Int. J. Service and Computing Oriented Manufacturing, Vol. 2, Nos. 3/4, 2016 205

Environmental assessment tool to analyse the presence of critical and valuable raw materials

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Abstract: The aim of this paper is show the software 'Sustainable Electronics' (SE), developed in the University of Zaragoza as an environmental impact assessment tool, specially developed to design components taking into account the presence of critical and valuable raw materials consumption; simulating environmental impact and measuring the overall raw material consumption, taking into account material composition of the electronic components. It considers raw material acquisition, manufacturing processes, transports and end of life. This software allows us to easily update and use the datasets provided by Life Cycle Inventory databases, such as, for example, EcoInvent, developed by the Swiss Centre for Life Cycle Inventories. The methodology has been tested through the software in an electronic board of a touch control used in an induction hob. As result, it has been obtained that there is a high consumption of materials such as copper, tin or aluminium.

Keywords: life cycle assessment; LCA; environmental impact simulation; methodology; critical materials; material composition.

Reference to this paper should be made as follows: Bachiller Gómez, P., Pina, C., Elduque, D., Clavería, I., Javierre, C. and Sarasa, J. (2016) 'Environmental assessment tool to analyse the presence of critical and valuable raw materials', *Int. J. Service and Computing Oriented Manufacturing*, Vol. 2, Nos. 3/4, pp.205–225.

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This paper is a revised and expanded version of a paper entitled 'Environmental assessment tool to analyze the presence of critical and valuable raw materials' presented at the 27th European Modeling & Simulation Symposium (EMSS2015), Bergeggi, Italy, 21–23 September 2015.

1 Introduction

Nowadays, companies and the society are truthfully concern on reducing the environmental impact of products and services. The concept of eco design began in the 1990s in order to produce more sustainable products and also with the purpose of prevention in the design instead of correction afterwards. Focused on the design stage, material selection takes an important role on the environmental performance, as it affects the whole product life cycle, from raw material acquisition to the end of life of the product.

In order to reduce the environmental impact of a product, methodologies and techniques such as life cycle assessment (LCA) allow researchers to assess and reduce the impacts to the ecological environment. LCA is a 'cradle to grave' method to analyse the environmental impact of products or processes (Guinée, 2002; U.S. EPA, 2006); allowing to evaluate the environmental impact throughout the life cycle by means of ISO 14040 standards (International Standard Organization, 2006). This tool has been used to model a wide range of products: from wind turbines (Martínez et al., 2009, 2015), electronic boards (Elduque et al., 2014) or induction hobs (Pina et al., 2015) to compost production (Leiva-Lazaro et al., 2014), food packaging (Fernández et al., 2013) or wine production (Jiménez et al., 2014).

Currently, in the electronic industry there is a large concern about the materials that affect environmental impact and it is considered important to measure the environmental impact of a component considering the influence of the material composition. The composition of an electronic component must be analysed taking also into account the presence of critical raw materials.

The criticality of a material is determined by means of the environmental risk, economic importance and supply risk (European Commission, 2014). Firstly, the concept of critical material emerged in 1939 by the US Administration. But when determining the criticality of a material is necessary to consider that the demand of materials is volatile in time.

With technological change, an increase in the demand of some materials in a specific moment supposes the decrease of others, creating changes in risk indicators of these materials (European Commission, 2010; Achzet and Helbig, 2013). For example, in 2010, the restrictions on the exportation of neodymium in China caused a global supply chain crisis, as a result, prices increased by one order of magnitude (Sprecher et al., 2015).

Nowadays the methodology used to determine the criticality of a material is based in the combination of three main indicators (Chapman et al., 2013; Binnemans et al., 2013; Graedel and Nuss, 2014):

- economic vulnerability: the end of life recycling has to be taken into account and also the economic benefit that these raw materials have at the sectors in which them arise
- supply risk: this value arises from a combination of the stability in the production of the material in a specific country, the substitutability of the material and end-of-life recycling rates of the studied material
- ecological risk: this value is estimated taking into account similar criteria than supply risk, raw material country concentration, the ability to be substituted and the recyclability of the material.

As Peck points out (Peck et al., 2015), critical materials are 'invisible' as they are normally alloyed with other materials. For this reason, researchers are using LCA and life cycle sustainability assessment to systematically compile inventories of the consumption of resources (Mancini et al., 2015; Sonnemann et al., 2015). Environmental impact indicators for criticality are still currently being developed, as authors are developing several perspectives (Dewulf et al., 2015; Glöser et al., 2015; Rorbech et al., 2014; Adibi et al., 2014). The consumption of critical materials has been studied for products such as solar photovoltaics (Goe and Gaustad, 2014), bulbs (Lim et al., 2013) or iron alloys (Nuss et al., 2014).

Currently, there is a huge increase in the demand of electronic devices, due to their cheap prices and high efficiency. This demand supposes the generation of huge quantities of waste of electrical and electronic equipment (WEEE) and consequently, the European Union has introduced several laws as the WEEE Directive (European Parliament, 2012) with the purpose of reduce waste production, or energy-using products (EuP 2005/32/CE) (European Parliament, 2005) and energy-related products laws (ErP2009/125/CE) (European Parliament, 2009) to protect the environment by means of eco design. Furthermore, European Union laws have focused on reducing the environmental impact, by means of chemical control and restriction of hazardous substances (REACH 1907/2006) (European Parliament, 2006) (RoHS 2002/95/CE) (European Parliament, 2003).

Several authors have studied ways to reduce the overall consumption of critical materials, focusing specially on recycling (Rademaker et al., 2013; Dhammika Bandara et al., 2014; Eckelman et al., 2014), recovery (Gutierrez-Gutierrez et al., 2015; Funari et al., 2014; Hennebel et al., 2015) and also on reducing the consumption of raw critical materials in new products, such as permanent magnets (Mcguiness et al., 2015).

From an environmental point of view, the application of a suitable eco design methodology is very interesting in the electrical and electronic industry, improving all phases of the product's life cycle and analysing the influence of material composition on the environmental impact (Gómez et al., 2015).

The aim of this paper is to show the software 'Sustainable Electronics', developed in the University of Zaragoza as an environmental impact assessment tool, specially designed to simulate environmental impact and to measure the overall raw material consumption, allowing researchers to reduce the consumption of critical and valuable materials.

2 ‘Sustainable Electronics’ environmental assessment methodology

Nowadays, most LCA models are carried out with professional databases such as EcoInvent, which is one of the most used Life Cycle Inventory databases, developed by Swiss Centre for Life Cycle Inventories. However, these databases provide generic data that are not always adequate for specific products. Our methodology is based on a LCA model, which uses customised datasets to simulate the environmental impact and also quantify the critical materials consumption.

