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

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

Bachelor thesis presented to University of São Paulo and Technical University of Denmark as one of the requirements to achieve the bachelor degree in Environmental Engineering at Engineering School of São Carlos

Concentration area: Product development and ecodesign

Supervisor: PhD Daniela Cristina Antelmi Pigosso

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2013

AUTORIZO A REPRODUÇÃO E DIVULGAÇÃO TOTAL OU PARCIAL DESTE TRABALHO, POR QUALQUER MEIO CONVENCIONAL OU ELETRÔNICO, PARA FINS DE ESTUDO E PESQUISA, DESDE QUE CITADA A FONTE.
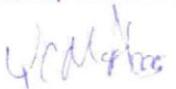
FOLHA DE APROVAÇÃO

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To FAPESP (São Paulo Research Foundation),

This bachelor thesis is presented as the final scientific report of the undergraduate research project scholarship granted to Isabela Ianhez Issa, student of Environmental Engineering at Engineering School of São Carlos (EESC), process number 2012/06890-5. This document presents all the methodology, activities and results of all phases of the research project.
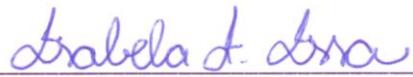
Student: Isabela Ianhez Issa

Supervisor: Henrique Rozenfeld

I dedicate this work to all those who believe
in the beauty of their dreams.

ACKNOWLEDGEMENTS

"A journey of a thousand miles begins

with a single step."

Lao Tsé

ABSTRACT

The establishment of measurable product-related environmental performance indicators (EPIs) during the product development process (PDP) is often cited as a successful factor for effective ecodesign implementation. Ecodesign is a proactive approach that incorporates environmental issues into the PDP, aiming to improve the environmental performance of the developed products. The use of EPIs enables the monitoring of product performance throughout the accomplishment of improvement objectives. Despite the existence of several researches related to environmental indicators, companies still face difficulties in their selection and application. In this context, this research aims to develop a guide to support companies in the selection of EPIs. By means of a systematic literature review, 261 EPIs were identified and systematized in a digital database. The EPIs were classified according to a set of selection criteria, which aims to support companies in the identification of the relevant EPIs. The digital database is used in the context of the guide, which proposes a five-step approach for EPIs selection. Based on the improvement opportunities identified from a case study in Denmark, an improved version of the guide was developed and further applied in a case study in Brazil. An important conclusion obtained during the application of case studies in different companies is that the definition of environmental priorities and objectives is the main activity to conduct a successful selection of performance indicators. In both case studies the companies could select, customize and create a set of EPIs. Results from evaluations indicate that the guide can support the selection of these indicators.

Keywords: environmental performance indicators, ecodesign, product development

RESUMO

ISSA, I.I. Desenvolvimento de um guia para auxiliar a seleção de indicadores de desempenho ambiental de produtos. 2013. 246 páginas. Trabalho de Graduação. Escola de Engenharia de São Carlos, Universidade de São Paulo e Universidade Técnica da Dinamarca, São Carlos, 2013.

O estabelecimento de indicadores de desempenho ambiental (IDAs) mensuráveis durante o processo de desenvolvimento de produtos (PDP) é citado muitas vezes como um fator de sucesso na implementação efetiva do *ecodesign*. O *ecodesign* é uma abordagem proativa que incorpora questões ambientais no PDP, com o objetivo de melhorar o desempenho ambiental dos produtos desenvolvidos. O uso de IDAs possibilita o monitoramento do desempenho do produto na realização de objetivos de melhoria. Apesar da existência de várias pesquisas relacionadas a indicadores ambientais, as empresas ainda enfrentam dificuldades em sua seleção e aplicação. Neste contexto, esta pesquisa tem como objetivo desenvolver um guia para apoiar as empresas na seleção de IDAs. Por meio de uma revisão bibliográfica sistemática, 261 IDAs foram identificados e sistematizados em um banco de dados digital. Os IDAs foram classificadas de acordo com um conjunto de critérios de seleção que visam apoiar as empresas na identificação dos IDAs relevantes. A base de dados digital é utilizada no contexto do guia, o qual propõe cinco passos para a seleção de IDAs. Com base nas oportunidades de melhoria identificadas em um estudo de caso na Dinamarca, uma nova versão do guia foi desenvolvida e então aplicada em um estudo de caso no Brasil. Uma importante conclusão obtida durante a aplicação dos estudos de caso em diferentes empresas é que a definição de prioridades e objetivos ambientais é a principal atividade para se realizar uma seleção bem sucedida de indicadores de desempenho. Em ambos os casos as empresas puderam selecionar, customizar e criar um conjunto de IDAs. Os resultados das avaliações indicam que o guia pode auxiliar a seleção desses indicadores.

Palavras-chave: indicadores de desempenho ambiental, ecodesign, desenvolvimento de produto

SUMMARY

1 Introduction

This document is organized in the following structure: section 1 presents the introduction, containing the context and motivation, the research objectives and the literature review; section 2 presents the methodology and the research structure; section 3 presents results and discussions of each research phase; section 4 presents the conclusions and section 5 the bibliographic references.

This section describes the context and motivation (section 1.1), the research objectives (section 1.2) and the literature review regarding environmental performance indicators (section 1.3).

1.1 Context and motivation

Industry is recognized as one of the major sources of pollution and resource depletion on natural environment (HERVA *et al.*, 2011). Besides the industrial activities, products impact the environment throughout its entire life cycle, from extraction of raw materials and manufacturing to use and final disposal (BAUMANN *et al.*, 2002).

Sustainable Development is defined as a development that meets the current needs without compromising the necessary resources for the next generations (THE WORLD COMMISSION ON ENVIRONMENT AND DEVELOPMENT, 1987). The concept of sustainable development is often linked to the "Triple Bottom Line", which consists of the environmental, social, and economic dimensions of corporate performance that has been used as a basis for many sustainability assessment tools (BAKSHI, 1993; FIKSEL, 2003).

Those concepts have inspired people and organizations to search for new ways to develop more and to measure their progress toward this goal. In this context, indicators have emerged as one widely accepted tool to be used all levels – national, community, organization, and company (VELEVA *et al.*, 2003). This work is focused in the environmental dimension of sustainability.

Environmental protection at corporate level has evolved from an "end-of-pipe" approach to preventive and proactive approaches over the last ten years and it has become gradually accepted that a product oriented approach can be more attractive than a process oriented one (WEENEN, VAN, 1995). Ecodesign, or Design for Environment (DfE), is a proactive environmental management approach employed in the Product Development Process (PDP) which aims to

improve the environmental performance of products[1] (JOHANSSON, 2002; NIELSEN; WENZEL, 2002). The German Federal Environmental Agency (2000) estimates that more than 80% of all product-related environmental impact is determined during the product development phase. In this context, ecodesign is seen as a powerful strategy to reduce the environmental impact of products (AZKARATE et al., 2011).

The use of environmental performance indicators (EPIs) to evaluate, predict and monitor product performance is identified as an essential element for effective ecodesign implementation (FIKSEL et al., 1998), as they can provide an early warning to prevent environmental damages (HERVA et al., 2011). In fact, the establishment of measurable goals and performance indicators are a fundamental element of any successful program. The final objective of the product environmental performance measurement is to change a behavior; in this case, to change the way that products are developed (FIKSEL et al., 1998; HUSSEY et al., 2001).

In this research, EPIs which aim to monitor the environmental performance of products are called product-related EPIs. According to ISO 14031 (ISO, 1999), these EPIs can be classified as Operational Performance Indicators (OPIs), which are defined 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 (JASCH, 2000). Many companies have used EPIs on reporting as an environmental strategy itself instead of using EPIs as a tool to measure progress towards environmental targets, and these indicators are mainly developed for communication and benchmarking purposes (HERVA et al., 2011; REN, 2000).

Product-related EPIs measure the environmental performance of individual products or the complete range of products in the portfolio of a company. They can also measure improvements in products' environmental performance and indicate relative advantages or disadvantages in comparison to other products (KRAJNC; GLAVIC, 2003).

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[1] The environmental performance of products or services is defined as the sum of all the impacts caused by them in their life-cycle (NIELSEN; WENZEL, 2002).

Krajnc & Glavic (2003) argue that is recommendable that a company first begins with simple and easy to implement measures of compliance and resource efficiency and then moves toward more complex indicators, addressing supply-chain and life cycle impacts, for instance. The selection and use of environmental performance indicators as a quantitative tool is a simple and rapid approach to quantify and improve the environmental performance of products (BOVEA; PÉREZ-BELIS, 2012). Assuming that indicators used to monitor the environmental performance of products should be easy-to-use in order to assist the effective implementation of ecodesign in the earliest phases of the PDP (PERSSON, J.-G., 2001), this research focused in the study of leading EPIs. Leading EPIs aim to produce measures that will inspire effective actions in improving the environmental performance of products, as they are related to the environmental aspects[2] of a product's life cycle.

Despite the existence of several studies in literature about environmental performance indicators, there are some factors that still hamper their use in companies. Authors often focus their researches in the development and application of a specific or a set of EPIs (HERVA *et al.*, 2011; THORESEN, 1999). As a consequence, general principles regarding the development, selection and use of EPIs are not widely discussed in literature, and aspects related to systematization of EPIs for ecodesign need to be further investigated (PERSSON, J.-G., 2001; THORESEN, 1999).

It becomes necessary to identify, classify and systematize the existing environmental performance indicators in order to assist the effective implementation of ecodesign. Therefore, this research aimed to fill this gap and support companies in the selection of these EPIs to monitor the environmental performance of their products.

1.2 Research objectives

The main objective of this research is to support companies in the selection of EPIs to monitor the environmental performance of products during PDP according to company's strategic objectives.

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[2] 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 (OLSTHOORN *et al.*, 2001).

This objective can be deployed into the specific objectives below:

- Identification and systematization of existing EPIs for measuring and monitoring the environmental performance of products;

- Classification of these indicators according to the ecodesign operational practices of Ecodesign Maturity Model (EcoM2) and to relevant criteria for the selection of EPIs;

- Development of a guide to support the selection of these indicators.

1.3 Literature review

This section presents the state of the art regarding environmental performance indicators (EPIs) in ecodesign context.

Over the last thirty years, research and technologies have been developed focusing on corrective actions on the environment due to the passive attitude that companies had adopted until then. In the beginning of this process the focus was on solutions called "end-of-pipe", i.e., solutions that sought to reduce the emission of harmful substances to the environment (JOHANSSON, 2002).

However, in the last ten years several companies around the world have become aware that preventive and proactive approaches are much more attractive than corrective actions, both economically and ecologically. The preventive approach, known as Pollution Prevention and Cleaner Production, aims to reduce waste generation already at the source, reducing the cost of treatment and final disposal. In order to maximize the potential of Cleaner Production, it was gradually accepted that the approach focusing on products is more attractive than just facing the production process, which characterize the proactive approach (WEENEN, VAN, 1995).

Ecodesign, or Design for Environment (DfE), is a proactive environmental management approach employed in the Product Development Process (PDP) which aims to improve the environmental performance of products[3] without compromising the performance, functionality, aesthetics, quality and cost of them (JOHANSSON, 2002; NIELSEN; WENZEL, 2002). The major opportunities for the improvement of the environmental performance of products

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[3] The environmental performance of products or services is defined as the sum of all the impacts caused by them in their life-cycle (NIELSEN; WENZEL, 2002).

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are in the initial phases of PDP, when most of the decisions and technical specifications are taken (GUELERE FILHO; ROZENFELD, H, 2006).

Several ecodesign practices have been developed in the last decade in order to address environmental issues in product development (PIGOSSO, D. C. A.; ROZENFELD, HENRIQUE, 2011). In order to support companies in the implementation of these ecodesign practices, a framework called Ecodesign Maturity Model (EcoM2) 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 practices implementation, based on the current maturity profile and strategic objectives and drivers of this company (PIGOSSO, D., 2012).

Since the 1990's, a variety of environmental indicators were proposed to support the decision-making process in politics and business and to evaluate the environmental effects of these decisions. 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 are important to pointing the way and encouraging progress toward sustainable development (CUNNINGHAM *et al.*, 2004; PERSSON, J., 2001).

According to the European Agency for Environment (EEA, 1999), an environmental indicator monitors progress in pursuing environmental goals. Environmental indicators can be used for the following purposes (JASCH, 2000):

- Comparison of the environmental performance over time, highlighting the potential optimization of environmental aspects in a product or process;

- Assessment of the environmental performance of companies, processes and products, enabling environmental benchmarking among these companies;

- Being a communication tool in environmental reports; and

- Being an information instrument to the workforce, motivating them in pursuing the environmental goals.

Environmental indicators 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 (PERSSON, J.-G., 2001).

According to ISO 14031, 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. When performing EPE, the selection of suitable environmental performance indicators (EPIs) for the organization is the most important step (CHIANG, S.-Y. *et al.*, 2010). These indicators must be objective and verifiable (JASCH, 2000).

EPIs are used to measure and evaluate the environmental performance of technology and/or activities. They are divided into two subgroups: management performance indicators (MPIs) and operational performance indicators (OPIs) (CHIANG, S.-Y. *et al.*, 2010; JASCH, 2000). MPIs provide information about management efforts to influence the environmental performance of the organization's operations. They are useful in measuring environmental management targets, for instance, number of environmental audits undertaken and percentage of employees with environmental training (JASCH, 2000). OPIs are defined, according to ISO 14031 (JASCH, 2000), as "a type of EPI that provides information about environmental performance of the operations of the organization, and OPIs relate to:

1. the design, operation, and maintenance of the organization's physical facilities and equipment;

2. the materials, energy, products, services, wastes, and emissions related to the organization's physical facilities and equipment; and

3. the supply of materials, energy and services to, and the delivery of products, services and wastes from the organization's physical facilities and equipment".

Besides being used to perform EPE, EPIs can be used to support companies in selecting environmentally friendly techniques, conducting benchmarking, environmental reporting and establishing an environmental management system (EMS) (REN, 2000). The EPIs studied in this research aim to measure the environmental performance of products, and they can be classified OPIs. Although the standard provides examples of EPIs, it doesn't discuss which data should be collected to what scope and which methods should be used to evaluate them (JASCH, 2000; THORESEN, 1999).

EPIs which measure the environmental performance of individual products or the complete range of products in the portfolio of a company are named

product-related EPIs. They can also measure the improvements in their environmental performance and indicate relative advantages or disadvantages in comparison to design alternatives and to other products (KEOLEIAN *et al.*, 1994; KRAJNC; GLAVIC, 2003).

The context in which indicators are applied is also important in the development and selection of indicators. Persson (2001) proposes two main categories of indicators to be used in PDP: indicators to be used in external communication and indicators to be used in design as problem pointers. This classification can be linked to the concept of lagging and leading indicators proposed by Neely et al (2000). In this context, it can be defined two main groups of product-related EPIs:

- **Lagging EPIs:** As lagging indicators are used to measure the final results of a process, they can be related to the environmental impacts[4] that a product can cause during its whole life cycle. These indicators measure the changes on the environment caused by product's life cycle.

- **Leading EPIs:** They are focused in measuring the technical characteristics of the product and its development, which can indicate areas of improvement or redesign. Leading EPIs measures the environmental aspects[5] of a product's life cycle activities.

This classification considers the cause-effect relation between environmental aspects and impacts.

2 Methodology and research structure

According to Gil (1999), scientific methods adopt intellectual and technical procedures in the construction of knowledge, and they must be followed in scientific research of natural and social phenomena. This research follows the hypothetical-deductive approach, which adopts a hypothesis that lead the phenomena of interest and seek to refute them through experimentation (GIL, 1999). The hypothesis to be tested in this research is formulated as:

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[4] According to ISO 14001 (1996), an **environmental impact** is defined as any change in the environment, which results wholly or partially from an organization's activities, products or services (OLSTHOORN *et al.*, 2001).

[5] 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 (OLSTHOORN *et al.*, 2001).

"The systematization of product-related EPIs and a step-by-step guide can support companies in the selection of indicators to monitor the environmental performance of products."

The experimentation is done by means of a case study for theory-testing, whose objective is testing propositions and, if necessary, reformulating them (DUL; HAK, 2008). The main activities of a theory-testing research are, then, formulating the propositions and testing weather they can be supported.

The research comprised four main phases, which are presented in the figure 1 below:
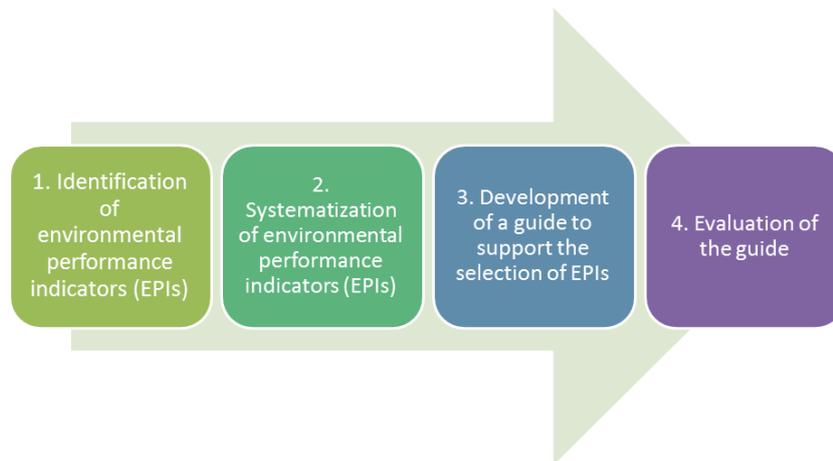
Figure 1: Phases of the research

The research phases are described below:

2.1 Phase 1: Identification of environmental performance indicators (EPIs)

The first phase of the research comprised the identification of EPIs used to measure and monitor the environmental performance of products through a Systematic Literature Review as scientific research method.

The Systematic Literature Review is a means of evaluating and interpreting all the available studies relevant to a particular research question (KITCHENHAM, 2004). Biolchini et al. (2005) presents a model to conduct a systematic literature review that comprises three steps: (1) Planning, (2) Execution and (3) Analysis. During the planning step, the objectives of the literature review are defined and the Systematic Review Protocol is developed, which is a document that

specifies the research question and the methods used to conduct the review. It is also defined in the protocol the inclusion and qualification criteria used during execution, when the studies are identified, evaluated and selected according to these criteria. The last step consists in the extraction and synthesis of the knowledge obtained from the analyzed studies.

The systematic literature review was composed by three main steps:

Step 1.1: Planning

The Systematic Literature Review Protocol was developed, which defined the objectives of the literature review and the relevant criteria used in the evaluation and analysis of the studies.

Step 1.2: Execution

The first identification of the studies was conducted using the criteria defined in the Systematic Literature Review Protocol, composed by the search for studies in databases, the evaluation and the selection of them.

Step 1.3: Analysis

Information extraction and the synthesis of the studies selected about environmental performance indicators were accomplished.

The systematic literature review provided the identification and collection of environmental performance indicators in a database and the consolidation of the state of art. The results from this phase are described in section 3.1, and the state of the art is presented in section 1.3 (Literature review).

2.2 Phase 2: Systematization of environmental performance indicators

The second phase comprised the systematization of the EPIs identified in the previous phase of this research according to a set of defined criteria in order to support the selection of these EPIs by companies.

The systematization was composed of two steps:

Step 2.1: Definition of classification criteria

It was defined a set of criteria for the classification of the identified indicators in order to facilitate the search and selection of EPIs in the database according to companies' needs.

Step 2.2: Classification of EPIs according to defined criteria

The EPIs identified and recorded during the literature review were classified according to the criteria defined in the previous step.

The classification of identified EPIs provided a systematic database of indicators which aimed to aid the guide to support the selection of EPIs developed in the next phase. The results from this phase are described in section 3.2.

2.3 Phase 3: Development of a guide to support the selection of EPIs

From the results obtained in the last two phases, phase 3 comprised the development of a guide to support the selection of EPIs to monitor the environmental performance of products.

The guide was developed based on the concepts of environmental performance evaluation and EPIs in order to introduce its importance in the PDP of a company. Moreover, the developed guide explains how to use the database of environmental performance indicators systematized in the previous phases of the research. Phase 3 comprised two steps:

Step 3.1: Raising ideas

The creation process of the guide started, with brainstorming and discussions in the ecodesign group of DTU (Technical University of Denmark) to raise ideas and ways to structure the guide, to define which information it should contain, and to adapt the academic knowledge in a language easy to understand for companies.

Step 3.2: Development

The content, layout, diagramming and impression of the guide were developed and concluded, based on a step-by-step approach for the selection of performance indicators for life cycle management.

The guide was developed based on a step-by-step approach to select and implement EPIs using the database developed during the previous phases of this research. The results from this phase are described in section 3.3.

2.4 Phase 4: Evaluation of the guide

The last phase of the research consisted in the evaluation the developed guide by means of case studies for theory-testing.

According to Dul and Hak (2008), a case study is defined as a study in which a single or a small number of cases in their real life context are selected and the results obtained from these cases are qualitatively analyzed. It is also used as a way to track the progress of a study to further examine and validate previous empirical results (VOSS *et al.*, 2002). In a theory-testing research, case studies can be used to test the formulated hypothesis.

Two case studies were performed in companies from different countries. From the results of case study 1 the guide was improved and tested during case study 2. The main steps of this phase are described below:

Step 4.1: Case study 1

The developed guide was applied and evaluated in a Danish company.

Step 4.2: Improvement of the guide

From the results obtained during case study 1, the guide was improved in a new version.

Step 4.3: Case study 2

The new version of the guide was applied and evaluated in a Brazilian company.

The results from this phase are described in section 3.4, and section 3.4.4.4 presents discussions regarding case studies in these different companies' contexts.

3 Results and Discussions

This section presents the results from this research. The identification of environmental performance indicators (phase 1) is presented in section 3.1, and the systematization of these indicators (phase 2) in section 3.2. In section 3.3 it is described the development of the guide to support the selection of EPIs (phase 3). Section 3.4 presents the evaluation and improvement of guide by means of case studies (phase 4).

3.1 Identification of environmental performance indicators (EPIs)

This section presents the results obtained during phase 1 of the research, which comprised the identification of environmental performance indicators from the literature.

The systematic literature review conducted in this research followed the model proposed by Biolchini et al. (2005). Then, the phase 1 of the project was divided in three main steps, as proposed in the model: Planning (section 3.1.1), Execution (section 3.1.2) and Analysis (section 3.1.3). The results of each step are described below.

3.1.1 Planning

The planning step of a systematic literature review established the main focus of the research, its central questions and objectives, and also the criteria used to find, evaluate, select and analyze studies. All these definitions were developed and they are presented in the Systematic Literature Review Protocol (see Appendix A) (BIOLCHINI *et al.*, 2005).

The main goal of this systematic review was to raise the state of art of environmental performance indicators (EPIs) to monitor the environmental performance of products, identifying these EPIs and the information related to them (such as name, unit of measurement, formula, etc).

Ten studies were selected to form the set of primary studies (see Appendix A). These studies were important in the definition of keywords and strings relevant

to the search process. They were selected from a set of studies used in the development of the original project and indicated by the specialist Daniela Pigosso, post-doc in Ecodesign at Technical University of Denmark (DTU).

The relevant keywords were then extracted from the set of primary studies and from the research presented by Cobra (2012), which contains *ecodesign* synonyms. The strings to search at electronic databases were defined and it was composed by the union of the 25 keywords related to *ecodesign* and 9 related to *indicators.*

The indexed electronic databases used in the search process were the ones which offer papers online, with free access or signed by University of São Paulo, and which present relevance to the research topic, in this case, ecodesign. In order to verify which databases were relevant to the research, the work of Cobra (2012) was consulted and some previous searches were made using the string previously defined. During these previous searches, it was found a large number of studies related to environmental performance evaluation of products, exceeding the initial expectations of this research project. Then, in order to refine the results, the term *product development* and *product design* were added to the string, and this refinement has proved very positive.

The qualification criteria of a systematic literature review were important during the evaluation of the studies found from the search process. Normally, it can be used as qualification criteria: research methodology, number of citations, impact factor of the journal, relevance of the author in the research's topic, and so on, and these criteria were established according to the needs of the research, aligning the scope of results. In order to ensure that the EPIs found are the most widely used and recognized, only journal papers were selected to be analyzed.

The inclusion criteria for the selected studies must show exactly what the studies must contain to be included in the review. The studies which did not contain these criteria were excluded from the review when applying the reading filters presented below. First, just studies that contain the proposition, application or review of EPIs were selected (1).

In order to refine more the studies to be analyzed, two others inclusion criteria were included and applied during execution step (section 3.1.2). The second

criterion was defined according to the scope of application of EcoM2, which is applicable in companies that develop capital and consumer goods. Just studies that focus on capital and consumer goods were selected (2).

The third inclusion criterion was defined according to the results of the systematization of EPIs (section 3.2). At the first moment, the criterion Leading/Lagging EPIs was used to classify the identified indicators during the literature review. Assuming that EPIs used to monitor the environmental performance of products should be easy-to-use in order to assist the effective implementation of ecodesign in the earliest phases of the PDP, this criterion was used as an inclusion criterion in the literature review, in order to focus the research just in leading EPIs. This type of indicators can influence directly the environmental aspects of products' life cycle and consequently in their environmental performance. Then, just studies that present leading EPIs were selected (3).

To be selected, a study should contain all three inclusion criteria defined above. In order to evaluate the inclusion criteria in each study, three studies selection procedures were defined in the protocol. The selection procedure consists in reading the title, abstract and keywords of a study. If using this procedure the inclusion criteria could not be detected, the study was submitted to the reading of its introduction and conclusion (second selection procedure). If the inclusion criteria still could not be detected, the study was fully read (third selection procedure).

The protocol also defined how selected papers were stored and recorded, and how the analysis (section 3.1.3) should be performed.

3.1.2 Execution

This activity comprised the search for studies in the selected electronic databases and the selection of these studies according to the criteria defined in the Systematic Literature Review Protocol (Appendix A). The execution of the review was performed in three main activities: the initial identification, when studies were found and stored, the evaluation and the final selection of the studies to be analyzed.

The search process in electronic databases was performed between May and October of 2012. The search was made according to the keywords and strings

defined in the review protocol (Appendix A) in the selected electronic databases.

In Table 1 is presented the amount of studies found in databases using the defined string, the amount published in international journals and the amount of stored studies[6].

Table 1 – Number of studies found performing the search process between May and October of 2012

Database	Amount of studies found	Amount of journal papers	Amount of studies stored
Engineering Village	3429	1459	927
Scopus	1296	734	445
Emerald	452	452	245
Science Direct	76	51	38
ISI Web of Knowledge	60	29	19
ProQuest	36	24*	17
IEEE	25	1	1
TOTAL	5374	2750	1692

*The search was restricted to three databases available at ProQuest: *Engineering Research Database*, *Materials Research Database* e *ProQuest Deep Indexing: Technology*.

The evaluation of the stored papers consisted in the application of the inclusion criteria when using the studies selection procedures defined in the review protocol (see Appendix A). Papers which did not satisfy all the inclusion criteria were excluded from the literature review. When there were doubts regarding some of the inclusion criteria, the paper was submitted to the second selection procedure, and, when necessary, to the third one. Papers in which the inclusion criteria could not be detected when applying these procedures were excluded from the literature review; papers in which all the inclusion criteria could be detected in at least one of the selection procedures didn't need to be subjected to the others, they were directly selected.

The evaluation was performed in two phases. In the first phase the Inclusion Criterion 1 was applied, resulting in the selection of 258 papers. In the second phase, the Inclusion Criterion 2 and 3 were applied in these pre-selected set of

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[6] The difference between the number of journal papers found and stored exists due to the fact that the download of these papers are restricted to publishers signed by the University of São Paulo.

papers, and the final evaluation resulted in 82 papers selected. Figure 2 below illustrates the evaluation process:
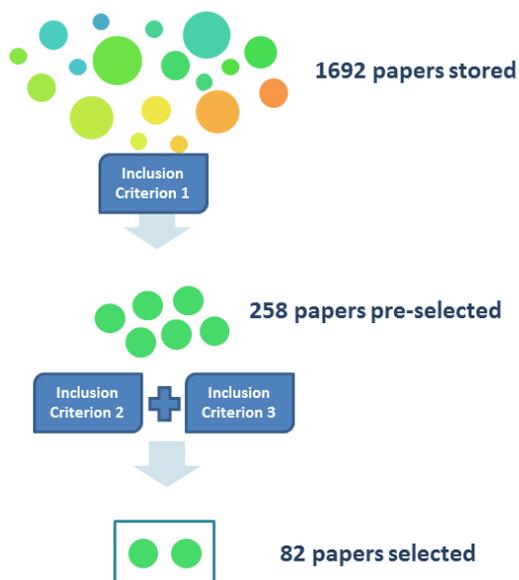
Figure 2: Evaluation process conducted in the systematic literature review

After conducting the evaluation of the studies identified in the literature, the selected papers were stored using the software *Mendeley*[7] and their main information recorded in a spreadsheet, as defined in the review protocol (see Appendix A). All set of primary studies were included in the literature review.

The evaluation process resulted in 82 papers selected to be analyzed (section 3.1.3), recorded in Appendix B (Record of selected studies). The retention rate against the initial number of stored studies is 4.85%.

3.1.3 Analysis

This last step of the systematic review comprised two activities, evolving data extraction and review synthesis. All the selected studies were read and the information regarding environmental performance indicators were extracted and recorded. Data extraction also included the identification and record of the environmental performance indicators found in the literature and its information (such as name, symbol, formula and unit of measurement).

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[7] *Mendeley* is a desktop and web program for managing and sharing research papers and a reference manager.

It was identified more than 250 different EPIs, presented in Appendix D (Record of environmental performance indicators). This appendix corresponds to the improved database of indicators conducted after the case study 1, presented later in this document (section 3.4.2 - Improvement of the guide). Also, during the identification of EPIs, the initial classification of these indicators according to the first set of defined criteria was conducted, as explained in section 3.2.1 (Definition of a classification criteria).

At the end of the systematic review, a report was developed regarding the synthesis of the analyzed studies, and all the information recorded was reviewed. This report is a review of studies about environmental performance indicators, in which it was possible to identify the relevant authors in this topic, the concept evolution regarding environmental performance evaluation, the availability of studies in this topic, and so on (LEVY; ELLIS, 2006).

The synthesis report was developed during the literature review, and it is composed by the state of art about environmental performance indicators (section 1.3 – Literature review) and the record of environmental performance indicators extracted from the selected studies (Appendix D). A descriptive analysis of the selected papers is presented in Appendix C (Descriptive analysis of selected studies).

3.2 Systematization of environmental performance indicators (EPIs)

This section presents the results from phase 2 of the research, which consisted of the systematization of the EPIs identified in the first phase. This phase comprised two main steps: Definition of classification criteria (section 3.2.1) and Classification of EPIs according to defined criteria (section 3.2.2).

According to Persson (2001), indicators can be classified regarding a large number of dimensions which need to be considered in the design of a relevant indicator (or a set of indicators) for a specific purpose. In this research, it was aimed to identify the relevant dimensions to be considered when selecting EPIs for PDP.

Persson (2001) presents some interesting dimensions for eco-indicators, and his work provided the first understanding of which could be a relevant classification criteria. For instance, it can be cited as a dimension the system level considered by an indicator or a set of indicators, which could be: global,

national, regional, or corporative level, considering their mass and energy flows, and in a product or component level. In this classification, the product-related EPIs studied in this project can be classified in the product/component level. The author also briefly describes other dimensions, such as: purpose (decision support or declaration purpose); type of values attributed (target values or constraints); and type of measure (absolute or relative measures) (PERSSON, J., 2001).

3.2.1 Definition of a classification criteria

The main goal of this step was to define the classification criteria that can support companies in the selection of product-related EPIs to monitor the environmental performance of products for PDP. In this sense, it was expected that these criteria can facilitate the search, selection, customization and creation of indicators, according to company's needs.

The definition of the classification criteria for EPIs was conducted in two moments: the initial criteria definition and the final criteria definition. The first definition considered six criteria and the first classification was conducted during the last step of the systematic literature review (see section 3.1.3 - Analysis). Concluding the analysis of all studies and the initial classification of the identified EPIs provided a database containing the indicators, the information related to them and the systematization according to the criteria defined in this first moment (Ecodesign Operational Practices, Life Cycle Stages, Environmental Aspects, Type of measure, Lagging/Leading EPIs and Type of Analysis). The database of EPIs was then reviewed, in order to evaluate the relevance of the selected criteria in supporting the selection of these indicators in product development. As a result, in the final definition, it was selected five criteria to classify EPIs. More information and detail about the initial classification criteria and its review is presented in Appendix E (Initial classification criteria definition for environmental performance indicators).

Each final classification criterion is described below:

- **Ecodesign Operational Practices**

The Operational Practices of EcoM2 address technical issues in product development and are directly related to product's life cycle, providing guidelines

and design options for the development of products with an improved environmental performance (PIGOSSO, D., 2012).

EcoM2 presents 468 ecodesign operational practices systematized in strategies, guidelines and design options. The strategies are detailed in guidelines, which provide a description on how one strategy can be reached; and the guidelines are detailed in design options (PIGOSSO, D., 2012).

The model adopts six ecodesign strategies to classify the operational practices: 1) Minimize Energy Consumption; 2) Minimize Material Consumption; 3) Extend Material Life Span; 4) Optimize Product Life Time; 5) Select Low Impact Resources and Processes; and 6) Facilitate Disassembly. Figure 3 below presents an example of one guideline and its related design options of the strategy number 5.

When applying the ecodesign operational practices in a company, it is important to monitor how they are applied, to define goals and to measure the environmental performance of the developed products. The use of EPIs can support the evaluation of the environmental performance of products. Then, it is important to classify EPIs according these ecodesign practices. The EPIs identified in phase 1 of the research were classified according to the guidelines provided by these practices.
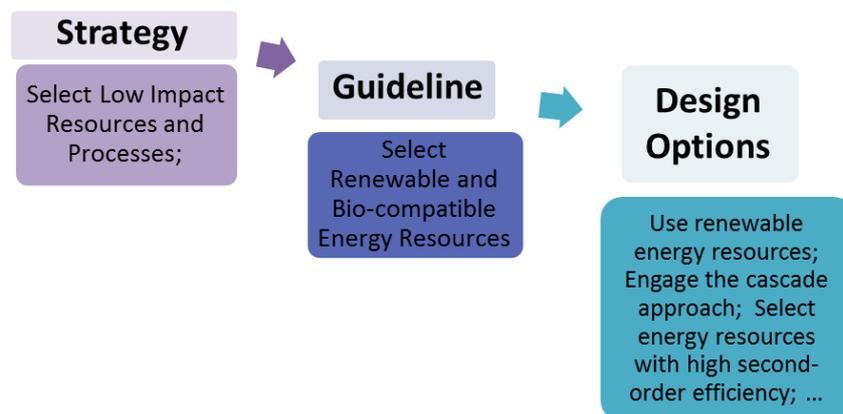
Figure 3: Example of one guideline and its related design options of strategy 5) Select Low Impact Resources and Processes, elements of the ecodesign operational practices (PIGOSSO, D., 2012).

- **Life Cycle Stages**

Products cause environmental impacts along their whole life cycle. Considering a system view of the product life cycle may help the company to define the boundaries of its potential influence on environmental impacts (THORESEN, 1999). The use of EPIs classified according to life cycle stages can support the company by providing an overview of the environmental impacts caused along their products' life cycle, pointing the way to improve the environmental performance stage by stage. The life cycle stages were defined, adapted from Yarwood & Eagan (1998) and UNEP (2007) (Figure 4), and the identified EPIs were classified according to them:

- **Pre-manufacturing:** comprises all activities involved in the raw material extraction, processing and transport. It also considers the procurement of recycled materials and parts/components for remanufacturing and reuse.

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

- **Environmental Aspects**

An environmental aspect from an activity in product's life cycle may cause a change in the natural environment, defined as environmental impact. Classifying EPIs according to environmental aspects can support companies when defining what to improve the environmental performance. The use of environmental aspects as a classification criterion was also important because it allowed the relation between these aspects and the life cycle stages: for each life cycle stage, it can be related inputs of material and energy (aspects Material and Energy Consumption) and outputs of material and energy (aspects Solid waste, Waste water and Gaseous emissions).

The environmental aspects are defined (YARWOOD; EAGAN, 1998; KRAJNC; GLAVIC, 2003), and the identified EPIs were classified according to them:

- **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 consumption:** 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.

In order to complement the understanding of these environmental aspects, it was added to them an input-output approach. The input-output approach is used often to support the development of environmental indicators, as it is used in the Inventory Analysis of an LCA (Life Cycle Assessment) (KLÖPFFER, 1997). This approach is also used to characterize manufacturing systems, as proposed by Singh et al (2007) and Krajnc & Glavic (2003). The input-output approach which characterizes the environmental aspects of product-related EPIs was then adopted as shown in figure 5. Each environmental aspect can be related to all products' life cycle stages.
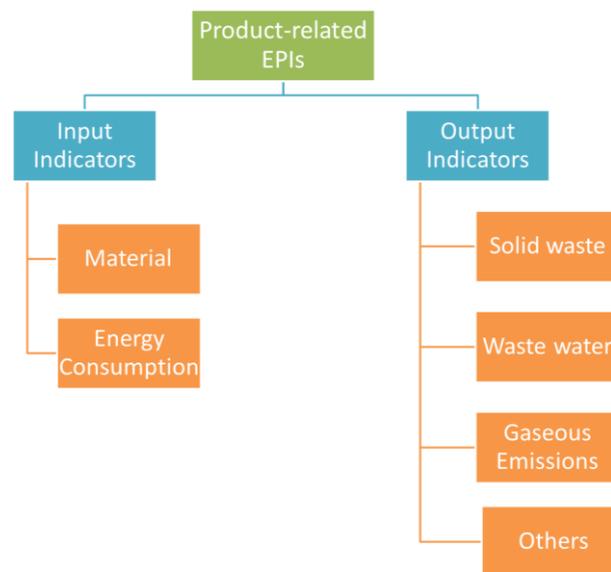
Figure 5: Product-related EPIs distinguished into input and output indicators. The category "Others", classified as output indicators, refers to different emissions, such as noise and radiation, for instance.

