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Life Cycle Assessment – A Tool for Sustainability and Business Opportunity

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ABSTRACT

Life Cycle Assessment (LCA) is a tool used to determine the complex interaction between a product, service or process with the environment. Results from a full LCA study provide the basis for improvement of environmental performance as the study identifies the key ecological impacts and stages of the life cycle of the product which contribute to environmental consequences. The many practical applications of LCA include its use in improving a product or process, material selection, eco-labelling and as a marketing strategy. As LCA is still a developing field, there are limitations in performing the study, the major issues being the availability of inventory data and uncertainties in impact assessment methodologies.

The main aim of this article is to provide the background necessary for understanding the application and relevance of LCA in sustainable development of the palm oil industry.

ABSTRAK

Penilaian kitaran hayat (LCA) adalah suatu kaedah yang digunakan untuk menentukan interaksi kompleks di antara produk, perkhidmatan atau proses dengan alam sekitar. Kajian LCA yang lengkap merupakan asas dalam melaksanakan pemuliharaan alam sekitar, di mana ia dapat mengenal pasti impak ekologi utama dan peringkat kitaran hayat produk yang memberi kesan kepada alam sekitar. Antara penggunaan LCA yang dipratikkan termasuk penggunaan dalam usaha penambahbaikan produk atau proses, pemilihan bahan, melabelkan eko dan juga sebagai strategi pemasaran. Namun begitu, LCA merupakan satu bidang yang masih pada peringkat awal. Oleh itu, data inventori yang diperlukan untuk menjalankan kajian ini masih terhad. Ketidakpastian dalam kaedah penilaian impak juga merupakan antara masalah yang dihadapi.

Tujuan utama penulisan ini ialah untuk memberikan maklumat asas bagi memahami penggunaan dan kaitan LCA dalam pembangunan industri sawit yang mampan.

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INTRODUCTION

Man is understandably anthropocentric although the values of the majority are not exclusively so. Many people care about others as well as animals and the environment, but man's achievements and progress have primarily stemmed from the need to address his own concerns. The health of the earth's ecosystems has been sorely neglected in the creation of anthropogenic ecosystems to increase the quality of man's life, and consequentially the environment has been modified to suit man when rightly man should have adapted himself to suit the environment. Along with the progress in science and technology, man has successfully improved his quality of life but often at the expense of the environment. The earth's natural resources have been gradually drained to support the growing human population and increasing consumption. A wealth of new materials has since been created to protect man against pests and diseases and to improve hygiene and health. Used materials or waste invariably end up in the air, water and on land, causing adverse impacts on the environment. Some of these discards have cumulative effects on human health, and many 'diseases of civilization' like cancers, diabetes, cardiovascular and neurodegenerative diseases have been attributed to environmental pollutants.

Besides health concerns, the world is now facing the greatest economic and social crisis of all time – climate change. Environmental issues are now front-page news and top the agenda on economic reforms, especially in the light of the Stern Review (Stern, 2007) that underscores the effect of global warming on the world economy. In his book, *Six Degrees – Our Future on a Hotter Planet*, Mark Lynas (2007) looks at the frightening consequences with each degree rise in temperature up to 6°, and argued that temperature increases can be avoided as long as man is committed to the effort of adapting to the environment instead of changing it. Green issues are now no longer the domain of eco-warriors such as Greenpeace (Ostopowich, 2002), Friends of the Earth (FoE) (Lamb and FoE, 1996) and World Wide Fund for Nature (WWF) (2008a) as it has become almost mandatory for companies and organizations to have a policy on climate change if they are to remain globally competitive.

'The weather has gone crazy/mad' is an often heard declaration. Climate change leads to a higher frequency of extreme weather changes and is believed to be responsible for the increasing intensity of floods and droughts in many countries. Between late 2005 and early 2006, a few states in West Malaysia experienced the worst floods in 30 years. In January 2007, devastating floods in Pahang, Melaka, Negri Sembilan and Johor displaced more than 110 000 people. Fortunately, environmental issues have been addressed in the Ninth Malaysia Plan (2006) which outlines the policies and key programmes for the period 2006-2010. The programmes are organized under five thrust areas, with the fourth thrust on the improvement of the standard and sustainability of the quality of life. Included in this thrust area are strategies for the promotion of environmental stewardship. The government stresses preventive measures to mitigate and minimize pollution as well as to address other adverse environmental impacts resulting from development activities. Steps will also be taken to identify and adopt action plans to promote sustainable natural resource management practices in relation to land, water, forest, energy and marine resources. The efforts are aimed at protecting the environment and conserving natural resources. The plan also promotes the greater use of environmentally sound technologies through the adoption of self-regulatory measures and the practice of the Life Cycle Approach (Environmental News No. 68, 2003) in production processes and product development. To facilitate efforts by industries to use Life Cycle Assessment (LCA), SIRIM Berhad (Chen and Wan Mazlina, 2005) has been given the mandate to build a National Life Cycle Inventory database for electricity generation, water supply, petroleum and natural gas exploration and the production of petrochemicals.

Currently, the basic challenge facing the Malaysian palm oil industry is to sustain global competitiveness in the face of stagnating productivity and increasing production costs. Malaysia lost her position as the world's largest producer of palm oil, primarily because of limited land area for expanding oil palm cultivation. With the introduction of new regulatory requirements and trade obligations relating to environmental concerns and sustainability by palm oil importing countries such as the European Union (Schlegel and Kaphengst, 2007), an environmental performance audit of the palm oil industry is of the utmost importance.

LCA AND SUSTAINABILITY

The Brundtland report (1987) defines sustainability in the following manner: 'Sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs. Man has the ability to ensure sustainability'.

In simple terms, our future generations have a right to enjoy and use the resources to which we have access now. These include clean air and water, a stable climate, varied biodiversity and habitat, pristine or virgin forests and productive natural resources. Many make the mistake of equating sustainability with environmental issues alone. The fact is there are actually three areas of concern in sustainability, namely, the environment, economic and social aspects. As these are man's fundamental concerns, sustainability should be a mandatory business policy. Sustainable development is what every industry should strive for and achieve as proof of their social, economic and environmental obligation.

Sustainable issues are actually the drivers behind tools and approaches for their quantification, and LCA is such a tool. As one of the dimensions of sustainable development, LCA is a sustainable initiative or an integral part of a sustainable strategy.

LCA is in effect a mechanism for monitoring the trends and threats to the environment. LCA provides the necessary information to support the implementation of policies on sustainability. Through improvement analyses based on LCA, a concrete policy can be drawn up for responsible use of resources so that the sustainability issues are addressed accordingly.

After having stressed the earth's ecosystems (thankfully not yet to the point where they cannot recover), the road to sustainability is a long and difficult one (Anderson and Bausch, 2006). Along the way, challenges that must be overcome include changing the mindset; dealing with environmental systems management, environmental policies of trade partners, corporate social responsibility, renewable and non-renewable resources; risk assessment and management; costs analyses as well as LCA. A good start to addressing sustainability is to carry out a full LCA study, because engaging in LCA is a key element for gaining credibility on sustainability claims by the palm oil industry (United Nations, 2004).

WHAT IS AN LCA STUDY?

The growing interest in LCA has been driven by spotlights on environmental issues such as the Academy award-winning documentary feature, *An Inconvenient Truth,* written and starred by Al Gore, the former US Vice President (2007). Wal-Mart, the largest grocery retailer in US, and TESCO, the British-based international grocery and general merchandising retail chain, also have played a big role in highlighting the importance of environmental accountability. The former officially launched the Wal-Mart Scorecard (Wal-Mart Stores, Inc. Packaging Modelling) which measures packaging sustainability through various metrics, including greenhouse gas (GHG) emissions, product-to-package ratio, and the amount of renewable energy used throughout the manufacturing and delivery processes (Wal-Mart, 2008). On its part, TESCO has commissioned Environmental Resources Management Limited (ERM) to map the total direct carbon footprint of the TESCO business in countries in which the group operates. For the financial year 2006/2007, TESCO revealed a direct carbon footprint of 4.13 t of carbon dioxide equivalent for the TESCO group, with the UK business alone emitting 2.25 t or 55% of the total direct emissions.

LCA was first used in the early 1970s by the energy sector to monitor the impact of energy consumption in the face of rapidly depleting fossil fuels. The emergence of LCA as a tool for measuring environmental impact began in earnest in the nineties (SETAC, 1993a, b; 1994; 1995; 1997) as a result of discussions on how to monitor and measure progress towards sustainability. When applied correctly, it is a tool for identifying sustainable activities as it assesses environmental impacts along the whole life cycle – from cradle to grave – of an activity, process or product.

LCA can be defined as a step-by-step process for evaluating the environmental burdens associated with an activity, product or process. The method based on the life cycle of the activity, product or process identifies and quantifies energy and materials used and wastes released to the environment, and thereby assesses the impact of those energy and material use and wastes to the environment (Arnold, 1993). As a follow-up to the impact assessment, the study then determines and weighs the associated problem areas or hotspots so that improvements can be made. Such improvements can be in terms of increased efficiency, reduction of energy input or emissions. Thus, a full LCA study also identifies and evaluates opportunities to bring about environmental improvements.

