PRODUCT-RELATED ENVIRONMENTAL PERFORMANCE INDICATORS

A guide to support the selection of product-related environmental performance indicators

This guide was developed at the Nucleus of Advanced Manufacturing (NUMA), in collaboration with two universities, University of São Paulo (USP) and Technical University of Denmark (DTU). The financial support was provided by the São Paulo Research Foundation (FAPESP).

The guide is a result of a research project regarding environmental performance indicators conducted in 2012 and 2013. The main goal of the guide is to support companies in the selection of performance indicators for monitoring the environmental performance of products.

Authors: Isabela Issa, USP Environmental Engineering

Daniela Pigosso, DTU Mechanical Engineering

Supervisors: Henrique Rozenfeld, USP Industrial Engineering

Tim McAloone, DTU Mechanical Engineering

2013

Contents

Introduction 7

Environmental Performance Indicators: Background and Motivation 9

How can you use EPIs in your work? 11

Selecting product-related EPIs in 5 steps 13

Step 1: Define environmental priorities and objectives 15

Step 2: Pre-select EPIs 17

Step 3: Select EPIs from the database 21

Step 4: Customize and create new EPIs 23

Step 5: Implement product-related EPIs 25

Final remarks 27

Appendix A: Life Cycle Stages 29

Appendix B: Environmental Aspects 33

Appendix C: Types of measure 37

Useful literature 39

Introduction

Products impact the environment throughout their entire life cycle – from the extraction of raw materials and manufacturing to use and final disposal. Recognizing the responsibilities in this phenomenon, companies are increasingly working to reduce the environmental impact of their activities. Product development is an activity with an important influence on environmental impacts, since it defines, for instance, which materials and technologies will be used during product's life cycle.

Ecodesign is a proactive environmental management approach which aims to improve the environmental performance[1] of products throughout their whole life cycle. Considering the environmental issue in product development leads to competitive advantages, legal compliance, image improvement and cost reduction. The application of ecodesign also promotes product innovation and new business opportunities.

Several ecodesign practices have been developed in the last decade in order to address environmental issues in product development. In order to support companies in the implementation of these ecodesign practices, a framework called Ecodesign Maturity Model (EcoM2)[2] has been developed. EcoM2 is a framework with an evolutionary approach that aims to support companies in the implementation of ecodesign by diagnosing the maturity profile of the company and establishing a roadmap for ecodesign practice implementation, based on the current maturity profile and strategic objectives and drivers of this company.

A common assumption in ecodesign is to develop easy to use and consolidated methods which can be used in the earliest phases of the PDP. However, what is observed is that many of the analytical tools and methods that measure the environmental performance of products are too complex. The selection and use of environmental performance indicators as a quantitative tool, however, is a simpler and rapid approach to quantify and improve the environmental performance of products.

The establishment of measurable goals and performance indicators are then a fundamental element of any successful ecodesign program, as they can provide an early warning to prevent environmental damage. In this Guide, you are invited to know how to use environmental performance indicators (EPIs) to change the way your products are developed by considering their environmental performance.

This Guide is intended primarily to environmental managers responsible to define the set of indicators to measure the environmental performance of products, but it can also be useful for product developers and all staff of a company looking to measure the environmental performance of their products. The Guide is composed by this full text here presented, a support material illustrating the five step approach in selecting EPIs, and a digital database containing more than 250 EPIs.

[1] The environmental performance of products or services is defined as the sum of all the impacts caused by them in their life cycle.

[2] Pigosso, D.C.A., 2012. *Ecodesign Maturity Model: a framework to support companies in the selection and implementation of ecodesign practices*. Escola de Engenharia de São Carlos (EESC-USP). (http://www.eco-m2.com/en/)

Environmental Performance Indicators: Background and Motivation

Since the 1990's, a variety of environmental indicators were proposed to characterize the environmental performance of products and processes. They aim to support the decision-making process in politics and businesses, in order to evaluate the environmental effects of the decisions, and point the way to sustainable development.

In general, indicators are considered as a set of condensed information of a complex process and system state and are often used to identify and characterize changes in a system. They can also be used to measure the effectiveness of a process, as the Product Development Process (PDP), because they allow the comparison of design alternatives and the recommendation of areas for improvement. According to the European Agency for Environment (EEA), an environmental indicator monitors progress in pursuing environmental goals.

Environmental Performance Evaluation (EPE) is defined as a process to select environmental indicators and to measure, analyze, assess, report and communicate an organization's environmental performance against predefined criteria, according to ISO 14031. When performing EPE, the selection of suitable environmental performance indicators (EPIs) for the organization is the most important step. These indicators must be objective and verifiable.

In this Guide, the product-related EPIs are classified as **Operational Performance Indicators** (OPIs). OPIs are defined, according to ISO 14031, as "a type of EPI that provides information about environmental performance of the operations of the organization". They are related to the supply of materials, energy and services, and the delivery of products, services and wastes from the organization's physical facilities and equipment.

Product-related EPIs are indicators which measure the environmental performance of individual products or the complete range of products in the portfolio of your company. They can also measure the improvements in their environmental performance and indicate relative advantages or disadvantages in comparison to other products.

The product-related EPIs presented in this Guide can be characterized as **Leading EPIs**. This type of indicators aims to produce measures that will inspire effective actions in improving the environmental performance of your product. They are focused in measuring the technical characteristics of your product and its development, and environmental aspects[3] of your product's life cycle activities, which can indicate areas of improvement or redesign.

Despite the existence of several studies in literature about environmental performance indicators, there are some factors that still hamper their use in companies, such as a lack of classification of these indicators, a lack of knowledge about their similarities and differences, and on how they can be used together to achieve meaningful and comprehensive evaluations. This Guide aims to help you in the selection and use of these EPIs to monitor the environmental performance of your products.

[3] According to ISO 14001 (1996), an environmental aspect is defined as an element of organization's activities, products or services that interacts with the environment. Some examples of environmental aspects can be the energy consumption and solid waste generation.

How can you use EPIs in your work?

The consideration of the environmental issues in product development has the potential to bring business advantages, image improvement and costs and risks reduction. The main drivers for ecodesign adoption and the use of EPIs to assess environmental performance in your company are:

- More and emerging product-related laws and regulations establishing life cycle thinking for product development;
- Opportunities for reducing costs and increasing revenues, enhancing competitiveness; and
- Increased stakeholder's awareness about environmental issues.