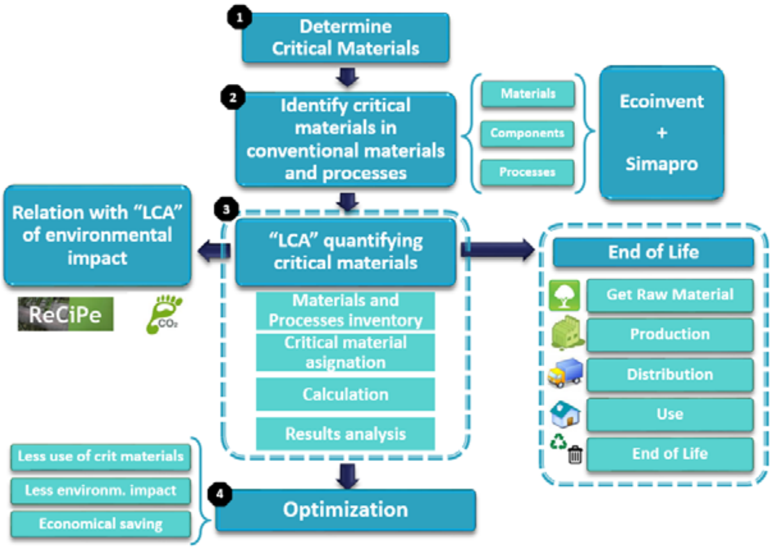
2.1 General approach

The main goal of the methodology, shown in Figure 1, is to calculate the critical material consumption of an electrical or electronic component, simulating the environmental impact. For this reason, it is necessary to know all material compositions of all the parts in a component or product.

Once analysed and compared the critical material composition of the components and also, of the products, the user decides the design of the component or the product depending on the life cycle of the component.

This methodology allows the user to compare different designs of the same component depending on the quantity of critical materials in the composition of the component. The user could choose the component with less critical or valuable raw material and also with less environmental impact.

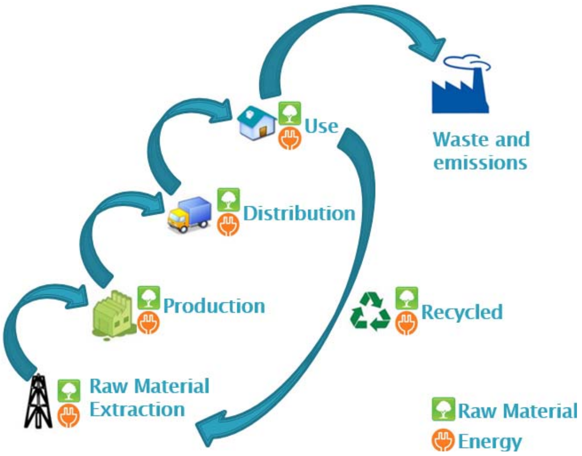
Figure 1 Methodology diagram (see online version for colours)



2.2 Life cycle stages

The software carries out environmental impact simulations by means of a LCA model that takes into account all the critical and valuable materials consumed in the life cycle. All the life cycle phases (Figure 2) of the component have to be taken into account, from getting raw materials to the end of life of the component.

Figure 2 Life cycle stages (see online version for colours)



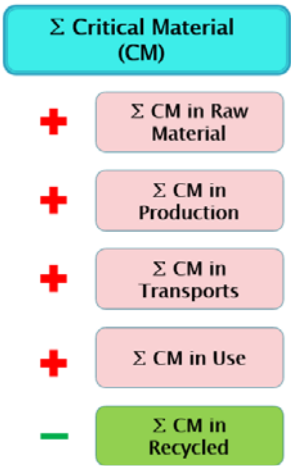
Raw material extraction, directly associated with material composition and also with the presence of critical materials, is the beginning of the life cycle of a product, followed by production process and distribution stage, where must be considered all energetic consumption and raw materials. Finally, use phase and the end of life of the component, where in the last one, it has been considered two treatments, recycling and land filling. By mean of recycling treatment, the component is transformed into raw material after the end uses.

There will be processes that have more critical materials consumption than others, affecting also the environmental impact simulation results, so all of the processes must be taken into account.

2.3 Environmental impact

The calculation methodology consists of an improved LCA adjusted to critical materials, where the total amount of critical materials is obtained from the life cycle using the critical materials in raw materials of the components, critical and strategic materials in production and in distribution processes. Furthermore, the end of life phase is considered in the calculations of critical materials (Figure 3).

Figure 3 Critical material calculation (see online version for colours)



The methodology considers different end of life scenarios to calculate the amount of critical materials and the environmental impact.

Also, the LCA has been calculated with ReCiPe Endpoint methodology and IPCC 2013 method. The first one, ReCiPe has been developed as an endpoint attempt to align the CML 2002 midpoint and Eco-indicator99 systems, while IPCC 2013 is an update of the method that lists the climate change with a timeframe of 20, 100 and 500 years (Goedkoop et al., 2013).

2.4 Results

The methodology can carry out the LCA model calculations, taking into account all the critical and valuable materials consumed in the life cycle.

Results should be clear and concise, in order to help the user to understand them. So that, the results would be:

- list of critical and strategic materials
- environmental impact simulation results
- summary of critical and strategic materials percentages.

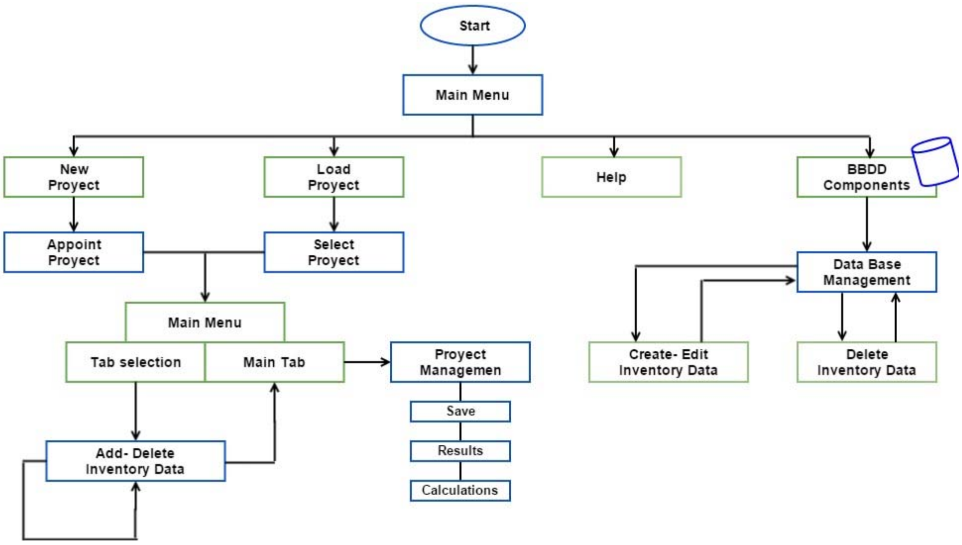
In order to obtain appropriate results with this methodology, it is necessary to build a customised database structure that helps calculations. As this methodology will be applied to the electrical and electronic field, these are the components that should be considered for the particularisation of the methodology in that field: materials, boards, components, connections and processes.