- **Type of measure**

EPIs can be classified according to their measurement type, as defined by Jasch (2000). Cerdan et al. (2009) discuss about the usability of relative and absolute measures, arguing that indicators expressed in terms of relative

measures are more easily generalized to a broader spectrum of products than the corresponding indicators expressed in absolute measures. On the other hand, absolute measures are useful when characterizing the product's life cycle from an input-output analysis (JASCH, 2000). As the type of measure deals with the usability of indicators and the goal of the company when measuring the environmental performance, it was considered important to classify EPIs according to this criterion.

Regarding relative and absolute measures, many authors discuss about this topic and present this classification criterion in their studies, such as Kroll and Carver (1999), Jasch (2000), Azapagic and Perdan (2000), Persson (2001), Krajnc and Glavic (2003) and Cerdan et al. (2009). From these approaches, it can be defined in more detail:

- **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 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; relative to a baseline product, reflecting the improvement rate between it and the new option for product development; and relative to an ideal condition in a design option, reflecting how far the real condition is from the last.

According to these definitions, the identified EPIs were classified in absolute or relative measures.

- **Keywords**

This criterion is set of 48 keywords created to optimize the search for EPIs in the database during the application of the guide developed in the research phase 3 (Development of a guide to support the selection of EPIs). To develop these keywords, it was identified important characteristics of what each indicator measures which were not covered by the other classification criteria. "Disassembly", for instance, is a keyword related to end-of-life stage and solid waste as environmental aspect. However, before the development of the set of keywords, there was no specific classification for EPIs which measure disassemblability. In this sense, the set of keywords was developed and it is presented below:

- Assembly;
- Disassembly;
- End-of-life;
- Environmental label;
- Failure;
- Identification of materials;
- Instructions to users;
- Acidification;
- Air emissions;
- Auxiliary materials;
- Biodegradable materials;
- By-products;
- Co-generation of energy;
- Defective products;
- Energy loss;
- Energy source;

- Intensity of use;
- Landfill;
- Laws and regulations;
- Lifetime;
- Maintenance;
- Material recovery;
- Material selection;
- Eutrophication;
- Greenhouse gases;
- Hazardous materials;
- Hazardous waste;
- Land area;
- Material consumption;
- Noise;
- Ozone depletion;
- Photochemical ozone creation potential;
- Radiation;

- Packaging;
- Recyclability;
- Reliability;
- Remanufacture;
- Reuse;
- Suppliers;
- Transportation;
- Recycled materials;
- Renewable materials;
- Residual products;
- Solid waste;
- Source of water;
- Waste water;
- Water reuse;
- Water use.

3.2.2 Classification of EPIs according to defined criteria

The first classification of EPIs was performed in parallel with the analysis of selected papers (section 3.1.3), and a review was conducted to the final definition of these criteria during the definition of the classification criteria (section 3.2.1). The main result of this step is the systematization of product-related EPIs, presented in Appendix F. This appendix corresponds to the improved systematization of EPIs

conducted after the case study 1, presented later in this document (section 3.4.2 - Improvement of the guide). The digital database of product-related EPIs is available on web[8].

From the database of EPIs and its systematization some conclusions can be traced and discussed. A quantitative analysis has been performed according to the criteria defined and presented above. This analysis was performed after the improvement of the guide in step 4 (see section 3.4.2), when the category of environmental aspects "Others" was replaced by "Energy loss" and a new category for life cycle stages was created, "General activities", which contain activities which go through all product life cycle, and can influence all of them (see section 3.4.2).

Most of EPIs (36.4 %) found in the literature are related to the end-of-life stage of product's life cycle, followed by manufacturing and design and pre-manufacturing (Figure 6). Some examples of indicators related to end-of-life are: "percentage of parts in the product to remanufacture", "recycling performance", "percentage of parts reused after reconditioning", and "total number of fasteners". Most of them are related to disassembly, reuse, and remanufacturing of products and recycling of materials, which are well known environmentally friendly strategies for product life cycle management.

Manufacturing and design and pre-manufacturing have shown also to be important life cycle stages, comprising 66 and 61 related EPIs, respectively. The "total amount of liquid waste" and the "rate of defective products" are examples of EPIs related to manufacturing, which are also indicators of cleaner production, aiming to reduce emissions and waste. The development of pollution prevention and cleaner production in the last decade can explain this high number of indicators. Most of indicators related to pre-manufacturing are about selection of non-toxic, harmless and biocompatible materials and material consumption, such as the source of water used. "Energy consumption for transportation from source" and "energy content of raw materials" are also examples of EPIs related to this life cycle stage.

In relation to environmental aspects (Figure 7), most of EPIs were developed to measure aspects related to material and solid waste. "Total material consumption" and "total solid waste amount" are examples of these indicators. It is interesting to

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[8] Available at: http://www.portaldeconhecimentos.org.br/index.php/por/content/view/full/16361 .

notice that most of EPIs classified as related to material and solid waste are also related to end-of-life stage. Again, they are mainly linked to disassembly and use of recycled materials, as end-of-life strategies (reuse, remanufacturing and recycling), and material consumption.

Energy appears as the third environmental aspect with more related EPIs. This aspect is very important when developing energy using products, and there emerging laws and regulations concerning energy use, such as EuP Directive (2009).
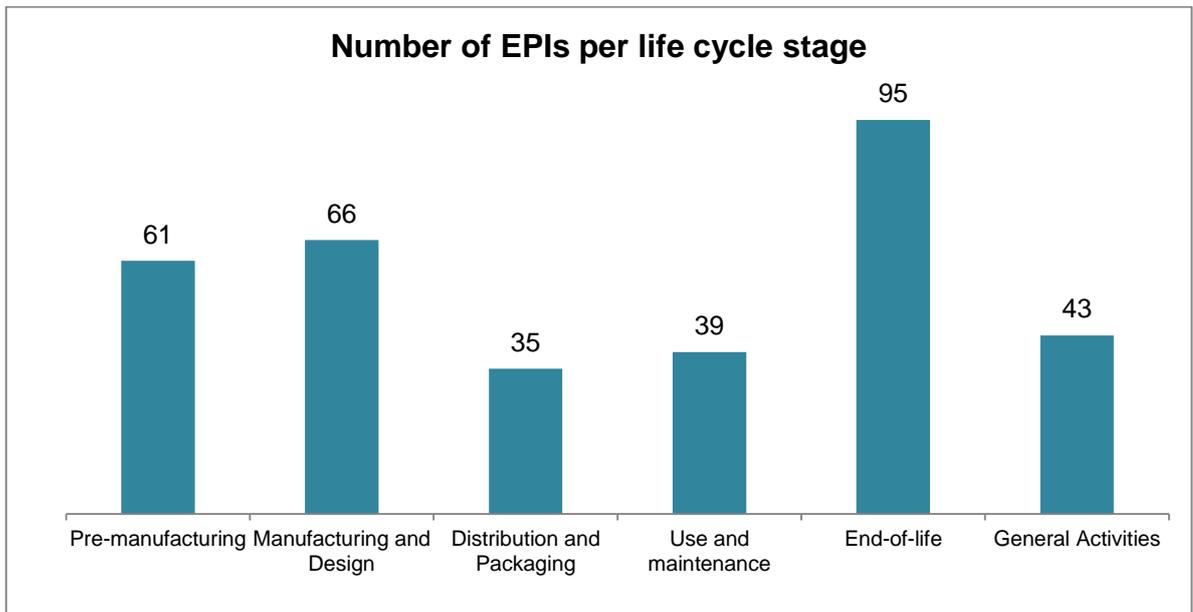
Figure 6: Number of EPIs per life cycle stage
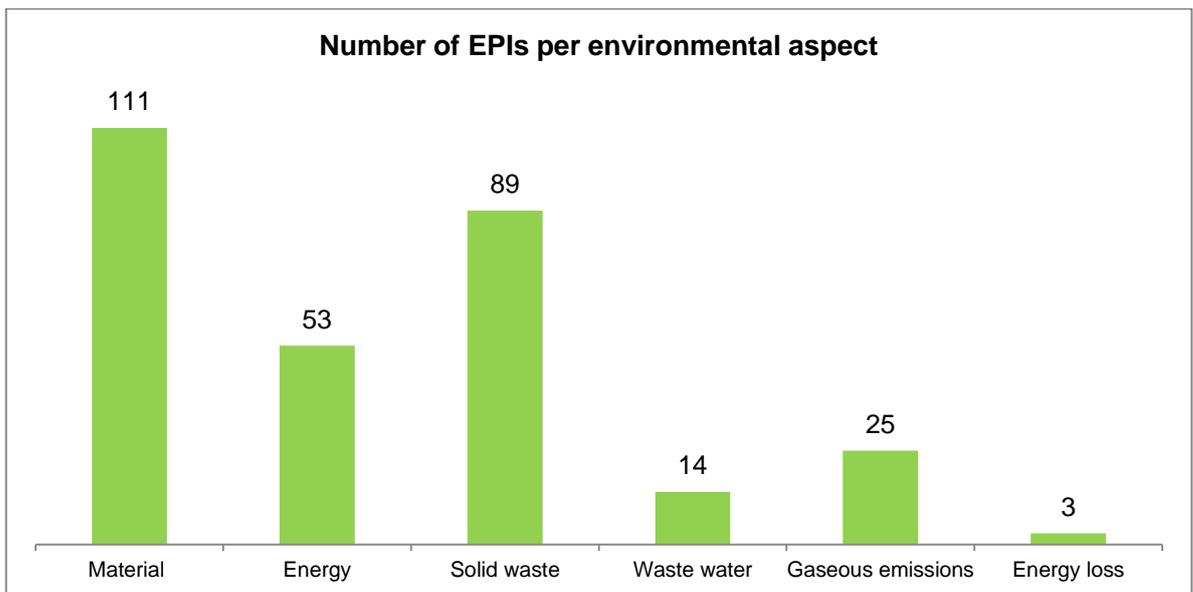
Figure 7: Number of EPIs per environmental aspects

There is a relation between life cycle stages and environmental aspects: for each life cycle stages there are inputs of materials and energy. It can be observed that there is a tendency in developing indicators to measure the performance of products' end-of-life and of the material consumed and discarded (as input and output of processes).

The analysis according to the type of measure (Figure 8) has shown very balanced. It was found in the literature about the same quantity of absolute and relative measures. It indicates that EPIs are being used in both formats, depending on the goal of the company when measuring environmental performance.
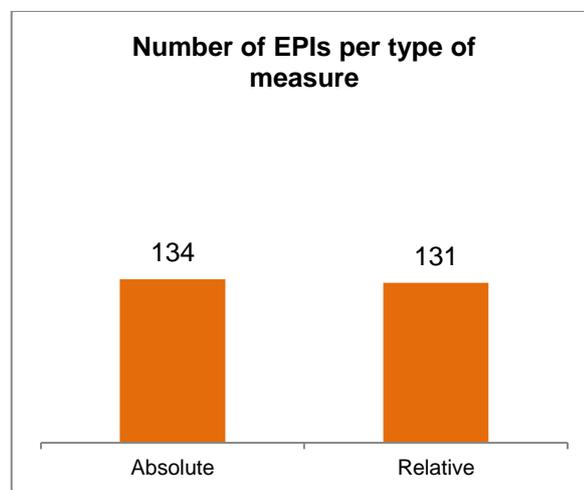
Figure 8: Number of EPIs per type of measure

3.3 Development of a guide to support the selection of EPIs

This section presents the results from phase 3 of the research, which comprised the development of a guide to support the selection of the product-related EPIs identified and systematized in the previous phases of this research. It was divided in two steps: Raising ideas (section 3.3.1) and Development (section 3.3.2).

The guide was developed based on the concepts of environmental performance evaluation and environmental performance indicators in order to introduce its importance in the PDP of a company. Moreover, the developed guide aims to explain how to use the database of environmental performance indicators systematized in the previous steps of the research, according to business needs.

3.3.1 Raising ideas

The creation process of the guide started with brainstorming and discussions in the section of Engineering Design and Product Development of DTU (Technical University of Denmark). The goal was to raise ideas and ways to structure the guide, defining which information it should contain, and adapting the academic knowledge gained in a language easy to understand for companies.

This step was performed during meetings with ecodesign experts at DTU, and the main questions proposed during these meetings which led the development of the guide were:

- Who are the main readers of the guide?
- How should be a step-by-step approach to lead the selection of EPIs?
- How the classification criteria should be used in the selection process of EPIs?

3.3.2 Development

This step comprised the creation of the guide, including the preparation of the content. The content of the guide was mainly developed by answering the questions proposed in the previous step.

The guide was 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.

A step-by-step approach was developed in order to make the guide easy and clear to the reader by consulting two ecodesign experts, Prof. Ph.D. Tim McAloone and post-doc Daniela Pigosso.

The developed approach is simple and it is composed of 5 steps, focusing on how to use the database of EPIs developed in the previous steps of this research. They cover the identification of environmental priorities for product development, the selection of EPIs from the database constructed in phases 1 and 2 of this research, and the implementation of these EPIs within the company. The steps were validated by experts, and they are:

(1) Define the environmental priorities (define objectives for environmental performance improvement in product development);

(2) Pre-select EPIs (apply the filters in the database using the classification criteria),

(3) Select EPIs from the database (select indicators presented in the database),

(4) Customize and create EPIs (adapt the set of selected EPIs to the company's needs), and

(5) Implement product-related EPIs (define how to embed environmental performance measures for product development within the company).

The classification criteria defined in the previous phase of this research were used in the guide as filters of EPIs, supporting the steps 1 and 2. Information contained and presented in the guide was from the literature review and from discussions with experts at DTU. Also the layout and diagramming of the developed booklet was conducted.

The guide is composed by three main parts:

- the guide itself, as a full text (Appendix G);
- a support material, containing the step-by-step approach (Appendix H); and
- the Product-related EPIs Database, a result of the identification and systematization of EPIs (the database is a combination of the Appendices D and F in one Excel spreadsheet).

The full text of the guide presented in this document corresponds to the improved version conducted after the case study 1, presented later in this document (section 3.4.2 - Improvement of the guide).

3.4 Evaluation of the guide

This section reviews and describes the activities developed, the research methods and the main results of phase 4. It comprised the evaluation of the guide developed by means of a case study in a Danish company and its improvement based on the results of the case study, and a second case study performed in a Brazilian company.

The case studies comprised in this phase aimed to evaluate the guide developed to support companies in the selection of product-related EPIs, testing the hypothesis of the research: *"The systematization of product-related EPIs and a step-by-step guide can support companies in the selection of indicators to monitor the environmental*

performance of products." They were carried out according to the methodology proposed by Dul and Hak (2008).

For case selection, the following criteria were adopted:

- ✓ studied companies must develop capital and/or consumer goods;
- ✓ studied companies must aim to develop products with a better environmental performance.

The workshop was divided into two main parts: presentation of the guide and database, and observation of the application of the five-step-approach presented. The researcher should support this application just when requested by the users, acting as an observer. The evaluation questionnaire was the main tool used for the hypothesis evaluation, as it proposes standardized questions and enable the comparison of the answers. It was answered immediately after the workshop by employees that have applied the guide.

The object of measurement in these case studies was defined as satisfaction, i.e., how the project is perceived as successful by the company. This type of success refers to a value attributed by the company, where the variable can range from "Unsatisfactory" to "Very satisfactory" (DUL; HAK, 2008). The developed questionnaire aimed to measure the usefulness and easy-to-use of the guide, the usefulness and completeness of the classification criteria, the content of Product-related EPIs Database, and time-efficiency when using the guide to select EPIs. The developed evaluation questionnaire is presented in Appendix I.

This section presents the results of case study 1 (section 3.4.1), the improvement of the guide (section 3.4.2) and case study 2 (section 3.4.2). Section 5.4.4 presents the discussions regarding this phase and a comparison of results from the different case studies.

3.4.1 Case study 1

Company 1[9] is an European multinational company and one of the world's leading manufactures in the sector it operates. It has more than 65 years of experience, represented by more than 80 companies in 55 countries, and employing about

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[9] Due to a non-disclosure agreement signed, the name of the company and confidential information collected cannot be published and was omitted from this document.

17.000 people around the world. The case study was carried out in the headquarters of the company in Denmark.

The product development process (PDP) of Company 1 is managed by the headquarters of Denmark and in other locations. The company is interested in developing products with a better environmental performance, focusing on product sustainability as a whole. The workshop and the evaluation questionnaire were presented to environmental managers of the company responsible to integrate environmental issues into PDP.

Three meetings were conducted with the employees, in three consecutive days. In the first one, the research project and the guide were presented to them, lasting about 1 hour. The company has shown interest in applying the guide, as they were looking for EPIs to measure the environmental dimension of their products' sustainability.

During the last two meetings, the application of the five-step-approach was applied. The second meeting lasted about 2 hours and the third one about 6 hours. The evaluation questionnaire was applied in the end of the last meeting just after the application.

During the definition of environmental priorities in step 1 of the guide, Company 1 has shown knowledge on the environmental impacts caused by their products, and also presented objectives previously defined to improve and measure their environmental performance. It was possible because sustainability is one of the strategic goals of this company which has been implemented since some years ago. The company had already performed a Life Cycle Assessment, and they had defined main life cycle stages to be environmentally improved.

Then, steps 2 (Pre-selection of EPIs), 3 (Selection of EPIs) and 4 (Customization and Creation of EPIs) were followed. During the meeting, the employees used the classification criteria applying Excel filters to find subsets of EPIs. They applied these filters for each environmental priority defined in step 1, choosing at least one life cycle stage, one environmental aspect, one type of measure and one keyword. The set of keywords were very important in the pre-selection of EPIs, once it supported the users when focusing in specific classes of indicators, such as recyclability and disassembly, and it reduced the number of indicators to be analyzed in step 3. Each subset was analyzed and each indicator evaluated according to criteria presented in

step 3 (step 2 and 3 were applied iteratively). The main discussions when selecting these EPIs were about data gathering, on how the necessary information to calculate an indicator would be gathered within the company (which team or sector should have this information and who should be contacted).

The employees created a column in the database to mark and insert comments for interesting EPIs from each different subset, as potential indicators to be selected. The customization and creation of EPIs were performed (step 4), and the final set of selected EPIs comprised 27 indicators. From this set, 9 EPIs were selected to be used exactly how they are presented in the database, 12 were adapted and/or customized, and 6 new EPIs were created.

The distribution of selected EPIs per life cycle stages and environmental aspects are presented in Figures 9 and 10. These results are aligned and dependent of the environmental priorities defined during step 1. Also, the distribution according to absolute and relative measures is balanced (50% and 50%).

Step 5 was not performed during these meetings, as implementation of indicators is a longer process and depends on decisions taken not just by the environmental managers present at the workshop. The full set of EPIs should then be validated by the different stakeholders of the company.
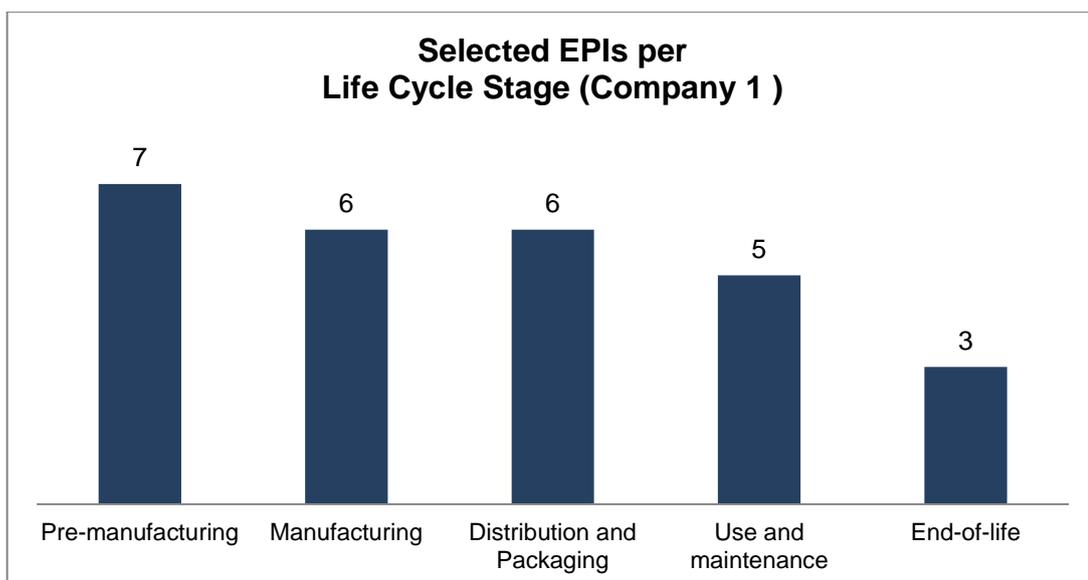
Figure 9: Number of selected EPIs for each life cycle stage at Company 1[10]
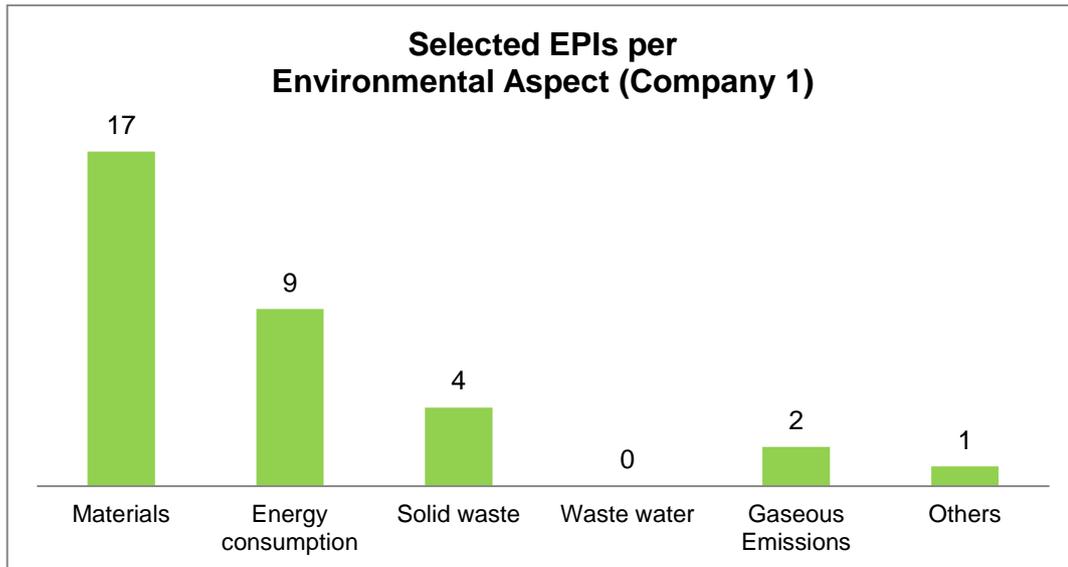
Figure 10: Number of selected EPIs for each environmental aspect at Company 1[10]

During the application of the guide, the employees provided some improvement suggestions, such as "Easier language (technical explanation) would be great, since not all people have a mathematical understanding"; the selection process "takes a lot of time, so it is best to suggest that experts from different areas should be gathered to discuss"; and "some of the keyword classification should be revised". Other suggestions are about creating a more user-friendly version, having a column where the user can mark the selected indicators, and creating an analysis of the selected indicators, in order to show many of each criterion the company is selecting.

The evaluation questionnaire was applied immediately at the end of the last meeting, and the results of the questionnaire are presented in figure 11.

Company 1 evaluated as satisfactory most of the evaluation criteria. None of them obtained "Needs improvement" or "Unsatisfactory" answers. The company considered the guide with a "logical approach", "easy to understand" and with "good visualization", and also a "good inspiration for different indicators". It provides evidence that the guide and the database developed supported the selection of EPIs to monitor the environmental performance of products, as proposed by the hypothesis. Company 1 also provided some comments and suggestions for improvement to the guide.

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[10] The analysis includes overlaps, since some indicators are classified according to more than one option for each criterion.

Evaluation of the guide by Company 1
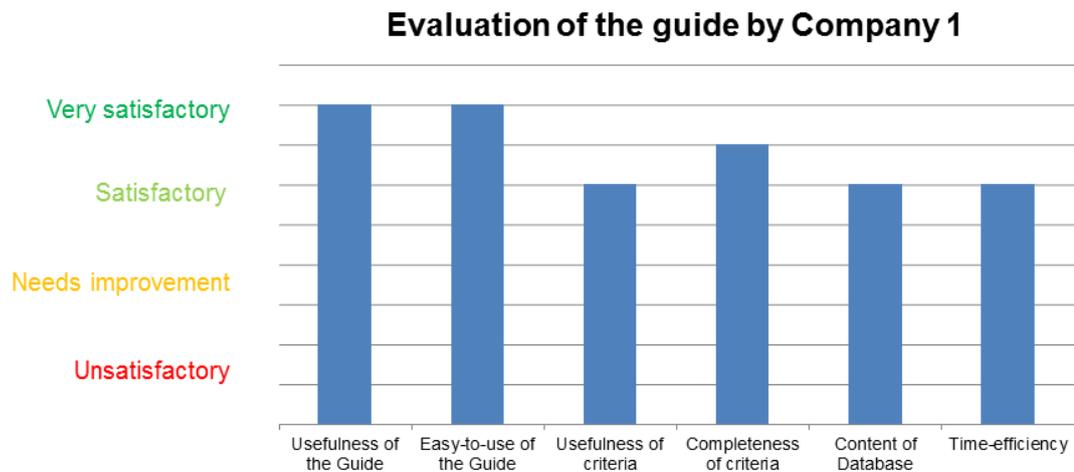
Figure 11: Evaluation of the developed Guide and Product-related EPIs Database by Company 1

Step 1 was identified as the most important and difficult to perform, as it depends on decisions taken in high level management and on a complete environmental performance evaluation. Furthermore, the selection process depends on the environmental priorities defined in this step, and the relevance of each indicator depends on how it is linked to the environmental strategies of the company.

Data gathering was an important criterion when selecting EPIs, as it depends on communication within the organization. The company also questioned when a new selection of EPIs should be performed, and emphasized that the guide should provide more information about this.

Some of the suggestions to the guide included making "Examples through the guide to make theoretical explanation understandable". In regards to the classification criteria, it was proposed that "possibly an indication of which part of development phase the indicator needs to be considered". Company 1 also suggested a review of the keywords classification and the development of a more user-friendly EPIs database. More suggestions are presented in step 4.2 (see section 3.4.2 – Improvement of the guide).

The results presented by the evaluation of Company 1 provide evidence that the guide and the database developed can support the selection of EPIs to monitor the environmental performance of products, confirming the hypothesis presented in this project.

Some limitations of research can be traced from the results obtained. The first one is about the importance of step 1, assuming that the success during the selection of EPIs by Company 1 can be partly attributed to the fact that the company had already defined some environmental objectives in product development. In addition, a limitation of the presented case study is it did not covered the application of step 5, and there is no results about how the selected EPIs were implemented within the company and how they effectively supported the improvement of product's environmental performance.

Another identified limitation is that as the indicators are extracted directly from the literature, sometimes they are not ready to be used and need to be carefully understood, decreasing the time-efficiency of using the database. Each author provides some specific EPIs, from different approaches (Cleaner Production, Design for Disassembly, Sustainable Development for Industry, Design for Recycling, etc.) and measurement types. A deeper study on the similarities and differences between these indicators and the inter-relation among them is indicated for future researches.

3.4.2 Improvement of the guide

This activity consisted in the improvement of the guide conducted after the case study at Company 1. In order to reach this goal, all the opportunities for improvement of the guide identified were presented, the opportunities for improvement were selected according to defined criteria, and the selected opportunities for improvement were applied and the guide was improved. The results of each sub-activity are now presented.

After conducting the application and evaluation of the developed guide at Company 1, some discussions regarding its results were performed in the section of Engineering Design and Product Development at DTU, in which professors and PhD students participated. From the results of the case study evaluation and these discussions, it was identified some opportunities for improvement of the guide.

The opportunities for improvement are presented below, in Table 2. They are divided into improvements for the guide and for the database (Product-related EPIs Database):

Table 2 - Opportunities for improvement gathered in Case study 1 and discussions at DTU

Code	Opportunities for improvement of the guide	Source
General observations		
I	Create examples throughout the guide to make the theoretical explanation understandable.	Case study 1
II	As the selection process takes a lot of time, the guide could suggest that experts from different areas should be gathered to discuss.	Case study 1
III	Provide in the guide information of how long it takes to be applied.	Case study 1
IV	Adapt the guide into a normative language for the companies in all steps, using less academic terms and telling the reader very clearly what they should focus on and carry out. Also use more figures to illustrate the steps, as figures presented in the support material.	Discussions at DTU
V	Adapt the name of the steps into a normative or prescriptive language.	Discussions at DTU
VI	Create a new section in the chapter "Environmental Performance Indicators: Backgrounds and Motivation", explaining how the company can use EPIs in its work.	Discussions at DTU
VII	Create a "top-list" of the most used units of measurement between the indicators.	Discussions at DTU
Observations for specific steps of the guide		
VIII	**Step 1:** Emphasize the importance of this step, since it depends on the knowledge of the company of its environmental gaps.	Case study 1
IX	**Step 1:** Provide more examples of tools for environmental performance evaluation.	Case study 1
X	**Step 5:** Explain better when a new selection is required.	Case study 1
XI	**Step 1:** Use a more normative language in this step.	Discussions at DTU
XII	**Step 3:** Use a more normative language, sharpening this step.	Discussions at DTU
Code	Opportunities for improvement of Product-related EPIs Database	Source
General observations		
XIII	Review how to filter in the database, by marking "X", to make sure that it is uniform; and creating a new selection tool for the filters, developing a more user-friendly database.	Case study 1
XIV	Provide an indication of which part of the development phase the indicator needs to be considered.	Case study 1
XV	Adapt an easier language to explain the EPIs (technical explanation), since not all people have a mathematical understanding.	Case study 1
XVI	Potential health and safety related aspects could be added in future research.	Case study 1
XVII	Review the classification according to the "Keywords", since some of them are not clear. For instance, review the keywords classification for "Packaging" and "Energy source".	Case study 1

…conclusion

XVIII	Provide examples for each indicator to make them clearer.	Case study 1
XIX	Create a field for the company mark the selected indicators, providing a general overview of this set.	Case study 1
XX	Create a new field for the customization of EPIs, where the company can fill with its company specific indicators.	Case study 1
XXI	Creating a warning system if the user hasn't selected indicators of some life cycle stage.	Case study 1
XXII	Provide an analysis of the selected indicators, indicating the percentage of indicators covering each life cycle stage, and also based in the other criteria.	Case study 1 and Discussions at DTU
XXIII	Create a spreadsheet with the selected EPIs, classified within the criteria (Keywords, Environmental Aspects, Life Cycle Stage and Type of measure)	Case study 1
XXIV	Review the classification according to the "Keywords", reducing the number of keywords, and relating "Recyclability" to incompatible and different materials, for instance.	Case study 1
XXV	Show better what exactly each indicator measures.	Case study 1
XXVI	Reclassify the indicators according to Life Cycle Stage.	Case study 1
XXVII	Review indicators which are very specific, trying to consolidate them with other more generic.	Case study 1
XXVIII	Relate the keywords "Disassembly" and "Maintenance".	Case study 1
XXIX	Provide a graphical analysis of the selected indicators according to the life cycle stages.	Discussions at DTU
XXX	Classify the EPIs according to customer's needs, defining what information could be given to each stakeholder.	Discussions at DTU
XXXI	Classify the EPIs according to the maturity level of a company in applying ecodesign practices.	Discussions at DTU
XXXII	Verify the relations between the indicators and create classes.	Discussions at DTU
XXXIII	Verify the most used variables in the indicators, analyzing them and providing a database of variables, so the company can use it to calculate the indicators.	Discussions at DTU
XXXIV	Adopt levels to classify the keywords, according to product-related aspects; the context of application of the product; and issues to be considered when developing it, such as legislation.	Discussions at DTU
XXXV	Identify the most generic indicators, which can be applied to all industry sectors.	Discussions at DTU
Observations for specific indicators		
XXXVI	Review the indicators 91, 92, 93, 94, 95, 96, 97, 98, 99, 100 and 101, and classify them as "Pre-manufacturing".	Case study 1
XXXVII	Improve the description of the indicators 96, 97, 98, 99, 100 and 101.	Case study 1
XXXVIII	Review the explanation of indicators 64, 76, 109 and 132.	Case study 1

All the opportunities for improvement presented in the table above were evaluated and subsequently selected to be applied in the guide. To evaluate each of them, two main selection criteria were used. The selection criteria were:

- Alignment with the scope of the research project: this criterion tries to identify if the opportunity for improvement is aligned to the scope and objectives of the research; and

- Demand of efforts to accomplish the improvement: this criterion evaluates the demand of efforts to accomplish the improvement, considering the size and timeline of the project.

After evaluating each opportunity for improvement, a set of improvements to be applied were defined. The improvements identified in the last task and their evaluation according to the criteria defined above are presented in Table 3:

Table 3 – Evaluation of the opportunities for improvement according to (1) the alignment with the scope of the research project and (2) demand of efforts to accomplish the improvement

Code	Opportunities for improvement of the guide	Source	Will this improvement be applied?	Selection criteria
General observations				
I	Create examples throughout the guide to make the theoretical explanation understandable.	Case study 1	No[11]	Demand efforts to accomplish the improvement
II	As the selection process takes a lot of time, the guide could suggest that experts from different areas should be gathered to discuss.	Case study 1	Yes	Alignment with the scope of research project
III	Provide in the guide information of how long it takes to be applied.	Case study 1	Yes	Alignment with the scope of research project
IV	Adapt the guide into a normative language for the companies in all steps, using less academic terms and telling the reader very clearly what they should focus on and carry out. Also use more figures to illustrate the steps, as figures presented in the support material.	Discussions at DTU	Yes	Alignment with the scope of research project
V	Adapt the name of the steps into a normative or prescriptive language.	Discussions at DTU	Yes	Alignment with the scope of research project
VI	Create a new section in the chapter "Environmental Performance Indicators: Backgrounds and Motivation", explaining how the company can use EPIs in its work.	Discussions at DTU	Yes	Alignment with the scope of research project
VII	Create a "top-list" of the most used units of measurement between the indicators.	Discussions at DTU	No[12]	Alignment with the scope of research project

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[11] Creating consisting examples would evolve more and deeper studies regarding the application of the guide and the implementation of EPIs.

[12] The study of recurrent units of measurement depends on deeper studies regarding implementation of EPIs in companies.

…continuation

Observations for specific steps of the guide				
VIII	**Step 1:** Emphasize the importance of this step, since it depends on the knowledge of the company of its environmental gaps.	Case study 1	Yes	Alignment with the scope of research project
IX	**Step 1:** Provide more examples of tools for environmental performance evaluation.	Case study 1	No[13]	Alignment with the scope of research project
X	**Step 5:** Explain better when a new selection is required.	Case study 1	Yes	Alignment with the scope of research project
XI	**Step 1:** Use a more normative language in this step.	Discussions at DTU	Yes	Alignment with the scope of research project
XII	**Step 3:** Use a more normative language, sharpening this step.	Discussions at DTU	Yes	Alignment with the scope of research project
	Opportunities for improvement of Product-related EPIs Database	**Source**		
	General observations			
XIII	Review how to filter in the database, by marking "X", to make sure that it is uniform; and creating a new selection tool for the filters, developing a more user-friendly database.	Case study 1	Yes	Alignment with the scope of research project
XIV	Provide an indication of which part of the development phase the indicator needs to be considered.	Case study 1	No[14]	Alignment with the scope of research project

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[13] Step 1 is not just dependent on environmental performance evaluation using tools, the company can trace its environmental priorities from different drivers.

[14] This suggestion would evolve deeper studies regarding EPIs and product development process management, which is out of the scope of this research.

…continuation

XV	Adapt an easier language to explain the EPIs (technical explanation), since not all people have a mathematical understanding.	Case study 1	No[15]	Demand efforts to accomplish the improvement
XVI	Potential health and safety related aspects could be added in future research.	Case study 1	No[16]	Alignment with the scope of research project
XVII	Review the classification according to the "Keywords", since some of them are not clear. For instance, review the keywords classification for "Packaging" and "Energy source".	Case study 1	Yes	Alignment with the scope of research project
XVIII	Provide examples for each indicator to make them clearer.	Case study 1	No[17]	Alignment with the scope of research project; Demand efforts to accomplish the improvement
XIX	Create a field for the company mark the selected indicators, providing a general overview of this set.	Case study 1	Yes	Alignment with the scope of research project
XX	Create a new field for the customization of EPIs, where the company can fill with its company specific indicators.	Case study 1	Yes	Alignment with the scope of research project
XXI	Creating a warning/information system if the user hasn't selected indicators of some life cycle stage.	Case study 1	Yes	Alignment with the scope of research project

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[15] This suggestion would evolve deeper studies on the use and on the similarities and differences between these indicators.

[16] It is out of the objective and scope of this research.

[17] Creating consisting examples would evolve more and deeper studies regarding the application of the guide and the implementation of EPIs.