Having recognized these drivers, it is time to monitor the environmental performance of your products. The selection and implementation of EPIs in your company is a strategic activity to fulfill the new market's needs regarding environmental issues, also ensuring that the industrial activities are moving in a sustainable direction. In general, you can use EPIs for the following purposes:

- Comparison of the environmental performance over time, highlighting the potential optimization of environmental aspects in your product or process;
- Assessment of the environmental performance of your company, processes and products, enabling environmental benchmarking;
- Communication tool in environmental reports; and
- Information instrument to the workforce, motivating them in pursuing the environmental goals.

In this context, this Guide aims to help you in selecting and implementing the most suitable EPIs for your company for monitoring the environmental performance of your products, following a five-step approach. The selection process can be performed to assess the environmental performance of your already developed and new products.

It is recommendable that experts from different areas of the company (such as manufacturing process design, health and safety, and product designers) should be gathered to discuss and participate in the selection process of the EPIs. It is estimated that the application of the guide can take from days to weeks, depending on the ecodesign maturity level of your company, its environmental strategic goals and how the set of EPIs will be implemented.

Let's start the selection of the EPIs for your company!

Selecting product-related EPIs in 5 steps

This Guide proposes a step-by-step procedure to select the most suitable product-related EPIs according to the company's goal, in order to improve the environmental performance of the developed products in their whole life cycle. Each step contains the main activities to be carried out in order to select and implement the most suitable environmental indicators for your company. It is also presented a flowchart structure illustrating which information is necessary to start performing each step and which information is obtained after performing this step.

The step-by-step procedure is presented in Figure 1.

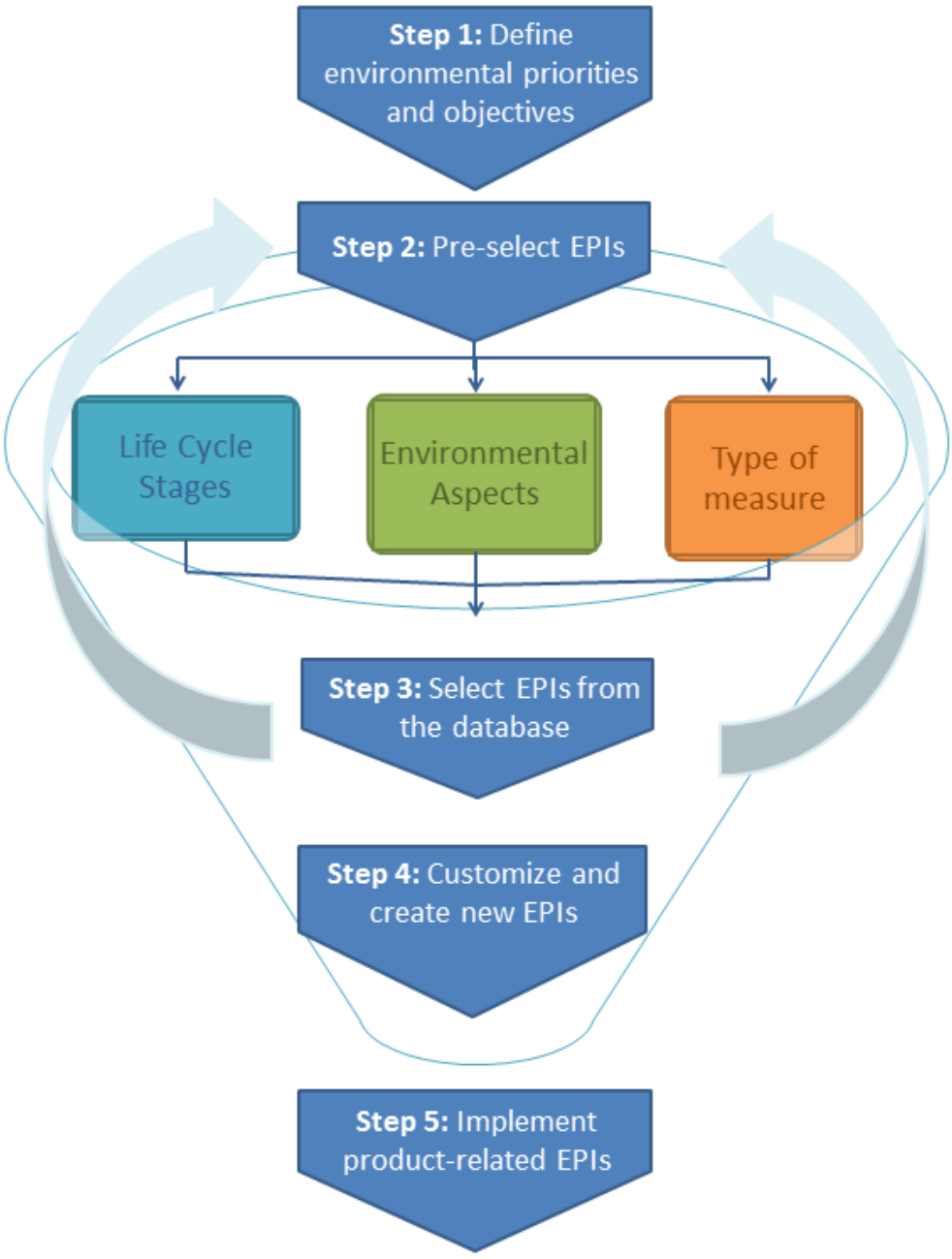


Figure 1: Selecting product-related environmental performance indicators in 5 steps

Step 1: Define environmental priorities and objectives

The first step in selecting environmental performance indicators is to define the environmental priorities and objectives in product development when measuring the environmental performance of products. These objectives translate the strategic environmental goals of your company in actions and practices to improve product development. This is a very important step, as the selected indicators must be consistent with the overall environmental goals of the company, assuring that the progress toward these goals is being measured.

The necessary information to start performing this step is the environmental impacts during your products' life cycle. You need to answer the following questions:

- **Where in the product's life cycle can you identify the major environmental impacts? During the pre-manufacturing, manufacturing, distribution and packaging, …?**

- **Which are the environmental aspects more relevant in your product's life cycle? Material consumption, energy use, solid waste, …?**

Using tools of environmental performance evaluation can help in this phase, such as full or simplified Life Cycle Assessments (LCA). If your company already has this information, it is time to analyze the identified environmental impacts and go for the main activity of this step, which will help you on how to minimize these impacts in product design.

Another way to start performing this step is to identify what your stakeholders expect in terms of environmental efforts and achievements, considering market's needs, legislation, image improvement, labeling, etc. These market's requirements are useful to define which environmental impacts are relevant to the market to be minimized.

