COMPARISON AND CLASSIFICATION OF ECO IMPROVEMENT METHODS

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Abstract

The number and breadth of eco-improvement methods has been steadily rising over the past decades to include design for X methods and more problem-solving oriented software, based on the Russian TRIZ methodology, and the integration of CAE software and optimization techniques. With such heterogeneous approaches, there is a need of a quantitative classification scheme to help the designer in choosing the best method for each environmental scenario.

In the present paper, we propose a comparison and classification, based on the number of eco-guidelines and their distribution on standard impact categories, of 17 of the most known Eco-improvement methods.

Furthermore, we propose an interactive selection software that gives the user the ability to exclude or give priority to some life cycle phases and impact categories; empowering him to select the most fitting eco-improvement method or to create a list of the relevant eco-guidelines across all the analysed methods.

Keywords: Ecodesign, LCA, classification

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1 INTRODUCTION

Over the last two decades, a growing number of methods and tools for Ecodesign has reached a vast audience, both in the academic and the industrial field. According to the taxonomy proposed by Maxwell et al. (2006), Ecodesign tools are part of a wide range of design approaches for reducing products environmental impacts. If compared with a full sustainable design, Ecodesign encompass environmental considerations for product design, but without employing ecological principles and without addressing social and ethical aspects (Knight and Jenkins (2009)).
After the concept of sustainable development was introduced, many organizations revised their own method to meet environmental requirements for products and services. During the 1990s, a high number of publicly funded projects has been conducted to develop an effective Design for Environment (DfE) approach (Nelson et al., 2009).
The Ecodesign field encompasses a vast number of tools, procedures, and norms, developed from private and public initiatives, aimed at reducing the environmental footprint of products, processes and services. A survey presented by Baumann et al. (2002) in early 2000s identified more than 150 existing methods and tools for green product development, highlighting the frequent lack of practical relevance or testing, and the tendency to develop new tools rather than to evaluate and improve existing ones. One of the reasons is surely the relatively recent introduction of environmental issues into the traditional design field (Russo et al. 2011).
This variety of methods generated some uncertainties regarding characteristics, differences and possible synergies among the tools, as well as issues on finding the best way for their implementation (Robèrt et al., 2002), (Vallet et al. 2009), (Fargnoli et al. 2005). Therefore, with the intent to pursue a higher comprehension, many authors tried to make sense of the fast-growing Ecodesign field by developing different classifications and comparisons. The authors conducted a deep analysis of the existing classification methods in the field of DfE, highlighting the preponderance of qualitative approaches. In fact, most of them are concentrated on identifying taxonomies and qualitative parameters that fit with existing methods, and just a few include questionnaires and expert interviews. The lack of quantitative and objective data is noticeable. There is a need for consistent methods for the assessment and selection of available Ecodesign methodologies, in order to help designers in choosing a suitable tool for their needs.
We propose a comprehensive comparison of existing eco-improvement methods based on a quantitative scoring scheme that values both the number of guidelines and their distribution among the impact categories and life cycle phases. The main goal of the study is to provide the designer with the means to choose the correct eco-improvement method based on the scope of the design effort and the relevance of the method to the product to be redesigned. For this, we propose an interactive selection scheme that tailors the scoring system to the user's choice of life cycle phases and impact categories; adjusting the classification around the user's design needs.
The structure of the paper is as follows. Section 2 presents a state of the art about previous classifications of eco-improvement methods and tools, section 3 details the data collection and analysis phase, as well as the proposed scoring system, and section 4 describes the current embodiment of the interactive selection scheme.

2 STATE OF THE ART OF PREVIOUS CLASSIFICATIONS

For what concerns comparative analyses, Knight and Jenkins (2009) involved a focus group of selected technical experts for a qualitative evaluation of a subset of eco-tools, investigating their potential applications along the overall design process. Luttropp and Lagerstedt (2006) analysed the existing eco-guidelines in order to define the so-called "Ten golden rules" for sustainable design. Panarotto and Törlind (2011) developed a qualitative analysis matrix of the most adopted Eco-tools based on the following parameters: Complexity/Time requirements; Use in companies; Aiding the innovation process; Final assessment of solutions; Observe products/market and Life cycle perspective.
In addition, with regards to the evaluation of the relationships among different approaches and the accessibility to DfE methods, Robèrt et al. (2002) defined five basic complementary levels to completely cover the horizontal design process and the vertical design dimension, from organizational aspects to final product features.

