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Teaching eco-design by using LCA analysis of company's product portfolio: the case study of an Italian manufacturing firm

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Abstract

Eco-design is a design paradigm aiming to the development of sustainable products. Life Cycle Assessment (LCA) is considered an eco-design tool able to assess the product environmental performances through a life cycle perspective. However, LCA shows some limitations in industry's daily practice and cannot be considered a standard for implementing eco-design. The paper aims to describe the implementation of a novel eco-design teaching approach involving company's employees from different technical departments. LCA analysis of company's product portfolio allowed to create a specific eco-knowledge, used to train designers and engineers on this subject for the implementation of eco-design actions during the development of new products (espresso coffee machine). Results highlighted relevant learning outcomes and significant improvements in terms of environmental sustainability of a new product design.

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Keywords: LCA; teaching; eco-design; eco-knowledge.

1. Introduction

Eco-design is defined as "the integration of environmental aspects into product design and development, with the aim of reducing adverse environmental impacts throughout product life cycle" [1]. Eco-design methods are spread in academic and scientific literature but their effective implementation within technical departments seems difficult [2][3][4]. Different barriers have been identified, such as: lack of allocated resources (man power and time), lack of information on environmental impacts, lack of expert knowledge, etc. [5][6]. Concerning the lack of eco-knowledge and expertise, teaching methods related to eco-design subject play a critical role for the implementation of eco-design strategies in manufacturing firms. In the last two decades, the education about ecological matters of future generations of decision-makers in industry (e.g. engineers, designers, managers) has been managed by schools and academia, including eco-design themes in undergraduate and graduate design curricula [7][8]. Life cycle engineering has been adopted as baseline for the development of engineering courses oriented to eco-design [9][10] and became a consolidated trend in engineering education [11]. However, pedagogical experiences and applications are scarce, and the results of these initiatives will only provide tangible outcomes in future years [12][13]. Isolated teaching initiatives oriented to eco-design practices in industries are available in literature. Past experiences demonstrated that the traditional teaching methods, such as university lectures or refresher courses, resulted not efficient to spread eco-knowledge in the industrial world [14][15]. The complexity and multidisciplinary aspects concerning sustainability constitute a major obstacle and a gap between what companies actually do and what they want to do is noticed [16]. Most companies are simply doing the minimum

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to meet legislation, and as a result, the potential of eco-design and eco-knowledge is still limited [17]. In addition, design methodologies oriented to sustainability are applied as isolated case studies for pilot products, rather than to be a standardized and integrated framework within the product development process [18]. In conclusion, it is noticed that the effective development of eco-design methodologies into the design process can be obtained by the profitable and effective integration between "education" and "industry innovation" [19]. The desired level of environmental awareness and eco-knowledge can be set by manufacturing firms with industry-focused eco-design researches, which needs to be formalized over education-focused approaches. These results strengthen the possibility to explore industry-based partnerships for cross-disciplinary eco-design teaching projects [20]. Therefore, an innovative training method, based on the learning-by-doing principles, seems the most promising solution to support companies towards the use of eco-design in their daily activities [21].

The paper describes the implementation of an eco-design teaching initiative inside an Italian manufacturing firm producing espresso coffee machines. The main novelty of the teaching strategy is related to: (i) the direct involvement of the company personnel in eco-design and life cycle activities, and (ii) the definition of eco-design strategies/tips based on the analysis of environmental performances of their past design solutions, adopted in the whole product portfolio. As a result, a specific eco-knowledge about products designed and manufactured by the company was acquired and shared among the involved company's employees. In addition, the paper reports the experience of the teaching activities including positive and negative outcomes. The most interesting outcome of this work is the possibility to use this case study as a baseline for the implementation of a standard "eco-design teaching approach" which can be scaled up in other industrial contexts and applications.

The paper is structured as follows: after this introduction, the teaching approach and its implementation is presented in section 2. Outcomes of the proposed teaching activity are presented in section 3. Challenges, limitations and outlook, including the transferability of the course design to other industrial sectors, are reported in section 4.