… continuation

XXII	Provide an analysis of the selected indicators, indicating the percentage of indicators covering each life cycle stage, and also based in the other criteria.	Case study 1 and Discussions at DTU	Yes	Alignment with the scope of research project
XXIII	Create a spreadsheet with the selected EPIs, classified within the criteria (Keywords, Environmental Aspects, Life Cycle Stage and Type of measure)	Case study 1	Yes	Alignment with the scope of research project
XXIV	Review the classification according to the "Keywords", reducing the number of keywords, and relating "Recyclability" to incompatible and different materials, for instance.	Case study 1	Yes	Alignment with the scope of research project
XXV	Show better what exactly each indicator measures.	Case study 1	Yes	Alignment with the scope of research project
XXVI	Reclassify the indicators according to Life Cycle Stage.	Case study 1	Yes	Alignment with the scope of research project
XXVII	Review indicators which are very specific, trying to consolidate them with other more generic.	Case study 1	Yes	Alignment with the scope of research project
XXVIII	Relate the keywords "Disassembly" and "Maintenance".	Case study 1	Yes	Alignment with the scope of research project
XXIX	Provide a graphical analysis of the selected indicators according to the life cycle stages.	Discussions at DTU	Yes	Alignment with the scope of research project

…continuation

XXX	Classify the EPIs according to customer's needs, defining what information could be given to each stakeholder.	Discussions at DTU	No[18]	Alignment with the scope of research project
XXXI	Classify the EPIs according to the maturity level of a company in applying ecodesign practices.	Discussions at DTU	No[19]	Alignment with the scope of research project
XXXII	Verify the relations between the indicators and create classes.	Discussions at DTU	Yes	Alignment with the scope of research project
XXXIII	Verify the most used variables in the indicators, analyzing them and providing a database of variables, so the company can use it to calculate the indicators.	Discussions at DTU	No[20]	Alignment with the scope of research project
XXXIV	Adopt levels to classify the keywords, according to product-related aspects; the context of application of the product; and issues to be considered when developing it, such as legislation.	Discussions at DTU	No[21]	Alignment with the scope of research project
XXXV	Identify the most generic indicators, which can be applied to all industry sectors.	Discussions at DTU	No[22]	Alignment with the scope of research project

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[18] This study is out of the objective and scope of this research.

[19] This study is out of the objective and scope of this research.

[20] The study of recurrent variables depends on deeper studies regarding implementation of EPIs in companies.

[21] This suggestion would evolve deeper studies regarding EPIs and product development process management, which is out of the scope of this research.

[22] This suggestion would evolve deeper studies on the use and implementation the guide and these indicators.

…conclusion

Observations for specific indicators				
XXXVI	Review the indicators 91, 92, 93, 94, 95, 96, 97, 98, 99, 100 and 101, and classify them as "Pre-manufacturing".	Case study 1	Yes	Alignment with the scope of research project
XXXVII	Improve the description of the indicators 96, 97, 98, 99, 100 and 101.	Case study 1	Yes	Alignment with the scope of research project
XXXVIII	Review the explanation of indicators 64, 76, 109 and 132.	Case study 1	Yes	Alignment with the scope of research project

The selected opportunities for improvement were grouped into seven tasks, as proposed in Table 4 below:

Table 4 – Opportunities for improvements grouped in activities

Code	Opportunities for improvement of the guide	Tasks
IV	Adapt the guide into a normative language for the companies in all steps, using less academic terms and telling the reader very clearly what they should focus on and carry out. Also use more figures to illustrate the steps, as figures presented in the support material.	Task 4.1.1.1: Language and presentation
V	Adapt the name of the steps into a normative or prescriptive language.	
VI	Create a new section in the chapter "Environmental Performance Indicators: Backgrounds and Motivation", explaining how the company can use EPIs in its work.	Task 4.1.1.2: New section
II	As the selection process takes a lot of time, the guide could suggest that experts from different areas should be gathered to discuss.	
III	Provide in the guide information of how long it takes to be applied.	
VIII	**Step 1:** Emphasize the importance of this step, since it depends on the knowledge of the company of its environmental gaps.	Task 4.1.1.3: Improve steps of the guide
IX	**Step 1:** Use a more normative language in this step.	
XII	**Step 3:** Use a more normative language, sharpening this step.	
X	**Step 5:** Explain better when a new selection is required.	
Code	Opportunities for improvement of Product-related EPIs Database	Tasks
XIII	Review how to filter in the database, by marking "X", to make sure that it is uniform; and creating a new selection tool for the filters, developing a more user-friendly database.	Task 4.1.1.4: Improve functions in the spreadsheet
XIX	Create a field for the company mark the selected indicators, providing a general overview of this set.	
XXI	Creating a warning/information system if the user hasn't selected indicators of some life cycle stage.	
XX	Create a new field for the customization of EPIs, where the company can fill with its company specific indicators.	
XXII	Provide an analysis of the selected indicators, indicating the percentage of indicators covering each life cycle stage, and also based in the other criteria.	
XXIX	Provide a graphical analysis of the selected indicators according to the life cycle stages.	
XXIII	Create a spreadsheet with the selected EPIs, classified within the criteria (Keywords, Environmental Aspects, Life Cycle Stage and Type of measure)	
XVII	Review the classification according to the "Keywords", since some of them are not clear. For instance, review the keywords classification for "Packaging" and "Energy source".	Task 4.1.1.5: Review the classification according to "Keywords"
XXIV	Review the classification according to the "Keywords", reducing the number of keywords, and relating "Recyclability" to incompatible and different materials, for instance.	
XXV	Show better what exactly each indicator measures.	
XXVII	Review indicators which are very specific, trying to consolidate them with other more generic.	
XXVIII	Relate the keywords "Disassembly" and "Maintenance".	
XXXII	Verify the relations between the indicators and create classes.	

… conclusion

XXVI	Reclassify the indicators according to Life Cycle Stage.	Task 4.1.1.6: Review the classification according to "Life Cycle Stages"
XXXVI	Review the indicators 91, 92, 93, 94, 95, 96, 97, 98, 99, 100 and 101, and classify them as "Pre-manufacturing".	
XXXVII	Improve the description of the indicators 96, 97, 98, 99, 100 and 101.	Task 4.1.1.7: Review specific indicators
XXXVIII	Review the explanation of indicators 64, 76, 109 and 132.	

The main goal of the proposed tasks was to implement the selected opportunities for improvement into the guide and into the Product-related EPIs Database. They are described below, where it is presented the specific goal of each activity and how it should be performed to reach this goal.

Tasks for improvement of the guide:

Task 4.1.1.1: Language and presentation

This task aims to adapt the language of the guide into a normative approach. The normative language is important to make the steps and suggestions of the guide even more direct and clearer, as it establishes rules to be followed. This change helps in telling the readers exactly what they should focus on and carry out. Also, the use of more figures and/or diagrams in the text can help in explaining better each step.

The following guidelines lead this task:

- Adapt all guide into a normative language;
- Adapt the layout and use more figures to explain each step; and
- Adapt the name of the steps into a uniform normative language.

Task 4.1.1.2: New section

This task aims to add a new section explaining how a company can use the EPIs in its day-by-day work. The new section is important to situate the reader when and how he should apply the guide and use EPIs to improve the environmental performance of his products. Also, information like how experts from different areas can support the selection of EPIs and how long the guide takes to be applied is provided in the section.

Task 4.1.1.3: <u>Improve the steps of the guide</u>

This task aims to improve the steps 1, 3 and 5, in order to let them clearer and normative to the readers, according to the opportunities for improvement presented before. To reach this task, discussions with experts at DTU were performed, and the structure of steps was reviewed.

Activities for improvement of Product-related EPIs Database:

Task 4.1.1.4: <u>Improve functions in the spreadsheet</u>

This task aims to adapt the Product-related EPIs in a more user-friendly version, by means of:

- Creating an introduction to the database, indicating how it should be used;
- Creating a field to the user marks the selected indicators;
- Create a spreadsheet with the selected indicators, providing an analysis of them both graphical and quantitative according to the classification criteria: Life Cycle Stages and Environmental Aspects;
- Create a field to the user fills with the selected and customized indicators.

The improvements in the database according to these guidelines provide a better interaction between the user and the database, and also an overview of the selected indicators.

Task 4.1.1.5: <u>Review the classification according to "Keywords"</u>

This task aims to review and reduce the number of keywords used to classify the EPIs, in order to make the selection process even easier and find correlations between the keywords and the other classification criteria, creating classes of EPIs. The following guidelines lead this task:

- Define a new set of keywords;
- Identify a correlation between the keywords and the criteria Life Cycle Stage and Environmental Aspects;
- Reclassify the indicators according to the new set of keywords.

Task 4.1.1.6: <u>Review the classification according to "Life Cycle Stages"</u>

This task aims to review the classification of EPIs according to "Life Cycle Stages" by using the new classification based on the "Keywords", also reviewing the indicators 91, 92, 93, 94, 95, 96, 97, 98, 99, 100 and 101.

Task 4.1.1.7: <u>Review specific indicators</u>

This task aims to review the explanation of some specific indicators, as presented in the opportunities for improvement:

- Improve the description of the indicators 96, 97, 98, 99, 100 and 101;
- Review the explanation of indicators 64, 76, 109 and 132.

Some of the non-selected opportunities for improvement which are not aligned to the scope of this research project can be explored in future research, as presented in the Table 5 below:

Table 5 – Opportunities of improvement for future research

Code	Opportunities of improvement for future research
VII	Create a "top-list" of the most used units of measurement between the indicators.
XIV	Provide an indication of which part of the development phase the indicator needs to be considered.
XVI	Potential health and safety related aspects could be added in future research.
XXX	Classify the EPIs according to customer's needs, defining what information could be given to each stakeholder.
XXXI	Classify the EPIs according to the maturity level of a company in applying ecodesign practices.
XXXIII	Verify the most used variables in the indicators, analyzing them and providing a database of variables, so the company can use it to calculate the indicators.
XXXIV	Adopt levels to classify the keywords, according to product-related aspects; the context of application of the product; and issues to be considered when developing it, such as legislation.
XXXV	Identify the most generic indicators, which can be applied to all industry sectors.

The guide was improved based on the proposed tasks above. It is now described how each task was applied. They are presented according to the chronological order of application, as there is a dependency between them:

Task 4.1.1.5: Review the classification according to "Keywords"

This task aimed to review and reduce the number of keywords used to classify the EPIs, in order to further facilitate the selection process, re-defining classes of EPIs. To perform this activity, an analysis of the old set of keywords was conducted.

During the analysis, the old set of keywords was firstly classified according to environmental aspects or activities during life cycle, as shown in table 6 below. This classification enabled the establishment of relations between the set of keywords and the classification criteria already used Life Cycle Stages and Environmental Aspects. The keyword "Biodegradable materials" is a material type related to the environmental aspect "Material", for instance, while "Packaging" is an activity related to the life cycle stage "Distribution and Packaging".

Table 6 – Classification of the old set of keywords according to environmental aspects or activity during life cycle

Old Keywords	Type
Acidification;	Environmental impact (related to one environmental aspect)
Air emissions;	Environmental aspect
Assembly;	Activity during life cycle
Auxiliary materials;	Environmental aspect
Biodegradable materials;	Environmental aspect
By-products;	Environmental aspect
Co-generation of energy;	Environmental aspect
Defective products;	Environmental aspect (related to Solid waste)
Disassembly;	Activity during life cycle
End-of-life;	Activity during life cycle
Energy loss;	Environmental aspect
Energy source;	Environmental aspect
Environmental Label;	Activity during life cycle
Eutrophication;	Environmental impact (related to one environmental aspect)
Failure;	Activity during life cycle

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Greenhouse gases;	Environmental impact (related to one environmental aspect)
Hazardous materials;	Environmental aspect
Hazardous waste;	Environmental aspect
Identification of materials;	Activity during life cycle
Instructions to users;	Activity during life cycle
Intensity of use;	Activity during life cycle
Land area;	Environmental aspect
Landfill;	Activity during life cycle
Law and regulations;	Activity during life cycle
Lifetime;	Activity during life cycle
Maintenance;	Activity during life cycle
Material consumption;	Environmental aspect
Material recovery;	Activity during life cycle
Material selection;	Activity during life cycle
Noise;	Environmental aspect
Ozone depletion;	Environmental impact (related to one environmental aspect)
Packaging;	Activity during life cycle
Photochemical ozone creating potential;	Environmental impact (related to one environmental aspect)
Radiation;	Environmental aspect
Recyclability;	Activity during life cycle
Recycled materials;	Environmental aspect
Reliability;	Activity during life cycle
Remanufacture;	Activity during life cycle
Renewable materials;	Environmental aspect
Residual products;	Environmental aspect (related to Solid waste)
Reuse;	Activity during life cycle
Solid waste;	Environmental aspect
Source of water;	Environmental aspect
Suppliers;	Activity during life cycle
Transportation;	Activity during life cycle
Waste water;	Environmental aspect
Water reuse;	Environmental aspect
Water use;	Environmental aspect

After this re-classification, a new set of keywords was defined. Some keywords were created and some excluded, in order to make the set smaller, more suitable and simple, supporting in a better way the selection of EPIs. According to the classification presented above, the keywords had different reviews. The set of keywords related to environmental aspects was used to complement the criterion Environmental Aspects, as they define subclasses of each aspect. For

instance, the keywords "Source of waste", "Solid waste amount" and "Hazardous waste" are subclasses of the environmental aspect Solid waste (see figure 12).

The set of keywords related to activities during life cycle were reviewed and related to the ecodesign operational practices, as explained later in this section, in Task 4.1.1.6.

The old set was composed by 48 keywords, and the new one, containing the subclasses the environmental aspects, contain just 30. The reduction rate is 37,5%, and it helps the reader when applying the pre-selection, as the number of options for each environmental aspect is smaller.

To implement this new set in the database of EPIs, the subclasses were included in the columns of environmental aspects. In the column "Energy", for example, you can find the subclasses "Source of energy", "Renewable energy", "Energy consumption" and "Co-generation of energy". This new classification can be seen in Appendix F (Systematization of environmental performance indicators).

During this activity, and using the Excel filter for each subclass, some indicators were reviewed and consolidated. From this review, some EPIs were grouped with other and excluded from the database. The Product-related EPIs Database comprises now 261 environmental performance indicators.

The environmental aspect "Others" was replaced by "Energy loss", considering that this aspect contain the subclasses "Radiation", "Noise", "Heat", "Vibration" and "Light". Also, the aspect called "Energy consumption" was renamed as "Energy", assuming that "Energy consumption" is a subclass of this aspect.
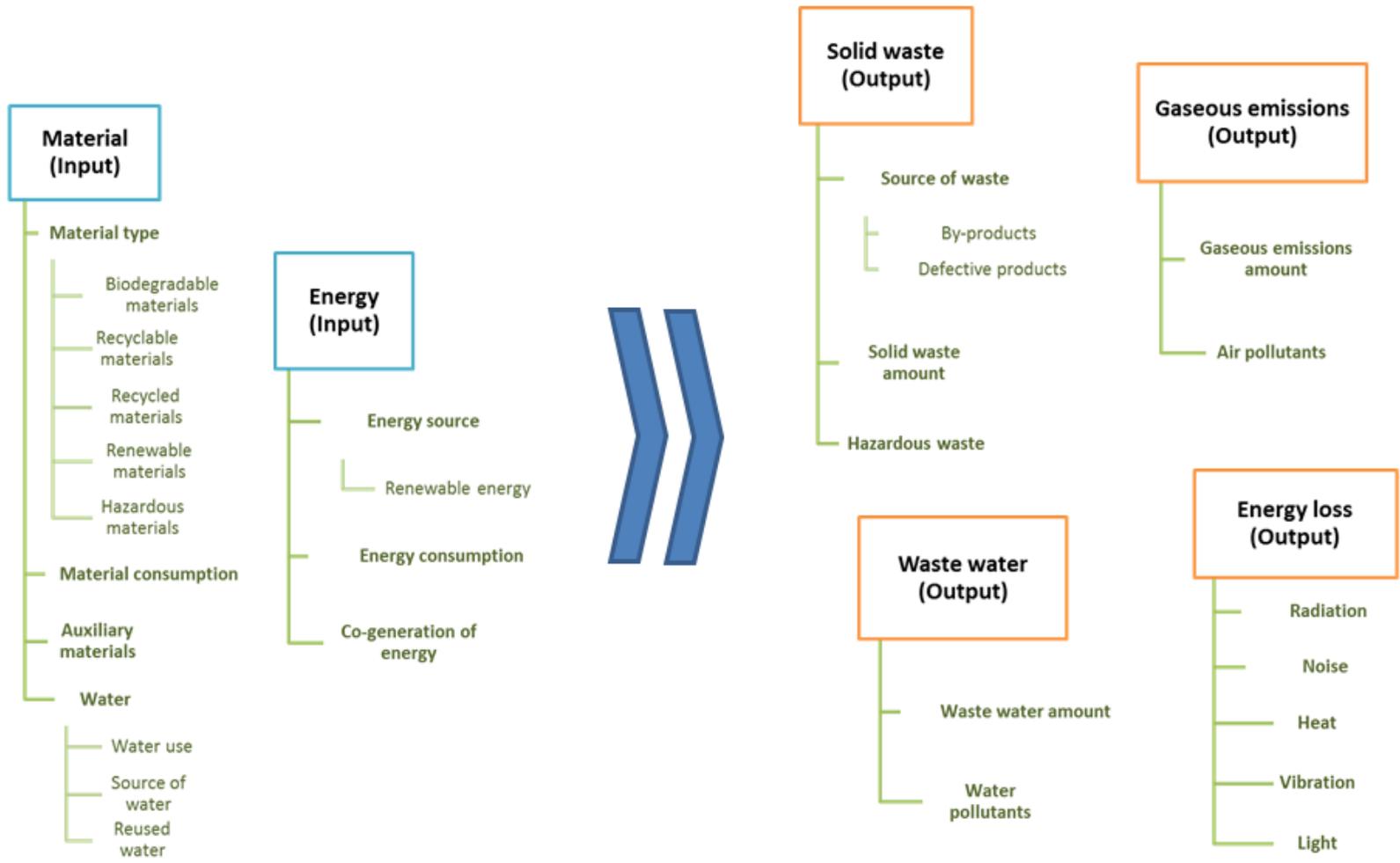
Figure 12: Environmental aspects and their subclasses

Task 4.1.1.6: <u>Review the classification according to "Life Cycle Stages"</u>

As explained above, the set of keywords related to activities during life cycle were linked to the ecodesign operational practices. These activities were classified according to the life cycle stage in which ecodesign tries to improve the environmental performance. For instance, the old keyword "Disassembly" was related to the operational practice "Facilitating Disassembly", and this practice is linked to the life cycle stage "End-of-Life".

Then, for each life cycle stage was defined a list of related ecodesign operational practices, as shown below. The classification according to the ecodesign operational practices, which was before a classification criteria, was reviewed and now merged into the classification according life cycle stage, as they are objectives for environmental improvement related to product's life cycle stages. It was used the levels of strategies and guidelines of ecodesign operational practices of EcoM2. The column of operational practices in the spreadsheet was included in the columns of life cycle stages according to the classification below.

A new category was created, "General activities", which contain activities which go through all product life cycle, and can influence all of them. Just the created subcategory "Laws and regulations" doesn't correspond to any ecodesign operational practice from EcoM2. The new classification can be seen in Appendix F (Systematization of environmental performance indicators).

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.

Task 4.1.1.7: <u>Review specific indicators</u>

The review of the indicators 64, 76, 96, 97, 98, 99, 100, 101, 109 and 132 was conducted improving the description of them. Some of these indicators are used to calculate others, and the explanation of all of them was improved. For instance, the indicator "Recycled Fraction" (code 100) is calculated by using the indicators "Re-assembled fraction" (code 97), and "Re-manufacturing Fraction" (code 98).

Task 4.1.1.1: <u>Language and presentation</u>

This task aimed to adapt the language of the guide into a normative approach, telling the readers exactly what they should focus on and carry out. The text of the guide was then reviewed, and it was rewritten in a more normative language, trying to tell directly to the reader what he needs to do to implement each step.

In addition, it was used more diagrams to explain and clarify each step, based on the structure presented in the support material. The names of the steps were normalized uniformly into a normative language, containing the main activity of each step.

Task 4.1.1.2: <u>New section</u>

As proposed, a new section was created in the guide, called "How can you use EPIs in your work?". The objective of this section is to show to the reader why and how he can use EPIs in his/her company. The section was written after discussions with ecodesign experts at DTU and with knowledge from the literature review. Also, this section explains how the guide can help the reader in this process, how it should be used and how long it could takes to be applied.

Task 4.1.1.3: <u>Improve the steps of the guide</u>

This activity aimed to improve mainly the steps 1, 3 and 5, in order to let them clearer and normative to the readers. All the steps of the guide were improved, especially these ones. To perform this activity, the diagrams used in the support material representing the inputs, activities and outputs of each step were used in the text, and the language was adapted to show better what the reader needs to carry on.

An important improvement was regarding step 1, as it was identified by Company 1 as a fundamental and difficult step to perform when selecting EPIs. It was better defined what should be environmental priorities and objectives in product development, and how to establish than based on market requirements or environmental impacts identified in product's life cycle.

Task 4.1.1.4: <u>Improve functions in the spreadsheet</u>

This task aimed to adapt the Product-related EPIs in a more user-friendly version, supporting the user when applying the guide. All the proposed guidelines for this task were followed. Besides the record and systematization of all EPIs found in the literature, the database contains now three new tabs, which presents instructions on how to use the database, and overview of selected EPIs, and a blank worksheet where the company can insert the full set of selected indicators. The database has this new structure:

- Introduction: explains how to use and navigate in the database;
- Product-related EPIs: contains all the EPIs stored in the database. This tab aims to support the steps 2 and 3 of the guide in pre-selecting and selecting indicators. Apply the filters according to life cycle stages, environmental aspects and type of measure to find subsets of EPIs, and then select the most suitable indicators marking an "X" in the field "Selection Tool";
- Selected EPIs and Analysis: provides an overview of the set of selected indicators to support step 4 of the guide, and also a quantitative analysis of this set according to life cycle stages and environmental aspects;
- Full set of EPIs: field where the user can fill with selected, customized and/or created EPIs from step 4 of the guide. This full set should be ready to be implemented in step 5.

The improved version of the guide is presented in Appendix G (Guide to support the selection of product-related EPIs), and the digital database is available on web[23].

3.4.3 Case study 2

Company 2 is an American multinational company and one of the world's leading manufactures in the sector it operates. The headquarters in South America are located in Brazil, which started its production activities in 1973. The company operates in two plants, where the products are developed, produced and assembled. Its products are inserted in a competitive market where efficiency and reduced costs are fundamental requirements.

The company is interested in applying ecodesign as a competitive and innovative approach. The Ecodesign Maturity Model (EcoM2) is being applied in its initial phases, and the company is now getting knowledge on ecodesign practices. The workshop and the evaluation questionnaire were presented to engineering supervisors which are interested in add environmental issues into PDP.

Two meetings were conducted with the employees in one day. The participants of the case study were the engineering director, product developers, project manager and quality and environmental systems supervisor. In the first meeting, the research project and the guide was presented to them in about 1 hour. The company has shown interest in applying the guide, as it was an opportunity for effective ecodesign implementation. During the second meeting the five-step approach of the guide was applied, which lasted about 3 hours and a half. The evaluation questionnaire was applied in the end of the last meeting.

Company 2 has shown difficulties in the definition of environmental priorities and objectives in step 1 of the guide. The company is certified with ISO 14001, and it has an environmental management system focused in the manufacturing process, but it does not have an evaluation of environmental performance throughout all products' life cycle. They don't have knowledge on life cycle environmental impacts, but they now clearly which are market requirements for their products, which is also an important input for performing step 1.

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[23] Available at: http://www.portaldeconhecimentos.org.br/index.php/por/content/view/full/16361 .

The participants then decided to focus on pre-manufacturing, manufacturing and use and maintenance life cycle stages to start the EPIs selection assuming that these stages could cause most of the environmental impacts and that use and maintenance stage could represent requirement from clients, but they had no clear environmental objectives for product development. It was the first attempt to go for step 2 and select indicators from the database.

In this first selection process, they got knowledge on how to think about products' life cycle and its environmental impacts. As they didn't have clear objectives to select options between the classification criteria, they analyzed all of them, and then they started to think about life cycle stages and environmental aspects that could represent the most relevant environmental impacts. In this phase, they used mainly the criteria life cycle stages and environmental aspects, and the subclasses of each one has shown very useful to focus in specific classes, such as "minimizing energy consumption during pre-production and production" as a subclass of pre-manufacturing and manufacturing stages, and "energy consumption" as a subclass of energy (environmental aspect). During this first selection attempt, they selected 50 EPIs.

It was a very interesting experiment for them, as in the begging they identified several potential EPIs to be used. But they realized that 50 EPIs could be a high number of selected EPIs, and that they could not be implemented like that. They recognized the importance of the step one, and that the selection process would be much easier if they have clear environmental objectives defined.

Then, they decided to go back to step 1 and define around three environmental objectives to perform another selection. As energy consumption is an important environmental aspect for their products, as it is a market requirement, they focused in minimizing this aspect, mainly in the pre-manufacturing, manufacturing and use phases.

Once defined this environmental objective, and focusing on absolute measures, they performed steps 2 (Pre-selection of EPIs), 3 (Selection of EPIs) and 4 (Customization and Creation of EPIs). Step 2 and 3 resulted in 10 EPIs marked with as 'X' in the database, which were carefully evaluated to be selected or not. The main discussions when selecting indicators from the database were regarding how to calculate each one of them, if it would be possible within the company or not. From this process 6

EPIs were selected. The distribution of selected EPIs per life cycle stages and environmental aspects are presented in figures 13 and 14. To perform these steps, the tabs "Product-related EPIs" and "Selected indicators and Analysis" in the digital database were used.

Selected EPIs per life cycle stage (Company 2)

Life cycle stage	Count
Pre-manufacturing	2
Manufacturing and Design	2
Distribution and Packaging	0
Use and maintenance	2
End-of-life	0
General Activities	3
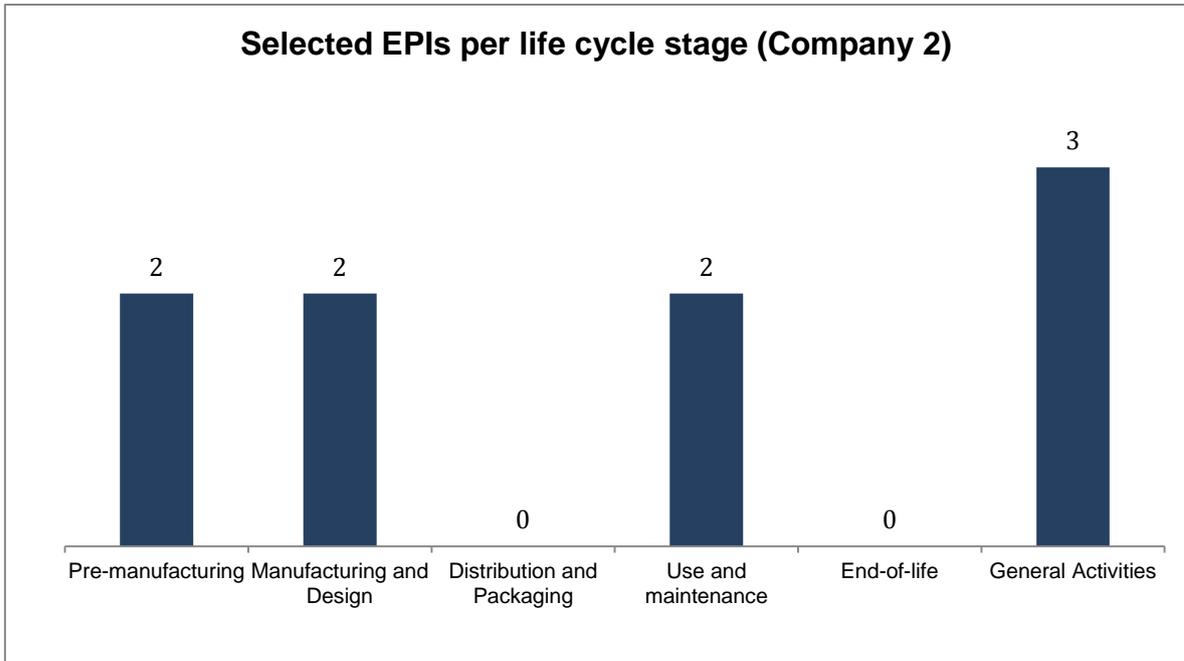
Figure 13: Number of selected EPIs for each life cycle stage at Company 2[24]

Selected EPIs per environmental aspect (Company 2)

Environmental aspect	Count
Materials	2
Energy	6
Solid waste	0
Waste water	0
Gaseous Emissions	1
Energy Loss	0
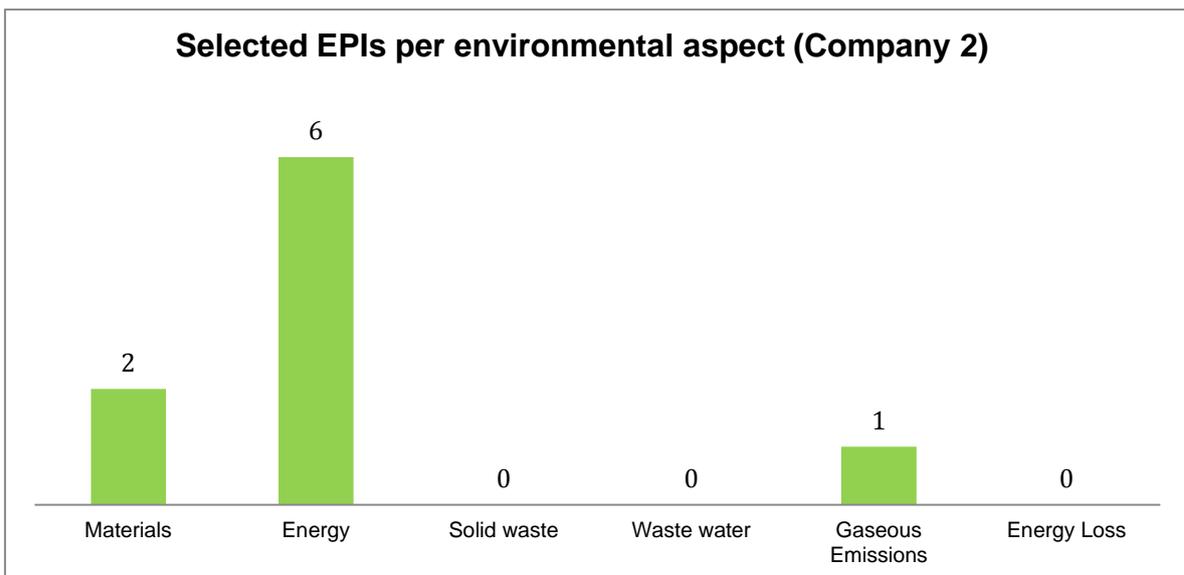
Figure 14: Number of selected EPIs for each environmental aspect at Company 2[24]

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[24] The analysis includes overlaps, since some indicators are classified according to more than one option for each criterion.

When performing step 4, 2 EPIs were adapted to relative measures, 1 was customized and 1 was deleted. In the end, they had selected 5 indicators to monitor energy consumption, which were compiled in the last tab of the digital database, "Full set of EPIs".

Step 5 was not performed during the workshop, as implementation of EPIs is a longer process. The full set of EPIs should then be reviewed according to others environmental objectives and validated by different stakeholders of the company and high management.

During the application of the guide, the employees recognized the importance of monitoring environmental performance of all products' life cycle, and they demonstrated interest in conduct deeper studies on environmental impacts caused by their products. They tested on practice how important is the definition of specific objectives when selecting performance indicators, and how it influences in the time-efficiency of this process.

The evaluation questionnaire was applied immediately at the end of the workshop, and the results are presented in figure 15:
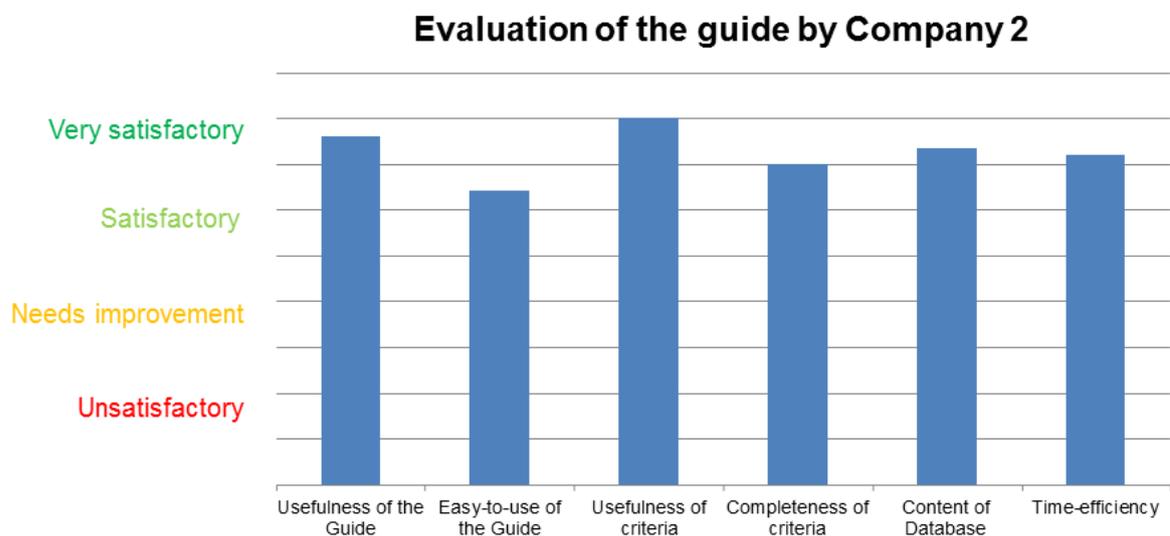
Figure 15: Evaluation of the developed Guide and Product-related EPIs Database by Company 1

Company 1 evaluated as "Satisfactory" and "Very satisfactory" most of the evaluation criteria. None of them obtained "Unsatisfactory" answers. The company considered

the database as a contribution in the definition of new indicators and the customization of the existing ones. It provides evidence that the new version of guide and the database developed supported the selection of EPIs to monitor the environmental performance of products, as proposed by the hypothesis. Company 1 also provided some comments and suggestions for improvement to the guide. Regarding the easy-to-use of the guide, the employees suggested that the database could be translated to Portuguese, and a better explanation on how to use the database could be given.

The results presented by the evaluation of Company 2 provide evidence that the guide and the database developed can support the selection of EPIs to monitor the environmental performance of products, confirming the hypothesis presented in this project. It was emphasized the importance of step 1, and how it leads all the selection of performance indicators. Also, Company 2 evaluated the selection of EPIs a long process that requires dedication to be effectively accomplished.

Some limitations of research can be traced from the results obtained. As Company 2 is in the initial phases of ecodesign implementation this step was the most difficult to perform, and still need to be reviewed. Also, there is the same limitation of case study 1, in which case study 2 did not covered the application of step 5, and there is no results about how the selected EPIs were implemented within the company.

3.4.4 Discussions

This section presents discussions regarding the application of the guide in Company 1 and its improvement and the application in Company 2, focusing on differences and similarities between the application in these companies and the EPIs selected for each one.

An important difference between the applications of the guide in companies 1 and 2 was the performance of step 1. Company 1 had defined environmental objectives for product development, and even though step 1 was already accomplished, they emphasized the importance of this step. On the other hand, Company 2 found several difficulties when trying to apply step 1. It can be attributed to the maturity level on ecodesign of each company.

Company 1 has been working with ecodesign over the last 20 years. Company 2 is in the initial phases of ecodesign application, and they are still getting knowledge on

this approach. The organization has not defined yet specific objectives for the ecodesign program or environmental strategic goals for products' life cycle. While step 1 was fundamental for the successful selection of EPIs in Company 1, this step acted as a motivation for Company 2 in order to establish environmental objectives to monitor the performance of products' life cycle coming from company's strategic goals.

The set of EPIs selected by Company 1 are better distributed along life cycle stages and environmental aspects than the set selected by Company 2, as can be seen in figures 9, 10, 13 and 14. Company 2 has decided to focus in just one environmental objective, and they have selected just 5 EPIs according to it.

These results show the evidence that a good selection process for EPIs depends on the definition of objectives for these indicators, as presented in the literature as a good practice on performance measurement. The relevance of an EPI on measuring and monitoring products' environmental performance depends on the clear relation objective-indicator.

Another important discussion is regarding the application of step 3 of the guide. For both companies, the main criterion to select EPIs from the database was data gathering, and how the necessary information could be obtained within companies. In this respect, as the team which applied the guide in Company 2 was composed by supervisors of different areas (engineering, product development, quality and environmental systems, etc) step 3 was easily applied. In Company 1 just the environmental managers responsible to add EPIs in product development applied the guide, and the discussion on data gathering was bigger, once they needed to contact different areas of the company.

Regarding the improvements for the guide performed after case study 1, it can be observed that the review of keywords according to environmental aspects and life cycle stages has shown very positive, as the systematization is more structured and Company 2 has shown satisfied with the new classification criteria configuration. The database has shown more user-friendly and easy to navigate, and the analysis of selected EPIs regarding life cycle stages and environmental aspects supported step 3 (selection of EPIs) and 4 (customization and creation of EPIs).

4 Conclusions

This section presents final remarks, conclusions and limitations of the research, and also suggestions for future scientific works.

Indicators of sustainability have emerged during the last decades in all levels (national, community, organization, and company) to track the progress towards sustainable development. As presented in the literature, the use of environmental performance indicators (EPIs) is identified as one of the successful factors for effective ecodesign implementation, and allows the comparison of design alternatives and the recommendation of areas for improvement. This research enabled the mapping of the state of the art and the systematization of 261 environmental performance indicators (EPIs). The literature review comprised the analysis of 82 papers published between 1992 and 2012.