Set up potential improvements

After answering the questions above, you will have identified the most relevant environmental impacts during the product's life cycle. The focus now is to find potential improvements for your product, establishing environmental priorities and objectives for product development. To find areas of potential improvements, you need to answer these questions:

- **What functions in your product are related to the environmental impacts identified?**

- **What could be changed in your product to improve its environmental performance?**

- **Where can you see improvements in environmental performance during your product's life cycle?**

Having answered the questions above, you are now able to establish the priorities in product development and the main environmental aspects to be improved. These environmental priorities and objectives are very important to Step 2, as they will guide the selection of EPIs. Some examples of what you can define as an environmental objective are:

- Minimizing Material Consumption;
- Select Renewable and Bio-compatible Materials;
- Facilitating Remanufacturing;
- Facilitating Disassembly (more examples can be found in Appendix A).

Reaching the end of this Step, you should have a list of the environmental priorities and objectives in product development to improve the environmental performance of your product.

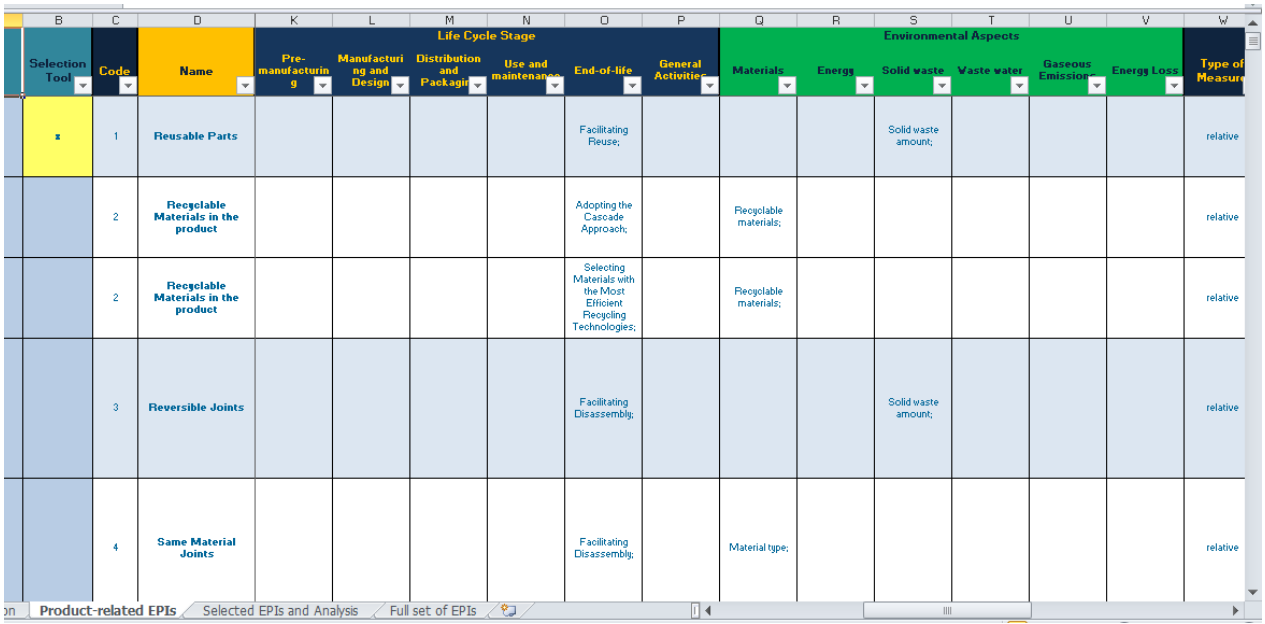
Step 2: Pre-select EPIs

A **Product-related EPIs Database** has been compiled to aid this step (free download at: http://www.portaldeconhecimentos.org.br/index.php/por/content/view/full/16361). The database comprises a list of more than 250 indicators, classified according to a set of criteria to support companies in the selection of the most suitable indicators according to their objectives. These criteria were considered simple and relevant to be used when selecting EPIs in product development. Step 2 consists in pre-selecting indicators from this database.

The classification criteria of the product-related EPIs are:

- **Life Cycle Stages (check appendix A):** Product's life cycle is divided in five stages - pre-manufacturing, manufacturing, distribution and packaging, use and maintenance and end-of-life. For each life cycle stage it is defined a set environmental objectives to be considered in product development (Figure 3);
- **Environmental Aspects (check appendix B):** An environmental aspect is an element of product's life cycle that interacts with the environment - material, energy, solid waste, waste water, gaseous emissions and energy loss. Each environmental aspect is divided in subclasses (Figure 4); and
- **Types of measure (check appendix C):** Indicators can be classified according to their measurement type, which can be absolute or relative.

The database is an Excel spreadsheet, where indicators are presented in lines (Figure 2). In the columns you can find more information about the indicator, such as its formula, unit of measurement, and also the desired trend when improving environmental performance. The next columns consist of the classification criteria used to select the product-related EPIs, which are Life Cycle Stages, Environmental Aspects, and Types of measure. The last two columns in the indicator contain the reference paper where the indicator was identified, as well the recurrence in literature.



	B	C	D	K	L	M	N	O	P	Q	R	S	T	U	V	W
				Life Cycle Stage						Environmental Aspects						
	Selection Tool	Code	Name	Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Materials	Energy	Solid waste	Waste water	Gaseous Emission	Energy Loss	Type of Measure
	x	1	Reusable Parts					Facilitating Reuse;				Solid waste amount;				relative
		2	Recyclable Materials in the product					Adopting the Cascade Approach;		Recyclable materials;						relative
		2	Recyclable Materials in the product					Selecting Materials with the Most Efficient Recycling Technologies;		Recyclable materials;						relative
		3	Reversible Joints					Facilitating Disassembly;				Solid waste amount;				relative
		4	Same Material Joints					Facilitating Disassembly;		Material type;						relative

Product-related EPIs | Selected EPIs and Analysis | Full set of EPIs

Figure 2: Screenshot of Product-related EPIs Database

To start this step, the main input is the list of environmental priorities defined in Step 1. These priorities will lead the selection when applying the criteria presented above. For each environmental priority you can relate a life cycle stage and environmental aspects. You can also choose absolute or relative indicators according to your goal when measuring EPIs.