When LCA is used in combination with economic analysis or Life Cycle Costing (LCC), it gives an insight into environmental and economic aspects, and can be used to determine the economic feasibility of the product, process or activity. Depending on the goals and scope of the LCA, it can vary from the simple to the detailed complex. However, a full life cycle will avoid the issue of 'shifting of burdens', namely the shifting of environmental burdens to other life phases. An example is the avoidance of a particular packaging material in the product-manufacturing phase which then results in higher impacts on the product-use phase because of the need to account for the disposal of used packaging material.

STANDARDIZATION OF LCA STUDIES

Any LCA study, especially essential for those commissioned for legislative purposes, must be carried out according to the ISO 14040 series of standards. The ISO 14040 series (Marsmann, 2000) covers a number of environmental topics and is part of a family of standards under ISO 14000 which are standards on environmental management. The standards were developed to provide a practical toolbox to assist in the implementation of actions to support sustainable development.

ISO 14040 is a framework for the standards ISO 14041, ISO 14042 and ISO 14043 that are concerned with the specific phases of an LCA. These three ISO standards are now integrated, harmonized and replaced by ISO 14044 which is the standard outlining the requirements and guidelines for LCA.

LCA METHODOLOGY

According to ISO 14040, there are four main phases in LCA as depicted in *Figure 1.*

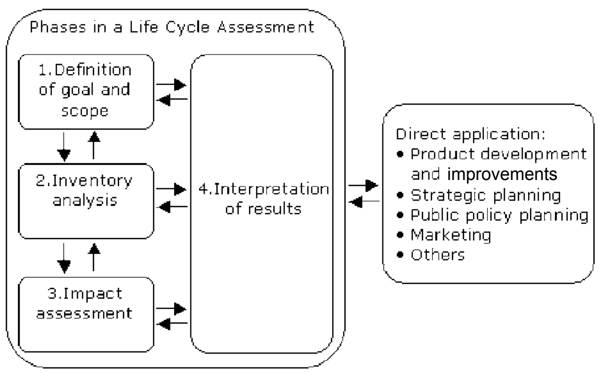


Figure 1. LCA methodology according to ISO 14040.

Phase 1: Goal Definition and Scoping

The ultimate goal of an LCA study is to produce a product, process or activity that has the lowest emission to the environment and makes the least demand on use of raw materials and energy. To effect this, the scope of the evaluation and intended use of the LCA must be addressed. A key element of this phase is to determine the limits of the study, *i.e.* the system boundary. Theoretically, the LCA should include all upstream and downstream activities associated with a product. In practice, however, the study can be scoped such that only key processes that can be influenced or controlled are identified. For example, in the production of packed cooking oil, certain additives not common to all cooking oils may be excluded from the study. Both temporal (time scale) and spatial (geographic coverage) boundaries of the evaluation will indicate the type of data required for the study. Decisions that must be made in this phase include what are to be evaluated, the purpose of the evaluation and the environmental issues of concern. The *functional unit* which defines the amount, weight and quality of the specific product investigated must also be identified, *e.g.* 5 kg cooking oil in a PET (polyethylene terephthalate) bottle.

Phase 2: Life Cycle Inventory Analysis

This is the most resource-intensive phase of an LCA study. In this step, it is best to create a process tree or flow chart in which all processes – from raw material extraction through to wastewater treatment – are mapped out and connected. Inputs and outputs in terms of materials and energy are to be determined in order to establish materials and energy balance for each stage or event within the scope of the LCA evaluation. A *Life Cycle Inventory* (LCI) is then carried out to gather, compile and quantify data on inputs and outputs.

Setting a boundary for this phase is extremely important as it will define the input data that should be collected and included in the analysis as well as the data that should be excluded.

Allocation is also an important consideration. Inventory analysis takes time and effort, and often mistakes are made. Life cycle impact assessment is evaluated on the basis of the data compiled and verified in this LCA phase. In certain cases, the input and output flows of a process or product system are partitioned. The issue of allocation arises when a process/system produces more than one product, *e.g.* a palm oil mill produces both crude palm oil (CPO) and kernels. In such cases, the calculation of the inventory results must be carried out in such a way that the input and output inventory flows are assigned appropriately to the product and co-products. Allocation can be based on weight, economic value, market price or calorific value (energy).

Phase 3: Life Cycle Impact Assessment (LCIA)

In this phase, input and output data are translated into indicators for assessing the potential impacts on the environment, health, humans, *etc*. In short, LCIA attempts to describe environmental consequences of the activity, process or product being studied. ISO has established three broad categories of concern that should be tracked in impact analysis. These *impact categories* are:

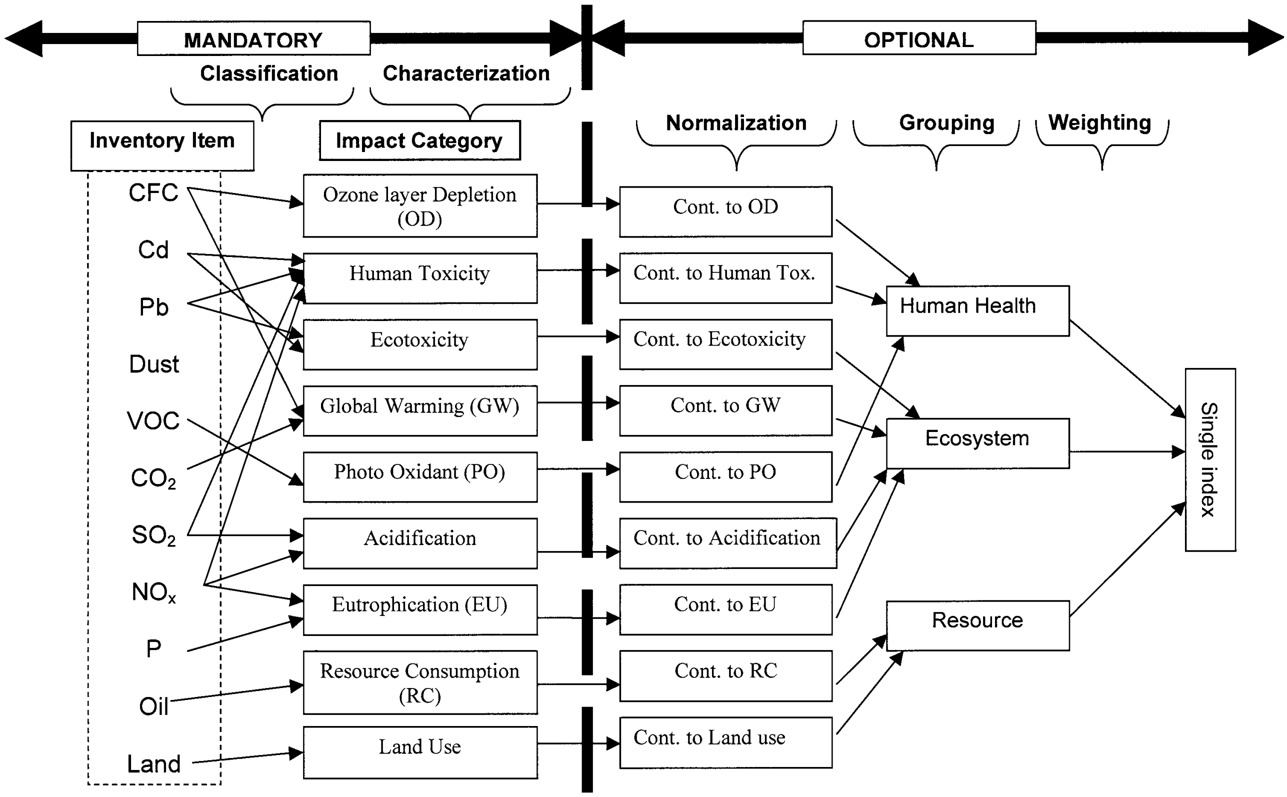
- resource use;
- human health; and
- ecological consequences.

The different steps in an LCIA, in accordance with ISO 14040, include both mandatory and optional steps (*Figure 2*).

Step 1: Classification and characterization (mandatory). In *classification*, environmental burdens with the same environmental impact are grouped together. Accordingly, substances in the inventory data that contribute to greenhouse effects or ozone layer depletion are divided into two classes. It must be noted that certain substances are included in more than one class as in the case of nitrogen oxides or NOx which has an impact on human toxicity, acidification as well as eutrophication.

Once impact categories are identified, the LCI results are then converted to common units within each impact category by a process known as *characterization*. Science-based conversion factors called *characterization factors* are used to convert and combine the LCI results into representative indicators of impacts to human and environment health. The results can be aggregated into category indicators as shown in *Table 1*. Characterization provides for comparison of the LCI results within each impact category. For example, all greenhouse gases can be expressed in terms of carbon dioxide (CO_2) equivalents by multiplying the relevant LCI results by a CO_2 characterization factor and then combining the resulting impact indicators to provide an overall indicator of GWP (Global Warming Potential).

