Università Politecnica delle Marche
Scuola di Dottorato di Ricerca in Scienze dell'Ingegneria
Curriculum in Ingegneria Meccanica e Gestionale

Ecodesign methods and tools: development of integrated systems to foster sustainability in industrial companies

Ph.D. Dissertation of:
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Advisor:
Prof. Michele Germani

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XIV edition – new series

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ABSTRACT

In the last years, the environmental problem has become very serious and the concept of environmental sustainability has become important also inside industrial contexts. In order to promote the environmental consciousness and to favor the design and manufacture of sustainable products, a lot of ecodesign methods and tools have been developed. However their use inside companies is still quite low, due to their complexity, time consuming and need for specific knowledge. From these considerations it comes the need for approaches that allow to realize effective environmental analysis in a simplified and rapid way. The research goal of this PhD thesis can be synthetized as the definition of a new approach to foster the implementation of ecodesign strategies inside industrial companies. The CRB (Case Base Reasoning) tool developed at first as a module of the G.EN.ESI software platform and then optimized as a stand-alone tool, aims at supporting designers by collecting ecodesign guidelines and company best practices in a structured and well organized framework. Data stored on the tool database can in fact contribute to increase the knowledge of the user on the ecodesign issue, facilitate the retrievement of improvement solution strategies and reduce the time for solving problems. Designers, also if with low skills on environmental issues, are in this way supported in the application of ecodesign strategies and can design and manufacture green and sustainable products. The implementation of the CBR tool into two industrial cases has allowed to validate the tool, optimize its functionalities and evaluate its usability.

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INTRODUCTION

Context of the thesis

The central topic of this PhD thesis is Ecodesign and its effective integration in industrial contexts. Ecodesign, i.e. *the integration of environmental considerations into the traditional design activities* (ISO. 2011*)*, is always more recognized by many industrial companies as an important aspect. This is due to the emanation of numerous regulations and normative that force the consideration of environmental product performances and to the growing awareness of consumers on these topics.

Also the research and academic world has answered to this growing interest toward ecodesign, with the development of a high number of methods and tools, which try to support companies in the designing of ecological products and services. Baumann et al. (2002) have classified around 650 papers dealing with the green product development and Navarro et a. (2005) have identified more than 60 ecodesign tools available.

However if the industrial European context is analysed, and in particular the one of the Italian region, it is possible to observe that inside design departments the implementation of ecodesign activities is far from a practical day-by-day action. Companies usually do not consider the environmental aspects along all the product life cycle phases, but focus their attention on a limited number of aspects, which correspond to those ones forced by legislations (e.g. energy efficiency, REACH and RoHS restrictions, etc). Therefore they neglect product characteristics that can heavily contribute to the final environment load, such as raw material acquisition, distribution phase, or manufacturing processes.

As a consequence, it is possible to state that there is an evident divergence between the high number of ecodesign methods and tools available (both commercial and academic versions) **and their effective and practical use inside industrial companies**. The analysis of the most recent literature on this item shows in fact that several barriers limit the effective use of ecodesign methods and tools inside industrial contexts and among them the scarcity of resources (economic, time, staff and skills) and the complexity of tools are the most significant. Designers have to take into account a lot of parameters, constraints and priorities during the development of a product, and the environmental aspect is only one of the numerous variables to consider, as it is well described by the images proposed by Luttropp and Lagerstadt (2006) and shown in Figure 1.

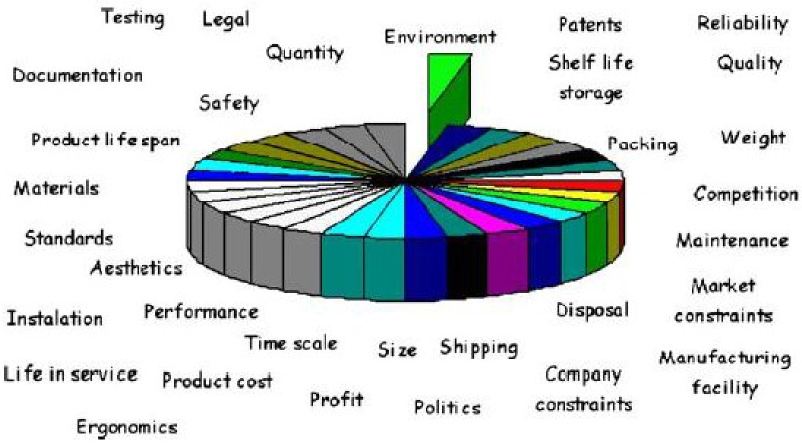


Figure 1. Considerations within the Design Process (Luttropp and Lagerstadt, 2006)

For this reason, the recent general tendency is shifted from the objective of proposing correct and detailed methods and tools that, in theory, consider ecodesign issues in the most exhaustive way, to the identification of strategies that allow companies to implement eco sustainable concepts in the best way, taking into account all of the limitations and constraints that are present in the complex and real companies' world. **New approaches attempt to propose simplified, integrated and effective evaluations that, at best, can be included in traditional design processes**.

Research objectives and Innovation proposed

As stated in the previous paragraph, the design process is influenced by numerous factors and designers have to simultaneously consider all of them when develop products. From this consideration comes the need for tools able to assist designers to consider the environmental aspects into the design process and to simply favor the implementation of strategies to improve the product environmental performances. These tools should be simplified, able to realize fast analysis, integrated in the traditional design processes.

The research goal of this PhD could be synthesized in the identification of a **new approach, methodology and tool for the integration of environmental aspects into the design process.** This thesis is a step toward the development of an innovative ecodesign approach and tool by proposing a decision support tool that links ecodesign guidelines, company eco-knowledge and product characteristics. It allows to take into account environmental considerations yet in the first design phases, allowing designers, with low skills on environmental items, to apply strategies for the development of ecological products.

This research thesis starts from the investigation of the aspects related to the lack of implementation of ecodesign tools and methods in industrial context, by realizing a deepen literature review on ecodesign methods and tools and their implementation inside companies, then proposes an approach that can favour the effective implementation of ecodesign activities in industrial contexts.

These objectives have been reached thanks to the active participation to the G.EN.ESI Project, an EU funded research and development project, which had the aims to develop a methodological approach and an integrated software platform for the improved environmental designing of electro-mechanical household appliances. In particular the PhD has been co-financed by the Università Politecnica delle Marche and ENEA, which have supported all the activities of the three year PhD course.

The G.EN.ESI project proposed a simplified approach, based on a structured methodology, composed by interoperable tools, which are integrated with the traditional ones used inside companies.

During the PhD and within the G.EN.ESI project, the CBR (Case Based Reasoning) tool has been developed. This tool has the main objective to support designers in the development of environmental sustainable products, by collecting in a structured and functional way ecodesign guidelines and company eco-knowledge. The implementation of this tool inside the department of the Faber company (as a module of the G.EN.ESI platform) and inside the Electrolux design department (as a stand-alone module) allowed to validate its methodology and understand its usefulness limits and potentiality.

As a regard to the specific activities conducted during the PhD courses, that will be described during the next paragraphs and chapters, they consisted in:

- Definition of the methodology, functionalities and contents of the CBR tool as one of the tools of the G.EN.ESI software Platform;
- Support to the Faber company in all the activities related to the implementation, test and validation of the G.EN.ESI platform into its departments. This activity allowed to directly understand the problems related to the implementation of ecodesign methods and tools in industrial companies and to reflect on possible strategies to overcome them and facilitate the effective ecodesign implementation;
- Definition of the questionnaires to evaluate the Platform usability and integration inside the FABER company.
- Test of the CBR tool in the Electrolux company supporting of all the activities connected to the implementation and evaluation of the tool;
- Optimization of the CBR tool according to the results of the second industrial implementation. Evaluation of its limits, strength and possible future development.
- Furthermore, also the development of the methodology, functionalities and contents for the End of Life (EoL) module of the LeanDfD tool has been realized.

Thesis overview

The thesis topic is the definition of an Eco design method and tool which is able to support designer in the implementation of ecodesign strategies to develop ecological products. In this paragraph an overview of the thesis is given.

Chapter 1 presents the results of the literature analysis on the item of ecodesign methods and tools and their implementation in industrial context. The structure proposed is the one of a literature review: from the classification of ecodesign methods and tools developed during the last twenty years according to their scope perspective, to the analysis of barriers related to ecodesign implementation in the industrial context. Finally, the link with possible solution strategies to overcome them is analysed.

Chapter 2 presents the G.EN.ESI project. The G.EN.ESI methodology and platform have the objective to propose a simplified approach that can foster the implementation of ecodesign strategies in companies, by proposing a simplified and integrated approach. The main objectives of the project, the partners involved, the developed methodology and the software platform with all its tools are presented. More emphasis in the description will be given to the CBR tool, which represents one the main results of this PhD work.

Chapter 3 presents the implementation of the G.EN.ESI methodology and software platform into the design departments of the FABER company. In particular, the redesign process of a cooker hood, conducted with the objective to improve its environmental performances, is presented. This chapter also contains the presentation of the usability evaluation procedure that allowed to understand the main strengths and criticalities of the G.EN.ESI tools.

Chapter 4 presents the implementation of the CBR tool (as a stand-alone module) in the design department of the Electrolux company (factory of Forlì), taken as a second industrial test case. The tool has been optimized according to the direct suggestions of designers in order to answer to their needs and it has been evaluated in usability terms.

Chapter 5 summarizes the main results obtained during the PhD and comes with the conclusion and the possible future tasks.

1 STATE OF THE ART

In recent decades, the sustainability concept has acquired growing importance, and a large number of methodologies, tools, standards and regulations have been developed to promote the implementation of its principles inside industrial companies. In the industrial field, ecodesign represents an approach to consider and integrate environmental aspects in the product development process (ISO, 2011) through the application of strategies aimed at reducing the negative environmental impact along the product life cycle phases.

The literature analysis in the field of ecodesign implementation – in particular, in the manufacturing sector – shows that many ecodesign methods and tools have been developed, but their use is still limited and often restricted to those areas affective by legislations. There is therefore a gap between what the research has produced and what is effectively used inside industrial companies.

The analysis of literature review works on this item, allows to justify the assertion that a lot of ecodesign methods and tools exist. They are mainly focused on classifying the high number of existing ecodesign tools and methods, and each of them proposes different criteria for their categorizing, among which:

- Product development context, i.e. the level of applicability of the ecodesign approach, namely at company level, product chain level, society, etc. (Baumann et al. 2002);
- Functional aspects; Navarro et al. (2005) presented a classification of 65 ecodesign tools according to functional aspects, especially in relation to the ecodesign activities and the product or service life cycle stage analysed;
- Stage of the development process and life cycle stage; Kortman et al. (1995) and Lenox and Ehrenfeld (1997) identified the design phase and life cycle stage in which the tool is used, in addition to the "degree of decision support" the tool provides to the user as characteristic parameters. In addition to these criteria, Bovea and Pérez Belis (2012) organize tools by using also the method applied to derive an environmental assessment and product requirements identified as additional objectives to reach;
- Tool characteristics and recommendations; Jain (2000) classified ecodesign tools into two main categories, according to the tool characteristics – quantitative and qualitative – and the recommendations they provide to the user;
- Support for the user; Byggeth and Hochschorner (2006) reviewed 15 different ecodesign tools to understand how they can support designers in trade-off situations that arise when environmental requirements are added to traditional ones;
- Level of integration in companies; Poulikidou et al. (2014) investigated the integration of environmental issues in four Swedish manufacturing companies. They analysed their organizational structure, the environmental aspects they address and prioritize,

drivers and barriers to an effective implementation of sustainable strategies and finally the tools used. The study is focused only to the Sweden Country.

As already stated, most of the review papers that has been produced in this sector, are mainly focused more on classifying tools, as a way to foster their use, than on broadly analyzing the situations in which they are supposed to be used and the possible barriers that can prevent the effective implementation and uptake of ecodesign thinking in companies. In parallel a lot of research papers analyse the context in which ecodesign tools or methods are used, deriving an analysis of the main barriers that prevent or limit their use and identifying possible strategies that can foster their effective implementation in companies.

What it is lacking is the correlation between tools and methods characteristics and barriers and strategies related to their effective implementation. With the aim to follow this objective, as the first step of the PhD a literature review was performed. Scientific works on the ecodesign tools and methods published in the last twenty years have been analyzed with a twofold purpose:

i) to critically update the existing reviews providing also analysis of tool weakness elements

ii) to integrate them with an analysis of the main barriers that limit their implementation within industrial companies and of possible solution strategies to overcome them.

1.1 Material and method adopted to realize the literature review

The analysis of the state of the art was conducting using the ScienceDirect, Wiley, Taylor and Francis and Emerald journals databases, including both peer reviewed articles and grey literature, covering a time span of 20 years, as shown in Figure 2.

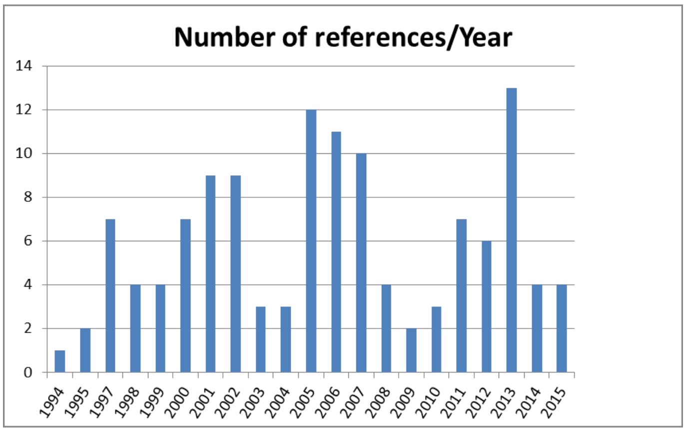


Figure 2. Temporal distribution of references derived from the literature. Web references are not included

The search of the papers was structured in two phases, using two different sets of keywords. First, multiple keywords were used to identify ecodesign methods and tools classification: “ecodesign tools”, “ecodesign methodology”, “ecodesign method”, “ecodesign approaches” and “ecodesign implementation in companies”, “ecodesign implementation in SMEs”. These terms have been selected by realizing a preliminary check of the most used keywords in some scientific papers taken as a reference. They were first type in singularly and then combined using the AND operator in association with the single keywords “barriers”, “strategies”, “stimuli” “obstacles” and “limitation”.

Life Cycle Assessment (LCA) tools were derived from the European Platform on LCA (eplca, 2014) by selecting those applicable to manufacturing companies and with active web links. Information and data about their objectives, functionalities and results have been retrieved from consecutive web research.

The analysis found 125 references (in particular 65 journal papers, 28 conference papers, 21 books, 4 PhD theses and 7 standards, legislative texts an technical reports). All of the references were collected, organised and analysed using the following categories of information:

- general information: title, authors, years;
- specific information: objective, main findings, conclusions, limitations of the study;
- main results: indication of whether the paper proposes theoretical methods, practical approaches, one or more tools, or if it is an evaluation of specific items or offers a survey. Each type of result has been broken down into further details to identify the scope of the methods and tools (e.g. theoretical methods for the integration of existing tools, software tools for the material selection phase, software tools for simplified analysis).

Then, the information retrieved was structured to create a classification of methods and tools according to a scope perspective, i.e. in relation to the subject and the intended use, together with the required information and data.

In addition, when the papers included an analysis about the implementation of tools /methods in companies, the following steps were performed:

- identification and collection of the main barriers and strategies related to the implementation of ecodesign tools and methods in industrial contexts;
- ranking of barriers and strategies according to the importance given by companies and on the basis of the authors of the analysed papers;
- grouping of barriers and strategies into categories (e.g. economic, staff and time barriers have been included into the general category “resources”).

1.2 Tools and methods framework

According to the review method described above, the identified methods and tools were clustered into eight groups. These eight groups cover the tools that have been mostly addressed in literature and presented as key for implementing ecodesign principles and approach. They are both quantitative and semi-quantitative tools, which target different applications and require different skills for their proper use. The first two, namely Life Cycle Assessment (LCA) and Computer Aided Design (CAD) Integrated tools, have the objective to quantify the environmental performances of a product or service along the whole life cycle. Diagram tools try to achieve the same objective through more qualitative evaluations, allowing the users to estimate the product's environmental sustainability through non detailed product information. Checklists and guidelines guide designers in choosing the best design solution by considering the product characteristics (e.g., the material to use to reduce the end of life impact), whereas the design for X approaches allows designers to optimize specific product requirements focusing on a specific design objective (e.g., design for disassemblability, in which the product disassembly is optimized to improve its maintenance). Then, methods to support ecodesign activities through structured framework are presented and collected according to their main objective.

1.2.1 **LCA tools**

LCA is a framework to quantify the environmental impact to product or services along their life cycle phases (ISO 14000 series, ISO 2000, 2006, 2011) and several tool based on this methodology exist to support the impact calculation. This macro category includes commercial software tools, used both directly and indirectly (i.e. through the support of consultancy services) by companies. GaBi ("GaBi ", 2013) and SimaPro ("SimaPro ", 2013) represent the largest share of LCA tools sold in the market are the most commonly used by researchers (Hermann and Moltesen, 2015 and Speck et al, 2015), and require a skilled practitioners for their use. In addition to the provision of comprehensive and sector-specific databases, which make them applicable in a variety of sectors, these tools offer different user interfaces to support the interpretation and exploitation of the results. Increasing interest has been focused on the OpenLCA software tool ("OpenLCA" 2013), an open source tool, freely available to perform LCA and footprint evaluations as a desktop application. The appeal of the tool is its architecture, which makes it flexible for working with different database structures, such as multi-regional input output databases, which can support the analysis of social aspects. This tool requires a deep expertise and is not directly used by companies.

Around this core of tools, many others have been developed, such as Quantis Suite 2.0 ("Quantis ", 2013), Sustainable Minds ("Sustainable Minds", 2013), the cloud-based software tool launched by the Enviance Company ("Enviance ", 2013), and LCA to Go (LCA to Go , 2013). These tools are more user-friendly, with a more immediate approach and simplified user interfaces. These LCA tools look are more directly useful for non-expert users.

Due to the difficulty in collecting a large amount of data to evaluate a product's environmental impacts with detailed LCA software tools, many Simplified LCA (S-LCA) tools have been developed. In these tools, simplifications occur at different levels: input data, calculation methods, and graphic interface. As such, the underlying structure and modelling of the software is not always available to the final users and needs to be correctly interpreted by the user on the basis of the assumptions made during the product modelling. EarthSmart (2013), X Pro ("EcoMundo", 2013), Corine ("EcoMundo", 2013) and eVerdEE (Naldesi et al., 2004) are web-based applications that belong to this second category; they allow first estimation of the carbon footprint for small organizations. Specifically for energy-using products, EuP manager ("EuP Manager", 2013) and ErpEcoreport (2013) help to identify the most important characteristics of a product to improve its environmental profile by employing the best available techniques, whereas the EIME (Environmental Improvement Made Easy) ("EIME ", 2014) tool supports the implementation of ecodesign principles through an intuitive and rapid life cycle product representation that considers compliance with international standards (e.g., Product Category Rule (PCR) and sector-based standards, ISO 1404X, ISO).

1.2.2 CAD integrated tools and methodology

The need to analyse the product in environmental terms during the first design phase and to directly evaluate the consequences of a design choice has led to the development of environmental impact analysis tools integrated with CAD systems. The advantages of these tools include using the data from the CAD models to feed the Life Cycle Inventory phase. Methodologies for CAD/LCA integration were proposed by Marosky (2007), who presented an algorithm allowing reciprocal data transfer between CAD (SolidEdge) and an LCA tool (SimaPro), and Gaha et al. (2011), who proposed this integration through a specific geometric database containing the environmental impacts of all of the product design technical solutions. Similarly, Yang (2012) developed a Rapid Life Cycle Assessment (RLCA) model in which design parameters correspond to environmental design information for the entire product life cycle. In the literature, it is also possible to identify many tool prototypes that aim to extract information from the product's CAD model to evaluate its environmental impact. For example, the DEMONSTRATOR, developed by Mathieux et al. (2013), connects CATIA CAD to the EIME SLCA software tool; EcoFit, proposed by Jain(2009), is a plug-in designed for 3DSmax using the EcoIndicator99 (EI99); EcoCAD, proposed by Cappelli, F., et al. (2007), is based on the product retirement information from the tree CAD structure; and the CAST Tool (Morbidoni et al. 2011), proposed an integration LCA and Life Cycle Costing with Product Lifecycle Management (PLM) systems. Leibrecht (2005) developed EcologiCAD, which aims to evaluate the environmental impact of virtual product prototypes using an approach based on a client server concept, where the information model also provides functionality to further applications via an application programmable interface (API). Concerning the commercial tools available in the market, SolidWorks Sustainability (“SolidWorks Sustainability”, 2013) is a CAD integrated analysis tool that estimates the environmental impact of the product by retrieving data directly from the design assembly; a CAD plug-in of the Eco Audit tool (“EcoAudit”, 2013) allows the user to analyse the product’s environmental profile (in terms of kg of CO2 and energy consumption) during its modelling through an integration with the Autodesk Inventor CAD software. These tools are useful to compare product versions and to understand the main product environmental criticalities, but they are not sufficient to obtain detailed results, due to simplifications, e.g., limitation in the data contained in their databases, possibility to associate a reduced number of production processes with components, simplification in the modelling of the use phase, and a limited number of impact indicators. Furthermore they are not compliant with LCA normative.

1.2.3 **Diagram Tools**

Diagram tools propose a qualitative or semi-quantitative assessment that can be performed when no detailed information of the product shape and life cycle is available. The MECO Matrix developed by Wenzel et al. (1997) is an example. This tool estimates the simplified environmental impact of each life cycle stage by calculating materials, energy, chemicals and other substances involved in the product life cycle. Other examples are the Environmental Design Strategy Matrix (Abramovici. et al., 2014, Allenby, 1994), which provides as output the environmental impacts against the functional product requirements, and the MET Matrix (Brezet and van Hemel, 1997), which performs the analysis by completing a table in which the rows correspond to the product life cycle phases and the columns correspond to the material, energy and waste used or produced by the product. The ERPA Matrix method, proposed by Graedel (2010), and the DFE Matrix (Johnson and Gay, 1995) provide environmental product assessment after performing a four-step method in which starting from product high priority identification, benchmark and trade-off analysis, a series of questions are presented to evaluate different product design alternatives.

Another approach is the Spider Diagram, which allows the user to assess the product against a set of environmental criteria and to visualize them in a diagram. The criteria can include material use, transportation, energy use, waste, toxicity and others, to which numeric values are attributed for their evaluation. It is possible to include the Eco Compass tool proposed by Johnson et al. (1995), the Ecodesign Strategy Wheel, developed by the Centre for Sustainable Design (CfSD) in the UK and the Delft University of Technology in the Netherlands, and the Ecodesign Web (Bhamra and Lofthouse, 2007), a step-by-step approach to identify the main drivers to improve the product in environmental terms. Despite the simplicity of these tools and the possibility to visualize the results in an explicit and clear way, they provide only qualitative results and general evaluations. For this reason, if they can analyse the product and explain the related flows (energy, material) these types of tool can be used to model the product for preliminary environmental evaluations, where the identification of sustainable criticalities is lacking.

1.2.4 **Checklists and Guidelines**

The checklist and guidelines approach is used for a quick evaluation of the product's environmental profile, and the results are particularly useful during the first design phases. Evaluations are simplified due to structured and established procedures that designers can follow, allowing non-experts to evaluate and improve product environmental performance. The Fast Five of Philips developed by Meinders (1997) and the Black, White and Grey List developed by Volvo (Nordkil , 1998) for material selection during the design phase belong to this category, together with the checklist examples for SMEs developed by Behrendtet al. (1997). Another example is the ECODESIGN Checklist Method (ECM) developed by Wimmer (1999). Many ecodesign guidelines can be retrieved from literature, with the aim to develop suggestions that designers can consult to improve the product's environmental profile. Due to the high level of generality that characterizes these types of guidelines, they can be applied to many different products, but it is difficult to translate them into design choices. The can be used as alerts, but they do not provide possible solution strategies. The Ten Golden Rules, proposed by Luttropp and Lagerstedt (2006), represent the most significant example of this typology of design recommendations. The Prescribing tools Strategy List (Tischner et al., 2000) provides suggestions to improve environmental performances of products along each life cycle stage. Other examples are the Ecodesign Pilot ("Ecodesign pilot ", 2005), the Eco User Centred Design (2008) approach, the EcoDesign Checklist (Tischner et al., 2000) and the ELDA (Rose , 2000) . Specific guidelines are further developed for particular life cycle phases, such as design for disassembly guidelines ("Design for Disassembly Guidelines", 2005) which can be used by designers to improve the product's behaviour at the end of life, and material selection guidelines ("ECO design guide" 2002) which provide suggestions for correctly selecting materials. In a more recent work, Allione et al. (2012) proposed a support tool called MATto, which is focused on the material selection phase and DahlströmI (1999) presented a method for the development of company-specific ecodesign guidelines, by analysing the product and its main characteristics. Lofthouse (2006) proposed a holistic framework for developing an ecodesign tool that fits industrial designers' needs by communicating in a simple language, resulting fin-relevant, product-specific ecodesign information and a starting point for ecodesign implementation.

1.2.5 Design for X approaches

The Design for X concept was developed to optimize specific product requirements, with the main objective to satisfy customer needs and respond to the high market pressure for product competitiveness. Within the field of ecodesign, it is possible to identify several Design for X approaches. Design for Disassembly, the Design for remanufacturing, the Design for recovery and material recycling and the Design for Energy Efficiency approaches will be presented in this paper. In Design for Disassembly the objective is to optimize the product's disassembly potential, to obtain the best solution in environmental and economic terms. The research studies proposed by Huisman (2003), Güngör (2006) and Cerdan (2009) highlight the importance of disassembly to facilitate material recycling, to comply with the current End of Life (EoL) legislations. A virtual disassembly environment, based on two different algorithms, is presented by Cappelli et al. (2007) and allows the realization of remanufacturing processes, that are recognized by Ijomah et al. (2007) as a technology that is, in environmental terms, preferable to recycling. In the Design for Remanufacturing category, Sundin (2004) created a correlation matrix between product properties and generic remanufacturing processes analysed the remanufacturing potential of household items and proposed design changes to facilitate the remanufacturing of two case study products (Sundin, 2001). Zwolinski et al. (2006) developed a computer-aided tool to incorporate remanufacturing in the early design phases. Hatcher, et al. (2011) presented a review and recognized that several problems exist with Design for Remanufacturing approaches in practice, which can be summarized as a lack of knowledge and understanding among designers, and very few products are remanufactured or designed for remanufacturing. Approaches belonging to the Design for material recycling category include thoseproposed by Huisman et al. (2003) and Mathieux et al. (2008) for calculating recyclability quantitative indicators, whereas et al. Giudice et al. (2005) develop a method for incorporating environmental considerations within material selection when considering components' functional and performance requirements. In the Design for Recovery category, Giudice et al. (2001) proposed methodology and tools to guide designers in the identification of the best EoL solution by the definition of an analytic recovery cycles model to define the reusable product parts. Several works propose methods and suggestions on how to improve a product's environmental performance through correct material selection. Ljungberg (2007) presented guidelines for the sustainable design of products, with particular attention to material selection, Holloway (1998) extended Ashby's method (1999) of material selection charts to consider the material's environmental impact. To support remanufacturing, recovery and recycling some Design for Supply Chain approaches were proposed Guide et al (2003), whereas Savaskan et al. (2004) examined several closed-loop supply chain structures to identify the most effective and efficient methods to facilitate product recovery. In relation to Design for Energy Efficiency and with the aim to correctly calculate the environmental impact related to the use phase, especially for energy using components, Domingo et al. (2013) proposed a scenario model to include all of the events that can or will occur during the use of the product by a generic user. Abramovici et al. (2014) introduced a method to support designers in performing energy assessments of mass-produced ErP design options and to verify their compliance with energy-related limit-value constraints.

1.2.6 Methods for supporting the company's ecodesign implementation and generation of eco innovation

Eco innovation and ecodesign method implementation can be facilitated and supported in companies, by the application of structured and organized methods and procedures. Le Pochat et al. (2007) proposed the integration method EDIMS and the related software program to overcome the difficulty of integrating ecodesign tools into the traditional design and production process. One of the most recent methods is the ecodesign maturity model of Pigosso et al. (2013) which proposed a management framework based on a step-by-step approach, aiming to support companies in implementing ecodesign. The method is composed of three main elements: ecodesign practices, ecodesign maturity levels and application method and its results have been applied with satisfactory outcomes into a large manufacturing company. This method attempts overcome those proposed by Willard (2005), Boks and Stevels (2007), Murillo-Luna et al. (2011), which have a managerial perspective and the common objective to define the steps companies have to follow to successfully implement ecodesign.

Other interesting approaches are related to supporting the generation of eco-innovation ideas. An example is the work presented by Jones (2001), i.e. the Product Ideas Tree diagram (PIT) which produces more ideas and facilitates the generation of idea sessions, making them more constructive. In line with this previous work, Jones et al. (2001) tested the potential using eco innovative tools in particular, the Standard Design Process Form (SDPF) and the Product Ideas Tree (PIT) diagram. The ideas generated using these tools help to identify 'compound' idea statements that obscurer the most valuable aspects of the ideas generated. With the aim of deriving generic guidelines to support the company's strategic decision system, Hallstedt et al. (2010) developed an innovative approach to asses of company decision systems regarding sustainability-related communication and decision support between the senior management and product development levels. Gaziulusoy et al. (2013) presented a method that links society (defined the macro level) and the team responsible for production (defined as the micro level) through the mean of the company itself, which acts as the agent in system innovation. Lewandowska and Kurczewski (2010) presented an ecodesign procedure based on the guidelines of the ISO 14062 standard and demonstrated the results obtained by the application of this method on a fridge freezer (Lewandowska and Kurczewski, 2014).

1.2.7 Methods for implementing the entire life cycle and user centred design for sustainability

Choices made along all phases of the design process, greatly influence the future environmental behavior of products and for this reason the simultaneous consideration of several specifications to support multi-objective strategies has been investigated by authors. Kobayashi(2005) proposed the product life cycle planning (PLC) method, which aims to incorporate environmental aspects into the conventional product development process. New solutions are evaluated, based on environmental, cost and quality aspects. Kobayashi (2006) also proposed a more advanced methodology that integrates the TRIZ methodology to generate innovative ideas at the product level. Another interesting approach proposed by several authors foresees the implementation of strategies that aim to modify the product use profile toward a more sustainable one. This method is very useful, especially for products characterized by high environmental impact during the use phase (e.g., the energy using products). When the energy efficiency of these products is high and further improvements cannot be achieved, then a possible sustainability strategy is represented by positively affecting user behavior. The user-centered design strategies consider the adaptation of product architecture as well as the implementation of feedback strategies to induce a correct use of a product. An example is provided by Jelsmaand Knot (2002). He defined the concept of scripting as a particular product layout able to force the user to sustainably use the product and, at the same time, make its unsustainable use difficult. Serna-Mansoux et al. (2014) presented a method aimed to aid in the development of a strategy focused on environmentally friendly use. A complementary approach, proposed by Rodríguez and Boks (2005), is characterized by adapting the product to user behavior after analyzing user interactions with the most common electronic devices. Wevera et al. (2008) identified the first two presented approaches as scripting and functionality matching, respectively, in addition to two other applicable approaches: eco feedback and forced functionalities, in which the product presents only an environmental oriented usage. By following this approach, Gyi et al. (2006) suggested evaluation based on simulations, prototyping and testing of the product usability and the relative user behavior to improve effective strategies to develop environmental oriented use products. Lockton (2008) proposed methods to make the user more efficient in the usage of products. In relation to the use phase consumption monitoring and evaluation, Domingo et al. (2011) presented a methodology based on the calculation of an indicator that enables a design team to drive energy efficiency more effectively during the design process. Collado Ruiz and Ostad-Ahmad-Ghorabi (2015) proposed a method to allocate use-phase impacts to different subsystems or components to allow the assessment of those parts that constitute a higher percentage of the overall impact.

1.2.8 **Methods for integrating different existing tools**

Many methods that aim to integrate existing ecodesign tools have been developed in the recent literature as a possible answer to improving their usability and to favor their real and effective implementation in companies. In particular, Tingstrom and Karlsson (2006) proposed a combined use of environmental effect analysis (EEA) and LCA to facilitate the effective consideration of environmental aspects during the design process. Another approach was presented by Cappelli et al. (2006), in which an integration of LCA, CAD and ecodesign guidelines converge in an Integrated Design for Environment methodology. Relatively new models have been developed to integrate the TRIZ (theory of inventive problem solving) methodology and existing ecodesign tools, with the aim of facilitating eco innovative product design. C.J. Yang et al. (2011) proposed an approach that integrates the Case Based Reasoning (CBR) and TRIZ methods. CBR can obtain the desired functional characteristics of a new design in an efficient way, and the TRIZ method ensures that designers can easily achieve design objectives due to the techniques provided by different technology fields. The same authors, in more recent research (2012), elaborated an evolution of this approach and suggested integrating the TRIZ and CRB methods with Simplified Life Cycle Assessment(s). Russo et al. (2011) proposed an approach based on the integration of LCA and TRIZ eco guidelines, with the aim of supporting the implementation of the ecodesign approach in small and medium European enterprises. The consultation of a set of TRIZ eco guidelines provides indications on how to develop alternatives or modifications to a given system to reduce its environmental impact. Sakao (2007) proposed a design methodology to support environmentally consciousness design of products by the integration of three tools: LCA, QFDE (Quality Function Deployment for Environment), and TRIZ. MacDonald (2005) proposed a strategic planning section for ISO 14001 integrated with the ‘‘back casting from principles’’ method, with the objective to help companies in moving toward the effective implementation of sustainable strategies.

Misceo et al. (2004) developed TESPI, a web tool aimed at supporting the environmentally conscious design, by integrating QFD and checklists, taking into account the product life cycle, the customers’ needs and the competitors’ products. The tool allows to realize a quality analysis where the user identifies the customers’ needs and requirements, assesses their relevance, compares its product with the competitors’ one and to assess the environmental performance of the product answering a checklist of environmental aspects.

1.3 Barriers for the implementation of ecodesign methods and tools in companies

Together with the tools and methods developed for supporting the introduction of an ecodesign approach in companies, this review has investigated the barriers that limit its full implementation in companies. In particular, starting from the analysis of barriers that the authors cited in this chapter have proposed in their papers (derived from their own experiences and from direct involvement of industrial companies through survey), we have further elaborate them and defined a classification into: general barriers related to ecodesign approach implementation in industrial contexts (related to management and cultural aspects) and specific barriers directly related to the weakness elements of the tools and methods and therefore connected to practical aspects and implementation difficulties.

In relation to general barriers to ecodesign implementation in industrial contexts, both theoretical studies and companies' direct analysis derive the same conclusion, which can be summarized by the work of Lindahl (2005), who found that the environmental issue's relative importance in the design process in comparison with other issues, is quite low.

An absence of demand from the market (Boks , 2005 and Masoni et al. 2012), lack of consumer awareness (Santolaria et al., 2011) and consequently commercial disadvantage for companies (van Hemel and Cramer, 2002) are proposed, even if the recent initiatives at the European level, such as the Single Market for Green Products (European Commission, 2013), are pushing the demand for green products, thus making the environment not just a cost but a competitive issue for all organizations. Thus, the barrier could be framed in terms of "not envisaged market opportunities", i.e. the company does not recognize any value-added in further qualifying their products and services in environmental terms.

Finally, human resources and difficulties in re-organizing them (Buttol et al. 2012, Charlesworth, 1998; Goodchild, 1998; Poole, 1999) lack of multifunctional nature of the staff (Hillary, 1997; University Bocconi, 1997), a lack of cooperation between departments (Boks , 2005) the large number of tools present (Araujo, 2001) and the scarcity of compulsory requirements (Johansson, 2002; Handfield et al., 2001; Santolaria et al., 2011) are identified as additional reasons for the scarcity of industrial ecodesign tool implementation in particular, and for more ecodesign approaches in general.

When general barriers are overcome by a companies, other specific ones, directly associated to tools and methods implementation, can occur. Ecodesign method and tool implementation in the manufacturing sector is a challenge commonly faced in the literature and the use of tools and methods, represents the primary way companies consider implementing ecodesign approaches. As a consequence it is important to identify which are the main weaknesses at the level of tools and methods.

In relation to quantitative tools (e.g. LCA), which can evaluate the product environmental performance along the entire life cycle with a high level of detail, the need to dispose of high data quantity and quality, and the time consuming and complexity of use them, prevents their use in companies. Furthermore this activity is usually perceived as not being able to guarantee a significant return in economic terms with respect to the resources dedicated. The CAD integrated software tools provide the possibility to automatically retrieve the product data needed for environmental evaluation, and this fact increases the tool usability. On the other hand, the CAD tools do not allow designers to compare different product trade-offs in terms of environmental and technical requirements and cost constraints during the design process. These further considerations complicate the design process, by adding complexity to the choice of the best solution among different alternatives. Moreover, the modification of product characteristics (e.g., material, mass) can result in significant revisions in the production processes or can cause variation in the suppliers, making designers (users' tools) unable to identify feasible modifications. As a consequence, only minimal product modifications might be evaluated. Furthermore, several of the identified tools exist only in a prototype or academic version.

The third and fourth categories, Diagram tools and Checklist and Guidelines, represent a powerful mean to introduce environmental considerations into company design departments. However, without previous knowledge of these issues, the tools are not able to provide a significant value-added for industries. Even if the tool do not require specific training session due to their high usability, the general suggestions are useful only if the beneficiary is an environmental expert that can understand the result and derive possible solution strategies. Finally, design for X tools, because they are focused on a specific objective, require that companies have previously identified the major product criticalities, in environmental terms, to improve them by applying these types of tools. This preliminary need, due to the complexity of performing environmental analysis can determine the application of a wrong tool if a detailed and correct product analysis is not conducted. With respect to methods and related barriers proposed by the literature (and presented in Sections 2.2 and 2.3), their implementation in companies is prevented by the need for re-organizing staff and personnel, which must be trained on specific matters and is consequently perceived as heavy activity, that does not correspond to significant economic return. The implementation is considered complex, over-formalized and not directly related to real industrial needs.

Starting from the weakness elements presented above, it is possible to summarize the main specific barriers related to the implementation of ecodesign tools and methods:

- the need for specific knowledge and the time-consuming efforts of performing these activities (Ritzén, 2000; van Hemel and Cramer, 2002);
- the scarcity of financial and personnel resources (Hillary, 2004);

- the over-formalization of methods and tools in comparison with the complexity of the product development processes (Cross, 2000; Blessing, 2002; Stempfle and Badke Schaub, 2002; Tukker et al., 2001), which have no life cycle perspective (Mathieux et al., 2002)

1.4 Discussion

On the basis of the outcomes of the analysis of the state of the art and functional to the next step related to the identification of strategies for overcoming them, a further classification of the barriers identified in section 2.3 in "internal" and "external" have been derived. This classification is functional to the identification of the strategies to be adopted for overcoming them. The internal barriers are company characteristics that involve the organization of personnel, product development process management, time planning and the decisions that can be made by the company's management team. With reference to the analysis above, the following can be classified as internal barriers:

a. Resources, both in economic, staff and time terms (e.g. extra time and extra resources to dedicate to environmental analysis);
b. Ecodesign tools (e.g. high number of methods and tools available in the market, among which it is difficult to identify the right one; high specificity of methods and tools, that require knowledge of environmental issues and training sessions to use them);
c. Product and related production processes represent a barrier due to the need for respecting specific technical requirements that are difficult to modify to obtain an improvement of the environmental performance (e.g., the use of recyclable materials could determine the modification of the shapes, weights and dimensions of product parts).

In contrast to internal, the external barriers can be identified as the outer entities with indirect influence on the company's behavior, in particular:

d. Market and customers influences, expectations and perceptions (e.g. difficult in the identification of market benefits and in the right interpretation of customers' needs);
e. Legislation, with obligation and norms to respect or lack of specific compulsory regulations (e.g. specific legislation for a limited type of product; no compulsoriness of environmental analysis);
f. Suppliers' involvement (e.g. lack of communication among buyers/external suppliers).

1.4.1 Possible strategies to overcome barriers

The analysis of the barriers shows that internal barriers are directly related to the tool and method weakness elements and to company characteristics, whereas external barriers do not depend on tools, methods or company properties.

For this reason, strategies to favor the implementation of ecodesign tools and methods in companies need to be split into several actions:

- Strategies related to Barrier b)

First, researchers and developers should improve tool characteristics and develop methods that meet company needs and expectation (See Table 1 and Table 2). In this direction, we can consider: integration of tools to allow multi-objective analysis, applicability in the early phases of the product development process, life cycle perspective and market aspect inclusion (Lindahl, 2005), development of knowledge sharing tools for the efficient reuse and evaluation of company knowledge in the sustainability field (Hallstedt et al. 2013), development of customized ecodesign tools, which facilitate the definition of environmental checkpoints, reviews, milestones and roadmaps, (Boks, 2005), development of free ecodesign tools, and ease of access for companies (Santolaria, 2011).

- Strategies related to Barrier a) and d)

Second, the company management team should be open to modification of traditional approaches. The company should have a multifunctional team to guarantee the awareness and understanding of problems due to the collaboration of people with different skills and knowledge, which can increase the possibility of solving problems (Lindahl, 2005; Le Pochat, 2007). The company should apply Product Life cycle Management (PLM) approaches to guarantee the effective and integrated management of product data (Bey et al., 2013), implement Product Oriented Environmental Management Systems (Tukker et al., 2001), define a clear commitment to sustainability in the company mission, identify key sustainability criteria for different product components (Hallstedt et al., 2013) and structure business models to support sustainable innovations (Boons and Lüdeke Freund, 2013). Handfield et al. (2001) suggested the definition of corporate environmental goals that are quantifiable and measurable, providing a precise objective to reach; the identification of a pilot project with a high probability of fulfilling the established environmental goals and the identification of sufficient time to train designers on the ecodesign tools and methods they will use during the project.

- Strategies related to Barrier f)

Furthermore, companies should structure strategic framework that will aid managers in evaluating green supply chain alternatives (Sarkis, 2003) and involve the procurement staff/buyers in the early phases of the product development process (Hallstedt et al., 2013; Kenneth et al. 2005).

Studies generally show that Green Supply Chain Management (GSCM) has a positive impact on environmental performance (Florida and Davison, 2001; Geffen and Rothenberg, 2000; Golicic and Smith, 2013). GSCM is a set of practices that have the objective of integrating environmental concerns into the organizational practices of Supply Chain Management (SCM) (Zhu, et al. 2008).

- Strategies related to Barrier e)

Authority should move toward more restrictive legislation, which will have a direct influence on company business objective definitions, market tendencies and customer behaviour. Bey et al. (2013), Jonbrink et al. (2013), Poulikidou et al. (2014) found that when companies apply ecodesign strategies, there is a clear dominance of regulation and standards as drivers. However, Hauschild et al. (2005) found an insufficient motivation for small and medium sized companies, which usually operate with a short time perspective in their planning. For this reason, the authors observe that companies should be motivated by legal requirements forcing them to consider the entire product life cycle. In confirmation of this statement, Santolaria et al. (2011) suggested the creation of an independent governmental institution for the promotion of ecodesign.

The absence of solution strategies related to the barrier c) is due to the high specificity of this barrier; only companies which know their product and production processes could identify strategies that allow them to solve trade-off situations that will occur on their product and production processes.

In the following, Table 1 contains tools grouped into the categories presented in Section 2, the relative barriers, weakness elements and possible strategies to improve them; Table 2 presents weakness and strength elements and barriers related to methods.

Furthermore, based on Bey (2013), Boks (2006), Johansson (2002) and Handfield et al. (2001) Table 3 was created to present barriers and the related possible strategies related to the implementation of ecodesign methods and tools in industrial companies.

1.5 State of the art - Conclusion

The thorough analysis of the literature in the field of ecodesign tools and methods confirm that despite the great number of approaches proposed by researchers and available also in commercial tools, **companies still have difficulty in their practical and effective implementation and use**. A further aspect confirming this statement is the large number of research works attempt to identify these barriers through direct survey and communication with companies. The results of these studies have highlighted that companies have difficulties modifying traditional design processes and do not like to dedicate extra time to activities that are not yet associated with successful strategies. Furthermore, the lack of full awareness about the product criticalities or potentialities, the need for specific knowledge of sustainable issues and the not yet decisive customer and legislation pressure, increase the gap between ecodesign methods and their implementation in industrial companies.

Therefore, the general tendency is shifted from the objective of proposing correct and detailed methods and tools that, in theory, consider ecodesign issues in the most exhaustive way to the **identification of strategies that allow companies to implement eco sustainable concepts in the best way, taking into account all of the limitations and constraints that are present in the complex and real companies' world**. Because complete, detailed and isolated product analysis cannot always be applied without modifying the traditional design processes, **new approaches attempt to propose simplified, integrated and effective evaluations that, at best, can be included in traditional design processes**. The researchers should also be oriented toward the comprehension of the real needs of industrial companies, which at the moment are not included in the tool and method development process. In addition, because industry is forced to respect legislations and standards for some parameters, tools and methods should include and support their direct control to become more useful and more attractive for companies.

Table 1 Principal tool barriers, weakness elements and possible improvements (reference: see Section 2.3)

Tools and Scope	**Barriers**	**Weakness elements**	**Possible improvements**	**Examples References**
LCA Calculation of environmental impact of products/services.	**Resources** Time effort Specific knowledge Staff Economic **Ecodesign Tool** High number of tools available **Supplier** Relationships buyers/suppliers	Need to dispose of a high quantity of data along the entire product life cycle Need to dispose of high quality data Need for training to use the tool Need for experiences on tool use to interpret results Licence purchase Difficulty in selecting the most appropriate tool available for the product Need for a strong relationship with the supplier to dispose of data on components acquired externally from company	Links to economic aspects (Schmidt, 2002) to allow companies to consider cost drivers Inclusion of market aspects (Lindahl, 2005) Simple software, which non-expert users can use following a short training (Rebitzer et al., 2004)	GaBi, http://www.gabi software.com Simapro, http://www.simapro.co.uk Quantis, http://www.quantis intl.com Sustainable Minds, http://www.sustainableminds.com Enviance company tool, http://www.enviance.com/solutions/environmental business intelligence LCA.aspx OpenLCA, http://www.openlca.org/
Simplified LCA Calculation of environmental impact of products/services without having complete data on product	**Resources** Staff Specific knowledge Economic **Ecodesign Tool** High number of tools available	Need experience to interpret the approximated results and shift them on the real product Need for training to use the tools Licence purchase Difficulty in selecting the most appropriate tool available for the product	Possibility to choose the simplification level according to the available product data	EarthSmart, http://www.earthshift.com/EarthSmart Xpro, http://www.ecomundo.eu/en/software/ Corine, http://www.corinecodesign.eu/en/content/corine project ecodesign approach EcoIt, http://www.pre sustainability.com/eco it EuP Manager, http://www.simpple.com/en/products/eupmanager EIME, http://www.codde.fr/en/lca software.com/ UsesLCA, http://cem nl.eu/useslca.html VSSM, Kara S., et al. (2007)

				EcoScan, http://ecotoolkit.eu/faq.php
CAD integrated tool Evaluation of product environmental profile in the first design stages Evaluation of environmental consequences of design choices	**Resources** Staff Economic **Ecodesign Tool** High specificity Simplification in product modelling	Need for training Licence purchase Limitation in databases Simplification in the product modelling Limited number of impact indicators Integration with specific CAD tool systems	More detailed impact indicators to accurately understand environmental criticalities Inclusion of market (Lindahl, 2005) and economic (Schmidt, 2002) aspects Possibility to model more details (e.g.. multiple processes, superficial treatments, additional life cycles)	Marosky methodology, Marosky, N. (2007) Gaha et al. Methodology , Gaha et al. (2011) Rapid LCA, Yahgl (2012) Demonstrator, Mathieux et al. (2013) EcoFit, Jain (2009) EcoCAD, Capelli et al. (2007) CAST Tool, Morbidoni et al. (2011) Solidworks Sustainability, http://www.solidworks.com/sustainability/ Eco Audit, http://www.grantadesign.com/ Ecologic CAD, http://www.solidworks.com/sustainability/
Diagram Tools Perform simplified environmental analysis through a mix of qualitative and quantitative data	**Resources** Staff Specific knowledge **Ecodesign Tool** High number of tools available	Need experience to interpret the approximated results Need experiences to insert user arbitrary estimations Possibility to perform only preliminary evaluation on product-related flows Difficulty in selecting the most appropriate tool available for the product	Possibility to integrate the qualitative results with an analyst module to quantify impact Allow the possibility to model the product structure in compliance with ISO 14040 to facilitate the product modelling if a successive LCA analysis is conducted	Matrix: MECO Matrix, Danish Institute for Product Development MET Matrix, Brezet (1997) ERPA Matrix, Graedel (2010) DFE Matrix, Johnson and Gay (1995) Environmental Design Strategy Matrix, Allenby (1994) Spider Diagram: EcoCompass Centre for Sustainable Design, Johnson et al. (1995) Ecodesign web, Bhamra and Lofthouse (2007)

Check list & Guidelines Quick evaluation of product environmental profile Suggestions on how to improve product behaviour	**Resources** Staff experiences	Need experience to insert arbitrary user estimations Need experience to interpret general suggestions	Indicates not only the problems but also possible ways to solve them Be referred to specific products and be specific for companies (Boks, 2005) Provide quantitative effects (in terms of environmental impact) related to the application/non application of suggestions	Check List: Philips Fast Five, Black, white and gray list (Volvo) Behrendt et al. Checklis, Behrendt et al. (1997) Guideline: Ten golden role, Luttropp and Lagerstedt (2006) EcoDesign Pilot, http://www.ecodesign.at/pilot/ONLINE/ENGLISH/INDEX.HTM EcoUser centred Design, Wevera et al. (2008) ELDA, Rose (2000), Disassembly guide, Design for Disassembly Guidelines (2005) Material selection guide, Allenby (1994), MATto tool, Cristina Allione et al. (2012), Dahlstroml guide, DahlströmI (1999), Lofthouse guide, Lofthouse (2006)
Design for X Approach Specific scope for each approach Improve a specific product characteristic in environmental terms	**Ecodesign Tool** High number of tools available High specificity **Resources** Staff experiences	Difficulty in selecting the most appropriate tool available for the product Need to understand the product criticalities before starting the analysis to select the right tool Evaluation of single phases of the product life cycle	Allow the possibility to integrate different Design for X tools, to consider and solve impact transfer among life cycle phases	Design for DISASSEMBLY: Huisman (2003), Gungor (2006), Cerdan (2009) Ijomah et al. (2007) Design for REMANUFACTURING: Sundin (2004, 2001), Zwolinski et al. (2008) Mathieux et al. (2008), Giudice et al. (2005) Design for RECOVERY: Giudice et al. (2001), Ljungberg (2007), Holloway (1998) Design for ENERGY EFFICIENCY: Domingo et al. (2013)

Table 2 Method strength and weakness elements

Methods	Barriers	Weakness elements	Strength elements	Examples References
Methods generation of eco innovation	**Resources** Staff experiences Time Staff **Ecodesign Tool** Complexity	Need to acquire experiences on the methods principles Need of training Need of time to apply the method Need of skilled staff on the matter Complex and elaborated approach	Provide structured and organized methods and procedures Facilitate the generation of idea sessions, making them more constructive	Pigosso et al. (2013) Le Pochat et al. (2007) Jones (2001) Hallstedt et al. (2010) Jones et al. (2001) Gaziulusoy et al. (2013) Lewandowska and Kurczewski (2010), (2014)
Methods for implementing the entire life cycle and user centred design for sustainability	**Resources** Staff experiences Time Staff **Ecodesign Tool** Complexity	Need to acquire experiences on the methods principles Need of training Need of time to apply the method Need of skilled staff on the matter Complex and elaborated approach	Provide structured and organized methods to support multi-objective strategies Incorporate environmental aspects into the conventional product development process	Kobayashi (2005), (2006) Jelsma and Knot (2002) Rodríguez and Boks (2005) Wever et al. (2008) Gyi et al. (2006)
Methods for integrating different existing tools	**Resources** Time effort Staff Economic **Ecodesign Tool** High number of tools available Complexity	Specific and detailed analysis Need of training to use tool Need of experiences on the tool use to interpret results Licence purchase Difficult in selecting among those tools available the most appropriate for the product to analyse Complex and elaborated approaches	Improve ecodesign tools usability by favouring their integration Integration with tools traditionally used inside companies	Tingstrom and Karlsson (2006) Cappelli et al. (2006) C.J. Yang et al. (2011) Russo et al. (2011) MacDonald (2005) Dufrene et al. (2013) Germani et al., 2013

Table 3 Summary of the main internal and external barriers and strategies retrieved from literature (Bey, 2013; Boks, 2006; Johansson, 2002 and Handfield et al., 2001)

Internal		**External**	
Barriers	**Strategies**	**Barriers**	**Strategies**
Resources (time, economic, staff)		**Market**	
Time effort needed to conduct supplementary environmental analysis Time for implementation of tools in the company system Time for maintenance Time for training sessions Acquisition of licences Perception of high cost for tools Lack of awareness of benefits achievable High cost for certifications/verifications Lack of accessible financial support Need for knowledge of ecodesign issues Need for knowledge of existing ecodesign tools Need to dispose of a multifunctional team Lack of management commitment Organizational complexity Lack of environmental vision Management instability Lack of specialist staff Lack of cooperation between departments	Timing re-organization to train personnel Good level of education and training provided to personnel Establishment of clear environmental goals Address environmental considerations as business issues Development of cross-functional teams Support from environmental experts in the design and development activities Establishment of good contacts between departments about environmental issues Identification of key roles	Difficulty in identification of the advantages/disadvantages connected with the application of ecodesign strategies for products High competitiveness Lack of marketing studies Benefits are non-tangible Lack of awareness of benefits Difficulty in interpreting customer perception Perception of no demand from the market Lack of involvement of sales and marketing departments	Market research to understand customers' needs Market research to understand competitors' product environmental profiles Adoption of a strong customer focus Training of customers in environmental issues Adoption of a business model perspective Marketing survey Involvement of departments that have contact with customers
Ecodesign Tools		**Legislation**	
High number of tools	Selection of tools adequate for the	No compulsory requirements	Development of company-specific

High number of tools in the prototype versions Tools are too complex Tools are too specific Divergence from real industrial needs and those tools proposed by research Large quantity of data required High quality of data required Evaluation of single life cycle phases	company and project objective Use of customized ecodesign tools Use of integrated tools Use of tools integrated with traditional design tools Use of simplified tools Use of tools that consider the entire life cycle of products Selection of tools that can conduct multi-criteria analysis	Perception of bureaucracy Lack of clear legislative framework Specificity for product categories No responsibility for producers Not enough legislative incentives No support in regulations and legislation application	environmental rules, principles and standards Development of company-specific guidelines Elaboration by national states of more restrictive environmental legislation
Product and related production process		**Supplier**	
Complexity of the product development process Lack of standardization in the product development process Lack of environmental goals Lack of testing of product Conflict in functional/environmental requirements Best trade-off identification Identification of critical environmental issues	Standardization of the product development process Formalization of the product development process and inclusion of ecodesign activities Consideration of environmental issues at the beginning of the product design process Integration of environmental issues in the conventional product development process Introduction of environmental checkpoints, reviews and milestones into the product development process Adoption of a life cycle perspective Evaluation of the complete product life cycle	Difficulty in the relationships of buyers/suppliers Difficulty in obtaining detailed data from suppliers Lack of quality data from suppliers Difficulty in retrieving data form the complete supply chain	Establishment of a close relationship with suppliers Development of a good international network Good involvement of supplier expertise in the product development process Analysis of the complete supply chain to identify criticalities

2 THE G.EN.ESI PROJECT

The G.EN.ESI project (Figure 3) was an EU funded research and development project that had the aims to develop a methodological approach and an integrated software platform for the improved environmental design of electro-mechanical household appliances.