The first phase of the research focused on the identification of indicators used to measure and monitor the environmental performance of products in all life cycle stages and environmental aspects. From the systematic literature review, it can be concluded that the number of studies regarding environmental performance indicators is significant and it is increasing in the last decades. Most of these studies are from Europe and United States of America. The digital databases which provided most of these studies are *Scopus* and *Engineering Village*.

During the development of the research, the focus was on leading indicators, to be used during the product development process. They are related to operational activities that produce environmental aspects in an organization and can inspire effective improvements in product performance. These leading indicators should be simple to be understood and measured by ecodesign managers and product developers.

The second phase of the research focused on the definition of classification criteria for EPIs that could support the selection of these indicators by companies. Most of the identified EPIs are related to the "end-of-life", followed by "manufacturing and design" and "pre-manufacturing" life cycle phases. In regards to environmental aspects, most of them are related to material, solid waste and energy. Relative and absolute measures have shown balanced in the database. As the focus of the research was on product-related EPIs that could be used in all industrial sectors, may exist some important indicators for specific products that are not comprised in the

database. Also, these indicators could be related to other important life cycle stages and environmental aspects, depending on product type.

In order to support the selection of EPIs using the database a step-by-step guide was developed in the third phase of the research. The main goal of the guide was to support companies in the selection of EPIs for monitoring the environmental performance of their products according to strategic objectives and business needs.

The last phase of the research focused on case studies for theory-testing to evaluate the developed guide. From the first evaluation, results were compiled and the guide was improved based on suggestions to make it even more structured and easy-to-use. The new version of the guide was tested in the second case study. The evaluation of the developed guide in both case studies has shown very positive, indicating that the guide and its improved version can support companies in the selection of EPIs. It was observed that the systematization of these indicators according to life cycle stages and environmental aspects has increased the view and perception of companies on environmental impacts and performance of their products.

Furthermore, an important conclusion obtained during the application of case studies in different companies is that the definition of environmental priorities and objectives are the main activity to conduct a successful selection of performance indicators. There is no effective implementation of EPIs if they are not linked to environmental strategies and objectives of companies, and then the first step of the guide could be deeper studied and structured by means of action researches and case studies for theory-building, which could also comprise the implementation of these indicators within companies (last step of the guide). Additionally, it can be concluded that as more people from different areas in company participate in the selection process of EPIs, more easily step 3 is performed.

The following limitations of the research can be cited:

- The systematic literature review comprised just journal papers and it wasn't and iterative search process;
- The literature review did not comprise the focus on classification criteria for EPIs;

- The literature review did not focus on performance measurements systems, which could help and support the establishment of a more consolidated step-by-step approach for the guide;
- The case studies did not comprise the whole definition of environmental priorities and objectives for product development and the implementation and validation of selected EPIs within companies.

Some suggestions for future scientific works are:

- Mapping the inter-relation between indicators identified in the database and studying similarities and differences between them;
- Mapping of the relation between EPIs from the developed database to environmental indicators used in popular environmental reports;
- Deeper studies to provide an indication of which part of the development phase EPIs needs to be considered;
- Future studies on health and safety related aspects;
- Mapping the relation of EPIs and customer's needs, defining what information could be given to each stakeholder;
- Classification of EPIs according to the maturity level of a company in applying ecodesign practices;
- Deeper studies regarding the relation between leading and lagging EPIs and how they can be used in corporate environmental performance evaluation;
- Verification of the most common variables and units of measurement used to calculate EPIs, as it could provide a database of these variables for companies so they could easily calculate their indicators;
- Adapt an easier language to explain the EPIs (technical explanation), since not all people have a mathematical understanding;
- Create examples throughout the guide to make the theoretical explanation understandable, and also examples for EPIs of the database.

As identified during the literature review, studies regarding product-related environmental performance indicators are increasing in last years. During the case studies, both companies have shown a big interest in this topic and in applying the guide. This field is then becoming more interesting even for research and for application in companies, opening several possibilities for works towards more environmentally friend products.

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Appendix A – Systematic Literature Review Protocol

Product-related environmental performance indicators (EPIs)

The present protocol aims to guide the conduction of the systematic literature review, defining the objectives and the relevant criteria used in the evaluation, selection and analysis of the studies.

1. Definition of the research focus

The first specific objective of the research project is the identification and systematization of EPIs to monitor the environmental performance of products. Aligned to this goal, the systematic literature review has the main focus:

- Raising the state of art of EPIs to monitor the environmental performance of products.

The research focus can be translated into questions to be answered during the literature review, which can be defined:

- ✓ What are the EPIs developed to monitor the environmental performance of products?

- ✓ What is the information related to this indicators – name, unit of measurement, formula, etc.?

2. Definition of objectives

From the questions above, it is established the following objectives of the systematic literature review:

- Identify the main EPIs used to monitor the environmental performance of products;

- Identify the information related to these indicators - name, unit of measurement, formula, etc.

3. Primary studies

The record of the set of primary studies is presented below:

AZAPAGIC, A; PERDAN, S. Indicators of sustainable development for industry: A general framework. **Process Safety and Environmental Protection**, vol 78, p. 243-261, jul 2000.

CERDAN, C.; GAZULLA, C.; RAUGEI, M.; MARTINEZ, E.; FULLANA-I-PALMER, P. Proposal for new quantitative eco-design indicators: a first case study. **Journal of Cleaner Production**, v. 17, n. 18, p. 1638-1643, dez 2009.

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4.   Definition of keywords and strings

The keywords can be divided in two main groups, which contain similar keywords related to *ecodesign* and *indicators*:

- *Ecodesign:* clean design, design for environment, design for life cycle, design for life-cycle, design for the environment, eco design, eco-design,

ecological design, environmental conscious design, environmental product design, environmental product development, environmentally conscious design, environmentally sensitive design, environmentally sound design, green design, green product design, green product development, life cycle design, life cycle engineering, life-cycle design, life-cycle engineering, sustainability driven design, sustainable design, sustainable product design, sustainable product development

- *Indicator:* eco-indicators, ecometrics, eco-index, metrics, performance measurement, performance indicators, performance evaluation, management indicators, conditions indicators.

The string is composed by the union of the related keywords to *ecodesign* e *indicators*, and restricted by the terms *product development* and *product design*. As some of the databases do not accept quotation marks, the second string was also used.

("clean design" OR "design for environment" OR "design for life cycle" OR "design for life-cycle" OR "design for the environment" OR "eco design" OR "eco-design" OR "ecological design" OR "environmental conscious design" OR "environmental product design" OR "environmental product development" OR "environmentally conscious design" OR "environmentally sensitive design" OR "environmentally sound design" OR "green design" OR "green product design" OR "green product development") AND ("measurement" OR "performance measurement" OR "performance indicators" OR "indicators" OR "evaluation" OR "performance evaluation" OR "management indicators" OR "conditions indicators" OR "metrics") AND ("product development" OR "product design")

(clean design OR design for environment OR design for life cycle OR design for life-cycle OR design for the environment OR eco design OR eco-design OR ecological design OR environmental conscious design OR environmental product design OR environmental product development OR environmentally conscious design OR environmentally sensitive design OR environmentally sound design OR green design OR green product design OR green product development) AND (measurement OR

performance measurement OR performance indicators OR indicators OR evaluation OR performance evaluation OR management indicators OR conditions indicators OR metrics) AND (product development OR product design)

5. Definition of databases

The selected electronic databases are seven:

- *IEEExplorer* (http://ieeexplore.ieee.org),
- *ISI Web of Knowledge* (http://wokinfo.com),
- *Science Direct* (http://www.sciencedirect.com/),
- *Emerald* (http://www.emeraldinsight.com),
- *Scopus* (http://www.scopus.com),
- *Engineering Village* (http://www.engineeringvillage2.org) and
- *ProQuest* (http://www.proquest.com.br).

6. Establishment of qualification criteria for selected studies

- Qualification Criterion 1: only journal papers are selected to be analyzed.

7. Establishment of inclusion criteria for selected studies

- Inclusion Criterion 1: proposition, application or review of EPIs used to monitor the environmental performance of products;

- Inclusion Criterion 2: studies that follow the Inclusion Criterion 1 and focus on capital and consumer goods;

- Inclusion Criterion 3: studies that follow the Inclusion Criteria 1 and 2 and present leading[25] environmental performance indicators.

8. Procedures for studies selection

- Studies selection procedure 1: Reading of title, abstract and keywords;
- Studies selection procedure 2: Reading of introduction and conclusion;
- Studies selection procedure 3: Reading full paper.

9. Record documentation

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[25] Leading environmental performance indicator is a concept developed during the research and better explained in the phase 2 (Systematization of environmental performance indicators).

The selected studies are indexed in a record spreadsheet using the software Excel. The spreadsheet must contain the following information about the studies: year of publication, title, authors, country of origin, educational institution, journal and database where the study was found.

10. Search method

All search process is performed in the selected electronic databases using the defined strings, restricting the results to journal papers. The language used in the search and in the documents found is English, as it is a universal language accepted in scientific works.

11. Analysis and results presentation

The results of the systematic literature review are: state of art about environmental performance indicators and the record of environmental performance indicators extracted from the selected studies. Quantitative information concerning the search process are collected, such as the amount of studies found in each database, amount of studies stored and selected to the literature review, amount of studies per year and per country of origin, for instance. The environmental performance indicators found in the literature are extracted and stored in a record spreadsheet. Each indicator must have the following information: name, symbol, formula and unit of measurement.

Appendix B – Record of selected studies

Code	Year	Title	Authors	Journal	Country of Origin	Institution	Database	Overlap
[1]	2011	How can electronics industries become green manufacturers in Taiwan and Japan	Shih-Yuan Chiang • Chiu-Chi Wei • Te-Hsuan Chiang • Wei-Lin Chen	Clean Technologies and Environmental Policy	Taiwan	Graduate Institute of Technology Management, **Chung-Hua University;** National Applied Research Laboratories	ISI Web of Knowledge	ProQuest
[2]	2011	Development of an eco-ideation tool to identify stepwise greenhouse gas emissions reduction options for consumer goods	N.M.P. Bocken, J.M. Allwood, A.R. Willey, J.M.H. King	Journal of Cleaner Production	United Kingdom	Department of Engineering, **University of Cambridge**; Unilever Safety & Environmental Assurance Centre	ISI Web of Knowledge	Scopus
[3]	2001	Design of environmentally friendly products using indicators	T Lenau and N Bey	Journal of Engineering Manufacture	Denmark	Department of Manufacturing Engineering, **Technical University of Denmark**	ISI Web of Knowledge	Scopus, Primary study
[4]	2001	Eco-indicators in product development	J-G Persson	Journal of Engineering Manufacture	Sweden	Department of Machine Design/Engineering Design, **Royal Institute of Technology - KTH**	ISI Web of Knowledge	ProQuest, Scopus
[5]	2006	A systematic approach to eco-innovative product design based on life cycle planning	Hideki Kobayashi	Advanced Engineering Informatics	Japan	Environmental Technology Laboratory, Corporate R&D Center, **Toshiba Corporation** 1	ISI Web of Knowledge	ProQuest, Scopus
[6]	2002	ECoDE – An Environmental Component Design Evaluation Tool	S. W. Lye, S. G. Lee and M. K. Khoo	Journal of Engineering with Computers	Singapure	Division of Manufacturing Engineering, School of Mechanical & Production Engineering, **Nanyang Technological University**	ISI Web of Knowledge	Engineering Village, Scopus
[7]	2006	Life Cycle Tools within Ford of Europe's Product Sustainability Index	Wulf-Peter Schmidt and Frank Butt	The International Journal of Life Cycle Assessment	Germany	**Ford** Werke GmbH, Vehicle Recycling, Ford Werke GmbH, Vehicle Integration, Spessart Strasse	ISI Web of Knowledge	Scopus
[8]	2007	Eco-efficiency and ecodesign in electrical and electronic products	Taeko Aoe	Journal of Cleaner Production	Japan	**Matsushita** Electric Ind. Co. Ltd. (Panasonic)	Engineering Village	
[9]	2004	A Sustainability Assessment of a Biolubricant	Bryony Cunningham, Nigel Battersby, Walter Wehrmeyer, and Catriona Fothergill	Journal of Industrial Ecology	United Kingdom	**Shell** Global Solutions International B.V.	Engineering Village	

Code	Year	Title	Authors	Journal	Country of Origin	Institution	Database	Overlap
[10]	2006	A simulation system to support the establishment of circulated business	Toshimitsu Kumazawa, Hideki Kobayashi	Advanced Engineering Informatics	Japan	Environmental Technology Laboratory, Corporate R&D Center, **Toshiba** Corporation 1	Engineering Village	
[11]	2011	Review of corporate environmental indicators	Marta Herva, Amaya Franco, Eugenio F. Carrasco, Enrique Roca	Journal of Cleaner Production	Spain	School of Engineering. **University of Santiago de Compostela**; Process Engineering Group, Marine Research Institute IIM-CSIC	Engineering Village	Scopus, Science Direct, Primary study
[12]	2011	An assessment method and design support system for designing sustainable machine tools	Ander Azkaratea, Itziar Ricondo, Amaia Pérez and Paulino Martínez	Journal of Engineering Design	Spain	aProduct Department, **IDEKO** S.Coop; bDepartment of Projects and Rural Engineering, **Public University of Navarre**	Engineering Village	
[13]	1994	Disassembly-Oriented Assessment Methodology to Support Design for Recycling	E. Zussman, A. Kriwet, G. Seliger	Manufacturing Technology	Germany	**Technical University, Berlin**	Engineering Village	
[14]	2003	Indicators for measuring environmental sustainability: A case study of the pharmaceutical industry	Vesela Veleva, Maureen Hart, Tim Greiner, Cathy Crumbley	Benchmarking: An International Journal	United States of America	Sustainable Measures Inc., Winchester, Greiner Environmental Inc., Lowell Center for Sustainable Production	Engineering Village	
[15]	2004	A WEB-BASED SYSTEM FOR REVERSE MANUFACTURING AND PRODUCT ENVIRONMENTAL IMPACT ASSESSMENT CONSIDERING END-OF-LIFE DISPOSITIONS	H. C. Zhang, J. Li, P. Shrivastava and A. Whitley	Manufacturing Technology	United States of America	Department of Industrial Engineering, **Texas Tech University**; **Dell** Inc.; Techsolve	Engineering Village	
[16]	2004	Measurement of green productivity and its improvement	Tak Hur, Ik Kim, Ryoichi Yamamoto	Journal of Cleaner Production	South Korea and Japan	Department of Materials Chemistry and Engineering, School of Chemical and Biological Engineering, **Konkuk University**; Center for Collaborative Research, **University of Tokyo**	Engineering Village	
[17]	2010	A Schematic Method for Sustainable Material Selection of Toxic Chemicals in Design and Manufacturing	Chris Y. Yuan and David A. Dornfeld	Journal of Mechanical Design	United States of America	University of Wisconsin, University of California	Engineering Village	

Code	Year	Title	Authors	Journal	Country of Origin	Institution	Database	Overlap
[18]	2009	Proposal for new quantitative eco-design indicators: a first case study	Carlos Cerdan, Cristina Gazulla a, Marco Raugei, Eva Martinez, Pere Fullana-i-Palmer	Renewable and Sustainable Energy Reviews	Spain	Environmental Management Research Group (GiGa), Escola Superior de Comerç Internacional, U**niversitat Pompeu Fabra**; Centro Tecnológico de **Miranda de Ebro** (CTME)	Engineering Village	Primary study
[19]	2002	From environmental assessment results to Design for Environment product changes: an evaluation of quantitative and qualitative methods	MARC ERNZER and WOLFGANG WIMMER	Journal of Engineering Design	Germany and Austria	**Darmstadt University of Technology**; **Vienna University of Technology**	ProQuest	Scopus
[20]	2009	DEVELOPMENT OF A SET OF CRITERIA AS AN ECO-DESIGN TOOL FOR EVALUATION OF ENVIRONMENTAL IMPACT OF MATERIAL CHOICE	J.Simanovska, K. Valters, G. Bažbauers	Environmental and Climate Technologies	Latvia	**Riga Technical University**	ProQuest	
[21]	2011	Emergy as a Life Cycle Impact Assessment Indicator	Wesley W. Ingwersen	Journal of Industrial Ecology	United States of America	**Yale University**	Engineering Village	
[22]	1994	Sustainable Development by Design: Review of Life Cycle Design and Related Approaches	Gregory A. Keoleian and Dan Menerey	Air and Waste	United States of America	School of Natural Resources and Environment, **University of Michigan**	Engineering Village	
[23]	1999	BUILDING AN ECO-DESIGN TOOLKIT AT KODAK	D. M. Timmons	Eletronics and the Environment	United States of America	Design for HSE Program Office, Eastman **Kodak Company**	Engineering Village	
[24]	2006	Environmentally conscious design by using fuzzy multi-attribute decision-making	Tsai-Chi Kuo, Sheng-Hung Chang e Samuel H. Huang	International Journal of Advanced Manufacturing Technology	Taiwan and United States of America	**Ming Hsin University of Science and Technology; University of Cincinnati**	Engineering Village	Scopus
[25]	2004	Toward a Sectorwide Design for Environment Support System for the Rail Industry	WIM DEWULF, JOOST DUFLOU, ASA ANDER	Environmental Management	Sweden and Belgium	**Katholieke Universiteit Leuven, Bombardier Transportation**	Engineering Village	Scopus
[26]	2005	Incorporating work factors in design for disassembly in product design	Anoop Desai, Anil Mital	Journal of Manufacturing Technology Management	United States of America	**University of Cincinnati**	Engineering Village	
[27]	2012	The emergence of sustainable manufacturing practices	M. Despeisse, F. Mbaye, P.D. Ball and A. Levers	Production Planning and Control	United Kingdom	**Cranfield University**	Engineering Village	

Code	Year	Title	Authors	Journal	Country of Origin	Institution	Database	Overlap
[28]	2011	Product generational dematerialization indicator: A case of crude oil in the global economy	Jadwiga R. Ziolkowskaa, Bozydar Ziolkowskib	Energy	United States of America and Poland	**University of California at Berkeley; Rzeszów University of Technology**	Engineering Village	
[29]	2007	Synthesis and optimization of the recovery route for residual products under uncertain product demand	Joaquim Duque, Ana Paula F.D. Barbosa-Póvoa, Augusto Q. Novais	Computers and Operations Research	Portugal	**DMS, INETI; CEG-IST, DEG**	Engineering Village	
[30]	2003	SYSTEMS APPROACH TO CORPORATE SUSTAINABILITY A General Management Framework	A. AZAPAGIC	Trans IChemE	United Kingdom	**University of Surrey**	Engineering Village	
[31]	2007	Stakeholder needs study on indicators for IPP (Integrated Product Policy)	A°sa Sundkvist*, Go¨ran Finnveden	Journal of Cleaner Production	Sweden	**KTH Royal Institute of Technology**	Engineering Village	
[32]	2005	Indicators for environmental policy integration in the food supply chain (the case of the tomato ketchup supply chain and the integrated product policy)	Verginia Mintcheva	Journal of Cleaner Production	Sweden	**Lund University**	Engineering Village	
[33]	1997	Manufacturing processes modelling for environmental impact assessment	A.C.K. Choi, H. Kaebernick, W.H. Lai	Journal of Materials Processing Technology	Hong Kong and Australia	Department of Manufacturing Engineering, **The Hong Kong Politechnic University**; School of Mechanical and Manufacturing Engineering, **The University of New South Wales**	Engineering Village	
[34]	2001	A design methodology for the strategic assessment of a product's eco-efficiency	S. W. LYE, S. G. LEE and M. K. KHOO	International Journal of Production Research	Singapure	School of Mechanical & Production Engineering, **Nanyang Technological University**	Engineering Village	
[35]	2011	Measurement and analysis of product energy efficiency to assist energy star criteria development: an example for desktop computers	Seong-Rin Lim, JulieM.Schoenung	Energy Policy	South Korea and United States of America	Department of Environmental Engineering, College of Engineering, **Kangwon National University**; **Department** of Chemical Engineering and Materials Science, **University of California**	Engineering Village	

Code	Year	Title	Authors	Journal	Country of Origin	Institution	Database	Overlap
[36]	2010	Environmental performance evaluation and strategy management using balanced scorecard	Yu-Lung Hsu · Chun-Chu Liu	Environmental Monitoring and Assessment	Taiwan	Taiwan Petroleum Chamber of Commerce; **Chang Jung Christian University**	Engineering Village	
[37]	2007	Integrated Environmental Process Planning for the Design & Manufacture of Automotive Components	Satnam Singh, Dr. Jane Goodyer and Professor Keith Popplewell	International Journal of Production Research	United Kingdom and New Zeland	**Faculty of Engineering & Computing**, Engineering Manufacturing & Management Department; Institute of Technology & Engineering, **Massey University**	Engineering Village	
[38]	2000	Development of environmental performance indicators for textile process and product	Xin Ren	Journal of Cleaner Production	China	ERM China	Engineering Village	
[39]	1992	Approach to the Identification and Quantification of Environmental Effects during Product Life	R. Zust, R. Wagner;	Annals of the CIRP	Switzerland	**Swiss Federal Institute of Technology**	Engineering Village	
[40]	1997	Integrated Product Design in Chemical Industry. A Plea for Adequate Life-Cycle Screening Indicators	Andre Weidenhaupt and Konrad Hungerbiihler	SAFETY AND ENVIRONMENTAL PROTECTION IN CHEMISTRY	Switzerland	**Swiss Federal Institılte of Technology** Chemical Engineering Department	Engineering Village	
[41]	2011	Sustainable and safe design of footwear integrating ecological footprint and risk criteria	Marta Herva, Antonio Álvarez, Enrique Roca	Journal of Hazardous Materials	Spain	Sustainable Processes and Products Engineering Group, Department of Chemical Engineering, **University of Santiago de Compostela**; **Industrias de Diseño Textil, S.A.**	Engineering Village	
[42]	2012	Validation of a proposed instrument for measuring eco-innovation: An implementation perspective	Colin C.Cheng, EricC.Shiu	Technovation	Taiwan and United Kingdom	College of Management,Yuan Ze University; Birmingham Business School,University House	Scopus	
[43]	2012	Materials selection for cleaner production: An environmental evaluation approach	Rui Zhao, Gareth Neighbour, Pauline Deutz, Michael McGuire	Materials and Design	United Kingdom	Department of Engineering, **University of Hull**; Design and Environment, **Oxford Brookes University**; Department of Geography, **University of Hull**	Scopus	

Code	Year	Title	Authors	Journal	Country of Origin	Institution	Database	Overlap
[44]	2012	Strategy tool trial for office furniture	Cecilia Askham & Ole Jørgen Hanssen & Anne Lill Gade & Guro Nereng & Carl Peter Aaser & Per Christensen	International Journal of Life Cycle Assessment	Norway and Denmark	Ostfold Research; Jotun A/S; Scandinavian Business Seating AS; Department of Development and Planning, **Aalborg University**	Scopus	
[45]	2012	Design for sustainability in automotive industry: A comprehensive review	Ahmad Mayyasa, Ala Qattawia, Mohammed Omara, Dongri Shan	Renewable and Sustainable Energy Reviews	United States of America and China	Automotive Engineering Department, **Clemson University International Center for Automotive Research – CU-ICAR**; School of Mechanical Engineering, **Shandong Institute of Light Industry**	Scopus	
[46]	2011	Sustainable design of sprocket using CAD and Design Optimisation	S. Vinodh	Environmental Development Sustainability	India	Department of Production Engineering, **National Institute of Technology**	Scopus	
[47]	2012	A taxonomy of ecodesign tools for integrating environmental requirements into the product design process	M.D. Bovea, V. Pérez-Belis	Journal of Cleaner Production	Spain	Department of Mechanical Engineering & Construction, **Universitat Jaume I**	Scopus	
[48]	2002	DEA: A Method for Ranking the Greeness of Design Decisions	Jonathan D. Linton	Journal of Mechanical Design	United States of America	Department of Management, **Polytechnic University**	Scopus	
[49]	2001	GreenPro: a new methodology for cleaner and greener process design	Faisal I. Khan, B.R. Natrajan, P. Revathi	Journal of Loss Prevention in the Process Industries	Canada and India	Faculty of Engineering and Applied Science, **Memorial University of Newfoundland**; DLPD, BITS–Pilani; Chemical Engineering Group, **BITS–Pilani**	Scopus	
[50]	2001	A Multi-Objective Methodology for Evaluating Product End-of-Life Options and Disassembly	S. G. Lee, S. W. Lye and M. K. Khoo	International Journal of Advanced Manufacturing Technology	Singapure	Division of Manufacturing Engineering, School of Mechanical and Production Engineering, **Nanyang Technological University**	Scopus	

Code	Year	Title	Authors	Journal	Country of Origin	Institution	Database	Overlap
[51]	2010	CAD and DFM: enablers of sustainable product design	S. Vinodh & D. Rajanayagam	International Journal of Sustainable Engineering	India	Department of Production Engineering, **National Institute of Technology**	Scopus	
[52]	2009	Calculation of a Toxic Potential Indicator Via Chinese-Language Material Safety Data Sheets	Sheng-Bou Yen and Jahau Lewis Chen	Journal of Industrial Ecology	Taiwan	Department of Mechanical Engineering **National Cheng Kung University**	Scopus	
[53]	2010	Combination of case-based reasoning and analytical hierarchy process for providing intelligent decision support for product recycling strategies	Tsai Chi Kuo	Expert Systems with Applications	Taiwan	Department of Industrial and Systems Engineering, **Chung Yuan Christian University**	Scopus	
[54]	2010	Computer-aided Environmental Design System for the Energy-using Product (EuP) Directive	Yun-Cheol Kang, Doo-Man Chun, Yan Jun and Sung-Hoon Ahn	INTERNATIONAL JOURNAL OF PRECISION ENGINEERING AND MANUFACTURING	South Korea	School of Mechanical and Aerospace Engineering and Institute of Advanced Machinery and Design, **Seoul National University**	Scopus	
[55]	2003	Designing Resilient, Sustainable Systems	Joseph Fiksel	Environmental Science & Technology	United States of America	Eco-Nomics LLC	Scopus	
[56]	2009	Development of environmental consequence index (ECI) using fuzzy composite programming	N.S. Arunraj, J. Maiti	Journal of Hazardous Materials	India	Department of Industrial Engineering and Management, **Indian Institute of Technology**	Scopus	
[57]	2011	Disassemblability of end-of-life vehicle: a critical review of evaluation methods	T.F. Go, D.A. Wahab, M.N.Ab. Rahman, R. Ramli, C.H. Azhari	Journal of Cleaner Production	Malaysia	Department of Mechanical and Materials Engineering, Faculty of Engineering and Built Environment, **Universiti Kebangsaan Malaysia**	Scopus	
[58]	2003	Environmental performance of products: Benchmarks and tools for measuring improvement	Shane J. Schvaneveldt	Benchmarking: An International Journal	United States of America	Goddard School of Business and Economics, **Weber State University**	Scopus	
[59]	2005	Environmental aspects when manufacturing products mainly out of metals and/or polymers	Mats Zackrisson	Journal of Cleaner Production	Sweden	IVF Industrial Research and Development Corporation	Scopus	

Code	Year	Title	Authors	Journal	Country of Origin	Institution	Database	Overlap
[60]	2011	Environmental conscious product design using CAD and CAE	S. Vinodh	Clean Technology Environmental Science	India	**National Institute of Technology**	Scopus	
[61]	1997	Evaluating the environmental impact of products and production processes: a comparison of six methods	Edgar G. Hertwich, William S. Pease, Catherine P. Koshland	The Science of the Total Environment	United States of America	Energy and Resources Group and Environmental Health Science, **University of California at Berkeley**	Scopus	
[62]	2002	Strategic sustainable development — selection, design and synergies of applied tools	K.-H. Robért B. Schmidt-Bleek, J. Aloisi de Larderel, G. Basile, J.L. Jansen f, R. Kuehr, P. Price Thomas, M. Suzuki, P. Hawken, M. Wackernagel	Journal of Cleaner Production	Sweden, France, Japan, United States of America, Netherlands	Chalmers University of Technology and Goteborg University, The Natural Step Foundation, UNEP/Division of Technology, University of California, Thoreau Center for Sustainability, Sustainable Technology Development, United Nations University, Factor Ten Institute, Natural Capital Institute, Redefining Progress	Science Direct	
[63]	2004	Improving Environmental Performance Assessment. A Comparative Analysis of Weighting Methods Used to Evaluate Chemical Release Inventories	Michael W. Toffel and Julian D. Marshall	Journal of Industrial Ecology	United States of America	Haas School of Business, **University of California**	Scopus	
[64]	2006	Integrated design of remanufacturable products based on product profiles	Peggy Zwolinski*, Miguel-Angel Lopez-Ontiveros, Daniel Brissaud	Journal of Cleaner Production	France	**Grenoble University**	Scopus	
[65]	2005	Simplified LCA and matrix methods in identifying the environmental aspects of a product system	Tak Hur, Jiyong Lee, Jiyeon Ryu, Eunsun Kwon	Journal of Environmental Management	South Korea	Department of Materials Chemistry and Engineering, Innovative Environmental Technology center, **Konkuk University**	Scopus	
[66]	2010	Selection of green product design scheme based on multi-attribute decision-making method	Yang Gao, Zhifeng Liu, Di Hu, Lei Zhang & Guogang Gu	International Journal of Sustainable Engineering	China	School of Mechanical & Automobile Engineering, **Hefei University of Technology**	Scopus	

Code	Year	Title	Authors	Journal	Country of Origin	Institution	Database	Overlap
[67]	2010	Model scenario for integrated environmental product assessment at the use of raw materials stage of a product	Y.L. Wonga, K.M. Leeb, K.C. Yunga	Resources, Conservation and Recycling	Hong Kong e North Korea	Department of Industrial and Systems Engineering, **The Hong Kong Polytechnic University**; Department of Environmental Engineering, **Ajou University**	Scopus	
[68]	2006	Operational Sustainability Metrics Assessing Metric Effectiveness in the Context of Electronics-Recycling Systems	JENNIFER ATLEE AND RANDOLPH KIRCHAIN	Environmental Science & Technology	United States of America	**Massachusetts Institute of Technology**	Scopus	
[69]	2010	PIQET: the design and development of an online 'streamlined' LCA tool for sustainable packaging design decision support	Karli L. Verghese & Ralph Horne & Andrew Carre	International Journal of Life Cycle Assessment	Australia	**RMIT University**	Scopus	
[70]	2011	Potential Environmental Impacts of Light-Emitting Diodes (LEDs): Metallic Resources, Toxicity, and Hazardous Waste Classification	SEONG-RIN LIM, DANIEL KANG, OLADELE A. OGUNSEITAN, AND JULIE M. SCHOENUNG	Environemental Science Technology	United States of America	**University of California**	Scopus	
[71]	2008	Product end-of-life options selection: grey relational analysis approach	Joseph W. K. Chan	International Journal of Production Research	Hong Kong	**The Hong Kong Polytechnic University**	Scopus	
[72]	2011	Issues to consider, existing tools and constraints in biofuels sustainability assessments	Electo E. Silva Lora, José C. Escobar Palacio, Mateus H. Rocha, Maria L. Grillo Renó, Osvaldo J. Venturini, Oscar Almazán del Olmo	Energy	Brazil and Cuba	**Federal University of Itajubá**, ICIDCA e Instituto Cubano de Investigaciones de los Derivados de la Caña de Azúcar,	Engineering Village	
[73]	2012	Benchmarking of next- generation biofuels from a process perspective	Anna Voll and Wolfgang Marquardt	Biofuels, Bioproducts & Biorefining	Germany	**RWTH Aachen University**	Engineering Village	
[74]	1999	Disassembly analysis through time estimation and other metrics	Ehud Kroll, Brad S. Carver	Robotics and Computer Integrated Manufacturing	United States of America	**University of Missouri-Columbia/Kansas City**	Engineering Village	

Code	Year	Title	Authors	Journal	Country of Origin	Institution	Database	Overlap
[75]	2006	Development of eco-efficiency indicators for the Canadian food and beverage industry	Dominique Maxime, Michèle Marcotte, Yves Arcand	Journal of Cleaner Production	Canada	Agriculture and Agri-Food Canada, Food Research and Development Centre	Engineering Village	
[76]	2000	Environmental performance evaluation and indicators	Christine Jasch	Journal of Cleaner Production	Austria	Institute for Environmental Management and Economics, **Institut für ökologische Wirtschaftsforschung**	Primary study	
[77]	2003	Indicators of sustainable production	Damjan Krajnc, Peter Glavic	Clean Techn Environ Policy	Slovenia	University of Maribor	Primary study	
[78]	2000	INDICATORS OF SUSTAINABLE DEVELOPMENT FOR INDUSTRY: A General Framework	A. AZAPAGIC and S. PERDAN	Process Safety and Environmental Protection	United Kingdom	University of Surrey	Primary study	
[79]	1995	Evaluating Environmental Performance: A Case Study in the Flat-Panel Display Industry	Jonathan Koch and Gregory Keoleian	Proceedings of the 1995 IEEE International Symposium on Eletronics and the Environment	United States of America	University of Michigan	Primary study	
[80]	1999	Indicators for Environmentally Conscious Product Design	Fabio Giudice, Guido La Rosa, Antonino Risitano	Proceedings of the First international conference on Environmentally conscious design and inverse manufacturing	Italy	University of Catania	Primary study	
[81]	2005	Environmental indicators for ICT products - A practical approach based on four steps -	N. Warburg, A. Braune, P. Eyerer, C. Herrmann, N. Gallon	Proceedings of the 2005 IEEE International Symposium on Eletronics and the Environment	Germany	IKP University of Stuttgart, PE Europe GmbH	Primary study	
[82]	2006	Towards Indicators of Sustainable Product Design	Paulo Fernando de Almeida Souza, Hemane Borges de Barros Pereira	Engineering Management Conference, 2006 IEEE International	Brazil	University of the State of Bahia (UNEB), Universidade Estadual de Feira de Santana (UEFS)	Primary study	

Appendix C – Descriptive analysis of selected studies

This appendix contains an analysis of the studies included in the systematic literature review regarding environmental performance indicators (EPIs) through graphs.

From the 82 studies selected to be analyzed, most of them were found in the electronic databases Scopus and Engineering Village. Then, these two databases have proven the most relevant regarding studies about environmental performance indicators. Figure 1 below shows the distribution of selected papers per database:
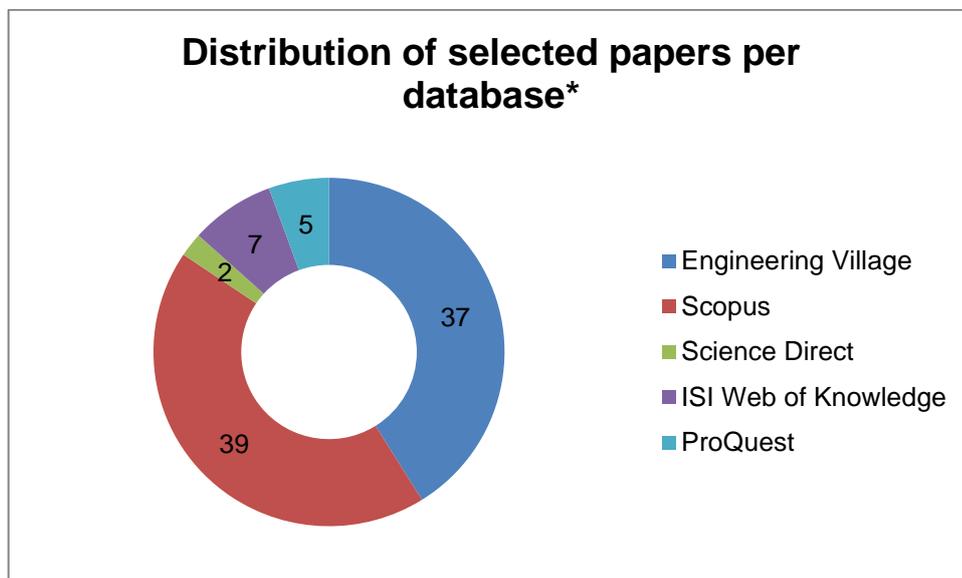
Figure 1: Distribution of selected studies per electronic database
*It is included in the numbers the overlap between databases.

There is an overlap between the databases used in the search process. It means that a same paper was found in two or three databases, for instance. From the 82 selected papers, 12 of them are part of the overlap set of studies between databases.

Figure 2 presents the distribution of selected papers per year of publication. It can be observed an increasing interest in studying and applying EPIs to monitor the environmental performance of products, pronounced since 1999. The years with the highest number of published journal papers were 2006, 2010 and 2011.