Step 2: Normalization. In ISO 14040, this step is optional and involves comparing the results with a fixed benchmark. Here, the impact of the category indicator results is divided by a reference value in a normalization procedure. The reference value can be selected based on the total emissions or resource use for a given area or the total emissions or resource use for a given area on a per capita basis.



Note: Cont. = contribute.

Figure 2. The flow and steps of Life Cycle Impact Assessment (LCIA).

TABLE 1. IMPACT CATEGORIES, CATEGORY INDICATORS AND CHARACTERIZATION MODELS

Impact category	Category indicator	Characterization model
Climate change	Infra-red radiation forcing for a time horizon of 100 years	IPPC – provides characterization factors , Global Warming Potentials (GWPs) for 20, 100 and 500 years.
Stratosphere ozone depletion	Stratospheric ozone breakdown	WMO – provides stratospheric ozone depletion potentials (ODPs) for a steady state in terms of CFC-11 equivalents.
Photo-oxidation	Tropospheric ozone production	UNECE Trajectory model.
Acidification	Acidification critical load	RAINS model of IIASA – marginal approach chosen and spatially differentiated background levels taken into account.
Eutrophication	Eutrophication critical load	Stoichiometric approach – establishing equivalency of macronutrients on the basis of their occurrence in biomass.
Human toxicity	-	USES 2.0 of RIMV – both fate and effect of the substances are included; a steady state model at world level without background levels is used.
Ecotoxicity	-	USES 2.0 of RIMV – both fate and effect of the substances are included. Also a steady state model at world level without background levels is used.

Source: ISO 14047.

Normalized data can only be compared within an impact category.

Step 3: Grouping. Grouping involves sorting or ranking indicators. Thus, indicators can be sorted by emissions to the air and water, or according to local, regional or global locations. Sorting indicators by ranking in terms of high, low or medium priority is based on value choices (*e.g.* company priorities, geographical relevance).

Step 4: Weighting. Weighting allows the assignment of relative importance to each impact category based on perceived importance or relevance. Factors based on value choices are used to convert the category indicators from different impact categories into a common unit. However, ISO standards do not allow weighting in comparative LCA studies for disclosure to the public. This is because weighting techniques and methods are derived not entirely from science but are also based on political value choices.

Phase 4: Interpretation/Improvement Analysis

This is the final and most important phase of an LCA study. Based on pertinent information obtained from LCIA, areas that require improvements can be identified. Here, results are interpreted and significant issues based on the results of the LCI and LCIA phases are identified for improvement. Conclusions and recommendations must be based on the facts from the study.

Completion of this phase will lead to an environmental profile in the form of a list of impact indicators for all the environmental impact categories considered in the impact analysis. Decisions on the impact of concern must then be made so that the improvements can be made accordingly. Currently, global warming is the most urgent issue, and consequently impacts brought about by emissions of GHG are often of top priority.

STREAMLINED LCA

As the term suggests, streamlined LCA (SLCA) is a simplified form of LCA. An SLCA does not include all material and energy flows, unit processes and potential impacts. Streamlining was mooted to make LCA more feasible, less costly and more immediately relevant while keeping the key features of a full-scale LCA. The usefulness of an SLCA is that, although less time and effort are involved, it still delivers the key results that would be provided by a full LCA. For example, a company may decide that the main focus on an SLCA relate to aspects associated with the manufacturing and disposal phases. It may also decide to consider only feed materials that are known to be detrimental to the enviroment.

In SLCA, the important elements to be considered are qualitative (in contrast with quantitative in a full LCA) inputs and outputs that can be omitted or ignored without affecting the overall result. One may then consider setting system boundaries to exclude processes that have insignificant environmental impacts, or to ignore environmental impacts which are of less importance to the study. An SLCA study can start with a LCA screening using a quality matrix approach. In this method, a matrix containing a series of questions supported by squares in the matrix, which summarizes information about the degree of environmental impacts, can be constructed. Answers to the questions can be in the form of graded scores, *e.g.* 0 – 5 with 0 representing poor performance while a score of 5 indicates excellent performance. *Table 2* is a hypothetical example of how an SLCA matrix may be used for cost-effective and simple communication of environmental impacts to non-experts, and to identify areas of concern before a full LCA is undertaken. The shaded squares can be filled with graded scores indicating key impacts of the product. Questions can also be designed such that only a 'Yes' or 'No' answer is needed. As both types of answers are subjective and arbitrary, they can only be used to call attention to the stage and impact category that deserve attention. Hence, an SLCA is a rapid technique for homing in on hotspots that need remediation. A cursory look at *Table 2* suggests that the main environmental impact comes from the source material used and the emission of solid waste.

THE BOUNDARY ISSUES AND THE FULL SUPPLY CHAIN

There are different phases in the life cycle of a product, namely:

- production phase;
- use phase; and
- end-of-life phase.

Each phase will have its own inputs and outputs (*Figure 3*). In turn, each of the rectangles within the system boundary is a subsystem boundary with its own inputs and outputs.

In the LCA of palm oil, it is very important to capture impacts across the entire upstream and downstream supply chain. Notwithstanding this, plantations, mills and refineries are not integrated entities, and the boundary within which each facility accounts for its environmental effects is usually defined as that which it can directly influence and control. Consequently, one of the most important issues in LCA is careful boundary definition. How-

TABLE 2. AN EXAMPLE OF A MATRIX APPROACH FOR STREAMLINED LIFE CYCLE ASSESSMENT (SLCA)

Characteristic	Raw material	Product manufacture	Packaging material
Source material undertaken from land	Yes	Yes	Yes
Synthetic and non-degradable materials	No	No	Yes
Bio-degradable	Yes	Yes	No
Solid waste	Yes	Yes	Yes
Liquid waste	No	Yes	No

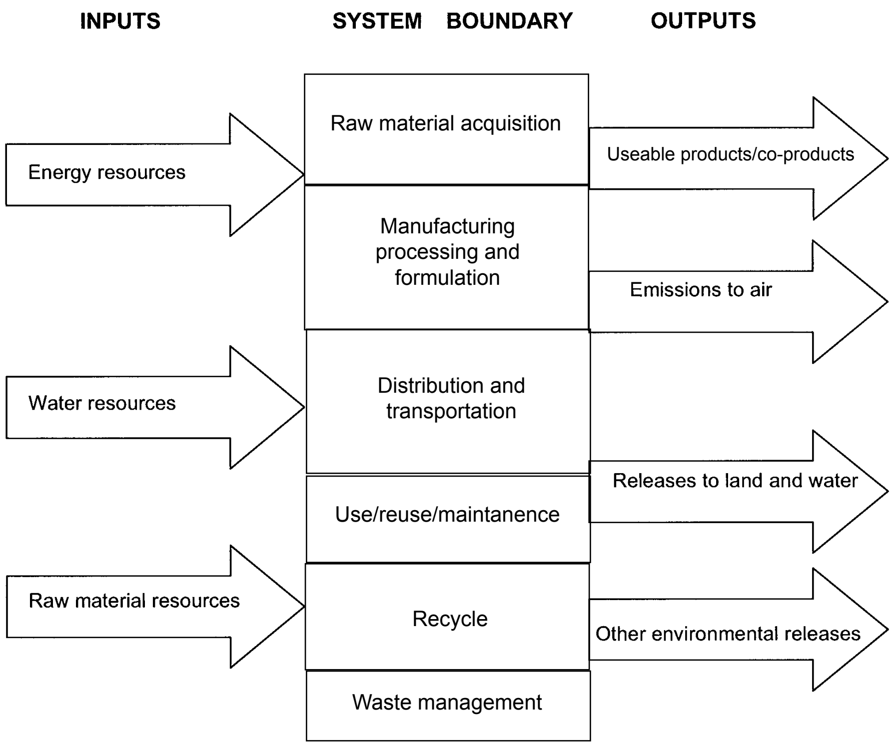


Figure 3. Input/output and system boundary.

ever, clear boundaries may be difficult and even impossible to define as a huge number of upstream suppliers also contribute to the production of palm oil. In general, first level suppliers, *i.e.* those who supply feed directly to the plant, are considered. Examples are the suppliers of phosphoric acid and bleaching earth for the production of refined palm oil. Secondary suppliers include the suppliers of feed to the primary suppliers, such as the acid used for the production of activated bleaching earth.

LCA AND FOOTPRINTS

The terms carbon footprint, water footprint and ecological footprint have increasingly appeared in the media of late, but the exact meaning and differences between them are not widely known. Surprisingly, not many individuals and organizations appreciate the relationship between these footprints and LCA. Although the intended purpose of these three footprints is different, all three share the similar concept as can be seen in the following explanations.