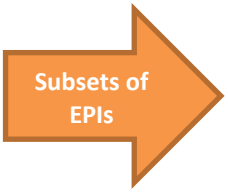
Pre-selection: applying Excel filters

The pre-selection of the EPIs consists of applying Excel filters in the database, according to your judgment of what is important to improve the environmental performance of your product. Applying these filters provides subset(s) of indicators related to the environmental priorities and objectives previously defined.

Each EPI in the database is related to at least one Life Cycle Stage, one Environmental Aspect and one Type of Measure. Some indicators can be related to more than one option within the criterion. There are indicators which consider the whole life cycle of a product, and indicators which can be related to more than one environmental aspect.

You can start choosing any criteria, depending on the environmental priorities and objectives defined in Step 1. The main goal in applying these Excel filters is to get subsets of product-related EPIs, and decrease the number of indicators which will be analyzed and selected in the next steps. Step 2 is an iterative step, which means that the user of the database can apply the Excel filters as many times as necessary, always remembering to clear the filters before performing a new one. Every time you get a new subset, you should apply step 3 and select EPIs from this subset. You can obtain one or more subsets of indicators, according to the defined environmental priorities and objectives, and selecting indicators from each of them.

The main output of this Step is the obtainment of the suitable subsets of indicators according to your environmental priorities and objectives. The next steps in this Guide will show you in how to select the indicators from these subsets.



Reaching the end of this Step, you should have subsets of EPIs from the database to start the selection process in Step 3.