Distribution of selected papers per year
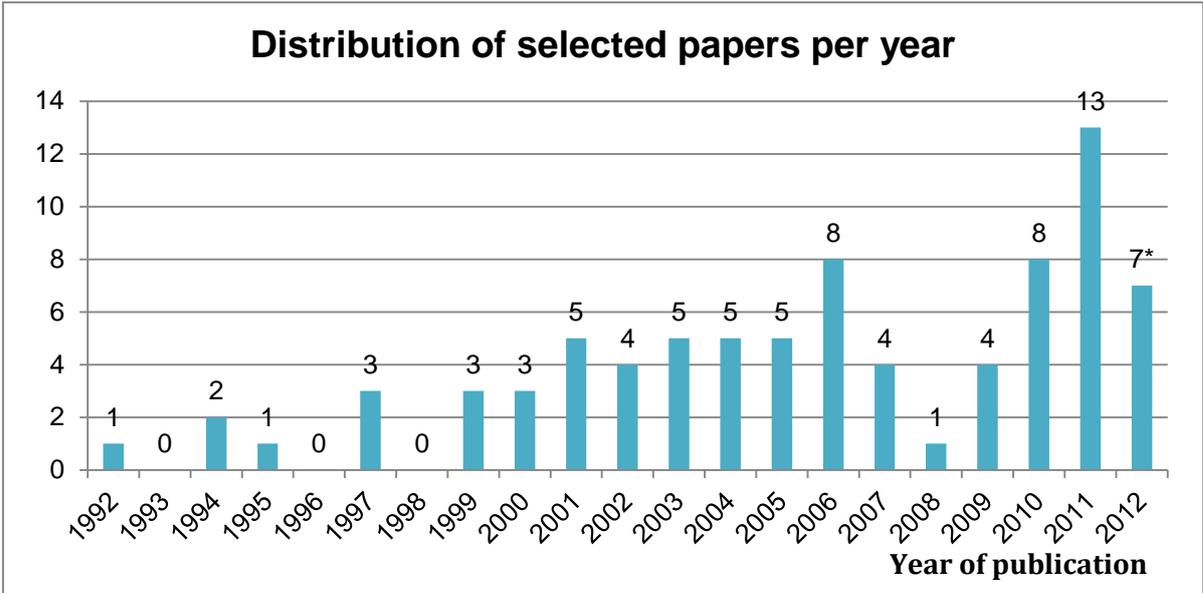
Figure 2 – Distribution of selected papers per year
*The search process comprised the period until October of 2012.

It is also interesting to analyze the distribution of selected papers per continent and country of origin. To perform this analysis, the countries of origin of all authors of each paper were considered. Figure 3 shows the distribution of papers per continent in percentage. It can be observed that Europe leads the studies in environmental performance indicators, comprising 41% of the selected papers. Asia and North America also have shown as relevant continents regarding this topic, comprising 31% and 23% of these studies, respectively.
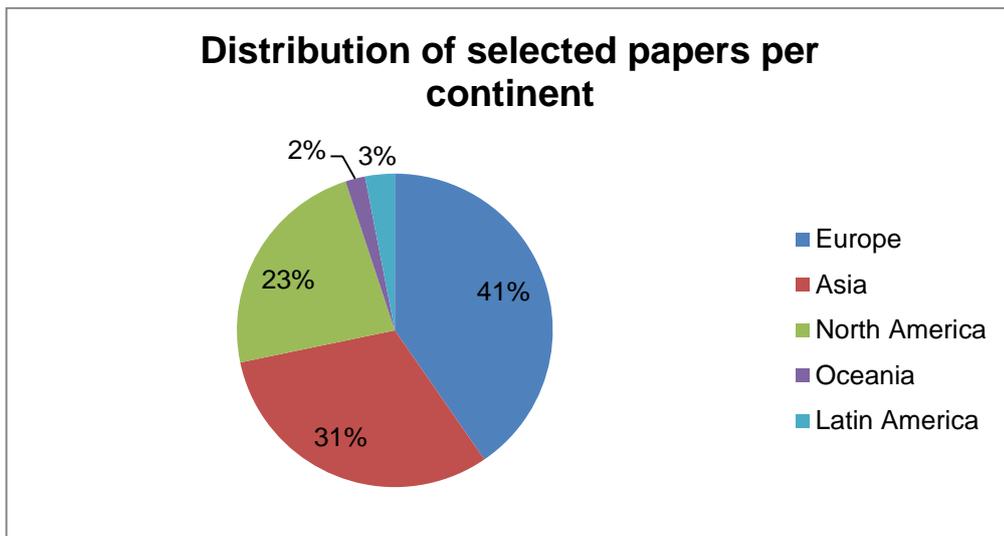
Figure 3 – Distribution of selected papers per continent

The distribution of selected studies per country of origin is presented in figure 4. It is important to notice that the number of papers per country includes overlap among papers that were conducted in two or more countries, due to collaborative research. Although Europe has proven to be the leader in publishing papers regarding the research topic, the United States of America is the country that has published the highest number of papers. The countries United Kingdom, Sweden and Taiwan have shown to be relevant as well.
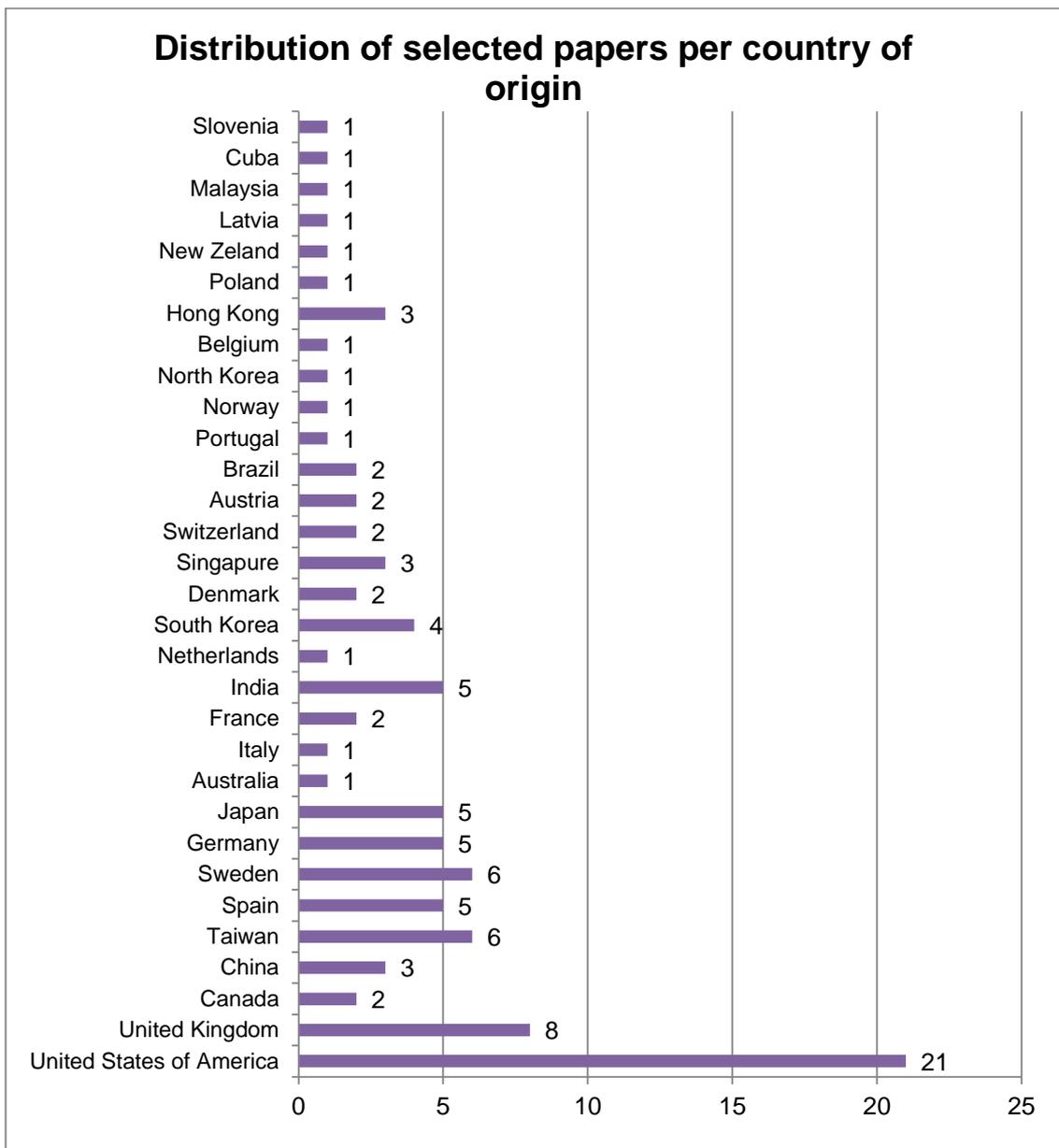
Figure 4: Distribution of selected papers per country of origin

Appendix D – Record of environmental performance indicators

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
1	**Reusable Parts**	.	This indicator measures the mass of elements or parts that can be reused relative to the total mass of the product.	Weight of reusable parts/Total weight of product	dimensionless	↑	[18] / [79] / [37]	3
2	**Recyclable Materials in the product**	.	This indicator measures the mass of recyclable in relation to the total mass of the product.	Weight of recyclable materials/Total weight of product	dimensionless	↑	[18] / [30] / [37] / [55] / [25] / [65] / [68] /[82]	8
3	**Reversible Joints**	.	The time required to disassemble reversible joints, such as screws and bolts, is much less than required for welded joints, so that the latter are much more complicated to disassemble and break up. This indicator quantifies the number of reversible joints relative to the total number of joints of a product.	Number of reversible joints/Number of total joints	dimensionless	↑	[18]	1
4	**Same Material Joints**	.	If the joints are made from the same material or materials that are compatible for recycling, there is no need for separate pieces before recycling, reducing the time of disassembly. This indicator measures the number of articulated parts that can be recycled together relative to the total number of joints of a product.	Same material joints/Number of total joints	dimensionless	↑	[18]	1
5	**Material identification labels**	.	One of the important aspects in the disassembly and subsequent recycling is identify which materials the product is made. This indicator measures the percentage of product parts that carry material identification labels.	Number of parts with label/Total number of different parts	dimensionless	↑	[18]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
6	**Tools for Disassembling**	.	The duration of the disassembly process is often related in a direct way with the types of joints between materials. The joints should be as simple and standard as possible, so little need dismantling tools. This indicator quantifies the number of tools required for disassembly relative to the total number of articulations of the product.	Number of necessary tools/Number of total joints	dimensionless	↓	[18].	1
7	**Time for Disassembly**	.	This indicator quantifies the total time required in the complete dismantling of all joints of the product.	Total time to take apart all joints of a product	min	↓	[18] / [25] / [24] / [74] / [68]	5
8	**Intelligent Materials**	.	This indicator measures the weight of "intelligent materials" relative to the total weight of the product. "Intelligent materials" are materials which undergo reversible physical or chemical changes under variations of magnetic or electrical fields, and they are capable of repeating this process indefinitely without losing their original properties. The use of intelligent polymers and metals is very important to reduce the disassembly time.	Weight of clever materials/Total weight of the product	dimensionless	↑	[18]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
9	**Time for Battery Changing**	.	This indicator measures the time necessary for disassembly and replacement of the batteries or other such user-serviceable parts. Existing parts that have a shorter useful life than others causes a loss of value of the product (e.g. batteries). It's necessary that these parts are easily accessible and visible, ir order to facilitate and economize on the process of their replacement, and to support the value of the entire product.	Time for replacement batteries (or other user-serviceable parts)	min	↓	[18]	1
10	**Laminated or Compound Materials**	.	Laminated or compound materials have limited potential for recycling. This indicator measures the mass of laminated materials or compounds in relation to the total weight of the product.	Weight of laminated or compound materials/Total weight of the product	dimensionless	↓	[18]	1
11	**Painted, Stained or Pigmented Surfaces**	.	The presence of painted, stained or pigmented surfaces problems often affect recycling processes, since these impregnations or alterations of the components complicate the separation for recycling due to the difficulty of separating the paint coats from the underlying materials. This indicator measures the sum of the painted, pigmented or stained surfaces relative to the total surface of the product.	Painted, Stained or Pigmented Surface/Total surface of the product	dimensionless	↓	[18]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
12	Ecological Rucksack	ER	The indicator Ecological Rucksack (ER) represents the sum of all input materials not included in the purchased product, but necessary in the production, use, recycling and final disposal - whole product's life cycle. It can also be a measure of material intensity, as ER gives a rough estimate of the resource intensity. Commonly, the rucksack of current technical products in terms of non-renewable materials is about 30 tons per ton of product and can reach much higher values, as for instance about 300 for such products as personal computers. It can also be used to evaluate the energy requirement for a particular product.	(sum of all material input during product's life cycle) - (product weight)	mg, kg, g	↓	[11] / [19] / [62] / [28]	4
13	Hazard Quotient	HQ	HQ is an indicator used in the risk assessment of toxic substances a product. A risk assessment involves identifying the type of toxic, an exposure assessment and risk characterization. HQ is the relationship between the exposure dose of the toxic to the user (dose), in $mg.kg^{-1}day^{-1}$ with respect to the dose reference to non-carcinogenic effects (RfDs) in $mg.kg^{-1}day^{-1}$, according to U.S. EPA and ORNL.	Dose/RfDs	dimensionless	↓	[11] / [41]	2

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
14	**Cancer Risk factor**	CR	CR is an indicator used in the risk assessment of toxic substances a product. A risk assessment involves identifying the type of toxic, an exposure assessment and risk characterization. CR is the relationship between the exposure dose of the toxic to the user (dose), in $mg.kg^{-1}day^{-1}$ and the slope factor for carcinogenic effects (SF) in $kg.day.mg^{-1}$, according to U.S. EPA and ORNL.	Dose . SF	dimensionless	↓	[11] / [41]	2
15	**Recycled Materials in the product**	-	This indicator measures the amount of recycled material relative the total mass of the product.	Weight of total recycled material/Total weight of material used in the product	dimensionless	↑	[4] / [76] / [68] / [24]	4
16	**Product Degree of Utilization**	.	When estimating the total utility of a product, the degree of utilization must be evaluated in addition to the product function. For many classes of products and for consumer goods in particular, the degree of utilization is really significant: lawnmowers are typically used less than 1 per cent of the time, and the average utilization for a passenger car is of the order of 5 per cent.	Relative measures of product utilization	Depends of the product's function	↑	[4]	1
17	**Total Air Emissions**	.	Sum of all air emissions in the production process.	Sum of all air emissions in the production process	kg or kg/PO	↓	[76]	1
18	**Discarded Packaging Materials per Product**		This indicator measures the mass of packaging material discarded per product.	Mass of packaging material discarded per product	kg/product	↓	[76]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
19	**Reused Packaging Materials per Product**	.	This indicator measures the mass of packaging material reused per product.	Mass of packaging material reused per product	kg/product	↑	[76] / [37]	2
20	**Auxiliary Materials recycled or reused**	.	This indicator measures the amount of auxiliary materials recycled or reused in the production process	Sum of all auxiliary materials recycled or reused in the production process	mass units	↑	[76]	1
21	**Reused Raw Materials**	.	This indicator measures the amount all raw material reused in the production process.	Amount all raw material reused in the production process	mass units	↑	[76]	1
22	**Reused Water**	.	This indicator measures the amount of water reused in the production process.	Sum of all water reused in the production process	volume units	↑	[76]	1
23	**Energy generated with by-products or process streams**	.	This indicator quantifies the energy generated with by-products or process streams.	Quantity of the energy generated with by-products or process streams	KWh	↓	[76]	1
24	**Hazardous materials used by contracted service providers**	.	This indicator measures the amount of hazardous materials used by contracted service providers. Decreasing this amount can avoid harm in the environment in the pre-manufacturing and manufacturing stages of a product's life cycle.	Quantity of the amount of hazardous materials used by contracted service providers	mass or volume units	↓	[76]	1
25	**Cleaning agents used by contracted service providers**	.	This indicator measures the amount of cleaning agents used by contracted service providers. Decreasing this amount can avoid harm in the environment in the manufacturing stage of a product's life cycle.	Quantity of the amount of cleaning agents used by contracted service providers	mass or volume units	↓	[76]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
26	Recyclable and reusable materials used by contracted service providers	.	This indicator measures the amount of recyclable and reusable used by contracted service providers. It can improve the environmental performance by selecting the most recycling/reusing efficient provider of energy and raw materials.	Quantity of the amount of recyclable and reusable materials used by contracted service providers	mass units	↑	[76]	1
27	Wastes generated by contracted service providers	.	This indicator measures the amount of waste generated by contracted service providers. It can be also measured for different types of waste generated.	Amount of waste generated by contracted service providers	kg	↓	[76]	1
28	Fuel consumption of vehicle fleet	.	This indicator quantifies the average fuel consumption of vehicle fleet of the industry.	Quantity of the average fuel consumption of vehicle fleet	volume units	↓	[76]	1
29	Freight deliveries by mode of transportation per day	.	This indicator quantifies the number of freight deliveries by mode of transportation per day.	Quantity of the number of freight deliveries by mode of transportation per day	freight deliveries/mode of transportation/day	Depends on the mode of transportation	[76]	1
30	Total land area used for production purposes	.	This indicator measures the total land area used for production purposes. It can be measured in terms of industry facilities and area needed to produce raw materials.	Total land area used for production purposes, as needed to produce raw materials and/or to implement the production process	area units	↓	[76]	1
31	Vehicles in fleet with pollution abatement technology	.	This indicator quantifies the total number of vehicles in fleet with pollution abatement technology.	Total number of vehicles in fleet with pollution abatement technology	vehicles	↑	[76]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
32	**Number of business trips saved through other means of communication**	.	This indicator quantifies the total number of business trips saved through other means of communication.	Total number of business trips saved through other means of communication	trips	↑	[76]	1
33	**Total number of products with reduced hazard properties**	.	This indicator measures the number of products of a company's portfolio introduced in the market with reduced hazardous properties	Quantity of products in portfolio introduced in the market with reduced hazardous properties	number of products	↑	[76]	1
34	**Total number of products which can be reused or recycled**	.	This indicator measures the number of products of a company's portfolio introduced in the market which can be reused or recycled.	Quantity of products in portfolio which can be reused or recycled	number of products	↑	[76]	1
35	**Rate of Defective Products**	.	This indicator measures the number of defective products relative to the number of manufactured products. Decrease this rate reduce solid waste generation, and wasted materials and energy.	number of defective products / total number of manufactured products	%	↓	[76] / [43]	2
36	**By-products**	.	This indicator measures the quantity of by-products generated. The unit of measure can be relative to product manufactured, in relation to production output, or in mass or volume units (absolute measures).	Quantity of units of by-products generated	units of by-products	↓	[76] / [43]	2
37	**Total number of products with environmental instructions**	.	This indicator measures the number of products in a company's portfolio with instructions regarding environmentally safe use and disposal.	Quantity of products in the portfolio with instructions regarding environmentally safe use and disposal	number of products	↑	[76]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
38	**Materials used during after-sales servicing of products**	.	This indicator measures the amount of materials used during after-sales servicing of products.	Quantity of materials used during after-sales servicing of products	mass or volume units	↓	[76]	1
39	**Specific Solid Waste Mass**	.	This indicator measures the solid waste generated in the manufacturing process per unit of product.	Quantity of waste produced per unit of product	mass or volume units	↓	[76]	1
40	**Waste stored on site**	.	This indicator quantifies the amount of waste generated in the manufacturing process stored on site.	Quantity of waste stored on site	mass or volume units	Depends	[76]	1
41	**Waste controlled by permits**	.	This indicator quantifies the amount of waste generated in the manufacturing process waste controlled by permits.	Quantity of waste controlled by permits	mass or volume units	↓	[76]	1
42	**Waste converted to Reusable Material**	.	This indicator measures the amount of waste generated by the production process converted to reusable material per year.	Quantity of waste converted to reusable material per year	mass or volume units/year	↑	[76]	1
43	**Specific Air Emissions per Substance**	.	This indicator measures emissions of specific substances per year, such as SOx, NOx, particles, etc.	Quantity of specific emissions per year	volume units/year	↓	[76] / [30]	2
44	**Specific Air Emissions per Product**	.	This indicator measures emissions of specific substances per unit of product or in terms of Production Output (PO) in kg, items, etc.	Quantity of specific emissions per unit of product	volume units/unit of product	↓	[76]	1
45	**Landfill Waste per Product**	.	This indicator measures the quantity of material sent to landfill per unit of product.	Quantity of material sent to landfill per unit of product	kg/product	↓	[76] / [37]	2
46	**Radiation released**	.	This indicator measures the quantity of radiation released during the manufacturing process.	Average quantity of radiation released	-	↓	[76]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
47	**Heat, vibration or light emitted**	.	This indicator measures the quantity of heat, vibration or light emitted during the manufacturing process.	Amount of heat, vibration or light emitted	energy units	↓	[76]	1
48	**Total Energy Consumption**	$E_{tot.}$	This indicator measures the total energy consumption of the manufacturing process.	Total energy consumed	J	↓	[77] / [14] / [27] / [76] /[30] / [33] / [43]	7
49	**Specific Energy Consumption**	$E_{spec.}$	This indicator measures the total energy consumption of the manufacturing process per production output.	Total energy consumed/Production Output	J/UP (Unit of Production, e.g. mass in t or kg, volume in m³, number, monetary value in EUR, etc.)	↓	[77] / [79] / [38] / [32] / [76]	5
50	**Source of Energy Fraction**	E_{source}	This indicator measures the quantity of each energy from different sources relative to the total amount of energy used in the production process.	Consumption per source of energy/Total energy consumption	J/J=1 (dimensionless)	Depends on the source of energy	[77] / [76]	2
51	**Renewable Energy Fraction**	E_{renew}	This indicator measures the quantity of renewable energy use relative to the total amount of energy used in the production process.	Renewable energy consumption/Total energy consumption	J/J=1 (dimensionless)	↑	[77] / [14] / [37]	3
52	**Energy for Recycling**	$E_{reclycl.}$	This indicator measures the energy required for recycling materials.	Energy used for recycling	J	↓	[77]	1
53	**Total Material Consumption**	$m_{mat., tot.}$	This indicator measures the absolute mass of material input to manufacture the product.	Total material input absolute mass in manufacturing	kg	↓	[77] / [76]	2

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
54	**Specific Material Consumption**	$m_{mat., spec.}$	This indicator measures the mass of material input per production output to manufacture the product.	(Total material input) mass/Production Output	kg/UP (Unit of Production, e.g. mass in t or kg, volume in m³, number, monetary value in EUR, etc.)	↓	[77] / [76] / [32] / [37]	4
55	**Fraction of Renewable Raw Materials**	$w_{renw. mat.}$	This indicator measures the renewable raw materials use relative to the total mass input in the manufacturing system.	(Renewable raw material input) mass/ (Total material input) mass	kg/kg=1 (dimensionless)	↑	[77] / [25]	2
56	**Raw Materials Efficiency**	$\eta_{raw mat.}$	This indicator measures the raw materials use relative to the production output of the manufacturing process, expressing the raw materials efficiency.	(Production output) mass/(Raw materials input) mass	kg/kg=1 (dimensionless)	↑	[77]	1
57	**Recycled Material Fraction**	$w_{recycl. mat.}$	This indicator measures the recycled material use relative to the total mass input in the manufacturing system. It can also be measured as an absolute indicators, refletinct the amount of recycled materials used in a period of time, for instance.	(Recycled material input) mass/(Total material input) mass	kg/kg=1 (dimensionless)	↑	[77] / [79] /[82] / [25] / [68] / [43] / [43]	7
58	**Variety of Hazardous Materials**	$N_{haz. mat.}$	This indicator measures the number of hazardous materials in the production process.	Number of hazardous materials used	number of hazardous materials	↓	[77]	1
59	**Hazardous Materials Input Mass**	$m_{haz. Mat.}$	This indicator measures the absolute mass of hazardous materials input in the production process.	Absolute mass of hazardous materials input	kg	↓	[77] / [76]	2

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
60	**Total Water Consumption**	$V_{water, tot.}$	This indicator measures the absolute volume of all water used in the production process. It can be also measured in amount of water used per year, and it can include reused water.	Absolute volume of all water used in the production process	m³	↓	[77] / [76] / [14] / [30]	4
61	**Specific Water Consumption**	$V_{water, spec.}$	This indicator measures the absolute volume of all water used in the production process relative to the production output; it can include reused water.	Water consumption volume/Production Output	m³/UP (Unit of Production, e.g. mass in t or kg, volume in m³, number, monetary value in EUR, etc.)	↓	[77] / [76] / [79] / [38]	4
62	**Volume Fraction of Water Type**	$\varphi_{water\ type}$	This indictor measures the consumption volume of water per type relative to the total consumption volume. In this context, type of water means the origin of the used water, if it's superficial, underground, reused...	Consumption volume per type of water/Total consumption volume	m³/m³=1 (dimensionless)	Depends on the type of water	[77]	1
63	**Mass Fraction of Products with an Environmental Label**	$w_{EL\ prod.}$	This indicator measures the mass fraction of products in portfolio with an Environmental Label.	Mass of products with environmental labels/Total mass of products	kg/kg=1 (dimensionless)	↑	[77]	1
64	**Mass Fraction of Products from Recyclable Materials**	$w_{recycl.\ prod.}$	This indicator measures the mass fraction of products in portfolio which are made of recyclable materials.	Mass of products from recyclable materials/Total mass of products	kg/kg=1 (dimensionless)	↑	[77]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
65	**Mass Fraction of Products Designed for Disassembly, Reuse or Recycling**	$w_{recov.\ prod.}$	This indicator measures the mass fraction of products in portfolio which are designed for Disassembly, Reuse or Recycling.	Mass of products designed for recovery/Total mass of products	kg/kg=1 (dimensionless)	↑	[77]	1
66	**Total packaging mass**	$m_{pack.}$	This indicador measures the total packaging mass used in the products.	Absolute packaging mass	kg	↓	[77]	1
67	**Packaging Mass Fraction**	w_{pack}	This indicator measures the total packaging mass used relative to the product mass production.	Packaging mass/Total mass of products	kg/kg=1 (dimensionless)	↓	[77] / [32]	2
68	**Mass Fraction of Reusable Packaging**	$w_{reus.\ pack}$	This indicator measures the total reusable packaging mass used relative to total packaging mass.	Reusable packaging mass/Total packaging mass	kg/kg=1 (dimensionless)	↑	[77] / [32] / [37]	3
69	**Total Solid Waste Mass**	$m_{s,\ tot.}$	This indicator measures the absolute mass of solid waste generated in the manufacturing process. It can be measured in a certain period of time, such as the solid waste mass generated in one day, month, year...	Absolute mass of solid waste generated	kg	↓	[77] / [76] / [14] / [30] /[82] / [43]	6
70	**Specific Solid Waste Mass per type of Waste**	$m_{s,\ spec.}$	This indicator measures the absolute mass of solid waste generated in the manufacturing process per type relative to production output.	Mass of specific type of solid waste/Production output	kg/UP (Unit of Production, e.g. mass in t or kg, volume in m³, number, monetary value in EUR, etc.)	↓	[77]	1
71	**Total Solid Waste Mass for Recovery**	$m_{s,\ recov.}$	This indicator measures the recovery solid waste absolute mass, including recycling, reuse and re-manufacture of materials and parts.	Recovery solid waste mass absolute (the recovery include recycling, reuse and re-manufacture)	kg	↑	[77]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
72	**Solid Waste Mass for Disposal**	$m_{s,\,disp.}$	This indicator measures the solid waste absolute mass generated for disposal, and can also be measured in a certain period of time.	Non-recovered solid waste mass absolute	kg	↓	[77] / [76] /[82] / [29] / [49]	5
73	**Recycled Solid Waste Mass Fraction**	$w_{s,\,recycl.}$	This indicator measures the recycled solid waste absolute mass relative to the total amount of solid waste generated.	Recycled solid waste mass/Total mass of solid waste generated	kg/kg=1 (dimensionless)	↑	[77]	1
74	**Disposal Mass Fraction**	$w_{s,\,non\text{-}recycl.}$	This indicator measures the relative quantity of non-recovered solid waste produced by the company.	Mass of non-recovered solid waste/Total mass of solid waste	kg/kg=1 (dimensionless)	↓	[77] / [68]	2
75	**Hazardous Solid Waste Mass Fraction**	$w_{s,\,haz.}$	This indicator measures the relative quantity of hazardous solid waste produced by the company.	Mass of hazardous solid waste/Total mass of solid waste	kg/kg=1 (dimensionless)	↓	[77]	1
76	**Hazardous Solid Waste Mass**	$m_{s,\,haz.}$	This indicator measures the total amount of hazardous solid waste produced by the company.	Mass of hazardous solid waste	kg	↓	[77] / [7]/ [79]	3
77	**Total volume of Liquid Waste**	$V_{l,\,tot.}$	This indicator measures the total volume of liquid waste produced by the company in a period of time.	Absolute volume	m³	↓	[77] / [76] /[82] / [27] / [33]	5
78	**Specific Liquid Waste Volume**	$V_{l,\,spec.}$	This indicator measures the relative quantity of liquid waste per unit of production.	Total volume of liquid waste/Production Output	m³/UP (Unit of Production, e.g. mass in t or kg, volume in m³, number, monetary value in EUR, etc.)	↓	[77] / [76] / [37]	3
79	**Non-polluted Liquid Waste Volume**	$V_{l,\,non\text{-}poll.}$	This indicator measures the total volume of non-polluted liquid effluents produced by the company (that has non-hazardous pollutants or is treated before released into the environment).	Absolute volume	m³	↑	[77]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
80	**Polluted Liquid Waste volume**	$V_{l, poll.}$	This indicator measures the total volume of polluted liquid effluents produced by the company.	Absolute volume	m^3	↓	[77]	1
81	**Specific Pollution Mass Ratio**	$R_{poll, spec.}$	This indicator measures the load mass of pollutants in water, such as Phosphorus, Nitrogen, Lead, etc.	Pollution load mass (e.g. P, N, AOX,...)/Production Output	kg/UP (Unit of Production, e.g. mass in t or kg, volume in m^3, number, monetary value in EUR, etc.)	↓	[77] / [76]	2
82	**Pollution Mass Concentration in Liquid Waste**	$C_{l, poll.}$	This indicator measures the mass of pollutants, such as Phosphorus, Nitrogen, Lead, etc, in relation of the total liquid waste volume.	Mass of pollutants/Liquid waste volume	kg/m^3	↓	[77] / [30]	2
83	**Greenhouse Gases Mass Fraction**	$w_{CO2equiv.}$	This indicator measures the mass fraction of greenhouse gases relative to the total mass of products manufactured.	Total mass of CO_2 equivalents/Total mass of products	kg/kg=1 (dimensionless)	↓	[77] /[73] / [37] / [30]	4
84	**Acidification Mass Fraction**	$w_{SO2equiv.}$	This indicator measures the acidification mass fraction relative to the total mass of products manufactured.	Total mass of SO_2 equivalents/Total mass of products	kg/kg=1 (dimensionless)	↓	[77] / [37]	2
85	**Photochemical Ozone Creating Potential Mass Fraction**	$w_{C2H4equiv.}$	This indicator measures the photochemical ozone creating potential mass fraction relative to the total mass of products manufactured.	Total mass of ethylene equivalents/Total mass of products	kg/kg=1 (dimensionless)	↓	[77]	1
86	**Eutrophication Mass Fraction**	$w_{PO4(-3)equiv.}$	This indicator measures the eutrophication mass fraction relative to the total mass of products manufactured.	Total mass of phosphate equivalents/Total mass of products	kg/kg=1 (dimensionless)	↓	[77]	1
87	**Life Cycle Solid Waste**	SW	This indicator measures the total solid waste generated by the product's life cycle. The factor $B_{i,l}$ is the amount of solid waste generated in each stage l of the cycle.	$$\sum_{l=1}^{L} B_l$$	mass units	↓	[7]/ [78]	2

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
88	**Life Cycle Material Intensity**	MI	This indicator represents the sum of all materials j used in the system of each stage l of life cycle.	$$\sum_{i=1}^{J}\sum_{l=1}^{L} M_{l,j}$$	kg	↓	[78]	1
89	**Life Cycle Energy Intensity**	EM	This indicator represents the sum of all energy type j consumption in the system of each stage l of the product's life cycle.	$$\sum_{i=1}^{J}\sum_{l=1}^{L} EN_{l,j}$$	MJ	↓	[78] / [55] / [45]	3
90	**Service Intensity**	SI	When the society can obtain a better service from the system at a lower environmental costs its service intensity increases. The SI indicator can be measured as the degree the company has closed the loop in providing the service as opposed to only selling the product. SI can either be measured quantitatively or expressed qualitatively, depending on the system.	Service provided by the product	-	↑	[78]	1
91	**Environmental improvements above the compliance levels**	ICL	The ICL indicator measures an average percentage decrease in environmental burdens for prescribed substances or substances that are of general concern but are not legislated, as CO_2. The factor $B_{c,i}$ is a level of burden j for company c; and the factor AL_i is a prescribed local or national level, or accepted target for this burden. The factor C depends on the type of analysis: in company- or process-oriented analysis, C=1, as you consider just one company; and in product-oriented analysis C can include all companies involved in the life cycle of the product, ranging from 2 or more.	$$\frac{\sum_{c=1}^{C}\frac{AL_j - Bc_j}{AL_j}}{C} \cdot 100$$	%	↑	[78]	1

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Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
92	**Packaging materials from suppliers**	-	The indicator expresses the mass of total packaging materials received from suppliers, considering the raw materials packaged used for manufacturing a product.	Total packaging received from suppliers	kg	↓	[79]	1
94	**Fraction for Re-assembly**	λ_{reass}	This indicator measures the volume fraction of re-assembly of a product by means the sum of the volumes of all the parts destined to re-assembly to the overall volume of the product. The product in examination is made up of n parts P_1, P_2, P_3..P_n each made of a single material, M. V_i are the material and volume of the i-th part P_i, and r parts are destined for re-assembly. It is used to calculate the indicator "Recyclable Fraction" (code 101).	$$\frac{\sum_{k=1}^{r} V_k}{\sum_{i=1}^{n} V_i}$$	dimensionless	↑	[80]	1
95	**Fraction for Re-manufacturing**	λ_{rem}	This indicator measures the volume fraction of re-manufacturing of a product by means the sum of the volumes of all the parts destined to re-manufacturing to the overall volume of the product. The product in examination is made up of n parts P_1, P_2, P_3..P_n each made of a single material, M. V_i are the material and volume of the i-th part P_i, and s parts are destined for re-manufacturing. It is used to calculate the indicator "Recyclable Fraction" (code 101).	$$\frac{\sum_{p=1}^{s} V_p}{\sum_{i=1}^{n} V_i}$$	dimensionless	↑	[80]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
96	**Fraction of Recyclable Material**	λ_{mat}	This indicator measures the volume fraction of recyclable material of a product by means the sum of the volumes of all the parts destined to recycling to the overall volume of the product. The product in examination is made up of n parts P_1, P_2, P_3..P_n each made of a single material, M. V_i are the material and volume of the i-th part P_i, and t parts are destined for recycling. It is used to calculate the indicator "Recyclable Fraction" (code 101).	$$\frac{\sum_{q=1}^{t} V_k}{\sum_{i=1}^{n} V_i}$$	dimensionless	↑	[80]	1
97	**Re-assembled Fraction**	F_{reass}	This indicator is related to the indicator "Fraction for Re-assembly" (code 94) by an α factor, which represents the volume losses involved in the recovery process with values lower than one. The product in examination is made up of n parts P1, P2, P3..Pn each made of a single material, M. Vi are the material and volume of the i-th part Pi, and s parts are destined for re-manufacturing. It is used to calculate the indicator "Recycled Fraction" (code 100).	$$\frac{\sum_{k=1}^{r} \alpha_k{}^{reass} . V_k}{\sum_{i=1}^{n} V_i}$$	dimensionless	↑	[80]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
98	Re-manufacturing Fraction	F_{rem}	This indicator is related to the indicator "Fraction for Re-manufacturing" (code 95) by an α factor, which represents the volume losses involved in the recovery process with values lower than one. The product in examination is made up of n parts P1, P2, P3..Pn each made of a single material, M. Vi are the material and volume of the i-th part Pi, and s parts are destined for re-manufacturing. It is used to calculate the indicator "Recycled Fraction" (code 100).	$$\frac{\sum_{p=1}^{s} \alpha_p{}^{rem} \, . \, Vp}{\sum_{i=1}^{n} V_i}$$	dimensionless	↑	[80]	1
99	Recyclabe Material Fraction	F_{mat}	This indicator is related to the indicator "Fraction of Recyclabe Materials" (code 96) by an α factor, which represents the volume losses involved in the recovery process with values lower than one. The product in examination is made up of n parts P1, P2, P3..Pn each made of a single material, M. Vi are the material and volume of the i-th part Pi, and s parts are destined for re-manufacturing.	$$\frac{\sum_{q=1}^{t} \alpha_{kq}{}^{mat} \, . \, Vq}{\sum_{i=1}^{n} V_i}$$	dimensionless	↑	[80]	1
100	Recycled Fraction	RF	The Recycled Fraction RF is an indicator of a second production product, which quantifies the saving of construction material. It is calculated by using the indicators "Re-assembled fraction" (code 97), and "Re-manufacturing Fraction" (code 98).	$F_{reass} + F_{rem}$	dimensionless	↑	[80]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
101	**Recyclable Fraction**	λ	The Recyclable Fraction λ quantifies the volume of the components present in the architecture destined for all kind of recovery process, and it expresses the saving of resources. It is calculated by using the indicators "Fraction for Re-assembly" (code 94), "Fraction for Re-manufacturing" (code 95), and "Fraction of Recyclable Material" (code 96).	$\lambda_{reass} + \lambda_{rem} + \lambda_{mat}$	dimensionless	↑	[80]	1
102	**Waste Disposal Fraction**	λ_{disp}	This indicator measures the volume fraction of the product which is not destined for any type of recycling, and must be disposed as waste. It is calculated by using the indicator "Recyclable Fraction" (code 101).	$1 - \lambda$	dimensionless	↓	[80]	1
103	**Useful Life**	UL	The Useful Life can be considered as an indicator of resource saving, which measures the period of time over which all or part of the product's architecture is used. If a product is not reused or remanufactured, its useful life is equal to time of use T. If there's any kind of recovery, it's necessary consider the time of use T, the number of direct reuses nr and a fraction of volume re-assembled and re-manufactured, ψ.	$[nr + \psi/1-\psi] \cdot T$	temporal units	↑	[80]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
106	**Diversity of Materials in Production**	-	A high diversity of materials utilized in the production process means complexity when connecting parts, difficulties in assembly and disassembly, and high demands of energy during manufacture. This indicator measures the number of different materials used in production process.	Number of materials utilized in the production process	number of different materials	↓	[82]	1
107	**Conformity to Law and Regulation**	-	This is an indicator which measures the accordance to environmental protection laws and regulations. It can be measured quantitatively, e.g. number of legal proceedings and prosecutions per year. The indicator can also be measured qualitatively, by checking "Yes" or "No".	Number of legal accordance to regulations, number of proceedings and prosecutions per year, ...	May vary	↑	[82] / [23]	2
108	**Packaging for Reprocessing**	-	This indicator expresses the residues from packaging post use by means quantifying the amount of used packs returned to production plant for reprocessing.	Amount of used packs returned to production plant for reprocessing	number of packs returned	↑	[82]	1
109	**Energy Consumption during Use Phase**	-	This indicator measures the amount of energy in the use phase, and it expresses the quality of responsible products in terms of low energy consumption during use phase, according to international standards. It can also be measured by type of energy used, such as the consumption of electrical energy during the lifetime of a product. It should be considered all the operational modes of a product (i.e., off-, sleep-, and idle-modes).	Amount of energy consumed in the use phase during the lifetime of a product	energy units	↓	[76] /[82] / [25] / [55] / [5] / [79] / [12] / [35]	8