Carbon Footprint

Most people are actually more familiar with the term carbon footprint (CFP) than LCA. CFP is the overall amount of carbon dioxide (CO_2) and other GHG emissions such as methane, nitrous oxide (N_2O), chlorofluorocarbons (CFCs), hydrofluorocarbons (HCFs) and sulphur hexafluoride (SF_6). The last three GHG did not exist until they were created through processes devised by man. Each GHG has a different global warming potential (GWP) and a

100-year period has been adopted to compare the predicted impacts of GHGs on global warming (GWP_{100}). Scientific models have come up with the following: 1 kg of methane has the same effect as 23 kg of CO_2, 1 kg of N_2O is equivalent to 296 kg of CO_2, and so on[1] (IPCC, 2001). The sum total of the GWP_{100} for each of the GHG gives the CFP, expressed as the carbon dioxide equivalent (CO_{2e}) as CO_2 equivalent factors have been assigned to all the GHGs.

A deficiency of determining the CFP for evaluating environmental impacts is that it does not account for other environmental impacts, *e.g.* biodiversity. The CFP is only a sub-set of the data covered by a full LCA which measures the whole spectrum of environmental categories, including eutrophication, human toxicity, ecotoxicity, *etc.* (*Table 1*). Hence, a CFP is an LCA limited to the analysis of emissions which impact climate change.

Water Footprint

If all of the earth's water is represented by 1 litre, only one teaspoon is available for us to use (WWF, 2008b). Fresh water is one of our most valuable resources, being a more important life-sustaining element than food. Unfortunately, most LCIA methods consider fresh water resources to be non-depletable and therefore there is no characterization factor for freshwater exhaustion (Koehler, 2008).

The water footprint is an indicator of water use that looks at both direct and indirect water use. Hence, the water footprint of a product or service is the total amount of fresh water used to produce the product, summed over the various steps of the production chain (Hoekstra, 2008). This is sometimes known as the virtual water content of a product. Water-intensive products, *e.g.* meat, dairy products, sugar and corn, cause global pressure on fresh water resources.

The impact of a water footprint depends on where and when water is extracted. In a country where water is plentiful, the environment is unlikely to be adversely affected. On a year-round basis, Malaysia experiences less than 5% water stress although there have been instances when certain parts of the country were affected by water shortage.

As in the case of CFP, LCA offers the framework for the collection of information on the water footprint of goods, services and processes.

[1] GWP_{100} of SF_6 = 22 200, and GWP_{100} of HFCs = 120-12 000.

Ecological Footprint

The ecological footprint measures consumption of natural resources and the amount of biologically productive land and sea needed to regenerate those resources and to absorb and render harmless the waste that is produced. In short, it represents the human demand on natural resources. The measurement of the ecological footprint has been criticized because it lacks a sound scientific standard – consider the difficulty of translating every impact into land and sea areas. The good news is that Malaysia is still an ecological creditor country (WWF, 2008b). The bad news is that Malaysia's biocapacity, the capacity to support a thriving diversity of species including humans, is only 0%-50% greater relative to the ecological footprint. If Malaysia continues with 'business as usual', she will soon join the ranks of the debtors.

LCA SOFTWARE TOOLS

LCA software programs have been developed to simplify the complex and data-intensive methods of LCA analysis. These software packages contain customized applications for the evaluation of products, services and processes. Basically the tool is programmed to help gain access to material and process data, to simplify calculations of inventory and impact, to improve results, and finally to present the results of the LCA. Most of these software packages contain a number of standard impact assessment methods, and each method can contain as many as 20 impact categories (Jobrink *et al.*, 2000). Examples of these evaluation methods include Eco-Indicator 99 (Netherlands), EPS (Environmental Priority System – Sweden), Eco-Point (Switzerland) and LIME (Japan).

LCA databases are also incorporated in the software. With the aid of the LCA software, LCA practitioners manage the database, build systems and make the calculations. They then follow through with a step-by-step interpretation to validate each of the conclusions drawn, and finally present the LCA report.

There are quite a number of LCA software packages available in the market. Most of the software programs are European-based and their prices range from free access to USD 20 000. Companies and organizations could refer to the report by Jobrink *et al.* (2000) for information on the LCA software tool that best fits their respective LCA needs. However, the tool chosen should satisfy a few basic criteria with regard to service, functionality and databases. The user should be assured of service in the form of quick support, such as a hotline service, including updating with new improved versions.

The functionality of the software is improved if it works under Microsoft Windows, an operating system familiar to the majority. The size of the database included in the software is also important to ensure that it has the required data, especially background data. One of the most important database issues is the source of the data. An LCA study carried out in an organization located in Asia, using European-derived data may produce inaccurate LCA results because of a number of differences (location, climate, *etc*.). If noise and land use are of concern to the LCA study in question, then the selected software must be one which addresses these issues. In addition to LCA, a number of these software packages also support environment and sustainability reporting, total cost accounting, design for environment, energy efficient studies, substance flow analyses, *etc.*

DATA COLLECTION AND SOURCES

Input and output data directly involved with the manufacture of a particular product can be obtained from the producer through measurements, questionnaires, interviews, literature search, theoretical calculations, database search and even qualified guessing. The two types of data in an inventory of inputs and outputs are foreground and background data. The former are those specific to the process, service or product being assessed, *i.e.* those within the system boundary. Background data refers to processes that support the foreground data, such as electricity, water, transport processes, waste treatment and auxiliary materials.

Public, proprietary, or restricted-access databases are available for the supply of background data, and these are continually updated to ensure that the data sets used are recent. As mentioned earlier, LCA software tools also supply a search for LCA databases. The Malaysian Government recognizes the need to develop a public LCA database with data applicable to Malaysia. The initial move to achieve this was taken under the Ninth Malaysian Plan with SIRIM Berhad being given the mandate to establish such a database. In the Asia Pacific region, Japan has been the prime mover of LCA activities. The Japanese National LCA Project which started in 1998 has culminated in the development of a publicly available LCA database to advance LCA methodology and practice throughout Japan. The LCI data for average Japanese production of a variety of materials are prepared with the cooperation of Japanese industrial associations, whilst calculations based on input/ouput tables, statistics and process models are used to fill in data gaps. Initially released only in Japanese, the database is now available in the JEMAI Pro software in English.

LCA OF PALM OIL

Theoretically, a complete life cycle system should start with all raw materials and energy sources from the earth, and end with all materials returned back to the earth, water or atmosphere. The complexity of the task in comprehensively measuring indirect sources of environment impact in the LCA of palm oil is tremendous. A detailed LCA study would involve all steps in the life cycle of palm oil including material and energy use for growing the palm – from conversion of land into oil palm plantations, the germination of seeds to seedlings, transportation to the plantation and so on, until the production of refined palm oil and its fractions, and its transportation to consumers. *Figure 4* shows part of the life cycle of the palm oil supply chain. The dotted line is the boundary of a gate-to-gate LCA study of a subsystem in the whole supply chain. The solid line represents the boundary for a detailed LCA study of the palm oil supply chain. All processes lying within the dotted or solid line boundaries will be considered for the gate-to-gate LCA study or full LCA study, respectively. All inputs and outputs are to be quantified. Foreground data represented by plain rectangles are foreground processes (source of foreground data) where key data will be collected directly from the plant/plantation/nursery. The shaded rectangles represent sources of background data which can be collected from published sources or proxies (same operation from overseas).

In a few cases, manufacturers have applied the LCA template to only their own operation. Applying LCA to a particular operation is a gate-to-gate approach. This gate-to-gate approach (represented by the area within the dotted line in *Figure 4*) uses the LCA template to assist in organizing and analysing data gathered within the facility. An example is a soap manufacturer using LCA to assess the environmental impact of producing soap without considering the effect of the production of feed material, *i.e.* the oil or fatty acids, or the disposal after use. While several practitioners call this approach a streamlined LCA, many would consider that it is more appropriately called an environmental assessment. As mentioned earlier, the advantage of this approach is that the LCI data can be gathered easily, and the processes under the study are directly controlled by the user. The disadvantage is that the benefits of looking at the life cycle of all the materials required in the production or process are lost.

Theoretically, the life cycle of a product begins with the removal of raw materials and energy sources from the earth for making the product. In the case of palm oil, land use changes is first considered before the palm fruits (renewable raw ma-