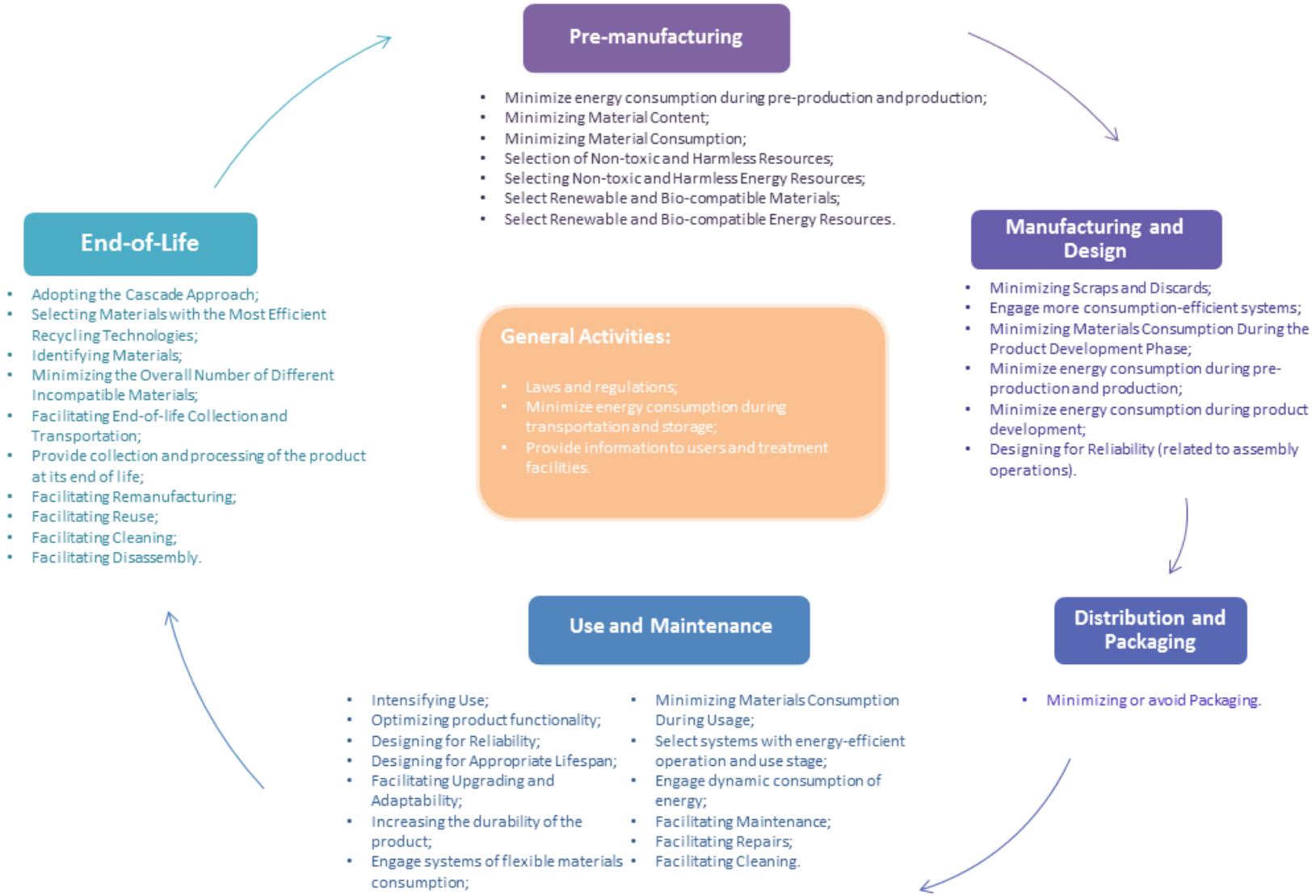


Figure 3: Life cycle stages and related environmental objectives

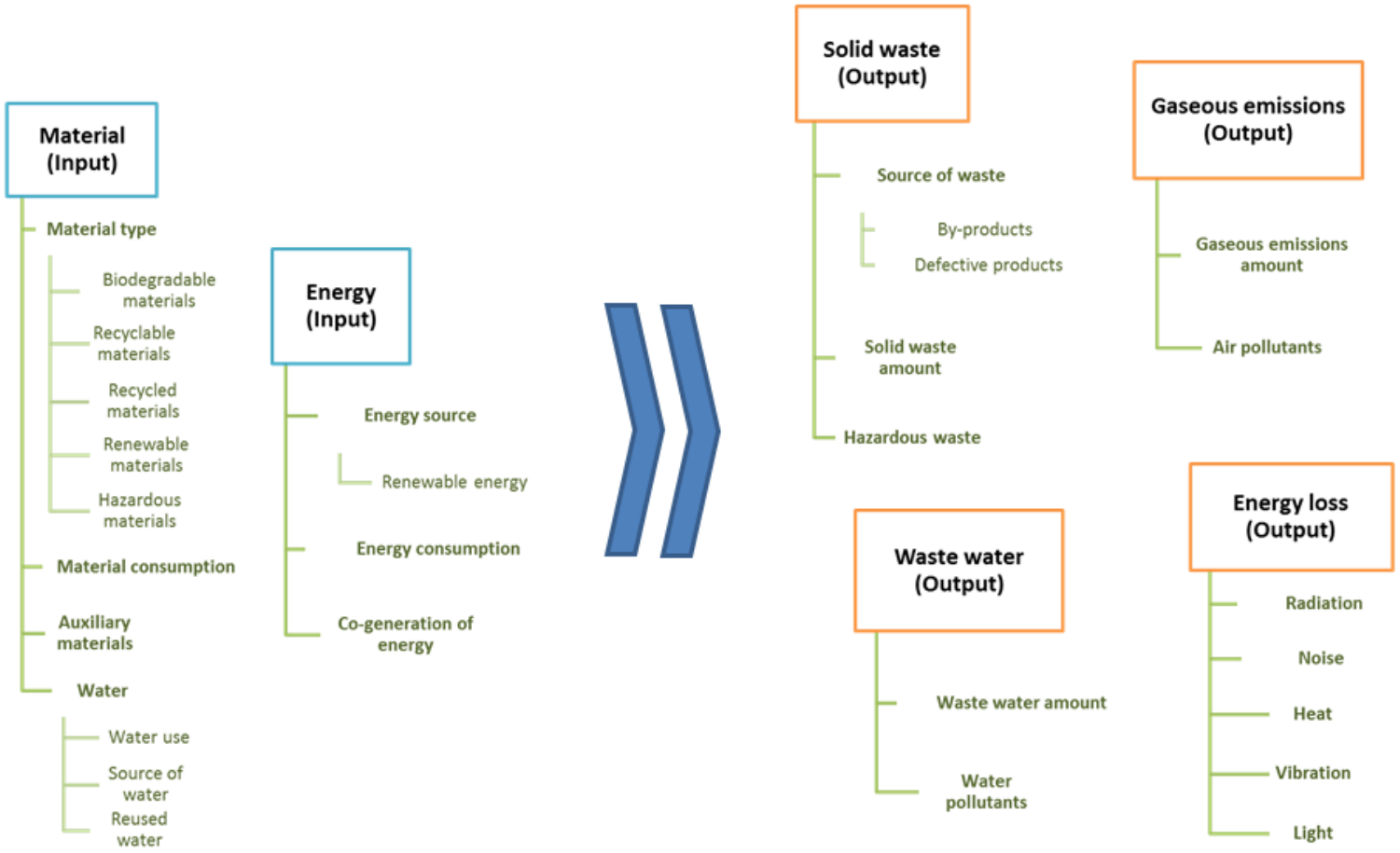
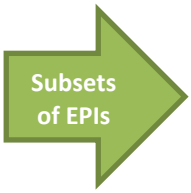


Figure 4: Environmental aspects and their subclasses

Step 3: Select EPIs from the database

After conducting the pre-selection of the product-related EPIs in the database, the next step consists of selecting the most suitable indicators for your product. Step 3 provides some criteria to be used in this selection process. It is recommendable to use a manageable number of indicators defined according the environmental priorities and objectives and they should be simple and easy to apply. You should avoid, for instance, selecting two or more different indicators that measure the same aspect of the product, such as two indicators that measure recyclability, for instance.



From Step 2, subsets of the indicators in the database should have been obtained. The task now is to select the most suitable indicators from the options presented in the database. To help you in this selection, you should use the column "Selection Tool" in the database, as shown in figure 2, in order to mark the EPIs that you are selecting.

Select EPIs according to your product

The selection is based on a set of criteria in applying and measuring the indicators, such as the type of product, time efficiency and data availability, for instance. The main question to be answered here is: which are the fundamental indicators to be selected?
To guide the selection of the most suitable EPIs, you need to evaluate each indicator in the subsets of the database by answering these questions:

- Is this indicator suitable to your product?
- How much data are required to measure this indicator? How difficult is to obtain these data? How much time do you have to measure the environmental performance?
- Does the data gathering of this indicator involve costs? Do we have a budget for this?
- How do we evaluate the easy-to-use of this indicator? Is this suitable to the goal in measuring environmental performance in our product development process?
- Does the use of this indicator require experts?

After answering these questions and evaluating the EPIs from the subsets, you should mark with an "X" in the Selection Tool column in order to have an overview of your selected indicators. The next step aims to complement this set of EPIs, as shown later in the Guide.

Reaching the end of this Step, you should have a set of EPIs selected from the database.

Step 4: Customize and create new EPIs

Having conducted Step 3 you should have a set of selected product-related EPIs. Step 4 explains how to customize the selected indicators and how to create new ones, if necessary.

The input for Step 4 is the set of EPIs selected from the Product-related EPIs Database. Despite being selected from the available options, the indicators may not be ready to be used, as they are not yet adapted to the reality of your company and products.

Customization

The indicators presented in the database are not sector-specific. They are general and can be applied in all types of companies which develop products. In this respect, it can be necessary to customize them to your own context and industrial sector before using in product development.

The customization of indicators aims to make them more suitable to the product under development, according to the industrial sector and context in which they are going to be applied. The product-related indicators will be different for the automotive and beverage industries, as the materials, manufacturing process and use phase are different. To customize product-related EPIs, it is important to keep in mind the nature of your product and its particularities, for instance the raw materials used, the energy resource, all the manufacturing processes involved, the packaging type and material, the use phase, and how it can be treated in its end-of-life. The customization of indicators leads to the adequacy of them to the operational activities conducted during the life cycle of a specific product.

To exemplify one possibility of customization, let's take a look in the indicator 43 – "Specific Air Emissions per Substance". According to the database, this indicator measures emissions of specific substances per year. In order to implement this EPI, however, it is important to define which substances in your product's manufacturing are relevant to its environmental performance; these substances could be, for instance, SO_x or NO_x.

Identification of missing EPIs

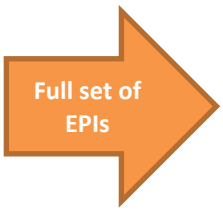
Another important activity in this step is to check if new product-related EPIs are required, once they were not identified in the database. One of the tabs of the database will help you in this step by providing an overview of the indicators chosen according to the life cycle stages and environmental aspects.

Although the database has a large quantity of indicators, it can be not enough to measure the environmental performance of some specific products. For example, if your company develops soap, an important environmental priority can be "Reduce waste water generation during use". To measure this priority, it could be interesting to measure the quantity of waste water generated to use the soap. This indicator, however, cannot be found in the database. To develop new EPIs you can use the classification criteria presented in this Guide:

1. Does the set of selected EPIs cover all the life cycle stages?
2. Does the set of selected EPIs comprise all environmental aspects?

3. Which type of measure will bring better results? Absolute or relative?

At the end of this step, it is expected that you have a full set of selected EPIs ready to be implemented in your company, with new EPIs customized and created.



Reaching the end of this Step, you should have the full set of EPIs ready to be implemented.

Step 5: Implement product-related EPIs

This last step comprises the implementation of the selected indicators in your company. It implies in thinking is aspects such as who is the responsible for measuring the indicators and the period of tracking, for instance.

After applying the pre-selection, the selection and the customization/creation of your indicators, it is time to think about how they will be applied in the activities of your company. The input for this last step is the full set of EPIs defined in the Step 4.

Define how to implement EPIs

In order to define the implementation of the selected EPIs, there are some criteria to be considered to formalize the environmental performance evaluation as a process in the company. You should define:

- **Responsible for measuring**: define who will be responsible for measuring and communicating the product-related EPIs;
- **Period of tracking:** define how often the indicators will be measured;
- **Improvement:** define goals to improve the environmental performance, and also the responsible staff to achieve them;
- **Communication:** define who will be communicated about the results of the environmental performance measurement;

The last point considered is about the evaluation of the selected set of EPIs, and for how long this set will be used. You need to evaluate for which kind of product or family of products you are using these EPIs, and define when is necessary to start a new selection process, from Step 1. It is important to ensure that the EPIs selected can really translate the main environmental impacts of your products, evaluating the set during a period of time.

After defining the criteria above, you are ready to start implementing the set of EPIs in your company. The implementation can be the longest Step to be applied, as it depends in creating the implementation plan and collecting data inside the company. You are ready to go!

Reaching the end of this Step, you should have all the definitions to start implementing the selected EPIs in your company.

Final remarks

After concluding the five steps of this Guide, your company may be able to measure and monitor the environmental performance of products. We believe that the proposed procedure can help you to identify and improve the environmental performance, and we hope that now you can develop more environmentally friend products!

Appendix A: Life Cycle Stages

Products cause environmental impacts along their whole life cycle (figure 5). Each product life cycle stage implies in the consumption of resources and generation of waste, which must be properly treated and disposed. It also implies in the consumption and release of energy. The life cycle stages considered in this Guide are presented below:

Pre-manufacturing: comprises all activities involved in the raw material extraction, processing and transport. It also considers the procurement of renewable, biodegradable, recyclable, and recycled materials and energy.

Manufacturing and Design: refers to the design and to the production and assembly processes. It includes all production flow of the product within a company, from the time the product is designed and the raw materials are procured until the product is ready for packaging, also including environmental impacts caused during product development process.

Packaging and Distribution: includes all the packaging and distribution of the products until they are delivered to the consumer, including material package for both transport and purchase.

Use and Maintenance: comprises the period that the product is used by customers, since they receive the product until the end of their useful life. It includes the use of consumables, maintenance, part replacements and overhauls, if necessary.

End-of-Life: when a product reaches its end-of-life, it means that it will not be used by the costumer anymore. The product and its parts then can be recycled, reused, remanufactured or removed from the life cycle entirely by landfilling or incineration.

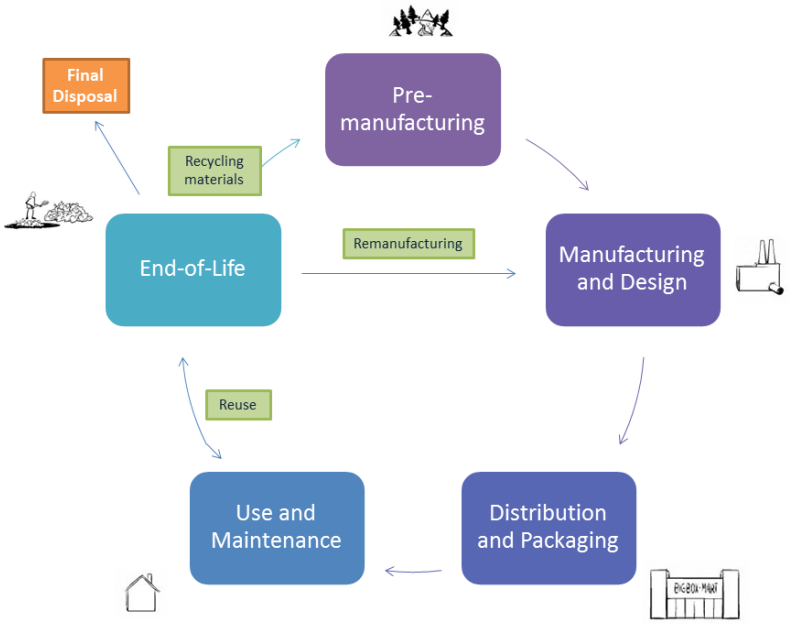


Figure 5: Life Cycle Stages, adapted from Yarwood & Eagan (1998), UNEP (2007) and The Story of Stuff Project (http://www.storyofstuff.org/).

Besides these five life cycle stages, you will find a category called **General Activities**, containing activities which go through all product life cycle, and can influence all of them.

As explained in Step 2, for each life cycle stage you can find in the database a list of pre-defined environmental objectives, extracted from the Ecodesign Maturity Model (EcoM2), and called Ecodesign Operational Practices (except the category "Laws and regulations"). Sometimes, the same indicator can be related to more than one environmental priority. When applying the Excel filter, you can select from the options available for each life cycle stage:

Pre-manufacturing:

- Minimize energy consumption during pre-production and production;
- Minimizing Material Content;
- Minimizing Material Consumption;
- Selection of Non-toxic and Harmless Resources;
- Selecting Non-toxic and Harmless Energy Resources;
- Select Renewable and Bio-compatible Materials;
- Select Renewable and Bio-compatible Energy Resources.

Manufacturing and Design:

- Minimizing Scraps and Discards;
- Engage more consumption-efficient systems;
- Minimizing Materials Consumption During the Product Development Phase;
- Minimize energy consumption during pre-production and production;
- Minimize energy consumption during product development;
- Designing for Reliability (related to assembly operations).

Distribution and Packaging:

- Minimizing or avoid Packaging.

Use and maintenance:

- Intensifying Use;
- Optimizing product functionality;
- Designing for Reliability;
- Designing for Appropriate Lifespan;
- Facilitating Upgrading and Adaptability;
- Increasing the durability of the product;
- Engage systems of flexible materials consumption;
- Minimizing Materials Consumption During Usage;
- Select systems with energy-efficient operation and use stage;
- Engage dynamic consumption of energy;
- Facilitating Maintenance;
- Facilitating Repairs;
- Facilitating Cleaning.

End-of-Life

- Adopting the Cascade Approach;
- Selecting Materials with the Most Efficient Recycling Technologies;
- Identifying Materials;
- Minimizing the Overall Number of Different Incompatible Materials;
- Facilitating End-of-life Collection and Transportation;
- Provide collection and processing of the product at its end of life;

- Facilitating Remanufacturing;
- Facilitating Re-use;
- Facilitating Cleaning;
- Facilitating Disassembly.

General Activities:

- Laws and regulations;
- Minimize energy consumption during transportation and storage;
- Provide information to users and treatment facilities.

Appendix B: Environmental Aspects

An **environmental aspect** is defined as an element of an organization's activities, products or services that interacts with the environment, according to ISO 14001 (1996). An environmental aspect from an activity in product's life cycle may cause a change in the natural environment, defined as **environmental impact**. This cause-effect relation between environmental aspect and environmental impact is illustrated in the figure 6:

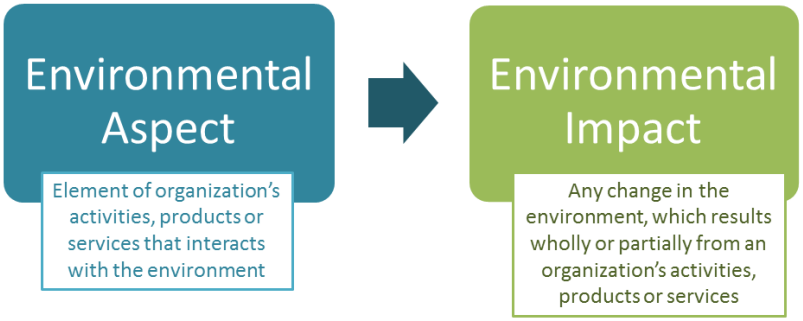


Figure 6: Environmental aspects lead to environmental impacts

As an example, the emissions of greenhouse gases (such as the carbon dioxide) are considered an environmental aspect, and global warming is the environmental impact associated to these emissions.

There are basically six environmental aspects considered in this: Material, Energy, Solid waste, Waste water, Gaseous emissions and Energy loss. Material and Energy consumption are related to all the inputs in product's life cycle, and Solid waste, Waste water, Gaseous Emissions and Energy loss are related to the outputs (figure 7). Each environmental aspect is divided in subclasses.

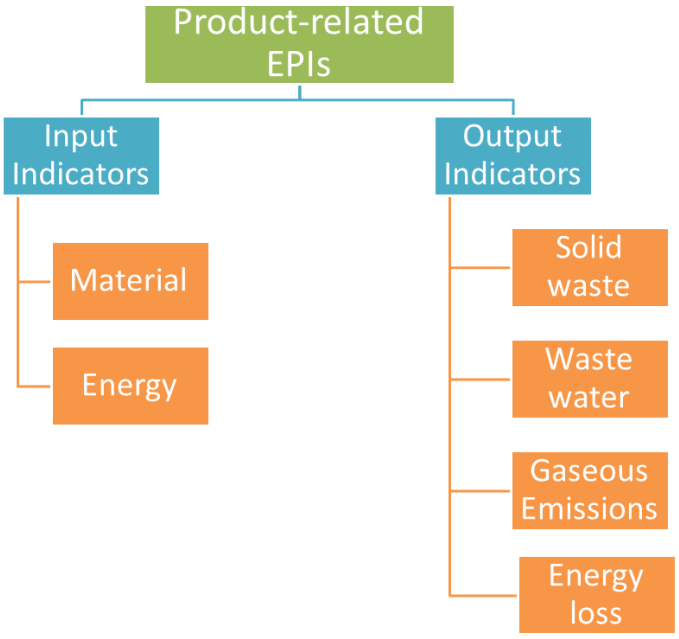


Figure 7: Product-related EPIs distinguished into input and output indicators

Material
The rational use of materials stems from the recognition that materials are not an inexhaustible resource, they are limited. Reducing material consumption during a product's life cycle and applying strategies such as reuse, recycling and remanufacturing aims to decrease the need of virgin raw materials, and also replace the problematic materials by using more environmentally safe alternatives.
This environmental aspect is related to all material inputs in product's life cycle, including water use. It includes the use of recyclable, recycled and reusable materials and components, and also the use of hazardous substances in the whole life cycle.

Energy
Energy generation and consumption result in a high pressure on the environment. The effects of using of fossil fuels are especially important, for example, as it results in greenhouse gases emissions. The use of renewable energy is one of the world's challenges in order to reach sustainability.
This aspect is related to all energy consumption during the whole product's life cycle, and considers the all different types of energy used.

Solid waste
Solid waste is one of the outputs of product's life cycle, and it reflects the inefficiencies of processes evolved as it represents the amount material not converted into useful products. Zero waste strategy is another ultimate goal of sustainability, and reflects the rational use of natural resources.
Reuse, recycling and remanufacturing are options for a product's end-of life, and represent actions oriented to waste reduction and cyclical use of materials. This environmental aspect is related to all solid waste generated in the whole life cycle of a product, including hazardous waste.

Waste water
Waste water is the environmental aspect related to the outputs of water use and emissions of pollutants in water. The once-through use of industrial water in manufacturing process became uneconomical and environmentally unacceptable, for instance, and also products which require a big amount of water use and generate waste water during use, such as soaps and detergents.

Gaseous Emissions
This aspect is related to substances released in the air, such as greenhouse gases and toxic emissions. Air emissions can cause diverse environmental impacts, such as greenhouse effect and climate change, acid precipitation and ozone depletion. Some of the basic air emissions indicators measures carbon dioxide, methane, particulate matter, volatile organic compounds (VOCs), etc.

Energy loss
This aspect is related to energy loss which can occur in all life cycle stages, such as noise, radiation, light, heat and vibration.

Each environmental aspect can be related to all products' life cycle stages. Figure 8 shows this relation, in which each life cycle stage has inputs and outputs of material and energy:

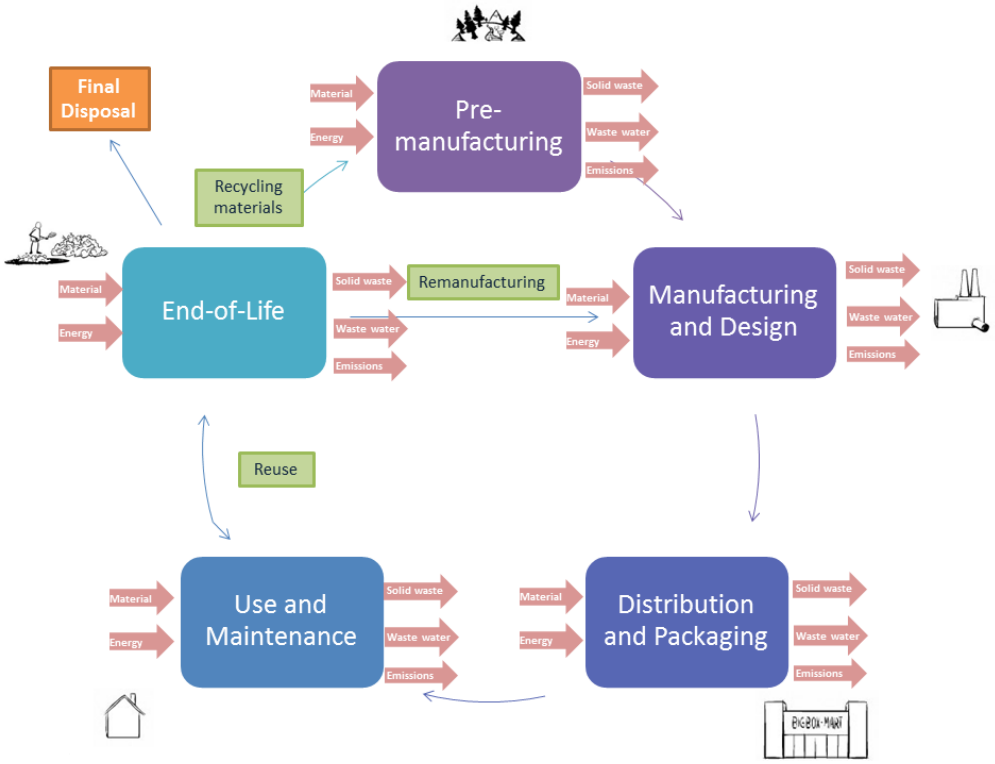


Figure 8: Relationship among product life cycle stages and environmental aspects. Adapted from Yarwood & Eagan (1998) and The Story of Stuff Project (http://www.storyofstuff.org/).

Appendix C: Types of measure

The use of absolute and relative measures can influence the results obtained when calculating the indicator and improving the environmental performance of a product in product development process. The indicators in the EPI Database were classified according to this criterion in order to clarify the type of measurement is being used and how the use each one of them can bring better results.

Absolute measures
Absolute indicators can be measured in terms of time estimation and from an input-output analysis, for instance. They can be calculated within a period of time, such as use of recycled material in the manufacturing process per year. Normally, this type of measure is useful when characterizing the product's life cycle, in order to have an estimation of the total environmental impact of the activities related to it.

Relative measures
Relative indicators are useful when comparing design options of the same product, and also for comparison of different products. They show more clearly what can be improved in design to reduce environmental impacts. This type of indicators can be dimensionless, and they are usually measured:

- Relative to one unit of product or production output manufactured, e.g. mass of recycled material used in the product relative to the total mass of the product;
- Relative to a baseline product, reflecting the improvement rate between it and the new option for product development, e.g. product weight reduction rate;
- Relative to an ideal condition in a design option, reflecting how far the real condition is from the last, e.g. the indicator "Assembly Design Efficiency".

Useful literature

Azapagic, A. & Perdan, S., 2000. Indicators of sustainable development for Industry: A General Framework. *Process Safety and Environmental Protection*, 78(July), pp.243–261.

Bovea, M.D. & Pérez-Belis, V., 2012. A taxonomy of ecodesign tools for integrating environmental requirements into the product design process. *Journal of Cleaner Production*, 20(1), pp.61–71. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0959652611002538 [Accessed February 28, 2013].

Chiang, S.-Y. et al., 2010. How can electronics industries become green manufacturers in Taiwan and Japan. *Clean Technologies and Environmental Policy*, 13(1), pp.37–47. Available at: http://www.springerlink.com/index/10.1007/s10098-010-0284-6 [Accessed August 3, 2012].

EEA, 1999. *Environmental indicators : Typology and overview*, Copenhagen, Denmark.

Herva, M. et al., 2011. Review of corporate environmental indicators. *Journal of Cleaner Production*, 19(15), pp.1687–1699. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0959652611001892 [Accessed September 5, 2011].

Jasch, C., 2000. Environmental performance evaluation and indicators. *Journal of Cleaner Production*, 8(1), pp.79–88. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0959652699002358.

Krajnc, D. & Glavic, P., 2003. Indicators of sustainable production. *Clean Technologies and Environmental Policy*, 5(3-4), pp.279–288. Available at: http://www.springerlink.com/index/23E9VM0YFGUEQDH4.pdf [Accessed March 13, 2012].

Neely, A. et al., 2000. Performance measurement system design: developing and testing a process-based approach. *International Journal of Operations & Production Management*, 20(10), pp.1119–1145. Available at: http://www.emeraldinsight.com/10.1108/01443570010343708 [Accessed October 29, 2012].

Olsthoorn, X. et al., 2001. Environmental indicators for business: a review of the literature and standardisation methods. *Journal of Cleaner Production*, 9(5), pp.453–463. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0959652601000051.

Persson, J., 2001. Eco-indicators in product development. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, 215(5), p.627. Available at: http://pib.sagepub.com/content/215/5/627.short [Accessed February 25, 2012].

Pigosso, D.C.A., 2012. *Ecodesign Maturity Model: a framework to support companies in the selection and implementation of ecodesign practices*. Escola de Engenharia de São Carlos (EESC-USP).

Ren, X., 2000. Development of environmental performance indicators for textile process and product. *Journal of Cleaner Production*, 8(6), pp.473–481. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0959652600000172.

Thoresen, J., 1999. Environmental performance evaluation — a tool for industrial improvement. *Journal of Cleaner Production*, 7, pp.365–370.

UNEP. Life Cycle Management: A Business Guide to Sustainability, 2007.

Yarwood, J.M., & Eagan, P.D., Design for Environment Toolkit: A Competitive Edge for the Future, Minnesota Office of Environmental Assistance and Minnesota Technical Assistance Program, Minnesota,1998.