2. Methods and Tools

This section describes the necessary steps to develop an eco-design teaching strategy within an industry. This study focuses on the implementation of the eco-design teaching approach within an Italian firm producing professional coffee machines. The need to implement an eco-design course comes from the company's management who decided to adopt a systematic strategy to improve the environmental features of their products. This initiative was the first one oriented to eco-design and eco-knowledge capitalization inside the company. For this reason, the company decided to start a collaboration with eco-design experts belonging to university avoiding "isolated" consultancy services. The choice of the company's management was to undertake a learning process for internal employees aiming to provide the necessary environmental skills and knowledge. Section 2.1 provides an insight about the context and the learning objectives, while Section 2.2 describes the adopted teaching method and activities.

2.1. Context and learning objective

The identification of the "context" for the implementation of the eco-design teaching strategy is necessary to undertake the process of learning objectives definition. In particular, the context was modelled considering two different domains: (i) external, related to the market/environment in which the company operates, and (ii) internal, related to the mission of the company. These two domains characterize the structure of the teaching activities and allow to choose the most suitable methods for the LCA analysis of product portfolio.

External domain includes the definition of the following aspects:

- the type of eco-design strategies to adopt (marketing, product certification, brand value, legislation, etc.);
- the type of life cycle analysis to use (full-LCA, carbon footprint, water footprint, etc.).

Concerning the case study, the type of eco-design strategies to adopt was based on two inputs: (i) the need to fulfill European regulations for professional coffee machines (e.g. eco-design, WEEE), and (ii) the growing environmental awareness of certain markets such as Northern Europe, United States and Japan. Both inputs are very important for the company aiming to maintain the competitiveness in the market. In addition, it is worth noticed that the company acts as supplier for important coffeehouse chains (e.g. Starbucks, McCafè), which are particularly careful about environmental sustainability aspects, as reported in their corporate responsibility reports. Therefore, they require to provide products certified from the environmental point of view using the LCA methodology and involving all the partners of the supply chain. The focus of the required product certification is on the greenhouse gas emissions and the global warming potential (GWP), calculated through the IPCC protocol that is currently the most widespread and accepted indicator [22].

Internal domain includes the definition of the following aspects:

- the personnel to involve in the teaching initiative;
- the type and number of products to analyze.

Ten people belonging to four company departments were involved in the eco-design teaching activities: (i) one person from the *Company management*, (ii) two persons from the *Marketing department*, (iii) five persons from the *Design and engineering department* and, (iv) two persons from the *Testing laboratory*.

Four models of professional coffee machines, one model of automatic coffee machine, and two models of coffee grinders were analyzed, representing the company's product portfolio. The chosen products cover both the low-end and the high-end market with the higher sales volume.

Concerning the learning objectives (Table 1), they were defined based on the taxonomy of knowledge defined by Bloom [23]. The entire Bloom's hierarchy is covered, with a focus on higher levels (i.e. evaluating, creating), which are the most interesting ones in case of industrial applications.

Table 1. Learning objectives of the eco-design teaching activities.

Learning objective	Bloom's level
State and *explain* the basic concepts of life cycle thinking and LCA methodology	I – Remembering
Identify the most important life cycle phases in the specific industrial sector (coffee machine)	II – Understanding
Use design data to build a product life cycle model	III – Applying
Compare different design alternatives from the environmental point of view	IV – Analyzing
Select the most appropriate design solutions according to classic (e.g. cost, performance) and environmental drivers	V – Evaluating
Define eco-design tips based on the main outcomes of the LCA analysis	V – Evaluating
Design/Re-design new/existing products to improve their eco-sustainability	VI – Creating
Interpret and *use* results for business negotiations	VI – Creating
Use the eco-knowledge to train the other personnel	VI – Creating
Recall eco-design tips in the conceptual design of new products	VI – Creating

2.2. Teaching method and activities

The adopted teaching method is essentially based on the learning by doing principles, applied by directly involving the company's employees in eco-design activities. During the first steps, the involvement was in the form of cooperation with the eco-design experts in specific tasks. At the end of the teaching period, instead, an assignment regarding a complete eco-design project was given. Fig. 1 illustrates the workflow, activities and timing of the proposed teaching method.