3 'Sustainable Electronics' software

This methodology has been implemented by means of a software tool, named 'Sustainable Electronics'. This tool has the aim of calculate the critical materials content and simulate the environmental impact of electrical and electronics devices.

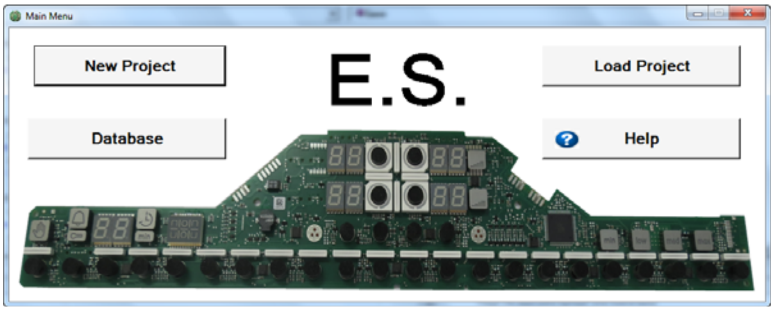
The structure of this software is divided in three main blocks, which are: new project/load project, databases and also results (Figure 4), where the user could evaluate quantity of critical materials and environmental impact. In the figure is shown the program flow, which gives a general view about the program tools. From 'new project', the user could named a project, while in block 'load project' it could be selected an existing project. The block 'database' shows the completed database that is available in the tool, it is allowed to create filters and manage the database.

Figure 4 Software structure (see online version for colours)



This structure of the software is represented in the main screen of the program (Figure 5).

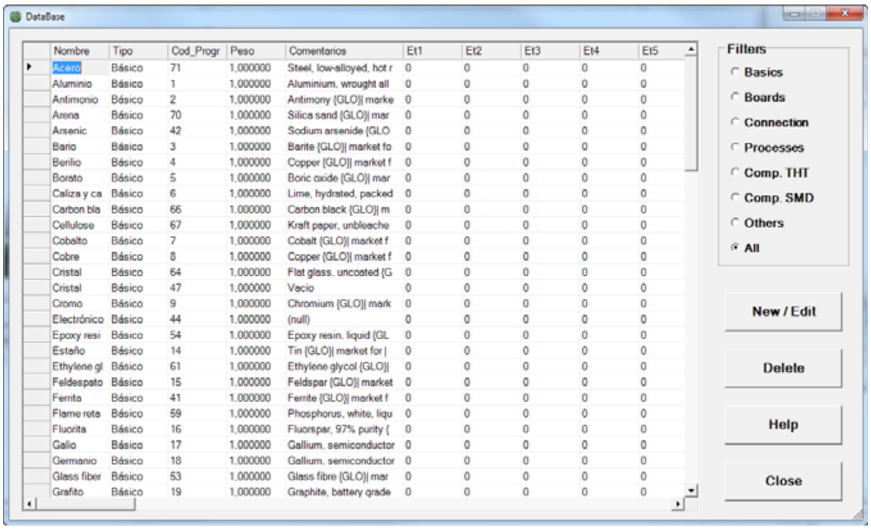
Figure 5 Main screen of the software (see online version for colours)



3.1 *Database (LCA model inputs)*

Selecting 'database' button from the main screen, the software shows the complete database (Figure 6). As mentioned before, navigating in this screen the user can filter and also manage the database, creating, editing and deleting inventory data.

Figure 6 Software database (see online version for colours)

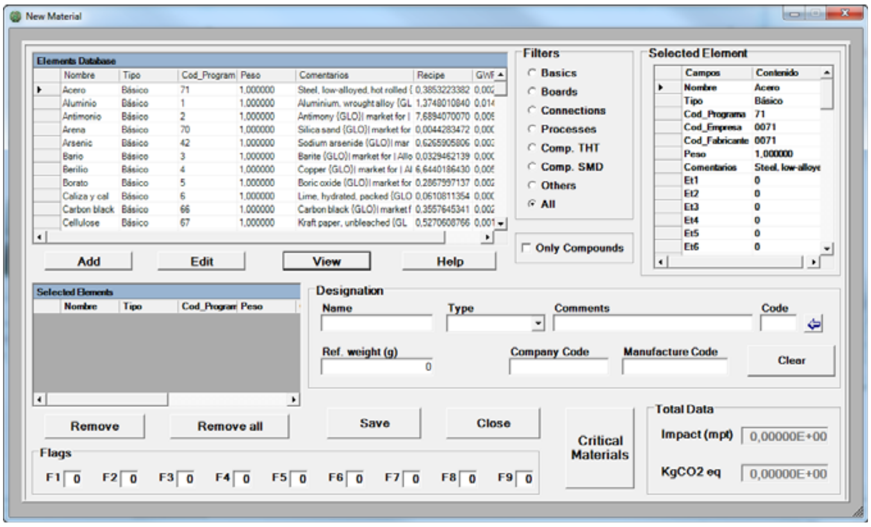


	Nombre	Tipo	Cod_Progr	Peso	Comentarios	Et1	Et2	Et3	Et4	Et5
▸	Acero	Básico	71	1,000000	Steel, low-alloyed, hot r	0	0	0	0	0
	Aluminio	Básico	1	1,000000	Aluminium, wrought all	0	0	0	0	0
	Antimonio	Básico	2	1,000000	Antimony {GLO}| marke	0	0	0	0	0
	Arena	Básico	70	1,000000	Silica sand {GLO}| mar	0	0	0	0	0
	Arsenic	Básico	42	1,000000	Sodium arsenide {GLO	0	0	0	0	0
	Bario	Básico	3	1,000000	Barite {GLO}| market fo	0	0	0	0	0
	Berilio	Básico	4	1,000000	Copper {GLO}| market f	0	0	0	0	0
	Borato	Básico	5	1,000000	Boric oxide {GLO}| mar	0	0	0	0	0
	Caliza y ca	Básico	6	1,000000	Lime, hydrated, packed	0	0	0	0	0
	Carbon bla	Básico	66	1,000000	Carbon black {GLO}| m	0	0	0	0	0
	Cellulose	Básico	67	1,000000	Kraft paper, unbleache	0	0	0	0	0
	Cobalto	Básico	7	1,000000	Cobalt {GLO}| market f	0	0	0	0	0
	Cobre	Básico	8	1,000000	Copper {GLO}| market f	0	0	0	0	0
	Cristal	Básico	64	1,000000	Flat glass, uncoated {G	0	0	0	0	0
	Cristal	Básico	47	1,000000	Vacio	0	0	0	0	0
	Cromo	Básico	9	1,000000	Chromium {GLO}| mark	0	0	0	0	0
	Electrónico	Básico	44	1,000000	(null)	0	0	0	0	0
	Epoxy resi	Básico	54	1,000000	Epoxy resin, liquid {GL	0	0	0	0	0
	Estaño	Básico	14	1,000000	Tin {GLO}| market for |	0	0	0	0	0
	Ethylene gl	Básico	61	1,000000	Ethylene glycol {GLO}|	0	0	0	0	0
	Feldespato	Básico	15	1,000000	Feldspar {GLO}| market	0	0	0	0	0
	Ferrita	Básico	41	1,000000	Ferrite {GLO}| market f	0	0	0	0	0
	Flame reta	Básico	59	1,000000	Phosphorus, white, liqu	0	0	0	0	0
	Fluorita	Básico	16	1,000000	Fluorspar, 97% purity {	0	0	0	0	0
	Galio	Básico	17	1,000000	Gallium, semiconductor	0	0	0	0	0
	Germanio	Básico	18	1,000000	Gallium, semiconductor	0	0	0	0	0
	Glass fiber	Básico	53	1,000000	Glass fibre {GLO}| mar	0	0	0	0	0
	Grafito	Básico	19	1,000000	Graphite, battery grade	0	0	0	0	0