The Project name G.EN.ESI stands for Green ENgineering and dESIgn and the project was co-financed by the European Commission within the VII Framework Programme FP7-NMP-201 l-SMALL-5 (Grant Agreement Number 280371). The Project was a three year research and development project which began in February 2012 and has been completed in January 2015.

The G.EN.ESI project, in order to answer to the not solved problems related to the lack of implementation of ecodesign methods and tools in industrial context, proposed a simplified approach based on a structured methodology and composed by interoperable tools, integrated with the traditional ones used inside companies.

The work realized during the PhD and described in this thesis (as already explained in the INTRODUCTION Section), was strictly connected to the G.EN.ESI project. As a consequence, this chapter describes not only the activities realized during the PhD, but also the main aspects of the G.EN.ESI project, in order to introduce the readers into the content of the project and to allow them to understand where the contribution given during the PhD is collocated inside the entire project.

As a regard to the specific activities conducted during the PhD courses, that will be described during the next paragraphs and chapters, they have consisted in:

- Definition of the methodology, functionalities and contents for the CBR tool as one of the tools of the G.EN.ESI software Platform;
- Support to the Faber company in all the activities related to the implementation, test and validation of the G.EN.ESI platform into its departments. This activity has allowed to directly understand the problems related to ecodesign methods and tools in industrial companies and to reflect on possible strategies to overcome them and facilitate the effective ecodesign implementation;
- Definition of the questionnaires to evaluate the G.EN.ESI platform usability and integration inside the FABER company;
- Test of the CBR tool in the Electrolux company, taken as second test case; supporting of all the activities connected to the implementation and evaluation of the tool inside the company;
- Optimization of the CBR tool, according to the results of the second industrial implementation. Evaluation of its limits, strength and possible future development;
- Definition of the methodology, functionalities and contents for the EoL module of the LeanDfD tool.

In the following paragraphs, the G.EN.ESI project (with its methodology, platform, workflow, users, etc) is described. More emphasis in the description will be given to those tools developed by the Università Politecnica delle Marche, and in particular to the CBR tool and EoL module of LeanDfD, developed during the PhD.

Figure 3. The G.EN.ESI logo

2.1 The G.EN.ESI Partners

The G.EN.ESI project aimed at better integration of environmental information and design considerations into the design and development process of electro-mechanical appliances. To address these aims a **multidisciplinary team of researchers and industrial partners has been gathered, offering expertise in ecodesign, material science, design and manufacturing, software development, Life Cycle Assessment, waste treatment and recycling.**
Scientific partners and their main roles in the project are described in the following.

Università Politecnica delle Marche

Figure 4. UNIVPM logo

The team at the Università Politecnica delle Marche in Ancona (Figure 4), Italy are based in the Design Tools and Methods Group (DT&M) of the Department of Industrial Engineering and Mathematical Science. This team was the Project coordinator and has coordinated the project from a technical and administrative point of view. At technical level, the main activity in which the DT&M Group was in charge was the development of three software tools of the Platform: the LeanDfD tool, the CBR tool and the DfEE tool. Furthermore it has contributed to the definition of the G.EN.ESI Methodology, has supported the industrial companies involved in the test activities and has followed all the dissemination activities.

ENEA

Figure 5. ENEA logo

The Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA, Figure 5), is specialised in applying research and technological

innovations within industry. The expertise of ENEA include development of LCA and Ecodesign methodologies and specialised tools for SME, that has been developed by performing several case studies in co-operation with Industries, Consortia, National and Regional Agencies and Public Authorities.
Within the G.EN.ESI project the team was in charge of the development of a tool for the detailed analysis of the environmental impacts of product life cycle (eVerdEE tool) and of supporting all the activities related to the definition of the methodology steps and platform functionalities. Enea has contributed to the development of the PhD research activities and has cofinanced the present PhD course.

Grenoble Institute of Technology

Figure 6. Grenoble INP logo

The team of the Grenoble Institute of Technology are based in the G-Scop Institute (Figure 6). The G-SCOP laboratory is recognised as a multidisciplinary laboratory, expert, among other disciplines, in integrated design. As an expert in sustainable design, the G-Scop Product Design Process team is involved in the definition of the ecodesign methodology for the development of G.EN.ESI software platform and is responsible of the Scientific Coordination of the project.

University of Bath

Figure 7. Bath University logo

The team at the University of Bath (Figure 7) are based in Mechanical Engineering. Within the G.EN.ESI Project they were in charge of project dissemination and research into ecodesign practices and methodologies.

Industrial partners and their main roles in the project are described in the following.

Granta Design

Figure 8. Granta Design logo

Granta Design (Figure 8) is the world leader in materials information technology. Within the G.EN.ESI project the GRANTA team was responsible at first for developing the software for the simplified analysis of product environmental impact: Eco Materials. They also have been responsible for all the software platform development, i.e. the integration of all the tools developed by the other partners to create an interoperable system

FABER Spa

Figure 9. Faber logo

Faber company designs and manufactures cooker hoods for an international market (Figure 9). The company has tested and implemented the G.EN.ESI software platform and methodology. They has also carried out, supported by scientific partners, all the preliminary activities needed for the definition of the G.EN.ESI Platform features, i.e. data on: their production processes, product development process and products details and characteristics. During the PhD all the activities related to the implementation of the G.EN.ESI results was directly conducted inside the design departments of the Faber company.

Bonfiglioli Vectron

Figure 10. Bonfiglioli Vectron logo

Bonfiglioli Vectron (Figure 10) specialises in the design and manufacture of electrical drive systems and electric motors. Within the G.EN.ESI project Vectron was one of the industrial partners and their departments have tested, implemented and evaluated the G.EN.ESI software platform.

Sibuet Environment

Figure 11. Sibuet Environment logo

Sibuet Environment (Figure 11) is a waste processing company based in France. Within the G.EN.ESI project they have brought expertise in the processing of electronic waste (WEEE directive) and help providing an understanding of the best Design for End of Life approaches for electro-mechanical appliances.

2.2 G.EN.ESI Project main objective

The G.EN.ESI project was developed from recognition of the existent gap between ecodesign tools and methods available in literature and their effective use in industrial companies. Its aim was to develop an integrated software platform for Green ENgineering dESIgn and product sustainability, in appreciation of the increasingly computer based activities of modern designers (Römer et al., 2001). **The main result was a software platform composed by several interoperable tools that provides designers with a timely yet comprehensive way of integrating environmental issues into the product design process. This result has been condensed into four operational objectives: rapidity, spread, usability and robustness**. The developed platform allows to "provide rapid environmental assessment", "promote the spread of both the principles and tools of ecodesign", whilst at the same time integrating "with the traditional tools used in the product design process" and providing informative and accurate results on a range of applicable factors (Germani, 2011).

2.3 The G.EN.ESI Methodology

The first result of the G.EN.ESI project was the definition of the G.EN.ESI methodology. It provides a structured workflow that supports the integration of environmental design activities and management within existing design and engineering departments. The methodology consists of a six step process as it is represented in the Figure 12.

Step 1: Define environmental drivers and business objectives.

In this first step, the company identifies the drivers that will guide the project and the business objective it want to reach. It is a very important phase to which the company has to dedicate resources by involving the management team. The objective is defined according to product specifications, e.g. environmental performance, costs, legislation, market, etc. and the company has to be sure to have a good understanding of the business case for environmentally improving of its products.

Step 2: Adopt a life cycle thinking approach to determine environmental impacts of the product.

The adoption of a life cycle perspective and the mapping of the environmental impacts related to each lifecycle phase (by LCA) will help company to identify unexpected impacts. The most significant environmental impacts in fact of a products may come from unexpected places. The relative contributions of each life cycle phase will also help companies to priority efforts, and help monitor the transfer of impacts from one life cycle phase to another.

Many tools are available to help the incorporation of environmental life cycle thinking within an organization. These range from in-depth quantitative LCA software programs which map all the environmental inputs and outputs of a product life cycle; through to quick and easy qualitative tools that support concept development activities.

Step 3: Aligning environmental 'hotspots' and business context and determine relevant indicators to guide the design.

The environmental "hotspots", i.e. the most environmental critical product aspects, identified by life cycle activities, must then be aligned with the wider business context. Aligning environmental issues with the business context, will further priorities company efforts and ensure that design focus makes good business sense. Knowledge gathering exercises such as literature reviews, competitive benchmarking, and legislative surveys will help company to understand the business issues related to environmental hotspots. These can then be translated into the design criteria that will drive environmentally improved product development.

Step 4: Conduct design development activities.

According to the target priority established on the previous phases, design development activities are conduct to optimize the product in environmental terms. Developing and sharing tailored environmental guidelines can be very useful during these early stage efforts to create a company repository of environmental knowledge.

Step 5. Integrate LCA throughout design development.

Design efforts must be checked throughout the process to ensure environmental improvements are being made and targets are reached. These checks will require a lifecycle focus to ensure that reductions in one lifecycle phase do not generate disproportionate increases elsewhere. To ensure that these checks do not disrupt design efforts, it is important that the lifecycle assessment methodology is quick to do and easily understood. The results of these lifecycle checks may also require further research and development activities, in essence returning to stage four. Stages four and five may in fact be repeated multiple times before a design is completed. In this step, reports are generated to collect the different changes operated during the redesign of the product. In this way design activities can be supported by the consultation of these past choices and as a consequence future applications of ecodesign approaches facilitated.

Step 6: Review design process and outcomes and revise long term strategy.

Once the design has been completed, the company needs to review the development process to understand the environmental achievement that occurred and the outcomes they produced. The review can then be used to identify the company's current environmental position and adjust the long term strategic goals accordingly. Step 6 will then naturally feed into Step 1 for the next generational product development.

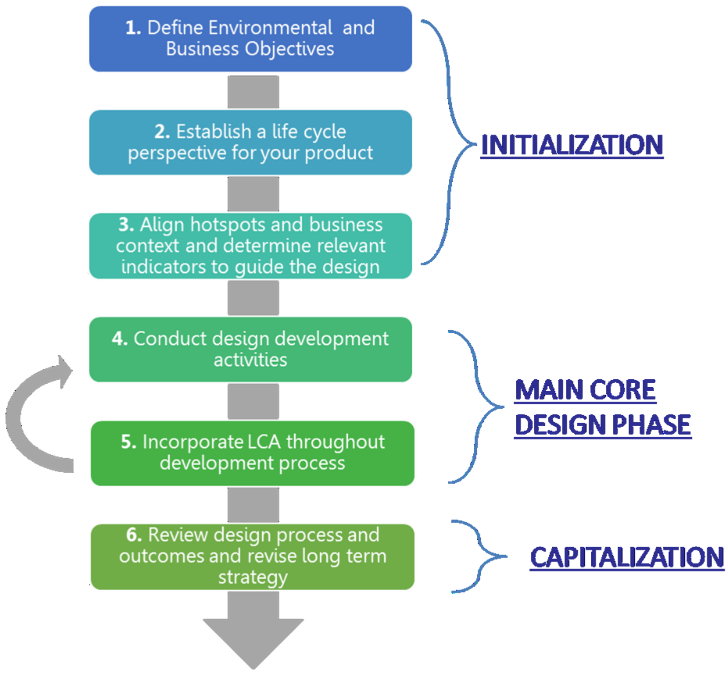


Figure 12. G.EN.ESI Methodology

2.3.1 Elements needed to support the methodology

The methodology helps the design teams:

- to integrate the environmental viewpoint;
- to facilitate the consideration of the different viewpoints;
- to help data capitalization and exchange;

in order to reduce the product environmental footprint and to avoid impacts transfers.

The G.EN.ESI methodology is an integrated approach, in which a multidisciplinary group considers the whole product life cycle. New organizations of the team, cooperation among company’s figures, a clear project management and dedicated and specific tools are therefore elements added to the traditional structure of the company.

These new elements determine some further changes in:

- **Data fluxes**, i.e. data on the product need to be exchanged among different departments, tools and personas;
- **Partnerships**, i.e. solid relationship established with suppliers to improve the environmental performances of component acquired from external companies;
- **Design process**, i.e. inclusion of environmental considerations, estimation and analysis in the traditional product development and design process;
- **Companies strategies and cultural approach**; i.e. add to traditional objective, also the sustainability and define a strategy to capitalize this modification;
- **Knowledge and skills**, i.e. increase the knowledge of the existent personnel on environmental matter or involve new personnel with this knowledge;

Consequently it is possible to define some elements needed to support the implementation of the G.EN.ESI methodology in a company:

- Tools for project management support
- Tools for design activities
- Specific stakeholders
- Vehicles of environmental information

The first two elements are present also in traditional design processes, e.g. CAD tools, PLM system, etc. while the third and fourth elements introduce some novelty elements and detailed in the following.

A design team consists of designers from different offices and departments (indicated in the following as designer), managed by a steering team, usually one person known as the Project manager. In a context of integrated design, like the one the G.EN.ESI methodology proposes, the project manager has a multidisciplinary role. He ensures the coordination between the different actors and their points of view in order to meet all the constraints.

An environment expert is also strongly recommended in order to manage ecodesign and the environmental issues in the product design process. **In G.EN.ESI Methodology, this expert is called the Environmental Design Manager.** Indeed, the project manager needs to be assisted by this environmental expert because he usually does not have the skills to understand the environmental data, the environmental indicators and thus he cannot take informed decisions. Thus the Environmental Design Manager is a member of the steering team. He can be an environmental expert of the company or if there is no environmental expert, it can be an external consultant. By working alongside the environmental manager, the project manager can learn environmental skills. When knowledge increases, environmental responsibilities will tend to be shared throughout the design team and the need for a distinct Environmental Design Manager reduces.

As a regard to information, in addition to internal ones, environmental data is also required from suppliers. The suppliers are therefore requested to share information about their products, components, materials, factories or other. The shared data will be useful to realise the environmental and cost analysis of the entire designed product. This close relationship between the suppliers and the design team is quite new and requires careful management. The information flow need to be supported in order to allow an effective exchange of data among different departments and different actors involved in the design/redesign process.

2.4 The G.EN.ESI Platform

Starting from the G.EN.ESI methodology, the G.EN.ESI platform has been developed.

The G.EN.ESI Platform is envisioned to be used by various actors within an enterprise and supply chain in order to assess the environmental impact of products throughout their life cycle.

The G.EN.ESI Platform consists of various tools, integrated in the same structure. G.EN.ESI tools will be synergistic and communicate to each other to support the whole product design process.

Each tool is dedicated to a specific life cycle phase and their integration in a same platform allows controlling the environmental and economic aspects along the entire product lifecycle.

The interoperability of the different tools will allow a flow of information in a quick and automatic way.

The tools included into the platform are:

- **Eco Material** is a tool dedicated to the management of the material selection and manufacturing phase. It helps designer in the selection of the most sustainable solution for materials and related manufacturing processes. The tool is based on the Granta Material Database which is composed of about 4000 fully characterized materials. It permits to search in the database and to compare different solutions in order to choose the most sustainable for each component. The designer will be always conscious of its choices and the consequences on the product.
- **Design for Energy Efficiency (DfEE)** is a tool oriented for energy using components and allows the company to accurately evaluate the use phase of the components in terms of energy consumption, environmental impact and the Total Cost of Ownership.
- **Lean Design for Disassembly (LeanDfD)** is a tool dedicated to product End-of-Life (EoL) management. The tool permits to evaluate the disassembly time and cost of the entire product or of a specific component (or subassembly). This assessment permits to manage the disassembly phase at EoL yet during the design phase, in order to promote closed loop scenarios (reuse or remanufacturing of components, recycle of materials). LeanDfD permits also to calculate the recyclability rate of the product and to provide suggestions to better manage the EoL phase and to increase the recyclability of products.
- **Simplified–Life Cycle Assessment (S-LCA)** tools allow the environmental impact calculation of the entire product life cycle. Considering all the choices made by the platform users (material and weight of each component, manufacturing processes, transport, etc…) the life cycle impact are calculated and shown in a detailed report to the user. In the G.EN.ESI platform, these functions are delivered by two tools: the **Eco Audit** tool and the **eVerdEE**, the first with a limited number of environmental indicators, the second with higher number of indicators and by a procedure compliant with ISO standards related to LCA (14000 series).

An additional tool has been thought to support designers in the implementation of the ecodesign guidelines, using a CBR (Case-Based Reasoning) approach.

The **CBR** is a tool which represents the knowledge and the best practices for mechatronic products. It helps designers in the design process of mechatronic products, through the acquired company knowledge and by the collecting of ecodesign guidelines.

The G.EN.ESI Platform contains also a web-based tool to exchange product related information among the company and its suppliers. This allows the lead company to consider the exact data for all the components of their products (also for those ones bought from other external entities).

The tools of the G.EN.ESI Platform can be grouped into three categories:

- **Specific tools**: this category collects the tools that allow to realize analysis on specific life cycle phases of the product and in particular they are: Eco Material, DfEE, LeanDfD.
- **Sustainability calculation module**: in this category the Eco Audit tool and eVerdEE are included, allowing to calculate the sustainability level of the product.
- **Guidance tool**: this category includes the CBR tool, that support the ecodesign process.

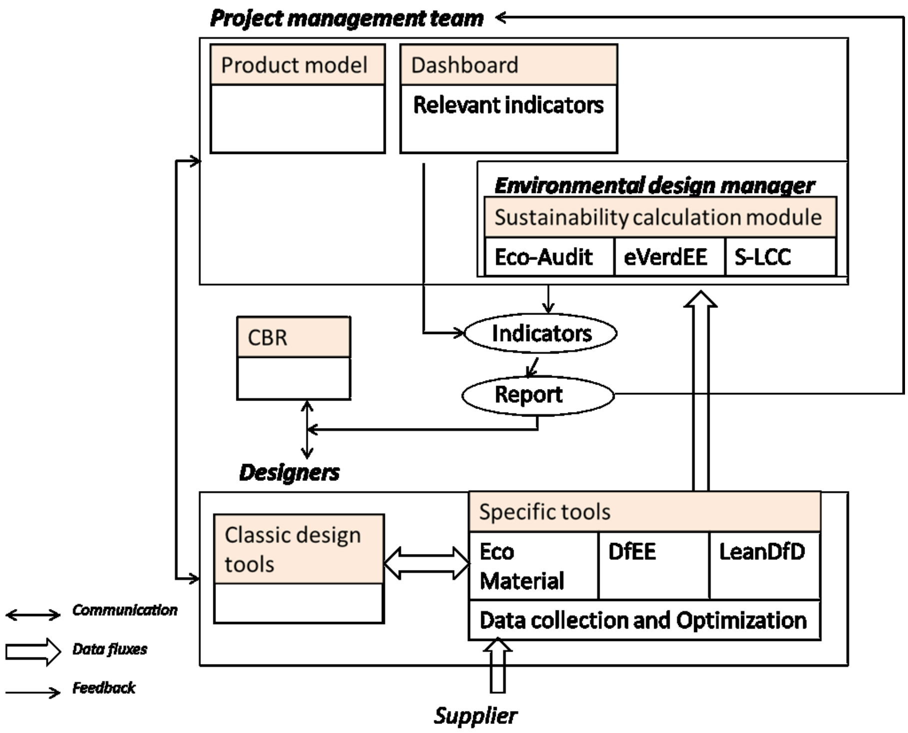


Figure 13. Data fluxes, feedback and communications among actors and design phases

The Figure 13 presents how the different stakeholders use the tools and what fluxes, communications and feedback are involved. In particular the Project management team defines at first the company business objective, which will guide the entire design project, through the identification of relevant indicators. Then the quantification of the product environmental impacts is realized by the environmental design manager, which uses the sustainability calculation module in collaboration with designers, who in parallel model and design the product with the specific tools of the platform and with the classical design ones. During their work, designers are supported by the CBR guidance tool. The results of these analysis will flow into a report, which is analyzed by the project management team, before taking final decisions.

Communications with suppliers is realized to retrieve data of those commercial components present inside the product and to allow an analysis of their environmental behavior.

Figure 14 illustrates the capability of the final interoperable platform developed in the G.EN.ESI project, with a central Corporate Database capable of informing decision makers with reference and primary data, and various interfaces easily accessed in traditional design tools (CAD), product life cycle tools (PLM), a user-friendly web interface which does not require knowledge of CAD or PLM, and specialized tools for Eco Design to support design decision-making.

The platform and its tools are supported by different databases:

- **Reference database**: generic materials, component and process information (from the Granta Material Universe, or EcoInvent for example)
- **Supplier database**: specific, bought-in materials and component information submitted by suppliers through the Supplier Portal
- **Company database**: specific, bought-in materials and component information (updated from supplier database), bill of materials information, specific in-house process and component information (i.e. all the information submitted by suppliers plus all the proprietary information about the product)
- **Tool specific databases**: additional information required for use of tools.

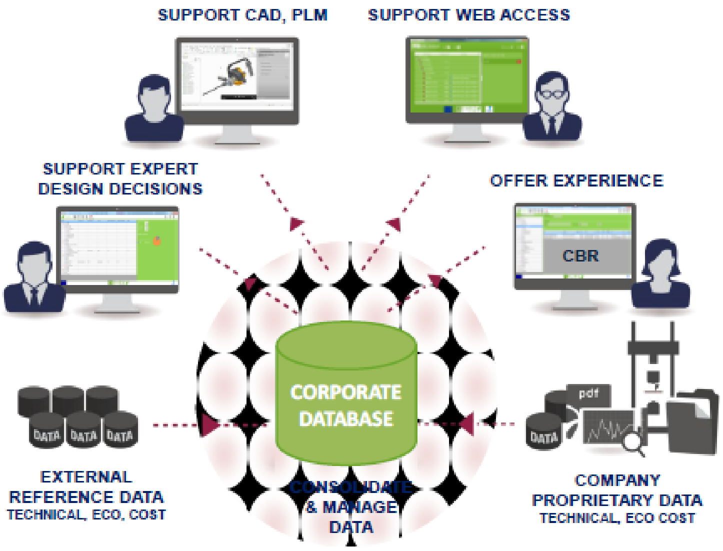


Figure 14. Illustration of the G.EN.ESI Platform and users

2.4.1 G.EN.ESI tools interoperability through an XML file

The G.EN.ESI tools extend the capability of S-LCA by analyzing specific life cycle aspects of mechatronic products for materials and process selection/substitution (Eco Material), energy efficiency in the Use phase (Lean Design for Energy Efficiency, DfEE), and disassembly at the End-of-Life phase (Design for Disassembly, LeanDfD). Eco Material enables the selection of materials and processes on the basis of technical, environmental and cost performance. The DfEE and LeanDfD tools report recommendations during the design process for enhanced mechanical-electrical performance and spatial/geometrical features for improved disassembly time, respectively. eVerdEE is an SLCA tool that allows a detailed analysis with more environmental indicators (presented in detail sin the following). The CBR tool helps designers during the product improvement phase with recommendations for the.

All the G.EN.ESI platform tools are interoperable each other's by their ability to pass Bill of Materials (BoM) information and results by a common XML file. Each tool of the G.EN.ESI platform can therefore write and read data from the XML file. XML stays for "*Extensible Mark-up Language*", a mark-up language that defines a set of rules for encoding documents, in a format, which is both human and machine-readable. The design goals of XML emphasize simplicity, generality and usability across the Internet. In fact, it was chosen to be the interchange format within the platform, ensuring the whole interoperability of the G.EN.ESI Platform tools.

The G.EN.ESI software platform thus can become an 'enhanced SLCA', accessible from a variety of environments (CAD, PLM, Web) and actors in the design process.

2.4.2 G.EN.ESI integration with commercial tools (CAD, PLM)

Some of the G.EN.ESI tools are integrated with commercial CAD tools and can automatically retrieve data from it. In particular LeanDfD, and Eco Material are integrated with CAD systems. They can retrieve the product structure (assemblies, sub-assemblies, components, etc…), all the name associated to product components, their mass, and their materials. The Eco Audit tool is integrated within CAD and PLM. Figure 15 illustrates the integration of Eco Audit in a Creo 2 CAD package. A tab in the Creo interface allows the user to switch the view shown in Figure 15 where materials and processes can be assigned to the various components of the Cooker Hood, and an Eco Audit performed to show the effect of design changes on environmental performance. Behind this interface is the integration of Eco Material, the database supporting technical and environmental information records for materials and processes, and the coding architecture of Eco Audit to allow for calculations. Figure 16 shows the integration of Eco Material and Eco Audit in Teamcenter PLM.

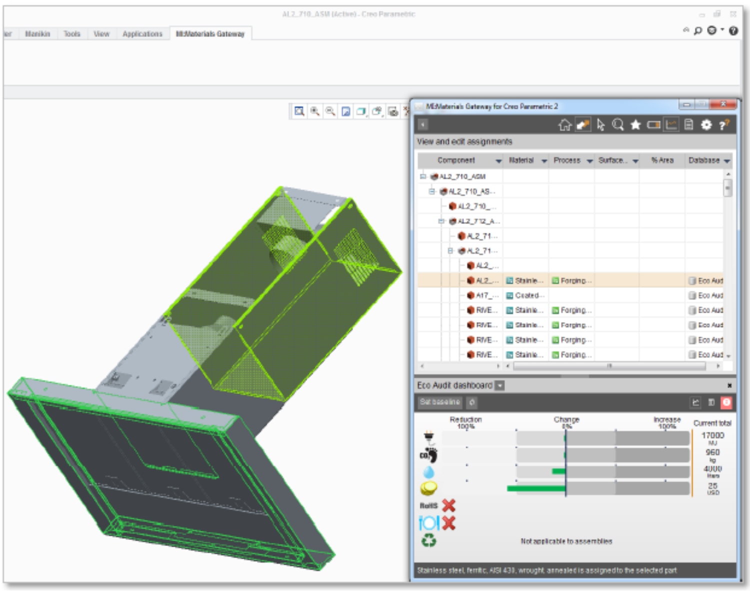


Figure 15. Integration of Eco Material and Eco Audit in CAD

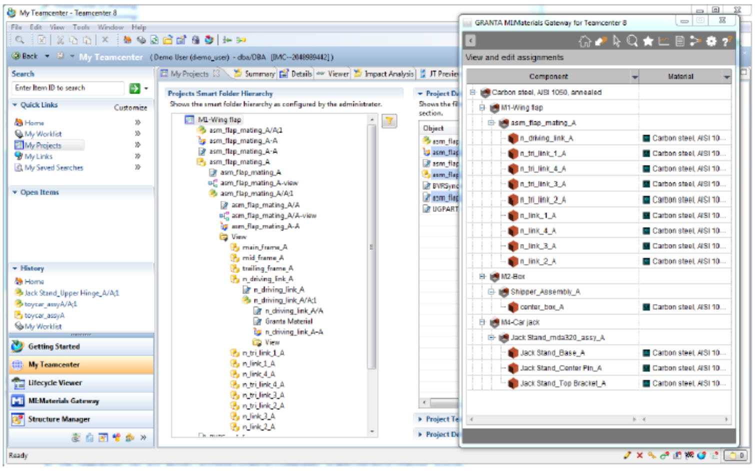


Figure 16. Integration of Eco Material and Eco Audit in PLM

2.5 The G.EN.SI Platform tools

In the following paragraphs the tools that constitute the G.EN.ESI platform are described. More emphasis will be given in the description to those developed as an activity of the PhD (CBR tool and the EoL module of the LeanDfD tool). For the other tools, their main properties and functionalities will be synthetically described.

2.5.1 Eco Material software tool

The objective related to the Eco Material tool (developed by Granta Design and shown in Figure 17) calls for the development of different ecodesign software tools which can guide the designers in the eco-sustainable choices in all phases of the product life cycle. **Eco Material represents the capability to select a material from a reference list with appropriate ecological, technical and cost data for fast analysis** (SLCA, Simplified Life Cycle Costing SLCC) **and comparison against other material options**. It has various data management interfaces (CAD, PLM, Web in the Genesi project) so that actors working in parallel but in different interfaces, can relate to each other's understanding and workflow for data selection and management, and can have confidence that they are accessing the same data. **The integration with CAD systems allows designers to rapidly understand the product main criticalities in environmental terms through simple impact indicators** (Carbon Footprint, Energy, Water) **and to compare different alternatives among which select the best ones.**

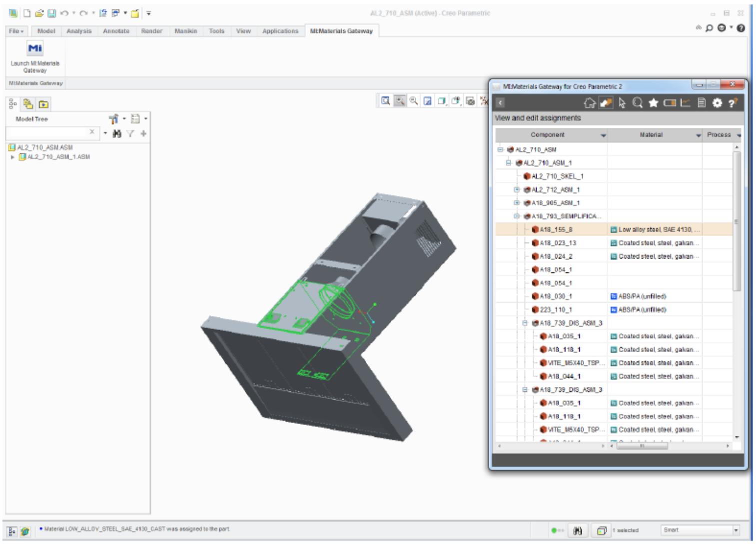


Figure 17. EcoMaterial software tool main interface

2.5.2 DfEE software tool

The DfEE software tool (developed by UNIVPM) is dedicated to the analysis of the use phase of products. In particular this tool is oriented to all those components which are responsible of the energy consumption inside the products (e.g. electric motors, lamps, etc.). The main objective of the DfEE tool is the accurate estimation of the energy consumption of products during the use phase, considering the use profile of the product. **The outputs of the tool is the calculation of the CO_2 footprint and the cost related to the use phase of the product** (Figure 18 and Figure 19). All of them are useful to compare different alternatives and to select the best one in environmental and economic terms.

Because the use phase is usually the most energy consuming lifecycle phase in mechatronic products (the field to which the G.EN.ESI project is focused on), this tool has a fundamental importance to support designers in the selection of the most appropriate energy using components and, as a consequence, to reduce the overall energy consumption, environmental impact and lifecycle cost.

The DfEE tool supports designers during the choice of the best solution (considering the environmental and cost performances) of energy using components. Its main user is therefore the company designer; however is foreseen also the use of the tool by an administrator, responsible to insert into the tool data, specifics and technical performances related to commercial component and stored in the tool Data Base (DB).

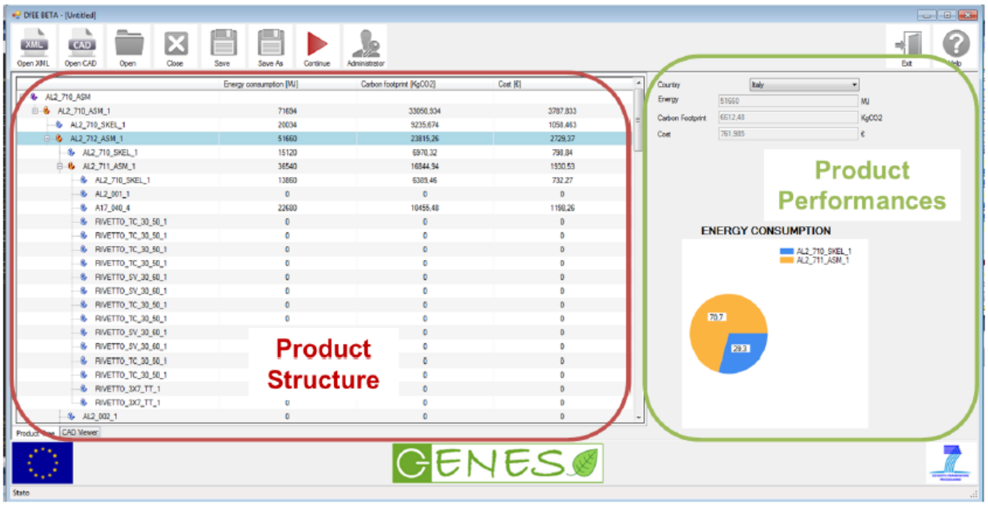


Figure 18. Summary interface with the Product Structure and Product Performances

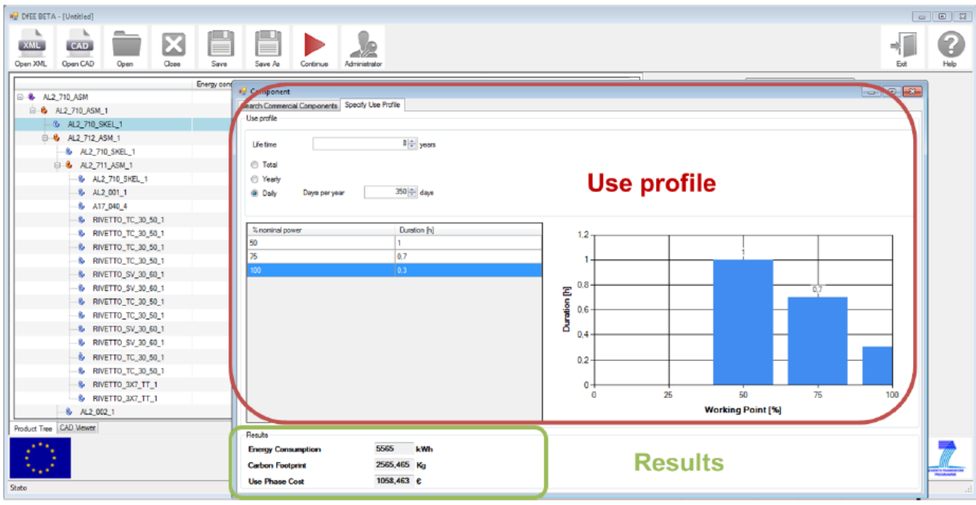


Figure 19. Specification of the use profile (red circle) and analysis results (green circle)

2.5.3 Lean DfD software tool

The Lean DfD software tool (developed by UNIVPM), is dedicated to the analysis of the Disassembly and EoL phases of products, in order to understand their disassemblability and their attitude to have a closed-loop lifecycle.

The main objectives of the LeanDfD tool is the possibility to understand the economic and environmental consequences related to the product disassemblability and the level of its recyclability. It is recognized that if companies want to promote closed-loop scenarios for their products, they need to easily manage the EoL phase during the first stages of the design process. For these reasons the possibility to analyse in detail these aspects with a dedicated tools allow designers to consider aspect that commonly are neglected. The tool is composed by two modules.

The first module (DfD module) allows the calculation of the disassembly time and cost of a particular component/assembly/subassembly of a product. The main application of this module is related to the optimization of the maintenance and recycling phase, which are closely linked to the level of disassemblability of products. High quality separated components and materials leads to a high quality recycling process. Reducing the time to disassemble a component from the entire product will lower the cost related to this operation, and deliver a more convenient recyclability strategy. All the details on the methodology at the basis of the tool are contained in Germani et al. (2014) and Favi et al. (2012).

The second module (the EoL module) aims to provide designers with useful indications of the recyclability level of the product under analysis.

The development of this second module, was one of the activities of the PhD (even if it can be considered secondary in respect to the development of the CBR tool, shown in 0).

The starting point for the development of this module, was the study of the recyclability processes for house hold appliances. This activity was conducted by involving Sibuet, partner of the project and dismantling center, and by directly visiting Italian dismantling centers of household appliances. This analysis has allowed to understand that for household appliances the following recyclability process is generally applied:

- manual separation of "critical components" (all those components that can't be shredded, because they contain hazardous materials or due to their high economic value);
- mechanical shredding of the remaining parts;
- mechanical separation of materials in homogeneous groups (metals, plastics, glass, etc…), to be sent to specific recycling centres;

It is possible to translate these three phases into three related recommendations for designers:

- allow the simple disassembly of critical components;
- use recyclable and homogenous materials and components;
- increase the efficiency of automatic separation procedures by avoiding the use of incompatible materials, which is impossible to separate and recycle;

The LeanDfD tool supports designers in apply these strategies, in particular the DfD module allows to evaluate the disassemblability time of components and subassemblies, identify the criticalities and evaluate the benefits of alternative connections.

The EoL module, allows to evaluate the recyclability rate of the product, identify where the criticalities are collocated, retrieve suggestions for improve the product recyclability.

The EoL module of the LeanDfD tool implements three modules:

1. Module for the numerical quantification of the recyclability level of the product
2. Module for the calculation of some environmental parameters related to the product recyclability
3. Module for supporting the selection of critical components in order to increase their environmental sustainability

Module for the numerical quantification of the recyclability level of the product

To meet the first objective, the alternative approaches which exist in the literature have been reviewed, and the one proposed by the JRC (JRC, 2012) has been selected as the best one to be implemented into the tool. This index is called "Recyclability Ratio".

The "Recyclability Ratio" (RRecycle) [%] is defined as the percentage (in mass) of the product which is potentially recyclable and it is calculated by the Equation 1.

$$R_{Recycle} = \frac{\sum_i \sum_k m_{recycle_{i,k}}}{m_{tot}} \cdot 100$$

Equation 1. Recyclability ratio

With:

- mtot= total mass of the product [Kg]
- mrecycle = potentially recyclable of the k-th material of i-th component [Kg]

The value of the potentially recyclable mass is calculated by the Equation 2, which considers the material, the disassembly process, the material contamination and its degradation level. In detail we have:

$$\boldsymbol{m_{recycle_{i},k} = m_{k,i} * D_{i,k} * C_{1i,k} * M_{Ri,k}}$$

Equation 2. Potentially recyclable mass

- mrecycle i,k= potentially recyclable mass of the k-the material of the i-th components [kg]
- mi,k = mass of the k-th component for which a recycling process is possible at its EoL [Kg]
- Di,k = disassembly index of the k-th material of the i-th component [%]
- C2,i,k = contamination index of the k.th material of the i-th component [%]
- MR,i,k = degradation index for the recyclability of the k-th material of the i-th component [%]

These parameters have been tabulated from JRC (2012) in relation to different categories of materials (plastics, glass, metals, etc…).

The **Disassembly index D** estimates, in percentage [%,], the aptitude of the product's components to be separated and addressed to further EoL treatments.

The methodology defined by the JRC, considers three different disassembly procedures (mechanical, manual and a mix of the two procedures) and for each of them different values of the Disassembly index. For household appliances, we can consider there is a mixed procedure, and the value of the D is obtained by:

$$\boldsymbol{D_{mixed} = D_{manual} * D\_mechanical}$$

Equation 3. Disassembly Index for the mixed case

Where, the Disassembly index for the mechanical shredding is related to the typology of material (Table 4) and the manual ones, is obtained by the calculation of the number of steps and time related to the disassembly (Table 5). In the second case, the number of steps and time is derived from the DfD module.

Table 4. Disassembly Index D mechanical (JRC, 2012)

Material	D mechanical [%]
Iron	95%
Precious metals (gold, platinum, silver)	95%
Aluminium	90%
Copper	85%
Other metals	80%
Plastics	50%
Other materials	0%

Table 5. Disassembly Index D manual (JRC, 2012)

Number n of steps for the manual disassembly	Manual disassembly: D manual [%]				
	Time t for disassembly [s]				
1	t<60	60<t<=120	120<t<=240	240<t<=360	t>360
2	100	90	80	70	60
3	98	88	78	68	58
4	96	86	76	66	56
5	94	84	74	64	54
6	92	82	72	62	52
…	…	…	…	…	…

The **Contamination Index C** estimates how much the presence of contaminants into the materials could potentially interfere with the product's reuse, recycle or recovery. For the calculation of the RRR indices, it is also important to introduce the complementary index of Absence of contamination C' [%] defined in the Equation 4 as:

$$C' = 1 - C$$

Equation 4. Absence of contamination Index

These two indices are tabulated in the following Table 6

Table 6. Contamination Index (JRC, 2012)

	C1 [%]	C1' [%]	Note
High	100	0	Contaminations regard hazardous substances regulated by RoHS Directive and substances classified as Substance of Very High Concern by the REACH Directive Contaminations regard incompatible plastics
Medium	50	50	Contaminations regard plastics with limited compatibility Contaminations are due to the use of shredders for the separation
Low	25	75	Contaminations regard the use of acoustic foam, metal inserts, paints, bracket, coatings, labels, glues or adhesives
None	0	100	None of the previous situations

The **Material Degradation Index M** estimates the attitude (measured as percentage [%]) of the product/component to be suitable for the reuse after its operational time. For the most common material the JRC has calculated the values contained in the Table 7.

Table 7. Material degradation MR index (JRC, 2012)

Material	**MR index**
Metals	1
ABS	0.84
Polycarbonate	0.77
PE-HD	0.85
PE-LD	0.71
PET	0.68
PP	0.81
PS	0.86
PVC	0.76
Paper	0.16
Glass	0.75

The tool is able to calculate the Recyclability Index by retrieving needed information automatically from the XML file and by some data inserted by the user.

In particular from the XLM file the EoL module of the LeanDfD tool retrieves:

- the mass
- the material typology
- the manual disassembly time

The user has to insert information related to the components affected by contamination (e.g. presence of hazardous materials, glued components, metal inserts, etc…) by answer to two questions in the main interface of the tool (Figure 20).

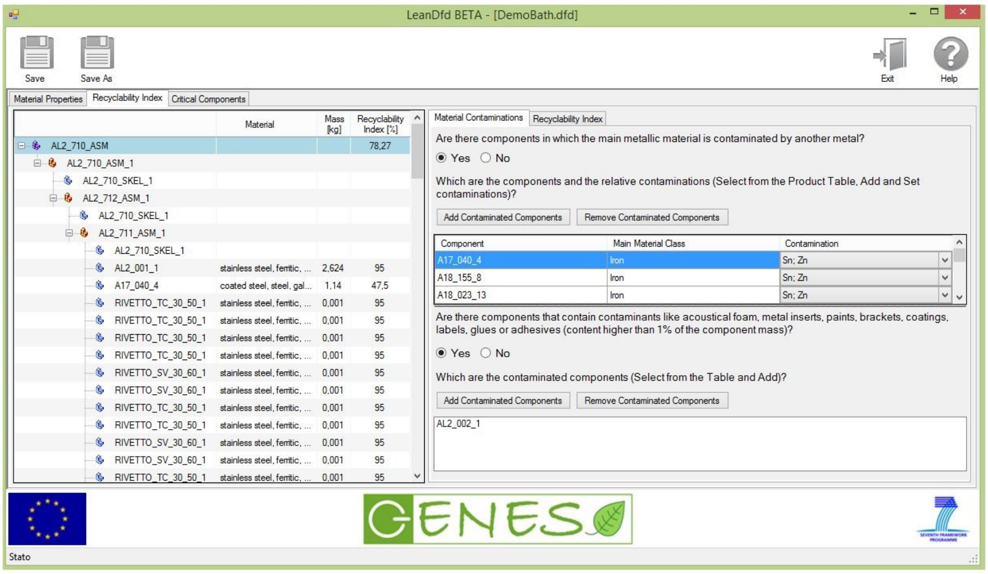


Figure 20. Main interface of the EoL module

The result the user can visualize in the tool is a percentage of recyclability mass for the entire product and all its components (Figure 21). In this way the user can at first have the indication of the product global recyclability rate and then, by visualizing the Recyclability Index of each component, understand where the criticalities are concentrated. By double clicking on the specific component, the user can visualize the indices that have determined the value of the recyclability index for the specific component and have the indication of the problems (contaminants, incompatibility, degradation, ect…). And as a consequence apply strategies to solve them.

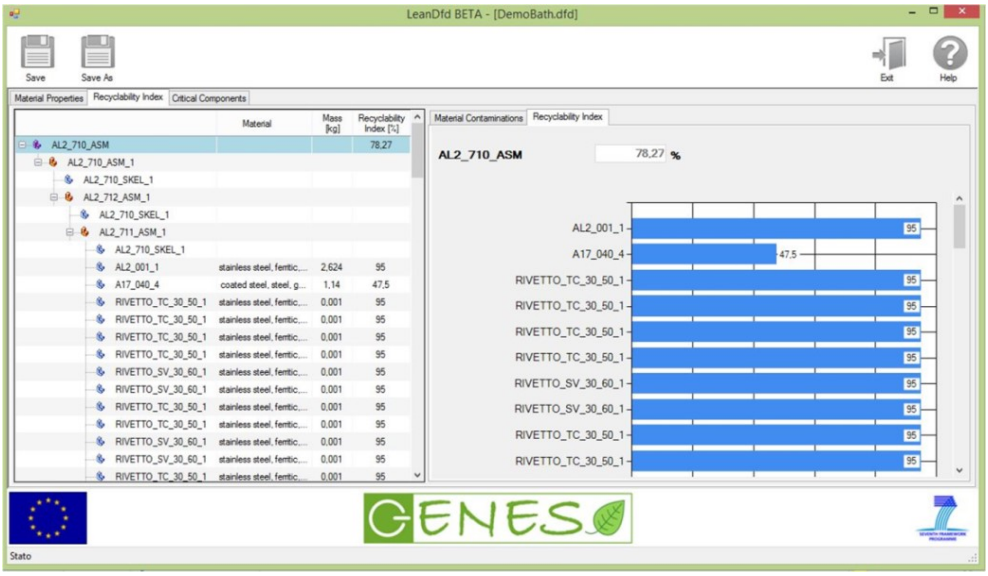


Figure 21. Recyclability calculation interface

Module for the calculation of Environmental parameters related to the product recyclability

In order to allow the user to have some indications representative of the EoL behavior of the components, the tool provides in the Material Properties interface (Figure 22), some useful indications to illustrate product EoL properties. The parameters selected for each component which are made available to the designer are:

- Incineration (Yes/No), (i.e. if the material is suitable for incineration)
- Hazardous (Yes/No),
- Biodegradable (Yes/No),
- Renewable (Yes/No).

Using the information stored in the BoM XML file the tool is able to automatically retrieve some properties relative to the EoL of all the material used in the analyzed product. In particular the user can understand if each material is hazardous, incinerable or biodegradable, which is the percentage of hazardous mass, incinerable mass and biodegradable mass in the product and finally can understand all the incompatibilities between plastics (if any);

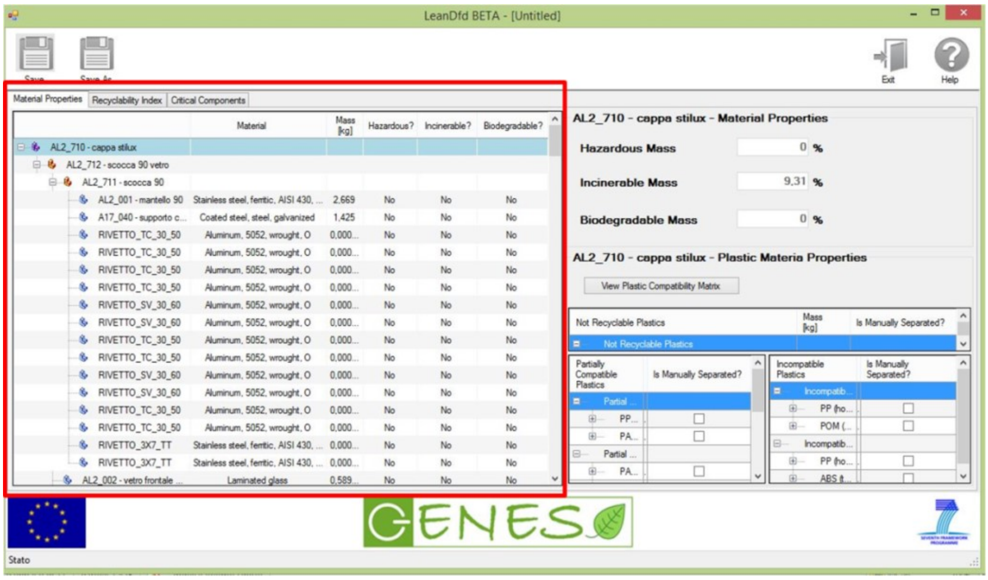


Figure 22. Material Properties interface

<u>Module for supporting the selection of critical components in order to increase their environmental sustainability</u>

Another important sheet of the tool is the one dedicated to critical component, i.e. all those components which need to manually disassemble before the product shredding, due to the presence of hazardous materials, high value materials, or reusable parts (e.g. electronic board, lamps, electric motor, stainless steel parts, etc…). The components to be studied may be:

- Critical Components for the EoL that need to be treated differently according to the EC Directive RoHS (Restriction of Hazardous Substances Directive) (e.g.: electrical and electronic components such as printed circuit boards, electric motors, transformers, lamps, polluting liquids etc.).
- Components made by materials with high residual value (e.g.: components in precious metals, copper etc.).
- Parts expecting a reuse scenario of EoL.
- Components to be kept or replaced (e.g.: lamps, motors, filters, batteries etc.).

- Basic layout components providing a measure of the total time disassembly of the product (e.g.: frames, supporting structures, etc.).

For these components, designers have to:

- Guarantee their easily manual disassembly
- Select the solutions that have the better behaviour in environmental terms

In order to support designers in this activity, an analysis of those components of the main house hold appliances, that require manual disassembly prior to the mechanical shredding of the product, and which cannot be recycled using traditional methods, has been undertaken and the Table 8 has been derived.

Table 8. Critical componens for several household appliances

Critical Component	**Washing machine**	**Cooker Hood**	**Dishwasher**	**Oven**	**Refrigerator**
Capacitor	X	X	X	X	X
Concrete balance weight	X		X		
Electronic Board	X	X	X	X	X
Cromed-Zinc-coated components	X	X	X	X	
Electric Motor	X	X	X	X	
Transformer	X	X	X	X	
Lamp		X		X	X
Pump	X		X		
Thermostats, sensors, switchs	X		X	X	X
Stainless stell drum	X				
Electric cables	X	X	X	X	X
Compressor					X
Oil					X
Refrigerator					X
Glass shelfs					X

For these components, specific documents have been prepared wherein designers can determine their criticalities or advantages, learn about their impact on environment and the recovery strategies applied for them, with the final aim at improving critical component environmental EoL performances. Designers can consult this document by accessing to the dedicated interfaces and by double clicking on the document they want to consults.

As a regard to the LeanDfD tool architecture, the Figure 23 shows it, with its main modules and databases.

