sector-specific energy use per unit of physical production
Industrial sub-sector	*Economic:* Energy intensity within industrial sub-sector measured as energy consumption per unit of value added in sub-sector *Physical:* Energy consumption measured as energy use per unit of physical production in sub-sector
Individual plant	*Economic:* Plant-specific energy intensity measured as energy consumption per unit of economic output *Physical:* Plant-specific energy consumption measured as energy use per unit of physical output
Industrial process	*Economic:* not available *Physical:* Process-specific energy consumption measured as energy use per unit of physical output

4.5.5 Cumulative Energy Demand (CED)

Cumulative energy requirements analysis (CERA) aims to investigate the energy use throughout the life cycle of a good or a service. This includes the direct uses as well as the indirect or grey consumption of energy due to the use of, e.g. construction materials or raw materials. This method has been developed in the early seventies after the first oil price crisis and has a long tradition. (Pimentel 1973, Boustead and Hancock 1979)

The cumulative energy demand (CED) which measures the energy use is widely used as a screening indicator for environmental impacts (Frischknecht et al. 2007). CED-values can also be used to compare the results of a detailed LCA study to others where only primary energy demand is reported. Furthermore, CED-results can be used for plausibility checks because it is quite easy to judge on the basis of the CED whether or not major errors have been made. However, due to the limited focus of the indicator, some researchers state that using CED is only sensible when combined with other methods (Kasser and Pöll 1999).

According to Huijbregts et al. (2006), fossil CED explains a significant part of the variation in products' different environmental impacts. Burning of fossil fuels has in fact been found to be the major contributor to several environmental problems in many studies. However, in addition to fossil CED, land use should be used as a separate indicator of environmental performance since the former does no imply the impacts of all energy sources, such as nuclear or hydro power.

There are several impact assessment methods to derive CED values (Table 11). The alternative methods vary in how they determine the energy content, whether they separate renewable and non-renewable primary energy sources, and how they handle nuclear and hydro energy. Choosing a suitable method for CERA is therefore a key question.

Table 11. *Some methods presented for the impact assessement to determine CED (based on Frischknecht et al. 2007)*

Name	Includes
Cumulative Energy Demand, CED (or KEA)	*Different types of renewable and non-renewable energy resources.*
Kumulierter Energie Verbrauch (KEV, Cumulative Energy Use)	*Energetic use of resources not including use of resources for materials, e.g. plastics.*
Graue Energie (grey energy)	*Non-renewable energy resources and hydro energy.*
Endenergie (end energy)	*Direct energy use not considering the supply chain. For the Minergie-calculations for houses all types of electricity consumption are multiplied with two.*
Consumption of non renewable energetic resources	*Non-renewable and unsustainably used renewable energy resources.*

4.5.6 Water footprint and water impact index

The concept of 'water footprint' was first introduced in 2002 by Hoekstra (Hoekstra et al. 2011). Water footprint is an indicator of water use that looks at both direct and indirect water use of a consumer or producer. The goal of assessing water footprints is to analyse how human activities or specific products relate to issues of water scarcity and pollution, and to see how activities and products can become more sustainable from a water perspective. The water footprint of an individual, community or business is defined as the total volume of freshwater that is used to produce the goods and services consumed by the individual or community or produced by the business[43]. It shows water consumption volumes by source and polluted volumes by type of pollution, geographically and temporally specified (Hoekstra et al. 2011). In the case of a product, the water footprint is the volume of freshwater used to produce the product, measured over the full supply chain. The focus of interest determines the way of assessing the water footprint, e.g. whether the interest is on one specific process step in a production chain, on the final product or on the producer or whole economic sector. As a tool, water footprint assessment provides insight, it does not tell people 'what to do' but rather helps people to understand what can be done.

The North American Veolia Water recently introduced a new indicator for environmental effects directed at water resources known as Water Impact Index[44]. This index incorporates multiple factors, i.e. consumption, resource stress and water

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[43] http://www.waterfootprint.org/?page=files/home

[44] http://www.wwdmag.com/Veolia-Water-Introduces-Water-Impact-Index-newsPiece21147

quality, and thereby covers broader aspects compared with the volume-based indicators such as water footprint. The Water Impact Index considers both direct and indirect influences of an activity from 'cradle to grave'. It incorporates the volume and quality of the water extracted and released back into the environment and adds the Water Stress Index. The Water Stress Index considers the local hydrological context and freshwater scarcity and thereby accounts for the level of stress on the resource.