Filters
○ Basics
○ Boards
○ Connection
○ Processes
○ Comp. THT
○ Comp. SMD
○ Others
● All

After customising the database, the software allows to select the required components, in order to create the inventory (Figure 7). For an electronic board, the researcher can select between components, boards, production processes and also connections and other elements thanks to the previous work and research that have been performed in order to create the database.

Figure 7 Database personalisation's (see online version for colours)



Elements Database

	Nombre	Tipo	Cod_Program	Peso	Comentarios	Recipe	GWI
▸	Acero	Básico	71	1,000000	Steel, low-alloyed, hot rolled {	0,3853223382	0,002
	Aluminio	Básico	1	1,000000	Aluminium, wrought alloy {GL	1,3748010840	0,014
	Antimonio	Básico	2	1,000000	Antimony {GLO}| market for |	7,6894070070	0,005
	Arena	Básico	70	1,000000	Silica sand {GLO}| market for	0,0044283472	0,000
	Arsenic	Básico	42	1,000000	Sodium arsenide {GLO}| mar	0,6265905806	0,003
	Bario	Básico	3	1,000000	Barite {GLO}| market for | Allo	0,0329462139	0,000
	Berilio	Básico	4	1,000000	Copper {GLO}| market for | Al	6,6440186430	0,005
	Borato	Básico	5	1,000000	Boric oxide {GLO}| market for	0,2867997137	0,002
	Caliza y cal	Básico	6	1,000000	Lime, hydrated, packed {GLO	0,0610811354	0,000
	Carbon black	Básico	66	1,000000	Carbon black {GLO}| market f	0,3557645341	0,002
	Cellulose	Básico	67	1,000000	Kraft paper, unbleached {GL	0,5270608766	0,001

Filters
○ Basics
○ Boards
○ Connections
○ Processes
○ Comp. THT
○ Comp. SMD
○ Others
● All

☐ Only Compounds

Selected Element

	Campos	Contenido
▸	Nombre	Acero
	Tipo	Básico
	Cod_Programa	71
	Cod_Empresa	0071
	Cod_Fabricante	0071
	Peso	1,000000
	Comentarios	Steel, low-alloye
	Et1	0
	Et2	0
	Et3	0
	Et4	0
	Et5	0
	Et6	0

Selected Elements

	Nombre	Tipo	Cod_Program	Peso

Designation
Name
Type
Comments
Code
Ref. weight (g) 0
Company Code
Manufacture Code

Flags
F1 0 F2 0 F3 0 F4 0 F5 0 F6 0 F7 0 F8 0 F9 0

Total Data
Impact (mpt) 0,00000E+00
KgCO2 eq 0,00000E+00

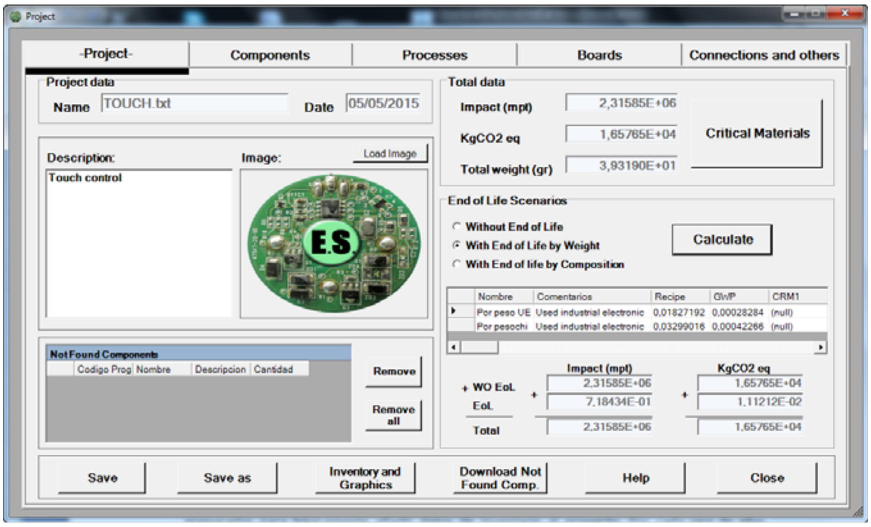
The most complex option in this screen is block 'new/edit' where the inventory could be created, filling the required fields, and also editing those that already exist.

3.2 *Software development*

‘Sustainable Electronics’ software allows researchers and engineers to analyse different design alternatives in order to reduce the impact to the ecological environment and diminish the use of critical raw materials, showing the overall quantity of critical and valuable raw materials in each component, process, board or connection.

Users can take design decisions taking into account critical materials and according to the environmental impact.

Figure 8 Project screen (see online version for colours)



Project data

Name: TOUCH.txt

Date: 05/05/2015

Description: Touch control

Image:

Total data

Impact (mpt): 2,31585E+06

KgCO2 eq: 1,65765E+04

Total weight (gr): 3,93190E+01

End of Life Scenarios

○ Without End of Life
● With End of Life by Weight
○ With End of life by Composition