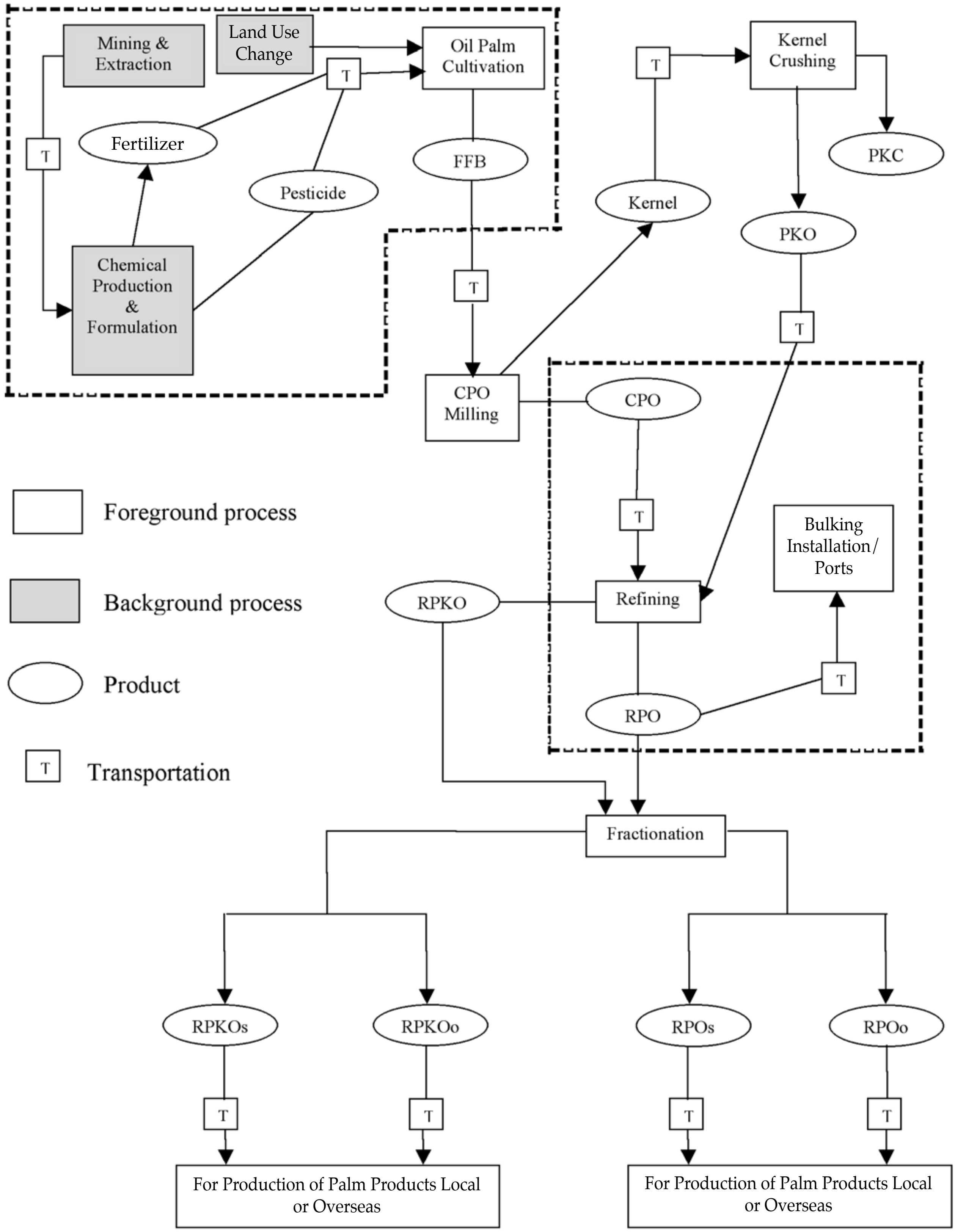


Figure 4. The palm oil supply chain.

terials) and fertilizers (extracted from the earth and are non-renewable materials) needed for oil palm cultivation, and transportation of the fruits to the mill for oil extraction (fossil fuel for lorries, a non-renewable material) would be considered raw materials.

During the milling of the oil palm fruits, the raw materials are processed into economic products, namely the crude oil and kernels. Subsequent production of refined palm oil consists of a number of steps including refining, fractionation, filling/packaging and distribution of the finished products to retail outlets or consumers.

The use phase involves consumers' use of the oil, and this stage includes use of the oil as it is presented, or use of the oil as a raw material for the production of other products, *e.g.* margarine, soap, oleochemicals, *etc*. Again, all energy demands and releases/emissions to land, water and air from both oil storage and consumption must be accounted for.

The recycle and waste management phase of palm oil is associated with the disposal of waste products (*e.g.* spent bleaching earth, wastewater) generated from palm oil production as well as used packaging material for palm and palm oil products. Ideally, LCA studies should be performed on all palm products.

There are still barriers to conducting a successful LCA of the palm oil supply chain. One of this is the lack of public LCI databases and the fact that the Malaysian LCI databases are still being developed.

MPOB LCA PROGAMME

The environmental research needs and strategy of MPOB are outlined in the MECO report (2006). In 2006, MPOB embarked on a full LCA study of the palm oil supply chain to provide generic data for the palm oil industry as well as to endorse the sustainability of palm oil production. A particular refinery or mill can use the generic data (*i.e.* data without regard for geographic variability in the life cycle inventory of the LCIA) to carry out LCA of their respective activities. Spatial differentiation will increase the discrimination power of the LCIA only if generic data are those from countries with geographical and climatic conditions very different from Malaysia, *e.g.* Europe and USA. As Malaysia is a fairly small country, the use of generic data in different locations will not make too much of a difference in the LCIA.

The LCI data for palm oil were first collected based on sub-systems, *i.e.* gate-to-gate, by different researchers. The sub-systems include activities/processes in oil palm nurseries and plantations, mills (Vijaya *et al*., 2006; 2008a, b), kernel crushers, refineries, fractionation plants, biodiesel plants, and in the manufacture of palm-based products and oleochemicals. LCI data were collected from these sub-systems through questionnaires disseminated to stakeholders and palm-related agencies such as PORAM (Palm Oil Refiners Association of Malaysia) and MPOA (Malaysian Palm Oil Association). On-site visits were then carried out to verify data extracted from the questionnaires. Background data for resource exploitation of supporting feed materials such as fertilizers, bleaching earth and chemicals were obtained through available databases in various LCA software (*e.g.* SimaPro, Jemai LCAPro and GaBi), literature and public database searches (*e.g.* LCAccess EPA-sponsored website), as well as the National LCA Database Project under SIRIM Berhad.

The LCA for the various gate-to-gate studies are reviewed by the LCA Technical Working Group, the LCA Technical Committee and the National Committee on LCA Studies for the Oil Palm Industry comprising representatives of the stakeholders, SIRIM Berhad and the MPOB LCA team. These review meetings check the reliability of the data before the subsequent phases of LCIA and improvement analysis.

THE MODEL LCA TEAM

A successful LCA study needs coordinated efforts from a team comprising members who understand the palm oil supply chain and the associated transport modelling, with knowledge of both public and private databases and is familiar with the ISO 14000 series of standards. In a full LCA study, the LCA team leader is the environmental expert within the organization whose primary role is to coordinate the LCA project. The leader can be supported by team members consisting of:

- an engineer who oversees the engineering systems in the organization;
- manufacturing or operations personnel well-versed with the operational aspects;
- a purchasing representative who provides the data on purchases, and coordinates the study with vendors;
- a marketing representative who is responsible for supplying public statements about the environmental status of the product or service;
- representatives of the stakeholders who provide information on the concerns of the stakeholders

and give comments on the scope and technical review of the study;
- vendors who affect the purchasing decisions by providing technical data on material inputs; and
- outside expert/s recruited to carry out a critical review of the LCA study and give credibility to the results.

DRIVERS AND BENEFITS OF LCA TO THE PALM OIL INDUSTRY

The first concern upon the introduction of a new approach or regulation is cost. A non-LCA practitioner may initially view LCA as being costly, extremely complex and tedious to perform. It cannot be denied that complexity is unavoidable, especially if a detailed and accurate LCA study is involved (Arnold, 1993). This complexity can be reduced partially by an SLCA, but purists would strive to incorporate whatever details are important in the LCA. However, if criteria that determine what can be discarded or ignored are clearly defined at the very beginning, the study will be much easier to undertake. It is therefore vital to spend time in drawing up rational system boundaries, tightening the scope of the study, and to identify and address only issues that require immediate attention, *e.g.* climate change as opposed to biodiversity. The study is made easier by asking the right questions, laying out correct and clear objectives, and having the right people and tools to carry it through.

Having said that, the real driver and benefit of a full LCA study is the need to fulfil environmental regulations relating to trade of climate-sensitive goods. Climate change demands immediate attention and an international response. LCA enables a company to carry out eco-efficiency analyses which is a harmonization of economic and ecological considerations. Assessing the environmental impacts of human activities and industries is now an integral part of emerging company policies and an LCA study is a transparent presentation of the environmental performance for policy makers. Besides compliance to regulations, LCA gives the market advantage for environmental preferred products. The company's image can be improved by introducing environmental-friendly and ethical practices into the supply chain. A sector which has carried out an LCA study goes into the global market with increased competitiveness. In addition, engaging in LCA is also a key element for gaining credibility on sustainability claims made by the industry.

One of the drivers for LCA is a benchmark against which the environmental performance of palm oil production can be compared with other vegetable oils. Here, special mention must be made of 'comparative assertions' because of the need for this comparison. ISO 14040 defines comparative assertion as: 'environmental claim regarding the superiority or equivalence of one product versus a competing product which performs the same function'.

In essence, it is a claim that one product or service is better than or equal to another, and for this declaration to hold, an outside review is required to substantiate the claim. For this critical review, an outside expert provides an impartial audit of the study.