4.5.7 Ecolabels

Ecolabels are markings affixed to products that pass eco-friendly criteria laid down by the government, association or standards certification bodies[45]. The criteria utilize extensive research based on the product's life cycle impact on the environment. Products with an ecolabel have been assessed and verified by an independent third body and are guaranteed to meet certain environmental performance requirements. Ecolabels therefore differ from green symbols and environmental claims, which are unverified and created by the manufacturer or service provider. Ecolabels may focus on certain environmental aspects of the product, such as energy consumption, water use, source of natural resources, e.g. wood, or they may encompass multiple environmental aspects. Ecolabels are usually funded and backed by the national government, but administered by an independent body. Acquisition of an ecolabel is voluntary, but it can offer industry a competitive advantage both nationally and internationally by implying good environmental performance. Ecolabels also provide consumers a tool to compare prices against the environmental performance of products. Ecolabeling can have implications for trade and can influence the design and manufacture of products.

The ISO standard (ISO 14025) divides ecolabels into the following three categories, all of which have different purposes, target groups and sources (Table 12):

- Type I – predetermined requirements and third-party certification;
- Type II – self-declared environmental claims by the producing company; and
- Type III – environmental declarations based on life cycle assessments; no set requirement limits but the results are third-party certified.

Table 12. *The three ecolabel categories and their characteristics (Tonteri et al. 2003).*

Type I **ISO 14024**	**Type II** **ISO 14021**	**Type III** **ISO/TR 14025**
Environmental Labels	**Environmental Claims**	**Environmental Declarations**
Selected criteria as hurdles, demonstrating environmental excellence	Single issues describing specific environmental characteristics	Life cycle performance data, aim is continuous improvement
Life cycle thinking	Life cycle thinking	Llife cycle assessment
✓ Mandatory certification ✓ Issued by private or publics, accredited institution	✓ Issued by manufacturer ✓ Certification possible	✓ Mandatory 3rd party validation ✓ Cerification possible ✓ Issued by private, accredited institution
Public product group based criteria	Claims must be based on available public initial information	Initial information data should be available except private company information
like: Swan Label, European Eco-Label	like: Recyclabillity, Compostable	like: Environmental Product Declaration

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[45] http://www.gdrc.org/sustdev/concepts/05-e-label.html

A reputable ecolabel is a simple and effective way to enable consumers to make environmentally sound purchases. The organization behind the label sets all the requirements and limits and assesses the product's environmental impact. An independent third party checks whether the product fulfils the requirements. Products that do not meet the requirements are easy to identify since they are not permitted to carry an ecolabel. The Nordic Ecolabel (Swan) and the EU Ecolabel (Flower) are the most widely adopted ecolabels. Several national ecolabels are also in use, such as Bra Miljöval (Sweden) and Blue Angel (Blaue Engel, Germany).

4.5.8 Environmental certificates

From the generic certificates that describe the environmental performance at corporate or company level the ISO 14000 standard family is the best known and widely adopted. This standard family comprises a group of international standards on environmental management and provides a framework for the development of an EMS and the supporting audit programme. ISO 14001 is the corner stone standard of the ISO 14000 series. It specifies a framework of control for an EMS against which an organization can be certified by a third party. Other standards in the ISO 14000 series (Table 13) are guidelines which aim to enhance achieving registration to ISO 14001.