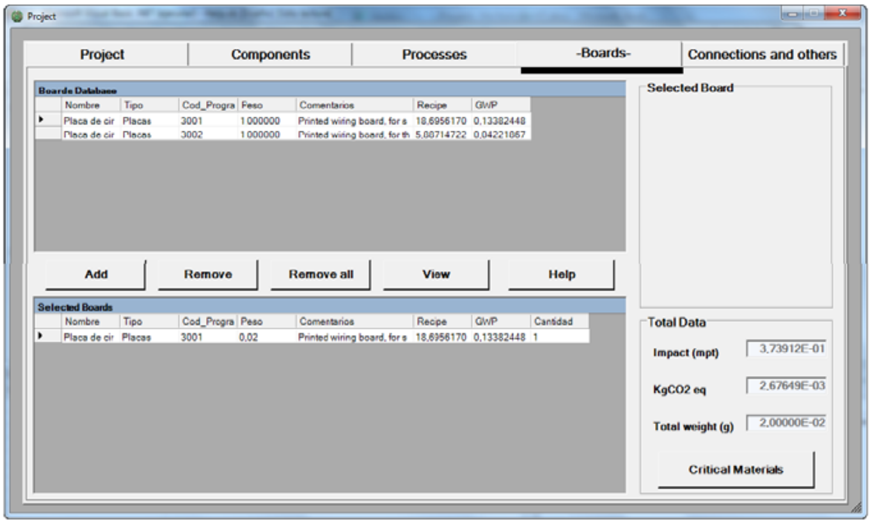
	Nombre	Comentarios	Recipe	GWP	CRM1
▸	Por peso UE	Used industrial electronic	0,01827192	0,00028284	(null)
	Por pesochi	Used industrial electronic	0,03299016	0,00042266	(null)

	Impact (mpt)	KgCO2 eq
+ WO EoL	2,31585E+06	1,65765E+04
EoL	7,18434E-01	1,11212E-02
Total	2,31585E+06	1,65765E+04

Not Found Components

	Codigo Prog	Nombre	Descripcion	Cantidad

Figure 9 Boards screen (see online version for colours)



Boards Database

	Nombre	Tipo	Cod_Progra	Peso	Comentarios	Recipe	GWP
▸	Placa de cir	Placas	3001	1 000000	Printed wiring board, for s	18,6956170	0,13382448
	Placa de cir	Placas	3002	1 000000	Printed wiring board, for th	5,88714722	0,04221867

Selected Boards

	Nombre	Tipo	Cod_Progra	Peso	Comentarios	Recipe	GWP	Cantidad
▸	Placa de cir	Placas	3001	0,02	Printed wiring board, for s	18,6956170	0,13382448	1

Selected Board

Total Data

Impact (mpt): 3,73912E-01

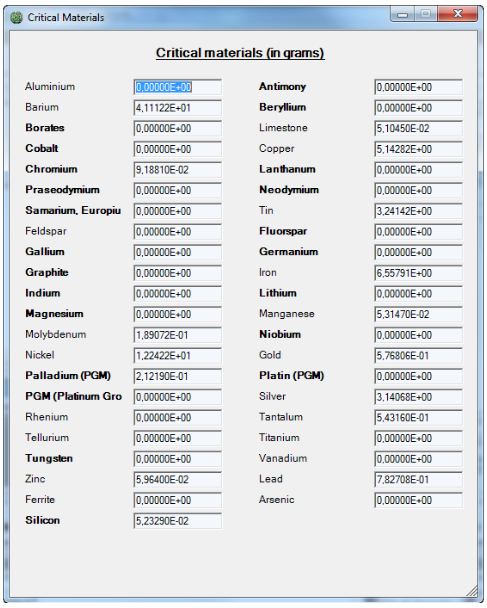
KgCO2 eq: 2,67649E-03

Total weight (g): 2,00000E-02

Figure 8 shows 'new project' and 'load project' options, where there are several tabs such as project, components, processes, boards and connections and others, the user can navigate through them creating its own project. The main screen is 'project', where it is shown a summary of the project with data such as the name, the creation date or an image of the project, among others.

All of these screens are prepared for easily adding data from the inventory to the project and in each screen the inventory data of each type are available. Thereby, in 'board' screen appears inventory data regarding that field (Figure 9).

Figure 10 Critical materials screen (see online version for colours)



Critical materials (in grams)

Aluminium	0,00000E+00	**Antimony**	0,00000E+00
Barium	4,11122E+01	**Beryllium**	0,00000E+00
Borates	0,00000E+00	Limestone	5,10450E-02
Cobalt	0,00000E+00	Copper	5,14282E+00
Chromium	9,18810E-02	**Lanthanum**	0,00000E+00
Praseodymium	0,00000E+00	**Neodymium**	0,00000E+00
Samarium, Europiu	0,00000E+00	Tin	3,24142E+00
Feldspar	0,00000E+00	**Fluorspar**	0,00000E+00
Gallium	0,00000E+00	**Germanium**	0,00000E+00
Graphite	0,00000E+00	Iron	6,55791E+00
Indium	0,00000E+00	**Lithium**	0,00000E+00
Magnesium	0,00000E+00	Manganese	5,31470E-02
Molybdenum	1,89072E-01	**Niobium**	0,00000E+00
Nickel	1,22422E+01	Gold	5,76806E-01
Palladium (PGM)	2,12190E-01	**Platin (PGM)**	0,00000E+00
PGM (Platinum Gro	0,00000E+00	Silver	3,14068E+00
Rhenium	0,00000E+00	Tantalum	5,43160E-01
Tellurium	0,00000E+00	Titanium	0,00000E+00
Tungsten	0,00000E+00	Vanadium	0,00000E+00
Zinc	5,96400E-02	Lead	7,82708E-01
Ferrite	0,00000E+00	Arsenic	0,00000E+00
Silicon	5,23290E-02		

Once data are added, in project screen the results could be calculated and viewed by users. In panel 'total data' appears environmental impact and also, pressing 'critical materials' button, critical materials window is shown (Figure 10), where the user can see the quantities of critical and strategic materials.

These screen shows 43 critical and strategic materials, where 22, marked in bold letters, are considered by the latest EU report as critical (European Commission 2014).

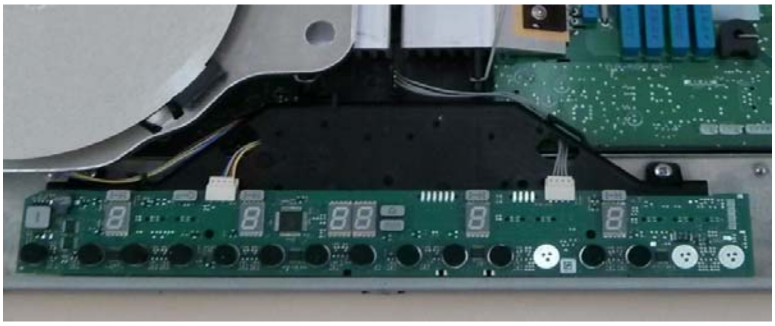
4 Software application

The main goal of the software application is to show the methodology and the software, and at the same time, show the performance of the tool.

4.1 Touch control

As previously mentioned, this implementation will be carried out in the field of electronics, specifically the tool is used to calculate critical materials content and simulate the environmental impact in a touch control device, shown in Figure 11.

Figure 11 Touch control (see online version for colours)



It is an electronic control board, called 'touch control', used in induction hobs.

4.2 *Touch control inventory*

The inventory for this application consists on data related to electronics, such as capacitors, resistors, diodes, transistors and so on, boards and processes as welding SMD technology.