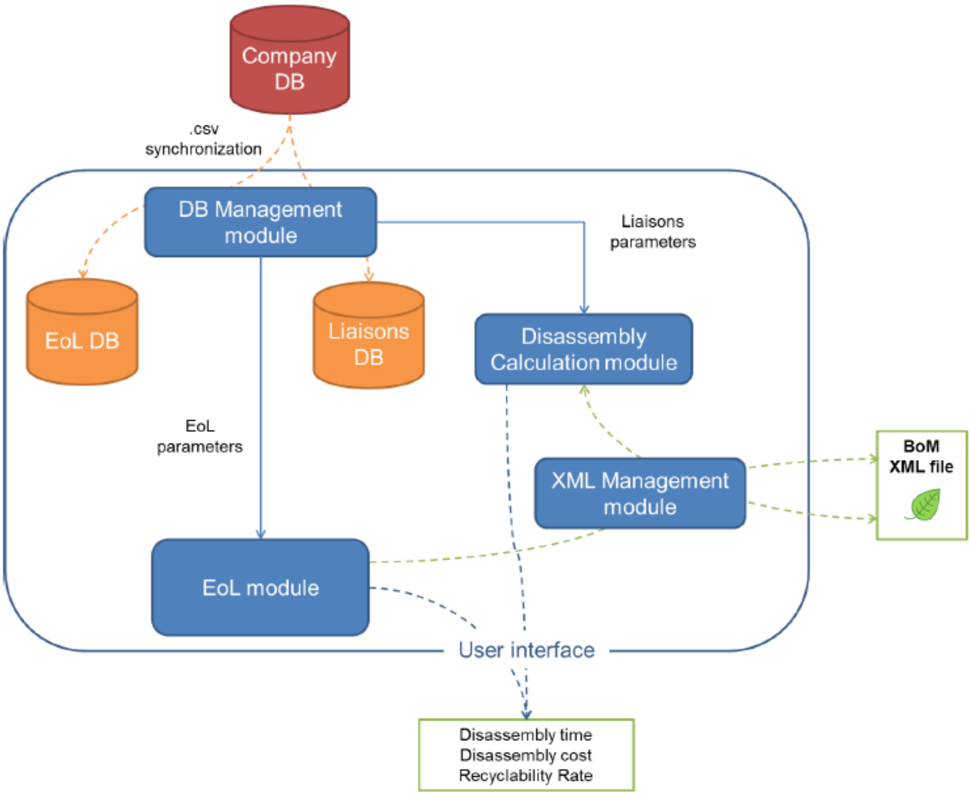


Figure 23. LeanDfD tool structure: modules and databases

The internal database of the tool are:

- The EoL DB in which all the parameters necessary to the EoL module are stored. In particular it is composed by the following tables:
  - Product Families: this table stores the product families (e.g. household appliances, etc…). Each product family can contain more than one product typology;
  - Product Typologies: this table stores the product typologies (e.g. cooker hoods, washing machines, ovens, etc…). Each product typology can contain more than one critical component;
  - Critical Components: this table stores the critical components (e.g. electric motors, capacitors, lamps, etc…). For each critical components the DB stores an attachment relative to the EoL information;
  - Materials: this table stores the materials, univocally identified by a Guid and characterized by a set of characteristics (possibility to recycle, heat of combustion, possibility to dismantle in a landfill, biodegradable or not) as well as a set of index for the recyclability rate calculation (material degradation and disassembly index);
  - Plastic Compatibility: this table stores a matrix about the compatibility between different plastic, in order to understand if two or more plastics can be recyclad together (compatible polymers) or not (partially compatible polymers or incompatible polymers);

    - Plastic Contamination Index: this table stores the Contamination Index relative to compatible, partially compatible or incompatible plastics, used to calculate the recyclability rate;
    - Metal Classes: this table stores the metal classes for metallic materials;
    - Metal Contamination Index: this table stores the Contamination Index to characterize the different possible metal contaminations chosen by the tool user.
- The Liaison DB in which all the information related to liaisons are stored. In particular, it contains:
    - Liaison Types: this table stores all the liaison typologies (e.g. screw, nut, pin, etc…) that it is possible to find in a product. Each liaison type is univocally characterized by an Identifier (ID) and a standard disassembly time, that represents the disassembly time in standard condition;
    - Liaison Classes: this table stores all the liaison classes, to which each liaison Type belong to (e.g. Threaded, Shaft-Hole, Rapid joint, etc…);
    - Liaison Type Properties: for each Liaison Type, different properties are defined in order to consider the liaison type condition (e.g. wear, screw length, screw diameter, etc…)
    - Liaison Type Factors: for each Liaison Type Property a corrective factor is defined; this factor is multiplied for the standard disassembly time to obtain the effective disassembly time (for the specific liaison type condition defined by the user);
    - Liaison Class Properties: for each Liaison Class different properties are defined to consider the liaison class condition (as in the case of the liaison type properties)
    - Liaison Class Factors: for each Liaison Class Property a corrective factor is defined; also this factor is used to obtain the effective disassembly time (for the specific liaison class condition defined by the user);
    - Tools Table: The different tools, that can be used to disassemble all the liaisons, are stored in a specific table and they are associated to a particular liaison type or class. In this way not all the disassembly tools can be selected for all the liaison types or classes. Each tool is characterized by: Name, Unitary cost (used for the disassembly cost calculation), Liaison classes (for which the tool can be used) and Liaison Types (for which the tool can be used).

The main modules which compose the LeanDfD tool are:

- **The XML Management module** which is able to import/export the necessary information from/to the G.EN.ESI BoM XML exchange file. In particular this module can import in the LeanDfD tool all the data stored in the exchange file (e.g. product structure) and can export the disassembly time and cost and the for the specific “target” component/sub-assembly identified by the user and the recyclability rate related to the entire product.

- **The DB Management module** has the task to interface the LeanDfD tool modules with the two internal databases (EoL DB and Liaisons DB) and with the Company DB. In particular this module manages data like liaison classes, types and properties to allow their use by the two calculation modules.
- **The Disassembly Calculation module** carries out the estimation of all the feasible disassembly sequences for the "Target" components/subassemblies that the user has specified. From the disassembly sequences and on the basis of liaisons and related properties specified by the user, the tool extracts the disassembly time and cost for the particular disassembly sequences chosen by the user. All the information related to unitary costs (e.g hourly labour cost, disassembly tools costs, etc.) and times (e.g. standard disassembly time for each liaison) is retrieved by this module from the Liaisons DB.
- **The EoL Calculation Module**, allows to calculate the EoL performances for the analysed product, in environmental terms. In particular it allows to understand the most important EoL properties for the material used in a product, it allows to calculate the recyclability rate for the entire product and for each component and finally it also allows to understand the most important EoL characteristics for the critical components (electric motors, lamps, capacitors, electronic boards, …).

The general workflow of the LeanDfD tool is presented in the following Figure 24, in which the blue blocks represent the phases which are automatically performed by the tool, while the black blocks represent the phases which require some inputs from the user.

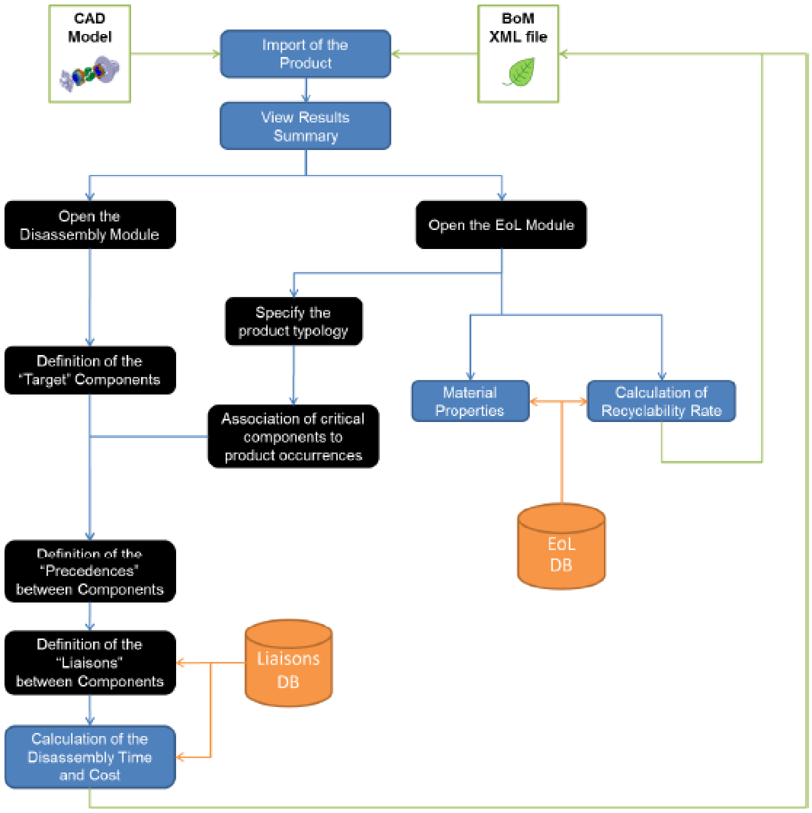


Figure 24. LeanDfD tool workflow

The steps of the LeanDfD tool workflow are:

1. The user open the Main interface (Figure 25 and Figure 26). The main interface is composed by 2 sections: the left one in which the product structure is visualized, the right one in which a summary of previous analysis is shown (relative to the whole product or component/subassembly). The user can:
    - Import a BoM XML file
    - Import a LeanDfD native file
    - Import a CAD file

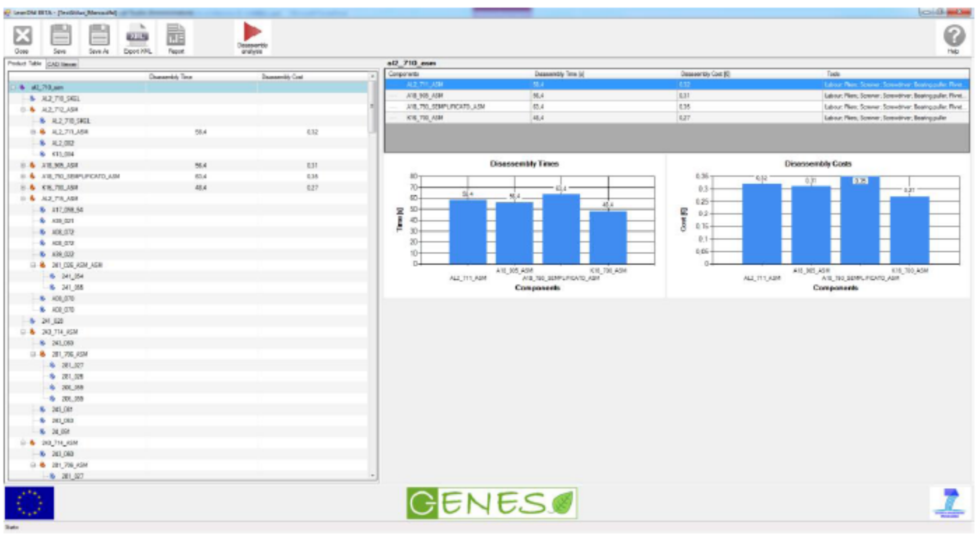


Figure 25. Summary interface with the Product Disassembly Performances

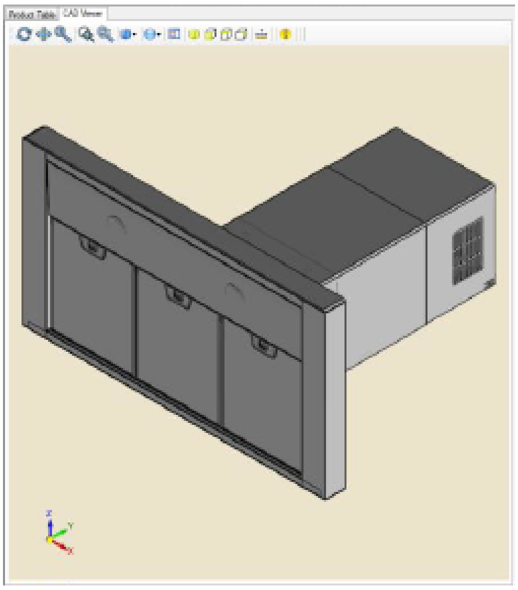


Figure 26. The CAD Viewer integrated in the LeanDfD tool

2. The user can choose to open: the Disassembly Module (Case 1) or the EoL one (Case 2).

For shortness needed, only the workflow of the EoL module will be described in the following, due to the fact the development of this module has represented one of the activity of the PhD.

Case 2 workflow description. If the user choose to launch the EoL module he can access to the following windows:

– **Material Properties**: using the information stored in the BoM XML file the tool is able to automatically retrieve some properties (Figure 27) relative to the EoL of all the material used in the analysed product. In particular the user can understand if each material is hazardous, incinerable or biodegradable, which is the percentage of hazardous, incinerable and biodegradable mass in the product and finally can understand all the incompatibilities between plastics (if any);

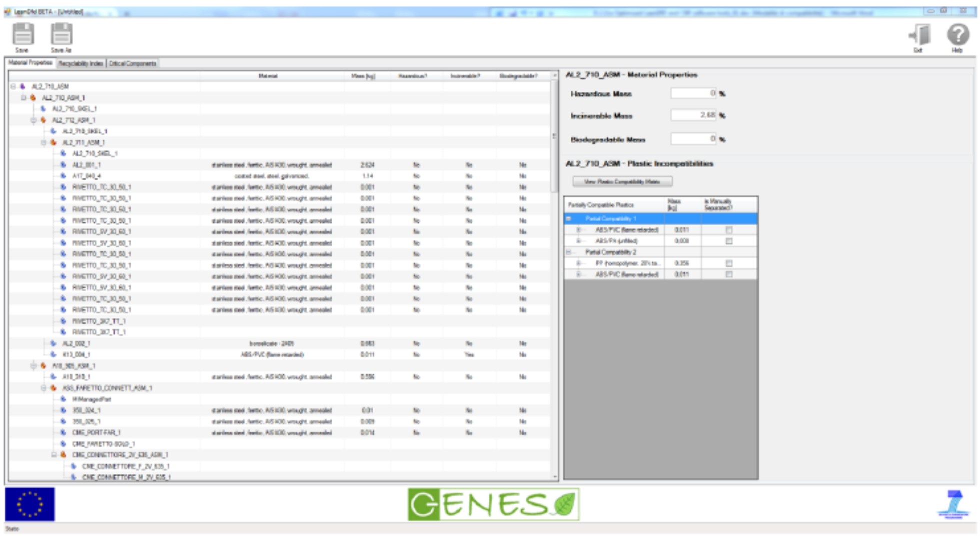


Figure 27. Material Properties analysis

– **Recyclability Index**: in order to calculate the recyclability index of the entire product and of each component, the user has to choose if there are metallic components contaminated with other metal (e.g. galvanized components) or components contaminated by other things (e.g. glues, adhesives or coatings) (Figure 28). This information are essential to set the contamination index of each component, that, in addition with the disassembly index and the material degradation, stored in the internal DB, are used to calculate the recyclability rate (Figure 29);

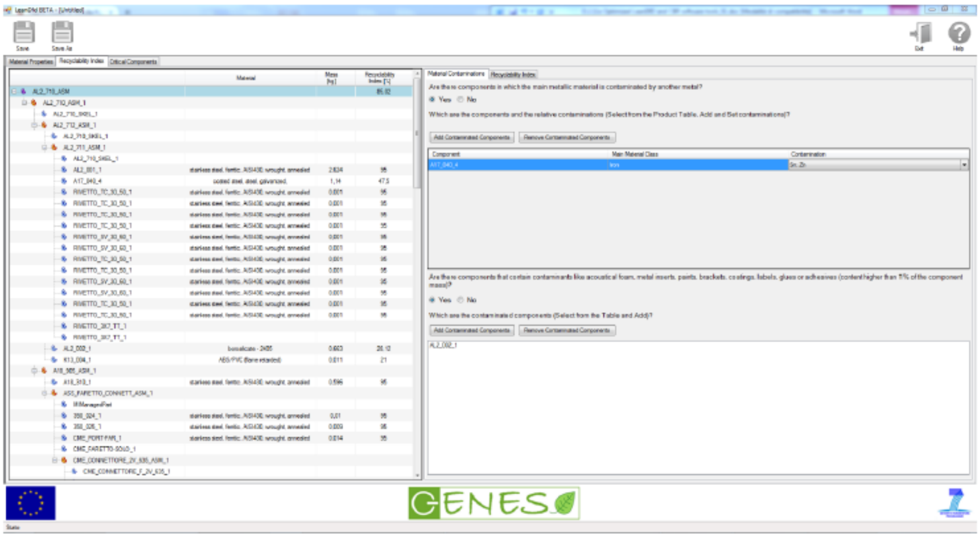


Figure 28. Interface for setting of material contaminations

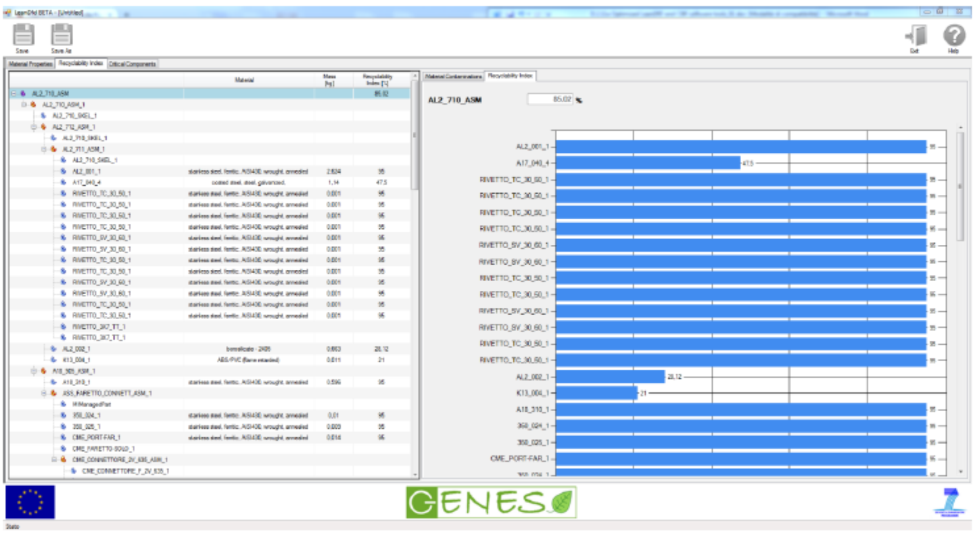


Figure 29. Recyclability Index analysis

– **Critical Components**: in this window, first of all the user has to choose the product typology (e.g. cooker hood). On the basis of this choice the tool is able to retrieve a list of standard critical components which is possible to find within the particular product typology. The user can successively associate some critical components to the product structure occurrences in order to:

  - Consult the critical component documentation about the EoL;

- Launch a disassembly Analysis of the Critical Component by the DfD module. For these particular components is in fact important to guarantee an high disassemblability because they are usually manually disassembled when the product is dismantled.

2.5.4 S-LCA analyst software tools

Within the GENESI platform, two simplified LCA software tools are developed: Eco Audit, and eVerdEE. While both serve the purpose of supporting the rapid evaluation of the environmental impacts of industrial products in design process, they differ in terms of context of the design and results delivered.

Eco Audit (developed by Granta Design) will manage the data assigned by the designers and stored in the CAD system or PLM database and also evaluate the environmental parameters in a dynamic way. Dedicated repositories for LCA analysis will be defined to associate each elementary item of the inventory (LCI) with a specific environmental impact value. Eco Audit in combination with Eco Material offers an Eco Design approach to improve the environmental impact of all life cycle phases. The reports from Eco Audit, highlight the environmental hot spots in the life cycle and the information provided is targeted for use by design and product decision-making by designers, with traceable links to internal company information and decisions (e.g. procurement, senior managers, etc.).

The eVerdEE tool (developed by ENEA) offers the user an extended environmental analysis with more indicators and detail. The main purpose of the tool is to guide a non-LCA practitioner through a scientific-based and detailed analysis, in line with ISO 14040 requirements. The eVerdEE tool (Buttol et al., 2006 and Naldesi et al. 2004) manages the data coming from the Bill of Material (BOM) file and allows additional data input by platform's users. The eVerdEE tool is distinguished from the Eco Audit tool by having more environmental indicators, and as such is a tool that is used after the design process to give insight to the breadth of environmental impact. In addition, the eVerdEE tool can input a multi-phased energy-consumption scenario for components such as motors and lights. It can read from the DfEE tool detailed energy consumption information (working points and duration of usage) about the energy-consuming product components such as motors and lights.

The possibility to automatically upload data coming from the other tools saves the user time and mistakes and guides the user in collecting additional data, e.g. about components replaced during the product lifespan or packaging materials, that are not usually managed by designers but that the user can collect from other staff inside the company.

eVerdEE provides the user with a detailed analysis that highlights the environmental hotspots in terms of most impacting life cycle phases, components or single processes, in relation to different impact categories, giving the user a detailed panorama that he can also use to elaborate specific and informed directions or suggestion back to the design team.

This tool uses a number of indicators to signify how sustainable a process, or activity, is. These include the following environmental impact categories:

- **Consumption of mineral resources** [kg antimony equivalent]. In eVerdEE a method has been selected that is based on 'ultimate reserves' and rates of extraction. The method expresses the consumption of individual mineral resources in kg (kilograms), relative to a reference resource (the metal antimony). An equivalency factor is therefore obtained for each individual mineral resource from the ratio of the impact of the specified mineral resource compared to the impact of a similar mass of antimony. The ultimate reserve is the quantity of resource that is ultimately available, estimated by multiplying the average natural concentration of the resource in the primary extraction media (e.g. the earth's crust) by the mass or volume of these media (e.g. the mass of the crust).
- **Consumption of biomass** [kg]. The term 'biomass' refers to any organic matter that is available on a renewable or recurring basis, including dedicated energy crops and trees, agricultural food and feed crop residues, wood and wood wastes and residues, aquatic plants, grasses, residues, fibres, animal wastes, municipal waste, and other waste materials. From biomass, a number of products can be created. The consumption of this resource, without regeneration of the reserves, can lead to serious consequences for the environment such as deforestation, soil erosion, aridity, species extinction and disruption of ecosystems. In eVerdEE the consumption of biomass is expressed in kg.
- **Consumption of fresh water** [m3] . Water is the most precious resource because it is essential to all life forms. High consumption of water causes environmental problems because it stresses rivers, lakes and groundwater aquifers. Dams may be required to flood areas of land to form reservoirs and this can cause serious ecological impacts. In eVerdEE water consumption, expressed in m3 (cubic metres), has been considered as a significant indicator of the sustainability of a process/activity.
- **Consumption of non-renewable energy** [MJ]. All forms of energy are stored in different ways in the energy sources that we use every day. The non-renewable energy sources are defined as "energy sources that we are using up and cannot recreate in a short period of time". We get most of our energy from non-renewable energy sources, which include fossil fuels (oil, natural gas, coal) and uranium. They are called fossil fuels because they were formed over millions and millions of years by the action of heat from the Earth's core and pressure from rock and soil on the remains (or 'fossils') of dead plants and animals. In eVerdEE oil, natural gas, hard coal, lignite and uranium are included in the evaluation of the consumption of non-renewable energy, which is expressed in MJ (mega-joules).
- **Consumption of renewable energy** [MJ]. Renewable energy sources do not depend on limited reserves of fuels, but belong to either inexhaustible sources (e.g. solar energy), physical cycles (e.g. the hydrological cycle), or to a biological system. Biomass is the most ancient source of renewable energy as it was used in prehistoric times. It is renewable in the sense that only a short period is needed to replace what is used. In eVerdEE the following types of renewable energies are considered: hydroelectric

energy, bioenergy and 'other energies' that include solar, wind and geothermal energies. The consumption of renewable energy is expressed in MJ.

- **Climate change** [kgCO2 equivalent]. The Earth's atmosphere is composed of a mixture of gases that surround the Earth, perform many functions and help to support life on our planet. Some of these gases are known as 'greenhouse gases' and they trap the sun's heat near the Earth's surface and keep the Earth warm. For thousands of years, the Earth's atmosphere has changed very little, but today we are experiencing difficulties in keeping the balance of these gases. When we burn fossil fuels, compounds such as carbon dioxide (CO2), carbon monoxide (CO) and nitrous oxide (N2O) accumulate in the atmosphere. This human-induced enhanced greenhouse effect causes environmental concern because increases in temperature will lead to changes in many aspects of weather, such as wind patterns, the amount and type of precipitation, and the types and frequency of severe weather events. The greenhouse effect can be quantified in terms of global warming potentials (GWPs). GWPs have been developed by the "Intergovernmental Panel on Climatic Change" (IPCC) for a number of substances that have the same effect as CO2, i.e. they absorb infrared (IR) radiation. GWPs are calculated for each greenhouse gas by considering its capacity for absorbing IR radiation and its longevity in the atmosphere. A GWP is obtained for each individual greenhouse gas from the ratio of the impact on global warming of the gas compared to the impact of a similar mass of CO2. Although there are many substances that affect climate change, in eVerdEE, due to its simplified nature, only the following substances are considered: carbon dioxide (CO2) of fossil origin, methane (CH4), nitrous oxide (N2O), CFC-11. If CO2 does not originate from a fossil source, but instead from biomass, then it is assumed that there is no addition to the atmosphere (and therefore no contribution to climate change) because the material was generated in the short term by fixing CO2 from the atmosphere.
- **Acidification** [kg SO2 equivalent]. Acid depositions in water and soil may result in a decrease in pH value. This can adversely affect plants and animals and damage surface coatings and building materials. Prevailing winds blow the compounds that cause acid depositions across state and national borders, sometimes over hundreds of miles. The main atmospheric substances that contribute to acidification are: sulphur dioxide (SO2), nitrogen oxides (NOx) and ammonia (NH3). Acid rain occurs when these gases react in the atmosphere with water, oxygen and other chemicals to form various acidic compounds. Sunlight increases the rate of most of these reactions. The acidification potential (AP) for each substance is defined as the ratio between the number of H+ ions (hydrogen cations) produced per kg of substance and the H+ produced per kg of SO2. Although there are many substances that affect acidification, in eVerdEE, due to its simplified nature, only the following airborne emissions have been considered: SO2, NOx, NH3.

- **Eutrophication** [kg PO4 equivalent]. Eutrophication refers to the potential impacts of enriching aquatic ecosystems with nutrients. The main nutrients are nitrogen (N) and phosphorous (P). The primary effect of surplus nitrogen and phosphorus in aquatic ecosystems is the growth of algae. The secondary effect is the decomposition of dead organic material (e.g. the algae) that may lead to reduced oxygen levels and sometimes to anaerobic conditions (absence of oxygen) and the liberation of toxic hydrogen sulphide. Eutrophication Potentials (EPs) are obtained for each substance by calculating the ratio of the impact on eutrophication of the substance compared to the impact of a similar mass of PO43-(phosphate).Although there are many substances that affect eutrophication, in eVerdEE, due to its simplified nature, only the following substances have been considered: nitrogen oxides (NOx) and ammonia (NH3) as airborne emissions; nitrogen (N), phosphorous (P), ammonium (NH4+) and nitrate (NO3-) as waterborne emissions.
- **Photochemical oxidation** [kg ethylene equivalent]. When solvents and other volatile organic compounds (VOC) are released into the atmosphere, they are often degraded within a few days by oxidation under the influence of light from the sun. If oxides of nitrogen (NOx) are also present, ozone can be formed. These oxides of nitrogen are not actually consumed during ozone formation, but have a catalyst-like function. This process is called photochemical ozone formation, also known as summer smog. Exposure of plants to ozone may result in damage of the leaf surface, leading to damage of the photosynthetic function, discolouration of the leaves, dieback of leaves and finally of the whole plant. Exposure of humans to ozone may result in eye irritation, respiratory problems, and chronic damage of the respiratory system. Photochemical ozone formation is an impact that affects the environment on both local and regional scales. Photochemical ozone formation can be quantified by using photochemical ozone creation potentials (POCPs). The POCP is defined as the ratio of the impact on the ozone formation of one substance compared to the impact of similar mass of ethylene (C2H4) in the same conditions. Although there are many substances that affect photochemical oxidation, in eVerdEE, due to its simplified nature, only the following airborne emissions are considered: methane (CH4), sulphur dioxide (SO2) and non-methane volatile organic compounds (NMVOC). 'NMVOC' includes all organic compounds (except methane) that evaporate to form a gas at ambient conditions. If you have more than one NMVOC present, you should sum the quantities and input this total figure.
- **Ozone layer depletion** [kg CFC-11]. The stratosphere, a zone located between 15 and 50 kilometres above the Earth's surface, contains the gas ozone. Stratospheric ozone is constantly being created and destroyed through natural cycles. Various ozone-depleting substances (ODS), such as halogenated compounds (e.g. CFCs, HCFCs, Halons etc.), accelerate the destruction processes resulting in lower than normal ozone levels. The stratospheric ozone acts as a natural protective layer for the Earth because it filters out

ultraviolet radiation (UV). A number of consequences can result from increased levels of UV reaching the earth, including genetic damage, eye damage and damage to marine life. Ozone Depletion Potentials (ODP) have been calculated by the World Meteorological Organisation (WMO) for a number of halogenated compounds. The ODP is the ratio of the impact on ozone of a chemical compared to the impact of a similar mass of CFC-11, the simplest type of CFC molecule. However, although there are many substances that affect ozone depletion, in eVerdEE, due to its simplified nature, only CFC-11 is considered. If you have other CFCs emitted from your process you may make a note in the documentation, but you must not sum the quantities of all CFCs. Only enter data for CFC-11.

- **Production of hazardous waste** [kg] According to the European Waste Catalogue (Decision 2000/532/EC) wastes are classified into two categories: hazardous and non-hazardous. Hazardous wastes are those substances that require special methods of disposal to render them harmless or less dangerous. If disposed of without proper treatment, hazardous waste can cause serious, long-lasting damage to both terrestrial and aquatic ecosystems. Human health impacts can also be severe. Examples of hazardous waste include some acids, alkalis, solvents, medical waste, resins, sludge and heavy metals. In eVerdEE the production of hazardous waste is expressed in kg.
- **Total waste production** [kg]. Waste contributes to several environmental problems including habitat destruction, surface and groundwater pollution and other forms of air, soil and water contamination. Depending on the disposal method, there may be other negative consequences, such as the creation of toxic substances from incineration or the emission of methane (which contributes to global warming) and other gases from landfills. Waste management must be carefully planned to minimise the risk associated with the handling and disposal of waste. Sustainable waste management encourages the generation of less waste, the re-use of consumables and the recovery (recycling or energy recovery) of waste that is produced. Solid waste is either classified as hazardous (e.g. some pesticides and solvents) or non-hazardous (e.g. water-based paint and scrap metal. In eVerdEE the production of total waste is expressed in kg.

2.5.5 CBR software tool

The CBR tool (developed by UNIVPM) represents the knowledge and the "best practices" for mechatronic products. It helps the designer in the design process of mechatronic products through the collection in a structured Data Base of ecodesign guidelines and the acquired company eco-knowledge.

The development of the CBR tool was the main activity of the PhD.

The staring objective of the CBR tool was to provide support to designers during the development of "green" products. At the beginning of the development of the tool, the first consideration was that designers usually not have knowledge on environmental topic. **Designers therefore need a tool that guides theme in acquiring practices on ecodesign**.

The CBR tool was therefore structured in order to be a repository of ecodesign knowledge. This ecodesign knowledge is represented by:

- **Ecodesign guidelines** retrieved from the literature, from which designers can retrieve suggestions for the designing of environmental sustainable products;
- **Company eco-knowledge**, i.e. all the past choices made on products and the relative representative information (in environmental terms);

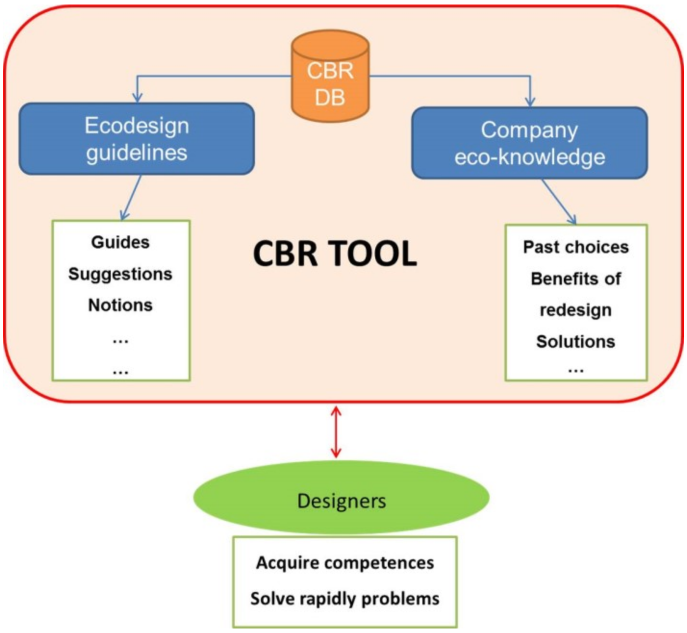


Figure 30. CBR Structure

As a consequence, the main advantages of this tool can be summarized in the possibility to dispose of knowledge on the ecodesign issues designers can consult in a rapid, organized and simple way, that supports and facilitates the ecodesign process.

The CBR tool has therefore a double aim: to collect guidelines that can increase the designers knowledge on ecodesign and to collect company past choices that has determined improvement of the product performances in environmental terms. Figure 30 shows the main structure of the CBR tool.

The main core of the CBR tool, is as a consequence its database, (realized by the use of the Access software), in which all the data are stored.

The first step in development of this tool was a deepen analysis of the literature on the matter of ecodesign guidelines.

The analysis of literature related to ecodesign guidelines shows that a high number of ecodesign guidelines exist and that they often provide only general indications to designers. This generality makes, from one side, ecodesign guidelines referable to a lot of different design process stages, but on the other, it does not guarantee their efficacious consultation by designers, and above their effective translation into design choices. (Bonvoisin, F. et al., 2010). When the G.EN.ESI project has started did not exists software tools with functionalities to consult the ecodesign guidelines and consult the past design choices, integrated with a design platform with the functionalities defined in the G.EN.ESI project.

To guarantee the generality of ecodesign guidelines and their application to different products of the same family, *standard components* have been defined. They are all the components that can be considered as representative for a specific product family, as they can be found in different modules of the same product family; an illustrative example is the cover of a cooker hood: every cooker hood has this component, and therefore it can be defined as standard ones, but each hood model has a different typology of cover (with or without visible welding, with or without aesthetic glass, with or without touch control, etc…).

Table 9. Examples of "high level of abstraction" guidelines related to product families

Product family	**Examples of high level guidelines**
Household appliances	Reduce the environmental impact of the use phase, which is the most important in terms of environmental impact
Household appliances	Consider the complexity of disassembly strategies and its influence on the environmental impact of the EoL stage
Electronic devices	Consider the presence of WEEE in the EoL phase
Electronic devices	Value the presence of precious materials

Table 10. Examples of "high level of detail" guidelines related to product components

Component	**Examples of high level guidelines**
All component	Material selection influence significantly the separation time
Plastic components	Consider the material compatibility and its influence on the "path" toward recycling
Iron or steel components	Avoid the contamination with copper, tin, zinc, lead or aluminum because reduces the recyclability
Iron or steel components	Production processes for these materials have more environmental impact than those for plastic materials

In order to facilitate the guidelines consultation and to make them useful for designers, ecodesign guidelines retrieved from the literature, have been subdivided in two main categories according to their level of abstraction: “high level of abstraction” and “high level of detail” guidelines.
The “high level of abstraction” guidelines are characterized by a significant degree of abstraction and are referred to a large number of product families; they contain sort of alarms useful to underline general criticalities associable to products in terms of environmental sustainability. These guidelines can be further subdivided in two subsections, depending if they are referred to a defined product family or to components. An illustrative example of high level of abstraction guidelines is shown in Table 9.
The “high level of detail” ecodesign guideline typology is subdivided in:

- Product-oriented general ecodesign guidelines: they are all those indications which can be associated to different product families, and that provide general recommendations valid for different products;
- Component-oriented general ecodesign guidelines: they are all those indications referable to almost all components of different product families and provide suggestions about specific components (e.g. cover, support, motor, damper, etc…) of a particular product family (e.g. cooker hoods, washing machines, refrigerators, etc…). Designers can use these advices to understand how to improve components in terms of environmental sustainability. They are related to standard components and referred to different life cycle phases of the product, from material selection to EoL phase;
- Component-oriented specific ecodesign guidelines: they mainly derive from EuP directives (EU, 2010, 2013, 2014) and they are associated to the standard components (e.g. electric motor, water pump, motor impeller, lamp, etc…) of the specific product family under analysis (e.g. cooker hoods, washing machines, refrigerators, etc…). These specific guidelines refer principally to the use phase and aim to minimize the energy consumption of the energy using components and as a consequence of the whole product.

An illustrative example of high level of detail guidelines is shown in Table 10.
All these ecodesign guidelines are related to several attributes, e.g. life cycle phase to which they are associated, objective they allow to reach and standard components to which they concern.
The final version of the CBR tool, contains 68 ecodesign guidelines retrieved from the literature. The tool allows the possibility to store for the most complex guidelines an attachment (in the .pdf format). It contains an explanation of the guideline, allowing to show to designers graphs, tables, numerical data and all the detailed studies related to the specific guidelines.
In addition to ecodesign guidelines, the tool contains also the so called eco-knowledge.
The eco-knowledge is represented by all the **choices made by the designers during the design process of a product.** These choices are related to the product/process data, such as material, dimensions, chemical and physical properties, manufacturing processes, transportations, EoL strategies, etc., and can be referred to a specific product/standard component. By the use of

commercial LCA software tools, designers or experts evaluate the environmental impact of the product they are designing and as a consequence the environmental performances of specific design choices. This information can be stored in the knowledge database and retrieved by designers during future design activities. The content related to the eco-knowledge it is of course strictly connected to the use of the tool by the company. As a consequence before the implementation of the tool inside the company test cases (Faber and Electrolux), this section is empty. In order to facilitate designers in the consultation of the product knowledge and past experiences, also in this case, it is necessary that choices are stored and ordered according to specific attributes, e.g. life cycle phase, objective and component which are referred to; in this way they can consult only necessary and appropriate information. Data that represent the eco-knowledge for a specific component/product are for instance the material used in a specific component, the production processes, component dimensions, weight and geometry; the environmental data are represented by the environmental impacts. In the case of a cooker hood cover design, some related choices can be "stainless steel" for the material, "laser cutting", "bending" and "resistance welding" for the production processes, and "carbon footprint" value for the environmental impact.

If designers have the possibility to know the correlation between design choices and their environmental impact, they can rapidly understand the consequences of specific choices on sustainability and how to modify a component or a product to reach clear objectives. In order to guarantee uniformity with the guidelines classification, also the knowledge is connected to product structure through standard components; all the past choices are in fact made on specific components that it is possible to link to standard ones.

The approaches to retrieve and re-use eco-knowledge information is based on CBR ones, which allows to rapidly and efficiently retrieve past information. Designers, during the design or redesign process, define:

- first of all a specific environmental objective they want to reach,
- they retrieve information (past design choices with the related environmental impacts) analysing the data stored into a knowledge database,
- they choose the solution which best satisfies the objective,
- and finally, they verify the effectiveness of the implemented choice.

These four steps, which represent the classical structure of the CBR methodology, permit to apply solutions that in the past and in similar context, have been implemented by someone inside the company, and as consequences allow solving in a rapid and efficient way, design issues, knowing in advance the related environmental consequences.

The architecture of the CBR software tool with the main modules and databases has been structured as it is represented in the following Figure 31.

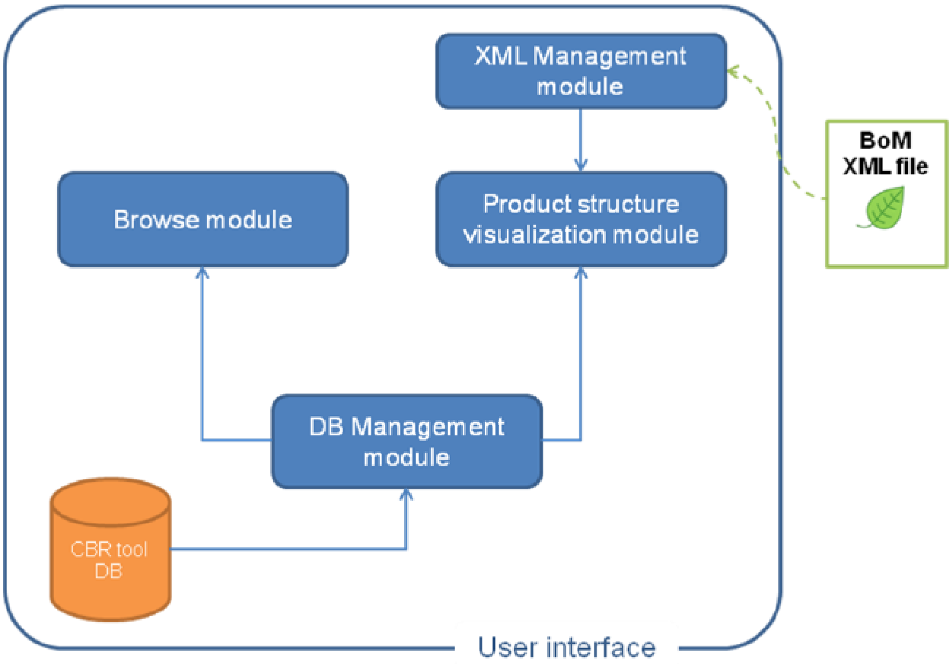


Figure 31. CBR tool architecture

The main modules are:

– **The XML Management module** is able to import/export the necessary information from/to the G.EN.ESI BoM XML exchange file. In particular this module can import in the CBR tool all the data stored in the exchange file (e.g. product structure).

– **The DB Management module** has the task to interface the other CBR tool modules with the tool internal CBR Tool database. In particular this module has the scope of retrieving the ecodesign guidelines from the database and filter them by attributes (lifecycle phase, objective, family, functional group and standard component).

– **The Browse module** has the function of presenting the ecodesign guidelines and knowledge to the user with the possibility to filter by attributes, it is directly connected with the DB Management module for this filtering activity.

– **The Product structure visualization module** has the function of visualize the product structure retrieved from the XML file by the XML Management module and present the ecodesign guidelines and knowledge for the product itself and each component, with the possibility to filter them by attributes. This filtering activity is performed by the DB Management module which is directly connected to this module.

The internal database of the tool is:

– **The CBR Tool DB** stores the ecodesign guidelines retrieved from different sources and classified by product family, functional group, standard components and lifecycle phases and the ecodesign Knowledge. Guidelines and knowledge are structured in the form of tables and in particular these table are composed by the following columns, as it is showed in the example provided in Figure 32:

- **Name**: a brief description of the guideline, in which its main content is summarized
- **Description**: a detailed description of the guidelines, it is expressed in a n explicit, simple and clear way, in order to be easily understood by the reader
- **Attachment**: possible attachment in which in depth analysis related to the guideline is contained
- **Phase**: life cycle phase to which the guideline is related
- **Objective**: the objective the life cycle allow to reach (the number of objectives is limited to avoid confusion and to allow designer to filter guidelines eaisliy)
- **Product family**: the product family to which the guideline is related (e.g. cooker hood, washing machine, etc…)
- **Functional group**: the functional group to which the guideline is related (e.g. motor, chassis, etc…)
- **Standard component**: the standard component to which the guideline is related (e.g. lamp, cable, etc…)
- **Rate**: the rate associated to the guideline according to the level of specificity (higher the specificity, higher the rate)

In order to make the text more readable, the complete structure and content of the CBR database is presented in **Appendix A**. An examples of attachment is presented in **Appendix B**.

Name	Foster the use of PS for plastic components wether is possible
Description	PS has a lower impact compared to several plastic materials and a low cost. Furthermore, PS has a good compatibility with most of the other plastic material, allowing the shredding of different plastics into a recyclable compound.
Attachment	Considerazioni sui materiali plastici
Phase	Material
Objective	Minimize material impact, Increase product recyclability
Product family	Frigorifero
Functional group	Refrigerazione, Struttura Esterna, Struttura Interna, Raccolta cibo, Apertura, Raccolta condensa
Standard Component	Condotte, Ventole, Cruscotto, Schienale, Basamento, Controporte, Vani, Piedi, Cassetti, Balconcini, Maniglie, Bacinella raccogli condensa
Rate	4/5

Figure 32. Example of ecodesign guideline

The general workflow of the CBR tool is presented in the following Figure 33, in which the blue blocks represent the product structure visualization mode, while the green blocks represent Ecodesign guidelines and Knowledge manual browse mode.

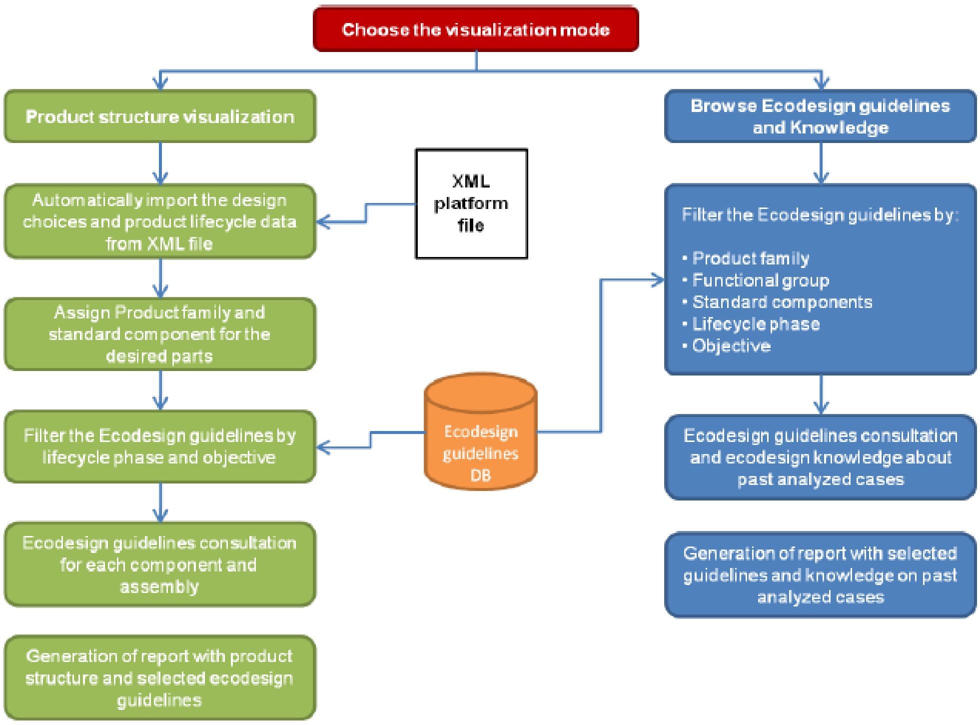


Figure 33. CBR tool workflow

The steps of the CBR tool workflow are:

- **Chose the visualization mode**: the user has to select the desired visualization mode, is possible to choose manual Ecodesign guidelines and Knowledge browse or product structure visualization. This last feature can be performed importing an XML file or a CAD file.

Product structure visualization mode:

- **Automatically import the design choices** and product lifecycle data from XML file or CAD file: the tool automatically import the complete product structure and the relative design choices made by the G.EN.ESI platform users in one of the tools.
- **Assign Product family** and standard components for the desired parts: the user assign the family of the product under investigation in order to filter the ecodesign guidelines by this attribute and assign a standard components to all the desired components for a further filtration. By this way for each component the ecodesign guidelines are filtered and presented to the user.
- **Filter the Ecodesign guidelines** by lifecycle phase and objective: the user can further filter the ecodesign guidelines specifying the lifecycle phase of interest or/and the objective to reach.
- **Ecodesign guidelines consultation** for each component and assembly: after the filtering activities the Ecodesign guidelines are presented to the user in a table and can be ordered by attributes.
- **Generation of report** with product structure and selected ecodesign guidelines, save the analysed project: at the end is possible to generate e report with the product

structure and the choices made for each component. It is possible to export all the guidelines selected for each assigned standard component and product notes containing the best practices followed for the product design. It is therefore possible to save the project in order to be stored in the Knowledge database, these CBR files constitutes the ecodesign knowledge about past design solutions.

Ecodesign guidelines and Knowledge browse visualization mode:

- **Filter the Ecodesign guidelines** by Product family, Functional group, Standard components, Lifecycle phase, Objective: the user can browse the Ecodesign guidelines filtering them by different attributes.
- **Ecodesign guidelines consultation**: after the filtering activities the Ecodesign guidelines are presented to the user in a table and can be ordered by attributes.

The CBR tool (Figure 34) provides the possibility to realize a report, in order to allow the user to have in a unique document all ecodesign guidelines he has consulted during the design/redesign process. This module is implemented in the "Product structure visualization" mode after the user has selected components form the product structured and retrieved guidelines from the tool DB. All the guidelines selected and filtered during the consultation phase, will be contained in the report file. It is a .csv file, that can be opened as an Excel file. It is structured in the following way:

- The first column contains the product structure in the tree format, with all the components of the analysed product;
- The second column contains the level of the component as it reported in the product structure;
- The third column contains all the guidelines that have been selected during the tool use.

Thanks to the report consultation, designers can visualize all the ecodesign guidelines they have selected during the design phase and retrieve them in future project.

The tool allows the user to organize the retrieved guidelines according to a rate. The rate is a score given to the guidelines according to their degree of specificity. The scale varies from 1 to 5; the guidelines to which is associated the rate of 1 are those characterized by a high level of generality, while to those retrieved from the company knowledge, in which some solutions to specific problems are presented, are associated a rate of 5 are. The user can visualize the rate in the last column of the ecodesign visualization table. By ordering ecodesign guidelines according to their rate, designers can consult at first more specific guides, then more general ones and be guided in the design-redesign process in an efficient way.

The CBR tool use and interfaces are very simply to use, due to the fact the main operation the user has to do is the filtering of guidelines or eco-knowledge according to several attributes (e.g. life cycle phase, objective, standard components…). To support the user during the use of the tool a User manual has been realized and presented in Appendix C.

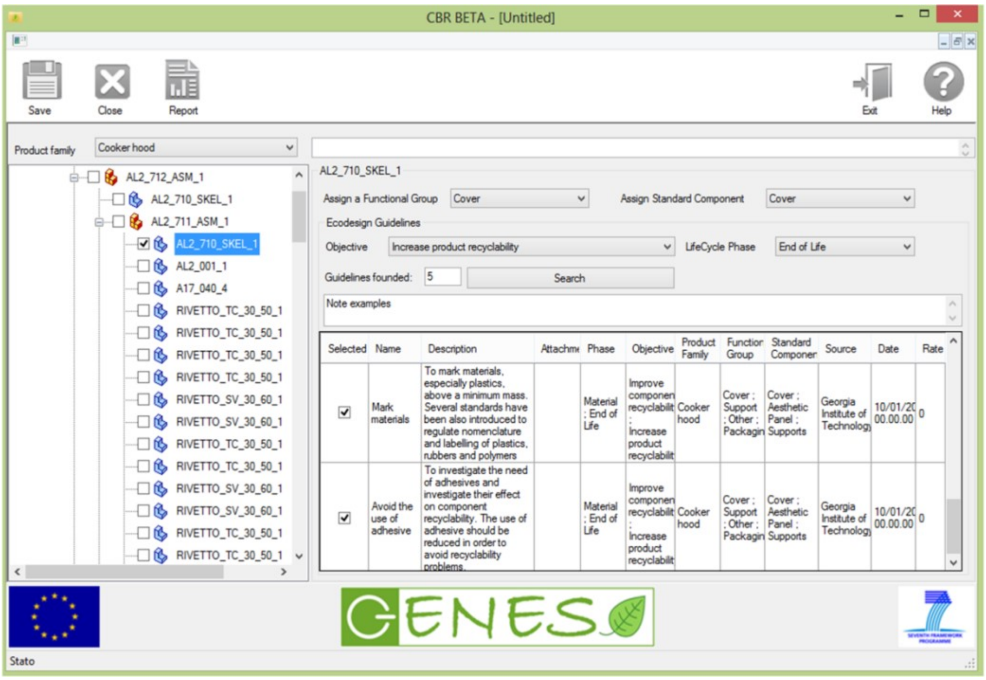


Figure 34. CBR main interface

2.5.6 Web Interface

The G.EN.ESI platform is envisioned to be used by various actors within an enterprise and supply chain in order to assess the environmental impact of products throughout their life cycle. As such, not all actors will be working in the environment of engineering tools (CAD and PLM). For this reason, a **Web Interface, named MI BoM Analyzer (Figure 35) presents the opportunity for any persons within an enterprise to enter product life-cycle information and generate an XML compatible with the G.EN.ESI tools for further product analysis**. Information from suppliers for bought-in parts is pivotal to completing a life cycle analysis for a product. As environmental regulations become increasingly stricter with an emphasis on transparency and disclosure, the declaration of environmental information throughout the tiers of a manufacturer's supply chain becomes more critical. The Web Interface wants to facilitate the inclusion of supplier engineering and environmental information, which would not typically be provided in a CAD file. The information from a supplier is seamlessly integrated into the manufacturer's central database system for inclusion as traceable information for environmental product analysis and reporting. The information is subsequently carried to other tools in the G.EN.ESI platform by the Engineering Bill of Materials (EBOM) for further analysis.

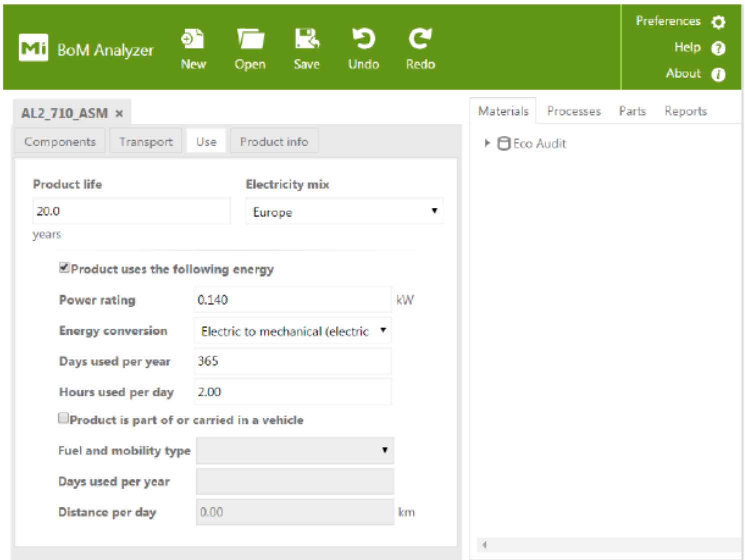


Figure 35. Use phase tab information fields of the Web Interface

2.6 The G.EN.ESI Platform workflow

All G.EN.ESI tools begin with an editable hierarchy of the components in the BOM as read directly from the CAD file or the Eco Audit XML file. The logical workflow of the platform is described in the following steps.