A consistent research presented by Byggeth and Hochschorner (2006) analysed the core characteristics of 15 Ecodesign methods and classified them using the following criteria:

- Methods and tools for environmental impact assessment. They study and assess environmental impacts associated with all the stages of a product life cycle, in order to highlight environmental criticalities and focus the designer attention on the most impacting aspects of the product. Such methods can be used both for the evaluation of a single product and for the comparison with a best in class. Life Cycle Assessment (International Organization for Standardization, Geneva, 2006) is the most adopted approach.
- Methods and tools for the comparison of environmental design strategies and product solutions. They provide a consistent comparison among different strategies or solutions during the design process, in order to identify the top performing in terms of environmental criteria. This category consists of intuitive and simple methods that necessarily require a reference product. For example, spider web diagrams (Wong et al, 2010) belong to this category.
- Methods and tools for active eco-improvement. They consist of guidelines with varying level of detail that help designers to adopt solutions that aim at reducing product environmental impacts. Some of them work as a step-by-step guide (checklist) that can be followed in order to maximize the product environmental performance.

More generally, we can identify two main categories: “Analysis and evaluation” and “Improvement” (Le Pochat et al., 2007). Ecodesign methods are thus divided in Eco-Assessment methods, that allow the analysis and evaluation of products environmental impacts, and Eco-Improvement methods, i.e. approaches that suggest possible solutions to overcome environmental criticalities by means of design guidelines. This paper will focus on the latter.

3 DATA COLLECTION AND ANALYSIS

We have collected and analysed a selected pool of 17 of the most popular guidelines-based eco-improvement methods and software, in order to categorize each individual guideline based on the targeted life cycle phase and environmental category. The paragraph 3.1 lists the chosen eco-improvement methods, each with a brief description, paragraph 3.2 explains how the methods were categorized, paragraph 3.3 describes the scoring scheme, and finally paragraph 3.4 outlines the classification main results.

3.1 Considered methods and tools

We have analysed the following methods:

The ten golden rules: developed by Luttropp and Lagerstedt (2006), they are a generalized series of guidelines that synthesize a long time experience of environmental-related academic studies. The proposed ten rules suggest the following ways of intervention: minimize toxicity, housekeeping, reduce weight, reduce energy, product upgrade, improve product life, protect, manage information, mix different materials, and reduce the number of components.

CONAI dossier 2010: developed by the CONAI consortium (www.conai.org) and based on a long experience of industrial applications, the dossier has organized more the 600 guidelines into a limited number of possible goals like reducing raw materials consumption, use of recycled materials, logistic optimization, packaging simplification, etc.

Design for Environment Guidelines (DFE): developed by the Japanese no profit organization Global Development Research Centre (www.gdrc.org), the method aims at reducing the product or service environmental impact during the design phase. In particular, it suggests a series of specific guidelines for each of these phases: material extraction; production; transport, distribution and packaging; use; end of life; disassembly, and recycling.

ECODESIGN online PILOT: developed by the Vienna University of Technology (www.ecodesign.at), the method collects a series of guidelines personalized and categorized according to five classes of products. Products with an intensive raw materials consumption (e.g. computers), products with an intensive manufacturing (e.g. furniture), products with a high impacting transport phase (e.g. bottles), products with a high impacting use phase (e.g. household appliances), and products with a problematic disposal (e.g. batteries).