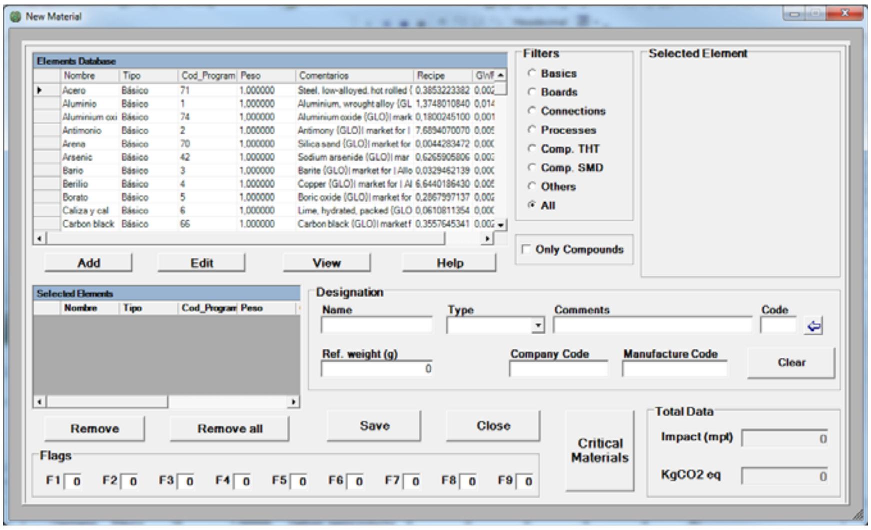
The entire inventory used in this software application, shown in Table 1, has been obtained from the manufacturer of the touch control and desoldering the electronic components. Also manufacturer's datasheets of the components have been used in order to consider the exact composition of the components of the studied case, the touch control of an induction hob, following the same methodology shown in Gómez et al. (2015).

Table 1 Summarised touch control inventory (see online version for colours)

Touch control induction hob			
Name	*Material*	*Units*	*Weight per unit (g)*
Small plastic parts	Nylon 6	7	0.199
Foam cylinders	Polyurethane, flexible foam	13	0.311
Ceramic capacitors SMD	Capacitor, for surface-mounting	52	0.0053
SMD0603 resistor	Resistor, surface-mounted	79	0.0019
Diode BAV 99	Diode, glass-, for surface-mounting	6	0.009
Tantalum capacitor	Capacitor, tantalum	1	0.237
Logical IC	Integrated circuit, logic type	5	0.102
Memory IC	Integrated circuit, memory type	2	0.057
Resonator	Resonator CPM SMD	1	0.013
7-segment displays	7 Segment display	6	0.75
LEDS	Light emitting diode	9	0.0015
PCB	Printed wiring board	1	37.995
Welding SMD technology	Mounting, surface mount technology	1	0.9355

Once the inventory is completed, elements that are not in the database of the software should be introduced in the tool from ‘new/edit database’ option (Figure 12).

Figure 12 Add or create data screen (see online version for colours)



Elements Database

Nombre	Tipo	Cod_Program	Peso	Comentarios	Recipe	GWI
Acero	Básico	71	1,000000	Steel, low-alloyed, hot rolled {	0,3853223382	0,00
Aluminio	Básico	1	1,000000	Aluminium, wrought alloy {GL	1,3748010840	0,014
Aluminium oxi	Básico	74	1,000000	Aluminium oxide {GLO}| mark	0,1800245100	0,001
Antimonio	Básico	2	1,000000	Antimony {GLO}| market for |	7,6894070070	0,00
Arena	Básico	70	1,000000	Silica sand {GLO}| market for	0,0044283472	0,00
Arsenic	Básico	42	1,000000	Sodium arsenide {GLO}| mar	0,6265905806	0,00
Bario	Básico	3	1,000000	Barite {GLO}| market for | Allo	0,0329462139	0,00
Berilio	Básico	4	1,000000	Copper {GLO}| market for | Al	6,6440186430	0,00
Borato	Básico	5	1,000000	Boric oxide {GLO}| market for	0,2867997137	0,00
Caliza y cal	Básico	6	1,000000	Lime, hydrated, packed {GLO	0,0610811354	0,00
Carbon black	Básico	66	1,000000	Carbon black {GLO}| market f	0,3557645341	0,00

Filters
○ Basics
○ Boards
○ Connections
○ Processes
○ Comp. THT
○ Comp. SMD
○ Others
● All

☐ Only Compounds

Selected Element

Selected Elements

Nombre	Tipo	Cod_Program	Peso

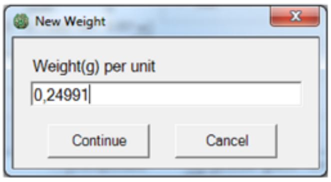
Designation
Name
Type
Comments
Code
Ref. weight (g) 0
Company Code
Manufacture Code

Flags
F1 0 F2 0 F3 0 F4 0 F5 0 F6 0 F7 0 F8 0 F9 0

Total Data
Impact (mpt) 0
KgCO2 eq 0

Weight of each component has to be introduced in the software every time that user wants to introduce a new component in database (Figure 13).

Figure 13 Weight introductions (see online version for colours)

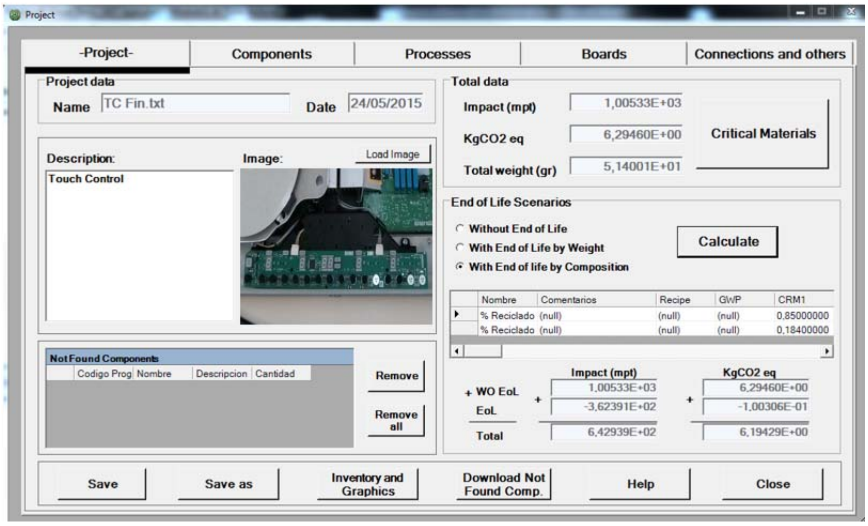


Weight(g) per unit
0,24991

After all the inventory of the project has been created, the next step is creating the application case. For that, it is necessary to access to ‘new project’ (Figure 14), where appears the main menu and it is compulsory named the project.

Browsing in tabs project, components, processes, boards, connections and others, data from the inventory should be introduced. Depending on the type of data it will be added in ones or in others (Figure 15).