1. **Creation of the EBOM**. The EBOM may be first created in CAD as the designer assigns materials and processes to the volumetric components of the design. The EBOM may also be created in the Web Interface. Alternatively, an EBOM for redesign may be uploaded in CAD, PLM or the Web Interface. Eco Audit is used at this stage to create the XML.

2. **Addition of Bought-in Parts and their environmental evaluation** – a bought-in part can be added to the XML file by first combining CAD files in CAD, or by combining XML files in the Web Interface. Once added, the environmental evaluation can be performed in Eco Audit by mapping environmental reference data to the components (Eco Material), or by updating records with supplier information communicated by an import template.

3. **Life cycle information assignments and evaluation** – using Eco Audit which is integrated with CAD, PLM and the Web Interface – all five life cycle phases can be quickly defined by either entering information directly to fields in Eco Audit, or by assigning materials and process records to the components in the EBOM which have environmental data. Eco Material is the material and process selection/substitution capability in Eco Audit related to environmental impact calculations, specifically carbon footprint (Green House Gas Emissions, GHG), energy consumption, water and manufacturing waste. Eco Material allows for evaluation based on cost, technical and environmental performance, thus enabling design decisions. The Eco Audit tool also allows for analysis of GHG and energy for the transport stages, use phase (mobile and/or static), and EOL phase. Transport can be added up amongst any of the life-cycle phases of the product. The Eco Audit analysis reveals the 'environmental hot spots' in the life cycle phase (i.e. phase with the highest environmental impact) from which the user of the G.EN.ESI platform can distinguish which phase-specific tool to choose from, for further design analysis and improvements. Changes to a design may be compared in Eco Audit against a benchmark design to show the effect of materials and process design decisions on environmental impact, as well as transport, use phase and end-of-life decisions.

4. **XML file generation** - the XML file is generated from the Eco Audit tool and carries with it the name, number, and size of components, arranged in the order of component assembly hierarchy, assignment of materials, processes and environmental life cycle decisions and analysis.

5. **CBR** – is able to help the designer in the application of the ecodesign guidelines or to efficiently re-use company knowledge. The user can browse the ecodesign guidelines, filtering them by objective or life cycle phase. The user can also consult ecodesign guidelines relative to specific products, functional groups or components. Finally the user can retrieve the company knowledge about similar products and re-use to improve the product under analysis.

6. **Life-cycle-phase specific design tools**

a. **DfEE** – is able to open the XML file, automatically recovering information about product structure and design choices. The user can assign energy using components (retrieving them from the internal DB) to the product occurrences and successively specify a detailed use profile (different working points are allowed) for each of them. On the basis of this information the DfEE tool is able to calculate the energy consumption, simplified environmental impact and use phase cost for each component and for the entire product.

b. **Lean DFD** – is able to open the XML file, automatically recovering information about product structure and design choices. The user can specify the precedences and liaisons between components and/or sub-assemblies in order to calculate the disassemblability, in terms of disassembly time and cost, for selected target components (e.g. critical components, components containing hazardous materials, precious components, etc.). The LeanDfD tool is also able to automatically calculate the recyclability rate for each component and for the entire product, on the basis of the material properties and compatibilities.

7. **Feedback to SLCA tools and Final Reporting**

a) The resulting XML file can be read back into the Eco Audit tool in the Web and PLM interface for final reporting with the use phase result of Eco Audit replaced by that of the DfEE tool (the change is indicated in the report). The case for material and process selection of the product may be revisited in the future as the start of a redesign or derivative new product design with the advantage of having the previous state of the art recorded in a single XML file (i.e. steps 2 through 7 can be revisited).

b) The XML file can be uploaded to eVerdEE tool. The user can then enrich the imported inventory by defining goal and scope of the simplified LCA study, inputting additional data to complete the inventory (e.g. about product maintenance, packaging) and document the data quality of the inventory. eVerdEE can then be used to calculate the impact assessment results for a larger list of environmental issues and to produce reports of inventory and impact assessment results. The user can compare two studies, e.g. the re-designed version of a product with the previous one or the competitor's product with one of its own, viewing the results displayed through a target plot.

3 FIRST CASE STUDY: IMPLEMENTATION OF THE G.EN.ESI SOFTWARE PLATFORM IN FABER. RESULTS AND LIMITS

The G.EN.ESI Methodology and Platform has been implemented during the project in the FABER company, in order to test and validate it. The FABER company, one of the commercial partners of the project, has in fact the objective to start a deepen analysis on environmental impacts of its products with the final aim to reduce their environmental load.

All the activities conducted inside FABER to implement the G.EN.ESI platform has been directly followed during the PhD. In particular:

- the functional and modular analysis of the reference product has been realized;
- the use of the G.EN.ESI tools has been supported inside the FABER design departments;
- the redesign activities has been supported, by providing help to designers in the identification of the best redesign solutions.

In the following, the steps of the implementation of the G.EN.ESI platform in the FABER company with the results obtained are presented.

3.1 The product case study

The object of the study was a domestic cooker hood manufactured by FABER for which a redesign process has been realized with the objective to improve its environmental behaviour. During the redesign all the tools of the G.EN.ESI platform has been used.

The reference model chosen was the Stilux one (Figure 36). It belongs to the “T-shape” family, generally placed on the wall, having both ventilation, and filtration functions. This model represents for the FABER company the most sold product and for this reason it has been selected as the project case study. **By implementing the G.EN.ESI methodology and platform, FABER had the possibility to understand the behavior in environmental terms of its product, to identify the main criticalities and to evaluate possible improvement strategies to adopt**. Thanks to the Life Cycle Costing module, also economic variables have been monitored during the project redesign.

Figure 36. The Stilux cooker hood

The Stilux cooker hood has among principal technical characteristics: a suction capacity of 660m3/h (at maximum speed), four different speed levels, an optional remote control, touch screen panel, easy cube module to facilitate the installation, electric motor with a power rate of 250 W, three aluminum-made filters, dishwasher safe, two halogen lamps (20 W each), 68 dB noise level at maximum speed.

In the product, the following main components can be identified (Figure 37):

- Upper chimney
- Lower chimney
- Reduction flange
- Easy cube module
- Electric motor (with a capacitor)
- Impeller
- Blower
- Base unit
- Spotlight bent
- Control bracket
- Glass panel
- Grease filters
- Cables
- Packaging parts (Carboard box, chimney protection and spacers)

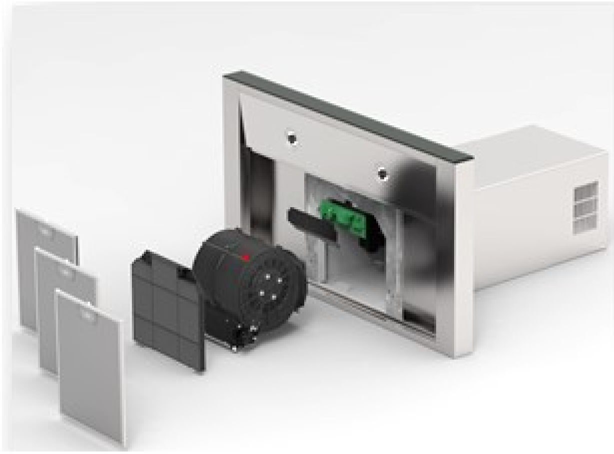


Figure 37. Exploded Stilux cooker hood model

The cooker hood belongs to energy related product category, for which there are several Ecodesign requirements regulated by the European Directive 2009/125/EC. The Directive sets environmental constraints for energy related products that account for significant volumes of sales or trade, since they have a large environmental impact. Household appliances are characterized by a considerable energy consumption during the use phase, which determines the highest environmental impact in comparison with manufacturing, transport or EoL phases.

Furthermore, most of the household appliances, including the cooker hood, are equipped with electronic parts such as electronic boards, capacitor and so on. Rare metals or particular coating treatments for these components play an important role regarding future EoL processes and the pressure on resources. In fact, the European Directive 2002/96/EC on waste electrical and electronic equipment (WEEE) has set a group of rules and actions to ensure each electronic components undergoes the most sustainable EoL processes. The objective of these regulations is to protect and improve the quality of the environment, and at the same time to protect human health and to use natural resources prudently and rationally.

When the project started, there were no specific norms to regulate use profiles for these products in literature. Therefore, the manufacturer has hypothesized two different scenarios for the cooker hood:

- **The simplified scenario**, characterized by a daily use with the motor switched on 1 hour per day (at the maximum velocity), while the lighting system 2 hours per day. Lifetime of nine years.
- **The realistic scenario**, with a more representative use of the motor, that is supposed to be used 12 minutes at the maximum velocity, 12 minutes at the third one, and 36 minutes at the second velocity. Lighting system use for 2 hours per day. Lifetime of nine years.

Fortunately, the more recent EU Directive 2010/30/EU (EU, 2010) together with the obligation of applying the Energy Label regulated by the European Regulation 65/2014 (EU, 2014) gave us the possibility of setting aside our own hypothesis and to stick to what is stated in the regulation. Hence, we built up another use-phase scenario, namely:

- **The energy label scenario**, characterized by a daily use of the cooker hood, with the motor switched on 1 hour per day (at the best efficiency point), while the lighting system used for 2 hours per day, considering a lifetime of nine years.

These data has been implemented in the study to evaluate energy consumption and carbon dioxide emission in the use phase.

3.2 Functional and modular analysis

The cooker hood has been analysed at first by the means of a functional and modular analysis. Functional analysis can be used to provide an abstract product model that describes its functions and sub-functions and their mutual relationships. This approach is useful either for the realization of a new product and for the optimization of an existing product. It allows to clearly identify functional groups, where designers can act in order to obtain the desired issue (Pahl et al. 2007).

In particular with the term "function of a product" is indicated "what a product should do", independently from the way in which this function is implemented. The function of a product can be seen as the relationship between inputs, necessary to the functioning of product, and the final outputs of this functioning. After the definition of the main function of a specific product, it is subdivided into a set of sub-functions, simply enough they can be considered elementary and not subdivided further.

A further instrument correlated with the functional analysis is the modular analysis.

A module is a set of correlated and independent components that has a one to one correspondence with a specific function of the product. Thanks to these instrumentations a product is described through a schematic structure of functions and modules, from which designers accomplish a detailed study to identify and solve product criticalities.

To establish the environmental criticalities of a product, it is possible to use a Life Cycle Analysis approach. If a preliminary functional and modular analysis has performed on the product, it is then possible to determine for each specific module and function its environmental impact. As a consequence designer can understand where it's necessary to intervene and what is necessary to modify to decrease the environmental impact of the examined product.

For a more comprehensive interpretation of the functional and modular analysis performed, the symbolism used in the schemes is described in Figure 38.

Each specific function is represented inside a box, where arrows arrive (inputs) and from which arrows leave (outputs). The function inside the box represents what a specific component of a product should do and the boxes with blue dotted line represent a module. The direction of the arrows represents the direction of the fluxes passing through the function. Within this formalism, three different types of arrows are used to identify three different fluxes involved in the function.

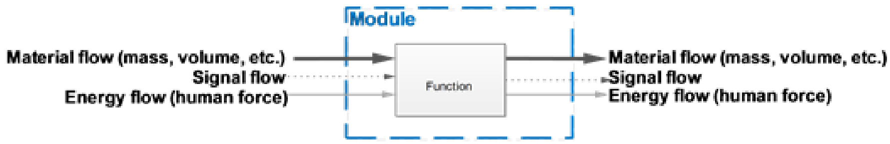


Figure 38. Symbolism used for the function/modular analyses

In particular:

- **Material flow**: it's usually referred to a material that has characteristic of form, mass, colour, etc. Materials can be mixed, separated, finished, transported, etc. Gas, liquid, solid, dust, row are typical example of material flows.
- **Signal flow**: it's the internal capacity to decide of a sensor or device. Signals are generated, separated, received, transmitted or stored.
- **Energy**: it's the capacity to modify material motion or condition. It can be electrical, kinetic, magnetic, optic and heat.

3.2.1 Functional and Modular Analysis of the cooker hood

In this paragraph the functional and modular analysis of the cooker hood taken as case study is presented. The analysis is illustrated in Figure 39.

For the cooker hood it has been possible to identify nine modules; each of them collects some functions.

- Support: it represents all the components that have the role to support the hood and other components of it. The input and the output of this module is the air stream which cross the components of the support to rich the filters. This module collects three different functions:
  - **Direct air**: it represents the components that direct air in the correct direction, with the aim of reducing the quantity of grease contained in the air by the passing into the filter.
  - **Support components**: this function is realized by all the parts that support components of the hood
  - **Support hood to wall**: this function is realized by those elements that permit to the hood of staying on the wall respecting specific structural requirements.
- Cover: it represents all the components that have the role to cover the internal element of the hood, both for aesthetic and structural reasons. It collects four different functions:
  - **Improve Aesthetic**: this function is realized by those components that cover the internal elements of the hood with the aim to improve the aesthetic of it;
  - **Support filters**: this function is realized by those components that have the role to support the filters of the hood; they have to guarantee the correct position of them in order to permit their correct functionality;
  - **Cover components**: this function is realized by those components that cover the internal elements of the hood;

    - **Support lights**: this function is realized by those components that support lights into the structure of the hood.
- **<u>Filters</u>**: this module contain the unique function to filter the air passing through the hood to absorb greases contained in it. The input of this module is the air stream and it has two different outputs, grease which remain trapped inside the filters and the air stream that continue its motion inside the hood.
- **<u>Motor + Impeller</u>**: this module contains two significant components for the hood functioning, the motor and the impeller that give to air the necessary energy to overcome the friction loss to cross the filters. The input is represented by the air flow, which is also an output, and the signal flow necessary to control the motor. From the motor there are also the coming out of noise and heat loss, which have to be minimize. This module collects two different functions:
    - **Convert electrical signal into move**: this function is realized by those components that convert the electrical signal coming from the electronic board into a different velocity of the motor rotation.
    - **Move air**: this function is realized by the impeller that, by the means of its rotation, aspirates air from the cooker to the filters.
- **<u>Blower</u>**: this module contain the unique function to transport air. The air is forced to cross the filter and to pass pipes by the moving of the blower. The input and the output of this module are represented by clean air.

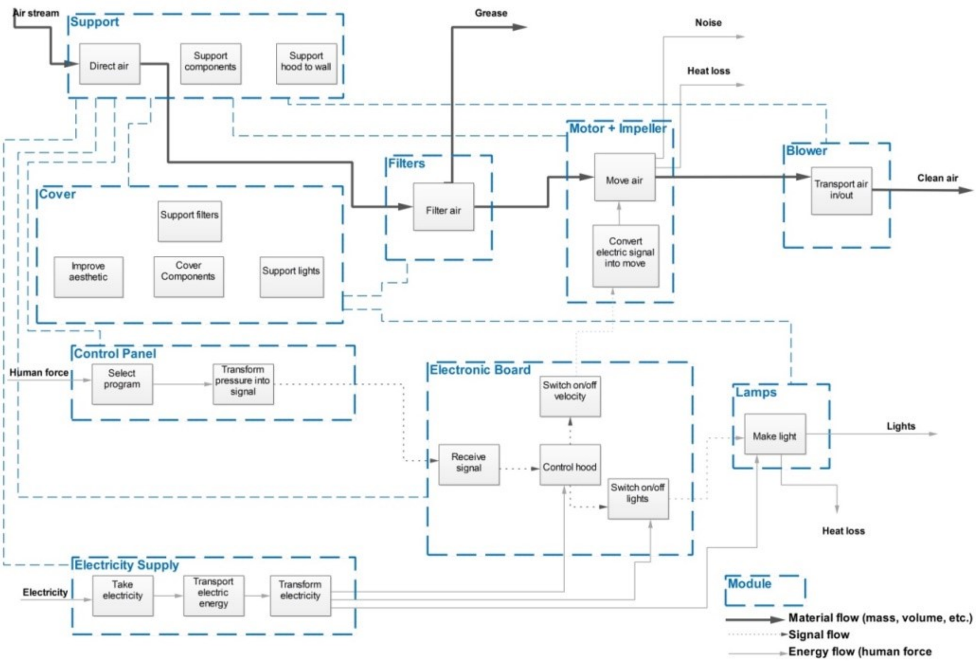


Figure 39. Cooker hood functional and modular analysis

- **Control Panel**: this module represents the user interface which allows users to view and select the different hood settings. The human force is the input of this module. In fact, the pressure applied by the user is the direct input to choose the velocity of the motor hood or to turn on/off the light. It collects two different functions:
  - **Select program**: this function is realized by the user, pushing the buttons to activate/ deactivate the hood, to select its velocity and to turn on/off the lights.
  - **Convert pressure into signal**: this function is realized by specific elements that convert the pressure applied by the user into a signal to control the motor and the lights.
- **Electricity Supply**: this module represents the equipment that provides and distributes electricity to the components; input and output are represented by electricity taken by network. It collects three different functions:
  - **Take electricity**: this function consist of taking electricity from the network to permit its use by the electrical components of the hood;
  - **Transport electric energy**: this function is realized by the wiring that transport electric energy to the different components of hood;
  - **Transform electricity**: this function is realized by specific elements that transform electricity into a signal to control the motor and the lights.
- **Electronic board**: this module collects all the functionalities of the electronic board, which has the role to make the hood enable to work according to the user indications. Inputs are human force and electricity and they are transformed in a unique output, electrical signal. It collects four different functions:
  - **Receive signal**: the signal from the control panel arrives to these elements that receive signal and send it to the specific components;
  - **Control hood**: this function receives electrical signal and send it to the components the user controlled by the relative buttons; it consist of a control on the velocity of the impeller and on the light of the hood;
  - **Switch on/off velocity**: this function, according to the choose of the user, controls the activation of the hood and velocity of the impeller;
  - **Make lights**: this function allows to the user to turn on/off the lights.
- **Lamps**: this module contains the unique function to make lights in order to illuminate the working plan. It receives electrical signal as an input and has the light as principal output; heat loss is another output, but it's undesirable.

In functional and modular analysis there are three main fluxes: material, signal flows and energy. I**n the specific case of a cooker hood these three flows are: air stream, human force and electricity**. It’s possible to describe their flow through modules.

- **Air flow**: the air flow, rising from the cooker, cross the support components which direct it toward filters. Here the filters absorb grease and impurities contained in the air and leave clean air flow. The clean air, aspirated by the motion of the blower, goes across it and goes out of the hood.

- **Human force**: the interaction of the users and the hood is realized by this second principal flow. The user can apply a force to the buttons of the hood and decide to activate its first function of absorbing grease from the air and other secondary functions like for instance turn on/off lights. The human force flow is transformed into signal by an electric board present in the hood.
- **Electricity**: the third flow is the electricity energy, that coming from the network and is transformed by electronic supply into signals and transported to each specific components of electronic board. Without this flow, the hood couldn't work.

It is also possible to notice mutual connections among modules. These connections or links can be considered spatial and structural relationships among the modules, which not involve material or energy flows. Spatial links depend on position or dimensional relationships among modules and structural links are related to construction needs of each specific element. Using these assumptions, modules are connected by a dotted line of the same colour used for the modules. The relationships present in the analysis can be summarized as follow.

Support module is structural connected with all the other modules that have to be sustained by it, in particular its components support:

- Control panel module;
- Electricity supply;
- Electronic board;
- Motor and Impeller;
- Blower;
- Cover module, which, at the same time is correlated to filters and lamps modules and provides to occlude the view of these elements.

3.3 Regulations concerning the performance

3.3.1 EN 61591: Household range hoods and other cooking fume extractors - Methods for measuring performance

This standard (EN, 2011) defines the main performance characteristics of cooker hoods and specifies methods for measuring these characteristics.

For the scope of this thesis we will go through just the performance related with the volumetric airflow and effectiveness of the hob light.

- **Test room.** The tests are carried out in a substantially draught-free room. The ambient temperature of the room is maintained at 20 ± 5 °C.
- **Installation.** The cooker hood is installed in accordance with the manufacturer's instructions.

3.3.1.1 **Volumetric Airflow Test**

The airflow is measured according to the method contained in ISO 5167-1.

The air outlet of the cooker hood is connected to a pressure compensation chamber (Figure 40). The grease filter is installed for the test. The air then passes through an auxiliary fan and baffle. An orifice plate or other suitable device is incorporated in order to measure the dynamic pressure for the calculation of airflow. Means are provided for the measurement of static pressure in the compensation chamber. The cooker hood is operated and by suitably adjusting the auxiliary fan or the baffle, the airflow corresponding to various pressures can be determined. The measurements are made with the controls positioned at the highest and lowest settings. The airflow of recirculating-air cooker hoods is determined when the pressure in the compensation chamber is at ambient pressure. The airflow of air-extraction range hoods is determined for discharge into a flue, which has the following pressure drop depending on the diameter of the air outlet orifice:

- working point 3 → 100 mm : 30 Pa
- working point 2 → 120 - 125 mm : 15 Pa
- working point 1 → 150 - 160 mm : 5 Pa

when there is an airflow of 200 m3/h and a pressure drop of 5, 15 or 30 Pa

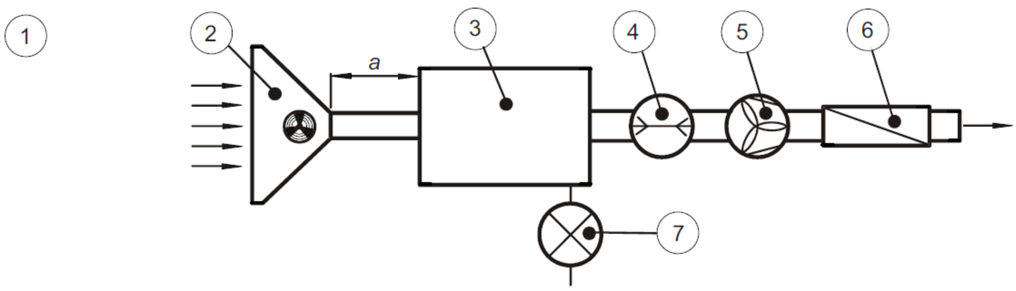


Figure 40. Measurement of air flow

a. Five times the diameter of the pipe
1. Air extraction cooker hood with internal blower
2. Cooker hood
3. Pressure compensation chamber
4. Orifice plate for airflow measurement
5. Auxiliary fan
6. Baffle
7. Static pressure gauge

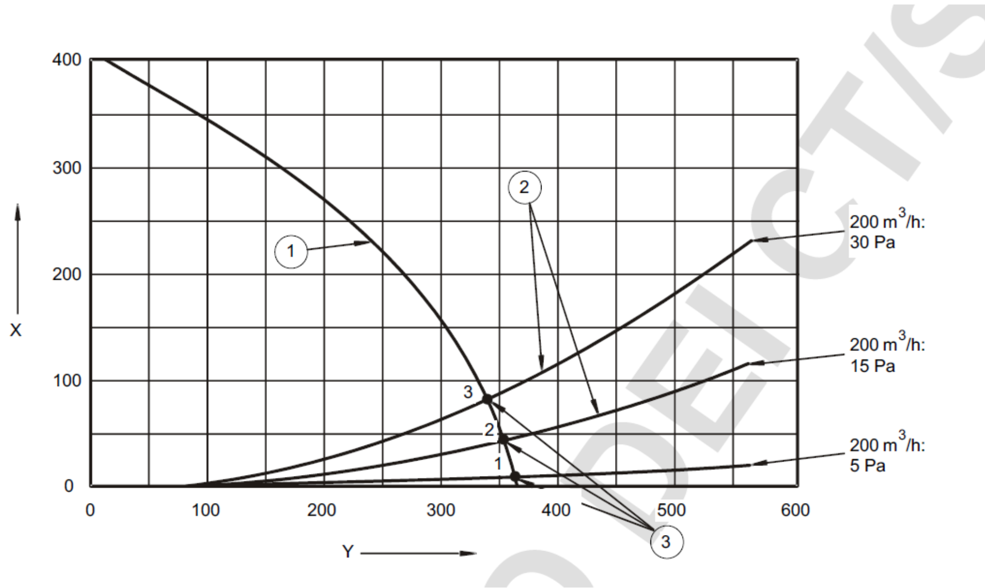


Figure 41. Pressure/Airflow curves

X. Pressure (Pa)

Y. Air flow m^3/h

1. Typical curve for range hood
2. Theoretical pressure air flow curve for the pressure
3. Working points

Figure 41 shows the pressure/airflow curves for nominal flues, a typical curve for a cooker hood and the derivations of airflow from it. The airflow is stated for the working point given for the actual diameter for both of the fan speeds, adjusted to a temperature of 20 °C and a pressure of 1013 hPa. The airflow is stated in m3/h.

3.3.1.2 **Effectiveness of the Hob Light**

The room in which the odor extraction test is performed is used to assess the effectiveness of the hob light, the range hood being positioned 600 mm above the hob. The range and adjacent worktops are covered with a sheet of matt-black painted plywood approximately 20 mm thick or similar board. The board is to extend at least 500 mm over each adjacent worktop. The rear wall between the hob and range hood is similarly covered with board or painted matt-black. The hob light is switched on and a suitable lux meter is used to measure the luminance at the points on the board described below (Figure 42).

If the cooker hood is intended to be installed over a 600 mm hob, the measurement points are point 1, 2, 3, 4 and 5. The arithmetic average of the five measurements is calculated and this value is stated as the luminance in lux.

If the cooker hood is intended to be installed over a hob larger than 600 mm, the measurement points are points 1, 2, 3, 4, 5, 6, 7, 8 and 9. The arithmetic average of the nine measurements is calculated and this value is stated as the luminance in lux.

In Figure 43 an examples of the test room is shown.

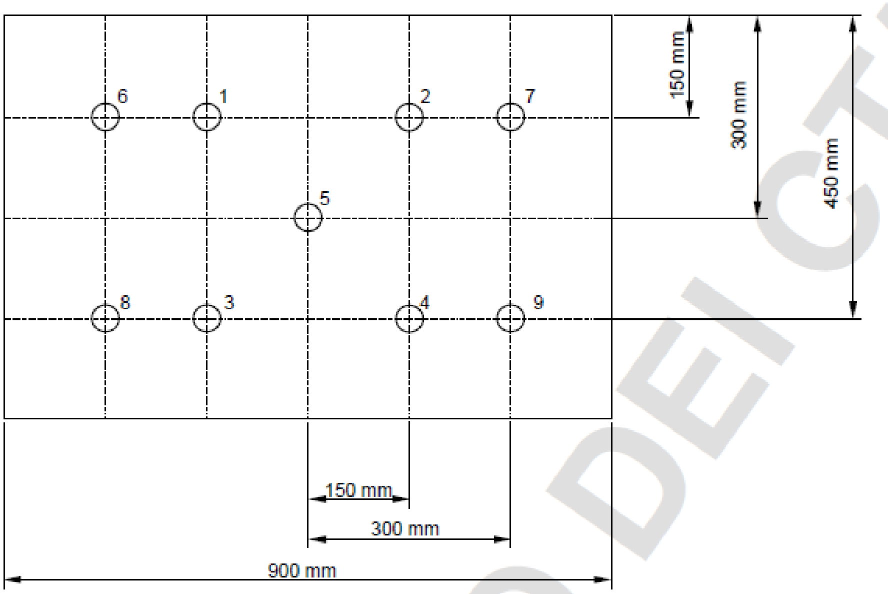


Figure 42. Light measurement points on the hob

Dimensions in millimetres

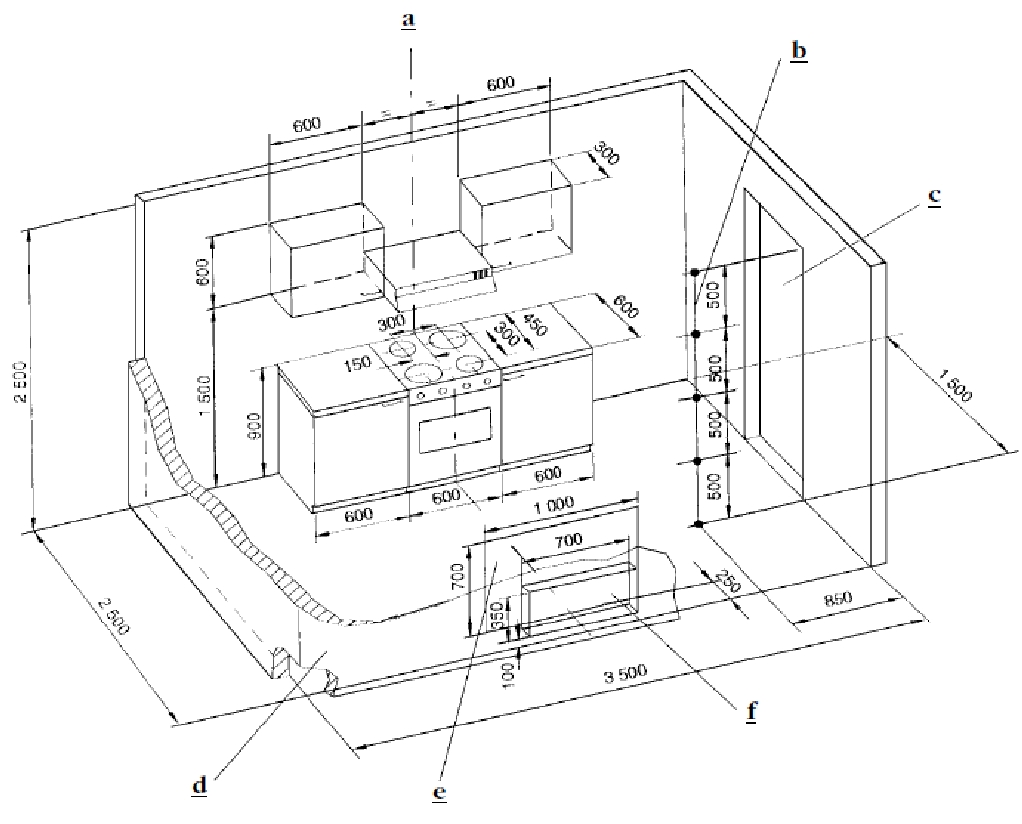


Figure 43. Example of a test room

3.3.2 European Regulation 65/2014

The European Regulation 65/2014 (EU, 2014), which defines norms for the energy labelling of cooker hoods, has entered into force the 1st January 2015. However cooker hood manufacturers, and among them FABER, yet during the G.EN.ESI project disposed of some preliminary documents and drafts of this regulation. For this reason the parameters included in this regulation has been taken into account during the project and for this reason and for completeness, the content of this regulation is presented in the following.

This Regulation establishes requirements for the labelling and the provision of supplementary product information for domestic electric range hoods, including when sold for non-domestic purpose.

This label, shown in Figure 44, summaries all the main energetic characteristics of the household appliance that will lead the customer to a more sensible purchase.

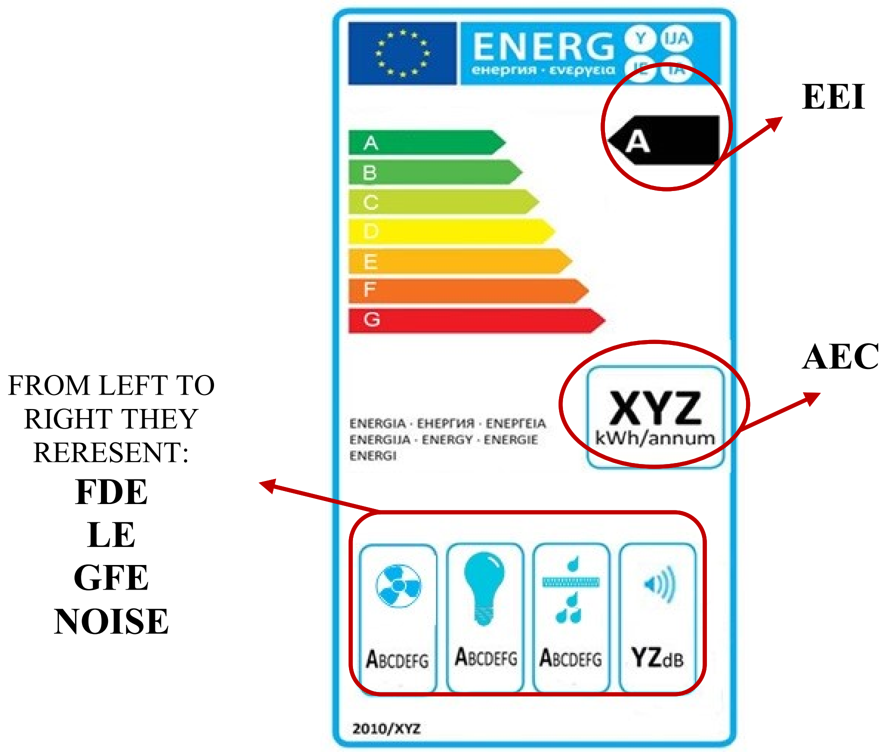


Figure 44. Energy Label

On the top part of the label different alphabetical values from G to A are indicated, corresponding to the energy efficiency classes, A being the most energy efficient, G the least efficient. This value is called **EEI**, Energy Efficiency Index (see **3.3.2.1**).

The central part of the label shows the annual energy consumption of the household appliance, namely **AEC**.

On the bottom section you can visualize different parameters, that is:

- FDE: Fluid-dynamics Efficiency Index;
- LE: Lighting Efficiency Index;

– GFE: Grease Filtering Efficiency Index;

– Noise Level in dB.

The Energy Label is going to be modified, year by year, by the more strict energy efficiency requirements dictated by the Community policies. The Figure 45 shows the Energy Label evolution for the next years.

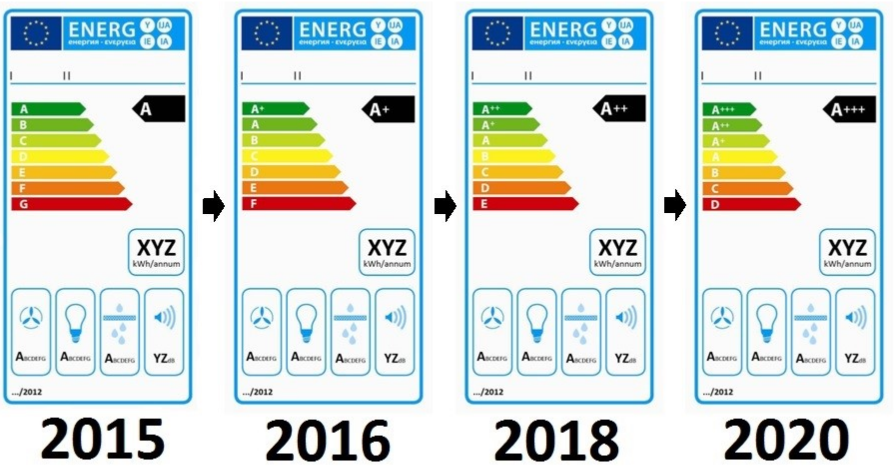


Figure 45. Energy Label evolution

3.3.2.1 Energy Label Calculations

The Fluid Dynamic Efficiency Index, FDE, is required to calculate the AEC, Annual Energy Consumption and the EEI, Energy Efficiency Index. FDE is defined as the ratio between the effectiveness of the suction system (namely the product of the volumetric airflow multiplied by the downstream static pressure) and the energy consumption. FDE at the BEP, best efficiency point, is calculated by the Equation 5, and is rounded to the first decimal place:

$$FDE = \frac{Q_{BEP} \cdot P_{BEP}}{W_{BEP} \times 3600} \times 100$$

Equation 5. FDE

– Q_{BEP} is the air flow, in m^3/h and rounded to the integer, at the best efficiency point

– P_{BEP} is the static pressure, in Pa, and rounded to the integer, at the best efficiency point

– W_{BEP} is the electric power consumption of the cooker hood, in W and rounded to the first decimal place, at the best efficiency point.

The Annual Energy Consumption, AEC, of a cooker hood is calculated by Equation 6, in kWh/year and recorded to the first decimal places, as:

$$AEC = \frac{[W_{BEP} \times (t_H \times f) + W_L \times t_L]}{60 \times 1000} \times 365$$

Equation 6. AEC

- W_{BEP} is the electric power consumption of the cooker hood, in W and rounded to the first decimal place, at the best efficiency point
- W_L is the nominal power consumption of the lighting system on the cooking surface, expressed in W and rounded to the first decimal place
- t_L is the average lighting time per day, in minutes ($t_L = 120$)
- t_H is the average running time per day for household range hoods, in minutes ($t_H = 60$)
- f is the time increase factor, related to FDE, rounded to the first decimal place, determined as in Equation 7:

$$f = \frac{-3{,}6 \times FED}{100} + 2$$

Equation 7. Calculation of "f" factor

The Energy Efficiency Index, EEI, is calculated by Equation 8 as:

$$EEI = \frac{AEC}{SAEC} \times 100$$

Equation 8. EEI

- AEC = annual energy consumption of the cooker hood, in kWh/year and rounded to the first decimal place
- $SAEC$ = standard annual energy consumption of the cooker hood, in kWh/year and rounded to the first decimal place.

The Lighting Efficiency Index, LE, is defines as the ratio of the average illumination provided by the household range hood on the cooking surface to the nominal power consumption of the lighting system. LE is calculated by Equation 9, in lux/W and rounded to the integer:

$$LE = \frac{E_{MIDDLE}}{W\_L}$$

Equation 9. LE

- E_{MIDDLE} is the average illumination of the lighting system on the cooking surface, in lux and rounded to the first decimal place
- W_L is the nominal power consumption of the lighting system on the cooking surface, in Watt and rounded to the first decimal place.

The Grease Filtering Efficiency, GDE, is measured according to EN 61591.
The Noise Level is measured as the airborne acoustical A-weighted sound power emissions of a cooker hood at the highest setting for normal use, intensive or boost excluded, measured according to EN 60704-2-13.

3.3.2.2 Energy Label Classes and Indexes

In Figure 46 the values of Energy Efficiency index (EEI), Fluid Dynamic Efficiency (FDE), Grease Filtering Efficiency(GFE), Lighting Efficiency Index (LE) are shown in relation to the Efficiency Classes.

Energy Efficiency Class	*Energy Efficiency Index*
A+++ (most efficient)	EEI < 30
A++	30≤ EEI <37
A+	37≤ EEI <45
A	45≤ EEI <55
B	55≤ EEI <70
C	70≤ EEI <85
D	85≤ EEI <100
E	100≤ EEI <110
F	110≤ EEI <120
G (least efficient)	EEI ≥ 120

Fluid Dynamic Efficiency Class	*Fluid Dynamic Efficiency*
A (most efficient)	FDE >28
B	23 < FDE ≤ 28
C	18 < FDE ≤ 23
D	13 < FDE ≤ 18
E	8 < FDE ≤ 13
F	4 < FDE ≤ 8
G (least efficient)	FDE ≤ 4

Grease Filtering Efficiency Class	*Grease Filtering Efficiency (%)*
A (most efficient)	GFE > 95
B	85 < GFE ≤ 95
C	75 < GFE ≤ 85
D	65 < GFE ≤ 75
E	55 < GFE ≤ 65
F	45 < GFE ≤ 55
G (least efficient)	GFE ≤ 45

Lighting Efficiency Class	*Lighting Efficiency index Ceced*
A (most efficient)	LE > 28
B	20 < LE ≤ 28
C	16 < LE ≤ 20
D	12 < LE ≤ 16
E	8 < LE ≤ 12
F	4 < LE ≤ 8
G (least efficient)	LE ≤ 4

Figure 46 EEI, FDE, GDE, LE

3.4 G.EN.ESI software platform implementation in FABER

After the product analysis, which allows to define the products modules and main characteristics, the implementation of the G.EN.ESI platform in the FABER company has been realized. **This implementation has multiple objectives: at first to validate the effectiveness of the methodology and the platform, then to optimize the product under analysis in environmental terms, third to evaluate the tool usability and provide suggestions to software developers to improve them.**

The first step was the identification of those figures that inside the FABER company has the characteristics of those ones identified by the methodology as needed figures to be involved during the implementation of the G.EN.ESI platform inside an industrial company. In particular, thy were:

Design Engineers: three design engineers have been involved during the validation:

- ***Nicola***: Industrial Engineer (Master degree). He has been recruited by the company two years ago as mechanical engineer. He is involved in the development of new hoods and cost reduction projects. He has a basic know how on Ecodesign and environmental related aspects/regulations. He worked mainly with the CAD system and he is one of the user of the software tools of the G.EN.ESI platform.
- ***Roberto***: Mechanical Engineer (Master degree), 25 years old. He has been recruited by Faber as designer and he was fully involved in the validation of the G.EN.ESI platform for 4 months. He knows the cooker hood product, he worked in cooperation with the company designers and laboratory engineers during whole the period. He has a basic know how on Ecodesign and environmental related aspects/regulations. He used all the software tools of the G.EN.ESI platform. He actively participated during the cooker hood re-design process, following feedbacks got from the G.EN.ESI platform.
- ***Riccardo***: Student of Mechanical Engineering, first level (Bachelor), 23 years old, intern at the company for two months. No skills concerning product design (also included cooker hood) and limited know-how on Ecodesign, environmental issues, and recyclability (scholar level). He used the G.EN.ESI platform during the thesis period, with a focus on LeanDfD.

Product Manager:

- ***Lorenzo***. Industrial Engineer (Master Degree) which guides cooker hood designers; he is responsible to develop new products for the company. He manages the entire product line life, specifies the market requirements for current and future products, and drives a solution set across development teams. His role also involves ensuring that all products comply with restricted substance legislation and implementing systems and tools to reduce energy and CO_2 emissions of the company, both from the factory and across the lifecycle of the product.

Environmental Manager:

- ***Simone***. Mechanical Engineer (Master degree). He has been recruited by the company after the degree. He is involved in innovation product projects about blowers development, noise reduction systems, lighting systems. He has a strong know how about Life Cycle Assessment (LCA), Ecodesign and environmental related regulations (Reach, RoHS, and WEEE) and standard (ISO 14062) from previous working experiences. He actively participated during the cooker hood re-design process, following feedbacks got from the G.EN.ESI platform.

3.4.1 Eco Material

The first step within the software platform implementation has been the analysis of the product by the Eco Material tool and in particular it was used in the form of the plug-in for the CAD software PRO\e. The cooker hood 3D model was opened into the PRO/e tool and then the Eco Audit tool was launched.

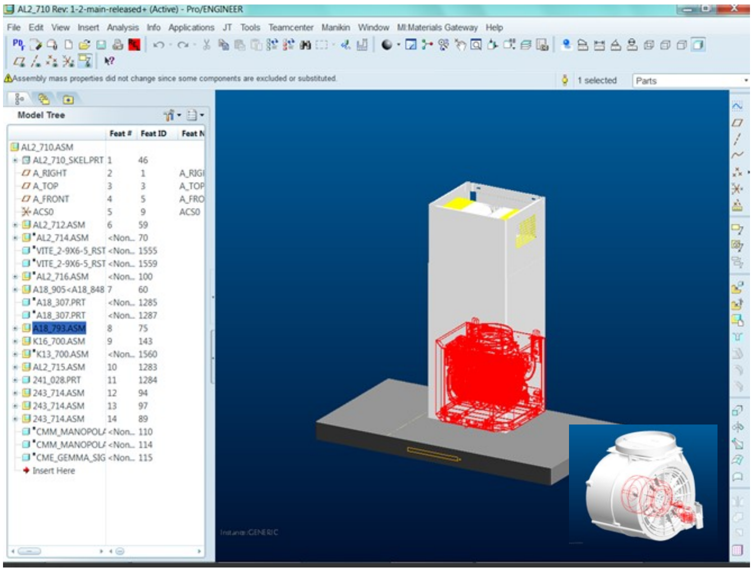


Figure 47. MI Material Gateway Plug-in

A complete version of the CAD model has been chosen, despite the dimensions and the huge amount of small components, such as screws and rivets.

The Figure 47 represents how the CAD plugin looks like. It replies exactly the "tree" of components from the CAD and gives the user the possibility to modify eventually, for each of them, the material, the process and the surface treatment which correspond to the ones of the real product. For each component of the product the user can insert data on material, processes and surface treatment by selecting them from a very extensive database. The objective is to model the product in order to make the modelling as much as possible similar to the real product. Of course, where it has been not possible for some components, simplifications are adopted.

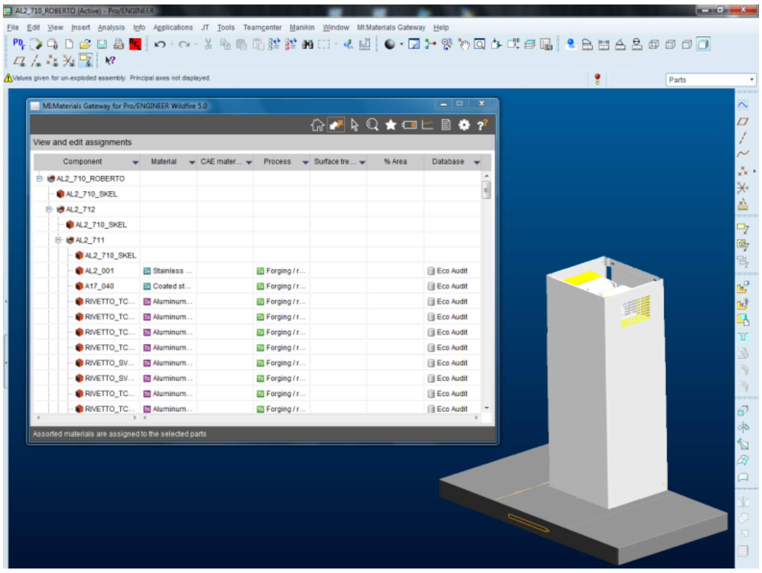


Figure 48. Automatically generated XML file

The procedure ends when the so-called XML file is exported.

The XML file generated by the tool (Figure 48), contains data on the product and represents a sort of extended Bill of Material, in which information on components, their mass, their materials, production processes and surface treatments are contained and stored.

3.4.2 MI BoM Analyzer

Once the first stage has been reached, the next one was to import the previously saved XML file using ECO MATERIAL BoM Analyzer. This tool enables the user to import and edit Bills of Materials for products, or build new BoMs from scratch. It is an easy-to-use web application. The user can add parts, group them into components and assemblies, define quantities and masses, copy and paste existing elements as the basis for new ones. This procedure can be repeated for all those components that are not present in the product CAD model, since they are bought from external entities. In this way it is possible to include in the product environmental impact calculation also all those components that are not produced inside the company, allowing to not neglect them.

In the cooker hood case, this step has been performed to add the motor and the lamps. These components in fact are not included in the CAD model, since they are bought from external suppliers.

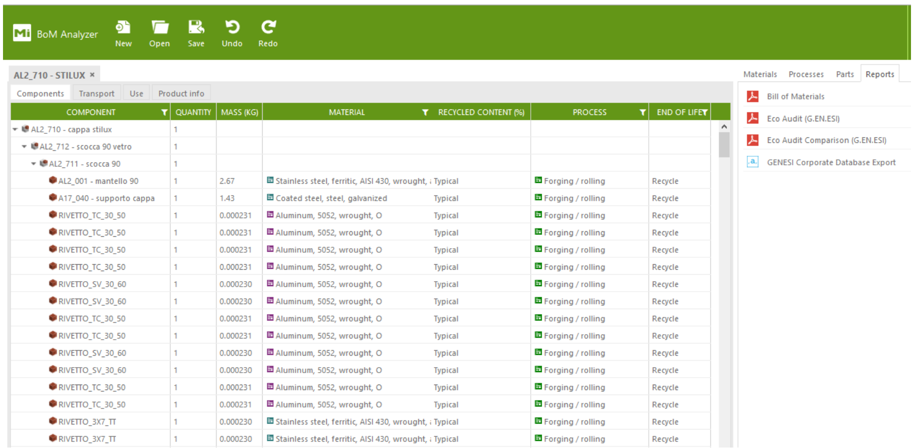


Figure 49. XML file within MI BoM Analyzer

The screenshot in the Figure 49 clarifies the structure of the MI BoM Analyser tool.
It contains four main tabs, that are: Components where data on components can be inserted by, Transport where data on transport phase can be included, Use where data on the use profile and connected information can be inserted, and Product info where additional note can be stored by the user. Each of them can be pressed to set different product characteristics (Figure 50).

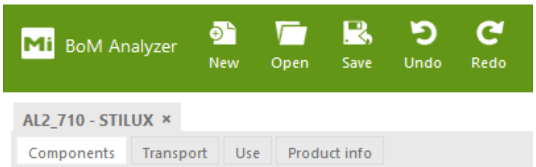
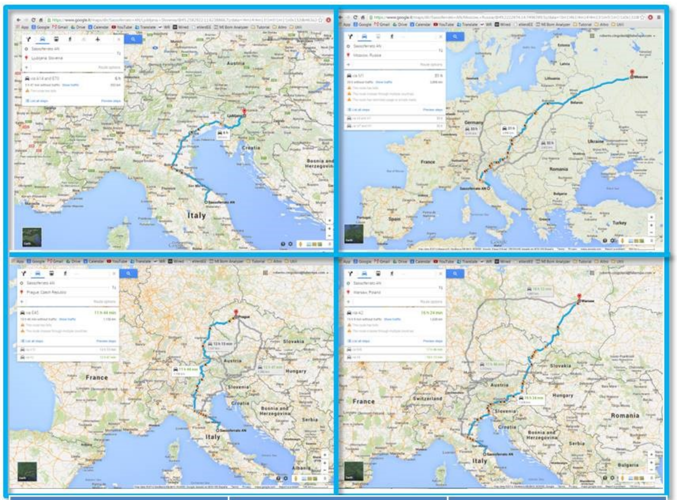


Figure 50. MI BoM Analyzer main tabs

In this case, data on product use, EoL and transport phases has been added.
Regarding the EoL, and in particular the scenario and treatment for each component, the possibility that the tool provides for each components are: Landfill, Recycle, Re-engineering (intending the remanufacturing process), Reuse. For the cooker hood, the most feasible for each component has been selected.
Regarding the information related to the recyclability rate of the material used to realize components, due to absence of information on this specific issue, the “Typical” scenario has been selected.
After the EoL scenario has been set for each component, the Transport phase has been modelled. The final-products distribution is calculated as an average of the shipping distances to the four most important buying countries as shown in the Figure 51. This particular analysis was carried by the help of a “marketing and communication” manager in FABER.



Destination	Type of transport	km
Moscow	Truck	2896
Warsaw	Truck	1938
Prague	Truck	1156
Ljubjana	Truck	593

Figure 51. Principal destinations of cooker hood and distances

The last important tab regards the modelling of the use phase. When the G.EN.ESI project has started there were no specific norms to regulate use profiles for these products in literature.

For the first part of the analysis, only the simplified scenario results are shown in Figure 52.

In particular data has been set as following: European electricity mix, 9 years of life-time, 365 days per year and 1 hour per day. The related power rating is 325 Watt [W], including both the contribution of motor and lamps.

Due to the fact the MI Bom Analyzer it is supposed to be used as a first screening tool, the quality of information is not so accurate and not detailed data on the use phase are needed in this step of the analysis. Data that the tool asks are illustrated in the Figure 52. In the detailed analysis, the use of the DfEE tool, has allowed to include more details on the use phase and to derive more detailed results.

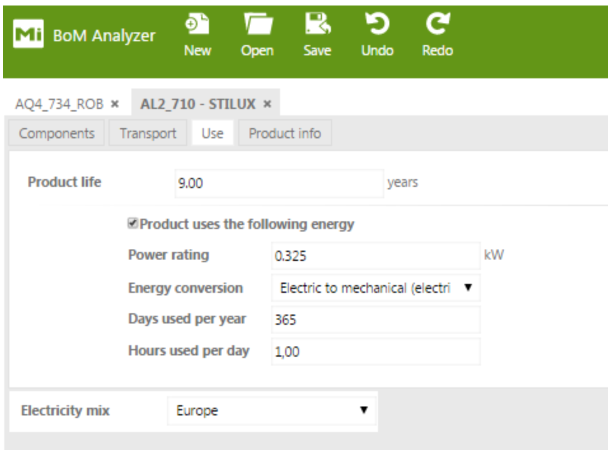


Figure 52. Use phase details within MI Bom Analyzer

After data on the product have been inserted in the tools, the updated XML file can be exported again together with the Eco Material reports. This report, obtained by the use of the S-LCA module (called Eco Audit) allows the user to derive the results of the simplified environmental impact calculation. The tool evaluates the environmental result in term of: Energy consumption [MJ] and Carbon footprint [kg of CO_2 equivalent].

Results from the preliminary study have confirmed expectations.

In fact, **the use phase has a much greater impact if, compared to the other phases**. Details are provided in the following Figure 53 and Figure 54. For confidentiality reason, the results are shown in percentage.