CONCLUSION

The present reality is that we have to deal with environmental deterioration with what we have. Currently, the main sustainability issues that the palm oil industry has to deal with are climate change and deforestation. It is envisaged that issues on water scarcity and fair labour conditions will follow suit. Mitigation using the LCA concept must be viewed as an investment for our future generations, if not for ourselves, because efforts in mitigating environmental degradation will translate into a concerted effort to combat the many environmental impacts resulting from mismanagement of natural resources and energy. LCA is the tool that puts the development of products, materials and their associated processing steps into the context of the most important issue of the moment, *i.e.* sustainability. A range of options can be taken to ensure sustainability, but a strong, deliberate and committed policy action is needed to motivate their deployment. The government must therefore ensure that the LCA approach is pervasive and persuasive in order to increase the critical mass of local LCA practitioners and become competitive in the process. Time and investment on LCA activities will be rewarded by the sustainable and secured development of the palm oil industry. "There is enough in the world for man's need but not for man's greed" - Mahatma Gandhi (1869-1948).

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Appendix 1

LCA GLOSSARY

Acidification potential Acidification potential is caused by direct outlets of acids or by outlets of gases that form acid in contact with air humidity and are deposited in soil and water. Examples are: sulphur dioxide (SO_2), nitrogen oxides (NOx), ammonia (NH_3). Acid depositions have negative impacts on natural ecosystems and the man-made environment including buildings. The main sources of emissions of acidifying substances are agriculture and fossil fuel combustion used for electricity production, heating and transport.

Allocation 'Partitioning of the input and output flows of a process or other product system to the product system under study.' (Source: ISO 14040.)

Analysing products (LCA studies) Evaluating the reduction of the product environmental negative effects and setting priorities in product improvement.

Benchmarking products A comparison of products to determine improvement, optimization and saving potentials.

Benchmarking sites A comparison of sites to determine improvement, optimization and saving potentials.

Best available techniques reference document (BREF) Best available techniques (BAT) reference documents created under the IPPC Directive 96/61/EC. 'The BREFs will inform the relevant decision-makers what may be technically and economically available to industry in order to improve their environmental performance and consequently improve the whole environment.' (Source: http://eippcb.jrc.es/)

Capacity building 'Improving and building the technical and managerial skills and resources within an organisation.' Here, related to the capacity to perform and/or review LCA studies and providing life cycle related services. (Source: World Bank.)

Carbon dioxide Gas naturally produced by any living organism during respiration, including through microbial decay of biomass, and taken up by plants during photosynthesis. Although it only constitutes 0.04% of the atmosphere, it is one of the most important greenhouse gases. The combustion of fossil fuels is increasing the carbon dioxide concentration in the atmosphere, which is generally accepted by scientists to contribute to climate change.

Carbon dioxide equivalent A metric measure used to compare the emissions from various greenhouse gases based upon their climate change potential (CCP). The carbon dioxide equivalent for other emissions is derived by multiplying the amount of the emission by the associated CCP factor, *e.g.* [x kg gas] * [y CCP-factor of the gas]. For example, the CCP100-factor for methane is 21 and for nitrous oxide 310. This means that emissions of 1 kg of methane and nitrous oxide are equivalent to emissions of 21 and 310 kg of carbon dioxide, respectively.

Category/impact category 'Class representing environmental issue of concern.' For example, climate change, acidification, eco-toxicity *etc*. (Source: ISO 14042.)

Characterization The process by which the significance of a product's environmental burdens is quantified.

Classification The process by which environmental burdens are grouped into impact categories such as acidification and global warming.

Clean Development Mechanism (CDM) A mechanism in the Kyoto Protocol that makes it possible for developed and developing countries to perform joint environmental projects in the developing country financed by the developed countries. The resulting emission reduction can be credited to the developed country, which paid for the improvement in the developing country.

Comparative assertion 'Environmental claim regarding the superiority or equivalence of one product versus a competing product which performs the same function.' (Source: ISO 14040.)

Comparative life cycle assessment A comparison of LCA results for different products, systems or services that perform the same function. Often the products, systems, or services are competitive.

Cradle-to-cradle Cradle-to-cradle is a way of thinking about life cycles. If the grave of one cycle can be the cradle of its own or another, the life cycles are called 'cradle-to-cradle'.

Cradle-to-gate	This is the LCA of the efficiency of a product or service until it is produced or delivered. It shows the environmental performance *per se*. It is often used for environmental product declarations (EPD).
Cradle-to-grave	A 'cradle-to-grave' assessment considers impacts at each stage of a product's life-cycle, from the time natural resources are extracted from the ground and processed through to each subsequent stage of manufacturing, transportation, product use, recycling, and ultimately, disposal.
Cut-off criteria	'Specification of amount of material or energy flow or level of environmental significance associated with unit processes or product system to be excluded from the study.' (Source: ISO 14040.)
Damage approach	See Endpoint Method.
Depletion of abiotic resources	The consumption of non-renewable resources, such as zinc ore and crude oil, thereby lowering their availability for future generations.
Design for Environment (DfE)	Design for Environment (DfE) or Ecodesign are methods supporting product developers in reducing the total environmental impact of a product early in the product development process. This includes reducing resource consumption as well as emissions and waste. New EU directives such as WEEE and RoHS introduce the concept of ecodesign. A sound life cycle-based Ecodesign can potentailly enable the provision of a reliable decision support at largely reduced efforts for performing the study.
Design for recycling (DfR)	'Design for recycling is a method that implies the following requirements of a product: easy to dismantle, easy to obtain 'clean' material-fractions, that can be recycled (*e.g.* iron and copper should be easy to separate), easy to remove parts/components, that must be treated separately, use as few different materials as possible, mark the materials/polymers in order to sort them correctly, avoid surface treatment in order to keep the materials 'clean'.' (Source: Danish EPA Eco Design Guide.)
Eco-efficiency	Joint analysis of the environmental and economic implications of a product or technology, aiming to support choosing the method for production, service, disposal or recovery that makes most ecological and economic sense, ensuring optimum conservation of resources, minimum emissions and waste generation at a low overall cost.
Eco-efficiency studies	See Eco-efficiency.
Eco-management and auditing scheme (EMAS)	A community scheme, adopted by the European Union in 1993, allowing voluntary participation by companies performing industrial activities, established for the evaluation and improvement of the environmental performance of industrial activities and the provision of the relevant information to the public. The objective of the scheme is to promote continuous improvements in the environmental performance of industrial activities by: a) the establishment and implementation of environmental policies, programmes and management systems by companies, in relation to their sites; b) the systematic, objective and periodic evaluation of the performance of such elements; c) the provision of information on environmental performance to the public.
Eco-design	See Design for Environment.
Eco-label	An 'eco-label' is a label which identifies the overall environmental preference of a product or service within a specific product/service category based on life cycle considerations. Eco-labels exists at EU level (the EU Flower), regional level (*e.g.* The Swan in Scandinavia), and national level (*e.g.* The Blue Angel in Germany).
Ecology	The branch of science studying the interactions among living organisms and their environment.
Eco-toxicity potential	The potential environmental toxicity of residues, leachate or volatile gases to the biocoenosis of plants and animals. Eco-toxic substances alter the composition of the species in ecosystems, destabilizing them thereby and additionally threatening sensitive species in existence.

Emission trading	A market-based approach that makes it possible for organizations or countries to buy and sell greenhouse gas emission reductions (as set out in Article 17 of the Kyoto Protocol).
Endpoint method	The endpoint method (or damage approach) tries to model the effects of emissions directly for the protection targets (natural environment's ecosystems, human health, resource availability). Endpoint methods typically follow the midpoint modelling considering the severity and reversibility of effects and the model's uncertainties.
Energy-using products directive (EuP)	Directive 2005/32/EC on the eco-design of Energy-using Products (EuP). 'Products such as electrical and electronic devices or heating equipment are covered by the directive that provides coherent EU-wide rules for eco-design and ensure that disparities among national regulations do not become obstacles to intra-EU trade. The Directive does not introduce directly binding requirements for specific products, but does define conditions and criteria for setting, through subsequent implementing measures, requirements regarding environmentally relevant product characteristics (such as energy consumption) and allows them to be improved quickly and efficiently.' (Source: http://europa.eu.int/comm/enterprise/ eco_design/)
Environmental aspect	An element of an organization's activities, products or services that can interact with the environment.
Environmental assessment	A detailed study of the reasonably foreseeable significant effects on the environment, beneficial as well as adverse, of a product, service or process. Life Cycle Assessment (LCA) and Environmental Risk Assessment (ERA) are examples of environmental assessment methods.
Environmental effect	'An environmental effect is caused by an environmental impact. The environmental effect may in turn give rise to a new impact in the impact pathway until the endpoint.' (Source: IPU, Denmark.)
Environmental impact	Impact on the environment and those human health effects that occur via uptake of toxic substances via air, water, and food.
Environmental impact assessment (EIA), strategic environmental assessment (SEA)	A technique used for identifying the environmental effects of development projects. As a result of Directive 85/337/EEC (as amended 1997), this is now a legislative procedure to be applied to the assessment of the environmental effects of certain public and private projects, which are likely to have significant effects on the environment.
Environmental indicator	An environmental indicator can be a measurable feature or features that provide managerially and scientifically useful evidence of environmental and ecosystem quality or reliable evidence of trends in quality. Thus, environmental indicators must be measurable with available technology, scientifically valid for assessing or documenting ecosystem quality, and useful for providing information for management decision-making. Indicators can be used to: • compare current conditions with desired performance, • show trends over time, to allow comparisons between different regions, • help judge the sustainability of current practices, and • define and publicize new standards and measures for assessing progress toward a sustainable future.
Environmental management systems (EMS)	A set of processes and practices that enable an organization to reduce its environmental impact and increase its operating efficiency. See also Environmental Management and Audit Scheme.
Environmental performance	'The actual measured results that an organization attains through environmental management.' (Source: ISO 14001.)
Environmental performance evaluation	An evaluation to quantify, understand and track the relevant environmental aspects of a system. The basic idea is to identify indicators (environmental, operational and management), which can be measured and tracked to facilitate continuous improvements. (Source: EEA, modified.)
Environmental product declaration (EPD)	An internationally standardized (ISO 14025) and LCA-based method to communicate the environmental performance of a product or service.
Environmental reporting	A process for publicly disclosing an organization's environmental performance.
Environmental risk	Likelihood, or probability, of injury, disease or death of humans resulting from exposure to a potential environmental hazard.