Philips’s Fast Five Checklist: introduced by Network (2008) and developed by Philips, the method compares the product to improve with a reference one, highlighting the best way to redesign it

according to 5 categories of intervention: energy consumption; degree of recyclability; content of hazardous waste; durability, reparability and preciousness, and alternative ways to provide the service.
PIT DIAGRAM, Product Ideas Tree: The PIT diagram is a method for clustering Eco-innovation ideas and documenting them clearly. The method combines: some key-starting points for Eco-innovation, a hierarchical structure for ideas, and the Mind mapping technique to produce valuable documentation in the form of maps.
Life-Cycle Design Strategy Wheel (LiDS): introduced and developed by (Brezet and Van Hemel, 1997), the method proposes eight classes of guidelines to evaluate the system at the current stage and to improve it.
NF E 01-005: a French normative of 2010 specific for mechanical products design, divided into five phases that suggest a certain number of improvement actions and provide a set of indicators to measure the quality of the results.
Ecodesign Checklist Method (ECM): developed by Wimmer (1999) and commonly used as a complement to the MET matrix, the method aims at reducing the product environmental impact during its design by way of a checklist and related strategies that cover the entire product lifecycle.
Ecodesign strategies (EEE) ECOSMES: developed by ECOSMES Masoni et Al. (2004), Ecodesign strategies outlines practical design considerations for producers of Electronic and Electrical Equipment (EEE).
Sony's green product check sheet and product profile: developed by Sony starting from 1954, it proposes long-term environmental improvement measures based on the entire product lifecycle.
Smart Ecodesign Checklist: developed by Clark and Charter (1999), Smart Ecodesign Checklist is intended to help manufacturers of passive electric components meet the ever-increasing demand for eco-friendly components. Each of the sections starts with a checklist, followed by background information and more detailed advice.
ECMA 341 - Environmental design considerations for ICT & CE products: This Standard applies to all audio/video, information and communication technology equipment. The purpose of the document is to help designers of products in the field of audio/video, information technology and communication to appropriately manage related environmental issues within the design process.
Ecodesign Strategies ECOSMES: developed by ECOSMES Masoni et Al. (2004), Ecodesign strategies targets the entire product life cycle with a set of guidelines arranged by life cycle phase (www.ecosmes.net/).
Eco-estimator: developed by Philips, Eco-estimator is an Ecodesign checklist focused on electrical and electronic products. It is a two-page questionnaire used to assess the total environmental impact of the product and compare it to a reference one.
Eco-map: developed by the University of Bergamo Russo et al. (2014), Eco-map is a smart framework for LCA-targeted eco-guidelines. It combines sustainable product development with problem solving methods like TRIZ (Russo et al. 2008).
Ecodesign Strategies IPPTEL: developed during the IPP-TEL project, the manual includes abstracts and conclusions from the studies conducted throughout the IPPTEL project and guidelines on the eco-design of electronic products, in combination with optimised end-of-life management options.

3.2 Categorization

To classify the different methods listed in the previous paragraph we identified two main category groups: life cycle phases and impact categories. The key life cycle phases are: Pre-manufacture, the acquisition of raw materials; Manufacture, the set of industrial processes involved in the production of the final goods; Use, the actual usage of the product; and End of life, the recycle and disposal of the exhausted goods. Impact categories represent a subdivision of each life cycle phase. Thirteen classes have been identified, ranging from material consumption, energy consumption, packaging and transport, to reparability, maintenance, and disassembly.
Thanks to this two category groups, we have a complete characterization of each method, describing when it acts and in which way; using the second level to refine the first. In the following, we describe the two category groups and their features.

3.2.1 Product lifecycle coverage

The most relevant environmental improvements are achievable through the optimization of the entire product life, from the procurement of the raw resources required for its creation, to its final disposal.

According to the well-known concept of cradle-to-grave (Vezzoli and Sciama, 2006) and its evolution, cradle-to-cradle (Braungart and McDonough, 2008), Eco-Improvement methods should encompass all the phases that characterize products lifecycles, allowing a global estimation of environmental impacts (Tsai et al., 2011). Product lifecycle coverage criteria takes under consideration the ability of a method to cover the whole product life cycle, in order to understand the extent to which designers can operate for the improvement of the environmental performance.

In literature, various interpretations and definitions about products life cycle have been presented. The most common approach defines four main phases and a few additional phases. The four main phases represents a temporal evolution of the product: Pre-manufacture, Manufacture, Use and End of life.