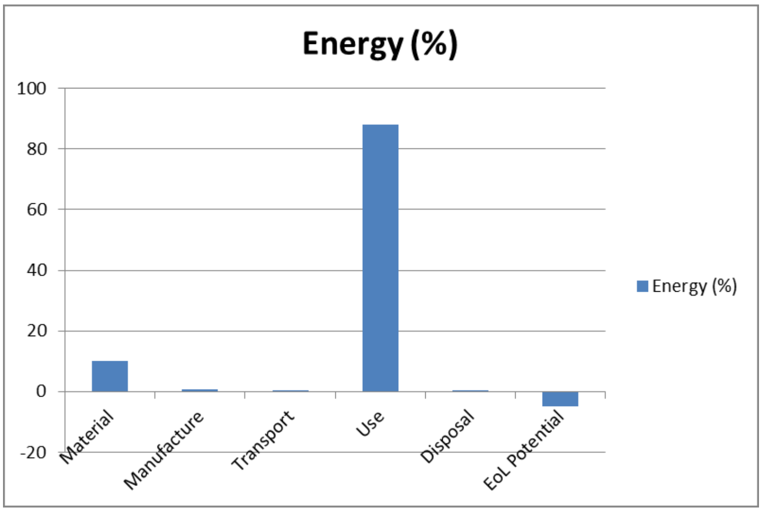


Figure 53. Energy consumption from the cooker hood life cycle

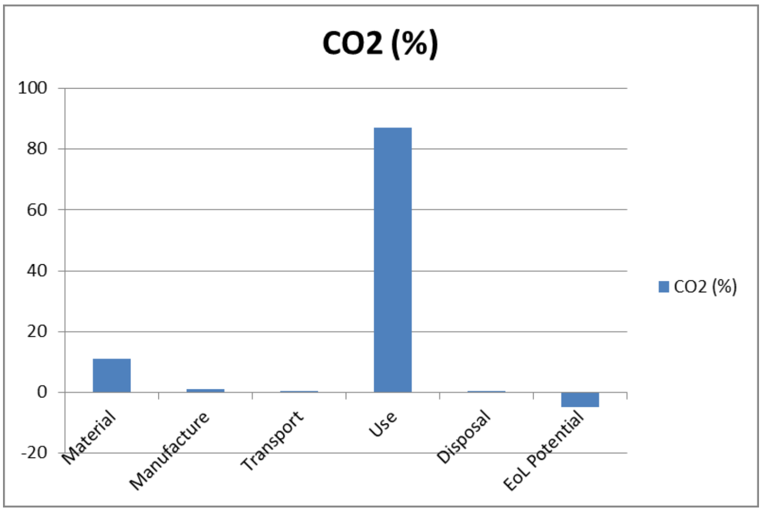


Figure 54. CO2 emissions from the cooker hood life cycle

The next step was to analyze in a more rigorous manner the use phase, since it has a substantial impact, and the EoL phase. These analyses will be realized respectively by the use of the DfEE and LeanDfD tool and explained in details in the next paragraphs.

3.4.3 DfEE

After the first and simplified analysis of the cooker hood, the G.EN.ESI Platform allows to deepen analyse the most critical phases of the product life cycle, with specific tools: the DfEE for the use phase and the LeanDfD for the EoL phase.

The main objective of the DfEE tool is the analysis of the energy using components (e.g. electric motor, lamps, etc…) with the purpose to estimate their energy consumption, the related CO_2 footprint and costs.

The flow goes on importing the XML file. It is important to clarify that at every stage, the above-mentioned XML file is enhanced with information provided by the platform tools.

Once the user has imported the output XML file from MI BoM Analyzer, he should indicate which the considered product lifetime is and which energetic mix he is operating with.

Then the user has to select the energy-consuming components he want to analyse, among different alternatives stored in the tool Data Base (compiled with company's data), and set their use-profiles.

The reference cooker hood use-profile foresees the motor simply working 1 hour per day at the maximum velocity, and 2 hours for the lamps. This explains why the graphs in Figure 55 and Figure 56, which are supposed to reply the working points for the motor and for lamps over the time-durations, have only one column.

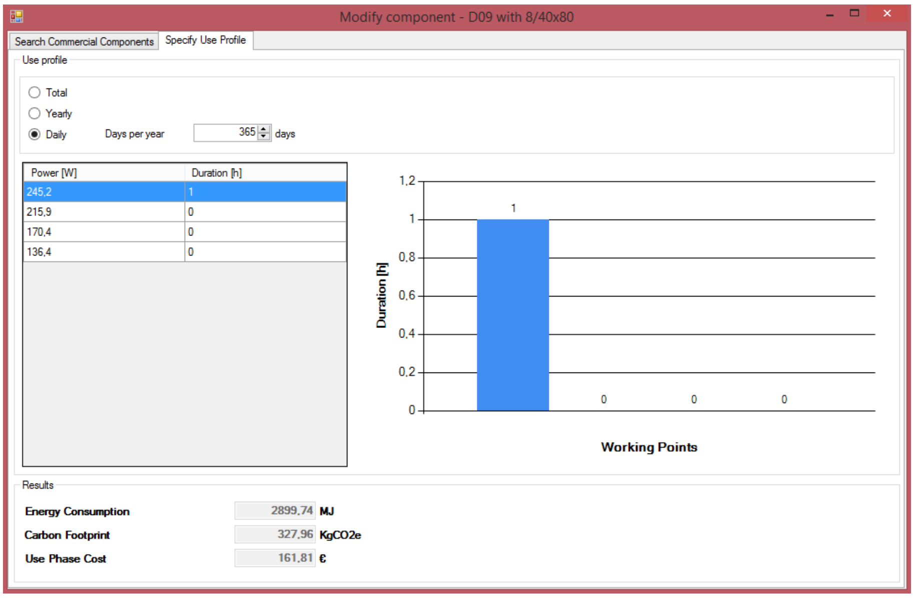


Figure 55. Simplified use-phase scenario_ motor's working points

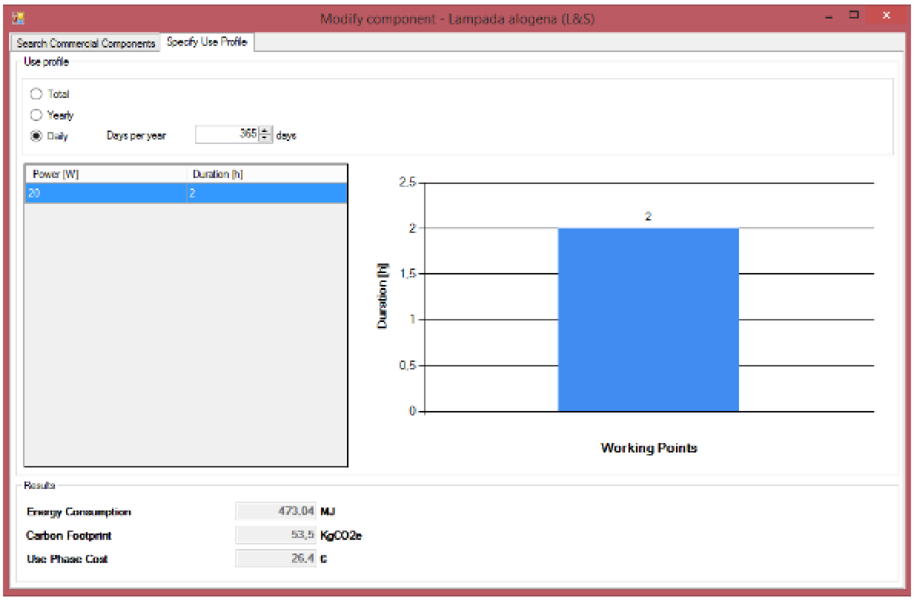
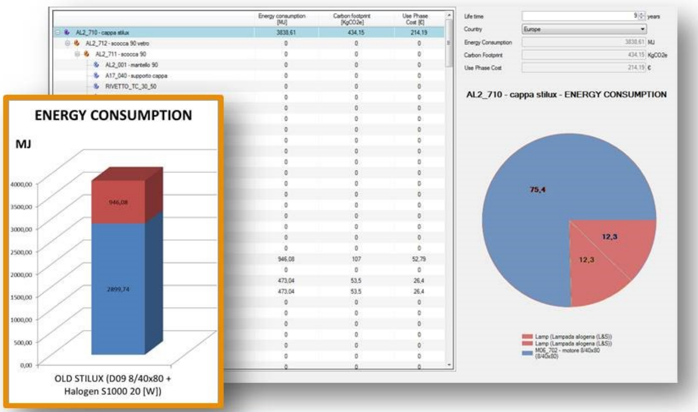


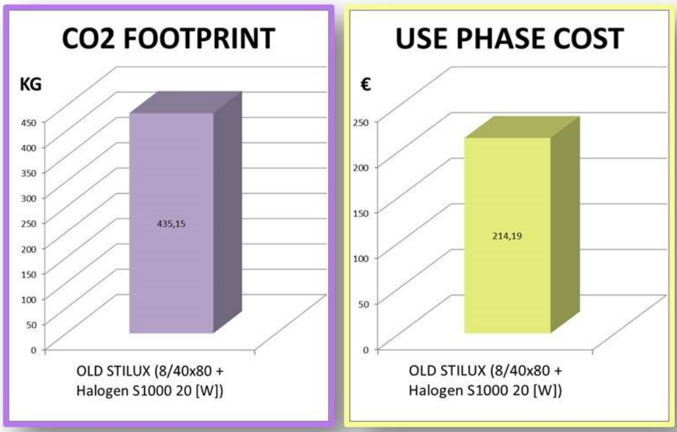
Figure 56. Simplified use-phase scenario _ lamp's working points

The results provided by the tool, firstly in terms of Energy Consumption, then CO_2 Footprint and Cost are showed in the following Figure 57 and Figure 58.



Energy consumption [MJ]			
Stilux cooker hood	Motor	Lamps	Total
	2899,74	946,08	**3845,82**

Figure 57. Simplified use-phase scenario_ motor's and halogen lamps' energy consumption



Stilux cooker hood	
CO_2 Footprint [KgCO_2 eq.]	435,15
Use Phase cost [€]	214,19

Figure 58. Simplified use-phase scenario_ motor's and halogen lamps' CO2 footprint and use cost

<u>Realistic Use-Phase Scenario</u>

In addition to the simplified use scenario, also the realistic ones has been analyzed. The realistic use-phase scenario, the one with a more representative use of the motor, considers:

- 12 minutes at the maximum velocity;
- 12 minutes at the third one;
- 36 minutes at the second velocity.

These considerations come from an interview that was done, at the beginning of this study, with a Faber sales manager. No one seems to use the cooker hood at the very first velocity, because otherwise it would make feel frustrated.

Differently from the simplified scenario, the graph showed in Figure 59 has three different columns with different heights, reflecting the real use of the motor.

The results-analysis of the realistic use-phase is shown in Figure 60 reflects a lower energy consumption in comparison with the simplified ones.

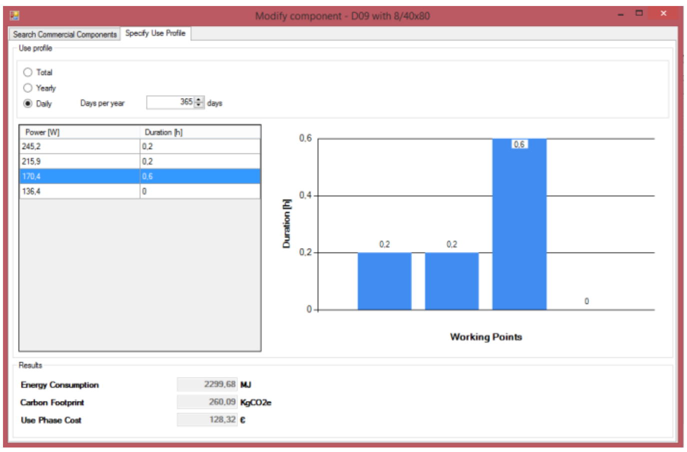
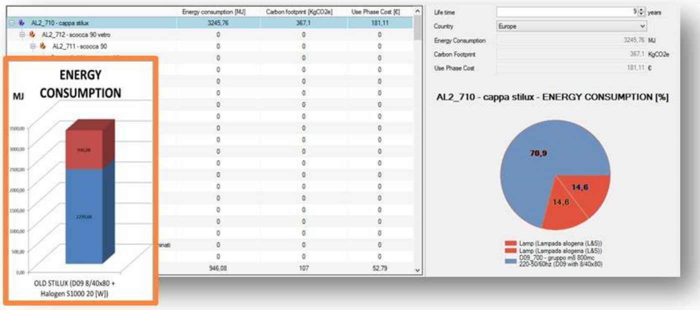


Figure 59. Realistic use-scenario _ motor working points over their time-durations

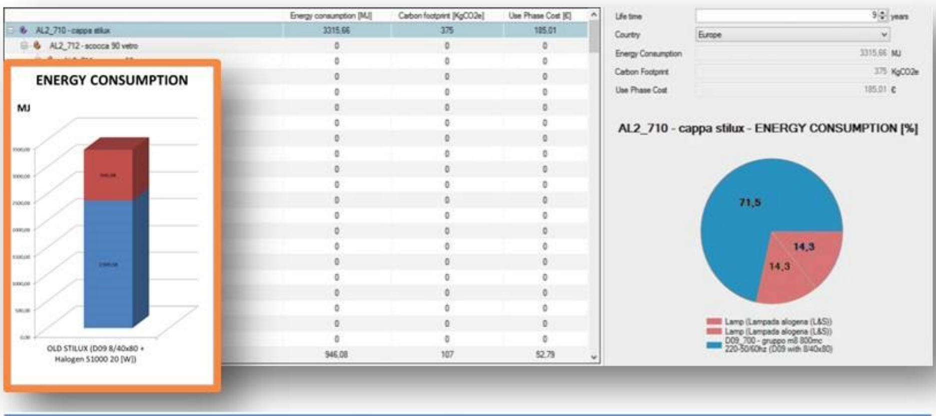


Energy consumption [MJ]			
Stilux cooker hood realistic use scenario	Motor	Lamps	Total
	2299,68	946,08	**3245,76**

Figure 60. Realistic use-phase scenario _ motor's and halogen lamps' energy consumption

Energy Label Use-Phase Scenario

For completeness, the results in terms of Energy Consumption for the reference cooker hood applying the Energy Label Use Scenario are showed in Figure 61. It reflects a lower energy consumption if compared with the Simplified Use Scenario, but a higher energy consumption if compared with the Realistic Use Scenario.



Energy consumption [MJ]			
Stilux cooker hood Energy laberl use scenario	Motor	Lamps	Total
	2369,58	946,08	**3315,66**

Figure 61. Energy Label use-phase scenario _ motor's and halogen lamps' energy consumption

3.4.4 **LeanDfD**

The LeanDfD supports the eco-friendly design and re-design through two different ways:

- Evaluating the product manual disassemblability of the product
- Evaluating the recyclability rate of the product

To provide this double objective the tool is composed by two modules, the first one for the analysis of the disassemblability time and cost (the so-called DfD module), and the second one for the calculation of the EoL performances in terms of recyclability (the so-called EoL module). Both the modules have been implemented in order to optimize the EoL phase of the reference cooker hood.

DfD Module

The first step is also in this case the importation of the ongoing XML file.

The user has at first to select the target components, to which the disassemblability analysis is focused on. Target components are those components for which the user want to realize the disassembly analysis. In the following all the steps performed to analyse the disassemblability of the cooker hood at its EoL phase are presented.

STAGE 1)

This activity was carried out both with the CAD model and a real Stilux cooker hood. The resulting identified target components are contained in the following Table 11:

Table 11 Cooker hood target components

<table>
<tr><th>Selection criterion</th><th>Component</th></tr>
<tr><td rowspan="7">Critical Components</td><td>Electric motor</td></tr>
<tr><td>Electrical capacitor motor circuit</td></tr>
<tr><td>Printed Circuit Board PCB for Motor Control</td></tr>
<tr><td>PCB of the filter for the attenuation of electromagnetic noise</td></tr>
<tr><td>Basic PCB for the control of the touch screen</td></tr>
<tr><td>Individual touch controls PCB</td></tr>
<tr><td>Electrical toroid transformer</td></tr>
<tr><td rowspan="2">Components to maintain or replace</td><td>Halogen lamps (x2)</td></tr>
<tr><td>Blower</td></tr>
<tr><td>Basic components layout</td><td>Metal cloak</td></tr>
</table>

This step corresponds to the selection, in the first tab of the DfD tool interface, of the target components from the product tree structure (Figure 62).

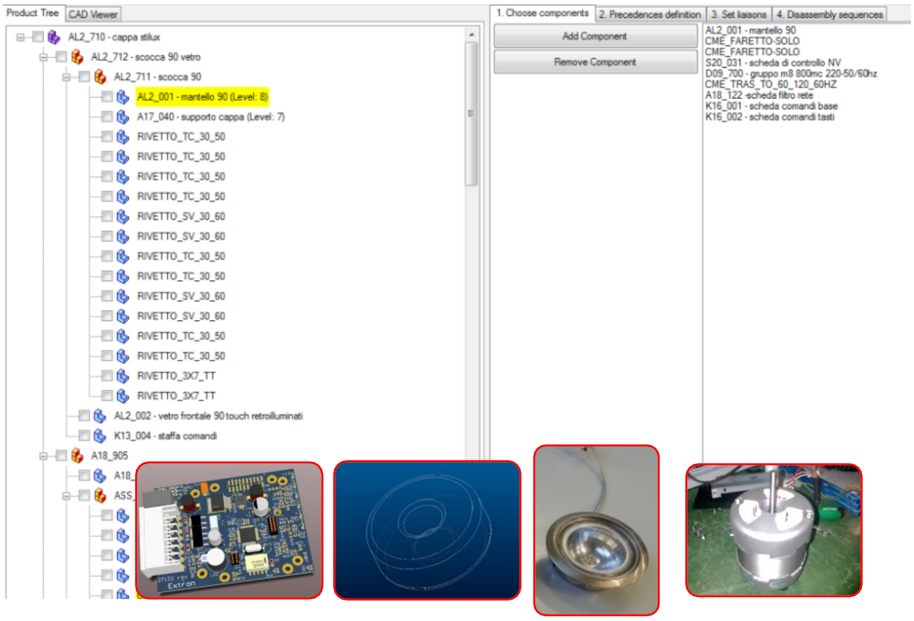


Figure 62. LeanDfD target components

In choosing target components, electrical wirings have been neglected, although the RoHS Directive states the need to separate them from the rest of the assembly before being treated. This hypothesis was necessary because otherwise it would have been very difficult to manage the individual cables within the structure. The wirings, in fact, are often in interlude positions between more components, and not being mostly present in the CAD model. For this reason the company has preferred not to consider them as target components.

Despite this, in presence of a wired connection between components, the removal phase of these connections have been considered.

Moreover, the fan block was inserted in the target components list since it has been evaluated from an extraordinary maintenance point of view, or even a replacement in case of a motor's failure.

The halogen spotlights can be considered as components to be studied, either because they can be replaced in case of exhaustion of illuminating capacity, or as they are critical components for the EoL.

The metal cloak (Figure 63) was chosen as the target component, by virtue of its structural function and the containment. In fact, the disassembly has been developed just imagining to fix the metal cloak as a reference and to go on with the removal of all other components until to remain in the end, with only the cloak. For this reason, the value of the time required to remove the cloak will be an indicator of the total cooker hood's disassembly time.

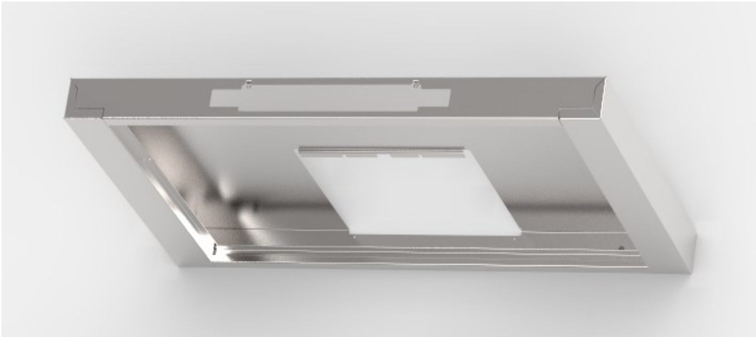


Figure 63. Cooker hood's metal cloak

STAGE 2)

Once those components have been chosen, the next phase was to set the precedencies, which means, to create a structure made by different layers, that reproduce the real connections among components in the product.

To understand how to build up the necessary levels-layout to assess a disassembly analysis, a non-destructive disassembly was carried out using specific tools; Figure 64 illustrates a frame-moment of the disassembly.

Figure 64. Non-destructive disassembly carried out in Faber

In this phase, the various components have been positioned in different levels, respecting the precedence relationships in disassembling identified by the study of the CAD model and dismantling manually performed.

In order to simplify the analysis, all components with negligible mass and the not helpful ones have been neglected (not incorporated into the structure levels). Have therefore been neglected: screws, plastic connectors, discharge conveyors, electrical wiring and metal supports for the wall installation.

It needs to clarify that this simplification does not affect the quality of the analysis, in fact, when defining the connections, it would not make sense to insert a link between a screw and a second component. It is clear that the utility of the screw, as fastening element, lies in the connection function between any two components A and B, and not between the screw itself and a component.

Two other assumptions have been made in order to allow the analysis: the metal cloak, the front glass and the support bracket have been considered as a single component. Actually, being glued, it would have been impossible to model the connection and predict a time of removal. The three sheets that constitute the Easy Cube housing, were also considered as a single component as welded together.

To be able to model the disassembly in a plausible manner, we had implemented the analysis of all the target components using two different files.

This decision was taken by noting that a single file, with a single layer structure, does not allow, via LeanDfD, to arrive simultaneously at the motor disassembly together with all the other components contained within the Easy Cube.

This issue occurs because, once you had access to the Easy Cube, you must remove the blower to be able to get to the condenser and the electric motor, while we must continue to "work" on the Easy Cube to remove the transformer, the card control and filter network (Figure 65).

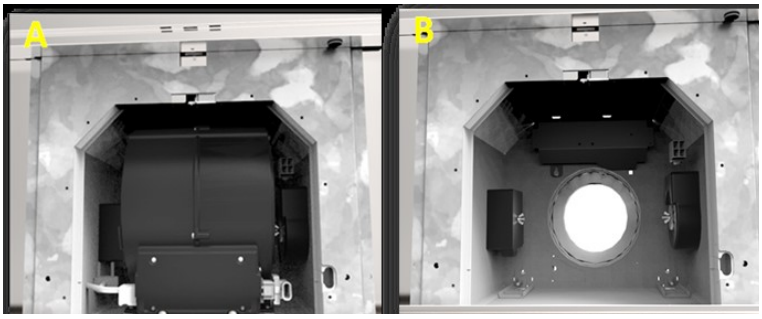


Figure 65. Focus inside the Easy-cube

In other words, a single-layer structure makes possible to model the disassembly, only when removing a sub-assembly, you do not need to proceed to disassemble simultaneously the same sub-assembly and the remainder of the structure from which it was removed.

For this reason two different files have been developed, the first one, in which we analysed the disassembly of: metal cloak, spotlights, PCB boards, fan block and transformer; and the second one in which we studied the condenser and the electric motor (Figure 66).

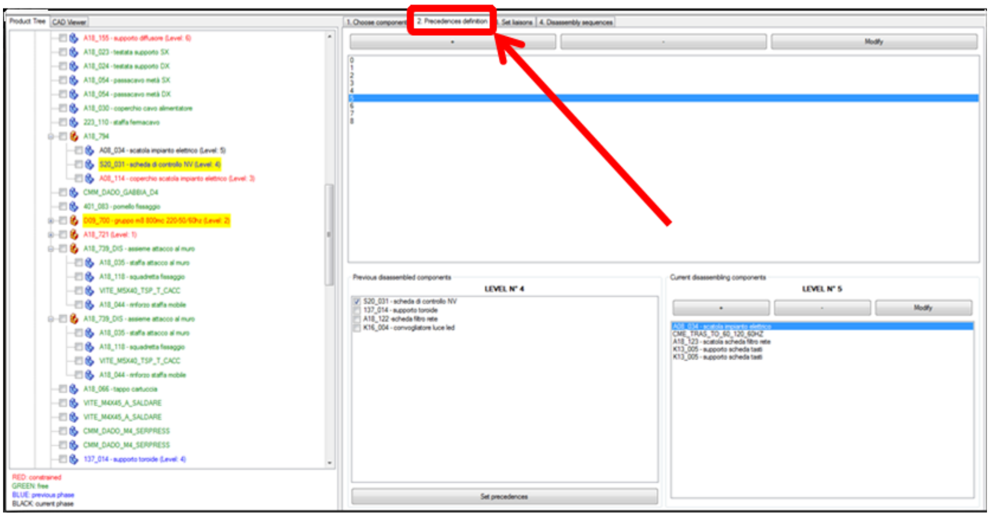


Figure 66. LeanDfD precedencies tab

STAGE 3)

The third tab regards the so-called liaisons, namely, the types of connections linking the components in the different layers.

All existing connections among the components previously included in the layered structure have been defined, specifying the characteristics for each settings via software (Figure 67 and Figure 68).

A particular choice made, is about the definition of the quick connections, named Dap Joint. For these types of connections we included the whole amount of the joints together, although, in some cases, as in the removal of the sheet support spotlights, the presence of multiple joints still allows to remove them at the same time, pulling the entire sheet with one motion. It is necessary to consider, during the analysis of the results, that the removal of these multiple links, may have been evaluated with overestimated times, as calculated by adding the effective time of removal of all individual joints.

All of the electrical connections to remove have been considered in the so-called "Electrical Plug", specifying time to time if they were involved in the removal of cables or rigid supports.

All connections with Phillips screws (crosshead type), have been defined by setting the type of head "with cylindrical notch", while the Torx screws have been set as "cylindrical with hexagonal notch". Then, for each screw, we specified the dimensional length and diameter of the threaded body.

Regarding the removal tools, we set:

- "Screwer" for the screws,
- "Spanner" for the nuts (except the so-called "butterfly nuts")
- "Rivet Puller" for the rivets,
- "Manual" removal for Dap Joints, wiring, and guides (with the exception of special connections that, during the performed simulation of disassembly, had been particularly difficult to remove and had requested the use of the flat head screwdriver; in these cases we chose the removal via "Other tools").

The cost of removal operations has been only imputed to the labour, while the costs of the tools used has been neglected.

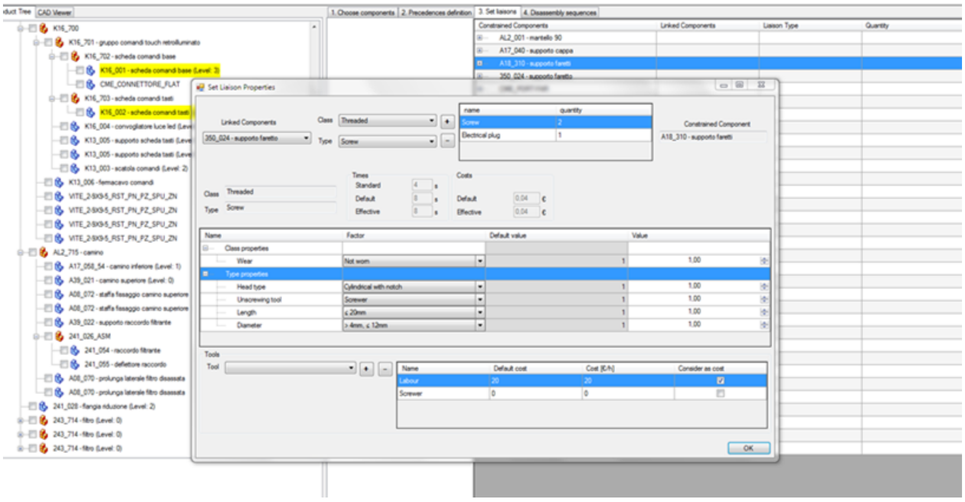


Figure 67. LeanDfD liaisons settings

In a summary of how the tab will look like when the liaisons have been set is provided.

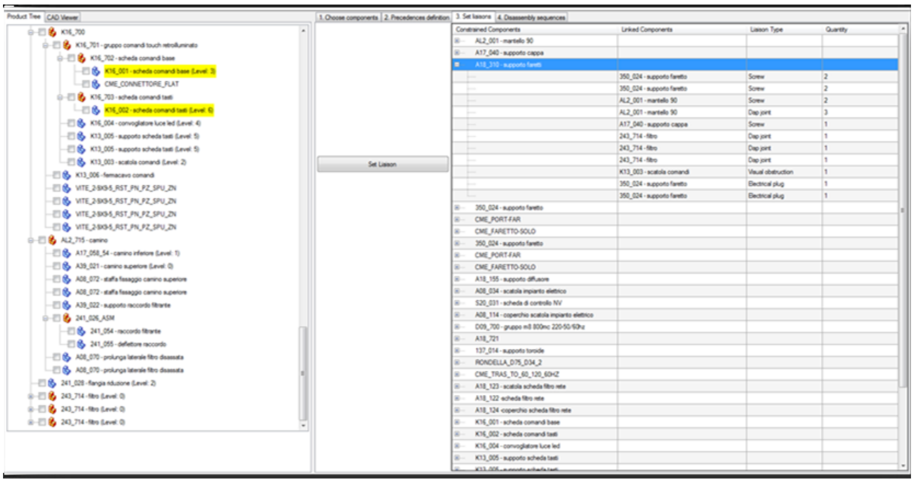
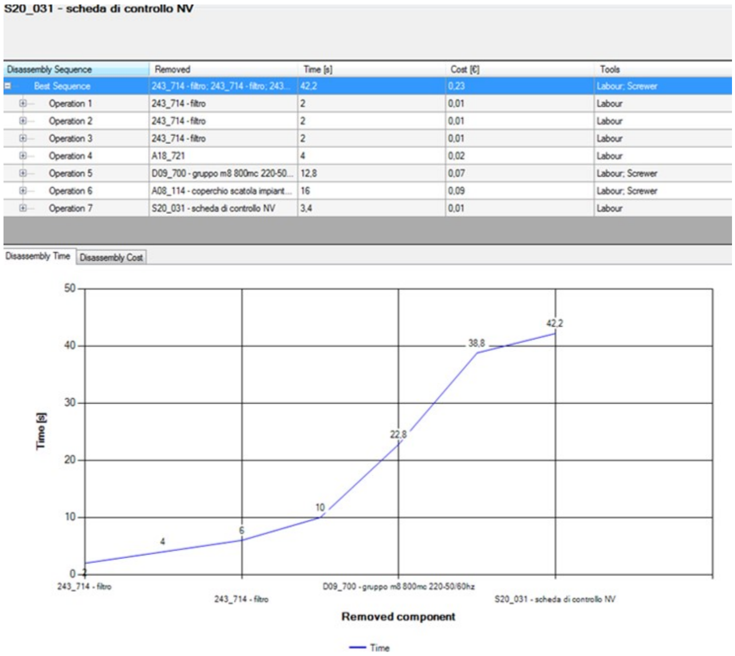


Figure 68. Summary of the already set liaisons

STAGE 4)

The final tool tab regards the visualization of the target removal sequences.

At this step the user has to choose the sequence that he desires to be shown and analyse results.


S20_031 - scheda di controllo NV

Disassembly Sequence	Removed	Time [s]	Cost [€]	Tools
Best Sequence	243_714 - filtro; 243_714 - filtro; 243...	42,2	0,23	Labour; Screwer
Operation 1	243_714 - filtro	2	0,01	Labour
Operation 2	243_714 - filtro	2	0,01	Labour
Operation 3	243_714 - filtro	2	0,01	Labour
Operation 4	A18_721	4	0,02	Labour
Operation 5	D09_700 - gruppo m8 800mc 220-50...	12,8	0,07	Labour; Screwer
Operation 6	A08_114 - coperchio scatola impiant...	16	0,09	Labour; Screwer
Operation 7	S20_031 - scheda di controllo NV	3,4	0,01	Labour

Figure 69. Disassembly sequence detail: S20_301 – scheda di controllo NV

Figure 69 shows the results for one of the target components' sequences (electronic board), but it is appropriate to state that these graph can clarify which is the most time-consuming operation, namely, the most sloped, allowing to figure out where can be necessary to put efforts with improvements.

The proposed sequence, output of the software, proves to be coincident with the realistic one based on the performed real manual disassembly during the simulation in Faber.

The rendering Figure 70 illustrates the correct order of removal.

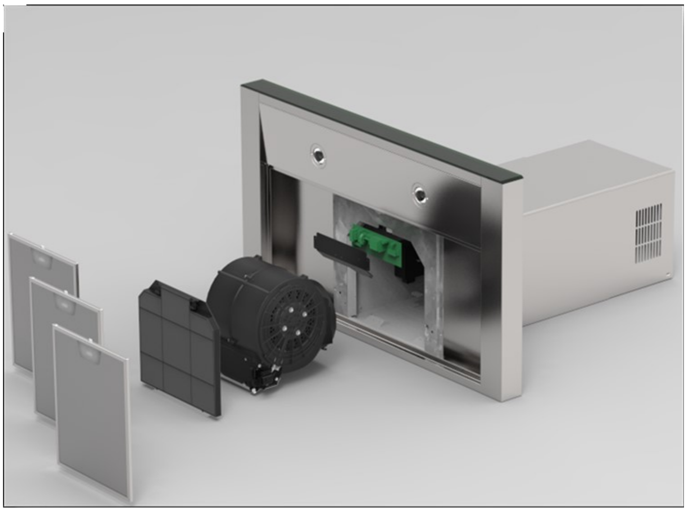


Figure 70. Rendering picture about the correct order of removal of the above-mentioned component

The whole time and cost for the target components removal, calculated with LeanDfD tool, are shown in Figure 71 and Figure 72.

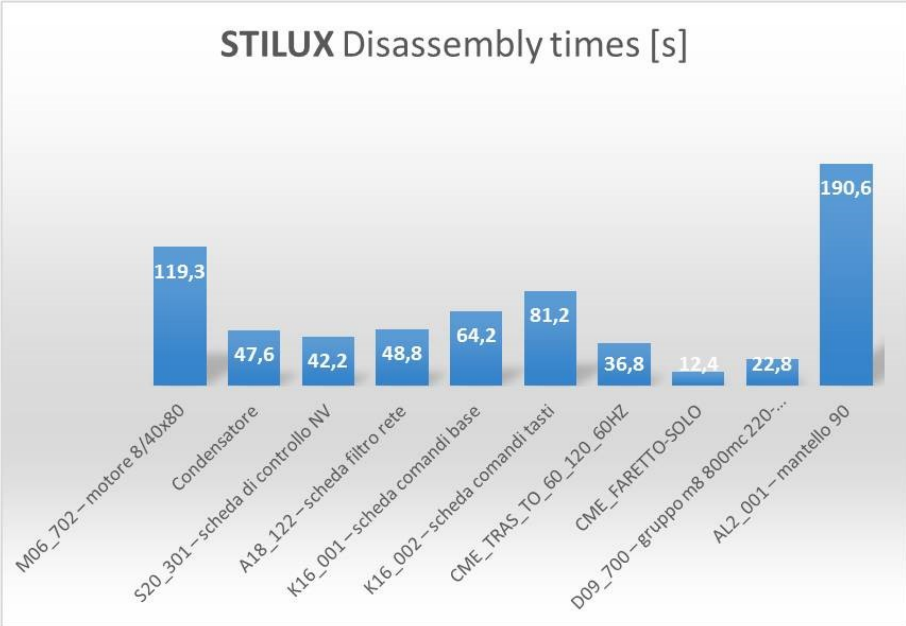


Figure 71. Stilux Disassembly Time

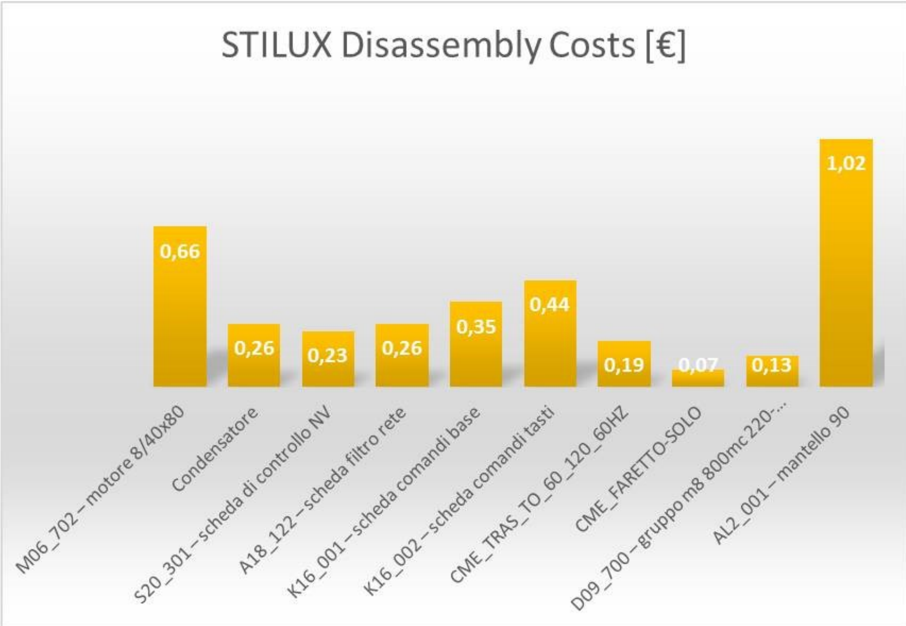


Figure 72. Stilux Disassembly Cost

The ongoing XML is now ready to go through the other Module, namely, EoL Module.

The quality of the XML file showing the BoM is crucial for a good analysis; in our case a BoM showing all the components effectively present in the cooker hood has been made, taking into account also screws or tiny components. Even the electric motor has been inserted in BoM, bringing each component of its sub-assembly.

Note that all PCBs and the capacitor, do not have a material assigned in the BoM because of the impossibility to set it via the tool BoM Analyzer GrantaMI.

End of Life module

After the disassembly examination has been concluded, the tool allows to continue through the End of Life module the analysis of the recyclability index for the reference cooker hood.

STAGE 1)

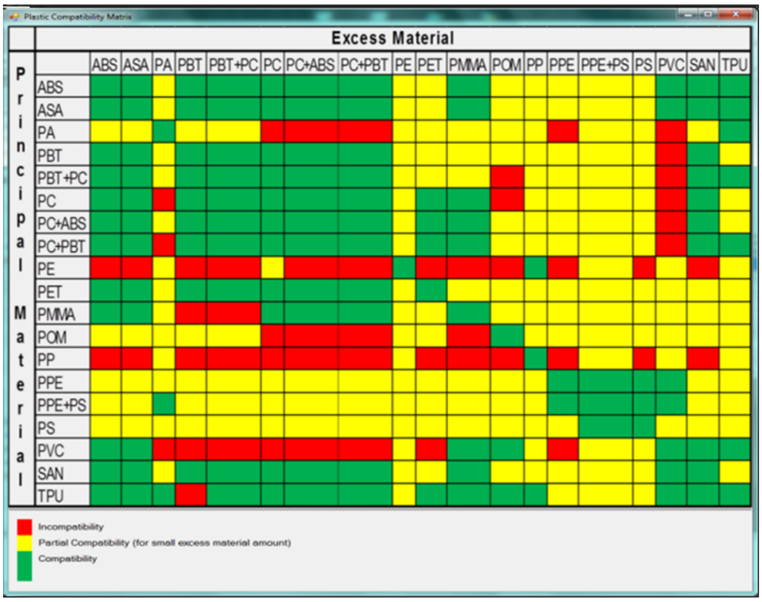
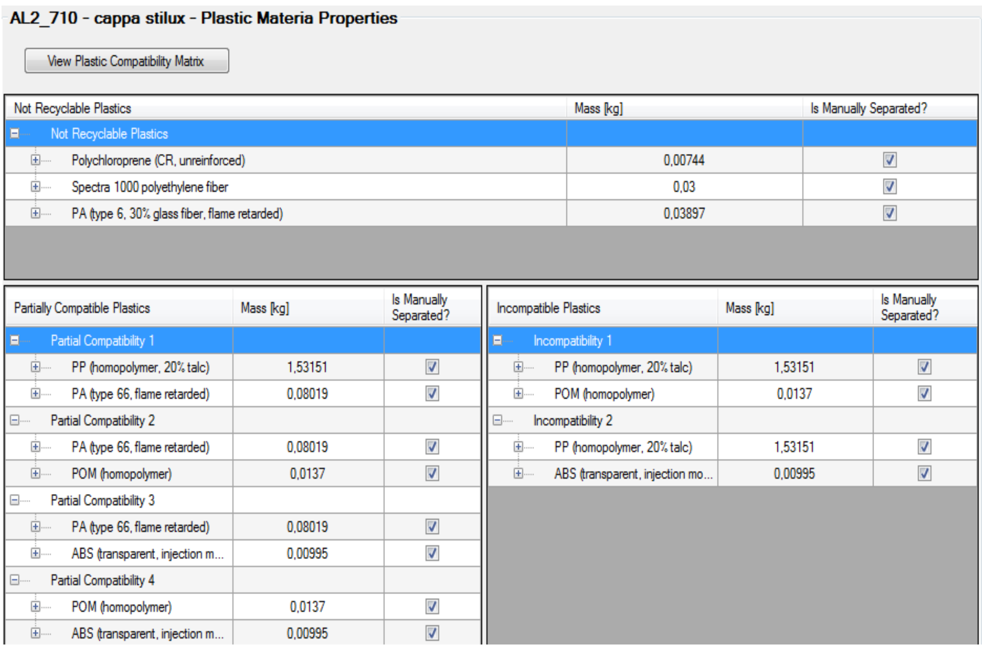


Figure 73. Plastic's incompatibilities matrix

The first steps concerning the fulfilling of EoL information related to the product under analysis. The tool guides the user in this step.

The tool, by analyzing the materials of each component realizes an evaluation of incompatible plastics (Figure 73). If incompatibilities are identified the tool ask if these components are manually separated before the product shredding or not. This information is important to allow the tool to calculate the final product recyclability index. In fact if incompatibilities are present it is necessary to recycle these typology of plastics to manually separate them.



Not Recyclable Plastics	Mass [kg]	Is Manually Separated?
Not Recyclable Plastics		
Polychloroprene (CR, unreinforced)	0,00744	☑
Spectra 1000 polyethylene fiber	0,03	☑
PA (type 6, 30% glass fiber, flame retarded)	0,03897	☑

Partially Compatible Plastics	Mass [kg]	Is Manually Separated?
Partial Compatibility 1		
PP (homopolymer, 20% talc)	1,53151	☑
PA (type 66, flame retarded)	0,08019	☑
Partial Compatibility 2		
PA (type 66, flame retarded)	0,08019	☑
POM (homopolymer)	0,0137	☑
Partial Compatibility 3		
PA (type 66, flame retarded)	0,08019	☑
ABS (transparent, injection m...	0,00995	☑
Partial Compatibility 4		
POM (homopolymer)	0,0137	☑
ABS (transparent, injection m...	0,00995	☑

Incompatible Plastics	Mass [kg]	Is Manually Separated?
Incompatibility 1		
PP (homopolymer, 20% talc)	1,53151	☑
POM (homopolymer)	0,0137	☑
Incompatibility 2		
PP (homopolymer, 20% talc)	1,53151	☑
ABS (transparent, injection mo...	0,00995	☑

Figure 74. Plastic material properties

The Figure 74 also shows the incompatibles due to the matching of PP-POM and PP-ABS, but again we can select “manually separated”, thus, positively solving this issue.

In summary, it is possible to state that not all the components with some kind of incompatibilities decrease the recyclability index since it is possible to separate these components.

The only polymeric material, which, in the definition of manual severability, requested a simplified assumption, has been the PA. This plastic material characterizes most of the connectors of the electrical wiring; these components have been neglected in the disassembly analysis, thus, they have not been removed from the sequences for removal of the target components, already calculated.

Despite this, it has been preferred to consider the connectors as manually removable because almost all of them is in fact disassembled from the structure of the cooker hood together with the components to which they are connected (think of the removal of the spotlights and the fan block).

STAGE 2)

Information about all contaminated components have been then placed in the appropriate screen, specifying the presence of zinc on the surface of the metal. These contaminations cause low Recyclability Index of the affected components.

In the cooker hood, some metal components are made of galvanized steel (chemically treated with zinc) for a very relevant weight.

Such processing is needed in order to better withstand the large presence of moisture, high saline and oxidizing agents, typical of the vapors and fumes produced during the cooking of food, which may cause corrosion of the untreated steel.

STAGE 3)

The STILUX has two not removable connections made of adhesive material between the metal cloak and the front glass, while the other one between the front glass and the support bracket of the touch controls group (Figure 75). This information has been inserted in the appropriate section of the EOL Module; this aspect also negatively influences the Recyclability Index of the three components contaminated by the adhesive.

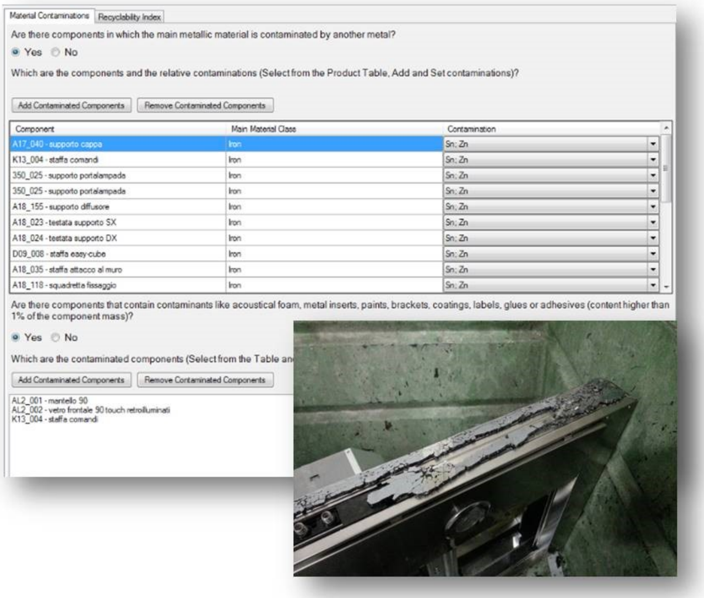


Figure 75. Materials contaminations and the glued glass criticism

STAGE 4)

Once the user has filled all the available settings, he can take the overall vision of the Recyclability Index of the hood. The result shows a value of 70.97% for the Recyclability Index of the cooker hood (Figure 76).

All the components that do not have contamination or presence of problematic materials, default Recyclability Index equal to 90% or 95% is assigned, depending on the material. Figure 76depicts the screen presentation of the results for the Recyclability Index calculated by the software.

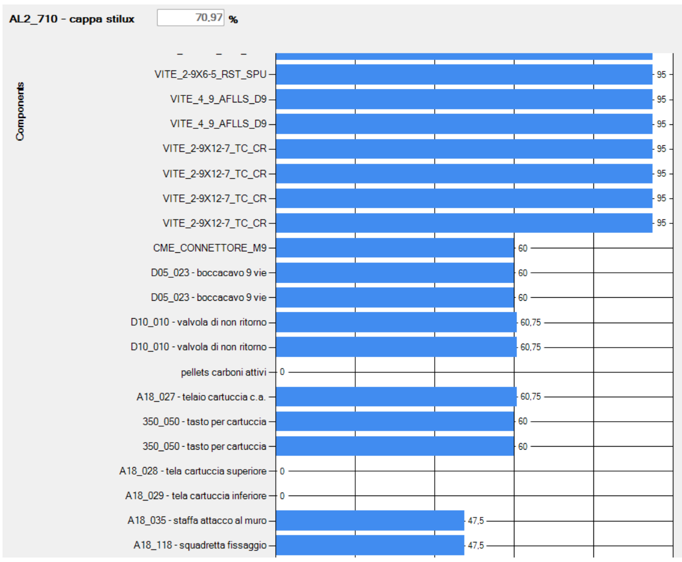


Figure 76. Recyclability Index

The components characterized by a particularly low Recyclability Index (RI) and therefore critical under this aspect are:

– non-recyclable plastic components

– glued components (the front glass corresponds to a RI = 28.12%, which, in virtue of its high weight, heavily impacts on the global RI);
– galvanized components (RI = 47.5%);
– plastic components (RI approximately equal to 60%, slightly variable depending on the polymer type).

3.4.5 eVerdEE

eVerdEE is a free WEB-based screening Life Cycle Assessment tool thought for European Small and Medium sized Enterprises. It's meant for all those who want to be able to self-analyze the environmental performance of their products and services. Its main feature is the adaptation of ISO 14040 requirements to offer easy-to-handle functions with sound scientific bases. Complex methodological problems are simplified according to the SMEs needs. The user-friendly inventory procedure offers predefined forms and a help-on-line. The database contains pre-elaborated environmental indicators of substances and processes for different impact categories.
After creating the new study the user will be presented with the inventory-phases menu. This menu is a list of all the life cycle phases that he needs to complete depending on the system boundaries chosen in the description card.
If "from cradle to grave" is selected for the system boundaries definition, all the life cycle phases will be listed on the inventory-phases menu (Figure 77).

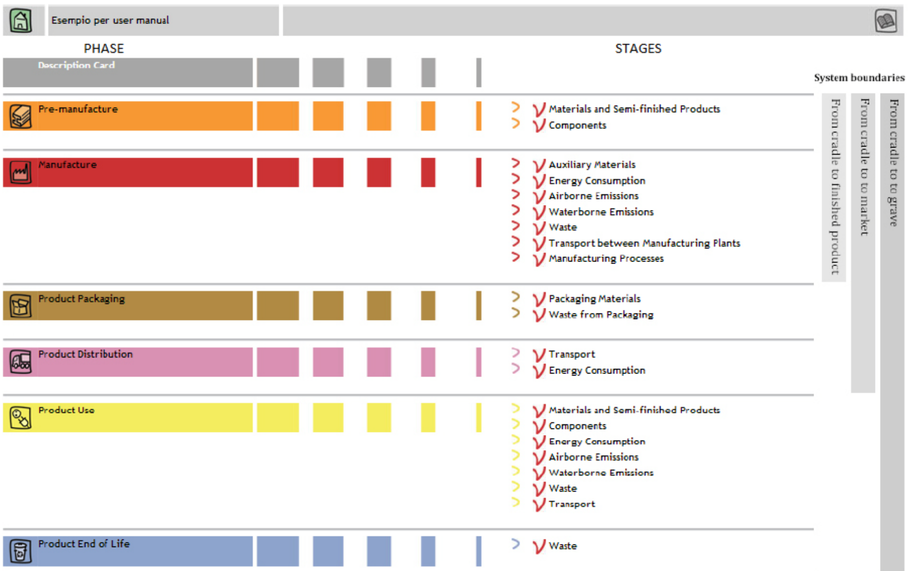
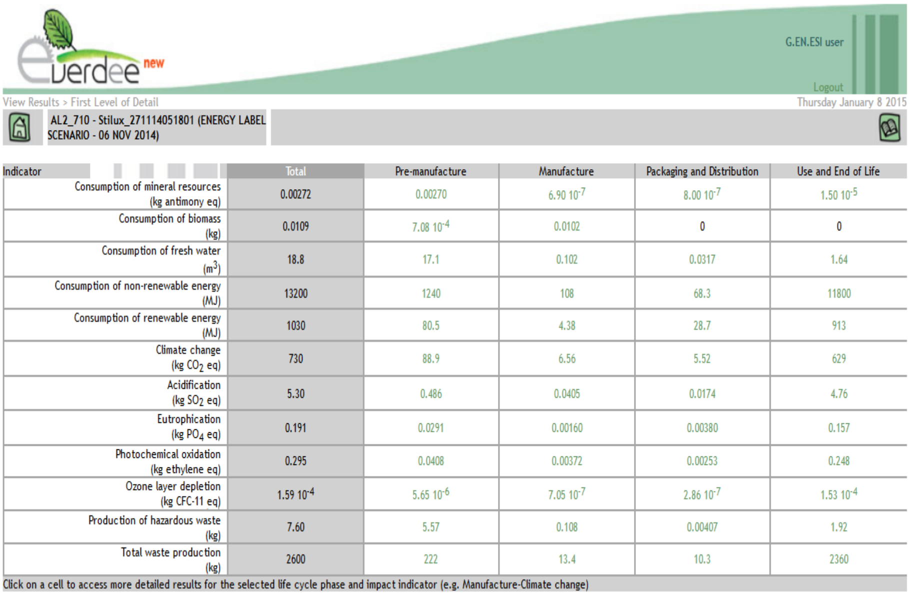


Figure 77. Inventory phase

After every phase has been completed, the study is ready to be analyzed.



Indicator	Total	Pre-manufacture	Manufacture	Packaging and Distribution	Use and End of Life
Consumption of mineral resources (kg antimony eq)	0.00272	0.00270	$6.90\ 10^{-7}$	$8.00\ 10^{-7}$	$1.50\ 10^{-5}$
Consumption of biomass (kg)	0.0109	$7.08\ 10^{-4}$	0.0102	0	0
Consumption of fresh water (m^3)	18.8	17.1	0.102	0.0317	1.64
Consumption of non-renewable energy (MJ)	13200	1240	108	68.3	11800
Consumption of renewable energy (MJ)	1030	80.5	4.38	28.7	913
Climate change (kg CO_2 eq)	730	88.9	6.56	5.52	629
Acidification (kg SO_2 eq)	5.30	0.486	0.0405	0.0174	4.76
Eutrophication (kg PO_4 eq)	0.191	0.0291	0.00160	0.00380	0.157
Photochemical oxidation (kg ethylene eq)	0.295	0.0408	0.00372	0.00253	0.248
Ozone layer depletion (kg CFC-11 eq)	$1.59\ 10^{-4}$	$5.65\ 10^{-6}$	$7.05\ 10^{-7}$	$2.86\ 10^{-7}$	$1.53\ 10^{-4}$
Production of hazardous waste (kg)	7.60	5.57	0.108	0.00407	1.92
Total waste production (kg)	2600	222	13.4	10.3	2360

Click on a cell to access more detailed results for the selected life cycle phase and impact indicator (e.g. Manufacture-Climate change)

Figure 78. First level Matrix with indicators

Results obtained from the analysis of the reference cooker hood are shown in the Figure 78 and confirm the ones obtained in the preliminary environmental analysis realized with Eco Audit. The most impacting phase is the use phase, which represents the main criticality for the product and therefore the first aspect to deepen analyse during the redesign phase.