Table 13. *The ISO 14000 standard family (ISO 2007a).*

Standard	Contents	Note
ISO 14004	guidance on the development and implementation of EMSs	
ISO 14010	general principles of environmental auditing	superseded by ISO 19011 (2002)
ISO 14011	specific guidance on audit an EMS	superseded by ISO 19011 (2002)
ISO 14012	guidance on qualification criteria for environmental auditors and lead auditors	superseded by ISO 19011 (2002)
ISO 14013/5	audit program review and assessment material	
ISO 14020+	environmental labeling and declaration issues	
ISO 14030+	guidance on performance targets and monitoring within an EMS	
ISO 14040+	life cycle issues	

Studies have been carried out on whether the adoption of ISO 14001 affects the preformance of companies. Barla (2007) collected monthly data from 37 Quebec's pulp and paper manufacturing plants between 1997 and 2003 for such a study. On the basis of this material he showed that: (i) ISO certification does not lead to a reduction in total suspended solid emissions or in the volume of rejected process water; (ii) discharge of biological oxygen demand decreases by some 9% following certification; (iii) those plants that adopted the ISO certification did not show a significant negative trend in emissions over the study period, contrary to the group of plants that did not adopt the ISO norm. The results also showed a very variable impact of ISO across the plants that adopted it. Barla (2007) found that most adopters either maintained or even increased emissions after ISO accreditation, and concluded that ISO certification may have more significant impacts on pollutants that are newly or not yet regulated (e.g. green house gases). Since the analysis focused on testing the impact of ISO certification of an EMS rather than its implementation per se, it is possible that implementing an EMS reduces emissions but that the ISO requirements do not improve its effectiveness. Barla stated that further research is needed particularly to identify factors that may explain why ISO succeeds in some organizations and fails in others.

Besides generic certificates, specific environmental certificates also exist for certain industries. For example the construction industry generally relies on energy performance certificates (EPC). EPCs give information on how to make a building more energy efficient and reduce carbon dioxide emissions. The LEED[46] (Leadership in Energy and Environmental Design) certification provides a broader approach to the environmental performance in construction industry. LEED is a rating system developed and administered by the U.S. Green Building Council (USGBC), which is a nonprofit coalition of building industry leaders. LEED aims to promote sustainable building and development practices and it measures several environmental aspects, such as water efficiency, indoor air quality, sustainability in site selection and local environmental concerns, to name a few. Sustainability in construction is also addressed in the standard ISO 21930 (ISO 2007b), which includes guidelines for the environmental declaration of building products.

4.5.9 Indexes and matrices describing hazards or risks

Hazard to human health and ecosystems caused by production systems and products is one of the determinants of their environmental efficiency and sustainability. In process hazard analysis, matrices are a common means of assessing the risks related to processes (Table 14).

Table 14. *Example of a risk ranking matrix used in process hazard analysis (based on Sutton 2003).*

	Consequence				
Frequency		Low	Moderate	Severe	Very Severe
	Low	D	D	C	B
	Medium	D	C	B	B
	High	C	B	B	A
	Very High	B	B	A	A

In quantitative environmental hazard/risk assessment of chemicals, the potential hazards posed by the human toxicity or ecotoxicity of a mixture of substances are generally expressed as a **Hazard Index** (HI) (e.g. Sorvari 2010). Generally, HI is calculated from **Hazard Quotients** (HQ) of single chemicals. This assumes that the hazard quotient of each substance present in the mixture and their mechanisms of joint toxic actions are known. The aggregation method depends on the type of joint toxic actions. HQ is the ratio of estimated dose or concentration of a chemical to its safe dose/concentration. The exceeding of the value HI = 1, or HQ = 1 in the case of a single chemical, indicates that the acceptable (i.e. safe) concentration or exposure level has been exceeded. Lower cutoff values have also been applied, for example in order to account for unknown chemical sources and background (e.g. Belluck et al.2006). The Hazard Index approach has been used, for example in process safety assessment of chemical processes (Khan et al. 2001). **Margin of Safety (MOS)** and **Margin of Exposure (MOE)** are alternative indicators which describe potential hazards (e.g. WHO 2004). In practice, both are equivalent to the inverse of HQ. The exact definitions and basis of calculation vary, however.