Figure 14 Project screen (see online version for colours)



Project data

Name: TC Fin.txt
Date: 24/05/2015

Description: Touch Control

Image:

Not Found Components

Codigo Prog	Nombre	Descripcion	Cantidad

Total data

Impact (mpt): 1,00533E+03
KgCO2 eq: 6,29460E+00
Total weight (gr): 5,14001E+01

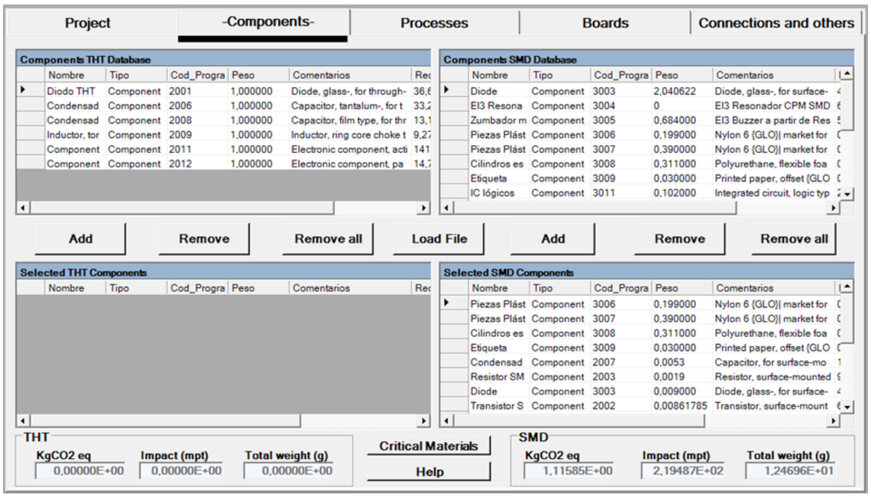
End of Life Scenarios

○ Without End of Life
○ With End of Life by Weight
● With End of life by Composition

Nombre	Comentarios	Recipe	GWP	CRM1
% Reciclado	(null)	(null)	(null)	0,85000000
% Reciclado	(null)	(null)	(null)	0,18400000

	Impact (mpt)	KgCO2 eq
+ WO EoL	1,00533E+03	6,29460E+00
+ EoL	-3,62391E+02	-1,00306E-01
Total	6,42939E+02	6,19429E+00

Figure 15 Components screen (see online version for colours)



Components THT Database

Nombre	Tipo	Cod_Progra	Peso	Comentarios	Rec
Diodo THT	Component	2001	1,000000	Diode, glass-, for through-	36,6
Condensad	Component	2006	1,000000	Capacitor, tantalum-, for t	33,2
Condensad	Component	2008	1,000000	Capacitor, film type, for thr	13,1
Inductor, tor	Component	2009	1,000000	Inductor, ring core choke t	9,27
Component	Component	2011	1,000000	Electronic component, acti	141
Component	Component	2012	1,000000	Electronic component, pa	14,7

Components SMD Database

Nombre	Tipo	Cod_Progra	Peso	Comentarios
Diode	Component	3003	2,040622	Diode, glass-, for surface-
EI3 Resona	Component	3004	0	EI3 Resonador CPM SMD
Zumbador m	Component	3005	0,684000	EI3 Buzzer a partir de Res
Piezas Plást	Component	3006	0,199000	Nylon 6 {GLO}| market for
Piezas Plást	Component	3007	0,390000	Nylon 6 {GLO}| market for
Cilindros es	Component	3008	0,311000	Polyurethane, flexible foa
Etiqueta	Component	3009	0,030000	Printed paper, offset {GLO
IC lógicos	Component	3011	0,102000	Integrated circuit, logic typ

Selected THT Components

Nombre	Tipo	Cod_Progra	Peso	Comentarios	Rec

Selected SMD Components

Nombre	Tipo	Cod_Progra	Peso	Comentarios
Piezas Plást	Component	3006	0,199000	Nylon 6 {GLO}| market for
Piezas Plást	Component	3007	0,390000	Nylon 6 {GLO}| market for
Cilindros es	Component	3008	0,311000	Polyurethane, flexible foa
Etiqueta	Component	3009	0,030000	Printed paper, offset {GLO
Condensad	Component	2007	0,0053	Capacitor, for surface-mo
Resistor SM	Component	2003	0,0019	Resistor, surface-mounted
Diode	Component	3003	0,009000	Diode, glass-, for surface-
Transistor S	Component	2002	0,00861785	Transistor, surface-mount

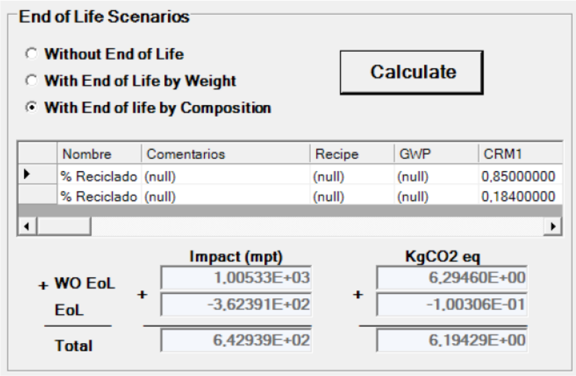
	KgCO2 eq	Impact (mpt)	Total weight (g)
THT	0,00000E+00	0,00000E+00	0,00000E+00
SMD	1,11585E+00	2,19487E+02	1,24696E+01

4.3 Touch control case results

Afterwards, once the project is completed, 'project' screen gives tool's options for calculating both critical materials and environmental impact.

'Sustainable Electronics' enables applying several ends of life scenarios, such as end of life by composition or by weight (Figure 16). The results simulated by the software show an environmental impact measurement in recipe of 642.9 mPt and of 6.19 Kg eq. CO_2 in carbon footprint.

Figure 16 End of life by composition scenario



○ Without End of Life
○ With End of Life by Weight
● With End of life by Composition

Nombre	Comentarios	Recipe	GWP	CRM1
% Reciclado	(null)	(null)	(null)	0,85000000
% Reciclado	(null)	(null)	(null)	0,18400000

	Impact (mpt)	KgCO2 eq
+ WO EoL	1,00533E+03	6,29460E+00
EoL	-3,62391E+02	-1,00306E-01
Total	6,42939E+02	6,19429E+00

In order to get more information regarding environmental impact or critical material composition, the results can be exported in an Excel file by means of button 'inventory and graphics'.