Environmental risk assessment (ERA)	The process of identifying and evaluating the adverse effects on the environment caused by a chemical substance. Often implied in the way that an environmental exposure to the chemical is predicted and compared to a predicted no-effect concentration, supplying risk ratios for different environmental media.
Environmental technologies action plan (ETAP)	A life cycle-based European strategy for eco-innovation and environmental technologies. It is composed of actions around three main themes: Getting from Research to Markets; Improving Market Conditions; Acting globally. A key aspect is the setting of performance targets for products that are based upon the technical and economic feasibility of their implementation in relation to the potential improvement for the environment.
External costs, externalities	The cost not included in the market price of the goods and services being produced, but caused by *e.g.* the emissions and damages these cause to goods and to the environment, which include costs of repair or compensation borne by the society in general.
Functional unit	When conducting an LCA, it is necessary to consider a process's energy and material flows through the input and output stages with respect to an appropriate unit, so that all flows are considered on an equal footing. Such a unit is called the functional unit and can take a number of forms including mass, volume or a given number of a manufactured article.
Global warming potential (GWP), better: climate change potential (CCP)	Changes in the global, average surface-air temperature and subsequent change of various climate parameters and their effects such as storm frequency and intensity, rainfall intensity and frequency of floods, *etc.* Climate change is caused by the greenhouse effect which is induced by the emission of greenhouse gases into the air.
Green procurement	A procurement process, which takes into account environmental elements when buying products and services. To prevent a mere shifting of burdens of environmental damages among life cycle phases or among environmental problems, an effective Green Procurement should be based on a life cycle thinking or life cycle assessment.
Green public procurement (GPP)	A procurement process carried out by public purchasers to take into account environmental elements when buying products and services. See also Green Procurement.
Greenhouse effect	The warming up of the atmosphere due to the reduction in outgoing long wave heat radiation, resulting from their absorption by gases such as carbon dioxide, methane, *etc.*
Hazardous waste	Wastes that because of their chemical reactivity, toxicity, explosiveness, corrosiveness, radioactivity or other characteristics, constitute a risk to human health or the environment.
Human toxicity potential (HTP)	The degree to which a chemical substance elicits a deleterious or adverse effect upon the biological system of humans exposed to the substance over a designated time period.
Impact assessment	The process by which burdens identified in an inventory are assessed so that an overall environmental impact can be identified.
Impact categories	Environmental burdens can have a number of potential effects on the environment, such as global warming, acidification and human health effects – these are called impact categories. To form an appraisal of the burdens, it is advisable to group the burdens into several impact categories to aid assessment.
Integrated pollution and prevention control (IPPC)	Directive 96/61/EC to prevent or, where that is not possible, reduce pollution from a range of industrial and other installations by means of integrating permitted processes based on the application of best available techniques (BAT).
Integrated product policy (IPP)	An approach founded on the consideration of the impacts of products throughout their lifecycle to improve the environmental performance of products in a cost-effective way.
Internalization of externalities	Incorporation of an externality into the market decision-making process through pricing or regulatory interventions. For example, internalization is achieved by charging polluters with the damage costs of the pollution generated by them, in accordance with the 'polluter pays' principle.
ISO 14000	A series of standards formulated or being prepared by the International Standards Organization (ISO), covering a number of environmental topics.

ISO 14001	The ISO standard on Environmental Management System, EMS, that can be adopted by any organization.
ISO 14040	The ISO Standard on Environmental Management System, EMS, concerning Life Cycle Assessment of products and processes. ISO 14040 is a framework for the standards ISO 14041, ISO 14042, and ISO 14043 that concern the specific phases of an LCA. (The ISO Standards 14041, 14042, and 14043 are integrated, harmonized, and replaced in 2006 by ISO 14044).
Joint implementation (JI)	A concept whereby a developed country can receive 'emissions reduction units' when it helps to finance projects that reduce net emissions in another developed country (including countries with economies in transition). (Defined in Article 6 of the Kyoto Protocol.)
Kyoto Protocol	International treaty that was adopted at the Third Session of the Conference of the Parties (COP) to the UN Framework Convention on Climate Change (UNFCCC) in 1997 in Kyoto, Japan. It contains legally binding commitments, in addition to those included in the UNFCCC. Countries included in Annex B of the Protocol (most OECD countries and EITs) agreed to reduce their anthropogenic emissions of greenhouse gases (CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6) by at least 5% below 1990 levels in the commitment period from 2008 to 2012.
Land use	An impact category related to the use (occupation) and conversion (transformation) of land area by product-related activities such as agriculture, roads, housing, mining, *etc*. Land occupation considers the effects of the land use, the amount of area involved and the duration of its occupation (quality-changes multiplied by area and duration). Land transformation considers the extent of changes in land properties and the area affected (quality changes multiplied by the area).
Life cycle	The consecutive and interlinked stages of a product system, from raw material extraction, through production of materials, intermediates and parts of products, through product use or service operation to recycling and/or final disposal.
Life Cycle Assessment (LCA)	Life Cycle Assessment (LCA) is a process of compilation and evaluation of the inputs, out puts and the potential environmental impacts of a product system throughout its life cycle.
Life Cycle Cost (LCC)	Two different uses for this term exist: a) the total cost linked to the purchase, operation, and disposal of a product [equivalent to 'Total Cost of Ownership' (TCO)]. b) the cost of a product or service over its entire life cycle, including external costs (see Externalities).
Life Cycle Engineering (LCE)	An integrated approach for the design and development of products and technologies that jointly analyses the environmental effects and costs from a life cycle perspective, paying special attention to product performance, technical feasibility of measures and other engineering aspects.
Life Cycle Impact Assessment (LCIA)	'Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a given product system throughout its life cycle.' (Source: ISO 14040.)
Life Cycle Impact Assessment methods (LCIA)	Methods which provide impact factors for elementary flows to evaluate the environmental effects of a product or a process, through its whole life cycle. See also Environmental Impact Assessment.
Life Cycle Initiative (UNEP/SETAC LCI)	'The Life Cycle Initiative aims to develop and disseminate practical tools for evaluating the opportunities, risks, and trade-offs associated with products and services over their entire life cycle to achieve sustainable development.' (Source: http://www.uneptie.org/pc/sustain/lcinitiative/)
Life cycle inventory	The result of gathering data on all the energy and material input flows required by a process or product and all the output emissions to air, water and land, including solid waste.
Life Cycle Inventory (LCI) analysis	'Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a given product system throughout its life cycle.' (Source: ISO 14040.)
Life Cycle Management (LCM)	Life Cycle Management is a business management concept based on life cycle considerations, which can be used in the development and application of sustainability