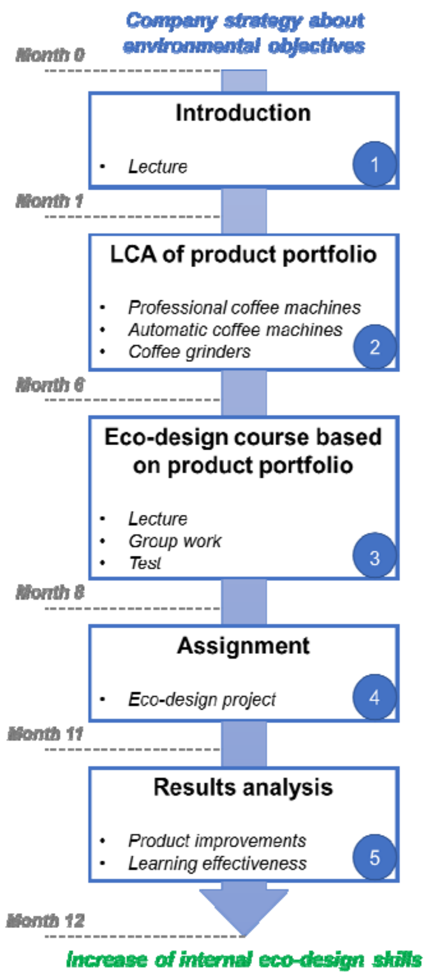

Fig. 1. Workflow of the proposed teaching method

2.2.1. Step 1: Introduction

The objective of the first step was to provide to the involved personnel basic concepts on life cycle design and LCA. This initial introduction was performed in 1 month with a total of 6 hours of lessons, equally divided in three (3) lectures. The main topics debated during these three lectures focused on the explanation of the following contents: (i) context and relevant environmental standard/legislation, (ii) life cycle thinking, and (iii) LCA methodology and tools.

2.2.2. Step 2: LCA of product portfolio

During the second step, the LCA analysis of the selected products were performed. Given the high number of products analyzed and the iterative nature of the LCA process, this step spanned for about 5 months. All the products have a high level of complexity, especially the professional coffee machines that are composed by hundreds of components/assemblies, manufactured by using a high number of materials (e.g. steel, copper, brass, plastics) and processes (e.g. metal casting, metal chip removal, plastic injection molding). Moreover, most of the components are delivered by external companies, thus also the supply chain is rather complex. Performing an LCA of these products required the involvement of environmental experts from university applying specific LCA standards (e.g. ISO 14040-14044).

The definition of the functional unit and system boundaries is an essential task in any LCA study. However, they are strictly correlated to the abovementioned context (both the internal and external domains). The functional unit was derived from the products and their context of use (e.g. preparation of coffee-based drinks, in specific geographical locations, in a specific lifetime). In the same way, the system boundaries were strictly correlated to the product characteristics and to the company. The manufacturing phase must be considered since the involved company internally design and assemble all the products. As for all the energy related products (ErP), it was expected that the use phase was the most impactful of the entire life cycle, thus it could not be neglected. The product end of life (EoL) is important since products must be WEEE compliant. In addition, the company intended to implement actions aimed at the direct management of the product EoL (e.g. collection of used products, component remanufacturing). For these reasons, a cradle to grave approach was required.