Relying on these considerations, methods and tools for Eco-Improvement specifically applicable to a single lifecycle phase have a low level of lifecycle coverage, while tools that encompass the entire life of the product have a high lifecycle coverage.

3.2.2 Impact categories coverage

Eco-Improvement methods provide specific guidelines for each considered phase. Guidelines are generally conceived to deal with common environmental topics, defined as essential points of matter, concerning the product life cycle, that are critical for the overall environmental performance. These criteria tend to emphasize methods that encompass the widest set of possible criticalities related to the product and the whole system around it.

In the Pre-manufacture phase, the topics to be considered are the ones related to raw materials and semi-finished products management, including resources extraction, processing, packaging and supply. Manufacturing comprises topics associated with production activities, such as energy consumption, waste production, internal logistics, packaging and transport. Topics considered in the product Use phase encompass the product useful lifespan, from the moment it exits the plant gates till the end of its useful life; including the necessity of consumables, functioning energy, as well as maintenance, repair and renewal. Lastly, a consistent Eco-Improvement method should comprise guidelines that provide the designer with effective information related to product End of life management, such as recycling, stocking and disposal.

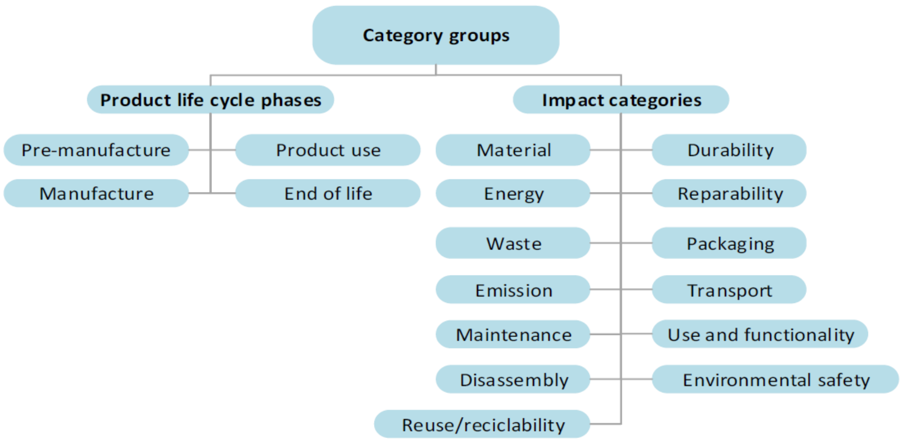

Figure 1. The analysed category groups

3.3 Analysis criteria

The proposed classification aims at characterizing each eco-improvement method as the sum of each of its guidelines. To do this we studied each single guideline to understand what life cycle phases it pertains to and what impact categories it targets. Finally, the sum of all the guidelines for each method matches the method classification.

In order to retain the total number of guidelines throughout the scoring procedure, each guideline total score is equal to 1. Thus, the score for each impact category or life cycle phase is equal to one divided by the total number of targeted categories.

- if the guideline explicitly specifies a precise feature to improve, we attribute the entire scoring of the guideline to said feature (score 1);

- if the guideline targets 2 or more features, we equally divide its scoring to the correspondent features (score 0,5 for the first feature and score 0.5 for the second feature);
- if the guideline contributes simultaneously to N features, we equally divide its scoring between all the features (score 1/N for each feature).

The following table details the scoring scheme:

Table 1. Guidelines analysis criteria

Eco-improvement method "A"					
Guidelines	**Text of the guidelines**	**Feature 1**	**Feature 2**	**Feature 3**	**TOTAL**
Guideline 1	*Text guideline 1*	1			1
Guideline 2	*Text guideline 2*	0,5	0,5		1
Guideline 3	*Text guideline 3*	0,33	0,33	0,33	1
Total		1,83	0,83	0,33	3
		61%	28%	11%	

As aforementioned, the sum of each line is always one, but, through the sum of each column, the designer can appreciate how the selected method arranges its guidelines, and whether it has a focus on a particular life cycle phase or impact category.
By applying the same scoring system to all the selected methods, we can obtain the complete classification, where each feature is equivalent to a life cycle phase or impact category.
The following table details the combined scoring scheme.