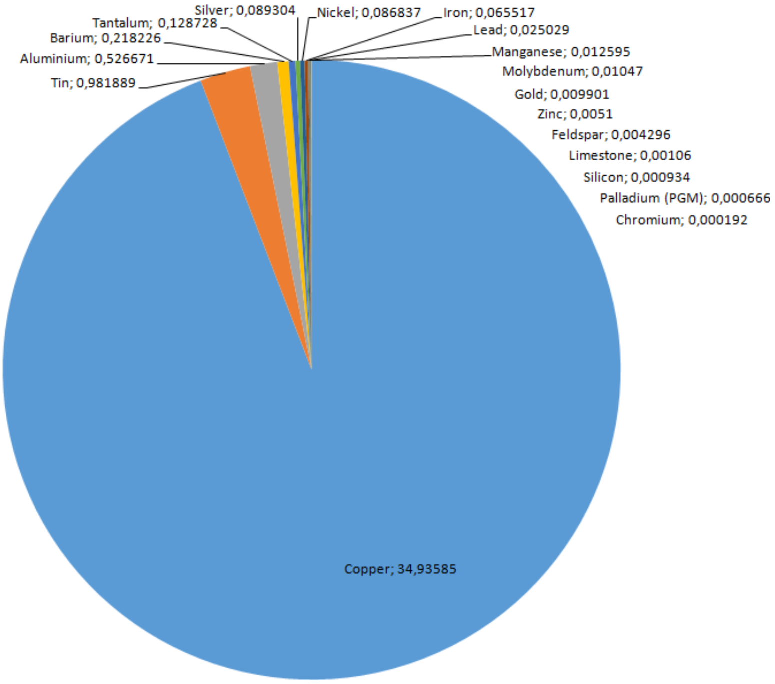
The PWB creates most of the environmental impact, followed by the SMD components. Although these components have a low overall weight, they generate a significant amount of impact and critical material consumption.

Table 2 Overall material consumption

Material	*Consumption (g)*
Copper	34.93585
Tin	0.981889
Aluminium	0.526671
Barium	0.218226
Tantalum	0.128728
Silver	0.089304
Nickel	0.086837
Iron	0.065517
Lead	0.025029
Manganese	0.012595
Molybdenum	0.01047
Gold	0.009901
Zinc	0.005100
Feldspar	0.004296
Limestone	0.001060
Silicon	0.000934
Palladium (PGM)	0.000666
Chromium	0.000192

Table 2 and Figure 17 show the consumption of critical and strategic materials in the studied touch control. The quantity of copper is the highest, mostly due to its use in the printing wiring board, followed by tin, used in components soldering, and aluminium, which is used mainly in the buzzer.

Figure 17 Overall material consumption (see online version for colours)



Furthermore, there is an option in the software that allows highlighting materials with a high consumption, either global consumption or in percentage. It can be really useful for future regulations, also could be implemented to adapt the software to the legislation.

Table 3 and Figure 18 show critical and strategic material consumption of SMD components. These are essential because, although SMD components have a low weight, the total consumption of critical and strategic material and the environmental impact is important.

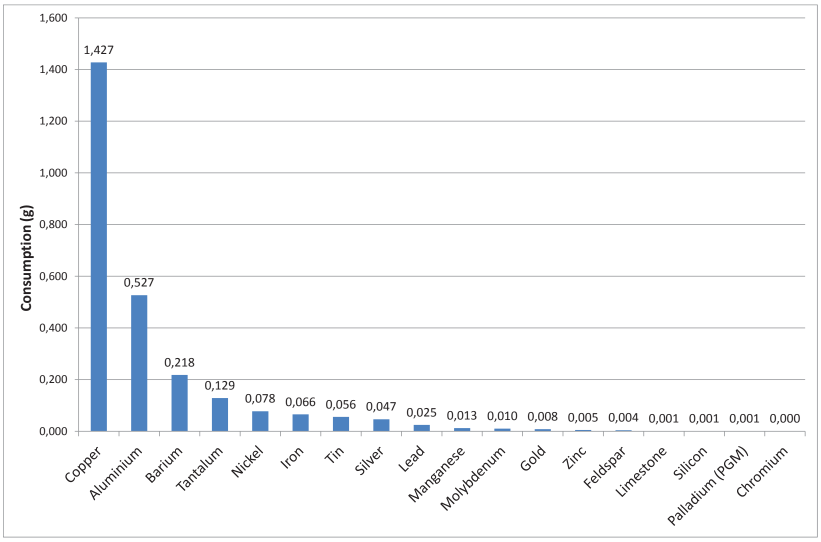
Table 3 SMD components material consumption

Material	*Consumption (g)*
Copper	1.427462
Aluminium	0.526671
Barium	0.218226
Tantalum	0.128728
Nickel	0.077808
Iron	0.065517
Tin	0.055989

Table 3 SMD components material consumption (continued)

Material	*Consumption (g)*
Silver	0.046820
Lead	0.025029
Manganese	0.012595
Molybdenum	0.010472
Gold	0.008097
Zinc	0.005100
Feldspar	0.004296
Limestone	0.001060
Silicon	0.000934
Palladium (PGM)	0.000666
Chromium	0.000192

Figure 18 SMD components material consumption (see online version for colours)



The value of copper consumption is the highest in SMD components, followed by aluminium, barium and in fourth place tantalum.

Once analysed the environmental impact and the overall critical and strategic material consumption, several conclusions can be reached. For example, there are several materials with economic importance, such as gold and silver. The first one, gold, with a consumption of 0.0099 grams, was used mostly in integrated circuits and transistors whereas silver, with 0.0089 grams, was used in soldering processes. On the other hand, there are also materials that present supply risk, such as palladium and chromium, which are used in SMD resistors.

5 Conclusions

The software 'Sustainable Electronics', developed in Visual Basic .NET, allows the user to quantify the critical and strategic materials associated with the design of a component; also the user can simulate the environmental impact.

The user interface makes easy for the user to compare between different components design, making material selection easier. It consists on an improved LCA adjusted to take into account the composition and the presence of critical materials, which has been calculated with ReCiPe and IPCC 2013 methodology.

Furthermore, the influence of material composition has been taken into account analysing the presence of critical raw material and although it has been developed for electrical and electronic components, it could be adapted to other sectors easily.

The simulation of the environmental impact of an induction hob delivers an environmental impact result of 642.9 mPt in Recipe and 6.19 Kg eq. CO_2 in carbon footprint. Furthermore, the consumption of copper, tin and aluminium supposes a significant amount of environmental impact and material consumption.

This analysis can be used to generate new eco design proposals, changing critical components by others with less critical material consumption. For example, the substitution of SMD transistors for components without gold content, such as the ones offered by several electronic components suppliers, would decrease the environmental impact, and also reduce cost and supply risk.

All these results can be achieved thanks to the modelling and simulation of the environmental impact carried out in this study. This approach will allow companies to reduce supply risk, environmental impact and costs.

Acknowledgements

We would like to thank Ignacio Alecha for his valuable help. Furthermore, the research in this paper has been partially supported by the Spanish MINECO under Project RETO RTC-2014-1847-6, and has been developed by members of the I+AITIIP (DGA-T39) research Group recognised by the Regional Government of Aragon (DGA) (FSE-EU).

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