Different company departments were actively involved to support the external experts in specific tasks of the LCA study. The company's management was involved to define the objective of the analysis (i.e. to understand the environmental performance of products, to identify the most relevant criticalities). The marketing department was involved for understanding the most appropriate way to communicate results, both internally and externally. Based on the defined external domain (i.e. the market), the GWP indicator [22] was adopted to measure environmental sustainability in the coffee machine sector and to disseminate results. During the life cycle inventory phase, the design and engineering department was involved for the collection of relevant data about materials, manufacturing processes and supply chain. Considering the product complexity and the amount of technical documentation (e.g. drawings, bill of materials), the life cycle inventory was performed with the support of employees, both the one involved in the training program and the other ones who were in charge to manage product related information (e.g. supplier data, manufacturing processes, maintenance plans). Another important contribution was given by the laboratory department, involved to define the use scenarios and the related data about energy consumption. Currently, no use scenarios for coffee brewing equipment are defined in legislations or international standards. A standard protocol to measure the energy consumption of these products in the different working conditions (e.g. during the coffee extraction, during stand-by, during the supply of hot water or steam) is also missing. Therefore, the marketing and commercial departments were involved to define a set of standard use scenarios based on end user typologies (e.g. small bars vs big coffee houses) and aspects related to geographical locations (e.g. in the United States there is a higher consumption of hot milk-based drink than in Europe). The laboratory department defined a standard measurement protocol and apply it to collect relevant data about energy consumption for each use scenario. A result of the testing activity for the Italian use scenario is reported in Fig. 2.

ITALY use scenarios	Intensive	Medium
Number of COFFEE per hour [#/hour]	40	24
Number of CAPPUCCINO per hour [#/hour]	16	12
Number of TEA per hour [#/hour]	6	6
Number of warming up per day [#/day]	1	1
Working time [h/day]	18	12
Lifetime [years]	5	5
Energy consumption for COFFEE [kWh/day]	7.5	3.0
Energy consumption for CAPPUCCINO [kWh/day]	9.3	4.7
Energy consumption for TEA [kWh/day]	0.9	0.6
Energy consumption for warming up [kWh/day]	1.3	1.3
Energy consumption for stand-by [kWh/day]	3.3	2.9
Total energy consumption per day [kWh/day]	22.3	12.5
Total energy consumption per year [kWh/year]	7814.0	4359.1
Total energy consumption per lifetime [kWh]	39070.0	21795.6

Fig. 2. Italian use scenarios for life cycle inventory.

2.2.3. Step 3: Eco-design course based on product portfolio

The direct involvement of different departments in specific tasks of the Step 2, allowed to stimulate the employee's awareness about the common issues to face, the data to collect and the aspects to consider during an environmental assessment and/or an eco-design project. After the completion of all the LCA studies, the third step focused on providing to company's employees additional skills about eco-design and environmental sustainability, in order to make them able to autonomously manage and develop future eco-design projects. The duration of the course was 30 hours, spread over 2 months (about 4 hours per week). The course included:

- lectures for the explanation and discussion of results (about 80% of the course time);
- practical group works and activities to apply the knowledge acquired during lessons (about 10%); and
- test (assessment) to verify the learning (about 10%).

The course was followed by employees belonging to the marketing and commercial department, design and engineering department, and laboratory department. The course was mainly focused on analyzing and discussing the results obtained with the LCA of the product portfolio. The main objective was to extrapolate specific eco-knowledge from LCA results of the analyzed products, in order to provide to the involved personnel useful best practices to be used in future eco-design projects. Details about the lesson typologies, duration and contents are reported in Table 2.

Table 2. Course organization.

Lesson	Contents	Type	Duration
1	Life cycle analysis of professional coffee machines	Lecture	5 [h]
2	Comparison among coffee machines models	Lecture	3 [h]
3	Life cycle analysis of coffee grinders and automatic coffee machine	Lecture	2 [h]
4	Comparison among coffee grinders	Lecture	1 [h]
5	Test (assessment) 1	Test	1 [h]
6	Analysis of the manufacturing phase (including comparison among design alternatives)	Lecture	6 [h]
7	Analysis of the use phase (including comparison among technologies and use scenarios (e.g. Italy vs USA)	Lecture	6 [h]
8	Analysis of the EoL phase (including comparison among EoL scenarios (e.g. recycling vs remanufacturing)	Lecture	2 [h]
9	Test (assessment) 2	Test	1 [h]
10	Re-design of a coffee machine	Team work	3 [h]

2.2.4. Step 4: Assignment

At the end of the course, an assignment was given to the involved department: the development of an eco-design project aimed at the environmental improvement of an existing coffee machine. The principal "actors" of this step was the employees, while the environmental experts only acted as supports in the trickiest phases, to correctly address the project towards the best design solution. According with the management indications, the eco-design project was focused on a model of professional coffee machine, with the following main specifications: (i) external dimensions of 815 x 565 x 565 [mm], (ii) two (2) brewing groups with dedicated controls, and (iii) nominal power of 4,5 [kW]. The same product was the object of a previous optimization project; however, due to the lack of eco-knowledge, only cost reduction solutions had been implemented. The objective of the assignment was to improve the environmental performance of the product, while maintaining the full set of functionalities and with cost constraints (+5% maximum deviation with respect to the original solution). The available input data were essentially the results of the full LCA, carried out by the environmental experts during Step 2. The main environmental hotspot was related to the use phase which is responsible of about the 95% of the overall life cycle impact (considering an Italian use scenario, product life cycle of 5 years, switch-on time of 12 hours per day). Among the energy used, a relevant percentage (about one third of the total) is consumed during the warm-ups and the stand-by phases. Concerning the material and manufacturing, the most important contributions are due to the following assemblies: (i) brewing groups: 55 [kg CO_2eq]; (ii) framework: 51 [kg CO_2eq]; (iii) main boiler: 48 [kg CO_2eq].

During the eco-design course (Step 4) several specific best practices (tips) have been defined (Table 3). These design guidelines represented the eco-knowledge that the employees used during the eco-design project assignment (3 months) to define and implement the most appropriate re-design strategy. The final expected result was a re-designed version of the coffee machine.

Table 3. Eco-design tips.

#	Tip
1	Energy efficiency technologies shall be used to reduce the overall energy consumption
2	Insulation measures shall be adopted to reduce heat dispersion in boilers and pipes
3	Smart sensors and technologies shall be adopted to reduce the stand-by consumption (e.g. automatic switch off)
4	Electronically controlled electric motors shall be adopted to regulate the power absorption
5	Aluminum alloys are impactful materials compared with other solutions (e.g. carbon steel) but have a higher recyclability ratio
6	Stainless steels are impactful materials and where possible must be substituted with carbon steel
7	Plastics are lightweight materials, but their recycling at the EoL is challenging
8	Components weight, and thus the quantity of material used for their manufacturing, must be minimized
9	The use of different plastic typologies shall be avoided in order to favor product recyclability at the EoL
10	The use of varnished parts shall be avoided to limit the environmental issues related to manufacturing and EoL
11	Number of threaded joints shall be reduced in the external chassis to improve the reachability of internal parts
12	Rapid joints solutions shall be adopted to favor an easy disassembly of components that need to be maintained during the useful life or are candidate to reuse/remanufacturing at the EoL

2.2.5. Step 5: Results analysis

Following the assignment provided during the previous step, the employees involved in the eco-design training plan worked as a team to provide design solutions able to reduce the environmental load of a professional coffee machine. A brief discussion of some solutions is reported in this section.

The first solution implemented in the new coffee machine model was the adoption of the T3 (three-dimensional temperature control) technology. This technology allowed to reduce the overall amount of energy required to brew coffees, thanks to the adoption of two additional boilers, with smaller dimensions than the main boiler, and located near the brewing groups. During the coffee brewing, only a small amount of water contained within the secondary boilers is warmed up at the required temperature (approx. 97°C). In this way, it is possible to reduce the temperature in the primary boiler (approx. 80°C) generating a sensible reduction of the energy consumption for coffee brewing of approx. 35%. The second solution adopted for the new model was the use of insulation materials around the main boiler, the pipes and the additional boilers. The insulation material allowed to reduce the overall electric energy consumption during the use phase (approx. 4%). A third solution adopted and reported in this work was the reduction of materials and weights of the two brewing groups (heads) where the additional boilers were mounted. In this case a chromium-plated ring was removed, and the mass of brass was reduced of approx. 25% (Fig. 3).