Table 2. Methods comparison criteria

Methods	**Number of guidelines**	**Feature 1**	**Feature 2**	**Feature 3**
Method "A"	3	1,83	0,83	0,33
Method "B"	9	6	3	
Method "C"	50	30	12,75	7,25
Total		**37,83**	**16,58**	**7,58**

The combined results across the entire list of considered methods is particularly useful not only as a selection tool, but also to determine trends and areas which have been so far ignored by current eco-improvement methods.

3.3.1 Deviation and quantity

To help the designer in choosing the correct eco-improvement software for his needs, the proposed analysis determines the quantity of relevant guidelines and their distribution among the environmental impact categories and life cycle phases. The number of relevant guidelines, combined with their distribution, is a measure of how comprehensive or specific a software is. Thus, an eco-improvement method with a high number of guidelines and a narrow distribution, like NF E 01-005, will probably feature very specific guidelines, targeted to a specific life cycle phase or a subset of impact categories. On the contrary, a software with a high number of guidelines and a broad distribution, like Ecodesign Strategies IPPTEL, should be a very comprehensive method, applicable in most instances, though with a more generalized approach.
The methods' distribution was determined as the reciprocal of the standard deviation of the number of times each life cycle phase or impact category is targeted by an eco-guideline. Thus, a method with a high distribution score arranges its guidelines evenly across both life cycle phases and impact categories.
To distinguish between life cycle phases and impact categories, the two separate standard deviations were composed as follows:

$$\sigma = \sqrt{\left(\frac{\sigma_{ph}}{n^\circ_{phases}}\right)^2 + \left(\frac{\sigma_{cat}}{n^\circ_{categories}}\right)^2 + \left(\frac{\sigma_{ph}\cdot\sigma_{cat}}{n^\circ_{phases}\cdot n^\circ_{categories}}\right)^2} \Big/ \left(n^\circ_{phases} + n^\circ_{categories}\right) \quad (1)$$

Where:

- σ_{ph} is the method standard deviation among the selected life cycle phases
- σ_{cat} is the method standard deviation among the selected impact categories
- $n°_{phases}$ and $n°_{categories}$ is the number of selected phases and impact categories respectively

N.	Software	Life Cicle Phase: pre-manufacure	Life Cicle Phase: manufacture	Life Cicle Phase: product use	Life Cicle Phase: end of life	Categories: material	Categories: energy	Categories: waste	Categories: emission	Categories: maintenance	Categories: disassembly	Categories: reuse/reciclability	Categories: durability	Categories: reparability	Categories: packaging	Categories: transport	Categories: use and functionality	Categories: environmental safety	Guidelines	Distribution
1	The Ten Golden Rules	23%	23%	23%	33%	23%	13%	3%	5%	7%	0%	10%	22%	13%	0%	3%	0%	0%	10	
2	CONAI dossier 2010	25%	25%	25%	25%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	7	
3	DFE: Design for Environment Guidelines	25%	15%	37%	23%	32%	10%	6%	14%	1%	0%	7%	9%	2%	2%	6%	0%	11%	30	
4	ECODESIGN online PILOT	31%	33%	17%	19%	8%	3%	2%	2%	8%	7%	16%	11%	8%	5%	5%	16%	8%	36	
5	Philips's Fast Five Checklist	16%	16%	41%	28%	8%	13%	10%	0%	0%	0%	15%	20%	10%	0%	0%	13%	10%	10	
6	PIT DIAGRAM: Product Ideas Tree	5%	32%	32%	32%	32%	18%	18%	0%	0%	5%	14%	9%	0%	0%	0%	5%	0%	11	
7	LiDS: Life-Cycle Design Strategy Wheel	30%	20%	33%	17%	22%	19%	7%	0%	2%	2%	13%	3%	2%	3%	9%	14%	6%	33	
8	NF E 01-005	26%	25%	36%	13%	23%	11%	7%	5%	1%	4%	13%	2%	1%	3%	6%	15%	9%	52	
9	ECM: Ecodesign Checklist Method	29%	21%	32%	18%	23%	17%	11%	0%	1%	1%	13%	1%	1%	3%	11%	13%	3%	35	
10	Ecodesign strategies (EEE) ECOSMES	20%	30%	30%	20%	42%	14%	0%	5%	2%	5%	12%	3%	0%	3%	0%	14%	0%	11	
11	Sony's green product check sheet and product profile	25%	25%	25%	25%	28%	11%	0%	0%	0%	11%	22%	11%	0%	11%	0%	0%	6%	9	
12	Smart Ecodesign Checklist	24%	20%	37%	20%	27%	12%	12%	3%	2%	7%	1%	7%	1%	7%	2%	9%	10%	23	
13	ECMA 341 - Environmental design for ICT & CE products	16%	16%	14%	53%	23%	10%	1%	7%	0%	12%	5%	2%	1%	5%	0%	21%	14%	41	
14	Strategie di ecoprogettazione ECOSMES	11%	22%	42%	25%	25%	10%	5%	0%	2%	3%	8%	3%	9%	7%	0%	17%	10%	29	
15	Eco-estimator	25%	25%	25%	25%	18%	8%	0%	0%	0%	15%	10%	0%	8%	10%	0%	19%	12%	13	
16	Ecodesign Strategies IPPTEL	23%	26%	23%	28%	17%	12%	4%	1%	1%	2%	11%	2%	1%	14%	11%	14%	8%	45	
17	Eco-map	20%	34%	24%	23%	18%	9%	3%	1%	1%	1%	9%	0%	0%	14%	39%	1%	5%	80	