	strategies. Life cycle management is about minimizing environmental burdens throughout the life cycle of a product or service.
Life cycle risk analysis	A method for evaluating the probability of adverse effects of a substance, industrial process, technology or natural process from a life cycle perspective.
Life cycle sustainability	A method which takes jointly into account the economic, social and environmental aspects throughout the whole life of a product or technology.
Life Cycle Thinking (LCT)	The concept of Life Cycle Thinking integrates existing consumption and production strategies towards a more coherent policy-making, and in industry, employing a bundle of life cycle-based approaches and tools. By considering the whole life cycle, the shifting of problems from one life cycle stage to another, from one geographic area to another, and from one environmental medium or protection target to another, is avoided.
Life Cycle Working Environment (LCWE)	Inclusion of social working environment issues such as human working time, qualifications, workers' health, accidents, child work, *etc.* in LCA by means of quantitative indicators.
Material flow analysis (MFA)	'An evaluation method which assesses the efficiency of use of materials using information from mate-rial flow accounting. Material flow analysis helps to identify waste of natural resources and other materials in the economy which would otherwise go unnoticed in conventional economic monitoring systems.' (Source: Eurostat.)
Material recovery	The restoration of materials found in the waste stream to beneficial use which may be for purposes other than the original use.
Material Safety Data Sheet (MSDS)	Information on a product's health and environmental hazards such as safe handling, transportation, storage, physical data (*e.g.* boiling, melting and flash points), toxicity, health effects, first aid, reactivity, disposal, protective equipment, and spill/leak procedures.
Mid-point method	'A term that specifies the results of traditional LCIA characterization and normalization methods as indicators located between emission and endpoint damages in the impact pathway at the point where it is judged that further modelling involves too much uncertainty.' (Source: IPU, Denmark.)
Monitoring the effects of environmental policy	The process of following up the effects of the decisions and actions established in the environmental policy.
Non-renewable resources	Include minerals, ores and fossil fuels. Their use as material and energy sources leads to depletion of the Earth's reserves as they cannot be renewed in human relevant periods of time.
Ozone	Ozone, the triatomic form of oxygen (O_3), is a gaseous atmospheric constituent. In the troposphere, it is created both naturally and by photo-chemical reactions involving gases resulting from human activities (photochemical smog). In high concentrations, tropospheric ozone can be harmful to a wide range of living organisms. In the stratosphere, ozone is created by the interaction between solar ultraviolet radiation and molecular oxygen (O_2). Stratospheric ozone plays a decisive role in the stratospheric radioactive balance. Depletion of stratospheric ozone, due to chemical reactions, results in an increased ground-level flux of ultraviolet (UV-) B radiation.
Ozone depletion potential (ODP)	The integrated change in total stratospheric ozone per unit mass emission of a specific compound, relative to the integrated change in the total ozone per unit mass of a reference emission (*e.g.* CFC-11).
Ozone-depleting substance	A compound that contributes to stratospheric ozone depletion. Ozone-depleting substances (ODS) include CFCs, HCFCs, halons, methyl bromide, carbon tetrachloride and methyl chloroform. The most relevant ODS are very stable in the troposphere and only degrade under intense ultraviolet light in the stratosphere. When they break down, they release chlorine or bromine atoms, which then deplete ozone.
Performance indicator	Performance indicators compare actual conditions with a specific set of reference conditions. Some of them measure the 'distance(s)' between the current environmental situation and the desired situation (target): distance to target assessment.

Photochemical ozone formation (or photochemical oxidant creation) ‘Chemical reactions brought about by the light energy of the sun. The reaction of nitrogen oxides with hydrocarbons in the presence of sunlight to form ozone is an example of a photochemical reaction.’ (Source: California Air Resources Board. Glossary of air pollution terms.)

Product stewardship Product stewardship is ‘the responsible and ethical management of the health, safety and environmental aspects of a product throughout its total life cycle.’

Quantifying indirect effects Measuring the results of products or processes, not directly linked with them, *e.g.* the environmental impacts related to the production of materials, which are used in the analysed process.

Radiation eecycling Energy that is radiated or transmitted in the form of rays or waves or particles.
(1) A resource recovery method involving the collection and treatment of a waste product for use as raw material in the manufacture of the same or a similar product.
(2) The EU waste strategy distinguishes between:
- reuse meant as a material reuse without any structural changes in materials;
- recycling meant as a material recycling only, and with reference to structural changes in the products; and
- recovery meant as an energy recovery only.

Responsible care A voluntary programme developed by the chemical industry that helps it to raise its standards and win greater trust from the public. Under Responsible Care, the worldwide chemical industry is committed to continual improvement to all aspects of health, safety and environmental performance and to open communication about its activities and achievements.

Restrictions of hazardous substances (RoHS) Directive 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS) is, together with directive 2002/96/EC on waste electrical and electronic equipment (WEEE), designed to tackle the fast increasing waste stream of electrical and electronic equipment and complements the European Union measures in landfills and incineration of waste. Directive 2002/95/EC requires the substitution of various heavy metals (lead, mercury, cadmium, and hexavalent chromium) and brominated flame retardants (polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE)) in order to prevent the generation of hazardous waste. (Source: http://europa.eu.int/comm/environment/ waste/weee_index.htm)

Review of environmental reports A verification of the information contained in a report that addresses the environmental performance of a company.

Review of LCA reports The process intended to ensure consistency between a life cycle assessment report and the principles and the requirements of the international ISO 14040 series standards on life cycle assessment. It can be carried out by an expert (internal or external) or a panel of interested parties.

Risk Expected losses (of lives, persons injured, property damaged and economic activity disrupted) due to a particular hazard for a given area and reference period. Based on mathematical calculations, risk is the product of hazard and vulnerability.

Risk assessment The procedure in which the risks posed by inherent hazards involved in processes or situations are estimated either quantitatively or qualitatively.

Risk management The process of evaluating alternative regulatory and non-regulatory responses to risk and selecting among them. The selection process necessarily requires the consideration of legal, economic and social factors.

RoHS See Restrictions of Hazardous Substances.

Screening A process used within a project to determine whether more in depth environmental assessments are needed as well as the type and level of these assessments.

SETAC The Society of Environmental Toxicology and Chemistry (SETAC) is a non-profit, worldwide professional society comprising individuals and institutions engaged in:
- the study, analysis and solution of environmental problems;
- the management and regulation of natural resources;

- environmental education; and
- research and development.

SETAC's mission is to support the development of principles and practices for the protection, enhancement and management of sustainable environmental quality and ecosystem integrity. SETAC is the scientific body that develops the LCA methodology.

Stakeholder — An institution, organization or group that has some interest in a particular sector, product or system.

Strategic environmental assessment (SEA) — '...a process to ensure that significant environmental effects arising from policies, plans and programmes are identified, assessed, mitigated, communicated to decision-makers and monitored, and that opportunities for public involvement are provided. SEA is being introduced by the Directive 2001/42/EC. (Sources: http://www.eu.int/comm/environment/eia/sea-legalcontext.htm; http://www.sea-info.net/whatisSEA.htm)

Streamlined LCA — An LCA with a reduced scope such that only those issues considered to be of principal significance are taken into account.

Supply chain management — 'The delivery of customer and economic value through integrated management of the flow of physical goods and associated information, from raw materials sourcing to delivery of finished products to consumers.' (Source: www.viradix.com/terminology.html)

Sustainability performance indicators (SPI) — A limited number of indicators used to find and keep track of the sustainability performance of, for example, projects, products or organizations. SPIs cover the economic, environmental (EPI), and social dimension of sustainability.

Sustainability ratings — The information from a company used to assess the integration efficiency of the three sustainability pillars into its business management.

Sustainability reporting — 'Sustainability reporting is a process for publicly disclosing an organization's economic, environmental, and social performance. ... Through sustainability reporting, organizations report on progress against performance goals not only for economic achievements, but for environmental protection and social well-being.' (Source: Global Reporting Initiative, GRI.)

Sustainability/ sustainable development — 'The concept of meeting the needs of the present without compromising the ability of future generations to meet their needs.' [From Our Common Future, report by the Brundtland Commission (1987)].

Sustainable development indicator — An indicator selected with the aim of providing information on the essence of sustainable development at the level of companies or countries; it may refer to systemic characteristics such as carrying capacities of the environment, or it may refer to inter-relations between economy, society and the environment.

System boundary — When conducting an LCA, it is necessary to identify the limits of the study, *i.e.* how far back and forward in a product's life-cycle from which it is necessary to gather data. For example, in the case of a washing machine, upstream options include placing the boundary at the factory gate (*i.e.* the point where materials are received) or at the point where raw materials are extracted from the ground.

System flows — The term is used to denote the energy and material inputs to a process or product and the output emissions to air, water and land, including solid waste.

Terrestrial and aquatic eutrophication potential (EP) — Excessive enrichment of waters and continental surfaces with nutrients, and the associated adverse biological effects.

Total cost of ownership (TCO) — The total costs to own a product throughout its life, including the costs of purchase, operation, maintenance and potential waste fees.

Toxicity — The degree to which a chemical substance elicits a deleterious or adverse effect upon the biological system of an organism exposed to the substance over a designated time period.

UNEP — United Nations Environmental Program http://www.unep.org/

Valuation — The process by which impact categories are assessed for their relative importance.

Waste electrical and electronic equipment (WEEE)

'Directive 2002/96/EC requires increased recycling of electrical and electronic equipment for limiting the total quantity of waste going to final disposal. Producers will be responsible for taking back and recycling electrical and electronic equipment. This will provide incentives to design electrical and electronic equipment in an environmentally more efficient way, which takes waste management aspects fully into account. Consumers will be able to return their equipment free of charge.' (Source: http://europa.eu.int/comm/environment/waste/weee_index.htm)

Waste management

Approach based on three principles (EU):

1) Waste prevention: as a key factor, the amount of generated waste should be reduced.
2) Recycling and reuse: if waste cannot be prevented, as many of the materials as possible, should be recovered, preferably by recycling.
3) Improving final disposal and monitoring: where possible, waste that cannot be recycled or reused should be safely incinerated, with landfill only used as a last resort. ' (Source: http://europa.eu.int/comm/environment/waste/index.htm)

Waste management strategy

An evaluation of the different options available for dealing with waste and their environmental and/or economic desirability.

Willingness to pay

The amount an individual is willing to pay to acquire a product or service; more specifically, also used with regard to the willingness to pay for the repair of environmental damages. This may be elicited from stated or revealed preference approaches.