3.5 Hotspots identification and related solution strategies

At this stage, after the identification of the main product environmental hot spots by the use of the Eco Audit tool and the analysis in details of the use and EoL phase it has been possible to identify all the main criticalities affecting the current cooker hood.

As it was already clear from the initial Eco Audit analysis, **one of the improvement areas can be found in the use phase, due to the energy-consuming components: the electric motor and the halogen lamps.** Those components induce a high energy consumption, and consequently, high CO_2 emissions and elevated costs.

Another issue can be related to both the disassembly and the EoL, characterized by a miscellaneous spectrum of components, made by different materials, even with some contaminations.

Starting from the above considerations and thanks to the useful analysis conducted by the use of the G.EN.ESI platform, the FABER company has investigated useful interventions to improve the product environmental behavior of its product and have used the same G.EN.ESI tools to quantify the improvement obtainable and to confirm the effectiveness of these solutions.

From the criticalities identification and in order to define possible solution strategies the CBR tool, developed by the UNIVPM was used (Figure 79). This tool aims to support the designer in the product development phase, taking into account the Ecodesign guidelines and company knowledge beside the standard design criteria. The tool collects ecodesign and company's knowledge and facilitate the search of solutions for a specific objective to reach. Once the user has opened it and has chosen the desired component from the "tree" to the left (retrieved from the XML file), he should select the product family, the functional group from the cascade list to which the product he is analysing belong. Then he has to select the standard component for which he wants to search eco design guidelines.

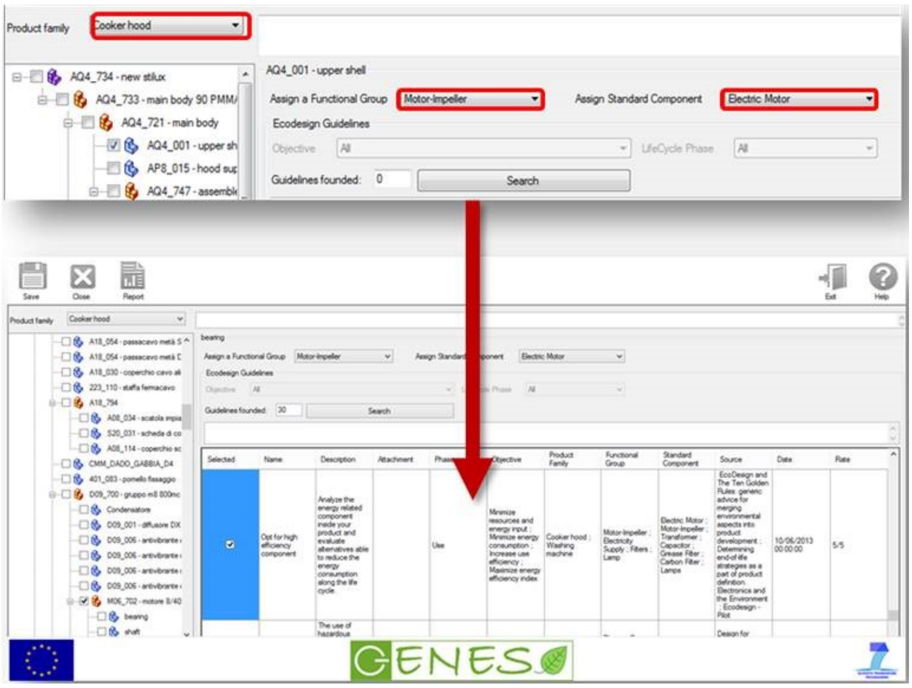


Figure 79. Main CBR interface

Automatically the software gives back the suggestions for possible improvements.
According to the criticalities identified and to the components to optimize, the tools has provided some general suggestions:

- Reduction of the energy consumption;
- Reduction of components (where it is possible), reducing weight without losing structural capacity;
- Promote the use of recyclable (and recycled) materials;
- Standardization of the materials. Try to use as less as possible different material with different manufacturing process, and different EoL treatments; try to avoid contaminations as the glued glass;
- Optimize the disassembly phase, in order to reduce the disassembly time, cost and various inefficiencies. Try to use quick release systems to avoid the use of particular tools.

These general suggestions allow designer to understand where focus his attention to improve the product. Other more specific suggestion try to provide some possible solution to adopt to reach the fixed objective; some of the most relevant were:

- Use energy using components characterized by high efficiency;
- In the case of electric motors consider that in general brushless motor are characterized by a higher efficiency in comparison with induction motor. Even if they have a higher

initial cost, considering their entire life cycle it guarantees a minor energy consumption and a minor cost;

- In the case of light system, consider that LED lamps have in general a longer life cycle and a minor energy consumption if compared with halogen lamp typology. Even if they have a higher initial cost, considering their entire life cycle it guarantees a minor energy consumption and a minor cost;
- In order to improve the disassembly of the product:
  - uniform the typology of connections used in the product
  - prefer rapid joint to screw
  - avoid the use of screw
  - avoid the use of glue to connect components
- Consider the material compatibility for plastics and metals. Avoid the use of non-compatible materials in the same component.

Based on these guidelines, the FABER company has defined possible solution strategies.
All the guidelines retrieved from the CBR tools were very intuitive and easy to comprehend. It is important to underline that they are general, due to the fact they have been retrieved from the literature. The definition of improvement strategies for the product will allow to define specific and company-oriented guidelines which will be more specific and directly related to the cooker hood product.

3.6 Redesign hypothesis

Starting for the result analysis and the CBR suggestion, the following components have been subjected to some revisions, in terms of shape, materials and even a complete substitution of some parts:

- Consumption's Optimization (Motor & Lamps)
- Easy-cube
- Blower
- Electronic components
- Material: frontal glass

3.6.1 Consumption's Optimization (Motor & Lamps)

The major efforts have been firstly put in the consumption's optimization, since the environmental emphasis is totally in the use phase. In fact, it has the largest impact due to the large energy consumption that characterize it. For this reason, investigations have been performed on those components that are strictly related to this result.
The energy-consuming components in the use phase are the electric motor and the lamps. Among these, the first one has the higher consumption.
The motor of the reference product was an asynchronous single-phase induction motor with a capacitor. The electric motor assembly is composed by a steady part called stator, and a rotating part called rotor. Both of these parts are composed by a series of thin steel made layers,

pressed on each other. In the rotor, those layers have a ring-shape and they are “trapped” inside an aluminium cage (squirrel-cage). Usually, the squirrel cage in the rotor is made out of die casting Aluminium, in order to ensure high mechanical strength and lightness.

In the stator instead, those layers provide channels for the induction coil. The rotating shaft goes through the rotor and it is paired with the stator thanks to two bearings located at the edges. Between the rotor’s external surface and the stator’s external surface, a little gap is present to let the rotor freely to rotate. There are two different induction coils. The main one is used during the operation time, while the second one is used to start the motor. The motor is equipped with a small start capacitor. Capacitors are found on single-phase motor and are used for starting and running the motor**. These motors are characterized by low price, high reliability and robustness. On the opposite, they have many losses that makes them not very efficient**.

In order to reduce CO2 and energy consumption, a more efficient motor must replace the current device. **The option that has been considered was a brushless motor**. Brushless motors are characterized by:

- No friction for the electric contacts;
- No electromagnetic noise due to the absence of brushes;
- Longer operation time;
- Less mechanical and electromagnetic losses;
- No risk of ignition spark at high speed;
- Low maintenance;
- High efficiency at different speed level;
- Higher efficiency;
- Low heat generation.

Of course as a drawback they are characterized by high cost due to the electronic device needed to control it. The power rate of the Brushless motor is lower than the one from the induction motor. In fact, thanks to a higher efficiency, the brushless motor is able to guarantee the same airflow, with a lower power rate. In short, it is able to ensure the same output in term of suction capacity, with a lower energy demand.

In order to optimize the use phase, the FABER company has decided to opt for a brushless motor (Figure 80).

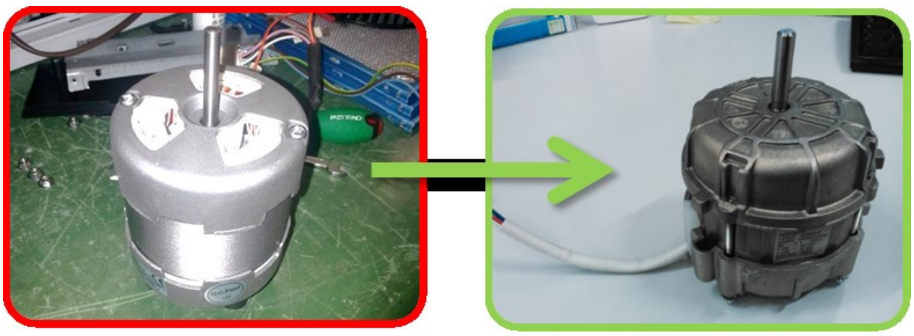


Figure 80. Asynchronous single-phase induction motor vs brushless motor

The same thinking has been replied for the lamps.

The reference STILUX had two halogen lamps (20W). There are different variables that must be considered in the choice of lamps:

- Watt consumption (must be lower)
- Light intensity [Lumen] (must be equal or higher)
- Price (must be lower)
- Operating time (must be higher)

Halogen lamps are characterized by high consumption and short operating time. The most suitable solution was represented by LED lamps. In order to get almost the same light intensity (lumen), only 1 or 2 W LED lamps are needed. Those lamps are characterized by a longer operation time. The only drawbacks, is their cost, as for the electric motor.

In the wide range of possibilities, the FABER company has chosen the new technology of Eco-Led (Figure 81).

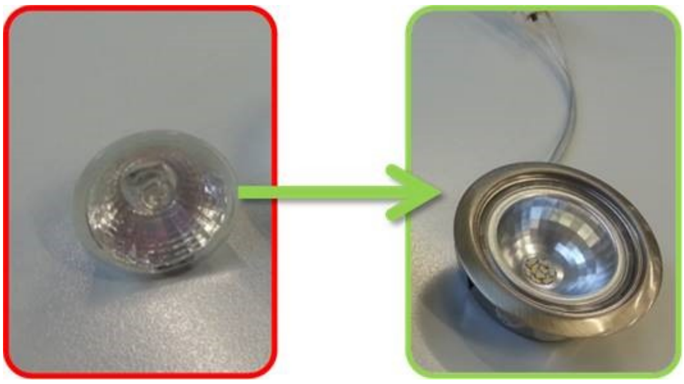


Figure 81. Halogen lamp vs EcoLed

3.6.2 Easy Cube

For the optimization of the EoL phase, and in particular of the disassembly phase, the FABER company has put the attention on the Blower assembly, trying to find a way that would allowed to remove it more quickly and possibly with no tools.

First of all, the FABER company proceeded to a standardization of the different screw types, abolishing the Torx for the Philips. Furthermore, in the reference cooker hood, the connection between the blower and the Easy-cube was realized by a pair of screws (Figure 82).

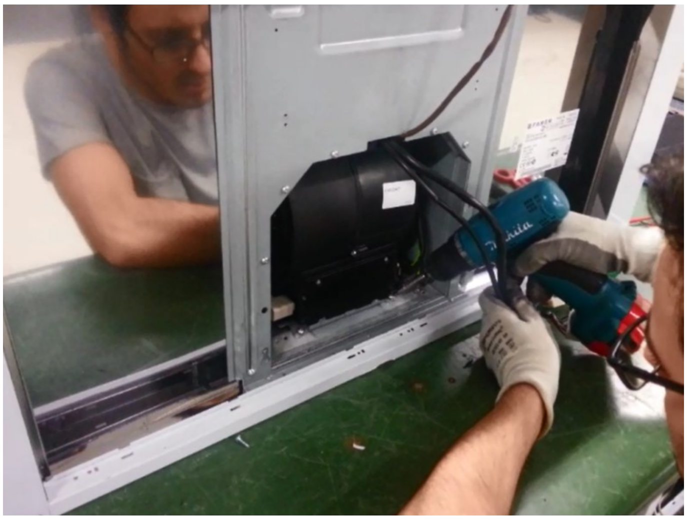


Figure 82. Blower removal with the help of the screwier (reference cooker hood)

The solution has been found in this quick release system, a new conception pair of rapid rotating joints that enable to a faster removal, just using hands (Figure 83).

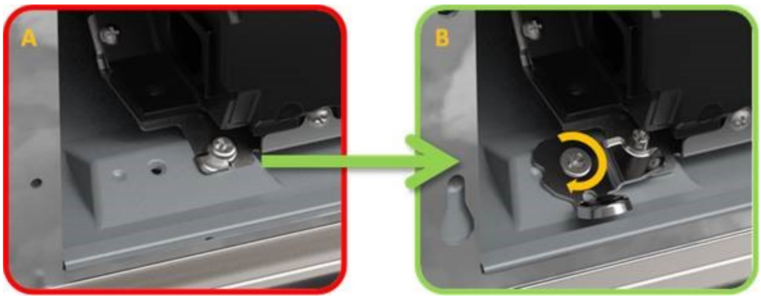


Figure 83. Comparison of solutions, screws vs rapid rotating joints

3.6.3 Blower

The blower optimization has concerned the selection of an effective way to connect the two plastic casings without screws. **The five connecting screws have been replaced by five rapid interlocking steel clips, which they may be removed with the aid of a simple flat-blade screwdriver, leading to a reduction of disassembly time** (Figure 84).

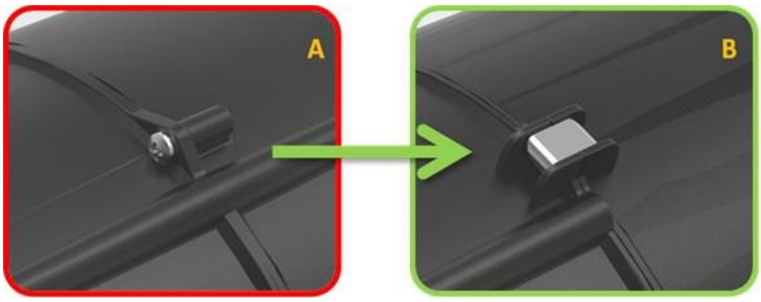


Figure 84. Comparison between screw and rapid interlocking steel clip

Figure 85. Focus on the butterfly nuts

Another improvement from the disassembly point of view has been made changing the four nuts constraining the motor to the blower case, with four butterfly nuts, removable just by hands (Figure 85).

3.6.4 **Electronic Components**

About the electronics, the adoption of the brushless motor brought to a consequent cut-off of the required electronic components, like the capacitor and the network filter, the one highlighted by a red circle in Figure 86. Moreover, the new type of electronic controls also led to the substitution of the toroidal filter with an electronic one and the two distinct PCBs with the only one, called Athena Light.

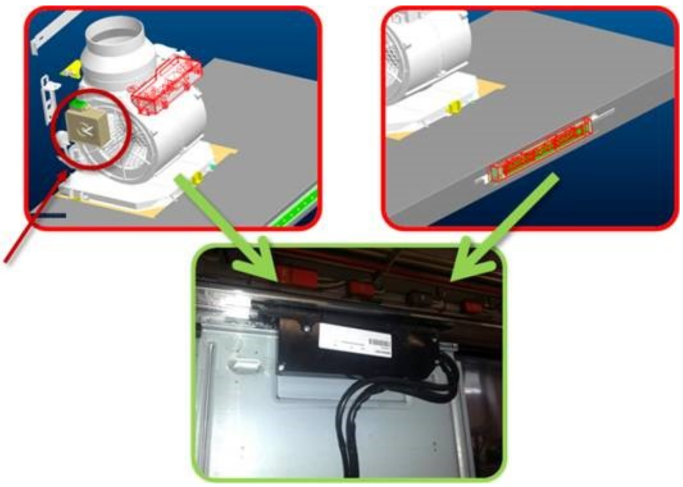


Figure 86. New solution called Athena Light

In the following Figure 87 is shown the benefit given by the substitution of the toroidal filter (about 600 grams of copper) with an electronic one.

Figure 87. Toroidal vs Electronic filter

Regarding the disassemblability, Athena Light has allowed to obtain a considerable reduction of the time required for assembly and disassembly of the entire cooker hood as will be shown in the next paragraphs.

The plastic box that encloses the PCB has been also realized using the technique of Design for Disassembly; it is in fact connected to the structure of the metal cloak by two quick joints: one acts as the hinge pin and the other, the type of snap-fit, allows the fixing (Figure 88).

Figure 88. The way of removing Athena Light

All of these changes carried out to the new configuration shown in Figure 89.

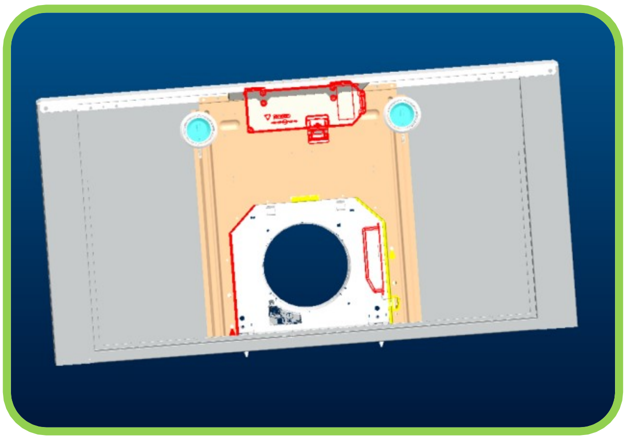


Figure 89. The inner part of the Easy-Cube for the redesigned cooker hood

3.6.5 Material: Front Glass

Another important improvement is related to the glued glass of the front panel, already highlighted as a criticality by LeanDfD within the EoL analysis. This part did not allow any kind of removal, due to the high gluing capacity of the adhesive connection that is present in the reference cooker hood model.

Contacting different suppliers, **FABER founded a proposal of a plastic material, the PMMA**, lighter than glass, but with the same transparency properties and the same possibility to obtain an identical glossy finish. This solution has allowed to avoid the glued connection.

3.7 Re-design results

The identification of the solution strategies was performed in an iterative process. All the possible solution strategies were in fact analysed with the G.EN.ESI tools in order to verify their effectiveness or not and to quantify the possible benefits obtainable. For clarity in the previous and following paragraphs only the final redesign solutions their analysis are presented.

As a regard the analysis of the redesigned prototype with the G.EN.ESI tools, this is illustrated with the same order of the previous analysis (for the reference cooker hood). Comparisons and improvements of the reference and redesigned cooker hood are shown in the following paragraphs.

3.7.1 Eco Material

The results obtained with the Eco Material tool are shown in Figure 90 and Figure 91, that shows respectively the consumption in [MJ * 10^3] and the carbon footprint [Kg of CO2] related to the reference cooker hood and to the redesigned one. This Eco Audit result summarizes quickly and easily how the hotspots present in the reference version of the cooker hood have been improved, especially the use-phase and the EoL potential. Regarding the use phase the substitution of the induction motor with the brushless ones, has determined a significant reduction of environmental impact, both in terms of CO2 and Energy. Regarding the EoL phase it may be possible to notice that there is an overall reduction, as a reflection of the substitution of the glued glass with the new solution of PMMA, which however corresponds to a more delicate manufacturing process.

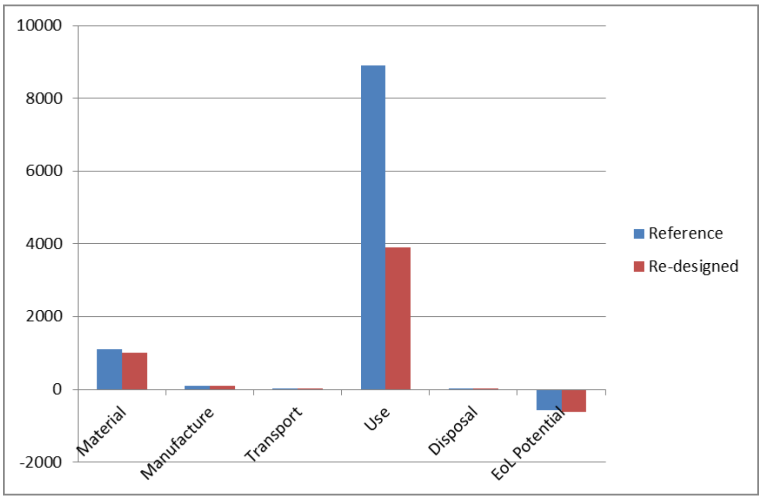


Figure 90. Comparison between the reference cooker hood vs the re-engineered one in term of energy consumption

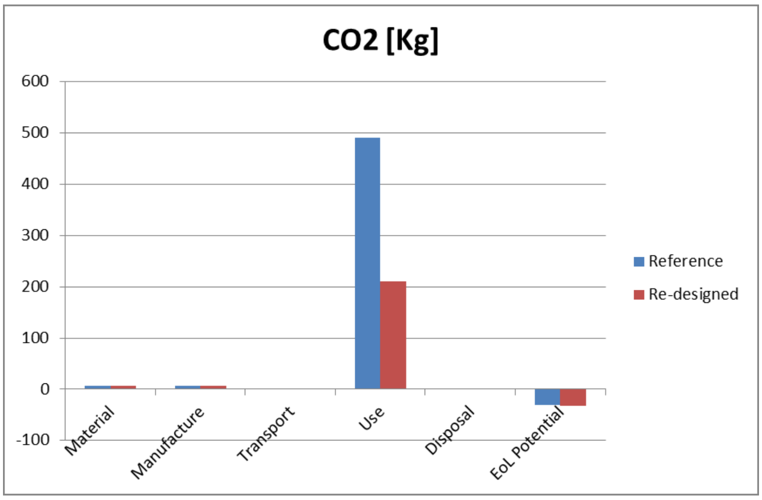
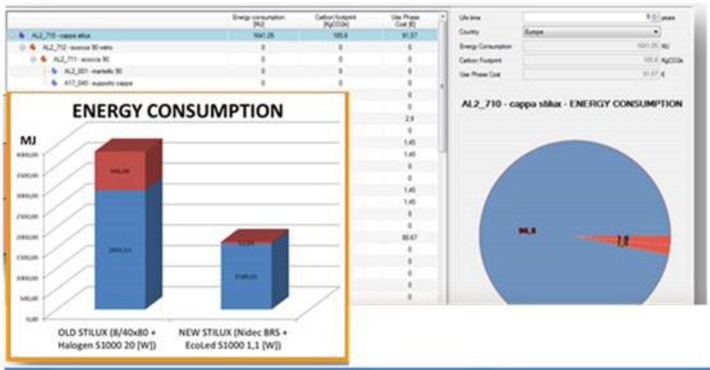


Figure 91. Comparison between the reference cooker hood vs the re-engineered one in term of CO2 emissions

3.7.2 DfEE

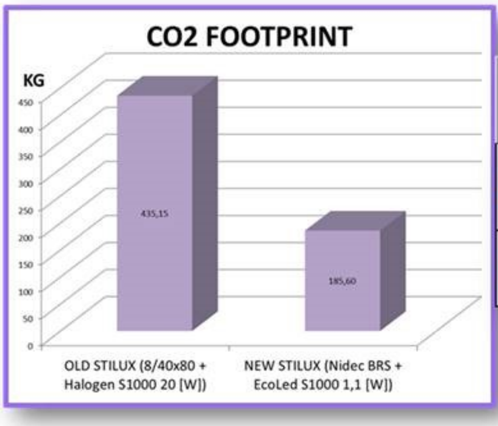
Simplified Use-Phase Scenario

For the re-designed cooker hood, thanks to the brushless motor and the Eco-Led, it has been possible to obtain a strong reduction in the energy consumption. The analysis was conducted with the DfEE tool and shown positive results visible in the following Figure 92, Figure 93, and Figure 94.



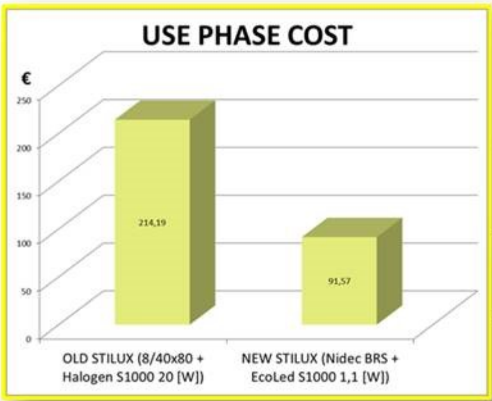
Energy consumption [MJ]			
Comparison	Motor	Lamps	Total
Reference Stilux cooker hood	2892,53	946,08	**3838,61**
Redesigned Stilux cooker hood	1589,01	57,03	**1646,04**

Figure 92. Comparison between reference cooker hood version vs the re-engineered one in terms of energy consumed during the use phase (simplified use-phase scenario)



	CO_2 FOOTPRINT [$KgCO_2e$]
OLD STILUX (8/40x80 + Halogen S1000 20 [W])	435,15
NEW STILUX (Nidec BRS + EcoLed S1000 1,1 [W])	185,60

Figure 93. Comparison between reference cooker hood version vs the re-engineered one in terms of CO2 footprint of the use phase (simplified use-phase scenario)



	USE PHASE COST [€]
OLD STILUX (8/40x80 + Halogen S1000 20 [W])	214,19
NEW STILUX (Nidec BRS + EcoLed S1000 1,1 [W])	91,57

Figure 94. Comparison between reference cooker hood version vs the re-engineered one in terms of costs related to the use phase (simplified use-phase scenario)

Realistic Use-Phase Scenario

Also the analysis of the realistic scenario has been done once the cooker has been redesigned. The realistic scenario implies that the cooker hood have different working points, and for each of them it is necessary to specify the duration, according to the company data (Figure 95). Once it has been done both for the brushless motor and the Eco-Leds, the tool provides the results for the re-designed cooker hood.

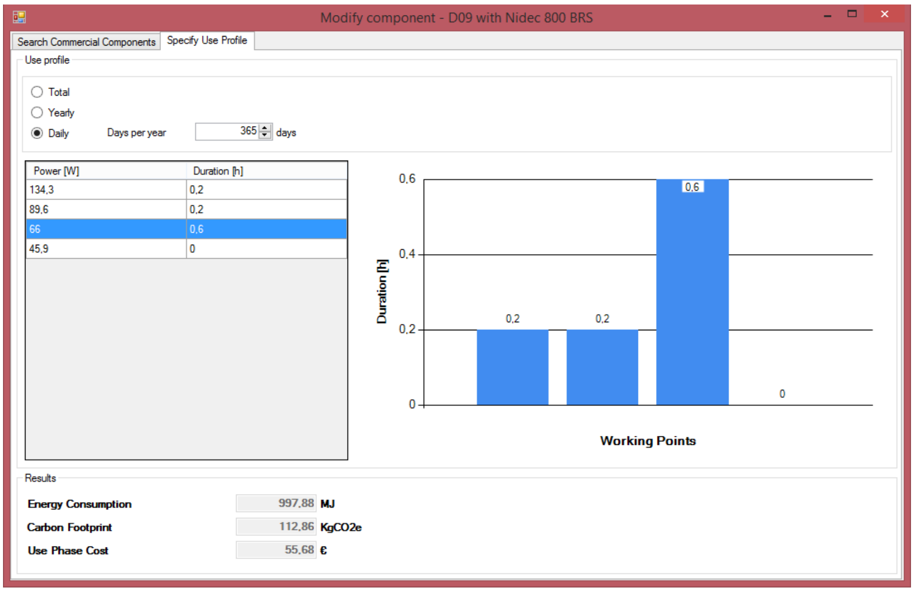
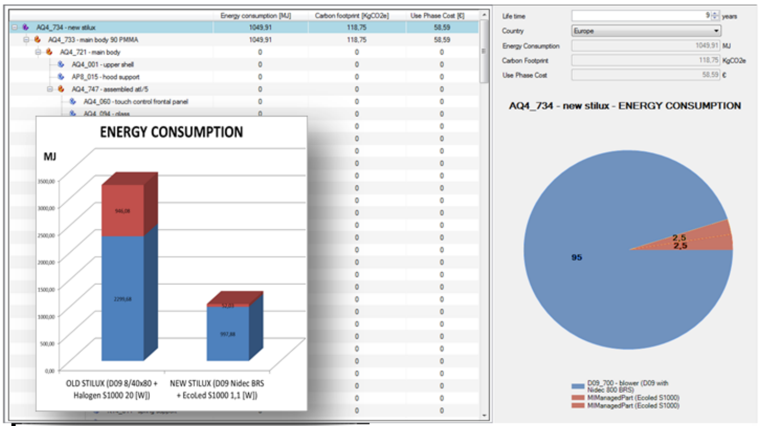


Figure 95. Realistic use-scenario _ Nidec motor working points over their time-durations

In Figure 96 , the results-comparison in terms of Energy Consumption for re-designed cooker hood vs the reference one, applying the realistic use-phase scenario.

The Realistic use scenario is characterized by a lower energy consumption in comparison with the simplified one. The same scenario with the re-designed cooker hood, which uses a brushless motor, reflect an even better energy consumption. In fact a brushless motor is good to work at lower velocities.

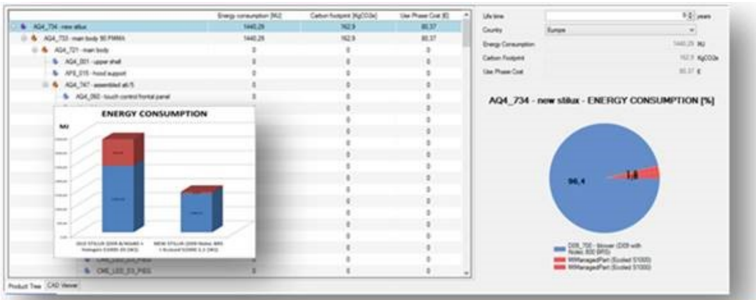


Energy consumption [MJ]			
Stilux cooker hood	Motor	Lamps	Total
	2299,8	946,08	**3245,76**
Redesigned Stilux cooker hood	997	52,03	**1049,91**

Figure 96. Comparison between reference cooker hood version vs the re-engineered one in terms of energy consumed during the use phase (realistic use-phase scenario)

3.7.2.1 Energy Label Use-Phase Scenario

In the same way the results for the last energy label scenario have been calculated. Also in this case, the use of brushless motor and ecoLed lamps, has determined a significant reduction in environmental impacts (Figure 97).



Energy consumption [MJ]			
	Motor	Lamps	Total
Stilux cooker hood	2369,6	946,1	**3315,7**
Redesigned Stilux cooker hood	1388,2	52,03	**1440,2**

Figure 97. Comparison between reference cooker hood version vs the re-engineered one in terms of energy consumed during the use phase (energy label use-phase scenario)

3.7.3 LeanDfD

DfD Module

In the following, the analysis of the EoL phase is presented for the redesigned version of the cooker hood. Both the disassembly and recyclability analysis have been performed to evaluate and quantify the benefits obtainable by the improving solutions adopted in the cooker hood.

STAGE 1)

The target components selection process is still the same as before. These components are summarized in Table 12:

Table 12 - Re-designed cooker hood target components

Selection criterion	Component
Critical components	Electric motor
	System control PCB
	Electronic transformer
Components to keep or substitute	EcoLed (x2)
	Blower
Basic layout components	Metal cloak

Looking at this table, it is possible to notice that the implementation of the new electronic control system with Athena Light together with the alternative brushless motor, have decreased the target components from 10 to 6, thus simplifying the system.

STAGE 2)

Regarding the layers structure and the definition of the precedencies, similarly to the previous case with the reference cooker hood, two different files to build up the analysis have been used. This occurred because otherwise it won't be possible to reach the electrical transformer, inside the Easy-Cube, during the disassembly. Anyway, the lower number of components allowed to a lower number of levels in the structure.

STAGE 3)

In this stage all the liaison present in the components interested in the analysis have been defined in the tool. Except for the two rapid rotational joints, which have been modelled as "rapid joint" class and "dap joint" type, with manual removal, all the others maintained the same configuration of the reference cooker hood.

STAGE 4)

The graph below shows a comparison between the disassembly times for the reference cooker hood and the ones for the re-designed model. Only the possible components to be compared have been reported in the graph in Figure 98. It is possible to notice a general decrease in terms of disassembly times for almost all the considered components, except for the two Eco-Led, due to their way of removal, different from the previous case in which was enough to remove two screws to have a direct access to them (Figure 98).

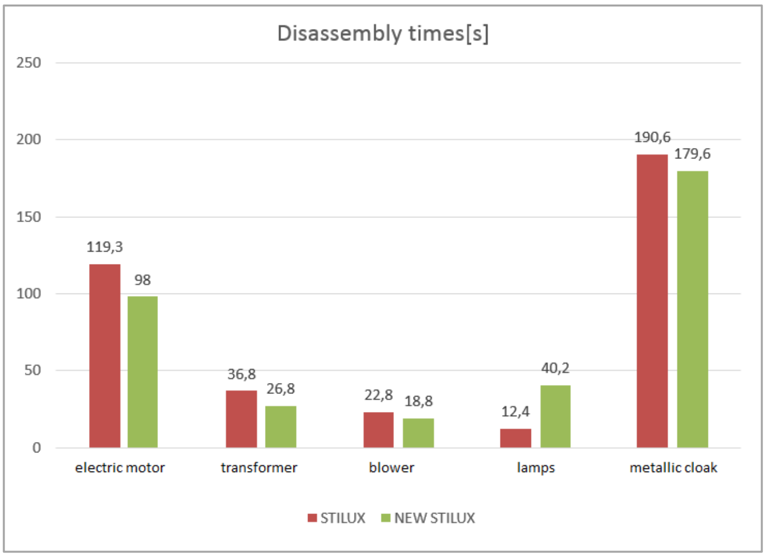


Figure 98. Comparison between reference cooker hood version vs the re-engineered one in terms of disassembly of critical components

As it is possible to see from the Figure 99, the adoption of the rotating quick-release screws, in place of the normal screws, also involves a time removal reduction for the entire blower assembly, which is the core of the cooker hood.

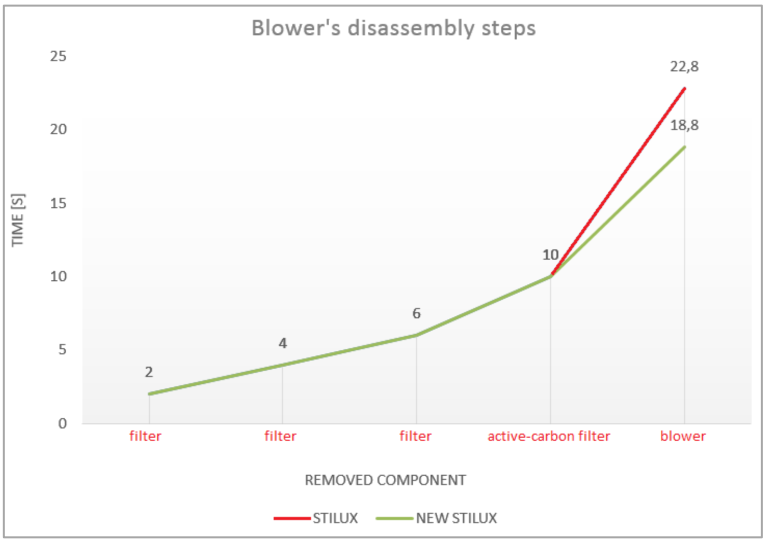


Figure 99. Comparison between reference cooker hood version vs the re-engineered one in terms of disassembly of the blower functional group

EoL Module

STAGE 1)

The introduction of PMMA and the study of its incompatibilities were the two differences analysed in this step. PMMA cannot stay in contact with PP and it is partially compatible with PA and POM, but does not matter, because it is possible to remove it manually.

STAGE 2)

No modification in comparison with the reference cooker hood from the metal contamination step, which is the same as the previous case.

STAGE 3)

If no changes are preset within the metal contamination, a great improvement has been made for this step. The new solution of the PMMA front panel, connected with some rapid joints, allowed to overcome one of the criticalities of the reference cooker hood.

But the glued support for Athena Light is still present.

STAGE 4)

The new global RI (recyclability index), calculated by the tool, has been increased by about 6 percentage points (Figure 100). A substantial contribution regard the metal cloak together with the frontal panel, as it is easy to figure out.

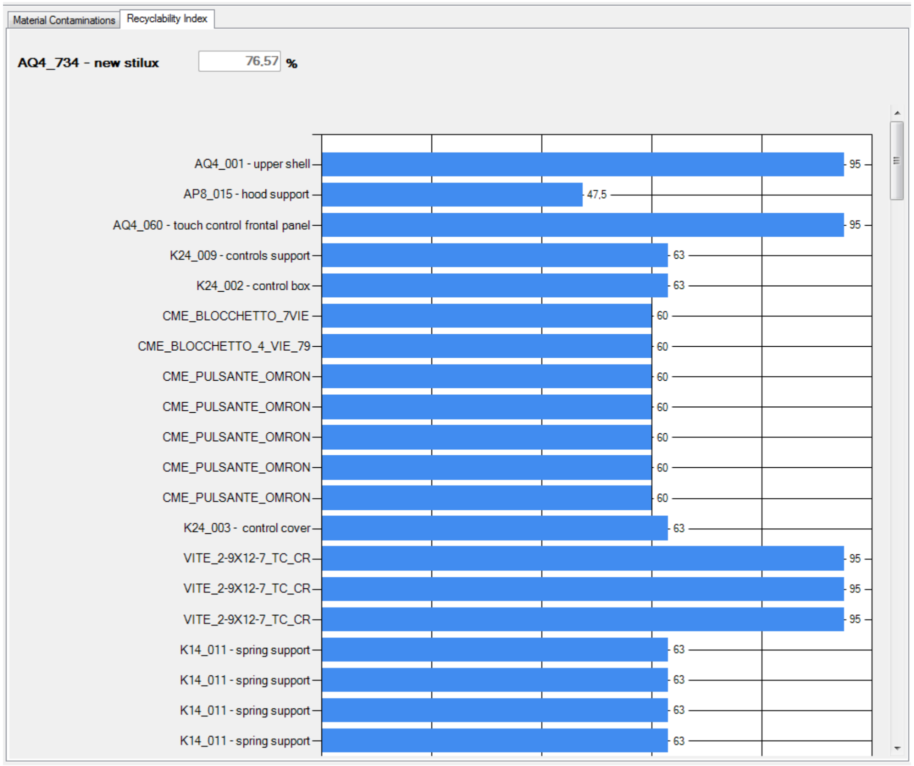


Figure 100. Re-designed cooker hood new recyclability index

Thus, in summary, with a cleverer selection of materials, as PMMA instead of glued glass, plastic compatibilities and contaminations, it has been possible to increase the recyclability index of the cooker hood of about 6 percentage points (Figure 101).

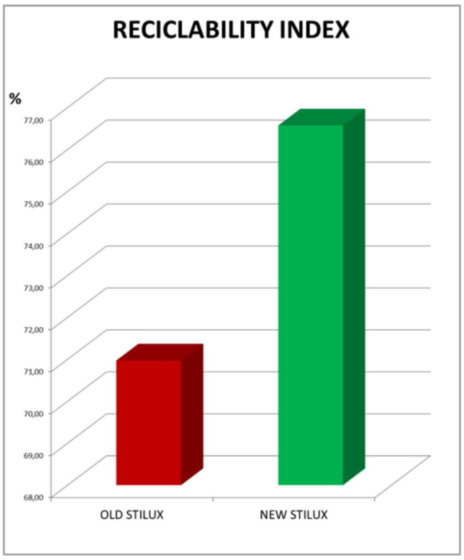
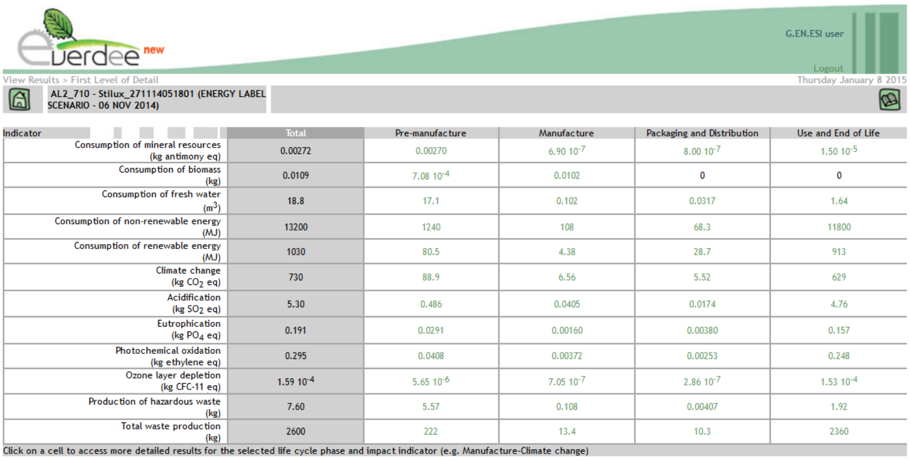


Figure 101. Comparison between reference cooker hood version vs the re-engineered one in terms of recyclability index

3.7.4 eVerdEE

Here the confrontation of the two different studies with eVerdEE (Figure 102 and Figure 103) are presented.



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G.EN.ESI user — Logout

AL2_710 - Stilux_271114051801 (ENERGY LABEL SCENARIO - 06 NOV 2014)

Indicator	Total	Pre-manufacture	Manufacture	Packaging and Distribution	Use and End of Life
Consumption of mineral resources (kg antimony eq)	0.00272	0.00270	$6.90\ 10^{-7}$	$8.00\ 10^{-7}$	$1.50\ 10^{-5}$
Consumption of biomass (kg)	0.0109	$7.08\ 10^{-4}$	0.0102	0	0
Consumption of fresh water (m^3)	18.8	17.1	0.102	0.0317	1.64
Consumption of non-renewable energy (MJ)	13200	1240	108	68.3	11800
Consumption of renewable energy (MJ)	1030	80.5	4.38	28.7	913
Climate change (kg CO_2 eq)	730	88.9	6.56	5.52	629
Acidification (kg SO_2 eq)	5.30	0.486	0.0405	0.0174	4.76
Eutrophication (kg PO_4 eq)	0.191	0.0291	0.00160	0.00380	0.157
Photochemical oxidation (kg ethylene eq)	0.295	0.0408	0.00372	0.00253	0.248
Ozone layer depletion (kg CFC-11 eq)	$1.59\ 10^{-4}$	$5.65\ 10^{-6}$	$7.05\ 10^{-7}$	$2.86\ 10^{-7}$	$1.53\ 10^{-4}$
Production of hazardous waste (kg)	7.60	5.57	0.108	0.00407	1.92
Total waste production (kg)	2600	222	13.4	10.3	2360

Click on a cell to access more detailed results for the selected life cycle phase and impact indicator (e.g. Manufacture-Climate change)

Figure 102. Results obtained for the reference cooker hood

G.EN.ESI user

Logout

View Results > First Level of Detail — Thursday January 8 2015

AQ4_734_ROB (STILUX NEW VERSION - ENERGY LABEL SCENARIO - 01 DEC 2014)

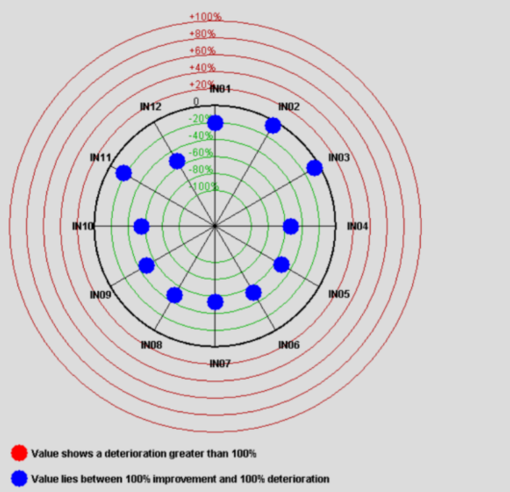
Indicator	Total	Pre-manufacture	Manufacture	Packaging and Distribution	Use and End of Life
Consumption of mineral resources (kg antimony eq)	0.00215	0.00214	$7.04\ 10^{-7}$	$7.98\ 10^{-7}$	$6.41\ 10^{-6}$
Consumption of biomass (kg)	0.0104	0	0.0104	0	0
Consumption of fresh water (m^3)	17.7	16.9	0.104	0.0317	0.702
Consumption of non-renewable energy (MJ)	6240	1010	112	67.6	5050
Consumption of renewable energy (MJ)	493	70.0	4.66	28.7	390
Climate change (kg CO_2 eq)	359	77.7	6.81	5.48	269
Acidification (kg SO_2 eq)	2.51	0.416	0.0423	0.0172	2.03
Eutrophication (kg PO_4 eq)	0.0997	0.0273	0.00166	0.00375	0.0670
Photochemical oxidation (kg ethylene eq)	0.150	0.0373	0.00384	0.00251	0.106
Ozone layer depletion (kg CFC-11 eq)	$7.03\ 10^{-5}$	$3.85\ 10^{-6}$	$7.53\ 10^{-7}$	$2.86\ 10^{-7}$	$6.54\ 10^{-5}$
Production of hazardous waste (kg)	6.26	5.33	0.110	0.00407	0.820
Total waste production (kg)	1200	171	14.2	6.82	1010

Click on a cell to access more detailed results for the selected life cycle phase and impact indicator (e.g. Manufacture-Climate change)

Figure 103. Results obtained for the re-engineered cooker hood

	Indicator
IN01	Consumption of mineral resources kg antimony eq
IN02	Consumption of biomass kg
IN03	Consumption of fresh water m^3
IN04	Consumption of non-renewable energy MJ
IN05	Consumption of renewable energy MJ
IN06	Climate change kg CO_2 eq
IN07	Acidification kg SO_2 eq
IN08	Eutrophication kg PO_4 eq
IN09	Photochemical oxidation kg ethylene eq
IN10	Ozone layer depletion kg CFC-11 eq
IN11	Production of hazardous waste kg
IN12	Total waste production kg

Position on target plot calculated using formula: (CompStudyValue-RefStudyValue)/RefStudyValue x 100



Title of the Reference Study (RefStudy)	AL2_710 - Stilux_271114051801 (ENERGY LABEL SCENARIO - 06 NOV 2014)
Title of the Study being compared (CompStudy)	AQ4_734_ROB (STILUX NEW VERSION - ENERGY LABEL SCENARIO - 01 DEC 2014)

Difference between Selected Studies				
Indicator	Reference Study	Study being compared	Difference (numerical value)	Difference (percentage value)
Consumption of mineral resources (kg antimony eq)	0.00272	0.00215	$-5.65\ 10^{-4}$	-20.8%
Consumption of biomass (kg)	0.0109	0.0104	$-5.55\ 10^{-4}$	-5.0%
Consumption of fresh water (m^3)	18.8	17.7	-1.09	-5.8%
Consumption of non-renewable energy (MJ)	13200	6240	-6990	-52.8%
Consumption of renewable energy (MJ)	1030	493	-533	-51.9%
Climate change (kg CO_2 eq)	730	359	-371	-50.8%
Acidification (kg SO_2 eq)	5.30	2.51	-2.79	-52.6%
Eutrophication (kg PO_4 eq)	0.191	0.0997	-0.0916	-47.8%
Photochemical oxidation (kg ethylene eq)	0.295	0.150	-0.145	-49.2%
Ozone layer depletion (kg CFC-11 eq)	$1.59\ 10^{-4}$	$7.03\ 10^{-5}$	$-8.93\ 10^{-5}$	-55.9%
Production of hazardous waste (kg)	7.60	6.26	-1.34	-17.6%
Total waste production (kg)	2600	1200	-1400	-53.9%

Figure 104. Comparison between the eVerdEE analyses of the reference cooker hood and the re-engineered one

The matrix contained in Figure 104 shown, for each indicator, the environmental impacts of both reference and compared studies and their value and percentage difference between new and reference study (negative value/percentage indicates an environmental improvement for the new study). Thanks to the Target plot graph, it is possible to see the new study improvement scenario. Here, the percentage differences between the studies is represented for every indicator: blue spots indicate an improvement (negative difference), red spots indicate a deterioration (all positive differences).

Thus, from the above spider's web graphs and tables it is possible to conclude that eVerdEE tool allows to calculate the relevant improvements in all the indicators considered for the redesigned cooker hood.

In particular, for some indicators, as the Climate Change, the Consumption of mineral resources or the Consumption of renewable and non-renewable energy, the percentage differences between the two considered cooker hood models are very high (about 50%), since these indicators are strictly related to the lifecycle energy consumption of the cooker hood, which has been improved with the adoption of high efficient motors and lamps.

3.7.5 **Life Cycle Costs Analysis**

At the end, also a simplified cost analysis has been performed. The graph shown in Figure 105 represents the sum of the different item-costs for the two cooker hood models.

Some of the increased item-costs, for instance the brushless motor and the EcoLeds, make sense in the overall reduction of cost, because their choices reflect a better use-phase energy consumption, a better EoL scenario in terms of recyclability, and a better, although tiny, disassembly cost.

For confidentiality reasons, we could not report the values of the item costs; Figure 105 present the values in the percentage form.

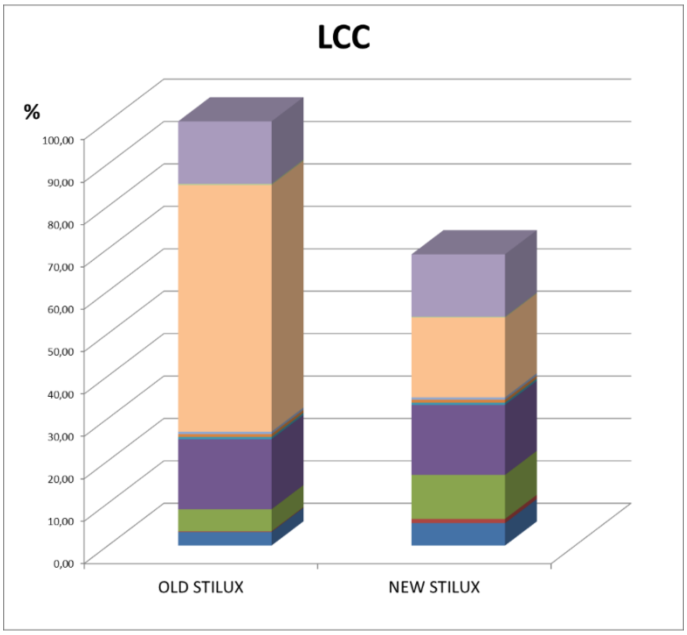


Figure 105. Comparison between reference cooker hood version vs the re-engineered one, in terms of percentage of costs for the entire lifecycle

3.8 Summary of the environmental improvements

This section aims to summarize how much has been achieved by the redesign of the cooker hood thank to the support provided by the implementation of the G.EN.ESI platform and tools during the redesign process.

For allowing the reader to have a better overview of the improvements, all of the considered indicators during the analysis among the different tools of the software platform have been reported in Table 13.

This is divided in two main columns, which represent the reference and the re-designed version of the cooker hood.

Moreover, the table has been split, according to the G.EN.ESI platform tools, in four group of rows. Each row contains some indicators that express the beneath value.

Table 13 – Summary of the environmental improvements

		REFERENCE COOKER HOOD	RE-DESIGNED COOKER HOOD
MI GRANTA	LIFE CYCLE ENERGY CONSUMPTION [MJ]	9500	4400
	LIFE CYCLE CARBON DIOXIDE EMISSION [kg of CO_2]	530	250
DFEE	USE PHASE ENERGY CONSUMPTION [MJ]	3838,61	1641,05
	USE PHASE CARBON DIOXIDE EMISSION [kg of CO_2]	435,15	185,60
	USE PHASE COST [€]	214,19	91,57
LEAN-DFD	METAL CLOAK (WHOLE COOKER HOOD) DISASSEMBLY TIME [s]	190,60	179,60
	RECICLABILITY INDEX [%]	70,97	76,57
eVERDEE	CONSUMPTION OF MINERAL RESOURCES [kg antimony equivalent]	0,00272	0,00215
	CONSUMPTION OF BIOMASS [kg]	0,0109	0,0104
	CONSUMPTION OF FRESH WATER [m3]	18,8	17,7
	CONSUMPTION OF NON-RENEWABLE ENERGY [MJ]	13200	6240
	CONSUMPTION OF RENEWABLE ENERGY [MJ]	1030	493
	CLIMATE CHANGE [kg CO2 equivalent]	730	359
	ACIDIFICATION [kg SO2 equivalent]	5,3	2,51
	EUTROPHICATION [kg PO4 equivalent]	0,191	0,0997
	PHOTOCHEMICAL OXIDATION [kg ethylene equivalent]	0,295	0,15
	OZONE LAYER DEPLETION [kg CFC-11]	0,000159	0,0000703
	PRODUCTION OF HAZARDOUS WASTE [kg]	7,6	6,26
	TOTAL WASTE PRODUCTION [kg]	2600	1200

Additionally, to go beyond the numbers, a percentage graph has been performed (Figure 106), showing all of the improvement-rates, expressed by the green columns, while the starting basis are depicted with the 100% red columns.