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
110	**Well-being**	-	This indicator verifies the degree of satisfaction and consequently the lastingness of a product, by means, for instance, of the number of complains and requests for technical assistance.	Number of complains and requests for technical assistance per period of time, e.g. lifespan	-	↓	[82]	1
111	**Distance traveled**	-	This indicator measures the total distances traveled for sourcing, production, retail, consumer.	Distance traveled for sourcing, production, retail and consumer	distance units	↓	[2]	1
112	**Load mode of transport**	-	This indicator measures how much the space capacity of transport is used, in percentage, in terms of area, volume and weight.	% Full (area, volume, weight)	%	↑	[2]	1
113	**Stock Keeping Unit**	SKU	This indicator measures the efficiency of packaging design, through the number of units packaged togheter. Improve this measure can decrease the total mass of packaging.	Efficiency of packaging design: e.g. individual wrappings or bulk.	number of units packaged togheter for storage	↑	[2]	1
114	**Re-packaging**	-	This indicator measures the number of times product is repacked throughout supply chain. Improve this measure can reduce material consumption during pre-manufacturing and manufacturing life cycle stages.	Number of times product is repacked throughout supply chain	number of re-packaging	↓	[2]	1
115	**Number of components**	-	This indicator expresses how easily can product be recycled based on its number of components.	Number of components of the product	number of components/unit of product	↓	[8] / [64]	2
116	**Weight per Distance Traveled**	-	This indicator relate the product weight to the distance that it's transported.	Weight/distance traveled	mass units/distace units	↓	[2]	1
117	**Volume**	-	This indicator expresses the total volume taken by the product warehousing, retail, and consumer homes.	Space consumed in warehousing, retail, and consumer homes	volume units	↓	[2]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
118	**Product Density**	-	The indicator measures the concentration or compaction of the product. Can it be denser or less diluted, for instance? Reduce the volume can help in transportation, storage, and reducing the mass of packaging material.	Level of concentration or compaction of product, measured by: Product weight / product volume	mass units/volume units	↑	[2] / [5]	2
119	**Temperature Changes throughout supply chain, consumer use and disposal**	-	This indicator expresses the temperature changes during the product's life cycle, considering: Sourcing and production, as heating or cooling for storage and processing; Retail, such as temperature for storage (hot or cool) and transport; Logistics and warehousing; Consumer Use, as storage (e.g. freezer) and product usage (e.g. boiling); and End-of-Life, for example incineration of waste and melting for recycling. Reducing this temperature changes can reduce energy consumption and gaseous emissions.	Temperature changes	ºC, ºF, K, ...	↓	[2]	1
121	**Recycled Plastics Used Ratio**	-	This indicator measures the percentage of recycled plastics used in the product.	(Weight of recycled plastics/Weight of all plastics used in the product) . 100	%	↑	[5]	1
122	**Recycled Containerboard Ratio**	-	This indicator measures the percentage of recycled containerboard used in the product, including the containerboard packaging weights.	(Weight of recycled containerboard/Weight of all containerboard used in the product, including packaging) . 100	%	↑	[5]	1
123	**Weight of Package**	-	This indicator measures the absolute mass of packaging of an unit of product.	Absolute mass of packaging of the product	g	↓	[5] / [55] / [65]	3

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
124	**Useful Lifetime**	LU	This indicator measures the product's useful lifetime. It is also used to calculate the indicator "Remaining Product Useful Lifetime" (code 131).	Time of durability	days or years	Depends of product type	[76] / [5] / [10] / [77] / [78] / [2] / [8] / [22] / [38] / [55]	10
125	**Maintainable period after sales**	-	This indicator measures the maintainable time of the product after sales.	Time of maintainable	years	Depends on the product and type of maintenance	[5]	1
127	**Lubricant and Coolant Fluids**	-	This indicator is used to access the consumption of lubricants and coolants required by the machine tool, or product. It's proposed by author to measure the environmental burden of a machine tool, but can be used for all energy using products. Lubricants and coolants can be related to health effects too.	Type of lubricants and coolants, and their consumption in manufacturing and use stages	volume units	↓	[12]	1
128	**Products in reuse business/ Products in sales business**	N_{sps}	Depending on the product's nature, design for reuse can improve the environmental performance of a service. This indicator measures absolute number of products supplied in sales business.	Absolute number of products supplied in reuse business/ Absolute number of products supplied in sales business	dimensionless	↑	[10]	1
129	**Product Usage Period in Sales Business**	P_{pus}	Depending on the product's nature, design for reuse can improve the environmental performance of a service. This indicator measures the useful lifetime of the product in sales business.	Useful lifetime of the product in sales business	temporal units	Depends	[10]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
130	**Product Usage Period in Reuse Business**	P_{pur}	Depending on the product's nature, design for reuse can improve the environmental performance of a service. This indicator measures the useful lifetime of the product in reuse business. This indicator is used to calculate the indicator "Remaining Product Useful Lifetime" (code 131).	Useful lifetime of the product in reuse business	temporal units	↑	[10]	1
131	**Remaining Product Useful Lifetime**	LU_r	Depending on the product's nature, design for reuse can improve the environmental performance of a service. This indicator measures the remaining useful lifetime in reuse business, where LU is the useful lifetime and R is the usage rate against the base market. According to the author, when the remaining product useful lifetime (LUr) and the remaining product value lifetime (LVr) are longer than the product usable period, the collected product is considered to be inventory for reuse. This indicator is calculated by using the indicators "Useful Lifetime" (code 124) and "Product Usage Period in Reuse Business" (code 130).	LU - R.Ppur	temporal units	↑	[10]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
132	**Product Value Lifetime**	LV	In the author approach, the product useful lifetime (LU) is the lifetime in the traditional sense, based on internal factors such as 'product failure' and 'physical degradation'; and the product value lifetime (LV) is based on external factors, such as technology infrastructure changes and attractiveness compared with competing products. Depending on the product's nature, design for reuse can improve the environmental performance of a service. This indicator measures the period which the product can be used without an upgrade. This indicator is used to calculate the indicator "Remaining Product Value Lifetime" (code 133).	Period which the product can be used without an upgrade	temporal units	↑	[10]	1
133	**Remaining Product Value Lifetime**	LV_r	Depending on the product's nature, design for reuse can improve the environmental performance of a service. This indicator measures the remaining period which the product can be used without an upgrade, by subtracting 'the period which is the period after the product is manufactured newly' (Pam) from 'the period in which the target product can be used without an upgrade' (LV). When the remaining product useful lifetime and the remaining product value lifetime are longer than the product usable period, the collected product is considered to be inventory for reuse. This indicator is calculated by using the indicators "Product Value Lifetime" (code 132).	LV - Pam	temporal units	↑	[10]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
134	**Mean Time Between Failure**	MTBF	This indicator measures the mean period of time between failures of the product.	Mean period of time between failures	temporal units	↑	[79]	1
135	**Heavy metal emissions to water**	-	This indicator measures the total amount of heavy metal emissions to water in tons per year.	Total amount of heavy metal emissions to water per year	tons/year	↓	[14]	1
136	**Greenhouse Gases from Energy Use**	-	This indicator measures the total CO_2 emissions from energy use during manufacturing in million tons.	Total CO_2 emissions from energy use	milion tons of CO_2 emission	↓	[14]	1
137	**CFC Emissions**	-	This indicator measures the total CFC emissions during manufacturing in tons of CFC-11 per year.	Total CFC emissions per year	tons of CFC-11/year	↓	[14]	1
138	**Greenhouse Gases from Transport during Life Cycle**	-	This indicator measures the amount of carbon dioxide from transport in product's life cycle.	Amount of carbon dioxide from transport in product's life cycle	CO_2 eqv.	↓	[14]	1
139	**Post-consumer Recycled Material Use**	-	Once a material or product reaches its end-of-life, it's considered "post-consumer", which can be reused, recycled or remanufactured. This indicator measures the total amount of post-consumer recycled material use per year in the manufacturing process. Post-consumer recycled material is distinguished from pre-consumer recycled material, which is the reintroduction of manufacture scraps back in the production process.	Amount of post-consumer recycled materials per year	tons per year	↑	[14]	1
140	**Number of Different Materials**	-	This indicator measures the number of different materials in the product. Decrease this number can facilitate the disassembly and recycling process.	Number of different materials in the product	number of materials	↓	[8] / [15] / [24]	3

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
141	**Number of Recoverable Materials**	-	This indicator measures the number of recoverable materials in the product.	Number of recoverable materials in the product	-	↑	[15]	1
142	**Number of Hazardous Materials**	-	This indicator measures the number of hazardous materials in the product.	Number of different hazardous materials in the product	-	↓	[15]	1
143	**Environmental Persistence**	T	The persistence of a chemical in the environment is an important factor for the human health impact assessment. This indicator measures the persistence of a toxic chemical in the environment, where M_j is the mass in the environmental compartment j, and k_j is the decay rate of the chemical in the compartment j.	$$\frac{\sum M_j}{\sum M_j k_j}$$	mg kg day	-	[17]	1
144	**Energy Content of Raw Materials**	-	The indicator Energy Content is defined as the energy necessary to extract and produce one kg of the raw material. It also depends on recyclability, for instance, usually the energy necessary for recycling of the materials is less than the energy used for primary production.	Energy necessary to extract and produce one kg of the raw material	MJ	↓	[19]	1
145	**End-of-life scenario**	-	This indicator measures the percentage distribution of the whole product end-of-life, e.g., the materials contained in the waste streams for recycling, incineration and landfills.	% distribution of the whole product at end-of-life	% per final destination	Depends	[19]	1
146	**Amount of Restricted Materials**	-	This indicator measures the absolute mass of all restricted materials used in production.	Absolute mass of all restricted materials	mass units	↓	[25]	1
147	**Amount of Prohibited Materials**	-	This indicator measures the absolute mass of all prohibited materials used in production.	Absolute mass of all prohibited materials	mass units	↓	[25]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
148	**Fraction of Reused Components**	-	This indicator measures the number of reused components relative to the total number of components.	Number of reused components/total number of components of the product	dimensionless	↑	[25]	1
149	**Suppliers with EMS**	-	This indicator measures the number of suppliers with an EMS (Environmental Management System)	Number of suppliers with EMS	number of suppliers	↑	[25]	1
150	**Secondary Energy Use**	-	This indicator measures the amount of secondary energy use during the use phase of a product. Secondary energy can be defined as the generation of energy or fuels from other (usually primary) energy or fuels.	Amount of secondary energy used during operation	energy units	Depends	[25]	1
151	**Combustion Emissions**	-	This indicator measures the total emissions from combustion in use stage.	Total combustion emissions during use	-	↓	[25]	1
152	**Spare Parts and Consumables**	-	This indicator measures the total number of spare parts and consumables of the product.	Number of spare parts and consumables	number of parts and consumables	↓	[25]	1
153	**Existence of Disposal/Recycling Manual**	-	Having a disposal/recycling manual is important to facilitate the correct end-of-life of products.	Yes/No	-	-	[25]	1
154	**Energy Saving in Use Phase**	E_u	This indicator measures the relative energy consumption of a product, where $Output_E$ represents the total energy of output and $Input_E$ the total energy of input. The energy saving can be a result of reducing power from extraneous energy sources within a product, and/or from reducing total energy consumption of the entire product during periods of non-use.	$Output_E/Input_E$	dimensionless	↓	[24]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
155	**Mass Fraction of Reused Components**	-	This indicator measures the relative mass of the reused component in the product .	Total reused component weight/total end of life product weight	dimensionless	↑	[24] / [76]	2
157	**Landfill Fraction**	REC_L	This indicator measures the relative mass of the product destined to landfill.	total landfill component weight/total end of life product weight	dimensionless	↓	[24] / [76]	2
158	**Toxicity Mass Fraction**	Mat_H	This indicator measures the hazardous materials in the product, in percentage.	(Total hazardous material weight/Total product weight) . 100%	%	↓	[24]	1
159	**Product Weight**	Mat_W	Reduce the total product weight can avoid the resource depletion. This indicator measures the absolute product weight.	Total product weight	mass units	↓	[24] / [55] / [65] / [15] / [25]	5
160	**Wastewater Treatment Rate**	-	This indicator measures the quantity of treated waste water relative to the total generation of waste water during the manufacturing process.	Treated waste water/Waste water generation	%	↓	[27]	1
161	**Hazardous Sludge Volume**	-	This indicator measures the generation of hazardous sludge volume during the manufacturing process.	Amount of hazardous sludge volume generated	volume units	↓	[27]	1
162	**Critical Water Mass**	CTWM	This indicator measures the maximum acceptable concentration limits of pollutant substances in water emissions during manufacturing.	pollutant emission mass at interval t(kg pollutant/h) / standard limit value (kg pollutant/kg water)	kg water/h	↓	[29] / [49]	2
163	**Recovery of Residual Products Energy Consumption**	-	This indicator measures the oil fuel consumption for managing the recovery of residual products that originate at industrial plants.	Oil fuel consumption for managing the recovery of residual products	volume units	↓	[29]	1
164	**Total Transportation during Manufacturing**	-	This indicator quantifies the total kilometers travelled in manufacturing stage.	Total kilometers travelled for production purposes	km/yr	↓	[30]	1
165	**Fossil fuel consumption in transportation**	-	This indicator measures the total amount of fossil fuel used in transportation in manufacturing.	Amount of fossil fuel used in transportation during manufacturing	t/yr	↓	[30]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
166	**Product Material Sold**	-	This indicator measures the mass of product sold per total amount of materials used to manufacture it. It can be used to measure the intensity of material use.	Mass of product sold per total amount of materials used to manufacture it	t/t	↓	[30]	1
167	**Pesticide use**	-	This indicator measures the amount of pesticide use in raw materials to the production output of a product, as tomato ketchup, for instance. In this case, the indicator measures the amount of pesticide used to produce the tomatoes needed to the production output of ketchup. This indicator shows whether a shift towards less pesticide intensive production is achieved, which is important for reducing the environmental impacts.	Amount of pesticide use/production output	t/t	↓	[32]	1
168	**Volume Fraction per Transportation Mode**	-	As different modes of transport differ in their efficiency, this indicator aims to measure the proportion of transport in the whole supply chain of transport means. For instance, the shift from road to rail transport for example can reduce the energy intensity with factor 2 according to a Swedish study and respectfully the environmental impact from transportation.	Volume by means of transportation/ Total transportation volume	t.km/ t.km	Depends on transport mode	[32]	1
169	**Intensity of transportation**	-	This indicator reflects whether there is improvement in the efficiency of the freight transportation in terms of improved logistics and distance travelled.	Volume of goods transportation/product output	t.km/ t.km	↓	[32]	1
170	**Mass Fraction of Recycled Packaging**	-	This indicator measures the total recycled packaging mass used relative to total packaging mass.	Recycled packaging mass/Total packaging mass	kg/kg=1 (dimensionless)	↑	[32] / [37] / [58] / [69]	4
171	**Recovered and Recycled Plastics**	-	This indicator will show improvements in the waste treatment of plastic waste.	Recovered and recycled plastics/total plastic waste in supply chain	t/t	↑	[32]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
172	**Product Solid Waste**	-	In this approach, the product is treated as solid waste if that it's not be reused or recycled.	Volume of solid waste = volume of non-recycled or non-reused part	mm³	↓	[33]	1
173	**Noise**		The most commonly used way to measure noise is to use a sound-level meter. Harm to human beings caused by noise is directly related to the strength of noise. This indicator measures the noise emitted from the manufacturing process. The impact of the noise can be evaluated by the number of complaints of the neighborhood.		dB(A)	↓	[33] / [30] / [76] / [66]	4
175	**Biomass energy per Product**	-	This indicator measures the use o biomass energy to manufacture the product.	Biomass energy used to manufacture the product	kg/product	↑	[37]	1
176	**Natural Gas consumption per Product**	-	This indicator quantifies the natural gas used to manufacture the product.	Natural gas used to manufacture the product	MJ/product	↓	[37]	1
177	**Electricity Consumption per product**	-	This indicator quantifies the electricity used to manufacture the product.	Electricity used to manufacture the product	kWh/product	↓	[37]	1
178	**Fuel consumption per product**	-	This indicator quantifies the amount of fuel used to manufacture the product, including petrol and diesel consumption for transportation.	Fuel used to manufacture the product	liters/product	↓	[37]	1
179	**LPG consumption per product**	-	This indicator quantifies the amount of LPG (Liquefied Petroleum Gas) used to manufacture the product.	LPG used to manufacture the product	liters/product	↓	[37]	1
180	**Product Fresh Water Use**	-	This indicator measures the amount of fresh water used per product manufactured, not including reused water in manufacturing.	Amount of fresh water used per product manufactured	liters/product	↓	[37]	1
181	**Product Hazardous Materials**	-	This indicator measures the amount of hazardous materials used per product manufactured.	Amount of hazardous materials used per product manufactured	kg/product	↓	[37] / [15]	2
182	**Packaging Recyclability per Product**	-	This indicator measures the amount of recyclable packaging per product manufactured.	Amount of recyclable packaging per product	kg/product	↑	[37]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
183	Distance From Source	-	This indicator expresses the distance from source in kilometers to get raw materials for production.	Distance from source of raw materials	km/product	↓	[37]	1
184	Scrap Recyclability	-	This indicator measures the percentage of scrap recyclability in the production process per product manufactured	Percentage of scrap recyclability in the production process per product manufactured	%/product	↓	[37]	1
185	Product Rejects	-	This indicator quantifies the amount of product rejects during the use phase.	Amount of product rejects	kg/product	↓	[37]	1
186	Product Scrap	-	This indicator quantifies the amount of product scrap during the use phase.	Amount of product scrap	kg/product	↓	[37]	1
187	Product Solid Waste Fraction	-	In this approach, the product is treated as solid waste if that it's not be reused or recycled.	Mass of non-recovered parts of the product/Total mass of product	% of weight/product	↓	[37]	1
188	Product Biodegradable Packaging	-	This indicator measures the mass of biodegradable packaging relative to the total packaging per product manufactured.	Percentage of biodegradable packaging per product	%/product	↑	[37]	1
189	Packaging Scrap	-	This indicator measures the mass of packaging scrap per product manufactured.	Amount of packaging scrap per product manufactured	kg/product	↓	[37]	1
190	Ozone Depletion Substances in the Product	-	This indicator measures the amount of ozone depletion substances in the product, such as CFC and HCFC.	Amount of ozone depletion substances in the product, such as CFC and HCFC	kg/product	↓	[37]	1
191	Transportation Distance for Disposal	-	This indicator quantifies the transportation distance for disposal of waste generated to manufacture a product. Increase this rate can save energy consumption and gaseous emissions.	Transportation distance for disposal of waste generated to manufacture a product	km/product	↓	[37]	1
192	Fuel Emissions-Exhaust in Logistical Waste	-	This indicator measures the fuel emissions-exhaust due to logistical waste per product manufactured during the production process.	Fuel emissions-exhaust per product	kg gas/product	↓	[37]	1
194	Biochemical Oxygen Demand	BOD$_5$	This indicator measures the BOD discharged in ppm in effluent or kg/t.	$\frac{\sum(annual\ consumption\ of\ chem\ i\ .\ BOD\ percentage\ i)}{annual\ production}(\frac{kg}{t}product)$	ppm in effluent or kg/t	↓	[38]	1
195	Chemical Oxygen Demand	COD	This indicator measures the COD discharged in ppm in effluent or kg/t.	Similar to calculation of BOD$_5$	ppm in effluent or kg/t	↓	[38]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
196	**Specific Solid Waste Mass**		This indicator measures the absolute mass of solid waste generated in the manufacturing process relative to production output.	Mass of solid waste/Production output	kg/UP (Unit of Production, e.g. mass in t or kg, volume in m³, number, monetary value in EUR, etc.)	↓	[38] / [76] / [49]	3
199	**Materials Reusability**	R_{us}	This indicator measures the amount of reused materials relative to the total material consumption in manufacturing.	amount of reused materials / total material consumption in manufacturing	%	↑	[43]	1
202	**Defects recyclability**	D_{rec}	This indicator express the rate of recycled defective products relative to the total number of defective products.	number of recycled defective products / total number of defective products	%	↑	[43]	1
204	**By-products recyclability**	B_{rec}	This indicator measures the amount of recycled by-products relative to the total amount of by-products generated in manufacturing.	amount of recycled by-products / total amount of by-products generated	%	↑	[43]	1
213	**Total time for product retirement**	-	This indicator measures the total time for product retirement from the market.	Time to collect the product from the user + Labor time to disassemble product + Time to reuse, remanufacture, recycle, or landfill the components	temporal units	↓	[50] / [57]	2
214	**Environmental Load Factor**	ELF	This indicator measures the quantity of waste generated to manufacture the product per product's weight.	(weight of waste) / (weight of the product)	dimensionless	↓	[49]	1
215	**Reliability**	R_p	Reliability is a measure of the useful life of a product. In the formulae, n = 1, 2, 3, . . . ,N; $R_n = e^{-t/MTBE_n}$ (the reliability of component n); t is the expected product life; and MTBFn is the mean time before failure for component n.	[R1 . R2 . R3 . . . Rn] (for a system in series) or [1 - (1 - R1).(1- R2).(1 - R3) . . . (1 - Rn)] (for a system in parallel)	**dimensionless**	↑	[34]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
216	**Life Cycle Water Consumption**	-	This indicator measures the amount of input water throughout all product's life cycle, including process water and cooling water. The water data obtained for metals must be treated with caution because cooling water is not always considered by all sources, and process water is often underestimated, especially for mining and beneficiation.	Amount of input water throughout all product's life cycle	L	↓	[54]	1
217	**Volatile Organic Compounds**	VOCs	Volatile organic compounds (VOCs) are indicators of smog and ground-level ozone, with accounting units of grams (g), and can also cause neurological health problems. This indicator measures the quantity of VOCs emissions during the any life cycle stage per production output.	Quantity of VOCs emissions in any life cycle stage per production output	mass units	↓	[54] / [38]	2
218	**Persistent Organic Pollutants**	POPs	Persistent organic pollutants (POPs) include the contents of dioxins and furans in the air that are relevant to the EuP, but no emissions to water. This indicator measures the quantity of POPs emissions during the any life cycle stage.	Quantity of POPs emissions in any life cycle stage	mass units	↓	[54]	1
219	**Heavy Metals**	HMs	Heavy metals (HMs) are expressed in mg Ni-eq. This indicator measures the quantity of HMs emissions during the any life cycle stage.	Quantity of HMs emissions in any life cycle stage	mass units in Ni-eq	↓	[54]	1
220	**Polycyclic aromatic hydrocarbons**	PAHs	The current accounting unit in legislation for polycyclic aromatic hydrocarbons (PAHs) is mg Ni-eq. This indicator measures the quantity of PAHs emissions during the any life cycle stage.	Quantity of PAHs emissions in any life cycle stage	mass units in Ni-eq	↓	[54]	1
221	**Particulate Matter**	PM	Particulate Matter(PM) is an indicator for human toxicity, such as respiratory problems. This indicator measures the quantity of PM emissions during the any life cycle stage.	Quantity of PM emissions in any life cycle stage	mass units	↓	[54]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
222	Disassembly Time Ratio	-	This indicator measures the percentual reduction in time to disassembly the product, comparing a baseline model to the new (redesigned) model.	Reduction in time to dismantle the product = (1 - nem model time)/baseline model time x 100%	%	↑	[58]	1
223	Labeling of materials types	-	This indicator measures the number of different materials identified in the product, in order to facilitate collection and recycling.	Number of different materials identified in the product	number of materials	↑	[58]	1
224	Recyclability Improvement Ratio	-	This indicator reflects the improvement of percentage of materials, by weight, for which recycling is feasible.	(new model percentage - baseline model percentage)/(100% - baseline model percentage) x 100%	%	↑	[58]	1
225	Recycled glass usage	-	This indicator measures the recycled glass usage as percentage of total glass weight in the product.	Recycled glass usage in the product/Glass usage in the product x 100%	%	↑	[58]	1
226	Recycled plastics usage	-	This indicator measures the recycled plastics usage as percentage of total plastic weight in the product.	Recycled plastics usage in the product/Plastics usage in the product x 100%	%	↑	[58]	1
227	Recycled paper usage	-	This indicator measures the recycled paper usage as percentage of total paper weight in the product.	Recycled paper usage in the product/Paper usage in the product x 100%	%	↑	[58]	1
228	Product Weight Reduction Ratio	-	This indicator measures the product weight reduction ratio.	(1 - new model weight in grams)/(baseline model weight in grams) x 100%	%	↑	[58]	1
229	Product Volume Reduction Ratio	-	This indicator measures the product volume reduction ratio.	(1 - new model volume in cm³)/(baseline model volume in cm³) x 100%	%	↑	[58]	1
230	Parts Count Reduction Ratio	-	This indicator measures the product count parts reduction ratio.	(1 - new model count parts)/(baseline model count parts) x 100%	%	↑	[58]	1
231	Initial Failure Rate	-	This indicator measures the initial percentage of product's failures. The initial period of a population of units of the product is characterized by a decreasing failure rate. It is what occurs during the "early life" of this population.	Initial Failure Rate	%	↓	[58]	1
232	Annual Failure Rate	-	This indicator measures the annual percentage of product's failures.	Annual failure rate	%	↓	[58]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
233	Energy consumption in standby mode	-	This indicator measures the energy consumption in standby mode.	Energy consumption in standby mode	Watts	↓	[58]	1
234	Energy Consumption during Use Improvement Ratio	-	This indicator measures the reduction in percentage of energy consumption during use phase.	(1 - new model)/(baseline model) x 100%	%	↑	[58]	1
235	Polystyrene Foam Usage Reduction	-	This indicator measures the polystyrene foam usage reduction ratio between a baseline model and a new one (redesigned).	(1 - new model weight in grams)/(baseline model weight in grams) x 100%	%	↑	[58]	1
236	Packaging Weight Reduction Ratio	-	This indicator measures the packaging weight reduction ratio between a baseline model and a new one (redesigned).	(1 - new model weight in grams)/(baseline model weight in grams) x 100%	%	↑	[58]	1
237	Disassemblability Evaluation Score	Ei	This indicator Ei is provided by Hitachi Disassemblability Evaluation Method (DEM), which is based in a 100 point scale, and provides simultaneously the disassembly time estimation. The score acts as an index for the two goals, which are a quantitative express for ease of disassembly and indication on areas that required improvements. In the equation, τ is the demerit constant, and f is time value for operations. The demerit score, τf, reflects the time values for operations that have potential to be improved , and it expresses the degree of improvement possibility and therefore shows the possible level of the part improvements. By concentrating on parts for which the index value (Ei) is particularly low, effective design improvements can be carried out in an efficient manner. An excellent design should achieve an evaluation score, Ei, more than 80%.	$E_i = 100 - τf = 100 -$ penalty point	%	↑	[57]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
238	**Total time for disassembly**	TTD	This indicator is used as a parameter to give a measure of the efficiency of a given disassembly sequence of a product. It's calculated based on the disassemble of each subassembly x_i. In order to calculate the TTD for alternative disassembly sequences of a product, the following information must be known: disassembly sequences of the product, disassembly time of each component of the product, disassembly directions and joint types of the components of the product.	$$TTD = \sum_{i=1}^{n}\left(T_{x_{i-1},x_i}\right)$$ Where $$T_{x_{i-1},x_i} = t_{x_i} \times (1+\alpha+\beta)\ \ i = 1,2,...,n$$ $(T_{x_{i-1},x_i}) = $ Adjusted time of disassembly of x_i being disassembled after x_{i-i}	temporal units	↓	[57]	1
239	**Preparation Time**	Tp	This indicator is used to estimate the disassembly time of each component of the product. It is used to calculate the indicator "Disassembly Time of Each component" (code 243).	Time for identifying joint elements (Tpb) + Time for searching and identifying tools(Tps) + Time for gripping tools(Tpg)	temporal units	↓	[57]	1
240	**Movement time**	Tm	This indicator is used to estimate the disassembly time of each component of the product. It is used to calculate the indicator "Disassembly Time of Each component" (code 243).	Time for moving between joint elements(Tmd) + Time for redirecting toward the side of joint elements(Td)	temporal units	↓	[57]	1
241	**Operation Time/Disassembly Time**	Td	This indicator is used to estimate the disassembly time of each component of the product. It is used to calculate the indicator "Disassembly Time of Each component" (code 243).	Time for aligning between tool and joint element(Tdal) + Time for tool operation area(Tda) + Time for basic separation of joint element(Tdb) + Time for intensity of work(Tw)	temporal units	↓	[57]	1
242	**Post-processing time**	Tpr	This indicator is used to estimate the disassembly time of each component of the product. It is used to calculate the indicator "Disassembly Time of Each component" (code 243).	Time for post-processing due to weight and size of the disassembled parts (Tprsw) + Time for post-processing due to movement of disassembled parts (Tprdt) + Time for post-processing due to hazard (Tprd)	temporal units	↓	[57]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
243	Disassembly Time of each component	-	This indicator is measured by the sum of the indicators "Preparation time" (code 239), "Movement time" (code 240), "Operation time" (code 241) and "Post-processing time" (code 242).	Preparation time (Tp) + Movement time (Tm) + Operation time (Td) + Post-processing time (Tpr)	temporal units	↓	[57]	1
244	Disassembly time of the product	-	This measure of the disassembly time of the product is the sum of the disassembly time of each component, indicator "Disassembly Time of Each component" (code 243).	Sum of the disassembly time of each component of the product	temporal units	↓	[57]	1
245	Fraction of Parts to Remanufacture	-	This indicator estimates the percentage of product destined to remanufacture.	Percentage of parts of the product to remanufacture	%	↑	[64]	1
246	Reuse cycle	-	This indicator measures the reuse cycle of a reusable product, in years.	Reuse cycle in years	years	Depends	[64]	1
247	First wear-out life	-	This indicator measures the first wear-out life of a reusable product, in years. When units of the product become old, they begin to fail at an increasing rate. It is called the "wearout" period.	First wear-out life in years	years	Depends	[64]	1
248	Second wear-out life	-	This indicator measures the second wear-out life of a reusable product, in years. When units of the product become old, they begin to fail at an increasing rate. It is called the "wearout" period.	Second wear-out life in years	years	Depends	[64]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
249	**Global wear-out life**	-	This indicator measures the global wear-out life of a reusable product, in years. When units of the product become old, they begin to fail at an increasing rate. It is called the "wearout" period.	Global wear-out life in years	years	Depends	[64]	1
250	**Technology Cycle**	-	Technological cycles are composed of technological discontinuities that trigger periods of technological and competitive ferment. In more complex assembled products, these technology cycles are applied at the subsystem level.	Technology cycle of a product in years	years	Depends	[64]	1
251	**Number of modules**	-	This indicator measures the number of modules of the product.	Number of modules of the product	number of modules	↓	[64]	1
252	**Active functions**	-	This indicator measures the number of active functions in the product.	Number of active functions in the product	number of functions	↑	[64]	1
253	**Number of types of fastener**	-	This indicator measures the total number of different types of fastener in the product.	Number of different types of fastener in the product	number of different types of fastener	↓	[64]	1
254	**Total number of fastener**	-	This indicator measures the total number of fasteners in the product.	Total number of fasteners in the product	number of fasteners	↓	[64]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
255	**Product architecture**	-	A modular design facilitates reuse, recycling and remanufacture.	Non-modular/Modular	-	Modular	[64]	1
256	**Replaced parts**	-	This indicator measures the percentage of replaced parts in a reusable/remanufacturable product.	Percentage of replaced parts in the product	%	↑	[64]	1
257	**Parts reused after cleaning**	-	This indicator measures the percentage of parts reused after cleaning in a reusable/remanufacturable product.	Percentage of parts reused after cleaning	%	↑	[64]	1
258	**Percentage of parts reused after repairing**	-	This indicator measures the percentage of parts reused after repairing in a reusable/remanufacturable product.	Percentage of parts reused after repairing	%	↑	[64]	1
259	**Percentage of parts reused after reconditioning**	-	This indicator measures the percentage of parts reused after reconditioning in a reusable/remanufacturable product.	Percentage of parts reused after reconditioning	%	↑	[64]	1
260	**Energy saved for remanufacturing**	-	This indicator measures the energy saved by using remanufactured product relative to the energy use for new product.	Energy saved by using remanufactured product/energy use for new product	%	↑	[64]5.	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
261	**Reconditioned parts used in the product**	-	This indicator measures the mass rate of reconditioned parts used in the product.	Mass of reconditioned parts/Total weight of the product	%	↑	[64]	1
262	**Product and Packaging Recyclability**	-	This indicator measures the total recyclability of the product, including packaging.	Mass of recyclable material in the product and its packaging/Total mass of product including packaging	%	↑	[65]	1
263	**Weight of Manual**	-	This indicator measures the weight of the user manual of the product.	Weight of the manual	g	↓	[65]	1
264	**Total Recyclable Material in Manufacturing**	-	This indicator measures the use of recyclable materials per period of time.	Mass of recyclable material processed per period of time	mass units/month	↑	[68]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
265	**Energy-weighted mass recovery index**	EnergyIndex	This indicator measures the energy saved due to material recovery, in percentage. It explicitly provide comparison between the secondary commodity with the primary commodity that would otherwise be used for a specific application. In the formula, $_k$ represents the kth embedded material in a given flow, and m_x represents mass of a given flow. The energy factors represents: Ep_1 = total energy use to make the primary material for use in application 1, Er_1 = total energy use to prepare the secondary material for use in application 1, and $Emax$ = the total energy use to make the most energy-intensive primary material for which the secondary material could be substituted.	$$\frac{\sum_j \sum_k (Ep_{kj} - Erkj).mkj}{\sum_i \sum_k Emax_{ki}.m_{ki}}$$	%	↑	[68]	1
266	**Packaging to Landfill**	-	This indicator measures the total mass of packaging used to landfill. It can be measured also relative to the total packaging used, as a percentage.	Total mass of packaging use destined to landfill	% or kg	↓	[69]	1
267	**Life Cycle Recyclable Packaging**	-	This indicator measures the packaging recyclable used in the whole product's life cycle.	Total mass of packaging recyclable used in whole life cycle	kg	↓	[69]	1
268	**Packaging per Packaging Level**	-	This indicator measures the mass of packaging used per packaging level (subretail, retail, merchandising, traded and pallet). It can be measured also relative to the total packaging mass used in the distribution system.	Mass of packaging use per packaging level (subretail, retail, merchandising, traded and pallet)	% and kg	↓	[69]	1
269	**Packaging Material Summary**	-	This indicator measures the number of each individual packaging material in packaging system format.	Number of each individual packaging material in packaging system format	number	↓	[69]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
270	**Number of parts to be disassembled**	-	This indicator measures the actual number of parts to be disassembled.	Actual number of parts to be disassembled	number of parts	↓	[74]	1
271	**Number of parts not theoretically required**	-	This indicator measures the difference between the total number of parts and theoretical minimum number of parts.	(Total number of parts) - (Theoretical minimum number of parts)	number of parts	↓	[74]	1
272	**Number of disassembly tasks**	-	This indicator measures the total number of disassembly tasks.	Total number of disassembly tasks	number of tasks	↓	[74]	1
273	**Tasks which don't result in direct removal of a part**	-	This indicator quantifies the number of tasks which don't result in direct removal of a part.	Total number of tasks which don't result in direct removal of a part	number of tasks	↓	[74]	1
274	**Number of different tools**	-	This indicator quantifies the number of different tools used in disassembly.	Number of different tools used in disassembly	number of tools	↓	[74]	1
275	**Tool manipulations**	-	This indicator quantifies the number of tool manipulations required in disassembly.	Number of tool manipulations	number of tool manipulations	↓	[74]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
276	Hand manipulations	-	This indicator quantifies the number of hand manipulations required in disassembly.	Number of hand manipulations	number of hand manipulations	↓	[74]	1
277	Assembly Design Efficiency	-	This relative measure shows how far the assembly efficiency is from the 100% in an ideal hypothetical design. The indicator compares a given design to a hypothetical design of the same product which consists of the theoretical minimum number of parts and where each part can be assembled with minimal effort.	3 x (Theor. Minimum Number of Parts) / Actual Assembly Time	%	↑	[74]	1
278	Component Type	CT	The connection type between components in a product reflects how difficult is to destroy the connection. In the formula, the factor C_i represents the interactive index of connection for part i, which can be obtained from the table from "Additional Material" in the next column, and the n represents the number of connections.	$$\frac{\sum_{i=1}^{n} C_i}{n}$$	dimensionless	↓	[66]	1
279	Structural Depth	SD	The disassembly performance is related to the structural depth between parts of a product. The structural depth is defined according to the relative positions between two parts. In the formula, the factor D_i represents this relative position: if a part is directly connected with the standard part, $D_i = 1$; if a part is connected with the standard part by another part, $D_i = 2$, and so on. The factor m represents the total number of parts.	$$\frac{\sum_{i=1}^{m} D_i}{m}$$	dimensionless	↓	[66]	1

Code	Name	Symbol	Detailed Description	How to measure	Unit	Desired Trend	References	Recurrence
280	**Energy consumption for disassembly**	EC	Disassembly process requires energy consumption, measured by this indicator. Reducing the energy consumption in disassembly improves the disassembly performance of the product. In the formula, E_i represents the energy consumption of destroying the connection of the part i, and m is the number of parts. In the next column, "Additional Material", you can find an example of measuring the energy consumption for disassembly E_i.	$$\frac{\sum_{i=1}^{m} E_i}{m}$$	energy units	↓	[66]	1
281	**Recycling Performance**	RP	The recycling performance RP is related to the product's recyclability, according to the end-of-life options, or "Recycling methods", showed in the table in the next column ("Additional Material"). In the formula, R_i is the recycling index of part n obtained from the table beside, W_i is the mass of part i, and n is the number of parts of the product.	$$\frac{\sum_{i=1}^{n} W_i R_i}{\sum_{i=1}^{n} W_i}$$	dimensionless	↑	[66]	1
282	**Energy Efficiency**	EE	The indicator EE is related to the energy efficiency of a part of the production process, as plastic injection. It can be measured by the relation between the real work performed by this unit and the energy consumption of doing this work.	$$\frac{W}{E}$$	dimensionless	↑	[66]	1

Appendix E – Initial classification criteria definition for environmental performance indicators

This appendix contains the information regarding the initial classification criteria definition and how it was refined until the final definition, presented in phase 2 (Systematization of environmental performance indicators).