Indicators implying specific process hazards/risks include at least Dow and Mond indexes, IFAL index, and the mortality index. **Dow Fire and Explosion Index (Dow FEI)** is the most widely used hazard index in process safety assessment, and commonly referred as the Dow Index. It uses the information on the flammability and reactivity of material to determine the potential energy released from it. The resulting material factor is multiplied with a unit hazards factor that describes process hazards caused by the use of chemicals. The **Mond Fire, Explosion and Toxicity**

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[46] http://www.usgbc.org > LEED

Index (Mond FETI) is an extension of the Dow Index and it takes into account some additional hazard factors, such as toxicity. **Dow Chemical Exposure Index (Dow CEI)** is a measure of the relative acute toxicity risks and it can be used for initial PHA, and in emergency response planning, among other things. It uses the information on the physico-chemical properties of the material, process, layout of the plant and the location of equipment and piping. The **Instantaneous Fractional Annual Loss (IFAL) Index** was developed by the Brittish Insurance Technical Bureau primarily for insurance assessment purposes. IFAL only considers fire and explosion hazards. Finally, the **mortality index** is a measure of the lethality of the hazardous materials, expressed as the number of deaths per tonne of material involved. (Khan et al. 2001)

Khan et al. (2001) developed a **safety weighted hazard index (SWeHI)**, an improved version of the Hazard Identification and Ranking (HIRA) technique. SWeHI covers the fire, explosion and toxic hazards. It is calculated as the ratio of the magnitude of the potential damage (i.e, Hazard Potential Index, B) to the credits due to control measures and safety arrangements (Hazard Control Index, A). Here B corresponds the area under 50% probability of damage. The credits considered by A include detection schemes and detection devices and equipment reliability, among other things.

Chemicals' hazard/risk assessment based on determining hazard indexes from chemical data requires chemical-specific reference values which correspond to the maximum safe concentration or dose. Cancer risks are generally expressed as the number of estimated cancer incidences instead of HQ/HI, and calculated using a slope factor for the dose-response curve. For those carcinogens with non-linear behavior, an approach equivalent to non-carcinogens is used instead. In addition, in some cases, the assessment of adverse health effects can be based on biokinetic models which describe the relationship between exposure and concentration in the body, e.g. in tissue or blood, taken into account the absorption, distribution, metabolism, and elimination of the chemical. Databases and other sources exist where different benchmarks, e.g. reference doses, are available. The problem is however, that due to the different methodologies, endpoints and safety factors used in their derivation, the final benchmarks can vary considerably. The variation in the case of benchmarks implying adverse ecological effects is much higher than variation in the human health risk based benchmarks. It is therefore important to know the basis of the benchmark and consider their suitability in the particular assessment case. (Sorvari 2010).

4.6 Examples of industry and company specific indicators and indexes

Several companies and industry sectors have adopted tailored environmental performance indicators and indexes (EPI) to report their performance. The company specific EPIs usually consist of one number or a score that describes the environmental performance of all of a company’s operations. It is benchmarked against a base year. Examples of some industry- and company-specific indicator sets and EPIs are presented below.

4.6.1 Environmental Performance Indicators for pulp and paper industry

The Environmental Paper Network (EPN, USA) has evaluated the environmental performance of American pulp and paper industry on the basis of tailored indicators (Roberts 2007). Only environmental aspetcts were considered in this evaluation and hence, economic performance, and social impacts were excluded. Altogether, data were collected for 55 different measures, i.e. indicators, of environmental performance (Table 15).

Table 15. *Environmental performance indicators for pulp and paper industry adopted by the Environmental Paper Network (USA) (modified from Roberts 2007).*

Environmental goal	Indicators
Minimizing paper consumption	• Paper and paperboard consumption: 1) global, by country and region, 2) global, by grade, 3) per capita • Paper consumption by grade in USA • Printing & writing paper consumption in USA, by end use
Maximizing Recycled Content	• proportion (%) of pulp made from recovered fiber • North American high grade deinking capacity • Recycled content in papers and paper products, by sector and grades within sector • Consistent minimum content recycled fiber specifications and standards • Range of recycled paper choices available in each grade • Volume of paper in the U.S. municipal solid waste stream • Recovery rates by grade of paper • Recovery rate for office papers • Percentage of recovered high grade papers directed to "highest and best use" such as printing & writing paper • Percentage of mixed paper in recovered paper collections vs. sorted papers • U.S. exports of recovered paper • Recycling capacity in developing nations
Sourcing Fiber Responsibility	• Monitoring endangered and high conservation value forests • Stakeholder engagement and agreements • Protection of endangered forests and high conservation value forests • Forest Stewardship Council (FSC) certifcation • FSC ceritfied paper products reaching consumers • Rate of conversion of forests to plantations • Percentage of plantation area certified py FSC • Number of corporate commitments to avoid conversion of forests • Use of herbicides on tree plantations • Use of synthetic fertilizers on tree plantations • Outdoor field trials of genetically engineered trees • Nort American availability of non-wood plant fiber for pulp and paper • Global availability of non-wood plant fiber for pulp and paper • Leading non-wood fibers in papermaking • North American pulping capacity for non-wood plant fibers • World pulping capacities for non-wood fiber
Employing Cleaner Production Practices	• Use of 1) wood, 2) water, 3) energy, 4) calcium carbonate • Emissions: 1) GHG, 2) SO_2, 3) NO_x, 4) particulate matter, 5) hazardous air pollutants, 6) VOCs, 7) total reduced sulfur, 8) mercury, 9) BOD, 10) COD, 11) TSS, 12) AOX, 13) dioxins and dioxin-like compounds, 14) total nitrogen and phosphorus • Solid waste • Effluent flow • Bleaching processes used for all bleached pulp

4.6.2 Key sustainability indicators for steel industry

Singh (2008) identified the key indicators included in the GRI system (see chapter 4.1.4) to be used for assessing the sustainability of a steel plant (Table 16). Identification was based on experts' rating of each sustainability factor using the AHP technique. Besides the environmental, economic and social performance, organizational governance and technical aspects were included as the fourth and fifth dimensions of sustainability.

Table 16. *Example of the use of sustainability indicators in accordance with the GRI system: the key indicators of a steel plant in the five sustainability component categories, presented in a descending order of their importance (based on Singh 2008). The codes of the corresponding generic indicators of the GRI system (GRI 2011), if identified, are shown in parentheses.*

	Organisational Governance	**Technical Aspects**	**Economic**	**Environmental**	**Society**
1	Leadership	Coke rate (Kg/thm)	Gross margin/ turnover ratio (EC1)	Particulate Matter stack emission load (Kg/tcs) (EN20)	Nos of fatal Accidents (LA7)
2	Strategic planning & resouce management	BF productivity	Net profit/average capital employed (EC1)	Percent utilisation of total solid wastes (%) (EN2)	Accident Frequency rate (LA7)
3	Cost competitiveness	Labour productivity	Net profit/total income or revenue (EC1)	Specific energy consumption (Gcal/tcs) (EN3 & EN4)	Absenteeism rate (% of total mandays available) (LA7)
4	Management tools	Export tonnage ratio	Investment in new processes and products (% of revenues) (EC1)	Specific Raw material Consumption (tonnes/tcs) (EN1)	Nos of employees trained (mandays/ employee/yr) (LA10)
5	Innovation & Knowledge management	Defects (%)	Turnover/ inventory ratio (EC1)	Specific water consumption (m3/tcs) (EN8)	Expenditure on peripheral development
6	Technology & Investment	Special grades production (%) of saleable steel		Specific carbon dioxide emissions (kg/tcs) (EN16)	Employee satisfaction (can involve several indicators)
7	Human resource management	New product development (% of saleable steel)		Specific effluent load (kg/tcs) (EN2)	Quality of life (can involve several indicators)
8	Order generation market dev. & customer satisfaction	Market performance (% increase in domestic share with prev. year)		Specific refrigerant consumption (Kwh/tcs) (EN1)	Employment generation (LA2)
9	Materials management	Customer satisfaction Index		Specific power consumption (Kwh/tcs) (EN3 & EN4)	Non-discrimination, diversity & opportunity (HR4)
10	Research & Development	Savings through suggestions & QC projects (Rs/tcs)		Specific refractory consumption (kg/tcs) (EN1)	Freedom of association (HR5)
11	Process management	Cost reduction (Rs/tcs)		Percentage green cover of total plant area (%)	Child & forced labour and human rights compliance (HR6 & HR7)
12	Information technology	Equipment availability (%)		Specific Hazardous waste generation (kg/tcs) (EN22)	Suppliers & contractors practices (can involve several indicators)
13		Order compliance (%)		Specific Heavy metals discharge load (kg/tcs) (EN21)	Concern for local communities (can involve several indicators)
14		No. of complaints		Average Noise level in the periphery of plant (dB)	Customer health & safety (PR1 & PR2)
15				Overall average Opacity (%) (EN21)	

4.6.3 Product Sustainability Index in automotive industry

Schmidt and Butt (2006) derived the following PSI indicators for use in the management of sustainability in the design and development of passenger vehicles:

- Life Cycle Global Warming Potential (greenhouse gas emissions along the life cycle)
- Life Cycle Air Quality Potential (Summer Smog Creation Potential, POCP) along the life cycle (VOCs, NOx)
- Sustainable Materials (recycled and natural materials)
- Restricted Substances (Vehicle Interior Air Quality)
- Drive-by-exterior Noise
- Safety (pedestrian and occupant)
- Mobility Capability (luggage compartment volumeplus weighted number of seats) related to vehicle size
- Life Cycle Ownership Costs (Vehicle Price + 3 years fuel costs, maintenance costs, taxation, insurance minus residual value).

The first two indicators are part of an LCA according to ISO 14040. Schmidt and Butt (2006) highlight that all materials are linked to environmental, social and economic impacts and cannot be inherent sustainable. However, recycled materials and renewably grown, natural fibres represent a kind of role model how limited resources can be used in a sustainable way. The benefits of overruling materials depend on the environmental consequences of using alternative materials, i.e. whether the former have a lower environmental impact along the product life cycle compared to the latter.

4.6.4 Indicators in other industry sectors

The EPI system used by Nortel, the Canadian-based telecommunications firm, includes 25 performance parameters in the following four broad categories:

- Compliance: notices of violation, fines, exceedances,and incidents;
- Environmental releases: releases to air, water, land and the global environment;
- Resource consumption: thermal energy, electricity, water consumption, and paper purchases; and
- Environmental remediation: number of remediation sites and risk factors. (Ethridge 1998)

Each of the four categories is weighted based on 1) its impact on the environment; 2) how directly the parameter measures environmental performance; 3) what control the company has over the parameter (e.g. influence by weather); and 4) financial and public risk to the company (Ethridge 1998). Finally, the environmental data are normalized to the costs of goods and labor.

Eastman Kodak, the imaging and film processing company developed an EPI for measuring environmental progress at its manufacturing sites (Ethridge 1998). Separate facilities are allowed to develop performance criteria that are appropriate to that site. The system is supplemented by corporate environmental performance standards audits for all facilities. The EPI is expressed in terms of a matrix instead of a single figure. Three different performance levels are used to rate each measure: a baseline level, a goal, and a stretch goal. A weighting factor that reflects the relative impact of each measure on overall environmental performance is then assigned for each progress measure.

Novo Nordisk, a Danish pharmaceutical and chemical company, has developed a sustainability index called an Eco-productivity index (Ethridge 1998). The index measures the use of raw materials, water, energy, and packaging relative to use in the defined base year.

4.6.5 Environmental Performance Indicators for waste management sector

Green Alliance[47] has developed environmental performance indicators for the waste management sector in UK (Green Alliance 1999). These indicators were designed for the companies dealing with controlled waste, including household, industrial and commercial waste. The indicators focus on the environmental considerations and thus, they do not to consider the economic and and social components. The indicators are as follows:

- Climate change. Alternative measures include total electricity consumption, total energy consumption, CO_2 emissions, GWP, tonnes of CH_4 collected, proportion of CH_4 collected that is utilised, number of landfill sites where power is generated from landfill gas, power generated from landfill gas in total MW, energy produced as CO_2 avoidance, CH_4 emission savings expressed as CO_2 equivalent,
- Air pollution measured as the amount of SO_x and NO_x,
- Transport. Alternative measures include total vehicle miles travelled by company cars and fleet vehicles, total use of fuel by fleet vehicles, volume of waste moved by rail or waterways in tonnes,
- Water measured as volume of water used,
- Land use and wildlife. Alternative measures include actual or planned end uses of restored land, number of trees planted per year and the total area covered by tree planting, hedgerow planting, changes in the populations of species,
- Waste minimization. Alternative measures include, contribution to waste minimization through consultancy services, contribution to education about waste minimization, contribution of a new product design to waste minimization: amount of waste recycled (tons), the capacity of MRF for handling waste (in tons), growth in the number of MRFs managed by a company, percentage of waste sent to the main categories of end destination, such as composting, recycling, re-use (if distinguishable from recycling), incineration and landfill,
- Environmental Management Systems indicated by the number of sites registered to a recognised EMS,
- Regulatory compliance. Alternative measures include number of prosecutions, number of breaches of site licences or discharge consents, number of enforcement notices issued, and the Environment Agency's Operator Performance Risk Assessment (OPRA) rating,
- Neighbourliness. Alternative measures include, number of complaints, communication, number of liaison committees, and funding of local community projects via environmental bodies.

The indicators are not ranked nor prioritized since their developers consider it inappropriate due to the fact that they all measure such different aspects.

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[47] Green Alliance is a Brittish environmental pressure group and an indipendent charity which works closely with the government, parliament, business and major environmental organisations with the focus on on leadership for the environment (http://www.green-alliance.org.uk/whatis/).

Conclusions

This literature survey showed that the concept of environmental efficiency (EE) is not established and it has seldom been properly defined. Overall, its use in industry is considerably more infrequent compared with other concepts such as sustainability/sustainable development, environmental performance and eco-efficiency. In this report, environmental performance was interpreted to be a synonym to environmental efficiency, as per the European and national ecodesign regulations (EU 2009b, Laki 1009/2010, VnA 2010). However, there is a need to clarify the concept of environmental efficiency in order to facilitate interpretation of companies' EE reporting.

There are numerous methods to assess and indicators to describe environmental efficiency or some of its components. The approaches and principles of these methods and indicators vary due to differences in industrial applications and desired outcome, i.e. for what purpose the results from the environmental efficiency assessment (EEA) are used. The use of variable methods (and indicators) makes comparison of the results from separate EEAs difficult. When choosing the EE methods it is important to be aware of their principles, suitability for EEA of a particular case, and any limitations and pitfalls they have. For transparency reasons, any limitations should also be acknowledged when interpreting the results.

LCA appears to be the most common method used in the assessment of environmental performance of companies and processes. The impact categories, normalization factors and weighting factors vary in different LCA methods causing variability in results and indicators determined based on them, when different methods are used in separate work steps. In contrast to other EE methods such as risk assessment, emissions below legal thresholds are considered in LCA ('less is better' approach) (Potting & Hauschild 1997a; b, Potting et al. 1999, Ref in Frischknecht et al. 2007).

Hazard and risk analysis provide data on the hazards, such a chemical spills and explosions, and they can complement an LCA based EE analysis. Both LCA and hazard/risk assessment look into the future. The time scales, however, vary. For example, the global warming potential that is one of the impact categories in LCA describes future impacts in a time frame of 20, 100 or 500 years and ozone depletion with an infinite time frame (Frischknecht et al. 2007). At the same time, LCA should consider all emissions and impacts 'from cradle to grave'. This holistic approach of LCA is not consistent with abovementioned harsh temporal cut-offs (Finnveden 1997 Ref. in Frischknecht et al. 2007). In environmental risk assessment, the time scale for human health effects is generally life time, default value being 70 years, but in the case of risks to groundwater quality it can extend to centuries (e.g. Sorvari 2010). In the case of ecological risks, the length of the time frame should depend on the life cycle of the organisms and ecosystems to be protected and no clear default values exist. Integrating these different temporal scales as well as spatial scales of environmental consequences is in fact a true challenge in EEA. Moreover, how the on line process control data, site-specific environmental monitoring data, results from modeling, and generic life-cycle data are aggregated for the monitoring and assessment of EE, is an open question.

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