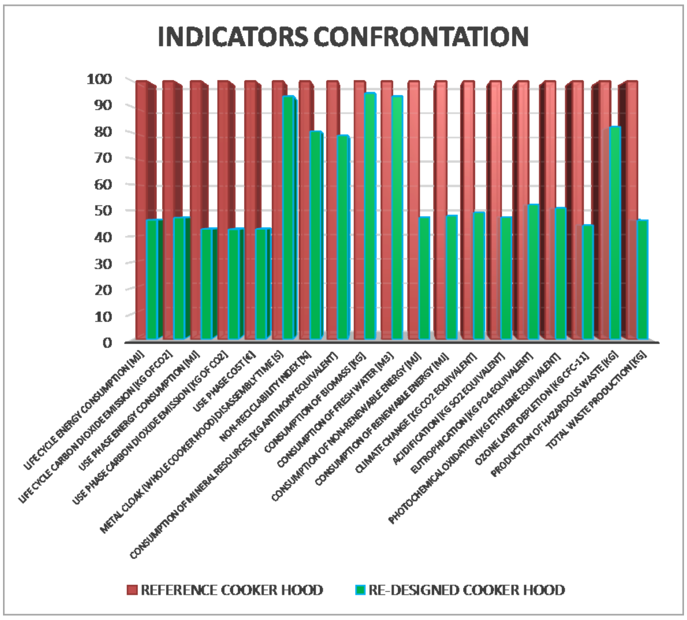


Figure 106. Indicators confrontation

3.8.1 **Prototype realization**

At the end of the redesign process, a physical prototype has been realized with the objective to understand the technical feasibility of the new solutions hypnotized. In the following the most significant images of the prototypes are shown from Figure 107 to Figure 117.

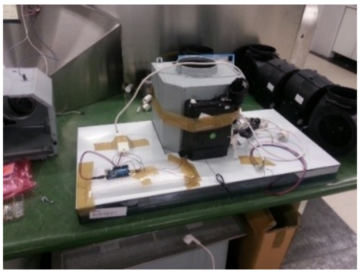


Figure 107. First version of the prototype

Figure 108. Different lamps possibilities, namely halogen, Led, EcoLed

Figure 109. The source of inspiration for the metal clips

Figure 110. Details of the metal clip

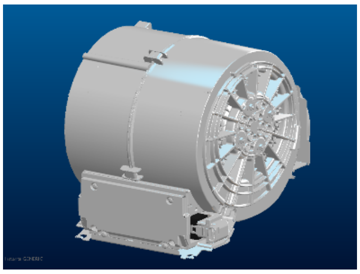


Figure 111. New blower with metal clips instead of screws and its printed version

Figure 112. New blower with metal clips and butterfly nuts

Figure 113. Drilling of the metal support for the new PMMA glass

Figure 114. Nuts hand-fixing over their plastic screws

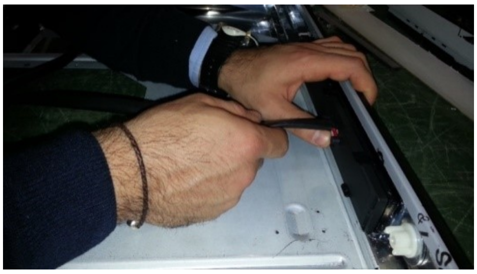


Figure 115. Final assembly of the new PMMA glass and electronic controls with their metal support

Figure 116. Focus on Eco-Led and the inside of the Easy-Cube

Figure 117. The complete prototype

3.9 GENESI SOFTWARE PLATFORM EVALUATION

At the end of the implementation of the G.EN.ESI Platform in the FABER company, its usability has been evaluated. Also the level of integration of the platform tools with those ones traditionally used inside the company has been evaluated.

The purpose of this evaluation is to analyse the usability reliability and repeatability of G.EN.ESI tools, to verify the robustness of the G.EN.ESI ecodesign platform, to understand the limits and the possible improvements. For this reason, usability questionnaires have been developed for each tool with the aim to be filled in by the selected users during the test of the platform.

3.9.1 Usability: definition and approached used

The G.EN.ESI platform is composed by a series of independent but interoperable design tools used for specific purposes along all phases of the life-cycle. In order to fully exploit the potentiality of the platform, it needs to be installed in the company system. Because of the heavy impact on the design process that may be due to the implementation of the GENESI platform, it is very important to consider its usability and user friendliness.

Among the most popular rules in literature, the Nielsen Heuristic rules (Nielsen, 1994) have been chosen as metric for software usability assessment. Nielsen's heuristic rules aim at evaluating the usability of the software, considering ten different abstract features. Those features require to be translated into quantifiable metrics in order to obtain a quantitative mark for the usability of the platform. This mark is related to the level of the acceptance from the user perspective. It is important to state that these rules aim to test the "usability in use", thus, even if it is considered as a usability inspection method, in our case, users will be asked to give feedback after they have experienced the real use of the system/tool. Rules derived from the Nielsen Heuristic rules are used for our assessment to fit our specific case. In the followings a description of the 12 retained rules is presented:

- **Compatibility**: the way the system looks and works should be compatible with user conventions and expectations;
- **Consistency & Standards**: the way the system looks and works should be consistent at all times;
- **Error Prevention & Correction**: the system should be designed to minimize the possibility of user error, with inbuilt facilities for detecting and handling; users should be able to check their inputs and correct errors or potential error situations before the input is processed;
- **Explicitness**: the way the system should work is structured and should be clear to the user;
- **Flexibility & Control**: the interface should be sufficiently flexible in structure, in the way information is presented and in terms of what the user can do, to suit the needs and requirements of all users;

- **Functionality**: the system should meet the needs and requirements of users when carrying out tasks;
- **Informative Feedback**: the system should always keep user informed about what is going on through appropriate feedbacks within reasonable time;
- **Language & Content**: the information conveyed should be understandable to the targeted users;
- **Navigation**: the system navigation should be structured in a way that allows a user to access support for a specific goal as quickly as possible;
- **Privacy**: the system should help the user to protect personal or private information belonging to the user or their clients;
- **User Guidance & Support**: informative, easy-to-use and relevant guidance and support should be provided to help user understand and use the system;
- **Visual Clarity Description**: information displayed on the screen should be clear, well-organized, unambiguous and easy to read.

Each rule takes into account a specific aspect of the tool usability. From this heuristic approach we have formulated questions for the GENESI platform users in order to transform qualitative information in quantitative ones. In practice a set of question for each rule has been prepared. Each question has three possible options (from a low to a high level) ranking the tool usability and acceptance. The questionnaire has been submitted to users (from FABER and VECTRON design office) of the platform after their familiarization with it.
Specific questionnaires have been developed for the evaluation of the G.EN.ESI tools usability according to the twelve rules identified and presented in the previous chapter. These questions allows user of a given tool to evaluate quantitatively some parameters of the tool under usage. Two different typologies of questions have been derived:

- **General**: the user provides an overall opinion on a metric (example for the compatibility rule: *When you open the tool, it is clear what steps you can/should perform*);
- **Specific**: the user provides an opinion on a specific aspect of a metric (example for the compatibility rule: *The tool is aesthetically pleasing to the user*).

This approach has been chosen to obtain some general opinion about the specific metrics chosen. This allows the software developers to understand if globally the tools satisfy the user expectations or not. The following ranking criteria have been chosen for the quantification of the user's opinions:

- **Disagree** (*score* = *3*): the tool does not meet minimal requirements indicated in the question and have to be modified and improved;
- **Undecided** (*score* = *6*): the tool meets minimal requirements indicated in the question, however further improvements may be useful;
- **Agree** (*score* = *9*): The tool fully satisfies the requirements indicated in the question.

The scores given by the users for each question have been summarized in a single value to compare the results of each user and for each tool. To do this comparison, a weight for each metric [1 ÷ 3] has been defined in accordance with the software developers and the company involved in the test. In particular, the metrics "*Consistency and standards*", "*Error Prevention and Correction*", "*Functionality" and "Privacy*" have been weighted with a value of 3, "*Compatibility*", "*Explicitness*", "*Flexibility and control*", "*Informative Feedbacks*", "*Navigation*" with a weight of 2 and "*Language and Content*", "*Visual Clarity Description*" with a weight of 1. The formula used for this evaluation is defined in Equation 10:

$$\text{Average Overall Usability Score} = \frac{\sum_{i,j} w_i \cdot r_{i,j}}{\sum_i w_i}$$

Equation 10. Average usability score

where w_i is the weight of the *i-th* metric, $r_{i,j}$ is the rank of the *i-th* metric for the *j-th* question.
In accordance with the scores the user can provide for each question, three levels of user satisfaction have been defined. From 3 to 6, the usability is not sufficient: several problematic aspects arose and therefore some important improvements needs to be applied to the tools to make them applicable and usable within an industrial context. From 6 to 8, the user is fairly satisfied, even if he proposes some recommendations to solve the most important issues. At last, from 8 to 9 an excellent satisfaction is recognized. No important issues have been recognized, so that the platform and its software tools are ready to be used within a company. In order to facilitate the questionnaire exploitations the questions have been inserted in an Excel spreadsheet. Each sheet contains a specific questionnaire related to a specific tool of the G.EN.ESI platform. The completed usability questionnaires are composed of a unique Excel file containing 7 sheets. 6 sheets are provided for the tools (CBR, DfEE, LeanDfD, Eco Material, MI: Gateway and eVerdEE tool) plus an instruction sheet, in which some notes and explanations. As an example the usability questionnaires for the DfEE tool is presented in the following Table 14.

Table 14. DfEE usability questionnaire

Questions: DfEE tool	
	1. Compatibility:
a	When you open the tool, it is clear what steps you can/should perform
b	When you open the tool, it is easy to understand how to activate a specific tool function
c	The tool icons are easily associated with the functions they perform
d	It is easy to enter all the required information through the interface
e	The tool is aesthetically pleasing to the user
2. Consistency & Standards:	

a	The search function is able to return the product stored and used by the company
b	There are no errors in the tool search function
c	There are no errors in the graphical representation of the product use profile
d	The report genrated from the analysis clearly summarises the energy consumption in the use phase, the environmental impact of the use phase and the total cost of the use phase
e	The information contained in the report provides a detailed analysis of use phase energy consumption
3. Error Prevention & Correction:	
a	The error messages displayed when incorrect data is entered are useful for the user
b	The error messages displayed when incomplete data is entered are useful for the user
c	The error messages are clear and easy to understand
d	The user is able to easily understand why errors messages appear
e	It is easy to correct incomplete or incorrect input data through the tool interface
f	The software allows the user to easily check input data before processing to minimise errors
4. Explicitness:	
a	The reason why the tool is structured in two separated parts (one on the left and one on the right) is clear for the user
b	The steps the user has to perform to begin the analysis are clear and easy to identify
c	When using the tool, the current analysis step is clear to the user
5. Flexibility & Control:	
a	The structure of the tool is flexible, allowing the user to perform the analysis steps according to his/her needs
b	The user is able to perform the analysis which he/she considers best for his/her needs
c	It is possible to update basic data stored in the database (materials, processes, related impacts, etc)
d	It is easy to update basic data stored in the database (materials, processes, related impacts, etc)
6. Functionality:	
a	The first tool output (energy consumption related to the use phase) is useful for your work and to understand product performance
b	The second tool output (carbon footprint related to the use phase) is useful for your work and to understand product performance
c	The third tool output (costs related to the use phase) is useful for your work and to understand product performance

d	The search function is able to represent your more frequent search of commercial components
e	It is possible to take into account country-specific data for machinery, equipment, etc. according to the elements contained in the tool database
f	The software is able to meet your needs
g	The software satisfies user expectations from a functional point of view
7. Informative Feedback:	
a	The tool clearly details the analysis carried out to create the output
b	A documented description of the process and analysis carried out from user input to tool output would be useful for the user
8. Language & Content:	
a	The tool functions are easy to understand and are written in a simple and direct language
b	The first tool output (energy consumption related to the use phase) is easy to understand and is written insimple and direct language
c	The second tool output (carbon footprint related to the use phase) is easy to understand and is written in simple and direct language
d	The third tool output (costs related to the use phase) is easy to understand and is written in simple and direct language
e	The tool table contents are clearly presented
f	Displaying the results as pie charts is useful to increase their readability and their comprehension
g	The language used throughout the tool is easily understandable for the user
9. Navigation:	
a	The tool structure allows the user to rapidly perform the required analysis
b	The search option is rapidly and easily identifiable inside the interface
c	The tool evaluation/calculation icons are quickly and easily identifiable inside the interface
d	The main interface icons are easy to find and accessible
e	Overall, navigation within the tool allows the user to easily and quickly access all functions
10. Privacy:	
a	The user can be confident that any company data input into the tool will be protected
b	The user can be confident that any company supplier data input into the tool will be protected
11. User Guidance & Support:	
a	The software contains guidance material which supports and helps the user to understand how it works
b	The user manual is easy for the user to understand

c	The user manual is written in a simple and direct language
d	The user manual is able to fully support the user during initial usage of the tool
12. Visual Clarity Description:	
a	All the information diplayed on the interface is clear
b	All the information displayed on the interface is well organised
c	All the information displayed on the interface is unambiguous and easy to read
13. Inter-operability and information flow:	
a	The detail of product structure improves the assessment of energy efficiency
b	The import/export function for the XML file is easy to perform
c	The import XML function within the tool operates as expected

3.9.2 USABILITY RESULT DISCUSSION

The above presented approach has been used to validate G.EN.ESI platform as a whole, through the analysis of each software tools integrated within the platform. Moreover, the integration between the G.EN.ESI platform and the company software tools has been investigated in order to catch the degree of maturity of the platform. The users involved in the usability evaluation were the same ones involved in the validation of the G.EN.ESI platform. In particular they were:

- FABER E1 (FE1): Simone - Lab engineer with ecodesign skills. Simone is a Mechanical Design Engineer (Master degree), 27 years old. He has been recruited by Faber as a lab engineer. He was fully involved in the G.EN.ESI project since the beginning of the project. He is involved in innovation product projects , such as projects linked with blower developments, noise reduction systems, lighting systems. He has a strong know-how in ecodesign and in environmental sciences, which are related to previous working experiences (e.g.: regulations). He has used all the software tools of the G.EN.ESI platform. He has actively participated during the cooker hood re-design process (facts established from feedbacks obtained from the G.EN.ESI platform).
- FABER E2 (FE2): Nicola - Mechanical engineer and designer. Nicola is an Industrial Engineer (Master degree), 26 years old. He has been recruited by Faber as a mechanical engineer. He was involved in the G.EN.ESI project during the WP4 training activities. He is involved in the development of new hoods, and cost reduction projects. He has a basic know-how in ecodesign, and in environmental sciences (related to regulations). He has mainly worked with PRO-e and used almost all the software tools of the G.EN.ESI platform.
- FABER E3 (FE3): David - Lab engineer. David is a junior mechanical engineer (Bachelor degree), 26 years old. He has been recruited by Faber as a lab engineer. He was involved in the G.EN.ESI project during the WP4 - training activities. He was

involved in defining the energy class of all the range hoods. He has a basic know-how in ecodesign, and in environmental sciences related to regulations.

- FABER E4 (FE4): Roberto - Young engineer. Roberto is a Mechanical Engineer (Master degree), 25 years old. He has been recruited by Faber as a designer and he was fully involved in the G.EN.ESI project since 4 months before now. He knows well the cooker hood product. He worked in cooperation with the Faber designers and laboratory engineers during the whole the period of the project. He has a basic know-how in ecodesign, and in environmental sciences (e.g.: regulations). He used all the software tools of the G.EN.ESI platform. He has actively participated during the cooker hood re-design process (facts established from feedbacks obtained from the G.EN.ESI platform).
- FABER E5 (FE5): Giuseppe - Young engineer. No specific information on his background and activities.
- FABER E6 (FE6): Riccardo - Young engineer. Riccardo is a student of Mechanical Engineering, first level (Bachelor), 23 years old. He had no skills concerning product design (including cooker hood) and limited know-how in ecodesign, environmental issues, recyclability (scholar level). He used the G.EN.ESI platform during his Ph.D., with a focus on LeanDfD. He worked in cooperation with Faber.

They were asked to fill in the usability test just after the usage of the platform on a real case, a cooker hood, by following the G.EN.ESI methodology. The tools under analysis have been the same ones presented in the previous sections. Each user has given his feedback only for those modules of the platform mainly used during the validation: this is the reason why Table 15 contains N/A scores.

One of the most important characteristics of the G.EN.ESI Platform is that each tool can be used separately from each other. The fact that each tool is self-contained leads to a better clearness of the context, and support intuitive operations.

It is possible to go through the user manuals with a minimum of time spent for it. Manuals are able support the user during the first use of the tool without overstraining him. The software interaction are ensured by data exchanged based on XML files. The platform access was based on a gateway. This gateway ensured the connection to the different CAD systems. A Web BoM Tool was furthermore used to enter manually all components into the system. In the case of an electrical motor with limited components the Web BoM Tool was sufficient to have a fast access to the G.EN.ESI Platform.

The G.EN.ESI Platform provides a clearly arranged software solution for the non-ecodesign experienced company. All displayed results are reduced to provide the most significant information to the user. This ensures the capacity of the development engineer to achieve the first usable result within a short time.

This usability analysis (Table 15) indicates that tool’s users have been globally satisfied with the use of the tools. It is possible to observe no usability rank value below 7.

This shows that tool's users have evaluated the usability and user friendliness of the tool platform as being good or excellent. However, it is necessity to evaluate more deeply the user's comments made on the 10 Nielsen heuristics. This will allows to identify possible usability improvements and to establish some recommendations for developers. The next section presents this analysis as well as recommendations deriving from observed issues by the users.

Table 15. G.EN.ESI platform usability results

	Simone	***Nicola***	***Lorenzo***	***Roberto***	***Riccardo***	***MEAN VALUE***
Eco Material	N/A	9	9	8,6	N/A	**8,9**
MI BOM Analyzer	8,1	9	9	8,7	N/A	**8,7**
DfEE	7,3	8,8	9	8,8	N/A	**8,5**
CBR	7,6	9	9	9	N/A	**8,7**
LeanDfD	7,1	8,9	9	8,7	8,6	**8,5**
EVerdEE	8,5	9	9	N/A	N/A	**8,8**
Integration within company	N/A	8,8	8,8	8,1	N/A	**8,6**

3.9.3 Recommendations for usability improvement

In order to help developers to integrate the usability comments in their future software development, a list of requirements to improve the G.EN.ESI tools usability has been established and is presented in this section.

- Recommendations for improving Mi Material Gateway usability
  - R1: The MI Material Gateway aesthetic can be improved to make it more userfriendly
  - R2: The database of the MI Material Gateway should be completed according to the database of the company.
- Recommendations for improving CBR usability
  - R3: A verification of the guidelines/attributes association is recommended to limit errors associated to the tool filtering functions
  - R4: Additional information about guidelines of the CBR might be integrated into the output report in order to make it more relevant
  - Necessity to notify the user that he probably doing something wrong (add an error message) when the user wants to associate a guideline to a sub-assembly
  - Integrate functionalities in CBR that can help the user to check input data
  - Improve user's information for performing the analysis / to clarify the way the tool is running
  - Add a functionality to allow the user to modify the guidelines database

    - The navigation into filtering toolboxes can be reviewed for CBR. A classification of objectives by themes can be made in order to limit the choices in the list of objectives and to improve readability
    - The development of a tutorial video of the CBR use would be helpful for improving user guidance and support
    - The user doesn't really need the XML file as a product tree. Having the results of the environmental analysis associated to part could be more useful for the selection of appropriate guidelines.
    - An automatic import of the knowledge DB could be implemented for better inter-operability and information flow of the tool.
    - Some information about how to translate guidelines into design choices could be added for each guidelines in order to support designers
- Recommendations for improving DfEE usability
    - When providing detailed information on energy, efficiency and time, it might be easier to document a form with the 3 fields rather than having to click several time if the user only wants to modify the last field
    - Identify and solve the errors in the tool search function
    - Error messages should be added in order to force the user to enter the right information for running the tool
    - Integrate a functionality in the DfEE tool to help the user to check input data
    - The database of the DfEE tool can be improved with the integration of more components and components types for more flexibility and control
    - An access to the DB by the user can be added in the tool
    - Integration of a section on the user manual on how to take into account country-specific data
    - A more detailed report of results can be proposed to the user in order to clarify the readability and comprehension of the results. (Column chart)
    - The integration of new guidance material which supports and helps the user in how to perform the analysis could be made to improve user guidance and support of the DfEE tool
    - Correction of errors related to the import/export function is needed.
- Recommendations for improving Lean DfD usability
    - The aesthetic of the tool could be improved
    - Improvement of information given to the user for a correct use of the interface
    - Necessity to develop a protocol to verify if the results are in line with real disassembly sequences, costs, time and recyclability index
    - Identify and solve errors appearing in the tool calculation module
    - The generation of one report summarizing all information (EoL and disassembly in the same document) can be realized in order to improve the quality of information displayed to the user

        - Integrate a functionality to help the user to check and correct input data if needed
        - A reorganization of the sections in the interface (list of components on the lower left corner and previous disassembled components in the right lower corner)
        - Improvement of calculation speed for LeanDfD will improve the flexibility and control as well as the navigation of the tool use
        - An access to the DB of the Lean DfD tool by the user can be added in the tool for an update of materials, processes and related impacts
        - Adding an icon on the disassembly sequence showing what type of operation was undertaken can clarify the interface to the user
        - A pie chart representation of product recyclability rate can be generated in the report to clarify the results
        - The development of a tutorial video of the use of Lean DfD tool would be helpful for improving user guidance and support. Moreover, more example and more details could be included in Lean DfD user's manual
    - Recommendations for improving Web BOM Analyzer usability
        - An access to the Web BOM Analyzer DB tool by the user can be added in the tool for an easy update of materials, processes and related impacts
        - Output files of the Web BOM Analyzer should be presented in an Excel format
        - The use of different colours in the comparison graph can improve the readability of the Web BOM Analyzer outputs
        - The main interface readability can be improved with the integration of pie charts (not only in the report)
        - The user manual associated to the Web BOM Analyzer tool need to be revised and completed
    - Recommendations for improving eVerdEE usability
        - The development of a tutorial video as well as a quick start guide of the use of eVerdEE would be helpful for improving user guidance and support
        - The displaying format of eVerdEE results could be improved in terms of clarity. The information provided as results are too numerous and could be simplified for a better comprehension from the users.
    - Recommendations for improving G.EN.ESI tools integration within company
        - More time should be dedicated to software tool manipulation during the training
        - Necessity to identify clearly the potential public for training material and to adapt the training material according to the public

Even if some "high priority" recommendation have been identified, from a general perspective, no critical issues emerged regarding usability of the tools tested and the overall functioning of the G.EN.ESI platform tools. For some tools, some possible improvements have been identified and recommendations have been set in order to assure the best usability of the G.EN.ESI tools. Specific issues have been identified regarding the completeness and access of the tools databases and also regarding aesthetic aspects of the interface for some of the tools. Other issues such as the definition of clearer information in user's manuals and improvement of results displaying format will have to be solved to improve usability.

3.9.4 G.EN.ESI platform: strength and weakness elements

After the conclusion of the G.EN.ESI project it has been possible to analyse its main strength and weakness elements and from them derive interesting conclusions and foresees actions for possible future development of the platform in industrial contexts.

At first an important advantage of the G.EN.ESI platform is the possibility to realize environmental analysis through simple, integrated and effective tools. Tools are in fact easy to be used, thanks to simplified and common interfaces, rapid in performing analysis and able to reuse data obtained from the use of other tools. **The results obtained, even if achieved by simplified analysis, are compared with those one of detailed analysis**. The CAD integration of the majority of its tools and their mutual interoperability, are elements really appreciated from the industrial world. The inclusion of a simplified tool for the calculation of the product life cycle costing is a value added of the platform.

Furthermore, each specific tool of the platform can be used also independently, allowing to realize if necessary partial but detailed analysis on specific product aspects (e.g. analysis of the use phase through DfEE, analysis of EoL phase through LeanDfD, analysis of the material phase trough Eco Material tool) and to optimize them, under the environmental aspect.

In parallel with these strength points, some weakness elements can be identified:

- **The project case study: the cooker hood**. The product chosen as case study for the validation of the project, the cooker hood, is characterized by a high level of simplicity; it has in fact few components and few materials. This fact has partially limited the development of the tools, due to the customization of their functionalities and databases, which respond to the specific needs of the Faber company and has a consequence of the cooker hood.
- **The Eco Material tool, core of the G.EN.ESI Platform**. The entire platform and in particular the interoperability of its tools is based on the MI: Material Gateway tool, developed by Granta. As a consequence there is an interdependence of the tools with this module. The fact that this tool has been developed by a commercial entity, has make difficult to test in other contexts the entire platform after the end of the project. As a consequence, without the core of the platform, it is not possible to implement in pilot project the other tools in an integrated contest.
- **The need of knowledge on environmental issues**. Even if the project has the objective to support companies in the implementation of ecodesign approaches, the presence inside the company of an environmental expertise is necessary. The interpretation of results, the identification of environmental business objectives and the realization of the more detailed analysis require a knowledge on environmental issues, that usually is not have by internal resources in the case of Italian industrial companies. Furthermore, the realization of complete analysis, requires a significant time, often too much for company.

Starting from these strength and weakness elements, it has been recognized the need of a second test of some modules of the G.EN.ESI platform, in order to understand how they can be modified and optimized for possible future research and developments.
In the last chapter, the implementation of the CBR tool in a second industrial context and the results obtained are presented.

4 SECOND CASE STUDY: THE ELECTROLUX EXAMPLE

4.1 Analysis of company’s needs and identification of the most useful tool of the G.EN.ESI platform

The main objectives of the second test case of the G.EN.ESI Platform in an industrial context was to verify the usefulness of its tools and to understand how and if the platform can really answer to company’s needs.

The second test case was performed inside the Electrolux company has been structured in several steps.

At first, the entire G.EN.ESI project was presented and illustrated to the persons in charge of environment in the R&D department. The methodology and its steps was illustrated, then the tools, their functionalities and the results they allow to obtain was described in details. Also the implementation in the Faber company of the G.EN.ESI platform was illustrated, with the aim to present the benefits obtainable by using the tools in a redesign project.

Inside the company, the interest on environmental issues is growing, due to the recent European legislations and to the future trends, which will foresee more restrictive norms in the near future. As a consequence, the company showed a significant interest on the G.EN.ESI platform and on the results it allows to obtain.

At the moment, the company manages environmental issues only in relation to:

- The use phase, and in particular it applies all strategies to improve the energy efficiency of its appliances (to be compliance with the Energy Label legislation)
- The material phase, and in particular on materials to use. Designers can use only the materials contained in an internal list (more restrictive in respect to the legislation on Hazardous materials, Reach and RoHS materials)
- The EoL phase, and in particular in relation to strategies to prolong the durability of some components, in order to extend and prolong the entire lifetime of the product

No other environmental considerations are taking into account. The reason of the limited consideration of environmental issues during the design phase, is due to the absence of legislation that force them. As a consequence:

- the expertise of the company’s personnel on environmental items is limited to those areas affected by legislations
- no specific tools are used (or have been used in the past by the company) to perform analysis of the environmental sustainability of products.

However the company recognizes the importance of dealing with environmental items, and it is sure that in near future the European Commission will promote new and more specific legislations related to the environment.

Starting from these assumptions, among the tools of the G.EN.ESI platform, **the CBR was identified as the most useful tool for this initial phase**. In fact the company recognized as very useful the possibility to dispose of a tool that:

- **collects general ecodesign guidelines, thus allowing designers to acquire knowledge on environmental issues**;
- **collects specific eco-knowledge that the company will produce during the time** and therefore facilitate the resolution of issues related to the improvement of environmental performances of products;
- **stores in a structured and organized way all the company specifications and rules designers have to consult during the design phase**.

A young mechanical designer was identified by the company to test and evaluate the CBR tool. He has no environmental knowledge and he belongs to the Oven Platform design team. He was trained on the tool functions and properties by one web training session in order to be able to use the tool independently.

4.1.1 The reference product

In parallel to the training of the future user of the CBR tool, the company has identified a reference product, among all ones of the oven platform. A multifunctional pyrolytic oven has been identified as a representative product, due to its high complexity and completeness both in terms of functions and components.
The model is EOC6631AAX (Figure 118) a pyrolytic multifunction oven in anti-fingerprint stainless steel, with electronic temperature regulation, retractable knobs, a meat probe, food sensor core temperature indication and an electronic child lock safety function.

Figure 118 Reference product

4.2 Definition of the CBR test procedure

The test of the CBR tool, has involved the company for a span of time of 4 months and was organized in the following step:

1. Delivery of the CBRv2 tool
2. First evaluation of the CBRv2 tool and definition of the company use scenario
3. Environmental analysis of the reference product through a commercial LCA tool
4. Plastic incompatibility analysis
5. Optimization and Customization of the CBR tool
6. Final evaluation of the optimized and customized CBRv2 tool

4.2.1 Delivery of the CBRv2 tool

Starting from the final version of the CBR tool developed during the G.EN.ESI project, a new version has been developed (and called in the following CBRv2), in order to be used by the Electrolux company. In particular, due to the fact the CBR tool links the guidelines contained into its database with the product structure, **the first modification was the implementation inside the tool database of the oven structure.** All the oven's components, have been grouped in functional groups and standard components, as it is shown in the following Table 16, accordingly to the form used by the company itself, and as a consequence well-known by designers.

Table 16. Functional group and standard components for the oven

Functional Group	**Standard component**
Body (chassis)	Chassis U-shape
	Hinge support
	Component carrier
	Motor support
Cooling system	Air Duct
	Radial motor plate
	Radial cooling motor
Cavity + insulation	Heating elements
	Insulation
	Tape insulation
	Side grid
	Fan cover
	Front frame
	Door gasket
	Cavity support

	Cavity
	Hot air fan
	Chimney
	Catalytic filter
	Lamp
	Side grid clip
	Heating element support
Door	Plastic door assembly
	Door panel
	Door glass
	Handle
	Handle adapter
	Hinge
	Closure
	Spacer bush
Control panel	Metal panel
	Glass front panel
	Panel buttons
	Knob hole cover
	Knob
Electronics	Timer Hexagon
	Electronic board oven
	Electronic board food probe
	Terminal box
	Oven switch
	Temperature thermostat
	PT500 sensor
	Wiring
	Klikson
Packaging	Polystyrene
	Wrapping
Accessories	Dripping pan
	Baking tray
	Telescopic runner

	Wire shelf
	Food probe
Documentation	User manual
	Labels
Steam module	Loading tube assembly
	Water drawer assembly
	Outlet valve
	Steam pipe
	Outlet filter assembly
	Overfilling pipe
	Water tank assembly
	Steam generator
	Steam cap adapter
	Steam hole cover
	Water level sensor
	Steam gasket
Other 16	Enamel
	Paint
	Screw
	Nut
	Washer
	Silicon
	Bag
	Clamp

The CBRv2 has only the browse module, in which the guidelines can be consulted by the user without the importation of the CAD model. This functionalities (e.g. the possibility to retrieve the product structure from the CAD model of the product) was in fact related to the XML exchange file, used in the G.EN.ESI project and not justified if the CBR was used as a stand-alone tool. It is important to notice that the browse module do not have the report functionality.
In relation to the data base content, all the specific guidelines related to the redesign of the cooker hood was eliminated and all the Faber company's knowledge removed from the tool database. The data base of the CBRv2 tools, as a consequence, contains only 52 general environmental guidelines retrieved from the literature.

4.2.2 First evaluation of the CBRv2 tool and definition of the company use scenario

Once the CBRv2 has been developed, the user has been trained on its use to evaluate its usability, accordingly to the methodology defined in 3.9.1. Furthermore, the user has provided the indication of the most useful tool use scenario and some indications on how to modify the tool to answer more specifically to the company's needs.

The usability questionnaire has been modified respect to the one used in Faber, by eliminating the questions related to the effectiveness of the guidelines contained in the tools, due to the fact the first version of the tool does not contain any specific guidelines, but only the general ones retrieved from the literature. The effectiveness of the tool has been evaluated during the final test, when an optimized version of the tool has been provided to the company, and specific knowledge was implemented into the tool data base, as described in details in the next paragraphs.

The first usability evaluation was composed by the questions presented in Table 17 and has provided the results contained in Table 18.

Table 17. CBRv2 usability questionnaire

Questions: CBRv2	
1. Compatibility:	
a	When you open the tool, it is clear what steps you can/should perform
b	When you open the tool, it is easy to understand how to activate a specific tool function
c	The tool icons are easily associated with the functions they perform
d	It is easy to enter all the required information through the interface
e	The tool is aesthetically pleasing to the user
2. Consistency & Standards:	
a	The filter functions return relevant guidelines to the user
b	There are no errors in the tool filtering function
c	In general, the software functions are consistent during each analysis step
3. Error Prevention & Correction:	
a	The error messages displayed when incorrect data is entered are useful for the user
b	The error messages displayed when incomplete data is entered are useful for the user
c	The error messages are clear and easy to understand

d	The user is able to easily understand why errors messages appear when using the tool
e	It is easy to correct incomplete or incorrect input data through the tool interface
f	The software allows the user to easily check input data before processing to minimise errors
4. Explicitness:	
a	The steps the user has to perform to begin the analysis are clear and easy to identify
5. Flexibility & Control:	
a	The structure of the tool is flexible, allowing the user to perform the analysis steps according to his/her needs
b	The user is able to perform the analysis which he/she considers best for his/her needs
6. Informative Feedback:	
a	The tool clearly details the analysis carried out to create the output
b	A documented description of the process and analysis carried out from user input to tool output would be useful for the user
7. Language & Content:	
a	The tool functions are easy to understand and are written in a simple and direct language
b	The tools outputs (guidelines) are easy to be understood and are written in a simple and direct language
c	The tool table contents are written in a clear way
d	Displaying the the guidelines within a table is useful to improve their readability and comprehension
e	The language used throughout the tool is easily understandable for the user
8. Navigation:	
a	The tool structure allows the user to rapidly perform the required analysis
b	The filtering toolboxes are quickly and easily identifiable within the interface
c	The tool evaluation/calculation icons are quickly and easily identifiable inside the interface
d	The main interface icons are easy to find and accessible
e	Overall, navigation within the tool allows the user to easily and quickly access all functions

9. **Privacy**:	
a	The user can be confident that any company data input into the tool will be protected
b	The user can be confident that any company supplier data input into the tool will be protected
10. User Guidance & Support:	
a	The software contains guidance material which supports and helps the user to understand how it works
b	The user manual is easy for the user to understand
c	The user manual is written in a simple and direct language
d	The user manual is able to fully support the user during initial usage of the tool
10. Visual Clarity Description:	
a	All the information displayed on the interface is clear
b	All the information displayed on the interface is well organized
c	All the information displayed on the interface is unambiguous and easy to read

Table 18. CBRv2 usability results – mean value (in red the criticalities)

	User evaluation – mean value
Compatibility	8.4
Consistency & Standards	8
Error Prevention & Correction	9
Explicitness	9
Informative Feedback	9
Language & Content	9
Navigation	6
Privacy	3
User Guidance & Support	8
Visual Clarity Description	6

The first evaluation of the CBRv2 usability has provided interesting results, showing that the tool is positively evaluated by the user in performing its functions and in the graphical content of its interfaces. Similar results have been derived also in the case of the Faber company, thus allowing to asses that the CBR tool was structured in order to have a sufficiently usability.

The only not sufficient value it is for the privacy evaluation. The user has associated to this aspect a very low evaluation due to the absence of indications on the tools of the way all the information stored in the tool data base are managed.
Also the Visual Clarity Description and Navigation metrics obtained a low evaluation, due to the fact the way guidelines are visualized has appeared as not clear for the user.
These aspects will be solved in the optimized version of the tool, and described in details in the following, according to the suggestions and indications given by the user.
The user in fact has also provided some suggestions to improve the tool functionalities and usability, and in particular:

- Add the Report module in order to have in a separated file the guidelines consulted and the eventually notes stored.
- Give the possibility to the user to select with a check the guidelines he has consulted and/or applied
- Improve the visualization of the guidelines. In particular when the tools retrieve the guidelines the user visualize in the specific column all the components and functional groups associated to the product. In the case of the oven, that has a lot of components, this visualization mode make not clear the guideline consultation.
- Add other filtering functions when company specific guidelines will be added into the tool data Base.

At the conclusion of the first usability evaluation for the CBRv2, also the most useful use scenario for the company has been identified. In particular during the re-design phase, designers can:

- Consult general ecodesign guidelines to be aware of those best practices that allow to reduce the environmental impact of products
- Consult specific ecodesign guidelines, related to a product realized inside the company, to understand the main product criticalities in environmental terms
- Consult company eco-knowledge (e.g. redesign hypothesis and related environmental impact) to be supported during the resolution of similar problems

As a consequence, the tool data base should contain:

- General ecodesign guidelines (yet included into the CBRv2 database)
- Environmental data of the reference product (included in the optimized version of the CBRv2 tool)
- Several redesign hypothesis and their related environmental impacts (included in the optimized version of the CBRv2 tool)

4.2.3 Environmental analysis of the reference product through a commercial LCA tool

To allow the implementation of the use scenario identified for the CBRv2 tool, an environmental impact analysis for the reference product was conducted, by the mean of the commercial tool

SimaPro. This analysis has allowed to identify the most critical components in environmental terms and to create the specific ecodesign guidelines. Furthermore, starting from the major criticalities, several redesign hypotheses have been defined and stored into the tool data base as company specific eco-knowledge.

In the following, the main assumptions and results of the LCA analysis are presented according to the reference norms (ISO 2006 a, b). No details are provided due to confidentiality of data.

Functions and functional unit

The functional unit was defined as a cooking cycle with a consumption of 0.93 kWh/cycle, for a life time of 19 years, for 120 cycles/years. The substitution of damaged parts was not included. The life time data has been provided by the oven manufacturer. The reference flow of this study was one oven (EOC6631AAX model). The reference year for this study was the 2015.

System boundary

The study was from cradle to the EoL. For each phase, resource consumption, air and water emissions, waste production and energy consumption have been considered.

Figure 119 shows the flow diagram of the process. The boundary of the system includes production of energy needed for the different processes; production of semi-finished products and components. Transport at all levels was not included in the analysis.

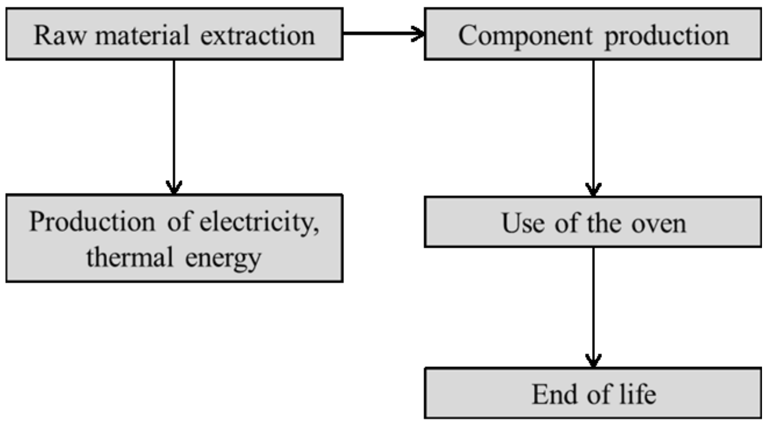


Figure 119. System boundary flow chart

Cut-off and assumptions

Within the current study, an initial identification of input based on mass, energy and environment have been performed. Regarding the mass significance each parts or components have been considered, excluded screw, electric cables, plugs.

For the energy consumption, no cut-off have been applied based on the environmental relevance.

Different assumptions have been considered in this study.

Many dataset regarding production processes and materials did not really correspond to production processes and materials mentioned in the BOM and assumptions have been realized according to production processes and material available in the Data base of the software tool used for the study.

Environmental impact categories, models and indicators

Impact categories, category indicators and characterization models, included within the current LCA study, are reported in the table below (Table 19.

Table 19. Impact assessment description (Institute of Environmental Sciences, Leiden University)

Impact category	**Unit**
Abiotic depletion	kg Sb eq
Abiotic depletion (fossil fuels)	MJ
Global warming (GWP100a)	kg CO2 eq
Ozone layer depletion (ODP)	kg CFC-11 eq
Human toxicity	kg 1,4-DB eq
Fresh water aquatic ecotox.	kg 1,4-DB eq
Marine aquatic ecotoxicity	kg 1,4-DB eq
Terrestrial ecotoxicity	kg 1,4-DB eq
Photochemical oxidation	kg C2H4 eq
Acidification	kg SO2 eq
Eutrophication	kg PO4--- eq

Types and sources of data

Data have been gathered from different types of sources. Data related to production processes for in-house processes and energy consumption during the use phase have been provided by the company. Data related to commercial parts, have been collected from the literature available on the web, with the collaboration of the company.

Selection of impact categories, category indicators and characterization models

The LCIA step includes:

- Selection of characterization method and its impact categories;
- Attribution of the inventory result to the selected impact categories (classification);
- Calculation of the results for each category indicator (characterization);
- Calculation of the relative contribution to a final result for each category indicator, respect to a reference value (normalization).

The impact assessment method used for this study, is the CML-IA baseline V3.02 / EU25 . This method have been developed by a group of scientists from the Center of Environmental Science of Leiden University in the 2001. The CML 2001 methodology gives a set of impact categories defined for the midpoint approach.

The CML impact assessment method has been chosen as the impact categories, category indicators and characterization models are internationally accepted. In fact, a general agreement on impact categories have not been achieved in every category. At the moment the debate is still open on the definition of different eco-toxicity categories. However, the majority of those recommended by the CML are among the most recognized and robust.

The categories represented can be considered consistent with the goal and scope as they highlight environmental impacts generated by the depletion of certain natural elements and the energy consumption, which are the most important stages of this product life cycle.

Time-related coverage

Data collected represent the current situation concerning the manufacturing process in Electrolux. Therefore, it is possible to assert that the time related coverage of the dataset used is contemporary.

Geographical coverage

The study refers to the Italian market, since the majority of manufacturing processes takes place in the Electrolux manufacturing plant, in Forlì (Italy). However datasets available do not refers to the Italian market, but to the European or International one.

Technology coverage

Data used in this study reflect a technology mix coverage.

Precision

Datasets used in this study are derived from the EcoInvent v.3

Completeness

All the material flows related to components have been estimated, based on information provided by manufacturer company and experts.

Representativeness

The data used reflect the true population of interest (i.e. geographical coverage, time period and technology coverage).

Consistency

The study methodology is applied uniformly to the various components of the analysis.

Collecting data

Data related to materials quantity, energy consumption, auxiliary materials, packaging, manufacturing processes needed to produce and operate the oven have been gathered in order to analyze environmental impact related to the product under study. The background system is represented by data related to extraction and raw material manufacturing processes, energy distribution and generation plants, and it includes secondary data, obtained from the literature available on the web and from commercial database, since it is assumed that markets related to these processes can be considered homogenous.

The foreground system includes specific data from the product system. In particular, information about physical characteristics of the materials used, data related to the manufacturing process, data related to materials and data related to the finished product. The foreground system includes both secondary data and primary data. In the Table 20, the type of data collected are represented.

Table 20. Foreground and background system and data characteristics

Life cycle stage	Data system	Type of data
Raw material extraction	Background	Secondary data (database LCA)
Materials and semi-finished parts manufacturing	Background	Secondary data (database LCA)
Manufacturing of electric and electronic components	Foreground	Secondary data (database LCA, literature)
Components and sub-assembly production	Foreground	Secondary data (database LCA)
Distribution	Foreground	Out of the boundaries
Use phase	Foreground	Data provided by the manufacturer

Data related to the use phase have been calculated according to the estimation of the daily use.

The majority of the background datasets (energy consumption, raw materials, auxiliary materials and manufacturing processes) have been collected from the commercial database EcoInvent v3.

The SimaPro v.8 and EcoInvent v3 have been used to create the LCA model and calculate the product environmental impact.

Components: materials

In this paragraph the product system is analyzed, by highlighting characteristics of its main components.

The oven is composed by different sub-assemblies which gather several components functionally related among each other. In particular we can recognize 6 assemblies:

- Chassis Assembly
- Upper Space Assembly
- Cavity + Insulation Assembly
- Rear Space Assembly
- Oven door assembly
- Control Panel Assembly

The majority of the information are based on the CAD file provided by the oven manufacturer. This file contains a series of assemblies and sub-assemblies. Each part that makes up the final product is designed and so the relative physical material.

Data and information related to the materials physical characteristics have been provided by Electrolux.

Distribution phase

The impact related to the distribution phase has not been evaluated, as a consequence the distribution phase has not been modelled.

Use phase

The following aspects have been considered in the use phase: electricity consumption during the use of the oven, e.g. during a cooking cycle.

Table 21. Calculation of energy consumption during the use phase

Parameters for the use phase	Total electric consumption
Electricity consumption [kWh/cycle]	0.93
Life cycle [years]	19
Cycles/years	120
Total Electricity consumption (MJ)	1943.7

The energy consumption profile has been estimated on the basis of the technical characteristics of the oven and technical recommendations from Electrolux. In Table 21 the calculation of the total energy consumption is provided.

Electricity

Dataset related to the energy production and its relative environmental loads have been retrieved from EcoInvent v3 database.

As regards the electricity mix used for the use phase, as the oven is supposed to be used in Italy, the Italian energy mix dataset has been used.

Transport

Transport included in the life cycle inventory regards only raw material. The dataset used for the raw material modeling includes in fact a medium transport. All the other transports (from suppliers to the manufacturing plant, from the manufacturing plant to the distributors, from the distributor to the user and from the user to the disposal plant) have been neglected for absence of data.

Allocation

This study does not involve different products and in addition, disaggregated data were retrieved from the manufacturing company, therefore allocation due to by-products is not needed.

Life Cycle Impact Assessment (LCIA)

Results from the Manufacturing, Use phase, and End of Life Phase, according to the system boundaries previously defined are shown in the following Figure 120.

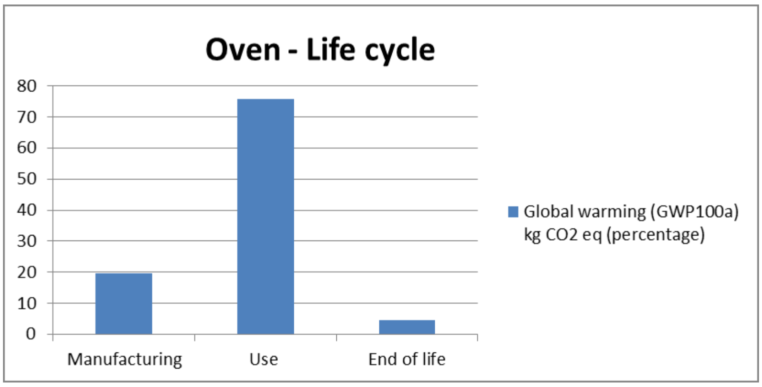


Figure 120. Result divided by life cycle phases after characterization (in percentage)

Results from the characterization have been normalized through the use of the set CML 2001 – Apr. 2013, West Europe Nov.2009. In this way, it is possible to highlight and to compare the magnitude of environmental issues generated in the entire oven life cycle, respect to a certain value that is meant as reference for a defined area. The normalization process allows the user to make comparison among different impact categories within the study. Results from normalization, for each impact category are shown in the figure below.

Life cycle interpretation and Identification of significant issues

Results obtained have highlighted that the environmental profile of the oven is heavily influenced by the use phase. If the use phase is excluded, and the Global Warming Potential is observed, the criticalities are focused on those components for which enameling and zinc coated processes are foreseen.

The impact of the manufacturing phase (including material) for the assemblies of the oven, showing that the most critical ones are the Cavity + Insulation Assembly, the Chassis Assembly and the Oven door Assembly.

In detail:

- Regarding the Cavity Flat Pyro Assembly, the most critical components are the cavity top, the cavity wrapper and the cavity bottom. Their impact is due mainly to the material and to the enameling process;
- Regarding the Chassis Assembly, the most critical component is the protection chassis. Its impact is due mainly to the enameling and zinc coated process;
- Regarding the Oven Door Assembly, the most critical component is the Handle profile. Its impact is due to the material and the related manufacturing processes.
- Regarding the upper space assembly, the most critical component is the Radial Comp. carrier. Its impact is due to the enameling and zinc coated process;
- Regarding the Rear Space Assembly and Control Panel Assembly, their impact is very low and can be neglected if compared with the other assemblies.

At last, as conclusion, recommendation imply the enlargement of the system boundaries in order to verify whether the inclusion of the transport phase, the distribution phase affects and bring added value to the goal and scope defined at the beginning. Quite surely, a more comprehensive study will increase its consistency level respect to the requirements of the goal and scope of the study.

The study has pointed out that, in line with the literature findings, the use phase represents the oven life cycle stage with greater potential impacts. Besides the use phase, the study underlines that the manufacturing process represents a relevant phase to be taken into consideration in the oven design, in particular with regard to zinc and enamel coated components. According to these suggestions, the company has considered possible alternatives to zinc and enamel coatings. Due to the importance of these superficial treatments, a very deepen study need to be performed inside the company to evaluate if the variation of these technologies is applicable. Due to the limited time scheduled for the test of CBR tool, no redesign hypothesis to solve this criticalities have been defined.

4.2.4 **Plastic incompatibility analysis**

According to the methodology developed by the JRC (JRC, 2012) and presented in paragraph 59, an analysis of incompatibility at plastic level was also developed, in order to verify the presence of criticalities. The results showed in Table 22, indicate that components on PC/ABS should be eliminated and substituted with other compatible with PA6T, PA66. Also the substitution of components in PBT is recommended.

Table 22. Incompatibility matrix for the oven case. In red high incompatibility, in yellow low incompatibility between mixture and excess components

Material	**%**	**Quantity**	**Typology of component**
PA66	6,72	1	Mixture component
PA6T +TPE	1,76	1	Mixture component
PA6T	80,86	1	Mixture component
PBT	3,16	2	Excess component
PC/ABS	2,46	1	Excess component
PC/ABS	1,64	1	Excess component
PA65/PA66	1,29	1	Mixture component
PA66	1,29	1	Mixture component
PBT	0,12	2	Excess component
PBT	0,59	1	Excess component
PBT	0,12	1	Excess component

Plastic incompatibility influence the way, those components should be recycled once the product will reach its EoL. In fact if incompatibilities are present, no mechanical separation of shredding fractions can be possible, with the consequence of no applicable recyclability strategies.
According to these suggestions, the company has considered some variations in the material of these critical components, that will be included on the redesign hypothesis for the oven. For confidentiality reasons, the content of this redesign hypothesis cannot be presented in this thesis.

4.2.5 **Optimization and Customization of the CBR tool**

According to the results of the first usability questionnaire, the definition by the company of the tool use scenario and the suggestions related to the improvement of the tool functionalities, an optimized and customized version of the CBRv2 tool was delivered to the company.
The optimization has involved the modification of the tool functions, utilities and graphical aspects, while the customization was consisted in populating the tool database with specific guidelines and company eco-knowledge, in addition to the general guidelines yet implemented into the first version of the CBRv2 tool.

In particular, as a regard to the **optimization phase**, the main modifications, in respect to the first version of the tool, were realized to the following points:

- **Visualization of guidelines**. In order to make the visualization of guidelines more clear for the user, the visualization of standard components and functional group columns were modified. In particular, the to the high number of objective, functional groups and standard components for the oven case, and due to the fact each guideline is associated to several of these attributes, the user visualises a lot of data, not all necessary. For this reason, the visualization of objective, standard component and functional group has been realized in a separated window. The user can open it, by double clicking on the relative space of the column. In this way, it has been possible to pass from the visualization in the main interface of only one guideline (Figure 121), to the one that allows the user to visualize more guidelines (Figure 122), thus making the information shows by the tool more clear.

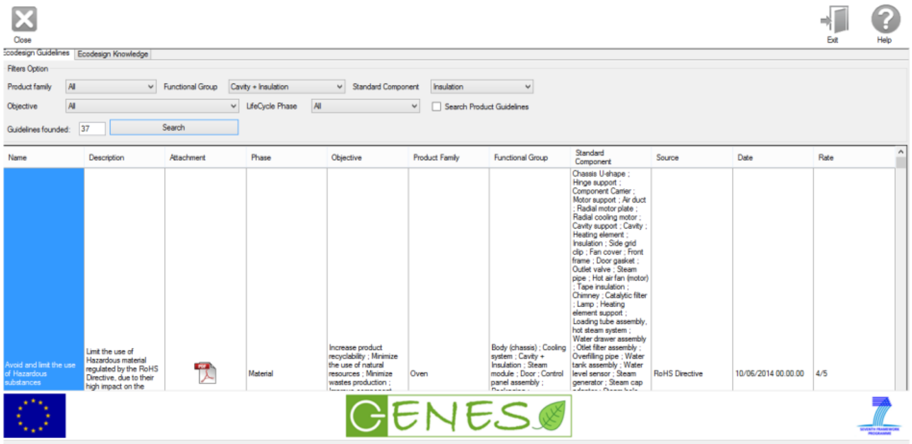


Figure 121. Main interface of CBRv2 tool

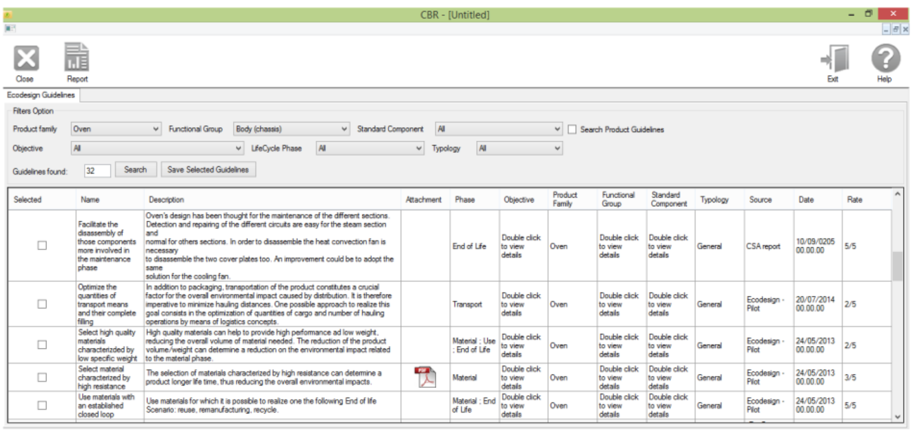


Figure 122. Main interface of the optimized version of CBRv2 tool

- **Selection of guidelines**. This function has been inserted in order to allow the user to select one or more guidelines from those ones the tool gives after the filtering option the user has inserted. The user can select one or more guidelines by checking them in the first column of the guidelines panel. (Figure 123).

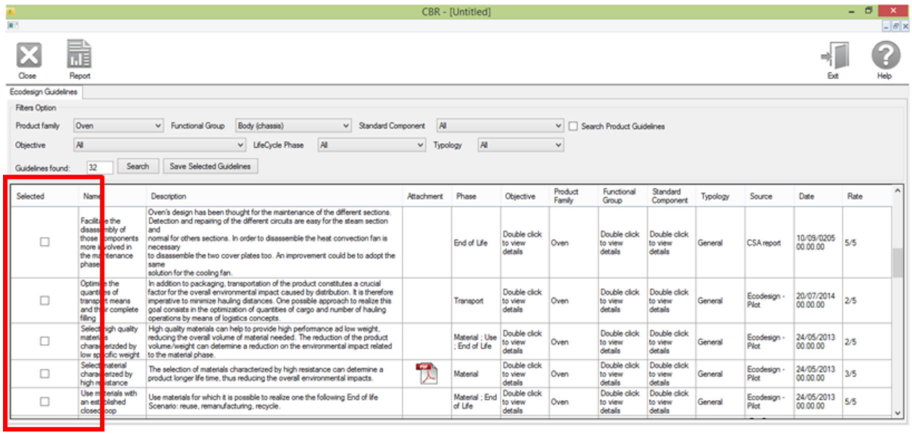


Figure 123. Possibility to select guidelines through check control

- **Manage module**. A manage module was added to the main interface of the tool. In particular, this module allows the user to save the guidelines he has selected from those ones filtered by the tool. After the user has selected by the check control guidelines, he can save them through the "Save selected guideline" button, then open the manage interface by clicking on the button "Manage guidelines" (Figure 124). A new window will open and the user visualize only the guidelines he has selected. At this stage he can add notes to the guidelines (e.g. how he has applied the guide or other further specifications he wants to store) and he can generate the report, through the specific function.

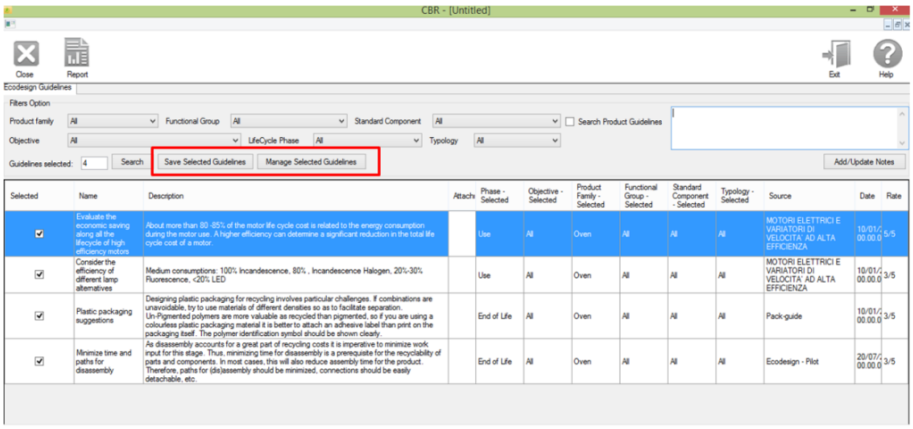


Figure 124. Manage module

- **Report module**. The possibility to generate a report with the guidelines consulted during the design project was added to the module used by Electrolux (Figure 125). The report contains: the guideline consulted, the functional group and standard component to which the guidelines have been associated by the user, the objective and the life cycle phases filtered associated to the selected guidelines. It also contains the note the user has added during the consultation/application of the specific guideline. The report is in the .csv report and it is opened and editable by an Excel file.

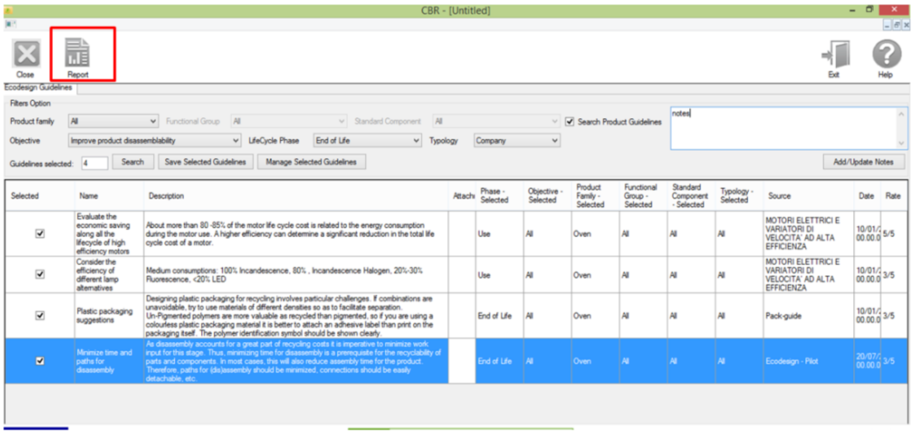


Figure 125. Report function

– **Typology specification**. Due to the high number of guidelines store in the optimized version of the tool, a further tab with the indication of their typology has been added (Figure 126). In particular the guidelines have been grouped into:

  - General: all the environmental guidelines retrieved from the literature and in general valid for a wide range of products and for different stage of the life cycle of products
  - Normative: all the guidelines directly derived from normative, both related to environment and to other aspects to take into account during the design phase
  - Company specific guideline: all the guidelines derived from specific analysis on the specific product produce inside the company.

This further possibility to filter guidelines facilitate the searching of guidelines to the user, which can go directly to the category he wants to consult and as a consequence he can reduce the time to consult guidelines.

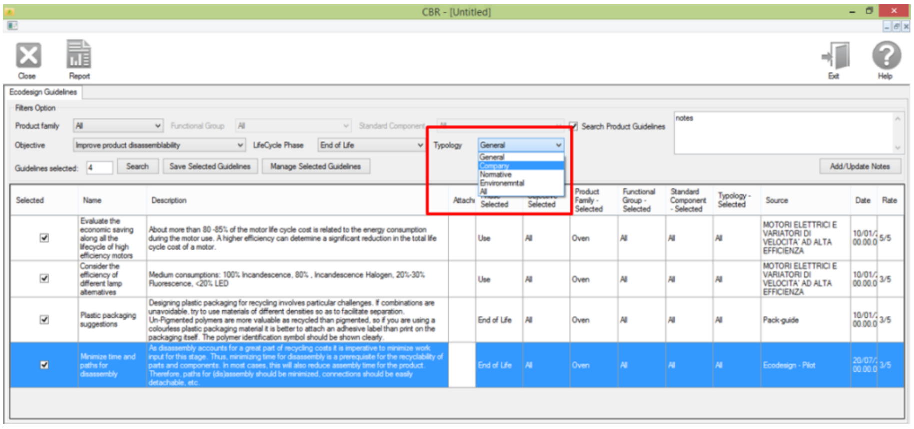


Figure 126. Guideline typology tab

– **Privacy communication**. According to the suggestion provided by the user of the tool, an explicit reference to the way guidelines are managed by the tool, has been added into the tool user manual. In particular guidelines are stored in a local memories, so the privacy is guaranteed by the company's itself.

As a regard to the **customization phase**, starting from the 68 general guidelines yet stored into the first version of the CBRv2 tool:

- The results of the LCA and incompatibility analyses were translated into specific company guidelines and associated to the relative components. **A total of 23 guidelines and related attachments were realized to describe the environmental profile of the oven**. These guidelines have been stored under the "company" typology.
- The redesign hypotheses related to the problem of plastic incompatibility were translated into specific company guidelines and associated to the relative components. A total of **3 guidelines and related attachments were realized to describe redesign hypothesis and the consequent benefits obtainable with their implementation**. These guidelines have been stored under the "company" typology.
- Company specific guidelines in the matter of environment (the so called internal environmental specification) were implemented into the tool database and associated to those components to which they are related. **A total of 30 specific guidelines were realized and stored into the tool database.** These guidelines have been stored under the "company" typology.
- Environmental norms and legislations that designers of the company usually use in their work, were implemented into the tool database and associated to those components to which they are related. The possibility to store also norms and legislations into a unique data base facilitate their consultation. **A total of 57 specific guidelines were realized and stored into the tool database.** These guidelines have been stored under the "normative" typology.

The customized version of the CBRv2 tool contains as a consequence a total of 181 guidelines (68 belong to the general category and already implemented into the first version of the CBRv2 tool, and the new 113, that belong to company and normative typologies).

4.2.6 Final evaluation of the CBR tool

The CBRv2 tool, after its optimization and customization, was delivered to the Electrolux design departments for the final test. For the usability evaluation, the same questionnaires has been proposed to the same user of the first tool evaluation and it provides the results shown in the following Table 23.

Table 23. CBRv2 (optimized and customized version) usability results – mean value

	First evaluation	***Final evaluation***
Compatibility	8.4	8.4
Consistency & Standards	8	8
Error Prevention & Correction	9	9
Explicitness	9	9

Informative Feedback	9	9
Language & Content	9	9
Navigation	6	8
Privacy	3	9
User Guidance & Support	8	8
Visual Clarity Description	6	9

It is possible to notice that the optimized version of the tool has determined an improvement in the usability evaluation; in particular it has determined an improvement for the Privacy, due to the fact the way guidelines are stored into the tool has been explained in an explicit way inside the used manual of the tool. Furthermore, the evaluation of performances inserted into the Navigation and Visual Clarity Description metrics has improved, due to the better organization of guidelines into the tool main interface and the adding of further filter options.

Due to the fact the optimized and customized version of the CBRv2 tool contains also specific company knowledge, in this case also the **evaluation of guideline effectiveness and the level of integration inside the company has been realized**. Specific questions have been defined and the results obtained are the shown in Table 24.

Table 24. CBRv2 (optimized and customized version) effectiveness evaluation – mean value

	Evaluation/ Answer
General aspects	
The information contained in the report is sufficient for collecting ecodesign guidelines and supporting designers during the redesign of the product	7
The software satisfies user expectations from a functional point of view, i.e. it is able to provide guidelines that can support and facilitate your design work	8
The software is able to meet your needs, facilitating your work and decreasing the time to find the information you need	7
The pre-defined objective selection function is able to represent the user's usual requirements	7
Impact on the traditional design process	
Is the impact of the CBR tool use in terms of time dedicated to the analysis admissible and compatible with the traditional time of the design process?	7
Is the impact of the CBR tool in terms of competence to acquire, admissible and compatible with the actual company employees competency or are necessary specific skills?	8
Personnel to involve if the tool will be implemented inside the company	
Is the personnel inside the company able to use the CBR tool and to interpret its results? (after appropriate training activities).	7

The introduction of the CBR tool inside the company needs the involvement of new personnel with specific background on ecodesign issues? Please answer to the question.
No specific knowledge is required
The introduction of the G.EN.ESI tools can determine new relationships among the different company roles involved inside the company? Please answer to the question.
Yes, due to fact the tool contains the results of analysis related to different product aspects
At the moment the tool is not able to analyse product environmental characteristics. Is this aspect in your opinion a limit for the tool?
Yes, it represents a limit. The tool does not allow to compare different design hypothesis if they have not been never analysed.
In your opinion, if the tool gives you the possibility to realize simplified environmental analysis, this will increase the tool strength.
Yes. The possibility to perform simplified, rapid but effective environmental analysis which can guide designer choices, not only in a static but also in a dynamic way, could represent an important advantage for the CBR user. Of course it is necessary that in this case the user has a basic knowledge on environmental analysis.

The results obtained in the evaluation of tool effectiveness and integration within the company appear very satisfactory. The tool according to the response of the user, provides results that can effectively support the designer work, facilitate the choice to take and reduce the time analysis thanks to the collecting of company eco-knowledge. The results obtained are in fact all sufficient.

4.3 Final remarks, limits and possible future developments

The implementation of the CBR tool inside a second industrial test case, has allowed to derive interesting results. At first, the tool was optimized in functionality and graphical aspects, that increase its level of usability and effectiveness. Secondly, **the test has demonstrated and confirmed that companies need tools that support and facilitate their work, reducing at the same time the time for problem solving**. The CBR tool appears therefore as a very useful tool, that needs to be further investigated to increase further its strength. This process should involve other companies and the collaboration with the Electrolux company will allow to go on in this activity after the conclusion of the PhD.

In particular the tool could be improved by adding a module able to calculate a simplified environmental impact of changes made on the product (by importing product data through the CAD interface system). In this way designers could evaluate directly the effects in environmental terms of choices they made on the product and create in a more rapid way the company knowledge. In fact at the moment, the company eco-knowledge is created and stored into the tool by realizing specific and detailed analysis (e.g. LCA analysis, disassembly analysis, EoL analysis) that require specific knowledge. So at the moment company needs to externalize these analysis, if no environmental knowledge is owned inside.

This fact represents an important limit for the CBR tool, which appears at the moment as a "static" tool, where can be stored the knowledge acquired by conducting separated analysis.

For this reason, next developments of the tool will start from this aspect in order to further improve the tool and increase its strength, by allowing designers to conduct also simplified analysis. This functionality could be realized by integrating the tool with a simplified environmental analysis tool, or by adding into the tool itself a module dedicated to the simplified environmental analysis of product.

Other companies will be involved into other tests in order to collect more and more feedbacks and make the tool the most near to real company's needs.

5 CONCLUSION AND FINAL REMARKS

This PhD thesis investigated the problems related to the lack of implementation of ecodesign tools inside industrial companies.

A deepen analysis of the most recently literature in the field of ecodesign methods and tools has been realized, obtaining a classification of tools and methods according to their scope perspective and a classification of barriers and strategies related to their use inside industrial contexts. Starting from this first result, a new tool that supports designers in the implementation of ecodesign strategies has been proposed.

The developed CBR tool links ecodesign guidelines, company eco-knowledge and product characteristics and allows to take into account environmental considerations in the first design phases. In this way, designers, even if with low skills on environmental sustainability, can be supported in applying strategies for the development of ecological products.

The CBR tool was at first developed as a module of the G.EN.ESI platform. The activities conducted inside the project, in particular the support given to the FABER company in the redesign process of a cooker hood by the means of the G.EN.ESI tools, allowed to understand directly the difficulties related to the practical and effective use of ecodesign tools inside an industrial company and to confirm and validate the conclusions derived from the analysis of the literature in this topic. Designers usually not have knowledge on environmental topics and therefore they need a tool that guides theme in acquiring practices on ecodesign. The CBR tool allows to overcome this lack thanks to the collection in its database of ecodesign guidelines and company eco-knowledge. Their organization into a structured database, their link with specific parameters and with the product structure, facilitate their retrievement and support the design phase without adding complexity. This last statement was confirmed by the good results in terms of usability obtained by the CBR tool during its implementation in the FABER company.

The implementation of the CBR tool (in an optimized and customized version) in a second company has allowed to understand the tool strength points, its limits and its potentiality, and has provided very interesting starting points for future improvements of the tool. The tool appeared very adaptable to the company's needs, due to the high flexibility of its database which can be filled in with specific company data. Furthermore designers has evaluated it as easily to be integrated into the traditional design phase, without conducting any substantial modifications on it and able to provide the needed support and to facilitate the implementation of ecodesign strategies.

These results, confirm the interest of industrial companies for the proposed approach and the need for future investigations and development of the CBR tool.

This tool at the moment has been developed in a prototypal way and it opens large possibility to improve it and to implement new functionalities, according to the results obtained during the test phases and to the future indications that the companies involved will provide.

Future works will cover the deficiencies come out from the test case analysis and in particular the first aspect to investigate will be the adding of a simplified environmental analysis module. This aspect could be reached by integrating the tool with a simplified environmental analysis tool, or by adding into the tool itself of a module dedicated to the simplified environmental analysis. Furthermore the value added represented by the possibility to integrate the tool with CAD systems will be evaluated during future activities with industrial companies.
In conclusion, the main results and contributions of this PhD thesis can be summarized as follow:

- Deepen review of the literature developed during the last twenty years in the matter of ecodesign tools and methods and in particular:
    - classification of tools and methods according to the scope perspective;
    - identification of the strength and weakness elements of each category;
    - classification into categories of the barriers related to the implementation of ecodesign tools and methods in industrial contexts;
    - analysis of the principal strategies that the most recent literature proposes to overcome these barriers.
- Development of the CBR tool, as a means for supporting the implementation of ecodesign strategies inside design departments, and in particular:
    - Definition of the methodology of the tool
    - Definition of its functionalities, database structure, and contents of its graphical interfaces
    - Collection of ecodesign guidelines from the literature
    - Implementation of the tool inside the FABER and Electrolux design departments
    - Optimization of the tool, customization and evaluation of its limits, strength and possible future developments

In conclusion it is possible to state that the PhD has allowed to develop a methodology and a tool that can represent a good and reliable means to support designers in the implementation of ecodesign strategies during the design process.

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APPENDIX A. CBR TOOL DATA BASE

In Table 25, the complete structure of the CBR data base is shown. It has been created by the Access Software tool. All the columns associated to the guidelines and their content are shown for two guidelines taken as an examples. In Table 26, all the 68 ecodesign guidelines retrieved from the literature are shown. In order to make the table readable, only the columns ID, name and description are presented. For confidentiality reasons, the company eco-knowledge (stored during the implementation of the tool in FABER and Electrolux), which is stored into the tool in the same structure, can't be shown.

From Table 27 to Table 35 all the tables created for the tool data base are shown, both for the cooker hood and oven case.

Table 25. CBR data base structure

tbl_Guidelines												
ID	Name	Description	Attachment	Phase	Objective	Product	Functional Group	Standard Component	Source	Date	Rate	Typology
71	Encourage the packaging re-use	Ensure that the packaging is designed for and is robust enough for re-use. Ensure that facilities for cleaning, repair or reconditioning are available if this is necessary before the packaging can be re-used	none	4	6	1	9	51;54	14	10/01/2014	3/5	1
74	Encourage the packaging separation	Construct your packaging so that the end-user can easily separate any components that should not go into the recycling process	none	4	6	1	9	51;54	14	10/01/2014	3/5	1

Table 26. Guideline Table

ID	Name	Description
66	Evaluate the economic saving along all the lifecycle of high efficiency motors	About more than 80 -85% of the motor life cycle cost is related to the energy consumption during the motor use. A higher efficiency can determine a significant reduction in the total life cycle cost of a motor.
67	Consider the efficiency of different lamp alternatives	Medium consumptions: 100% Incandescence, 80% , Incandescence Halogen, 20%-30% Fluorescence,
68	Consider the recyclability of different lamp alternatives	Recycling process for: Halogen: landfill, Incandescence Halogen: Landfill, Fluorescence: 95% Recycle, LED: Recycle
69	Consider the costs of different lamp alternatives	Medium Cost: Halogen: 1, Incandescence Halogen: 2, Fluorescence: 4, LED: 16Cost: Halogen: 1, Incandescence Halogen: 2, Fluorescence: 4, LED: 16
70	Consider the lifetime of different lamp alternatives	Lifespan: Halogen: 750 h, Incandescence Halogen: 1000 h, Fluorescence: 10000 h, LED: 20000 h
71	Encourage the packaging re-use	Ensure that the packaging is designed for and is robust enough for re-use. Ensure that facilities for cleaning, repair or reconditioning are available if this is necessary before the packaging can be re-used
72	Prefer slip-sheets to avoid pallets	Plastic slip-sheets can sometimes be used to avoid the need for pallets, particularly for overseas shipment and inter-company deliveries. Slip-sheets are strong enough to support the weight of the product load without the need for the rigid base that a pallet would provide. This will save both space and materials
73	Encourage the packaging recyclability	Try to avoid materials, combinations of materials or designs of packaging that might create problems in collecting, sorting or recycling. Minimise the use of substances or materials that might create technical, environmental or health problems in the recycling process or in the disposal of recycling residues.
74	Encourage the packaging separation	Construct your packaging so that the end-user can easily separate any components that should not go into the recycling process
75	Plastic packaging suggestions	Designing plastic packaging for recycling involves particular challenges. If combinations are unavoidable, try to use materials of different densities so as to facilitate separation. Un-Pigmented polymers are more valuable as

ID	Name	Description
		recycled than pigmented, so if you are using a colourless plastic packaging material it is better to attach an adhesive label than print on the packaging itself. The polymer identification symbol should be shown clearly.
76	Evaluate the purchasing cost of high efficiency motors	High efficient motor are characterize by higher purchasing cost in respect to a similar product with lower efficiency
77	Avoid and limit the use of Hazardous substances	Limit the use of Hazardous material regulated by the RoHS Directive, due to their high impact on the environment
78	Consider these suggestion when using electrical circuits	mount components on a printed circuit board with detachable leads, do not solder; use plugs that push into place and can easily be pulled out
79	Ensure reversibility of assembly procedure	Reversibility of assembly procedure is a prerequisite for easy disassembly in case of manufacturing defects and for repair work during use stage, and, in particular, for disassembly after end of life.
80	Design product structure for easy disassembly (uniform directionality for assembly and disassembly work)	Disassembly accounts for a great part of recycling costs. A clear and easily understandable structure ensures easy disassembly and thus reduces work input and costs. Uniform directionality for assembly and disassembly will also provide for ease of sorting structural components and optimize assembly work.
81	Minimize time and paths for disassembly	As disassembly accounts for a great part of recycling costs it is imperative to minimize work input for this stage. Thus, minimizing time for disassembly is a prerequisite for the recyclability of parts and components. In most cases, this will also reduce assembly time for the product. Therefore, paths for (dis)assembly should be minimized, connections should be easily detachable, etc.
82	Use easily detachable connections	Easily detachable connections (also after end of life!) reduce time consuming disassembly work. In addition, non-destructive disassembly is a prerequisite for the recycling or reuse of structural parts. If parts are damaged during disassembly only the material can be recycled; however, on account of the destruction of the material's structure this alternative yields less value than direct reuse of parts
83	Ensure easily visible access to connections for disassembly	Connections can be detached only if they can be easily found and accessed. Long searches for connecting parts will impair fast and efficient disassembly.
84	Ensure easy access to connecting parts	Connecting parts that are not or not easily accessible greatly impair disassembly. Work requires either special

ID	Name	Description
	for disassembling tools	tools (see example: long shank) or disassembly is cumbersome and time consuming because there is not enough room for using the tool.
85	Ensure functioning of connections over whole service life	Over time, external influences (aging, corrosion, soiling...) may impair the functionality of connecting parts. This makes it difficult or impossible to detach connections, thus complicating disassembly work considerably. Devices protecting connections from damage, such as covering caps over nuts and threads ensure detachability of connecting parts over the whole service life of the product.
86	Optimize the Component Design and Product Architecture	The correct design of products allow to facilitate its disassembly at End of Life phase, due to the use of appropriate connection elements and the correct disposition of its parts.
92	Facilitate the disassembly of those components more involved in the maintenance phase	Oven's design has been thought for the maintenance of the different sections. Detection and repairing of the different circuits are easy for the steam section and normal for others sections. In order to disassemble the heat convection fan is necessary to disassemble the two cover plates too. An improvement could be to adopt the same solution for the cooling fan.
93	Reduce the risk of fibre releasing in the air. Adopt strategies to avoid it.	In the multifunction electrical oven and the electrical oven the insulation needs some improvement intervention: the insulation sheets in fact should be covered (e.g. with aluminium sheet), in order to decrease the risks of release of some potentially dangerous air fibres (like asbestos), especially during the dismantling. Moreover because of the positioning of the insulation sheet very closed to the cooling fan, the risk of fibre releasing in the air could exist also during the late stage of appliance life.
94	Mark packaging materials	In order to facilitate the application of the correct disposal procedure, mark materials contained in the packaging with their chemical/commercial name.
95	Uniform the packaging material	Uniform the materials used in the packaging, trying to limit as much as possible the number of different materials used. At the moment, regarding Gas Hob, Induction Hob, Electricla Multifunctional Oven, Electrical Oven with Electrical Hob, the package components used were cardboard, plastics (LDPE and Polystyrene), seal assembly,

ID	Name	Description
		manuals/warranty paper.
96	Reduce the weight of packaging	In order to reduce the environmental impact related directly and indirectly to the packaging, reduce its weight. Prefer high quality materials, which allow to reduce the weight thanks to good performances. Electrolux products have shown a direct correlation between total wrapping material volume and total package volume and between total wrapping materials weight and total package weight. Maintain these direct correlation.
87	Optimize the quantities of transport means and their complete filling	In addition to packaging, transportation of the product constitutes a crucial factor for the overall environmental impact caused by distribution. It is therefore imperative to minimize hauling distances. One possible approach to realize this goal consists in the optimization of quantities of cargo and number of hauling operations by means of logistics concepts.
88	Preferably use reusable packaging	Robust packaging designed for multiple use reduces the overall input for packaging. Returnable packaging is particularly advantageous in the case of direct delivery. The supplier can take back and subsequently re-use packaging material.
89	Preferably use renewable raw materials for packaging	The use of renewable raw materials (i.e. non fossil materials, usually made from plant material) not only constitutes an adequate solution for the disposal of packaging material but also takes into account the issue of resources (renewables as an important criterion for sustainability).
90	Preferably use recycled materials or packaging materials suitable for established recycling processes	Using recyclable materials reduces the consumption of primary materials as well as the amount of waste generated. Materials for which there are already well established recycling channels facilitate recycling of packaging materials.
91	Label packaging materials (incl. instructions for disposal)	One of the prerequisites for recycling consists in clear labelling of packaging material. Packaging usually has only a very short life cycle; therefore labelling is particularly important in order to ensure appropriate recycling (value added) or environmentally acceptable disposal.
2	Select high quality materials characterized by low specific weight	High quality materials can help to provide high performance ad low weight, reducing the overall volume of material needed. The reduction of the product volume/weight can determine a reduction on the environmental impact related to the material phase.

ID	Name	Description
12	Select material characterized by high resistance	The selection of materials characterized by high resistance can determine a product longer life time, thus reducing the overall environmental impacts.
14	Use materials with an established closed loop	Use materials for which it is possible to realize one the following End of life Scenario: reuse, remanufacturing, recycle.
16	Avoid toxic substances	If the use of toxic substances cannot be avoided, a high detail in the BOM description is necessary for those substances. In this way an easily identification and separation could be guaranteed at their EoL.
18	Minimize material variety and select the same material for different parts where possible	Materials used in different product components should be uniformed, especially for components that are connected each other. In this way, their separation can be avoided, thus minimizing the disassembly operations and making easier recyclability operations.
19	Avoid the use of alloy's and composite materials	Alloy and composite materials have a low recyclability degree. Composites are mixtures of materials which have been chosen to achieve a particular set of properties – examples being glass reinforced plastics (GRPs), Carbon composites, and MDF. They are (generally) more expensive than standard materials, require specific production techniques and are generally difficult to recycle. However, given their structural properties, they should not be replaced with sub-standard materials for high-performance or safety-critical applications.
21	Use recycled materials	Prefer to use materials that come from recycled processes, instead of use virgin ones. Select materials with a high percentage of recycled inputs.
22	Select materials with a high level of recyclability	The use of recycled materials prevents non-biodegradable waste ending up in landfills. They also require less energy in terms of processing, and provided there is no contamination from other materials, can last several cycles before becoming obsolete. Reducing the number of additives used in materials can help reduce contamination and retain material properties.
23	Reduce the use of packaging and facilitate the identification of the packaging materials	Packaging materials should be reduced in weight and in volume, using the same case for different components if possible. A codification of packaging materials should be defined for the identification of EoL treatments.
27	Minimize material inputs	Simplification through the reduction of parts and general form will not only reduce waste and provide for easier end-of-life treatment, but will also reduce both assembly and disassembly costs. It is important that the

ID	Name	Description
		simplification of the design does not compromise its function or structural integrity. It is also important not to compromise the aesthetic qualities of the product, given how this may affect the product's perceived value and subsequent revenue.
29	Reuse materials present in the component	Prefer the use of the same materials in different product components, especially for those that are connected together, to increase their level of recyclability.
31	Minimize component number	Try to reduce the component number in order to reduce the whole product weight and consequently its environmental impact.
32	Optimize product functionality	A critical review of the structural design with a view to the functions needed may result in a considerable simplification by integration of functions. Combining several functions in one component does not only reduce material input but also facilitates assembly and disassembly as there are fewer connecting parts.
33	Select simple, easily dismountable and reparable parts	Assure that all components can be easily reached to be disassembled. Components that present high level of damage or wear should be collocated in strategic and easily accessible positions.
34	Ensure easy access to product component	In particular a rapid access should be guaranteed for critical component that need specific EoL treatments.
35	Identify components that are likely to wear or break and ensure easy access to these components	Components with the highest percentage of wear od damage should be identified and marked in the BoM with specific code. Assure that all components that have more frequent need of external actions are easily accessible. In this way the product can be repaired and its life time increase.
37	Optimize surface treatment	Opt for surface treatments or structural arrangements to protect products from dirty, corrosion, and wear. Consider that zinc and enamel coated have a high impect on the environment; if possible avoid them or identify possible technologial aternatives for them.
43	Reduce number of production phases	In order to minimize the environmental impact related to the use of the product, the minimization of production process con contribute to the reduction of product environmental load.
44	Minimize material inputs in packaging and select sustainable materials where	Opt for packaging solutions that minimize the weight, while determining a safety protection for the product.

ID	Name	Description
	possible	
45	Choose local suppliers where possible and select those that allow to minimize the distance from the production site	The selection of suppliers situated near to the production site is an important element to reduce the environmental and cost impact of the transportation phase.
46	Optimize transport planning, by preferring the transportation means that minimize environmental impact	Among the locally available systems choose the one that is environmentally most acceptable. Switching from transportation by truck to railroad or ship can drastically reduce damage to the environment.
47	Maximise amount of product per unit of packaging	Opt for solutions that minimize the packaging weight by inserting in the same case more than one product.
48	Opt for high efficiency component	Analyze the energy related component inside your product and evaluate alternatives able to reduce the energy consumption along the life cycle.
50	Maximize useful life of the product	Include in the product all those strategies that allow to optimize its functionality, increasing the life time and reducing the damage possibility
51	Optimize product modularity	Modular product has a positive impact on the minimization of components, due to a functional designing
52	Describe hazardous substances used in the product	The use of hazardous substances requires a high detailed descriprion in the BOM, in order to easly identify and sepate them to permit specific EoL tratments
53	Identify and mark materials used	The specification of materials used in a product, allow to easly identify the EoL tratments for the components. Specific material identification code should be used. Mark materials, especially plastics, above a minimum mass. Several standards have been also introduced to regulate nomenclature and labelling of plastics, rubbers and polymers
54	Realize a correct selection of fasteners	Fasteners play an integral part in the joining of components and subassemblies. In order to facilitate the product manual disassembly, to reduce its time and cost and to facilitate the material separation, designers should following some rules during the product design.
55	Reduce complexity of disassembly tools	Select connection types that can be disassembled with the use of simple tools. This facilitate the disassembly

ID	Name	Description
		operations and reduce the relative time, thus improving the product disassembly performances.
56	Collocate connection elements to make them rapid and simple to separate and to access	Easy access to connecting parts is a prerequisite for simple assembly and disassembly. Connecting parts should be arranged in such a way as to provide for good visibility and easy access with tools.
58	Use connection elements of similar dimension in order to minimize the number of tools needed for disassembly	The choice of similar connection elements determines the minimization of the number of tools needed for disassembly. This reduces the product disassembly time and cost.
59	Opt for high efficiency motors	In general brushless motor presents a higher efficiency in respect to asynchronous typology. Brushless motor typology in respect to asynchronous one allows to obtain an improvement of 20% in the efficiency
60	Maximize air flow rate for the same quantity of absorbed power	In the case of cooker hood, opt for blower able to maximize the air flow rate while minimizing the absorbed power
61	Opt for lamps with a low energy consumption	Consider the different lamp typologies energy consumption. Consult the attached document.
62	Evaluate the material compatibility	Identify if contaminations among components occur or not. Estimations should be based on the know-how of manufacturers and designers
63	Limit the surface covers	Identify and reduce surface covers (like paints, varnishes) and bonding agents (glues and adhesives) because of their potential to contaminate materials to be recycled.
65	Avoid the use of adhesive	Investigate the need of adhesives and investigate their effect on component recyclability. The use of adhesive should be reduced in order to avoid recyclability problems. if adhesives are necessary: — use adhesives with low hazardous solvent emission — minimise the use of silicone — choose seals which can be easily removed — remember clean surfaces facilitate recycling

Table 27. Product Table for oven

tbl_Products	
ID	Name
1	Oven

Table 28. Product Table for cooker hood

tbl_Products	
ID	Name
1	Cooker hood

Table 29. Functional group for oven

tbl_FunctionalGroups	
ID	Name
1	Body (chassis)
2	Cooling system
3	Cavity + Insulation
4	Steam module
5	Door
6	Control panel assembly
8	Wiring
9	Packaging
10	Electronic
14	Accessories
15	Documentation
16	Other

Table 30. Functional group for cooker hood

tbl_FunctionalGroups	
ID	Name
1	Blower
2	Cover
3	Electricity Supply
4	Electronic Control Board
6	Filters
7	Lamp
8	Support
9	Other
10	Motor-Impeller
17	Packaging

Table 31. Objective (for oven and cooker hood)

tbl_Objectives	
ID	**Name**
0	Minimize component weight
1	Reduce wear in the use phase
2	Increase product lifetime
3	Increase product recyclability
4	Minimize disassembly time
5	Minimize the use of natural resources
6	Improve packaging recyclability
7	Minimize transport impact
9	Minimize wastes production
10	Improve product reparability
11	Improve product disassemblability
12	Reduce maintenance
17	Minimize material consumption
18	Minimize transport impact
19	Minimize resources and energy input
20	Minimize energy consumption
21	Increase use efficiency
22	Maximize energy efficiency index
23	Improve component recyclability
24	Increase of lighting efficiency
25	Minimize component toxicity
26	Minimize risks for operators
27	Consider the food Preparation Global Component Specifications
28	Reduce the environmental impact of component

Table 32. Guideline Objective Table (for oven and cooker hood)

tbl_Phases	
ID	**Name**
0	Material
1	Manufacturing
2	Use
3	Transport
4	End of Life
5	General

Table 33. Standard component Table for the oven

ID	Name
1	Chassis U-shape
2	Hinge support
3	Air duct
4	Component Carrier
6	Radial motor plate
7	Radial cooling motor
8	Temperature thermostat
9	PT500 sensor
10	Electronic board oven
11	Electronic board food probe
12	Terminal box
13	Food probe
14	Loading tube assembly, hot steam system
15	Water drawer assembly
16	Cavity support
17	Cavity
18	Heating element
19	Insulation
20	Side grid clip
21	Fan cover
23	Dripping pan
24	Telescopic runner
25	Wire shelf
26	Front frame
27	Door gasket
28	Lamp + gasket
29	Outlet valve
30	Steam pipe
31	Hot air fan (motor)
32	Otlet filter assembly
33	Overfilling pipe
34	Water tank assembly
35	Water level sensor
36	Steam generator
37	Plastic door assembly
38	Metal panel
39	Door glass
40	Handle
41	Closure
43	Glass front panel
44	Panel buttons

ID	Name
45	Timer hexagon TT
46	Oven switch
47	Knob hole cover
48	Knob
49	Steam cap adapter
50	Steam hole cover
51	Polystyrene
52	Wiring
53	Motor support
54	Wrapping
56	Tape insulation
57	Chimney
58	Catalytic filter
59	Lamp
60	Heating element support
61	Door panel
62	Handle adapter
63	Hinge
64	Space bush
65	Klikson
66	Baking tray
67	Wire shelf
68	User manual
69	Labels
70	Outlet valve
71	Steam pipe
72	Steam gasket
73	Enamel
74	Paint
75	Screw
76	Nut
77	Washer
78	Silicon
79	Bag
80	Clamp
81	Indicator lamp
82	Cardboard
83	Glue
84	Grid

Table 34.Standard component Table for the cooker hood

ID	Name
1	Capacitor
2	Chimney
3	Cover
4	Aesthetic Panel
9	Motor-Impeller
10	Blower (right)
11	Blower (left)
12	Transformer
13	Electronic Board
14	Grease Filter
15	Carbon Filter
16	Lamps
17	Supports
18	Plastic Parts
19	Metal Patrts
20	Electric Motor
27	Packaging

Table 35. Sources Table (for oven and cooker hood)

tbl_Sources				
ID	**Name**	**Author**	**Source**	**Date**
16	CSA report			
1	ECODESIGN in the electronics industry - achieving legal compliance with the EU-directives and environmentally improving products by using the new EEE-PILOT	Wimmer W., Pamminger R., Stachura M., Grab R.	Fourth International Symposium on Environmentally Conscious Design and Inverse Manufacturing	2005
2	EcoDesign and The Ten Golden Rules: generic advice for merging environmental aspects into product development	Luttropp C., Lagerstedt J.	Journal of Cleaner Production, 14 (15-16), pp.1396-1408.	2006
3	User-centred design for sustainable behaviour	Wever R., van Kuijk J., Boks C.	International Journal of Sustainable Engineering, 1 (1), pp.9–20.	2008
4	Determining end-of-life strategies as a part of product definition. Electronics and the Environment	Rose C.M., Beiter K.A., Ishii K.	ISEE-1999. Proceedings of the 1999 IEEE International Symposium on. pp. 219–224.	1999
5	Design for Environment: A Method for Formulating Product End-of-Life Strategies	Rose C.M.	A dissertation submitted to the Department of Mechanical Engineering and the Committee on Graduate Studies of Stanford University in partial fulfilment of the requirements for the degree of Doctor of Philosophy	2000
6	Ecodesign - Pilot		http://www.ecodesign.at/pilot/ONLINE/ENGL	

tbl_Sources				
ID	Name	Author	Source	Date
			ISH/INDEX.HTM	
7	Georgia Institute of Technology		http://www.srl.gatech.edu/education/ME4171/DFR-Improve.ppt#3	
8	Design for Disassembly Guidelines			2005
9	ENEA E-learning platform		http://192.107.92.31/fadivgen2/index.asp	
13	MOTORI ELETTRICI E VARIATORI DI VELOCITA' AD ALTA EFFICIENZA			2007
14	Pack-guide		www.envirowise.gov.uk	2008
15	RoHS Directive		http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:174:0088:0110:en:PDF	2011
17	Electrolux internal specification			
18	JRC			
19	Oven LCA Report			

APPENDIX B: CBR TOOL ATTACHMENT

In this Appendix the content of an attachment is shown. In particular the example presented is related to the Fastener selection guideline.

Fastener selection guide

Fasteners play an integral part in the joining of components and subassemblies. In order to facilitate the product manual disassembly, to reduce its time and cost and to facilitare the material separation, designers should:

- Minimise the number of fasteners used within an assembly.
- Minimise the types of fastener used within an assembly.
- Standardise the fasteners used.
- Not compromise the structural qualities of the assembly by using too few or inadequate fasteners.
- Use snap-fits where possible to eliminate the need for a fastener
- Consider work-hardening, fracture, fatigue failure and general wear when designing snap-fits.
- Consider the use of destructive fasteners

		Recyclability		Detaching behaviour		Joining behavior		Carrying capacity	
		Material recycling	Product recycling	Destructive detaching expenditure	Detaching expenditure	Guidance expenditure	Joining expenditure	Fatigue strength	Static strength
Material connection	Adhesive bonding	average	poor	average	poor	poor	average	average	average
	Welding	good	poor	average	poor	poor	average	good	good
Fictionnal connection	Magnetic	average	average	n/a	good	average	good	average	average
	Velcro	average	average	n/a	good	good	good	poor	poor
	Nut & bolt (metal)	average	average	average	average	average	average	good	good
	Nut & bolt (plastic)	good	good	good	average	average	average	average	average
	Spring connection	good	good	n/a	good	good	good	poor	average
Positive connection	Snap	good	poor	good	poor	good	good	average	good
	Bent lever	good	good	average	good	average	good	average	good
	1/4 turn	good	good	average	good	good	good	average	good
	Press-turn	average	good	average	good	good	good	average	average
	Press-press	average	good	average	good	good	good	poor	average

In general, metal parts are easily recycled, but the following rules and guidelines apply:

- Corroded fasteners cause severe problems for fast removal of parts. Selects fasteners coating which minimize corrosion. Cadmium coating should not be used because of potential health and environmental hazard.
- If metal fasteners are used, prefer ferromagnetic metals to allow a magnetically sorting during dismantling
- Facilitate the access to fasteners
- Mark not visible links

- Avoid using hidden links

However, if the fastener is to be in contact with water and humid conditions, this may be to prevent corrosion. Anodizing is a possible option (N.B. Cadmium coatings should be avoided, given the potential health and safety risks they pose).

Access to the fasteners is also important. Holes which are complete (i.e. follow through the entire section of the component) allow for the fastener (e.g. snap-fastener) to be tapped out as opposed to being pulled out.

Consult the following table to evaluate different types of fasteners behaviour against recyclability, disassembly, accuracy of the link or loading capacity.

APPENDIX C: CRB TOOL USER MANUAL

Name of tool: CBR

Primary function of tool and the lifecycle phase it addresses: This tool aims to support the designer in the product development phase, taking into account the ecodesign guidelines and company knowledge along with classical design criteria. The tool addresses all the phases of the product life cycle, which the designers can improve in environmental terms through implementation of the guidelines and the suggestions contained in the tool database.

Primary users of tool and the corresponding interface by which they access it: the main user of the tool would be a design engineer.

Any secondary users of tool and the interface by which they access it: the main user of the tool would be supervised and supported by a product development manager, a sustainability manager and a product stewardship manager, who would be responsible for updating the internal tool databases.

Step-by-step process of operation from CAD/PLM/Web (including screen shots):

The user should initially:

- Chose the visualisation mode from the main interface (Figure 127) the user has to select the desired visualisation mode. He can chose to:
- Browse Ecodesign guidelines through the product structure visualisation (case 1). This feature can be performed by importing an XML BOM file;
- Browse Ecodesign guidelines and Ecodesign knowledge manually (case 2);
- Open a previous project saved in the CBR format (case 3) and then enter into the case 2 or case 3.

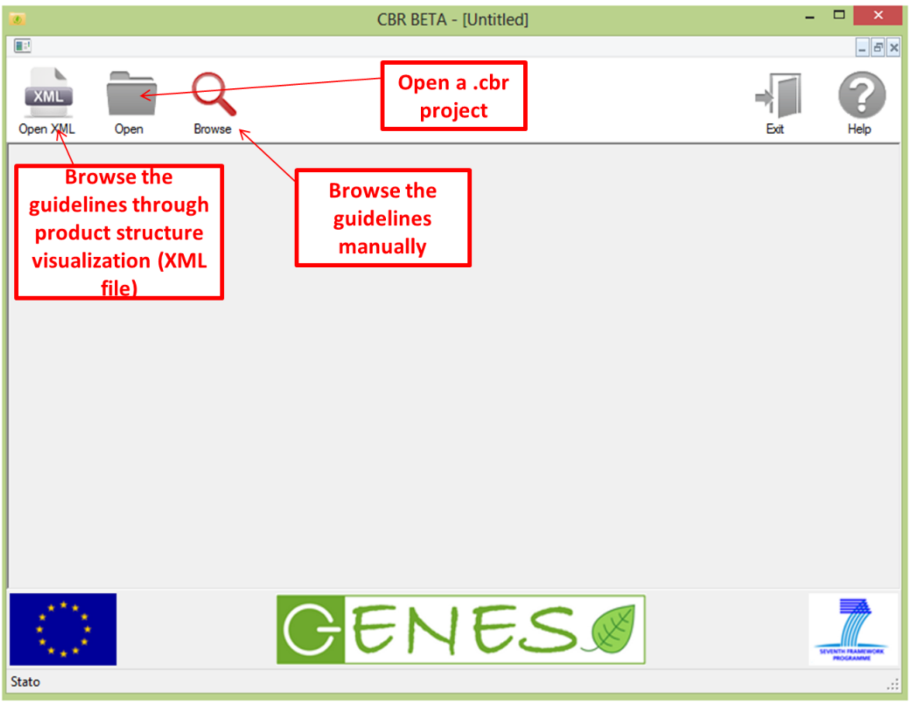

Figure 127. CBR first interface

Case 1: if the user choses the Product structure visualisation mode he has to click on the “Open XML” icon. The tool automatically imports the complete product structure and the related design choices made by the G.EN.ESI users in the other platform tools. Then the user has to perform the following steps (Figure 128):

- **Assign product family**. When the user assigns a family to the product under investigation the tool filters the ecodesign guidelines for the specific product family.
- **Select a component from the product structure**
- **Assign a functional group and standard components for the desired parts**. If he has selected a component from the product structure; he can also assign a functional group and a standard component in order to filter the results further. In this way, for each selected component, the relevant ecodesign guidelines are filtered and presented to the user in the table at the bottom of the interface screen.
- Filter the Ecodesign guidelines by lifecycle phase and objective: the user can further filter the ecodesign guidelines by specifying the lifecycle phase of interest and/or the design objective.
- **Ecodesign guidelines consultation for each component and assembly**. Once the guidelines have been filtered, they are presented to the user in a table. The table contains:
  - the guideline name;
  - a description of the guideline if clarification of the meaning is required;
  - a possible attached file, containing further details for the specific guidelines, helping the user to better understand the guideline meaning;
  - the phase or phases to which the guideline is related;
  - the objective/objectives that the guideline addresses;
  - the product family to which the guideline is related;
  - the source and the date when the guidelines were uploaded into the Tool Data-Base.
- **Generate a report** in which the product structure and selected ecodesign guidelines will be reported in a .csv file that can be opened through an Excel file. The product structure, the guidelines selected for each assigned standard component and possible notes are summarised in this file (Figure 129).
- **Save the analysed project**: at the end of the project, the user can save the project in order to be stored in the Knowledge database; these CBR files constitute the ecodesign knowledge about past design solutions that can be retrieved by the user in the knowledge section (Figure 129).

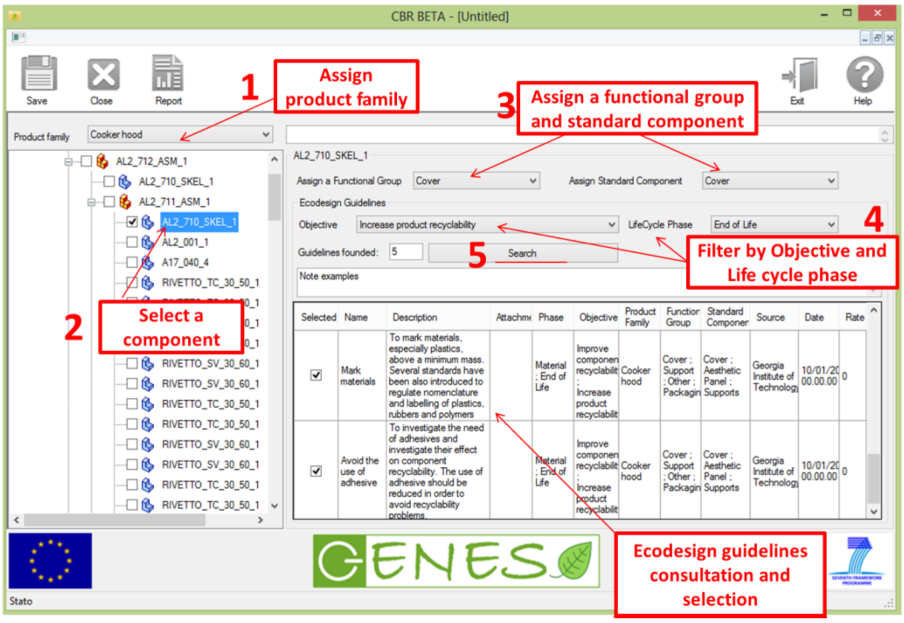

Figure 128. Tool main functions

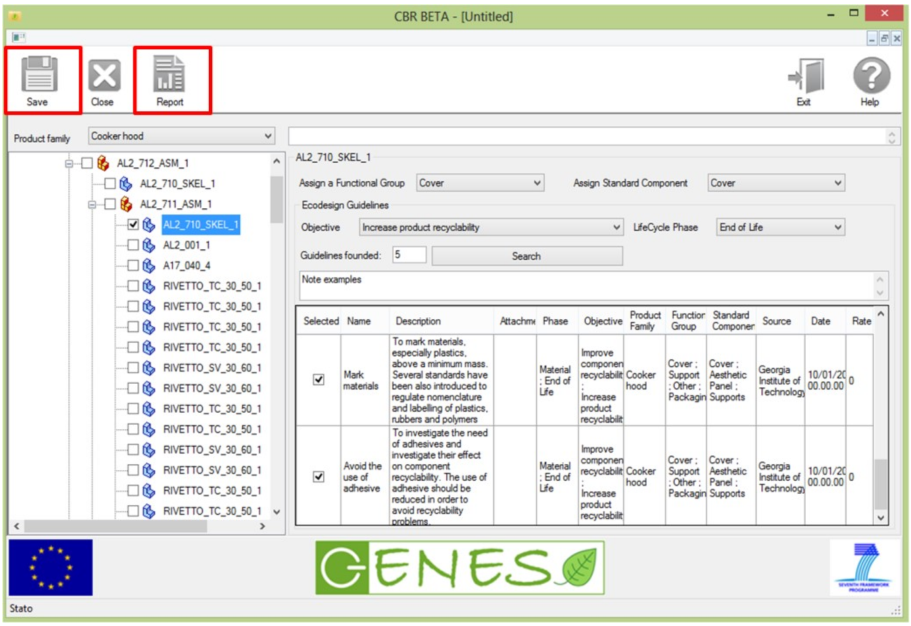

Figure 129. Save and Report functions

Case 2: If the user chooses the Ecodesign guidelines browse visualization mode, he has to click on the icon "browse" on the main interface which then opens the "Ecodesign guidelines" panel. The user at first should (Figure 130) Assign Product family, functional group and standard components for components he wishes to analyse. The user assigns a family to the product under investigation in order to filter the ecodesign guidelines by family, and can also assign a functional group and a standard component for a further filtration. Then he can:

- **Filter the Ecodesign guidelines by lifecycle phase and objective**: the user can further filter the ecodesign guidelines by specifying the lifecycle phase of interest or/and the design objective.

– **Consult Ecodesign guidelines, according to the filters selected**: after the filtering activities the Ecodesign guidelines are presented to the user in a table at the bottom of the interface screen.

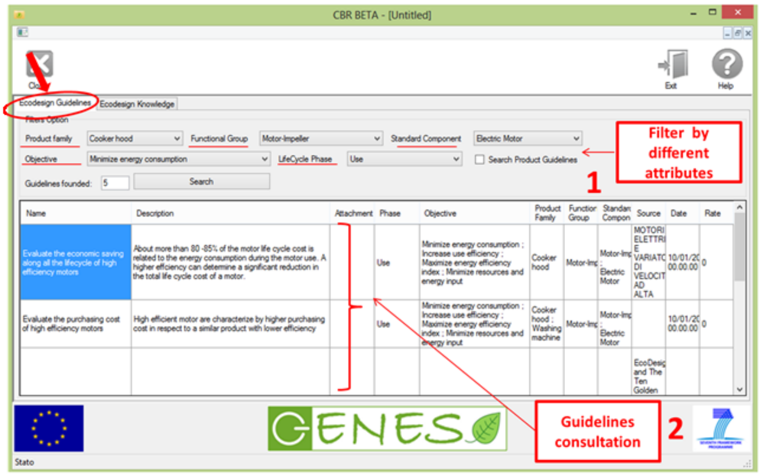

Figure 130. Browse visualisation mode of ecodesign guidelines

The user can also open the **Ecodesign Knowledge screen**. In this screen, he has to select a product family, to specify the folder in which previous .cbr projects have been saved (by using the "browse" function), and click on the icon "search". The tool automatically retrieves these previous projects, and the user, by double clicking on them, can view the detail of past projects. The user can in view (Figure 131):

– the product structure,

– the functional group,

– the standard component that corresponds to the components analysed with the tool,

– the guidelines consulted and the notes added during past uses of the CBR tool.

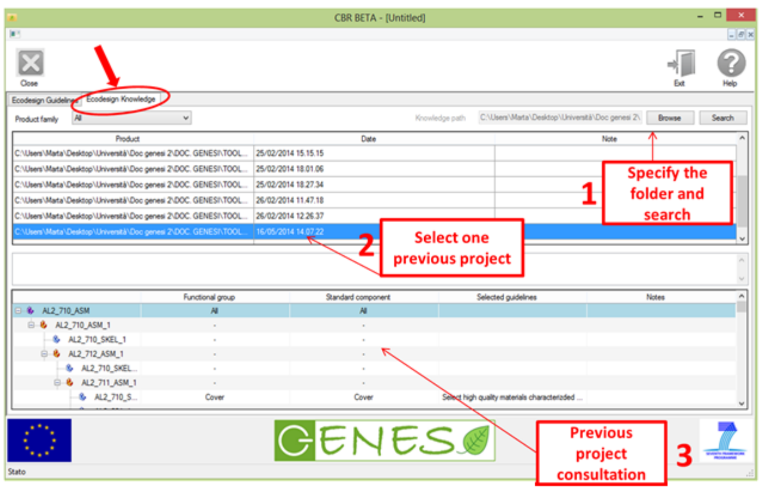

Figure 131. Browse visualization mode of company ecodesign knowledge