The initial definition considered six classification criteria, which are explained below. From the review process conducted after the initial classification of EPIs, three criteria remained (Ecodesign Operational Practices, Life Cycle Stages and Environmental Aspects), and three were modified or excluded (Type of measure, Lagging and Leading EPIs and Type of Analysis). Also a new criterion was added to make the selection process even easier, using keywords, as explained later in this section.

1. Initial classification criteria
The initial classification criteria are described below:

- **Ecodesign Operational Practices, Life Cycle Stages and Environmental Aspects:**

See the explanation of these at step 2.1 (section 3.2.1 - Definition of the classification criteria).

- **Type of measure:**

Jasch (2000) defines five classes of indicators according to measurement type, use and application: absolute, relative indicators, indexed indicators, aggregated depictions and weighted evaluations. EPIs were classified in the first moment according to these five types:

- absolute indicators, taken from input–output analysis;

- relative indicators, where input figures are referenced to other output variables;

- indexed indicators, where data is expressed as a percentage with respect to a total or a rate of improvement;

- aggregated depictions, where the final score is presented when same units are summed over more than one production step or product life cycle; and

- weighted evaluations, where the final score tries to depict figures of varying importance using conversion factors.

- **Lagging and Leading EPIs:**

According to Persson (2001), the context in which indicators are applied is important to be considered during the development and selection of metrics. He proposes two main categories of indicators to be used in product development:

- Indicators for eco-accounting: they can be used in external communication such as eco-labeling and product declarations for customers;

- Indicators to be used in design: they are used as problem pointers, facilitating improvements and supporting the selection between design alternatives.

It is interesting for the purpose of this research to relate the monitoring of environmental performance of products to the evaluation of company's strategic goals; in this case, it is considered that one of these strategic goals of the company is to improve the environmental performance of its products. Neely et al (2000) propose two different types of indicators to measure the performance of any program in a company: lagging and leading indicators.

Lagging indicators are known to measure the final results of a process. They are related to competitiveness and performance, and are the responsible to show if the strategic goals of a program are achieved. Leading indicators, on the other hand, are a type of indicators related to effective actions that should be taken so that the ultimate goal is reached, such as quality, flexibility, resource usage and innovation (NEELY; MILLS; PLATTS; RICHARDS; GREGORY; BOURNE; *et al.*, 2000).

Based on the approach proposed by Persson (2001) and Neely et al (2000), it can be defined two main groups of product-related EPIs:

- **Lagging EPIs:** When applying ecodesign in product development process, the main goal is to improve the environmental performance of products. As lagging indicators are used to measure the final results of a process, and considering this context, they can be related to the

environmental impacts[26] that a product can cause during its whole life cycle. These indicators measure the changes on the environment caused by product's life cycle.

▪ **Leading EPIs:** This type of product-related EPIs aims to produce measures that will inspire effective actions in improving the environmental performance of products. They are focused in measuring the technical characteristics of the product and its development, which can indicate areas of improvement or redesign. Leading EPIs measures the environmental aspects[27] of a product's life cycle activities, and are closely related to the Ecodesign Operational Practices of EcoM2.

The main difference between Lagging and Leading EPIs matches the difference between environmental impacts and environmental aspects. An environmental aspect from an activity in product's life cycle may cause a change in the natural environment, defined as environmental impact. Thus, basically, these two definitions have a cause-effect between them, illustrated by figure 1:
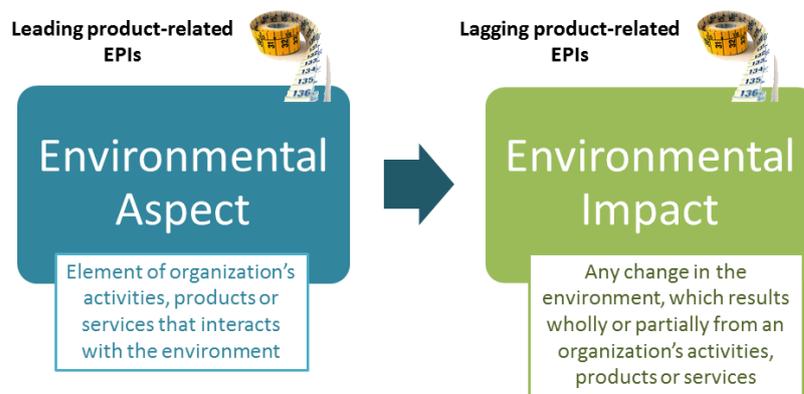
Figure 1: Relation between environmental aspects/impacts and leading/lagging EPIs.

- **Type of Analysis:**

Azapagic and Perdan (2000) present in their work a general methodological framework towards the standardization of indicators of sustainable development for industry. They argue that an appropriate standardization would enable the

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[26] According to ISO 14001 (1996), an **environmental impact** is defined as any change in the environment, which results wholly or partially from an organization's activities, products or services (OLSTHOORN *et al.*, 2001).

[27] 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 (OLSTHOORN *et al.*, 2001).

identification of more sustainable options through the comparison of similar products made by different companies and between different processes producing the same product, for instance.

Comparisons of the level of sustainability can only be made between systems that deliver the same function (AZAPAGIC; PERDAN, 2000). In this context, the authors propose three types of analysis that an indicator can provide, which are:

- Indicators of product-oriented analysis: the main purpose of this type of indicators is to allow the comparison between the different products in delivering an equivalent service or function. The comparison can be made between products of the same company or between products of different companies;

- Indicators of process-oriented analysis: the process-oriented indicators allow comparisons between different processes producing the same products and the assessment and tracking of process environmental performance;

- Indicators of company-oriented analysis: these indicators are related to the environmental performance of the whole company or its constituent parts. They are used for internal purposes, providing benchmarking of units within the company; or also for external purposes, in order to compare different companies delivering the same service/function.

2. Review of initial classification criteria

During the development of the research, it was found that a common assumption in ecodesign is to develop easy to use and consolidated methods which can be used in the earliest phases of PDP (PERSSON, J., 2001). The criterion "simple" and "easy-to-use" should be then incorporated to product-related EPIs. However, this criterion was too subjective, and the concept of leading and lagging EPIs helped to establish and define it. Leading EPIs are related to environmental aspects of products' life cycle, and they are simple and clear to enable and inspire actions for environmental improvement in product development. At the first moment, this criterion was used to classify the identified EPIs during the literature review. Then, according to the evolution of the research, this criterion was chosen to be an inclusion criterion of studies in the systematic literature review. After conducting the initial classification of EPIs, it was found in the database only 23 indicators classified as lagging. The

criterion Lagging and Leading EPIs was then excluded from the systematization, assuming that all EPIs found are leading indicators.

The criterion Type of Analysis was also reviewed in order to test its usability. It was found that most of the EPIs classified as indicators of process-oriented analysis were also classified in the category Manufacturing and Design, a products' life cycle stage (114 of 133 classified as process-oriented). It means that this criterion and the criterion Life Cycle Stage were being used to classify the same characteristics of the product. In regards to the indicators classified as product- and company-oriented, it was found that most of EPIs classified as company-oriented (18 indicators of the database) could also be used in product-oriented analysis. The criterion Type of analysis was then considered not useful and excluded from the systematization.

As the focus of the research was use leading EPIs to monitor the environmental performance of products, the two last categories of the criterion Type of measure (aggregated depictions and weighted evaluations) were considered a classification for lagging indicators, as they evolve some more complex methods for environmental performance evaluation. It was found in the database just 7 EPIs classified as aggregated depictions and just 5 classified as weighted evaluations. Also, the study of the concept of absolute and relative measures has shown that indexed indicators could also be classified as relative indicators. Thus, the criterion type of analysis was refined to just absolute and relative measures.

The new criterion was developed during the development of the guide in phase 3 of the research (see section 3.3 - Development of a guide to support the selection of EPIs), when it was found that although the three criteria applied in the Step 2 of the guide (Life Cycle Stage, Environmental Aspects and Type of measure) provides a subset of indicators, this subset still contains a large number of EPIs to be selected during Step 3. Thus, it was developed a criteria to support the selection and refine results in the database, which is using keywords to enable the identification of what exactly each EPI is measuring, such as "air emissions", "hazardous materials", "disassembly". The set contains 48 keywords.

Then, five classification criteria were selected in the final definition: Ecodesign Operational Practices, Life Cycle Stages, Environmental Aspects, Type of measure and Keywords.

Appendix F - Systematization of environmental performance indicators

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
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
5	**Material identification labels**					Identifying Materials;		Material type;						relative
6	**Tools for Disassembling**					Facilitating Disassembly;				Solid waste amount;				relative
7	**Time for Disassembly**					Facilitating Disassembly;				Solid waste amount;				relative
8	**Intelligent Materials**					Facilitating Disassembly;		Material type;						relative

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Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
9	**Time for Battery Changing**				Facilitating Upgrading and Adaptability;			Material consumption;	Energy consumption;					absolute
9	**Time for Battery Changing**				Facilitating Maintenance;			Material consumption;	Energy consumption;					absolute
10	**Laminated or Compound Materials**					Selecting Materials with the Most Efficient Recycling Technologies;		Recyclable materials;						relative
10	**Laminated or Compound Materials**					Minimizing the Overall Number of Different Incompatible Materials;		Recyclable materials;						relative
11	**Painted, Stained or Pigmented Surfaces**					Minimizing the Overall Number of Different Incompatible Materials;		Recyclable materials;						relative
12	**Ecological Rucksack**	Minimizing Material Consumption;	Engage more consumption-efficient systems;	Minimizing or avoid Packaging;				Material consumption;						absolute

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
12	**Ecological Rucksack**	Minimizing Material Consumption;	Minimizing Materials Consumption During the Product Development Phase;	Minimizing or avoid Packaging;				Material consumption;						
13	**Hazard Quotient**	Selection of Non-toxic and Harmless Resources;						Hazardous materials;						relative
14	**Cancer Risk factor**	Selection of Non-toxic and Harmless Resources;						Hazardous materials;						relative
15	**Recycled Materials in the product**					Adopting the Cascade Approach;		Recycled materials;						relative
15	**Recycled Materials in the product**					Selecting Materials with the Most Efficient Recycling Technologies;		Recycled materials;						relative
16	**Product Degree of Utilization**				Intensifying Use;			Material consumption;	Energy consumption;					relative
17	**Total Air Emissions**		Minimizing Scraps and Discards;									Gaseous emissions amount;		absolute and/or relative

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
17	**Total Air Emissions**		Minimize energy consumption during pre-production and production;									Gaseous emissions amount;		absolute and/or relative
18	**Discarded Packaging Materials per Product**			Minimizing or avoid Packaging;						Solid waste amount;				relative
19	**Reused Packaging Materials per Product**			Minimizing or avoid Packaging;				Material consumption;		Solid waste amount;				relative
20	**Auxiliary Materials recycled or reused**		Engage more consumption-efficient systems;					Auxiliary materials;		Solid waste amount;				absolute
21	**Reused Raw Materials**		Minimizing Scraps and Discards;							Solid waste amount;				absolute
22	**Reused Water**		Minimizing Scraps and Discards;					Reused water;						absolute
22	**Reused Water**		Engage more consumption-efficient systems;					Reused water;						absolute
23	**Energy generated with by-products or process streams**		Minimize energy consumption during pre-production and production;						Co-generation of energy;					absolute

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
23	Energy generated with by-products or process streams		Engage more consumption-efficient systems;						Co-generation of energy;					absolute
24	Hazardous materials used by contracted service providers	Selection of Non-toxic and Harmless Resources;						Hazardous materials;						absolute
25	Cleaning agents used by contracted service providers		Engage more consumption-efficient systems;					Hazardous materials;						absolute
25	Cleaning agents used by contracted service providers		Minimizing Materials Consumption During the Product Development Phase;					Hazardous materials;						absolute
26	Recyclable and reusable materials used by contracted service providers	Select Renewable and Bio-compatible Materials;				Selecting Materials with the Most Efficient Recycling Technologies;		Recyclable materials;						absolute

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
27	**Wastes generated by contracted service providers**		Minimizing Scraps and Discards;			Selecting Materials with the Most Efficient Recycling Technologies;				Solid waste amount;				absolute
28	**Fuel consumption of vehicle fleet**						Minimize energy consumption during transportation and storage;		Energy consumption;					absolute
29	**Freight deliveries by mode of transportation per day**						Minimize energy consumption during transportation and storage;		Energy consumption;					absolute
30	**Total land area used for production purposes**							Material consumption;						absolute
31	**Vehicles in fleet with pollution abatement technology**						Minimize energy consumption during transportation and storage;					Air pollutants;		absolute

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
32	**Number of business trips saved through other means of communication**		Minimize energy consumption during pre-production and production;						Energy consumption;			Gaseous emissions amount;		absolute
32	**Number of business trips saved through other means of communication**		Minimize energy consumption during product development;						Energy consumption;			Gaseous emissions amount;		absolute
33	**Total number of products with reduced hazard properties**	Selection of Non-toxic and Harmless Resources;						Hazardous materials;						absolute
34	**Total number of products which can be reused or recycled**				Facilitating Upgrading and Adaptability;	Facilitating Reuse;				Solid waste amount;				absolute
34	**Total number of products which can be reused or recycled**				Facilitating Maintenance;	Facilitating Remanufacturing;				Solid waste amount;				absolute

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
34	**Total number of products which can be reused or recycled**				Facilitating Repairs;	Adopting the Cascade Approach;				Solid waste amount;				absolute
34	**Total number of products which can be reused or recycled**				Facilitating Upgrading and Adaptability;	Selecting Materials with the Most Efficient Recycling Technologies;				Solid waste amount;				absolute
35	**Rate of Defective Products**		Minimizing Scraps and Discards;							Defective products;				relative
36	**By-products**		Minimizing Scraps and Discards;							By-products;				absolute and/or relative
37	**Total number of products with environmental instructions**						Provide information to users and treatment facilities;			Solid waste amount;				absolute
38	**Materials used during after-sales servicing of products**				Facilitating Upgrading and Adaptability;	Facilitating Reuse;		Material consumption;						absolute

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
38	Materials used during after-sales servicing of products				Facilitating Maintenance;	Facilitating Reuse;		Material consumption;						absolute
38	Materials used during after-sales servicing of products				Facilitating Repairs;	Facilitating Reuse;		Material consumption;						absolute
39	Specific Solid Waste Mass		Minimizing Scraps and Discards;							Solid waste amount;				relative
40	Waste stored on site		Minimizing Scraps and Discards;							Solid waste amount;				absolute
41	Waste controlled by permits		Minimizing Scraps and Discards;							Hazardous waste;				absolute
42	Waste converted to Reusable Material		Minimizing Scraps and Discards;							Solid waste amount;				absolute
43	Specific Air Emissions per Substance		Minimizing Scraps and Discards;				Minimize energy consumption during transportation and storage;					Air pollutants;		absolute

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
44	**Specific Air Emissions per Product**		Minimizing Scraps and Discards;				Minimize energy consumption during transportation and storage;					Gaseous emissions amount;		relative
45	**Landfill Waste per Product**		Minimizing Scraps and Discards;	Minimizing or avoid Packaging;						Solid waste amount;				relative
46	**Radiation released**		Minimize energy consumption during pre-production and production;				Minimize energy consumption during transportation and storage;						Radiation;	absolute
47	**Heat, vibration or light emitted**		Minimize energy consumption during pre-production and production;										Heat; Vibration; Light;	absolute
48	**Total Energy Consumption**		Minimize energy consumption during pre-production and production;				Minimize energy consumption during transportation and storage;		Energy consumption;					absolute
48	**Total Energy Consumption**		Minimize energy consumption during product development;				Minimize energy consumption during transportation and storage;		Energy consumption;					absolute

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
49	**Specific Energy Consumption**		Minimize energy consumption during pre-production and production;				Minimize energy consumption during transportation and storage;		Energy consumption;					relative
49	**Specific Energy Consumption**		Minimize energy consumption during product development;				Minimize energy consumption during transportation and storage;		Energy consumption;					relative
50	**Source of Energy Fraction**	Select Renewable and Bio-compatible Energy Resources;					Minimize energy consumption during transportation and storage;		Energy source;					relative
50	**Source of Energy Fraction**	Selecting Non-toxic and Harmless Energy Resources;					Minimize energy consumption during transportation and storage;		Energy source;					relative
51	**Renewable Energy Fraction**	Select Renewable and Bio-compatible Energy Resources;							Renewable energy;					relative
51	**Renewable Energy Fraction**	Selecting Non-toxic and Harmless Energy Resources;							Renewable energy;					relative

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
52	**Energy for Recycling**					Selecting Materials with the Most Efficient Recycling Technologies;			Energy consumption;					absolute
53	**Total Material Consumption**	Minimizing Material Content;	Minimizing Scraps and Discards;	Minimizing or avoid Packaging;				Material consumption;						absolute
53	**Total Material Consumption**	Minimizing Material Consumption;	Minimizing Materials Consumption During the Product Development Phase;	Minimizing or avoid Packaging;				Material consumption;						absolute
54	**Specific Material Consumption**	Minimizing Material Content;	Minimizing Scraps and Discards;	Minimizing or avoid Packaging;				Material consumption;						relative
54	**Specific Material Consumption**	Minimizing Material Consumption;	Minimizing Materials Consumption During the Product Development Phase;	Minimizing or avoid Packaging;				Material consumption;						relative
55	**Fraction of Renewable Raw Materials**	Select Renewable and Bio-compatible Materials;						Renewable materials;						relative
56	**Raw Materials Efficiency**		Minimizing Scraps and Discards;					Material consumption;						relative

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
56	**Raw Materials Efficiency**		Engage more consumption-efficient systems;					Material consumption;						relative
57	**Recycled Material Fraction**		Minimizing Scraps and Discards;			Adopting the Cascade Approach;		Recycled materials;						relative
57	**Recycled Material Fraction**		Minimizing Scraps and Discards;			Selecting Materials with the Most Efficient Recycling Technologies;		Recycled materials;						relative
58	**Variety of Hazardous Materials**	Selection of Non-toxic and Harmless Resources;						Hazardous materials;						absolute
59	**Hazardous Materials Input Mass**	Selection of Non-toxic and Harmless Resources;						Hazardous materials;						absolute
60	**Total Water Consumption**	Minimizing Material Consumption;						Water use;						absolute
61	**Specific Water Consumption**	Minimizing Material Consumption;						Water use;						relative
62	**Volume Fraction of Water Type**	Minimizing Material Consumption;						Source of water;						relative

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
62	**Volume Fraction of Water Type**	Select Renewable and Bio-compatible Materials;						Source of water;						relative
63	**Mass Fraction of Products with an Environmental Label**						Provide information to users and treatment facilities;	Material consumption;	Energy consumption;					relative
64	**Mass Fraction of Products from Recyclable Materials**					Adopting the Cascade Approach;		Recyclable materials;						relative
64	**Mass Fraction of Products from Recyclable Materials**					Selecting Materials with the Most Efficient Recycling Technologies;		Recyclable materials;						relative
65	**Mass Fraction of Products Designed for Disassembly, Reuse or Recycling**					Facilitating Disassembly;		Recyclable materials;		Solid waste amount;				relative

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
65	**Mass Fraction of Products Designed for Disassembly, Reuse or Recycling**					Facilitating Reuse;		Recyclable materials;		Solid waste amount;				relative
65	**Mass Fraction of Products Designed for Disassembly, Reuse or Recycling**					Adopting the Cascade Approach;		Recyclable materials;		Solid waste amount;				relative
65	**Mass Fraction of Products Designed for Disassembly, Reuse or Recycling**					Selecting Materials with the Most Efficient Recycling Technologies;		Recyclable materials;		Solid waste amount;				relative
66	**Total packaging mass**			Minimizing or avoid Packaging;				Material consumption;						absolute
67	**Packaging Mass Fraction**			Minimizing or avoid Packaging;				Material consumption;						relative
68	**Mass Fraction of Reusable Packaging**			Minimizing or avoid Packaging;				Material consumption;		Solid waste amount;				relative

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
69	Total Solid Waste Mass		Minimizing Scraps and Discards;	Minimizing or avoid Packaging;						Solid waste amount;				absolute
70	Specific Solid Waste Mass per type of Waste		Minimizing Scraps and Discards;	Minimizing or avoid Packaging;						Hazardous waste;				relative
71	Total Solid Waste Mass for Recovery		Minimizing Scraps and Discards;	Minimizing or avoid Packaging;						Solid waste amount;				absolute
72	Solid Waste Mass for Disposal		Minimizing Scraps and Discards;	Minimizing or avoid Packaging;						Solid waste amount;				absolute
73	Recycled Solid Waste Mass Fraction		Minimizing Scraps and Discards;	Minimizing or avoid Packaging;				Recycled materials;		Solid waste amount;				relative
74	Disposal Mass Fraction		Minimizing Scraps and Discards;	Minimizing or avoid Packaging;						Solid waste amount;				relative
75	Hazardous Solid Waste Mass Fraction	Selection of Non-toxic and Harmless Resources;								Hazardous waste;				relative
76	Hazardous Solid Waste Mass	Selection of Non-toxic and Harmless Resources;								Hazardous waste;				relative
77	Total volume of Liquid Waste		Minimizing Scraps and Discards;								Waste water amount;			absolute

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
78	**Specific Liquid Waste Volume**		Minimizing Scraps and Discards;								Waste water amount;			relative
79	**Non-polluted Liquid Waste Volume**		Minimizing Scraps and Discards;								Waste water amount;			absolute
80	**Polluted Liquid Waste volume**		Minimizing Scraps and Discards;								Water pollutants;			absolute
81	**Specific Pollution Mass Ratio**		Minimizing Scraps and Discards;								Water pollutants;			relative
82	**Pollution Mass Concentration in Liquid Waste**		Minimizing Scraps and Discards;								Water pollutants;			relative
83	**Greenhouse Gases Mass Fraction**	Selection of Non-toxic and Harmless Resources;					Minimize energy consumption during transportation and storage;					Air pollutants;		relative
84	**Acidification Mass Fraction**	Selection of Non-toxic and Harmless Resources;					Minimize energy consumption during transportation and storage;					Air pollutants;		relative

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
85	Photochemical Ozone Creating Potential Mass Fraction	Selection of Non-toxic and Harmless Resources;					Minimize energy consumption during transportation and storage;					Air pollutants;		relative
86	Eutrophication Mass Fraction	Selection of Non-toxic and Harmless Resources;					Minimize energy consumption during transportation and storage;				Water pollutants;			relative
87	Life Cycle Solid Waste		Minimizing Scraps and Discards;	Minimizing or avoid Packaging;						Solid waste amount;				absolute
88	Life Cycle Material Intensity	Minimizing Material Content;	Minimizing Scraps and Discards;	Minimizing or avoid Packaging;	Minimizing Materials Consumption During Usage;			Material consumption;						absolute
88	Life Cycle Material Intensity	Minimizing Material Consumption;	Engage more consumption-efficient systems;	Minimizing or avoid Packaging;	Minimizing Materials Consumption During Usage;			Material consumption;						absolute
88	Life Cycle Material Intensity	Minimizing Material Consumption;	Minimizing Materials Consumption During the Product Development Phase;	Minimizing or avoid Packaging;	Minimizing Materials Consumption During Usage;			Material consumption;						absolute
89	Life Cycle Energy Intensity		Minimize energy consumption during pre-production and production;		Select systems with energy-efficient operation and use stage;		Minimize energy consumption during transportation and storage;		Energy consumption;					absolute

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
89	Life Cycle Energy Intensity		Minimize energy consumption during product development;		Engage dynamic consumption of energy;		Minimize energy consumption during transportation and storage;		Energy consumption;					absolute
90	Service Intensity				Intensifying Use;			Material consumption;	Energy consumption;					relative
90	Service Intensity				Optimizing product functionality;			Material consumption;	Energy consumption;					relative
91	Environmental improvements above the compliance levels						Laws and regulations;	Hazardous materials;						relative
92	Packaging materials from suppliers			Minimizing or avoid Packaging;				Material consumption;		Solid waste amount;				absolute
94	Fraction for Re-assembly					Facilitating Disassembly;				Solid waste amount;				relative
95	Fraction for Re-manufacturing					Facilitating Remanufacturing;				Solid waste amount;				relative
96	Fraction of Recyclable Material					Adopting the Cascade Approach;		Recyclable materials;						relative

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
96	Fraction of Recyclable Material					Selecting Materials with the Most Efficient Recycling Technologies;		Recyclable materials;						relative
97	Re-assembled Fraction					Facilitating Disassembly;				Solid waste amount;				relative
98	Re-manufacturing Fraction					Facilitating Remanufacturing;				Solid waste amount;				relative
99	Recyclabe Material Fraction					Adopting the Cascade Approach;		Recyclable materials;						relative
99	Recyclabe Material Fraction					Selecting Materials with the Most Efficient Recycling Technologies;		Recyclable materials;						relative
100	Recycled Fraction					Adopting the Cascade Approach;		Recycled materials;						relative

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
100	**Recycled Fraction**					Selecting Materials with the Most Efficient Recycling Technologies;		Recycled materials;						relative
101	**Recyclable Fraction**					Adopting the Cascade Approach;		Recyclable materials;						relative
101	**Recyclable Fraction**					Selecting Materials with the Most Efficient Recycling Technologies;		Recyclable materials;						relative
102	**Waste Disposal Fraction**					Facilitating Reuse;				Solid waste amount;				relative
102	**Waste Disposal Fraction**					Facilitating Remanufacturing;				Solid waste amount;				relative
102	**Waste Disposal Fraction**					Adopting the Cascade Approach;				Solid waste amount;				relative

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Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
102	**Waste Disposal Fraction**					Selecting Materials with the Most Efficient Recycling Technologies;				Solid waste amount;				relative
103	**Useful Life**				Designing for Appropriate Lifespan;	Facilitating Reuse;		Material consumption;						relative
103	**Useful Life**				Designing for Reliability;	Facilitating Reuse;		Material consumption;						relative
103	**Useful Life**				Facilitating Upgrading and Adaptability;	Facilitating Reuse;		Material consumption;						relative
103	**Useful Life**				Facilitating Maintenance;	Facilitating Reuse;		Material consumption;						relative
103	**Useful Life**				Facilitating Repairs;	Facilitating Remanufacturing;		Material consumption;						relative
103	**Useful Life**				Intensifying Use;	Facilitating Remanufacturing;		Material consumption;						relative
103	**Useful Life**				Optimizing product functionality;	Facilitating Remanufacturing;		Material consumption;						relative
103	**Useful Life**				Increasing the durability of the product;	Facilitating Remanufacturing;		Material consumption;						relative

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
106	**Diversity of Materials in Production**					Minimizing the Overall Number of Different Incompatible Materials;		Material type;						absolute
107	**Conformity to Law and Regulation**						Laws and regulations;	Hazardous materials;	Energy consumption;					absolute
108	**Packaging for Reprocessing**			Minimizing or avoid Packaging;				Material consumption;						absolute
109	**Energy Consumption during Use Phase**				Select systems with energy-efficient operation and use stage;				Energy consumption;					absolute
109	**Energy Consumption during Use Phase**				Engage dynamic consumption of energy;				Energy consumption;					absolute
110	**Well-being**				Designing for Reliability;			Material consumption;	Energy consumption;					absolute
111	**Distance traveled**						Minimize energy consumption during transportation and storage;		Energy consumption;			Gaseous emissions amount;		absolute

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
112	Load mode of transport						Minimize energy consumption during transportation and storage;		Energy consumption;			Gaseous emissions amount;		relative
113	Stock Keeping Unit			Minimizing or avoid Packaging;				Material consumption;						relative
114	Re-packaging			Minimizing or avoid Packaging;				Material consumption;		Solid waste amount;				absolute
115	Number of components				Designing for Reliability;	Minimizing the Overall Number of Different Incompatible Materials;				Solid waste amount;				relative
116	Weight per Distance Traveled	Minimizing Material Content;					Minimize energy consumption during transportation and storage;		Energy consumption;			Gaseous emissions amount;		relative
117	Volume	Minimizing Material Content;		Minimizing or avoid Packaging;			Minimize energy consumption during transportation and storage;	Material consumption;						absolute

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
118	**Product Density**	Minimizing Material Content;					Minimize energy consumption during transportation and storage;	Material consumption;	Energy consumption;					relative
119	**Temperature Changes throughout supply chain, consumer use and disposal**						Minimize energy consumption during transportation and storage;		Energy consumption;			Gaseous emissions amount;		absolute
121	**Recycled Plastics Used Ratio**					Adopting the Cascade Approach;		Recycled materials;						relative
121	**Recycled Plastics Used Ratio**					Selecting Materials with the Most Efficient Recycling Technologies;		Recycled materials;						relative
122	**Recycled Containerboard Ratio**			Minimizing or avoid Packaging;		Adopting the Cascade Approach;		Recycled materials;						relative

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
122	**Recycled Containerboard Ratio**			Minimizing or avoid Packaging;		Selecting Materials with the Most Efficient Recycling Technologies;		Recycled materials;						relative
123	**Weight of Package**			Minimizing or avoid Packaging;			Minimize energy consumption during transportation and storage;	Material consumption;						absolute
124	**Useful Lifetime**				Designing for Appropriate Lifespan;			Material consumption;						absolute
124	**Useful Lifetime**				Designing for Reliability;			Material consumption;						absolute
124	**Useful Lifetime**				Facilitating Upgrading and Adaptability;			Material consumption;						absolute
124	**Useful Lifetime**				Facilitating Maintenance;			Material consumption;						absolute
124	**Useful Lifetime**				Facilitating Repairs;			Material consumption;						absolute
124	**Useful Lifetime**				Intensifying Use;			Material consumption;						absolute
124	**Useful Lifetime**				Optimizing product functionality;			Material consumption;						absolute

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
124	**Useful Lifetime**				Increasing the durability of the product;			Material consumption;						absolute
125	**Maintainable period after sales**				Facilitating Maintenance;			Material consumption;	Energy consumption;					absolute
125	**Maintainable period after sales**				Facilitating Repairs;			Material consumption;	Energy consumption;					absolute
127	**Lubricant and Coolant Fluids**	Selection of Non-toxic and Harmless Resources;	Engage more consumption-efficient systems;					Hazardous materials;						absolute
128	**Products in reuse business/ Products in sales business**					Facilitating Reuse;		Material consumption;						relative
129	**Product Usage Period in Sales Business**				Increasing the durability of the product;	Facilitating Reuse;		Material consumption;						absolute
130	**Product Usage Period in Reuse Business**				Designing for Appropriate Lifespan;	Facilitating Reuse;		Material consumption;						absolute
131	**Remaining Product Useful Lifetime**				Designing for Appropriate Lifespan;	Facilitating Reuse;		Material consumption;						absolute
131	**Remaining Product Useful Lifetime**				Designing for Reliability;	Facilitating Reuse;		Material consumption;						absolute

| Code | Name | Life Cycle Stage | | | | | | Environmental Aspects | | | | | | Type of Measure |
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
131	**Remaining Product Useful Lifetime**				Facilitating Upgrading and Adaptability;	Facilitating Reuse;		Material consumption;						absolute
131	**Remaining Product Useful Lifetime**				Facilitating Maintenance;	Facilitating Reuse;		Material consumption;						absolute
131	**Remaining Product Useful Lifetime**				Facilitating Repairs;	Facilitating Reuse;		Material consumption;						absolute
131	**Remaining Product Useful Lifetime**				Intensifying Use;	Facilitating Reuse;		Material consumption;						absolute
131	**Remaining Product Useful Lifetime**				Optimizing product functionality;	Facilitating Reuse;		Material consumption;						absolute
131	**Remaining Product Useful Lifetime**				Increasing the durability of the product;	Facilitating Reuse;		Material consumption;						absolute
132	**Product Value Lifetime**				Designing for Appropriate Lifespan;	Facilitating Reuse;		Material consumption;						absolute
132	**Product Value Lifetime**				Designing for Reliability;	Facilitating Reuse;		Material consumption;						absolute
132	**Product Value Lifetime**				Facilitating Upgrading and Adaptability;	Facilitating Reuse;		Material consumption;						absolute
132	**Product Value Lifetime**				Facilitating Maintenance;	Facilitating Reuse;		Material consumption;						absolute

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
132	**Product Value Lifetime**				Facilitating Repairs;	Facilitating Reuse;		Material consumption;						absolute
132	**Product Value Lifetime**				Intensifying Use;	Facilitating Reuse;		Material consumption;						absolute
132	**Product Value Lifetime**				Optimizing product functionality;	Facilitating Reuse;		Material consumption;						absolute
132	**Product Value Lifetime**				Increasing the durability of the product;	Facilitating Reuse;		Material consumption;						absolute
133	**Remaining Product Value Lifetime**				Designing for Appropriate Lifespan;	Facilitating Reuse;		Material consumption;						absolute
133	**Remaining Product Value Lifetime**				Designing for Reliability;	Facilitating Reuse;		Material consumption;						absolute
133	**Remaining Product Value Lifetime**				Facilitating Upgrading and Adaptability;	Facilitating Reuse;		Material consumption;						absolute
133	**Remaining Product Value Lifetime**				Facilitating Maintenance;	Facilitating Reuse;		Material consumption;						absolute
133	**Remaining Product Value Lifetime**				Facilitating Repairs;	Facilitating Reuse;		Material consumption;						absolute
133	**Remaining Product Value Lifetime**				Optimizing product functionality;	Facilitating Reuse;		Material consumption;						absolute

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
133	Remaining Product Value Lifetime				Increasing the durability of the product;	Facilitating Reuse;		Material consumption;						absolute
133	Remaining Product Value Lifetime				Intensifying Use;	Facilitating Reuse;		Material consumption;						absolute
134	Mean Time Between Failure				Designing for Reliability;			Material consumption;	Energy consumption;					absolute
135	Heavy metal emissions to water	Selection of Non-toxic and Harmless Resources;									Water pollutants;			relative
136	Greenhouse Gases from Energy Use	Select Renewable and Bio-compatible Energy Resources;	Minimize energy consumption during pre-production and production;				Minimize energy consumption during transportation and storage;		Energy consumption;			Air pollutants;		absolute
137	CFC Emissions	Selection of Non-toxic and Harmless Resources;					Minimize energy consumption during transportation and storage;					Air pollutants;		absolute
138	Greenhouse Gases from Transport during Life Cycle	Select Renewable and Bio-compatible Energy Resources;					Minimize energy consumption during transportation and storage;					Air pollutants;		absolute

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
139	**Post-consumer Recycled Material Use**					Adopting the Cascade Approach;		Recycled materials;						absolute
139	**Post-consumer Recycled Material Use**					Selecting Materials with the Most Efficient Recycling Technologies;		Recycled materials;						absolute
140	**Number of Different Materials**					Minimizing the Overall Number of Different Incompatible Materials;		Recyclable materials;						absolute
141	**Number of Recoverable Materials**					Adopting the Cascade Approach;		Recyclable materials;						absolute
141	**Number of Recoverable Materials**					Selecting Materials with the Most Efficient Recycling Technologies;		Recyclable materials;						absolute
142	**Number of Hazardous Materials**	Selection of Non-toxic and Harmless Resources;						Hazardous materials;						absolute

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
143	**Environmental Persistence**	Selection of Non-toxic and Harmless Resources;						Hazardous materials;						relative
144	**Energy Content of Raw Materials**	Minimize energy consumption during pre-production and production;							Energy consumption;					absolute
144	**Energy Content of Raw Materials**	Select Renewable and Bio-compatible Materials;							Energy consumption;					absolute
145	**End-of-life scenario**					Facilitating Reuse;				Solid waste amount;				relative
145	**End-of-life scenario**					Facilitating Remanufacturing;				Solid waste amount;				relative
145	**End-of-life scenario**					Adopting the Cascade Approach;				Solid waste amount;				relative
145	**End-of-life scenario**					Selecting Materials with the Most Efficient Recycling Technologies;				Solid waste amount;				relative
145	**End-of-life scenario**					Facilitating Disassembly;				Solid waste amount;				relative

