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Environmental Assessment Design Tool Specially Developed for Mechanical Engineering Students

Daniel Elduque [1,]*, Ana Elduque [1] , Jorge Santolaria[2] and Carlos Javierre[1]

[1] **Department of Mechanical Engineering, University of Zaragoza,C/ María de Luna 3, 50018, Zaragoza, Spain**

[2] **Department of Design and Manufacturing Engineering, University of Zaragoza,C/ María de Luna 3, 50018, Zaragoza, Spain**

E-Mails: daniel.elduque@gmail.com; anaelduque@gmail.com; jsmazo@unizar.es; carlos.javierre@unizar.es

* Author to whom correspondence should be addressed; Tel.: +34-876-555-211; Fax: +34-976-761-861

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Abstract:

Over the last two decades, environmental legislation has increased in Europe. Life Cycle Assessment allows researchers and engineers to measure the environmental impact of products, allowing them to reduce it and contribute to sustainable growing. The European Union has devoted several laws to introduce ecodesign measures in energy-using and energy-related products. However, although most industrial products (TVs, computers, cars...) are designed and developed by engineers, most of them have not received environmental training in their university studies. In order to teach environmental design concepts to mechanical engineering undergraduates, an environmental impact assessment tool has been created. In this paper the ECOCAD software is shown, as commercially LCA software is not prepared to be used by untrained users. ECOCAD allows students to easily analyze the influence of design decisions on the environmental impact of a component, allowing them to compare different materials (steel, aluminum, plastics... each one with different Young Modules and elastic admissible strains), calculating how the safety coefficient changes depending on the loading conditions. Also the environmental impact of manufacturing processes (stamping, plastic injection, thermoforming, die cast, extrusion....), transportation from suppliers, and to the final customers (truck, train, freight ship...), and end-of-life treatments (recycling, incineration, land-filling...) can be taken into account, allowing the students to fully understand how design decisions influence the environmental impact of a product and compare design alternatives.

Keywords: mechanical engineering; sustainability; design tool; environmental impact

1. Introduction

Over the last two decades, the European Union (EU) has increased environmental legislation. The EU monitors the evolution of the public opinion in the Members States with Eurobarometer surveys. These surveys help the European Commission to prepare legislation, make decisions, evaluate its work and provide information to feed into policy-making for the European Union and its institutions [1]. Over three-quarters of Europeans feel that environmental problems have a direct effect on their lives, affecting their quality of life, are willing to pay a plus for environmentally-friendly products and agree that European legislation is necessary for protecting the environment [2]. In the last decades several laws have been devoted to: introduce ecodesign measures in energy-using and energy-related products [3] [4], enhance recycling [5] and restrict the use of hazardous substances [6].

Life Cycle Assessment allows researchers and engineers to measure the environmental impact of products, allowing them to reduce it and contribute to sustainable growing. However, although most industrial products (TVs, computers, cars...) are designed and developed by engineers, most of them have not received environmental training in their university studies. In order to teach environmental design concepts to mechanical engineering undergraduates, an environmental impact assessment tool, ECOCAD has been created.

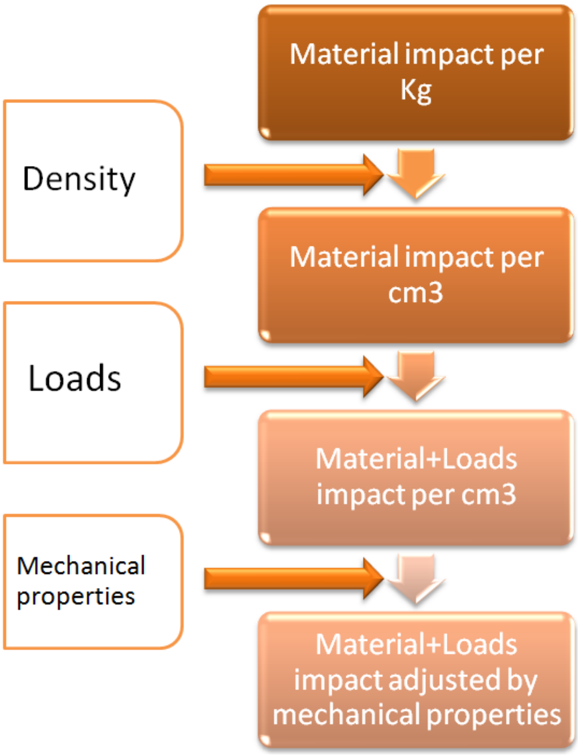
Sustainability Education in engineering schools is a topic which has been previously studied by numerous authors. Fenner et al have proposed a holistic eight-point framework to translate sustainability development aspects into civil engineering [7]. Kumar et al. believe that sustainability should be fully integrated into curricula and due to its interdisciplinary nature suggest a guideline for curriculum development [8]. Hadgraft also explained the renewal process of RMIT degree programs and the guiding ideas to introduce the principles of sustainable development [9]. Ashford addressed the challenges to redirecting engineering towards sustainability, proposing a trans-disciplinary approach to achieve sustainable development [10]. On the other hand, instead of modifying the whole curricula, other authors propose to introduce sustainability concepts by using new tools in classroom teaching [11] [12] [13]. Educational tools allow students to understand and examine sustainability concepts, and to think critically about different choices [11] raise awareness through education [12] and stimulate critical evaluation and the connections between concepts [13]. Our approach is similar to these two last studies, introducing sustainability concepts, by means of a LCA educational tool, in current engineering courses. In this paper the ECOCAD software is shown as a tool to introduce sustainability and Life Cycle Assessment concepts to mechanical engineering students, as commercially LCA software is not specially prepared to be used by untrained users.

2. Methodology for environmental assessment developed for mechanical engineering students

When the environmental impact of several mechanical component alternatives is compared without performing a full Life Cycle Assessment, it is usual to analyze the impact generated by the materials and production processes, comparing them by mPt per Kg, or Kg CO_2 eq. per kilogram. However, this approach is wrong, as it considers a partial functional unit that does not represent the whole environmental impact. To complete it, several factors have to be included to properly compare design alternatives. In order to explain several environmental impact related concepts to mechanical engineering students, and allow them to properly and easily compare the environmental impact of different design alternatives, a working methodology has been developed, that includes all the main factors (material mechanical properties, density, composition...) that have to be taken into account when studying mechanical designs, in a step-by-step process. This methodology will be implemented by a software tool specially developed for mechanical engineering students, which will be easier to use than professional LCA software, and will help them to analyze and compare the results.

Based on our experience, when designing a new component, a mechanical engineer has to select between different materials, like steel, aluminum, a wide range of plastics... these materials are usually present in environmental impact databases such as EcoInvent, but it is not usual to find the environmental impact of all the engineering plastics, those who are loaded with, per example, glass fiber, to improve its mechanical behavior. When analyzing plastics, besides having into account the impact of a material per Kg, mechanical engineers have to analyze the differences between several load percentages, as each one also has different mechanical properties (Young Modules and elastic admissible strains) and different density. This means that, for the same application, the thickness of the part must be reduced or increased to maintain the same safety coefficient, and also its weight changes. From a mechanical point of view, different safety coefficients also means different functional units, as the different design solutions do not have the same mechanical performance. Also, the way that the safety coefficient changes, depends on the loading conditions and the part geometry, meaning that these factors have to be taken into account. Furthermore, the differences in weight also affects other factors that have to be taken into account in a life cycle study, such as the environmental impact of manufacturing processes, transportation from suppliers, and to the final customers, and end-of-life treatments have to be considered. In order to simplify the use of the methodology, the end-of-life values provided for each material by IEC TR 62635 [14] will be shown to the students, allowing them to use them, or modify them to create a customized scenario.

Figure 1. Factors that influence mechanical design



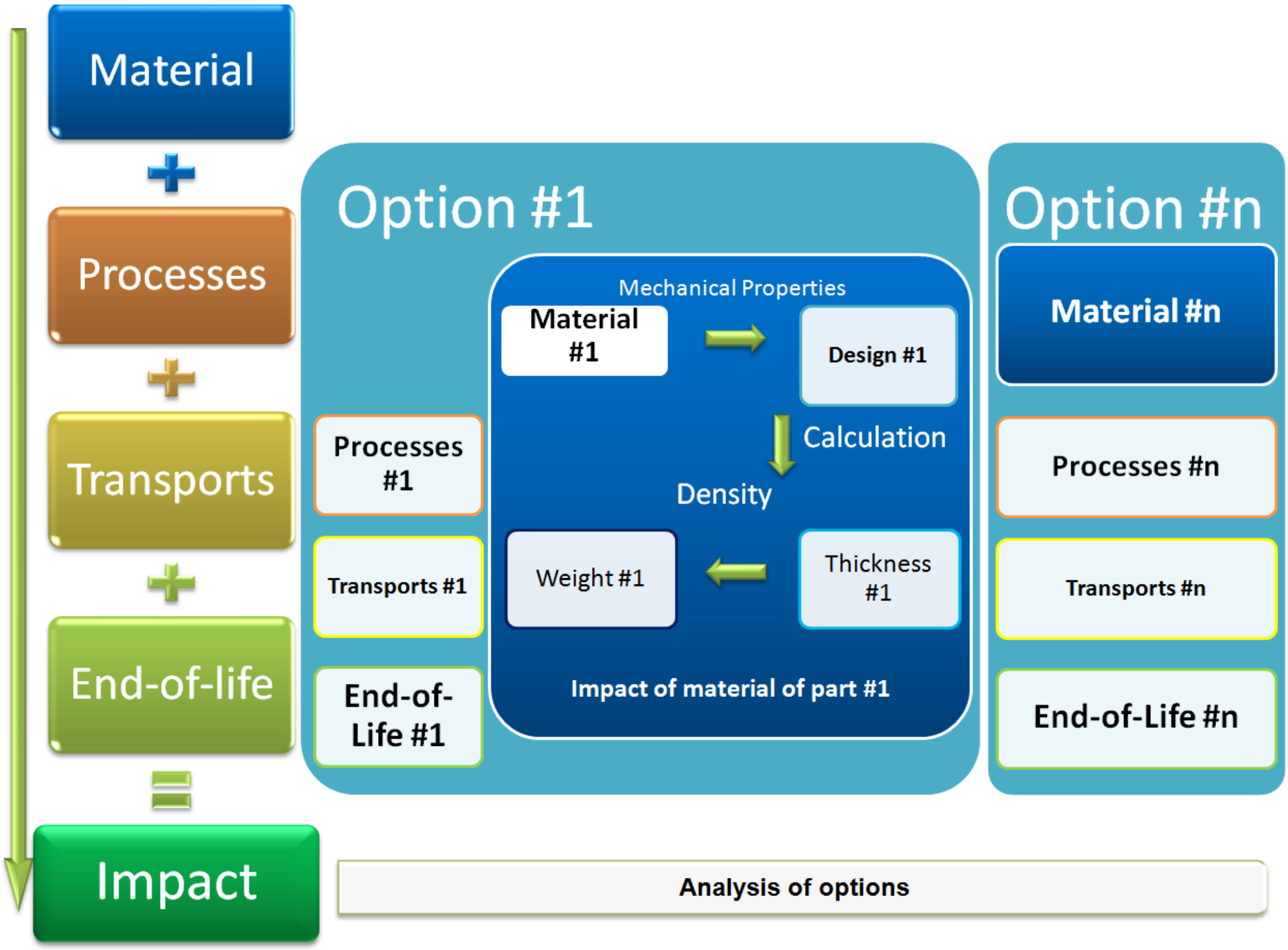
To assess the environmental impact of materials, processes... databases such as EcoInvent can be used. Two environmental impact calculation methodologies have been chosen: Recipe Endpoint (H/A) [15] and IPCC GWP 2013 [16]. Recipe Endpoint is a methodology specially suited for engineers, as it normalized and weights a wide range of environmental impact categories, providing a single endpoint value that is easy to understand. On the other hand, Global Warming Potential has also been selected as it is one of the most used environmental impact categories, and its use allows student to understand that sometimes even though the Carbon Footprint of a component may be reduced, the overall environmental impact measured with Recipe may increase, as GWP is just a partial measurement of the environmental impact.

Some authors have also developed methodologies to improve material selection in design [17]. As this methodology is oriented to teach mechanical engineering students the relationships between design decisions ant the environmental impact, it starts with the definition of "Reference component" a functional component, with an already chosen material, production processes shape and safety coefficient. From that starting point, several alternatives will be analyzed. Besides being able to select datasets from commercial databases, the student will also be able to create new datasets by creating mixes between them, per example, creating a mix for a glass fiber filled plastics that is not available in the database. However, in this methodology the use phase has not been included in a standard component study, as most mechanical components do not have a direct relationship with this stage (electricity consumption), although if the inertia reduction in a part is important, for example, in a car, its relationship with the use phase should be included.

2.1. Material and mechanical design

Once the data of the reference component is introduced, the rest of options will be compared. Depending on the chosen material and its mechanical properties, the thickness and weight of the component will vary so as not to change the safety coefficient of the component. The methodology helps the students, showing several load conditions (traction/compression, flexural...) and selection criteria (constrained displacement or constrained maximum strain). This means that the data needed to perform these calculations must be included in the methodology's material database.

Figure 2. Environmental impact methodology



2.2. End-of-life

The end-of-life scenario is directly linked to the material selection, so the students have to analyze how the percentages of recycling, incineration or landfill modify the overall environmental impact. The methodology also allow them to propose recycling values for the future, in order to understand how recycling trends may affect the impact of a product that is going to be used for 5, 10, 20 or even more years.

2.3. Production processes

Production processes are also highly linked with the material selection, so the methodology will allow students to compare the production processes the different alternatives, and how they modify the overall environmental impact.

2.4. Transportation

Transportation to the factory and from the factory to the consumer also has to be considered, as weight changes in the component directly affect these life cycle stages. Production processes are also highly linked with the material selection, so the methodology will allow students to compare the production processes, the different alternatives, and how they modify the overall environmental impact. In order to simplify the analysis, a list of standard suppliers and customers is included in the methodology, showing the means of transportation and distances.

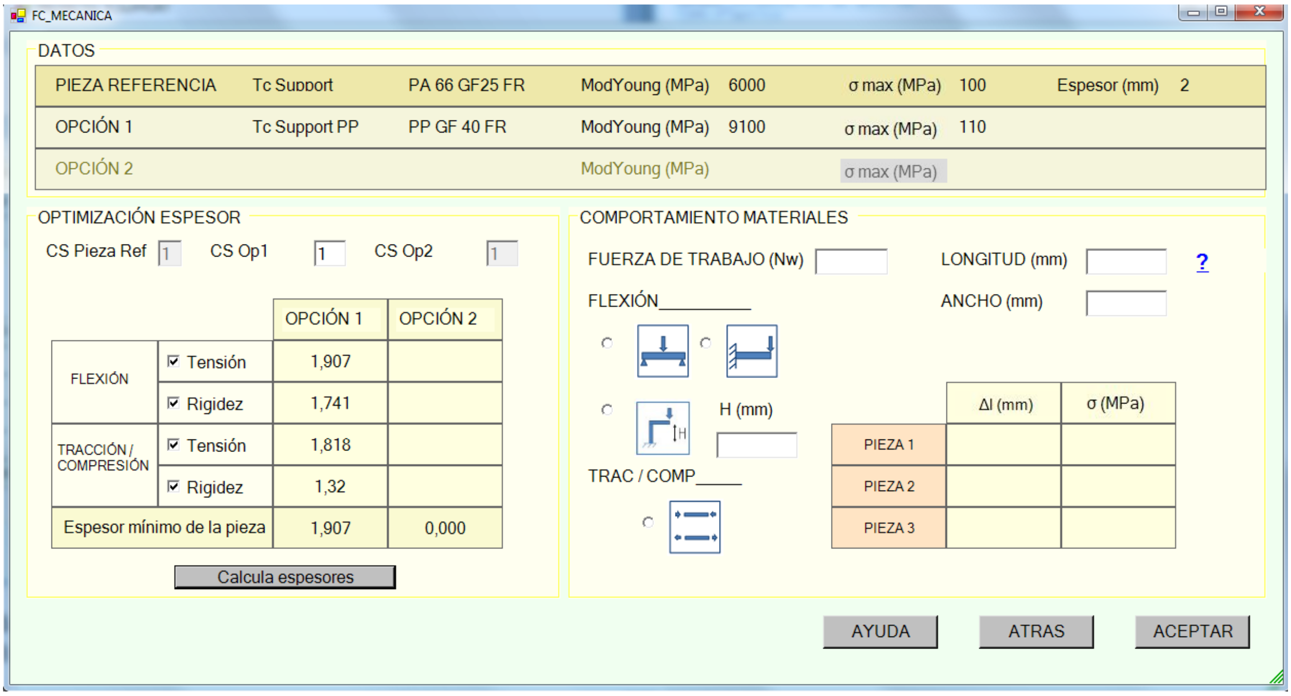
3. Environmental assessment design tool for mechanical engineering students

After explaining the different parts of the methodology, it has been implemented in a software tool, ECOCAD, which is shown in this section. ECOCAD allows students to easily analyze the influence of design decisions on the environmental impact of a component, allowing them to compare different materials (steel, aluminum, plastics... each one with different Young Modules and elastic admissible strains), calculating how the safety coefficient changes depending on the loading conditions, and also to include the environmental impact of manufacturing processes, transportation from suppliers, and to the final customers, and end-of-life treatments. This allows students them to fully understand how design decisions influence the environmental impact of a product and compare design alternatives. The main screen (Figure 3) allows the user to introduce data and analyze the several life cycle stages and it is easier to use than professional LCA software.

Figure 3. Main screen

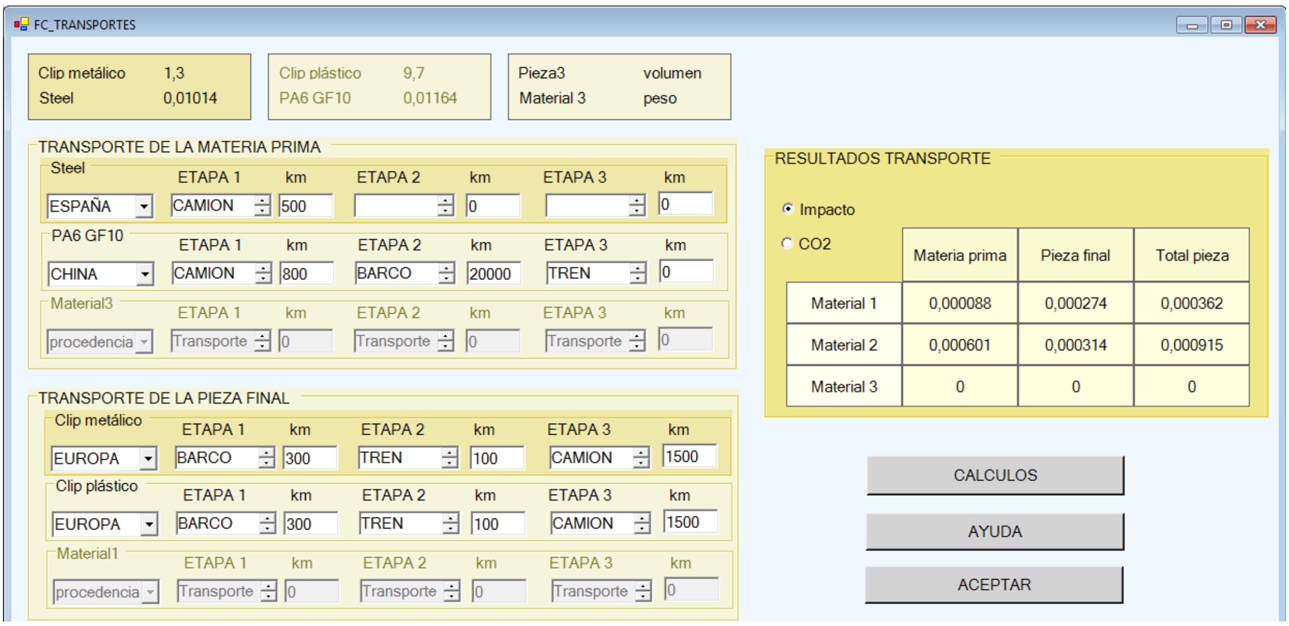
The mechanical design button shows the material selection and its relationship with the mechanical properties, thickness and safety coefficient (Figure 4). If the material is not in the database, the student can create it by mixing several materials.

Figure 4. Mechanical calculation screen



Other life cycle stages are also introduced in a step-by-step guided process (Figure 5).

Figure 5. Transportation screen



After introducing all the stages, the software shows a stage-by-stage comparison between the different design alternatives. In addition, with the aim of making the methodology more useful for mechanical engineers, the software also calculates the production costs and produces charts showing how the environmental impact and the cost varies with the thickness of the part for each design alternative.

4. Conclusions

The developed working methodology and its implementation with the ECOCAD software allows mechanical engineering students to learn how mechanical design decisions influence the environmental impact of components, allowing them to compare design alternatives and make material selection easier. This tool allows students to perform simplified Life Cycle Assessment without having to learn professional software and allowing them to understand how different factors modify the overall environmental impact.

Conflict of Interest

The authors declare no conflict of interest.

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