Figure 2. Eco-improvement software classification

3.4 Main results

The complete table of the 15 analysed methods shows the following trends:

- Main topics across the entire set of methods are: material consumption, energy consumption, reuse/recyclability, and use and functionality; on the contrary, the least considered categories are: maintenance, emission, and reparability.
- There are few category-specific methods (e.g. CONAI dossier 2010) and none phase-specific.
- Methods with a very low number of guidelines can show a high level of distribution (low standard deviation). This may be due to their intended broad applicability and generic approach, or to the fact that generic guidelines are hard to categorize and have an inherent broad applicability.

Essentially, we can identify two complementary approaches: on the one hand, some software have a high amount of eco-guidelines with a narrow distribution: Eco-map, ECMA 341, NF E 01-005, and ECODESIGN online PILOT; on the other hand, some software offer only a few guidelines with a broader scope: Eco-estimator, Sony's green product check sheet, and The Ten Golden Rules. Only one eco-improvement method tries the middle ground, offering a good amount of guidelines with an even distribution: Ecodesign Strategies IPPTEL.

The two different approaches are typically aimed at different design scenarios. An eco-improvement method with a broad scope, like The Ten Golden Rules, is best suited in the absence of a complete LCA (Life Cycle Analysis) of the product and it should be applied at the early stages of the design process, when the product itself is at the conceptual stage. Once the final product has been clearly defined and its environmental impacts have been studied in detail, there is a need of a more surgical approach. Eco-improvement methods with a narrow distribution across either the life cycle phases or the impact categories were devised for the latter scenario, where the environmental criticalities of the product have been defined.

4 INTERACTIVE SELECTION SCHEME

Working on the premise that no approach is best by itself, we devised an interactive selection scheme that will enable the designer to choose the eco-improvement software most fitting to his design needs. The selection scheme, based on the aforementioned table of figure 2, allows the designer to choose a subset of life cycle phases and impact categories (Fig. 3). Guidelines pertaining exclusively to a life cycle phase or impact category that has been excluded by the user are automatically removed from the table of figure 2, which in turn updates the results to show the number of relevant guidelines and the new distribution. The user will have a new classification tailored to his needs and will be able to select the most fitting eco-improvement method.

For example, we may find that Design for Environment Guidelines has the most guidelines targeting the consumption of raw materials at the pre-manufacturing stage, or that Smart Ecodesign Checklist has the most guidelines for reducing the energy consumption of the product use phase. By selecting only a subset of life cycle phases or impact categories, the designer will be able to gauge each software strong suit. Furthermore, a list of the relevant guidelines across all the analysed methods may be easily assembled, thus superseding each single software deficiencies.