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
146	Amount of Restricted Materials	Selection of Non-toxic and Harmless Resources;					Laws and regulations;	Hazardous materials;						absolute
147	Amount of Prohibited Materials	Selection of Non-toxic and Harmless Resources;					Laws and regulations;	Hazardous materials;						absolute
148	Fraction of Reused Components					Facilitating Reuse;				Solid waste amount;				relative
149	Suppliers with EMS						Laws and regulations;	Material consumption;	Energy consumption;					absolute
150	Secondary Energy Use				Select systems with energy-efficient operation and use stage;				Energy consumption;					absolute
150	Secondary Energy Use				Engage dynamic consumption of energy;				Energy consumption;					absolute
151	Combustion Emissions				Select systems with energy-efficient operation and use stage;							Gaseous emissions amount;		absolute

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
151	**Combustion Emissions**				Engage dynamic consumption of energy;							Gaseous emissions amount;		absolute
152	**Spare Parts and Consumables**				Minimizing Materials Consumption During Usage;			Material consumption;						absolute
152	**Spare Parts and Consumables**				Engage systems of flexible materials consumption;			Material consumption;						absolute
153	**Existence of Disposal/Recycling Manual**					Provide collection and processing of the product at its end of life;	Provide information to users and treatment facilities;			Solid waste amount;				absolute
154	**Energy Saving in Use Phase**				Select systems with energy-efficient operation and use stage;				Energy consumption;					relative
154	**Energy Saving in Use Phase**				Engage dynamic consumption of energy;				Energy consumption;					relative
155	**Mass Fraction of Reused Components**					Facilitating Reuse;				Solid waste amount;				relative

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
157	**Landfill Fraction**		Minimizing Scraps and Discards;			Facilitating Reuse;				Solid waste amount;				relative
157	**Landfill Fraction**		Minimizing Scraps and Discards;			Facilitating Remanufacturing;				Solid waste amount;				relative
157	**Landfill Fraction**		Minimizing Scraps and Discards;			Adopting the Cascade Approach;				Solid waste amount;				relative
157	**Landfill Fraction**		Minimizing Scraps and Discards;			Selecting Materials with the Most Efficient Recycling Technologies;				Solid waste amount;				relative
158	**Toxicity Mass Fraction**	Selection of Non-toxic and Harmless Resources;						Hazardous materials;						relative
159	**Product Weight**	Minimizing Material Content;						Material consumption;	Energy consumption;					absolute
160	**Wastewater Treatment Rate**		Minimizing Scraps and Discards;								Water pollutants;			relative
161	**Hazardous Sludge Volume**	Selection of Non-toxic and Harmless Resources;	Minimizing Scraps and Discards;							Hazardous waste;	Water pollutants;			absolute

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
162	**Critical Water Mass**	Selection of Non-toxic and Harmless Resources;									Water pollutants;			relative
163	**Recovery of Residual Products Energy Consumption**		Minimizing Scraps and Discards;						Energy consumption;					absolute
163	**Recovery of Residual Products Energy Consumption**		Minimize energy consumption during pre-production and production;						Energy consumption;					absolute
164	**Total Transportation during Manufacturing**						Minimize energy consumption during transportation and storage;		Energy consumption;			Gaseous emissions amount;		absolute
165	**Fossil fuel consumption in transportation**		Minimize energy consumption during pre-production and production;				Minimize energy consumption during transportation and storage;		Energy consumption;			Gaseous emissions amount;		absolute
166	**Product Material Sold**		Minimizing Scraps and Discards;					Material consumption;						relative
167	**Pesticide use**	Selection of Non-toxic and Harmless Resources;						Hazardous materials;						relative

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
167	**Pesticide use**	Select Renewable and Bio-compatible Materials;						Hazardous materials;						relative
168	**Volume Fraction per Transportation Mode**	Minimize energy consumption during pre-production and production;					Minimize energy consumption during transportation and storage;		Energy consumption;					absolute
168	**Volume Fraction per Transportation Mode**	Select Renewable and Bio-compatible Energy Resources;					Minimize energy consumption during transportation and storage;		Energy consumption;					absolute
169	**Intensity of transportation**		Minimize energy consumption during pre-production and production;				Minimize energy consumption during transportation and storage;		Energy consumption;					relative
170	**Mass Fraction of Recycled Packaging**			Minimizing or avoid Packaging;				Recycled materials;						relative
171	**Recovered and Recycled Plastics**					Selecting Materials with the Most Efficient Recycling Technologies;		Recycled materials;						relative

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Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
172	**Product Solid Waste**					Provide collection and processing of the product at its end of life;	Provide information to users and treatment facilities;			Solid waste amount;				absolute
173	**Noise**		Minimize energy consumption during pre-production and production;										Noise;	absolute
175	**Biomass energy per Product**	Select Renewable and Bio-compatible Energy Resources;							Energy consumption;					relative
176	**Natural Gas consumption per Product**		Minimize energy consumption during pre-production and production;						Energy consumption;					relative
177	**Electricity Consumption per product**		Minimize energy consumption during pre-production and production;						Energy consumption;					relative
178	**Fuel consumption per product**		Minimize energy consumption during pre-production and production;						Energy consumption;					relative

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Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
179	**LPG consumption per product**		Minimize energy consumption during pre-production and production;						Energy consumption;					relative
180	**Product Fresh Water Use**		Minimizing Scraps and Discards;					Water use;						relative
181	**Product Hazardous Materials**	Selection of Non-toxic and Harmless Resources;						Hazardous materials;						relative
182	**Packaging Recyclability per Product**			Minimizing or avoid Packaging;				Recyclable materials;						relative
183	**Distance From Source**	Minimize energy consumption during pre-production and production;							Energy consumption;					relative
184	**Scrap Recyclability**		Minimizing Scraps and Discards;					Recyclable materials;						relative
185	**Product Rejects**				Minimizing Materials Consumption During Usage;					Solid waste amount;				relative
185	**Product Rejects**				Engage systems of flexible materials consumption;					Solid waste amount;				relative

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
186	**Product Scrap**				Minimizing Materials Consumption During Usage;					Solid waste amount;				relative
186	**Product Scrap**				Engage systems of flexible materials consumption;					Solid waste amount;				relative
187	**Product Solid Waste Fraction**					Provide collection and processing of the product at its end of life;	Provide information to users and treatment facilities;			Solid waste amount;				relative
188	**Product Biodegradable Packaging**	Select Renewable and Bio-compatible Materials;		Minimizing or avoid Packaging;				Biodegradable materials;						relative
189	**Packaging Scrap**			Minimizing or avoid Packaging;						Solid waste amount;				relative
190	**Ozone Depletion Substances in the Product**	Selection of Non-toxic and Harmless Resources;										Air pollutants;		relative
191	**Transportation Distance for Disposal**						Minimize energy consumption during transportation and storage;		Energy consumption;					relative

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
192	**Fuel Emissions-Exhaust in Logistical Waste**						Minimize energy consumption during transportation and storage;					Gaseous emissions amount;		relative
194	**Biochemical Oxygen Demand**	Selection of Non-toxic and Harmless Resources;									Water pollutants;			relative
194	**Biochemical Oxygen Demand**	Select Renewable and Bio-compatible Materials;									Water pollutants;			relative
195	**Chemical Oxygen Demand**	Selection of Non-toxic and Harmless Resources;									Water pollutants;			relative
195	**Chemical Oxygen Demand**	Select Renewable and Bio-compatible Materials;									Water pollutants;			relative
196	**Specific Solid Waste Mass**		Minimizing Scraps and Discards;							Solid waste amount;				relative
199	**Materials Reusability**		Engage more consumption-efficient systems;							Solid waste amount;				relative

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Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
202	**Defects recyclability**		Minimizing Scraps and Discards;			Selecting Materials with the Most Efficient Recycling Technologies;				Defective products;				relative
204	**By-products recyclability**		Minimizing Scraps and Discards;							By-products;				relative
213	**Total time for product retirement**					Facilitating Reuse;	Provide information to users and treatment facilities;			Solid waste amount;				absolute
213	**Total time for product retirement**					Facilitating Remanufacturing;	Provide information to users and treatment facilities;			Solid waste amount;				absolute
213	**Total time for product retirement**					Facilitating Disassembly;	Provide information to users and treatment facilities;			Solid waste amount;				absolute
213	**Total time for product retirement**					Provide collection and processing of the product at its end of life;	Provide information to users and treatment facilities;			Solid waste amount;				absolute

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
213	**Total time for product retirement**					Identifying Materials;	Provide information to users and treatment facilities;			Solid waste amount;				absolute
213	**Total time for product retirement**					Minimizing the Overall Number of Different Incompatible Materials;	Provide information to users and treatment facilities;			Solid waste amount;				absolute
213	**Total time for product retirement**					Facilitating End-of-life Collection and Transportation;	Provide information to users and treatment facilities;			Solid waste amount;				absolute
214	**Environmental Load Factor**		Minimizing Scraps and Discards;							Solid waste amount;				relative
215	**Reliability**				Designing for Reliability;			Material consumption;	Energy consumption;					absolute
216	**Life Cycle Water Consumption**	Minimizing Material Consumption;	Engage more consumption-efficient systems;					Water use;						absolute
217	**Volatile Organic Compounds**	Selection of Non-toxic and Harmless Resources;										Air pollutants;		absolute

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
218	Persistent Organic Pollutants	Selection of Non-toxic and Harmless Resources;										Air pollutants;		absolute
219	Heavy Metals	Selection of Non-toxic and Harmless Resources;									Water pollutants ;	Air pollutants;		absolute
220	Polycyclic aromatic hydrocarbons	Selection of Non-toxic and Harmless Resources;										Air pollutants;		absolute
221	Particulate Matter	Selection of Non-toxic and Harmless Resources;										Air pollutants;		absolute
222	Disassembly Time Ratio					Facilitating Disassembly;				Solid waste amount;				relative
223	Labeling of materials types					Identifying Materials;		Material type;						absolute
224	Recyclability Improvement Ratio					Adopting the Cascade Approach;		Recyclable materials;						relative
224	Recyclability Improvement Ratio					Materials with the Most Efficient Recycling Technologies;		Recyclable materials;						relative

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Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
225	**Recycled glass usage**					Adopting the Cascade Approach;		Recycled materials;						relative
225	**Recycled glass usage**					Selecting Materials with the Most Efficient Recycling Technologies;		Recycled materials;						relative
226	**Recycled plastics usage**					Adopting the Cascade Approach;		Recycled materials;						relative
226	**Recycled plastics usage**					Selecting Materials with the Most Efficient Recycling Technologies;		Recycled materials;						relative
227	**Recycled paper usage**					Adopting the Cascade Approach;		Recycled materials;						relative
227	**Recycled paper usage**					Selecting Materials with the Most Efficient Recycling Technologies;		Recycled materials;						relative

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Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
228	**Product Weight Reduction Ratio**	Minimizing Material Content;				Facilitating End-of-life Collection and Transportation;	Minimize energy consumption during transportation and storage;	Material consumption;	Energy consumption;					relative
229	**Product Volume Reduction Ratio**	Minimizing Material Content;				Facilitating End-of-life Collection and Transportation;	Minimize energy consumption during transportation and storage;	Material consumption;	Energy consumption;					relative
230	**Parts Count Reduction Ratio**				Designing for Reliability;					Solid waste amount;				relative
231	**Initial Failure Rate**				Designing for Reliability;			Material consumption;	Energy consumption;					relative
232	**Annual Failure Rate**				Designing for Reliability;			Material consumption;	Energy consumption;					relative
233	**Energy consumption in standby mode**				Select systems with energy-efficient operation and use stage;				Energy consumption;					absolute
233	**Energy consumption in standby mode**				Engage dynamic consumption of energy;				Energy consumption;					absolute

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
234	Energy Consumption during Use Improvement Ratio				Select systems with energy-efficient operation and use stage;				Energy consumption;					relative
234	Energy Consumption during Use Improvement Ratio				Engage dynamic consumption of energy;				Energy consumption;					relative
235	Polystyrene Foam Usage Reduction		Engage more consumption-efficient systems;	Minimizing or avoid Packaging;				Material consumption;						relative
236	Packaging Weight Reduction Ratio			Minimizing or avoid Packaging;				Material consumption;						relative
237	Disassemblability Evaluation Score					Facilitating Disassembly;				Solid waste amount;				relative
238	Total time for disassembly					Facilitating Disassembly;				Solid waste amount;				absolute
239	Preparation Time					Facilitating Disassembly;				Solid waste amount;				absolute
240	Movement time					Facilitating Disassembly;				Solid waste amount;				absolute
241	Operation Time/Disassembly Time					Facilitating Disassembly;				Solid waste amount;				absolute

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Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
242	Post-processing time					Facilitating Disassembly;				Solid waste amount;				absolute
243	Disassembly Time of each component					Facilitating Disassembly;				Solid waste amount;				absolute
244	Disassembly time of the product					Facilitating Disassembly;				Solid waste amount;				absolute
245	Fraction of Parts to Remanufacture					Facilitating Remanufacturing;				Solid waste amount;				relative
246	Reuse cycle					Facilitating Reuse;				Solid waste amount;				absolute
247	First wear-out life					Facilitating Reuse;				Solid waste amount;				absolute
248	Second wear-out life					Facilitating Reuse;				Solid waste amount;				absolute
249	Global wear-out life					Facilitating Reuse;				Solid waste amount;				absolute
250	Technology Cycle				Designing for Appropriate Lifespan;			Material consumption;						absolute
251	Number of modules				Designing for Reliability;					Solid waste amount;				absolute
252	Active functions				Optimizing product functionality;			Material consumption;						absolute

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
253	**Number of types of fastener**					Facilitating Disassembly;				Solid waste amount;				absolute
254	**Total number of fastener**					Facilitating Disassembly;				Solid waste amount;				absolute
255	**Product architecture**				Designing for Appropriate Lifespan;	Facilitating Reuse;				Solid waste amount;				absolute
255	**Product architecture**				Facilitating Upgrading and Adaptability;	Facilitating Reuse;				Solid waste amount;				absolute
255	**Product architecture**				Optimizing product functionality;	Facilitating Reuse;				Solid waste amount;				absolute
255	**Product architecture**				Facilitating Disassembly;	Facilitating Reuse;				Solid waste amount;				absolute
256	**Replaced parts**				Facilitating Upgrading and Adaptability;	Facilitating Reuse;				Solid waste amount;				absolute
257	**Parts reused after cleaning**				Facilitating Cleaning;	Facilitating Reuse;				Solid waste amount;				absolute
258	**Percentage of parts reused after repairing**				Facilitating Repairs;	Facilitating Reuse;				Solid waste amount;				absolute

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
259	**Percentage of parts reused after reconditioning**					Facilitating Reuse;				Solid waste amount;				absolute
259	**Percentage of parts reused after reconditioning**					Facilitating Remanufacturing;				Solid waste amount;				absolute
260	**Energy saved for remanufacturing**	Minimize energy consumption during pre-production and production;				Facilitating Remanufacturing;			Energy consumption;					absolute
261	**Reconditioned parts used in the product**					Facilitating Remanufacturing;				Solid waste amount;				absolute
262	**Product and Packaging Recyclability**			Minimizing or avoid Packaging;		Selecting Materials with the Most Efficient Recycling Technologies;		Recyclable materials;						absolute
263	**Weight of Manual**	Minimizing Material Content;						Material consumption;						absolute

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
264	**Total Recyclable Material in Manufacturing**					Selecting Materials with the Most Efficient Recycling Technologies;		Recyclable materials;						absolute
265	**Energy-weighted mass recovery index**	Minimize energy consumption during pre-production and production;				Selecting Materials with the Most Efficient Recycling Technologies;			Energy consumption;					relative
266	**Packaging to Landfill**			Minimizing or avoid Packaging;				Material consumption;		Solid waste amount;				absolute and/or relative
267	**Life Cycle Recyclable Packaging**			Minimizing or avoid Packaging;				Recyclable materials;						absolute
268	**Packaging per Packaging Level**			Minimizing or avoid Packaging;				Material consumption;						absolute and/or relative
269	**Packaging Material Summary**			Minimizing or avoid Packaging;				Material consumption;						absolute
270	**Number of parts to be disassembled**					Facilitating Disassembly;				Solid waste amount;				absolute

Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
271	Number of parts not theoretically required				Designing for Reliability;					Solid waste amount;				absolute
272	Number of disassembly tasks					Facilitating Disassembly;				Solid waste amount;				absolute
273	Tasks which don't result in direct removal of a part					Facilitating Disassembly;				Solid waste amount;				absolute
274	Number of different tools					Facilitating Disassembly;				Solid waste amount;				absolute
275	Tool manipulations					Facilitating Disassembly;				Solid waste amount;				absolute
276	Hand manipulations					Facilitating Disassembly;				Solid waste amount;				absolute
277	Assembly Design Efficiency		Design for reliability;							Solid waste amount;				relative
278	Component Type					Facilitating Disassembly;				Solid waste amount;				relative
279	Structural Depth					Facilitating Disassembly;				Solid waste amount;				relative

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Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
		Pre-manufacturing	Manufacturing and Design	Distribution and Packaging	Use and maintenance	End-of-life	General Activities	Material	Energy	Solid waste	Waste water	Gaseous Emissions	Energy Loss	
280	Energy consumption for disassembly					Facilitating Disassembly;			Energy consumption;					absolute
281	Recycling Performance					Selecting Materials with the Most Efficient Recycling Technologies;		Recyclable materials;						relative
282	Energy Efficiency		Minimize energy consumption during pre-production and production;						Energy consumption;					relative

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.

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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[28] 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)[29] 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.

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

[29] 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/)

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.

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[30] 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.

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[30] 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:

o   More and emerging product-related laws and regulations establishing life cycle thinking for product development;

o   Opportunities for reducing costs and increasing revenues, enhancing competitiveness; and

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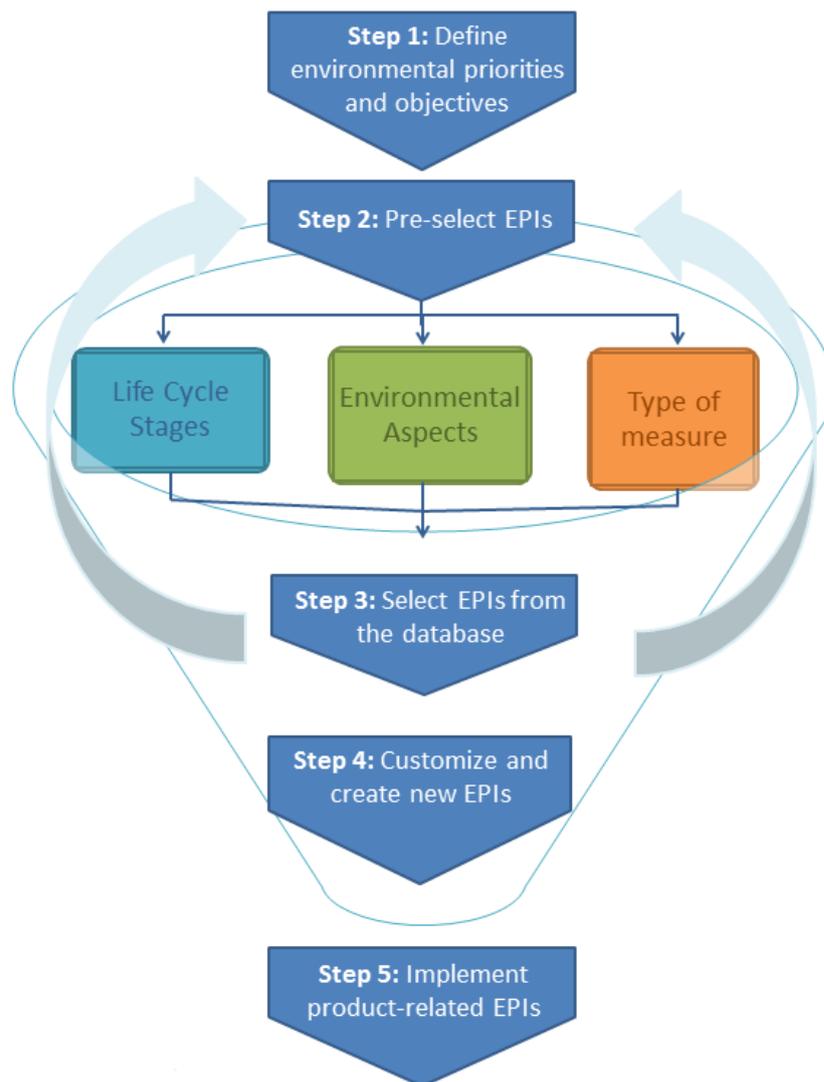
Figure 1: Selecting product-related environmental performance indicators in 5 steps

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:

Environmental impacts

- 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.

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:

Environmental priorities and objectives

- 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.

Selection Tool	Code	Name	Life Cycle Stage						Environmental Aspects						Type of Measure
			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	
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

Environmental priorities and objectives

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.

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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.

Subsets of EPIs

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

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.

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 Reuse;
- Facilitating Cleaning;
- Facilitating Disassembly.

General Activities:

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

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).

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.

Distribution and Packaging

- Minimizing or avoid Packaging.

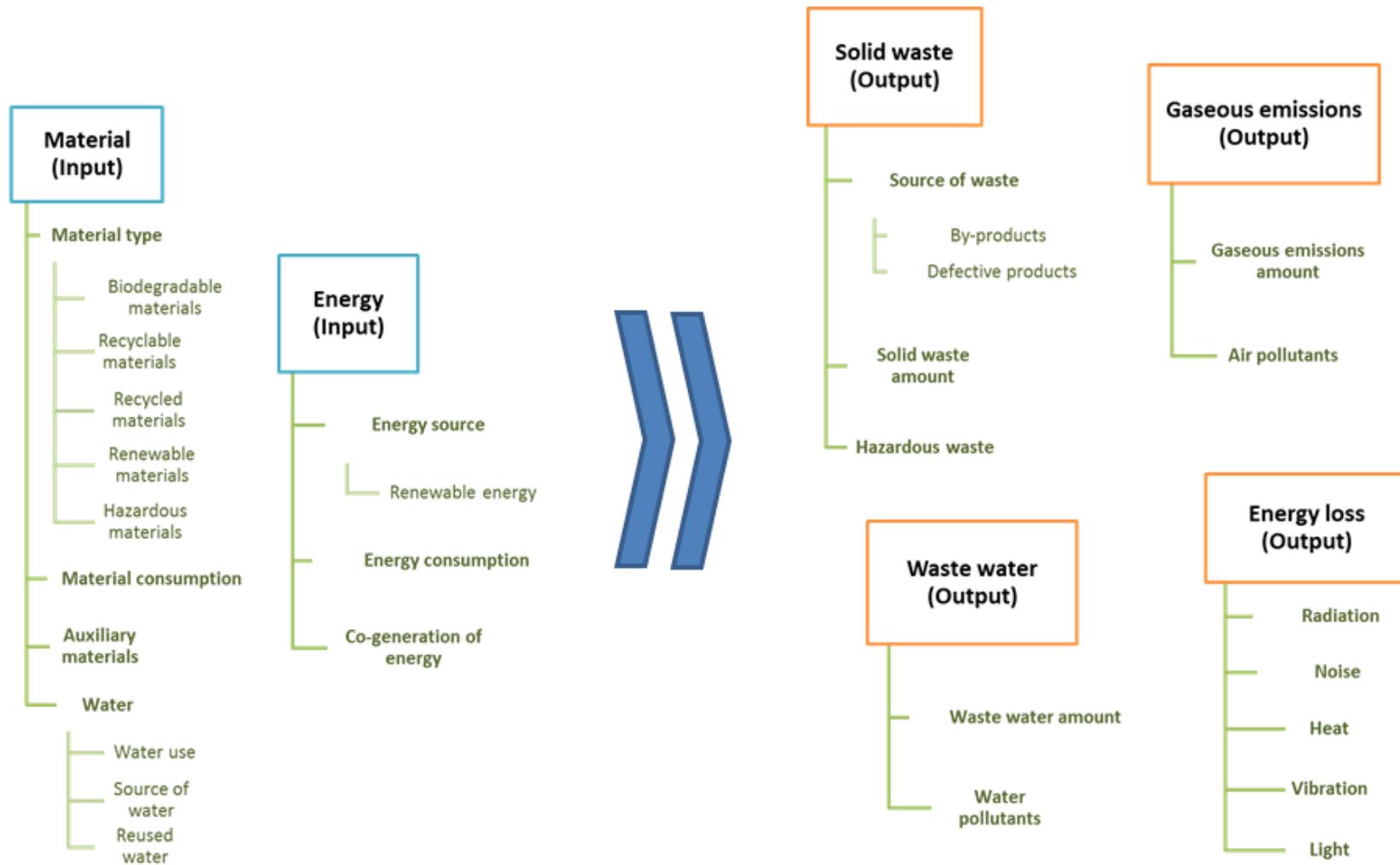**Figure 3: Life cycle stages and related environmental objectives**

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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.

Subsets of EPIs

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.

Set of EPIs

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.

Set of EPIs → 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.

Full set of EPIs

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.

Full set of EPIs

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!

Implementation

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!

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;

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- 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.

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:

Environmental Aspect

Element of organization's activities, products or services that interacts with the environment

Environmental Impact

Any change in the environment, which results wholly or partially from an organization's activities, products or services
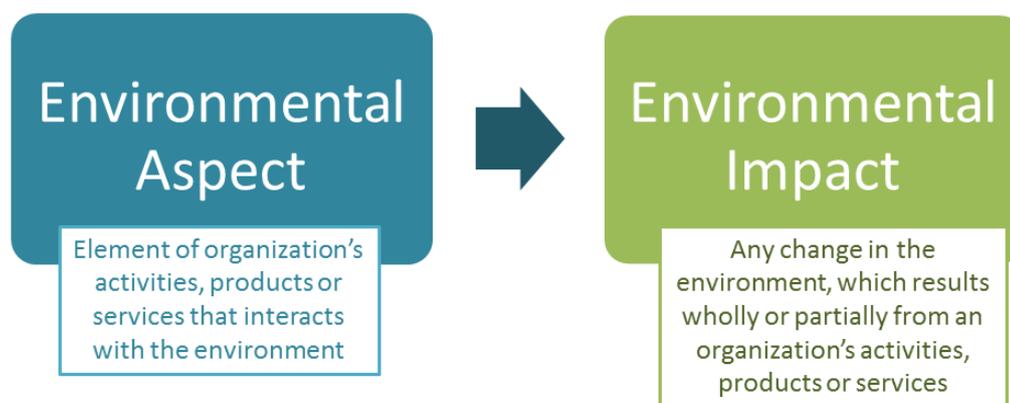
Figure 6: Environmental aspects lead to environmental impacts

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.

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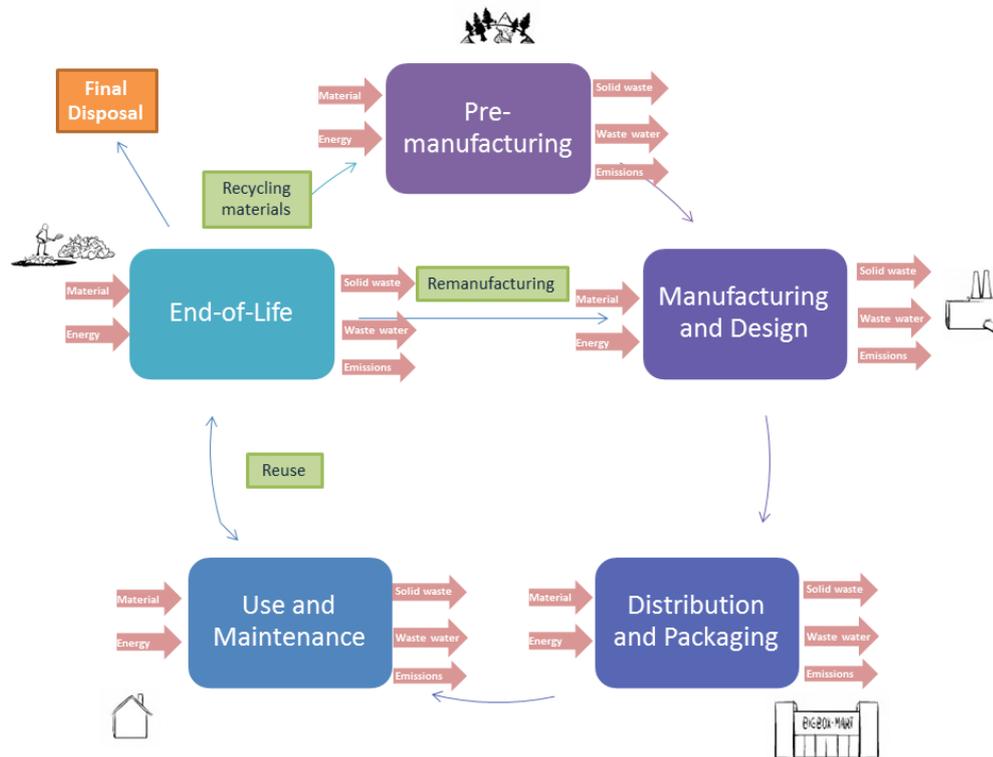
Figure 8: Relationship among product life cycle stages and environmental aspects. Adapted from Yarwood & Eagan (1998) and The Story of Stuff Project (http://www.storyofstuff.org/).

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".

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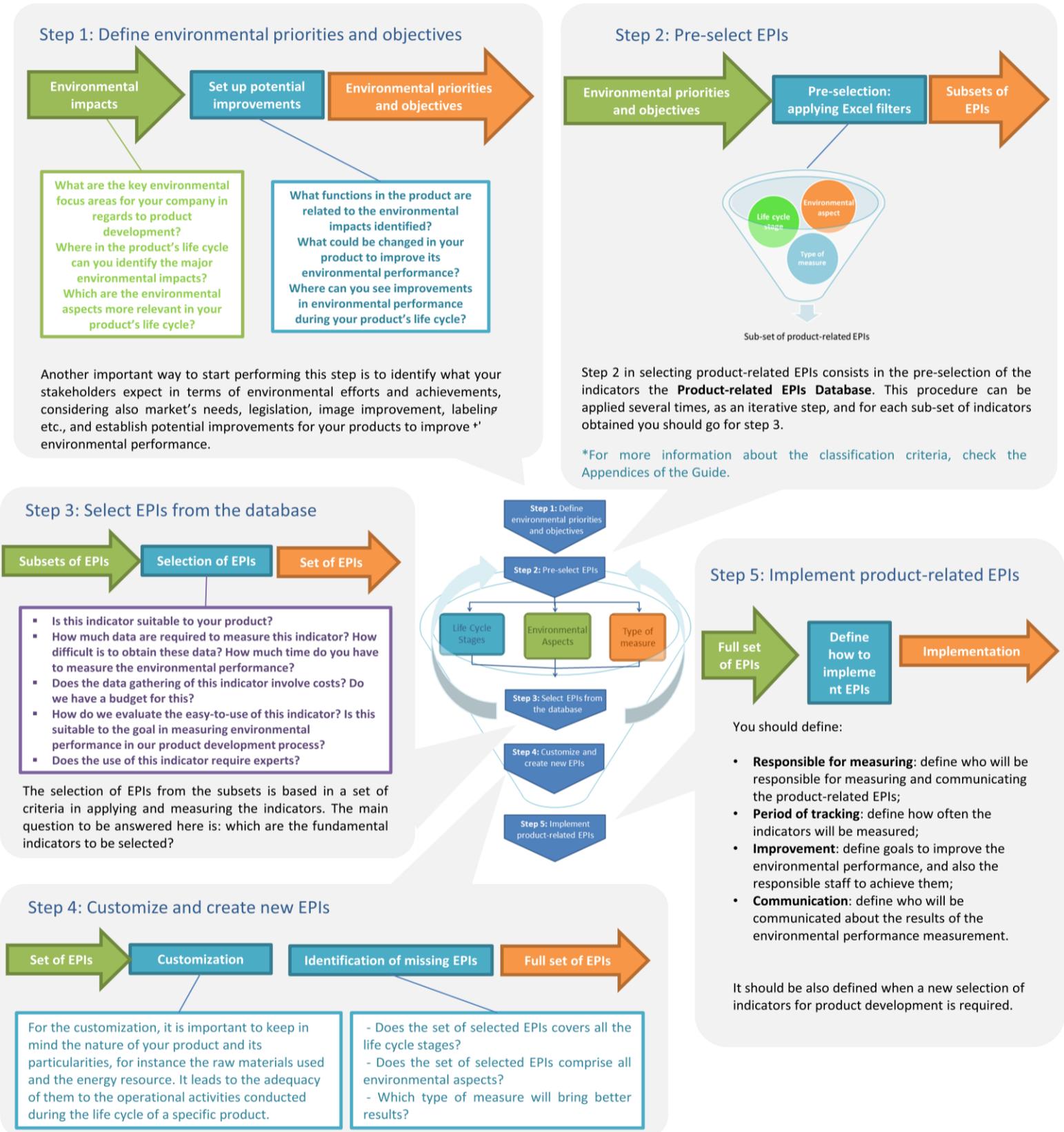UNEP. Life Cycle Management: A Business Guide to Sustainability, 2007.

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Selecting product-related EPIs in 5 steps

This poster is a support material for the guide : "PRODUCT-RELATED EPIs: A guide to support the selection of product-related EPIs". The Guide proposes a step-by-step procedure to select the most suitable environmental indicators according to your 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 aiming to select and implement the most suitable EPIs for your company.

Step 1: Define environmental priorities and objectives

Environmental impacts → Set up potential improvements → Environmental priorities and objectives

What are the key environmental focus areas for your company in regards to product development?
Where in the product's life cycle can you identify the major environmental impacts?
Which are the environmental aspects more relevant in your product's life cycle?

What functions in the 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?

Another important way to start performing this step is to identify what your stakeholders expect in terms of environmental efforts and achievements, considering also market's needs, legislation, image improvement, labeling etc., and establish potential improvements for your products to improve '' environmental performance.

Step 2: Pre-select EPIs

Environmental priorities and objectives → Pre-selection: applying Excel filters → Subsets of EPIs

Life cycle stage / Environmental aspect / Type of measure

Sub-set of product-related EPIs

Step 2 in selecting product-related EPIs consists in the pre-selection of the indicators the **Product-related EPIs Database**. This procedure can be applied several times, as an iterative step, and for each sub-set of indicators obtained you should go for step 3.

*For more information about the classification criteria, check the Appendices of the Guide.

Step 3: Select EPIs from the database

Subsets of EPIs → Selection of EPIs → Set of EPIs

- 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?

The selection of EPIs from the subsets is based in a set of criteria in applying and measuring the indicators. The main question to be answered here is: which are the fundamental indicators to be selected?

Step 1: Define environmental priorities and objectives

Step 2: Pre-select EPIs

Life Cycle Stages / Environmental Aspects / Type of measure

Step 3: Select EPIs from the database

Step 4: Customize and create new EPIs

Step 5: Implement product-related EPIs

Step 5: Implement product-related EPIs

Full set of EPIs → Define how to implement EPIs → Implementation

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.

It should be also defined when a new selection of indicators for product development is required.

Step 4: Customize and create new EPIs

Set of EPIs → Customization → Identification of missing EPIs → Full set of EPIs

For the customization, it is important to keep in mind the nature of your product and its particularities, for instance the raw materials used and the energy resource. It leads to the adequacy of them to the operational activities conducted during the life cycle of a specific product.

- Does the set of selected EPIs covers all the life cycle stages?
- Does the set of selected EPIs comprise all environmental aspects?
- Which type of measure will bring better results?

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Appendix I – Evaluation questionnaire

Questionnaire used during case studies to evaluate the "Guide to support the selection of product-related EPIs"

This questionnaire was developed to evaluate the "Guide to support the selection of product-related environmental performance indicators" according to the company perception after its application. It comprises three main items of evaluation: the Guide itself (1), the classification criteria of product-related EPIs (2) and the Product-related EPIs Database (3).

The questions can be answered by choosing one of the alternatives below:

( ) Very satisfactory

( ) Satisfactory

( ) Needs improvement

( ) Unsatisfactory

About the Guide:

1.   How do you evaluate the usefulness of the Guide in supporting the selection of product-related EPIs?

( ) Very satisfactory

( ) Satisfactory

( ) Needs improvement

( ) Unsatisfactory

Comments, suggestions, critics:

2.   How do you evaluate the easy-to-use of the Guide?

( ) Very satisfactory

( ) Satisfactory

( ) Needs improvement

( ) Unsatisfactory

Comments, suggestions, critics:

About the classification criteria of product-related EPIs:

3.   How do you evaluate the usefulness of the classification criteria to select product-related EPIs?

( ) Very satisfactory

( ) Satisfactory

( ) Needs improvement

( ) Unsatisfactory

Comments, suggestions, critics:

4.   How do you evaluate the completeness of the classification criteria to select product-related EPIs? Are they enough to support the selection?

( ) Very satisfactory

( ) Satisfactory

( ) Needs improvement

( ) Unsatisfactory

Comments, suggestions, critics:

About Product-related EPIs Database:

5.   How do you evaluate the content of the database?

( ) Very satisfactory

( ) Satisfactory

( ) Needs improvement

( ) Unsatisfactory

Comments, suggestions, critics:

6. How do you evaluate the time-efficiency of selecting product-related EPIs?

( ) Very satisfactory

( ) Satisfactory

( ) Needs improvement

( ) Unsatisfactory

Comments, suggestions, critics: