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EcoAudit: a Renewed Simplified Procedure to Facilitate the Environmentally Informed Material Choice Orienting the Further Life Cycle Analysis for Ecodesigners

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Design process determines 80% of the whole environmental impact generated by a product or service. This paper intends to describe a simplified renewed procedure for the analysis and selection of materials capable of providing fast and reliable information to those designers that are interested to minimize the life-cycle environmental burden of products and services, the so called EcoAudit. The here presented EcoAudit procedure assesses the burden associated to a component/product by means of a customized set of environmental impact indicators, without exploring all parameters that are usually provided by a LCA study.

The set of environmental impact indicators that are here adopted for this purpose are the energy consumption (energy breakdown in terms of direct and indirect contributors, MJ per functional unit), the global warming potential (in terms of CO_2 equiv per functional unit) and the end of life possibilities (in terms of effective practicable scenarios, i.e. of recycling). The first two indicators may be intended as "key environmental performance indicators" ("KEPIs").

This approach allows a fast preliminary ranking of materials and processes identifying the most relevant critical phases of a system, making the ecodesign process really starting. The integration within the Cambridge Engineering Selector 2009 EcoAudit tool allows to search and browse materials data, calculating the environmental load in a real time. [doi:10.2320/matertrans.MH200918]

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1. Introduction

Within the new socio-economic international scenario and the new opportunities that are arising from the global economic crisis, a renewed design approach focused on integrated social, economic and environmental sustainability is suitable to be adopted by environmentally conscious designers.

Design process determines 80% of the whole environmental impact generated by a product or service.[1)] This is the reason why it is important to develop a procedure able to support companies in the development of environmentally friendly new products or services in a rapid, reliable and pragmatic manner. This approach is, for instance, already stimulated and provided in Europe for those products belonging to the "Energy Using Products" group strengthen by the European Union Directive 2005/32/CE.[2)]

This paper intends to describe a simplified renewed procedure for the analysis and selection of materials capable of providing fast and reliable information to those designers that are interested to minimize the life-cycle environmental burden of products and services. This simplified renewed procedure is hereafter referred as the EcoAudit procedure.

The **EcoAudit procedure** derives from the LCA methodology in terms of structure, framework and requirements, but the procedure itself is simplified as the EcoAudit presented in this paper refer to a limited amount of input data and to secondary data coming from very well established LCA databases.

At present there are few examples of simplified tools for eco-materials selection[3,4)] and one of the most well known is the EcoAudit tool of the Cambridge Engineering Selector (CES) 2009 edition, developed by Granta-Design Ltd. UK.[5,9)]

The here presented EcoAudit procedure is based on the CES EcoAudit Tool, but it is a new procedure able to clarify the guidelines to approach the EcoAudit, independently from the tool and from the starting database. The present EcoAudit procedure assesses the burden associated to a component/product by means of a customized set of environmental impact indicators, without exploring all parameters that are usually provided by a LCA study. This option allows a fast preliminary ranking of materials and processes identifying the most relevant critical phases of a system, making the ecodesign process really starting.

2. Ecoaudit: One of the Existing Tools and the Renewed Simplified Procedure

2.1 CES 2009

The Cambridge Engineering Selector (CES) 2009 edition, developed by Granta-Design Ltd. UK, is one of most worldwide reliable database in terms of material families and design processes content. Recently CES included environmental information such as production energy requirement, CO_2 emissions and restricted substances regulations.

A ten years old cooperation between Granta-Design and the authors has now addressed the research for the integration of the most recognized LCA databases into the Cambridge Engineering Selector EcoAudit tool. The aim is to improve the EcoAudit tool layout adopting a strategy according to the renewed EcoAudit procedure presented in this paper. The EcoAudit report is based on some key environmental impact parameters, hereafter referred as "KEPIs", mainly the Global

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Warming Potential (GWP) and Gross Energy Requirements (GER). Results are reported as graphs and in tabular form, either as total amount either divided according to each component, enabling further quantitative analysis.

CES 2009 makes possible a real time EcoAudit evaluation of the impacts associated to the component/product during the main stages of its life cycle by means of few reliable indicators.

The EcoAudit tool inside CES user interface adopts a simple input-table template: the user enters various information (product composition, processing, usage, transportation, disposal) and Fig. 1 shows the final output of the calculation.

It is relevant to remark that the EcoAudit Tool is connected to the CES Selector, which allows searching and browsing materials data, combining it with the powerful Ashby methods to aid the standard design and business decisions.[6] The software allows to plot engineering, economic, and environmental properties—or combinations of them—within each other.

This software is then able to interact with the most common project tools available in the market (CAD, CAM, 3D modelling, etc.), and it allows to refer to critical references (e.g. Environmental Directive as REACH (CE) n. 1907/2006) regarding components that are under design evaluation.[7]

It is relevant to underline the possibility to digit primary information through the CES Constructor (one of the CES Software Components), directly in the datasheets of the software in the way to create a customized database. It is possible to test in real time the environmental burden of different materials and manufacturing process for each phase of the product life cycle. The flexibility of the tool induced the Authors to select CES as the most suitable system to support the here proposed EcoAudit procedure.

2.2 The EcoAudit procedure

Concerning the renewed simplified EcoAudit procedure it is important to recall the LCA methodology.

Life Cycle Assessment is the most internationally recognised methodology for the evaluation of environmental burdens, related to a product or a service during all of the life cycle stages, from the extraction of raw materials to the end of life. LCA is suitable to support policy making in many countries and thematic areas such as eco-design, integrated product policy, waste prevention and recycling, and sustainable use of natural resources. A full traditional LCA refers to indicators such as Acidification Potential, Ozone Depletion Potential, Global Warming Potential (GWP), Eutrophication Potential, Photochemical Ozone Creation Potential, and Gross Energy Requirements (GER). Hypothesis and assumptions, data quality, data inventory, data certification, calculation transparency, results replicability, improvement scenarios are just some of the many features that have to be respected in order to develop an LCA study according to the principles, framework, requirements and guidelines of the ISO 14040:2006 and 14044:2006 standards.[8,13,14]

A renewed EcoAudit procedure has been calibrated to address those designers not experts in LCA and environmental analysis to the best available technology selection, adopting a true Life Cycle Design point of view. Eco design, in fact, demands consideration of the full lifecycle impacts; but before product designers can minimize this damage, they need to estimate it in a quickly and effective way and to focus their efforts on the most significant life phases. But, as often discussed at international level, a rigorous approach to such a quantitative assessment requires time and efforts that often represent the main hurdle for design practitioners, with the consequent risk to bring the discussion to a more qualitative level, or, even worst, to abandon this approach.

For this reason, the environmental analysis in the ecodesign procedure may be split down in two main tasks:

(1) **Task 1**: EcoAudit + materials/process selection preliminary evaluation (EcoAudit procedure)

(2) **Task 2**: Full traditional LCA + materials/process selection verification and approval

Task 1 represents the real EcoAudit procedure. This procedure is the starting level to use the Life Cycle Assessment and the materials/process selection methodologies, with the pragmatic goal to quantify a selected set of indicators to address a quantitative discussion of the environmental impact at the design level in a reasonable short time.

The main impacts indicators that are here adopted for this purpose are the energy consumption (energy breakdown in terms of direct and indirect contributors, MJ per functional unit), the global warming potential (in terms of CO_2 equiv per functional unit) and the end of life possibilities (in terms of effective practicable scenarios, i.e. of recycling).

The choice to adopt the first two impact indicators (energy consumption and global warming potential) is due to the above mentioned need of simplification, maintaining, at the same time, a global vision of the whole environmental load. Among the typical LCA impact indicators energy consumption and global warming potential probably have the ability to cover each life cycle phase of the considered system and they are understood by most of the public.

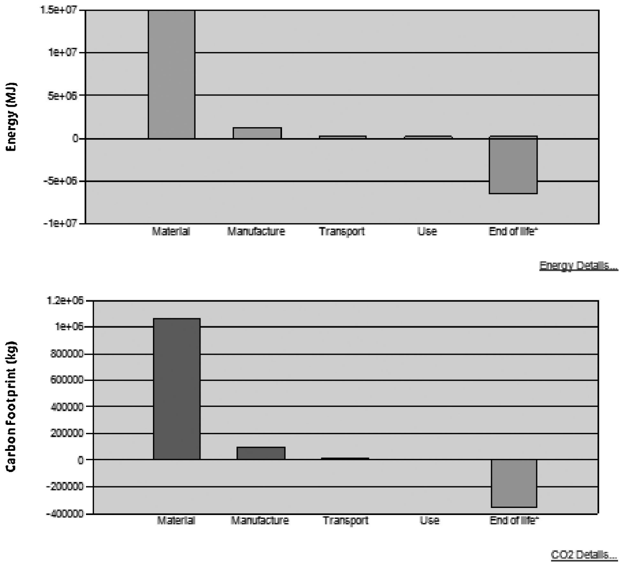
The end of life is then taken into consideration to specify the practicable scenarios referred to a component or material after the use phase. At this level, it could be useful to conduct a qualitative analysis about the possibility of disassembling the components of the product in order to identify the amount of material really reusable or recyclable.

Even if it is clear that the strengths and the weaknesses that are identified by the EcoAudit procedure strongly depend on the set of the selected environmental parameters that are used for ranking materials and processes, it allows the designer to be aware of a first set of reliable results to start an internal discussion about possible improvements to the project.

The already well known **Task 2** (Full traditional LCA) represents the further and deeper level for the environmental analysis of the system under study, providing the full list of environmental indicators and it requires specific expertise.

In Fig. 2 it is possible to compare the EcoAudit approach (Task 1) with the Full traditional LCA (Task 2).

The reliability of the EcoAudit procedure is checked by means of the control of the existing gap between Task 1 and Task 2 results, in terms of precision of the already mentioned KEPIs. In fact, the resulting KEPIs reliability (in terms of maximum percentage) let the designer to use the EcoAudit procedure in the most appropriate and correct manner, as briefly reported in the following case-study.



Phase	Energy (MJ)	Energy (%)	CO2 (kg)	CO2 (%)
Material	1.49e+07	88.9	1.06e+06	88.4
Manufacture	1.24e+06	7.4	9.82e+04	8.2
Transport	2.43e+05	1.4	1.73e+04	1.4
Use	2.01e+05	1.2	1.43e+04	1.2
End of life (collection & sorting)	1.75e+05	1.0	1.05e+04	0.9
Total	1.68e+07	100	1.2e+06	100
End of life (potential saving/burden*)	-6.39e+06	-38.1	-3.52e+05	-29.2
Total (including end of life saving/burden)	1.04e+07		8.53e+05	

*End of life saving/burden corresponds to the replacement of virgin material

Fig. 1 Example of an EcoAudit tool Report, Cambridge Engineering Selector, Granta-Design Ltd. UK.

In Fig. 3 it is possible to appreciate how the EcoAudit is integrated in the preliminary analysis of the ecodesign process.

Once the project briefing has been defined, the Design Process takes place according to the three phases presented in Fig. 3 which correspond to: Analysis, Design, Communication. In the Analysis phase there are different subphases

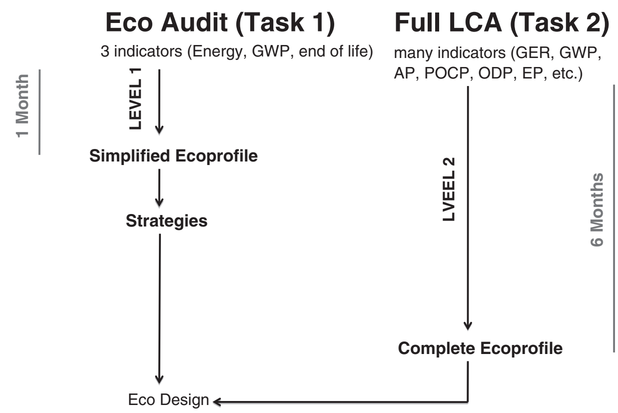


Fig. 2 Task 1 and Task 2 procedures.

focused on the analysis of the Scenario (technological context, target, benchmarking, economical context, etc.) and on a preliminary EcoAudit to define an ecological profile of the new concept. The EcoAudit procedure (Task 1) is fitted particularly for this phase during which the Designer has to manage fast and reliable information about the product to be developed.

The second Design phase is made of three subphases: preliminary design, advanced design, during which the project is executed in-depth, and the full LCA. The preliminary material and process selection deriving from the application of the EcoAudit procedure is now useful for the Goal and Scope definition of the complete LCA study (Task 2). The third phase is focused on environmental aspects Communication of the new concept, for example through ecolabelling as suggested by the ISO 14020.

The combination of the EcoAudit procedure with the CES Selector software results in a more than a versatile

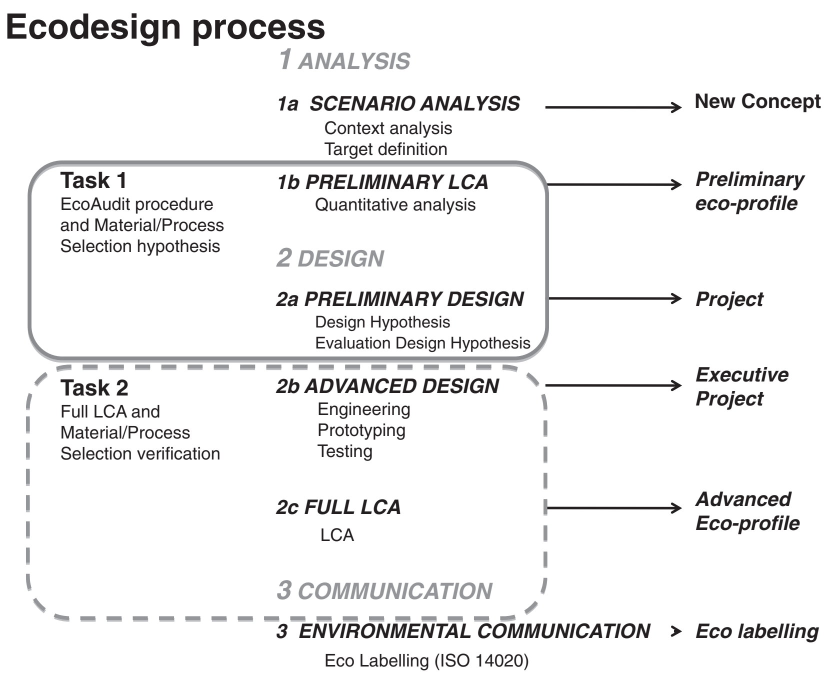


Fig. 3 The EcoAudit procedure into the Design Process.

and competitive tool, able to support the ecodesign for environmentally conscious designers, showing that the CES Software has a great potential for problem solving.

3. EcoAudit Procedure Scheme

The renewed simplified EcoAudit procedure adopts the LCA structure framework:

1. Goal and Scope Definition
2. Inventory Data
3. Impact Assessment
4. Results Interpretation

The EcoAudit procedure here considered is always to be referred to a design process. According to the Streamilined LCA approach,[15)] the EcoAudit procedure aims to optimise efforts concerning goal and scope definition by means of a limited set of impact indicators and to consider product design as the main field of application. The renewed simplified EcoAudit procedure basically refers to secondary inventory data and to a limited number of key environmental performance indicators (mainly GER and GWP), as previously discussed.

3.1 EcoAudit procedure input

The EcoAudit procedure foresees the use of inventory data coming from international and well established databases. This is an important point because these databases use allows to speed up the EcoAudit procedure. At the same time this is the reason why the EcoAudit procedure results are not as reliable as LCA results, where primary data are necessarily involved.

As the case study shows, this gap is manageable when designers have the need of environmentally sound choices.

The renewed simplified EcoAudit procedure is based on the following life cycle phases: raw materials, manufacturing, transport, use phase and end-of life, from the cradle to the grave. The KEPIs identification, GER and GWP, allows to simplify the EcoAudit procedure inventory data phase.

3.2 EcoAudit procedure results

Many different types of indicators have been developed to reflect a variety of aspects of ecosystems, including biological, chemical and physical. An impact indicator identifies the environmental burden for a specific category, such as, for example, the total amount of energy involved in the process, or the phenomenon caused by the emission to air or water, related to a production system. It is really important, during the material and process selection phase, to take into account the environmental aspects in order to compare different solutions through the same parameters.

The EcoAudit procedure starts taking into account the commonly used impact indicators available in the most significant databases, making a difference between purely technical ones addressed to experts, and the KEPIs represent the most communicative ones, addressed to the public.

The impacts indicators required by the Environmental Product Declarations International System are then adopted; the well known International EPD® System has the scope to provide relevant, verified and comparable information about a product-system.

There are also some other indicators that are also very communicative such as the ***Ecological Footprint***, ***Carbon Footprint***, ***Water Footprint***, etc.[11,12)] Some of them, like carbon and water footprint, derive from LCA results and for this reason require a life-cycle analysis background in any case.

4. Case Study

The EcoAudit methodology has been tested through some case studies in order to provide a basis to quantify the typical gap between the Task 1 and Task 2, by means of the selected KEPIs.

To do that, a specific case study on a new generation of wall hung boilers is here briefly reported. The original full study gives the results provided by the LCA analysis of the considered boilers (made by means of a suitable LCA software—the Boustead Model[10)]), integrated with those provided by the EcoAudit tool (made by means of the CES Selector by Granta-Design) typically used for ecodesign purposes. In other words Task 2 outputs are represented by the LCA (detailed) model, while Task 1 output by the CES EcoAudit tool.

It is clear that the comparison has the unique scope to test the here presented EcoAudit procedure; it is out of the goal to compare different softwares, such as the Boustead Model (BM) and the Cambridge Engineering Selector, developed with different scopes.

The wall hung boiler case study is made by components that carry out specific functions that concur to the final function considered.

A wall hung condensing boiler consists in a water heating machine that recuperates energy normally discharged to the atmosphere through fumes, using a heat exchanger able to recover residual heat in flue gas to warm up returning heat transfer fluid.

The wall hung boiler analysed (Fig. 4), is a so called "**A-group**", composed by 5 "**B-groups**" (structure, hydraulic group, combustion group, control group, packaging), which can be further broken down into different "**C-groups**" (and further Subgroups if necessary).

Therefore, the A-group can be considered as the whole system capable of producing the defined function, whereas B-groups carry out special functions which concur to the final function.

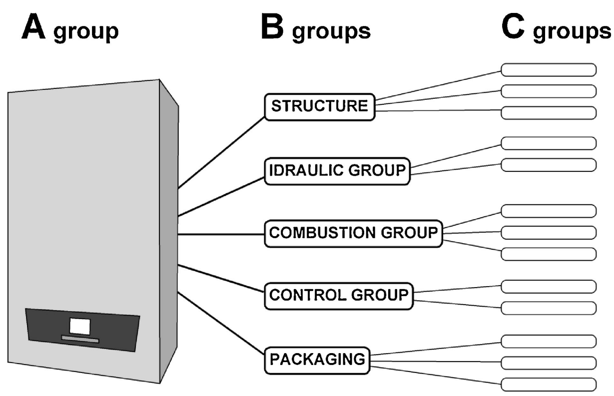


Fig. 4 The wall hung boiler components.

Table 1 Comparison between the LCA Boustead Model (BM) and the Granta EcoAudit Tool (CES) in terms of contributors to the Gross Energy Requirement (GER) for a selected number of components of the case study in terms of MJ per unit.

COMPONENT (B-group)	GER (MJ/unit)		
	BM	CES	variance % (rounded)
structure	560	474	−15
hydraulic group	620	667	8
combustion group	3628	2938	−19
control group	239	175	−27
packaging	222	287	29
Total (A-group)	**5270**	**4641**	**−12**

Table 2 Comparison between the LCA Boustead Model (BM) and the Granta EcoAudit Tool (CES) in terms of contributors to the Carboon Footprint (GWP) for a selected number of components of the case study in terms of kg CO_2 per unit.

COMPONENT (B-group)	GWP (kg CO_2/unit)		
	BM	CES	variance % (rounded)
structure	40	35	−13%
hydraulic group	41	48	17%
combustion group	284	168	−41%
control group	12	8	−33%
packaging	10	5	−50%
TOTAL (A-group)	**387**	**259**	**−33%**

The modular structure of the machine allows also assessing the importance of each B-group, independently on its particular purpose, but as a part of the whole system. Thus, with particular regard to the manufacturing phase, this approach was performed for each B-group.
This case study aims at calculating and comparing the contributors to the environmental burden of manufacturing phase calculated adopting either a full LCA approach either the EcoAudit procedure.

The System Boudaries of this study includes "cradle to gate" analysis of materials and semi-products, including operations at factory as well as supplier's plants level.
In detail the system comprehends:

(1) raw materials extraction, preparation and treatment for components manufacturing;
(2) manufacturing activities for purchased components.

The waste management process has not been considered in this study because the influence of the End of Life scenario will constitute part of a further work.

This case study aims to highlight and to compare the contributors to the environmental burden of the manufacturing phase for different components, as calculated adopting both the full LCA approach (i.e. Task 2) and the EcoAudit procedure (as described in Task 1).
The software Model used to perform the Inventory analysis (Task 1) is the *Boustead Model*; the database included in this software is also used to complete the information necessary to create the model of the product system (secondary data). Further secondary data sources are literature, published technical reports and other LCA databases.

The **database** of the Boustead contains "energy mix" data coming from the International Energy Agency (IEA), while process and transport data have been collected from various producers and operators since middle 70's and are continuously updated to keep the database in line with technological advancement; data included in this database reflect the averaged technological level of Western Countries industries. Now let's try to analyse Table 1 and Table 2 in detail.

It could be interesting to focus the attention immediately on the combustion group component (heat exchanger) environmental load: the environmental contributions to the GER and also to the GWP, during the manufacturing phase is the greater figure which covers more than 60% over the total, in both cases.

The heat exchanger, which is part of the combustion group, is made by approximatively 10 kg of secondary cast Aluminium, which is considered as processed in China and transported in Europe for the assembling phase. Using the EcoAudit procedure, within the CES Software, it is possible to select the recycled fraction contained in the cast aluminium card (100% recycled fraction), but the selection of the country energy mix is not allowed: data about aluminium production are then more generic than those used in the LCA software.

So, while in the BM model data are referred to the specific country energy mix where materials are processed, data used in the CES model come from the "Material Universe database" that takes into account only an average of a large geographical area (such as the European energy mix, for instance). This is one of the most important reasons to explain the gap reported in Table 1. Another important reason of the different values can be found in the level of detail of data about the aluminium production process: it is clear how a LCA software has in its domain (in its "DNA") a more detailed level for quantifying direct and indirect impacts of a process. This also thanks to relevant LCI (Life Cycle Inventory) works, which have been delivered by manufacturing association and normally used by LCA practitioners.

Therefore, this case study, together with other case studies, allows to quantify in a range between 10% and 40% the gap between the so called Task 1 and Task 2 approaches, depending primarily on the type of processes involved in the system boundaries. These indicative figures are referred to the use of "standard" materials, but can suffer of a limited reliability in case of recently introduced materials which request primary data; this constitutes the main limit of the CES EcoAudit Tool. However, within the next version of CES EcoAudit Tool, with the possible introduction of more detailed processes LCA-like data and the possibility to set specific energy mixes, the gap is expected to diminish in many situations. This sentence is valid when CES EcoAudit Tool results are compared with results obtained with typical LCA software how the Boustead Model is.

5. Final Considerations

The case study showed the limits of the preliminary approach (Task 1), but at the same time, the power to help in the quantification of the gap between Task 1 and 2 in order to allow the designer to define the most appropriate ecodesign strategy.

If the EcoAudit procedure can be considered only as a first step towards full ecodesign considerations, the ecodesigner knows this way the potential level of shifting of KEPIs after Task 1 approach. Using a specific tool such as the Cambridge Engineering Selector EcoAudit tool, this shift can be also quantified as above reported (in the case of traditional materials not requesting primary data).

Since in a preliminary ecodesign phase it is really important to evaluate the highest impacts of unit operations among the others for searching some better alternatives, the integration of the EcoAudit with the Material Selector allow to search and browse materials data, calculating the environmental load in real time. A preliminary evaluation of the confidence limits is here presented and the obtained results are very encouraging to use the here described simplified procedure.

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