A further option allows the user to give priority to some categories and life cycle phases, by specifying a low, normal or high preference (Fig. 3). This might be the case when the designer does not want to completely exclude one category, but wishes to give a greater importance to other topics. By defining a low priority for said category, the user retains all of its guidelines, but is presented with a radar diagram weighted on his choice of preferences (Fig. 3). The choice in preference has no effect on either distribution or number of relevant guidelines; however, by tweaking the graphical results it contributes in determining the final choice of eco-improvement method.

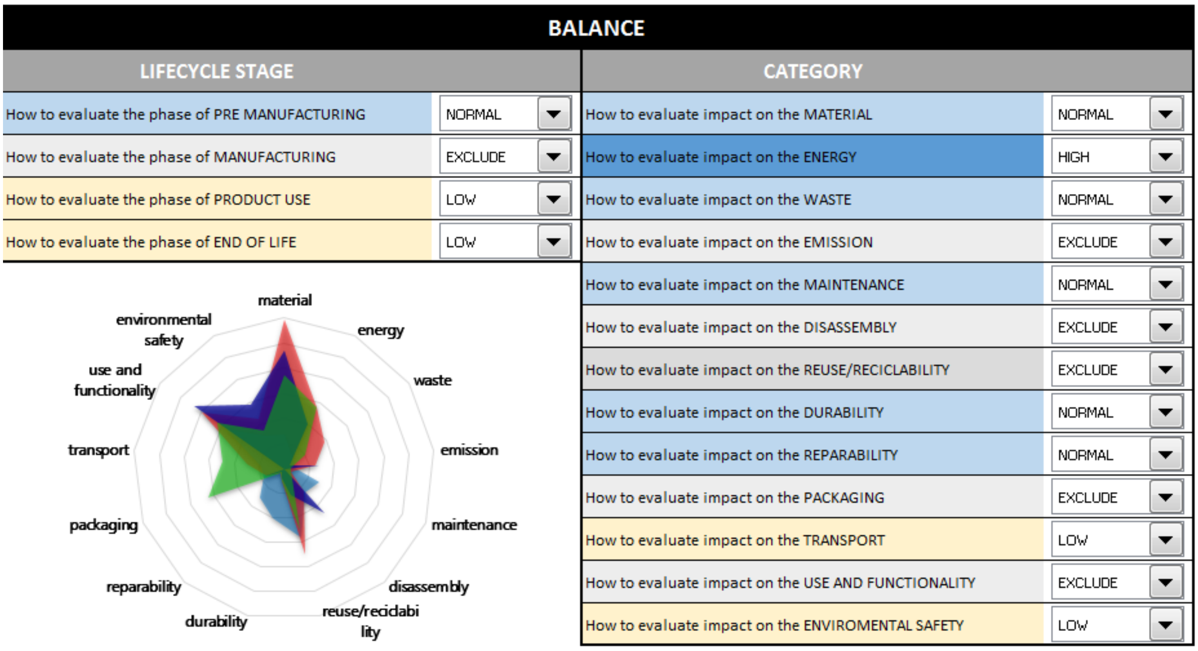

Figure 3. Interactive interface for eco-improvement methods selection

5 CONCLUSIONS

In the present paper, we proposed a possible classification of 17 of the most known eco-improvement methods, based on category groups that discriminate the product lifecycle phases and the categories of environmental impact. The analysed methods are very heterogeneous, in terms of both guidelines composition and their arrangement across the selected impact categories, and thus hard to compare. We proposed a simple scheme, based on standard deviation criteria, for comparing the methods on the number of guidelines and their distribution on the aforementioned categories. For each environmental topic, we provide a quantitative value that allows the designer to compare such heterogeneous methodologies.

An interactive selection scheme has also been proposed. Through the selection of a subset of life cycle phases and impact categories, the methodology yields a new classification tailored to the user's needs, empowering him to select the most fitting eco-improvement method. Moreover, a list of the relevant guidelines across all the analysed methods may be easily assembled, thus superseding each single software deficiencies.

A possible software implementation and an analogue process for eco-assessment methods are currently under development.

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