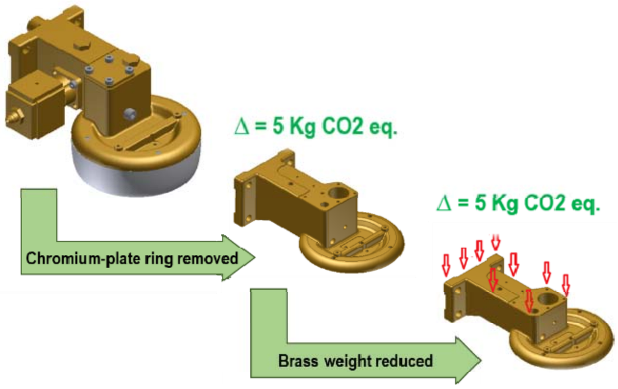

Fig. 3. Eco-design solutions adopted in the brewing group.

At the end of the assignment phase, the environmental experts together with the involved company's employees validated the solutions and quantified the obtained benefits. The LCA methodology was used to verify the environmental performances, while experimental measures were performed to verify the energy consumption of the re-designed coffee machine. The implementation of the eco-design action leads to a reduction of the total GWP of approx. 25%, compared with other professional coffee machine models. A specific reduction of 10 [kg CO_2eq] was observed for the manufacturing of each brewing group (originally 55 [kg CO_2eq]). Concerning energy consumption, a reduction of 20% of electric energy required during the daily use was measured. These results demonstrate the effectiveness of the course in supporting companies without eco-knowledge towards the improvement of their products.

3. General outcomes of the eco-design teaching approach

The eco-design teaching approach offered an opportunity to initiate the company to life cycle thinking. This structured partnership brought the company to be active in the field of environmental sustainability, creating a desired level of eco-knowledge about their products. The implementation of such a course allowed to reach the following results: (i) eco-design actions became an application of eco-design tips learned during the course, (ii) eco-design solutions were developed combining technical competences about the product and novel guidelines oriented to environmental sustainability, (iii) eco-design initiatives involved all the actors active during the product development process and contribute to increase their level of eco-knowledge and their awareness on environmental themes, (iv) time required for the implementation of the proposed eco-design teaching approach is closer with the "industry timing", than the necessary time generally required to train employees on LCA subject by using a traditional approach, and (v) results gained by the implementation of the eco-design teaching approach are robust enough to cope the industrial issues in this field.

From a general perspective, the proposed eco-design teaching approach proved to be effective in supporting the involved company toward the development of a product with important features oriented to environmental sustainability, such as energy efficiency, conscious use of resources, materials and manufacturing processes, high recyclability rate, etc. Even if in the context of a previous project company's employees tried to improve the sustainability of the initial version of the coffee machine, they had not been able to set a comprehensive eco-design strategy. Only with the knowledge acquired during the course, different feasible solutions were designed and implemented.

4. Conclusions

The present paper describes how a novel teaching approach on eco-design subject can be implemented in industries. The cooperation between academia (environmental experts) and manufacturing firm (company's employees) allowed to close the gap between the use of standardized methods (e.g. LCA) and useful tips for eco-design. The analysis of company's product portfolio and the involvement of different employees leaded to reach an increased level of eco-knowledge inside the company which can be shared in technical departments during the product development (both new and existing products).

The model can be easily replicated in different contexts considering the specific requirements and objectives. However, this is an isolated implementation of the method, and more case studies are necessary to understand limitations and advantages of this teaching approach. Speaking about the advantage, one of the most important one is connected to the learning objective which is not focusing on a specific tool for environmental assessment (e.g. LCA), but how the results derived by the assessment of company's product portfolio can be used to guide eco-design actions. Main limitation of the current teaching approach is the fact that eco-design actions requires always an assessment by the environmental experts. However, the engagement of an environmental manager or environmental lead inside the company could close the gap between the required level of expertise in environmental sciences and the desired level of eco-knowledge required to each company's employee. In this way technical and environmental competences can be coupled to develop more sustainable products.

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