ENVIRONMENTAL ASSESSMENT TOOL TO ANALYZE THE PRESENCE OF CRITICAL AND VALUABLE RAW MATERIALS

Patricia Gómez[a], Daniel Elduque[b], Carmelo Pina[c], Judith Sarasa[d], Isabel Clavería[e], Carlos Javierre[f]

[a],[c] BSH Electrodomésticos España, S.A., Avda de la Industria, 49, Zaragoza (Spain)
[b],[e],[f] i+, University of Zaragoza, C/ María de Luna 3, Zaragoza (Spain)
[d] Department of Chemical Engineering and Environmental Technologies, University of Zaragoza, C/ María de Luna 3, Zaragoza (Spain)

[a]patricia.gomez@bshg.com, [b]daniel.elduque@gmail.com, [c] carmelo.pina@bshg.com
[d]jsarasa@unizar.es, [e] isabel.claveria@unizar.es, [f] carlos.javierre@unizar.es

ABSTRACT

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 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. It considers raw material obtaining, manufacturing processes, transports and end of life. This Software allow us to easily update and use the datasets provided by Life Cycle Inventory databases, like for example EcoInvent, developed by the Swiss Center for Life Cycle Inventories. The methodology has been tested through the software in an electronic board of a Touch Control of an induction hob, obtaining that there is a high consumption of materials such as copper, tin or aluminum.

Keywords: life cycle assessment, environmental impact simulation, methodology, critical materials.

1. INTRODUCTION

Companies and the society want to reduce the environmental impact of products and services. The concept of ecodesign began in the 1990s in order to produce more sustainable products.

In order to reducing the environmental impact of a product, methodologies and techniques such as Life Cycle Assessment (LCA) are the key, as they allow researchers to assess and reduce the impacts to the ecological environment. This tool has been used to model a wide range of products: from wind turbines (Martinez et al. 2009) (Martinez et al. 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 there is a large concern about the materials that affect environmental impact. Due to environmental risk, economic importance and supply risk, materials can be considered as critical (European Commission 2014). The concept of Critical Material emerged firstly in 1939 by the US Administration.

In 2010, the restriction on the exportation of neodymium in China caused a supply chain crisis, as result, prices increased by an order of magnitude (Sprecher et al. 2015)

Although 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 & 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

When calculating the criticality of a material, it is necessary to take into account that an increase in the demand of some materials, in a specific moment, involves a decrease in the demand of others, due to technological change; creating changes in risk indicators of these materials (European Commission 2010) (Achzet & Helbig 2013).

As Peck (Peck et al. 2015) points out, 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 have been studied for products such as solar photovoltaics (Goe and

Gaustad 2014), bulbs (Lim et al. 2013) or iron alloys (Nuss et al. 2014).

Several authors have studied ways to reduce the overall consumption of critical materials, focusing specially on recycling (Rademaker et al. 2013) (Dhammika 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).

European Union laws have focused on reducing the environmental impact, by means of ecodesign (EuP 2005/32/CE) (European Parliament, 2005) (ErP 2009/125/CE) (European Parliament, 2009), chemical control and restriction of hazardous substances (REACH 1907/2006) (European Parliament, 2006) (RoHS 2002/95/CE) (European Parliament, 2003).

Applying a suitable ecodesign methodology is very interesting from an environmental point of view in electrical and electronic industry, improving all phases of electrical and electronic life cycle and analyzing 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, reducing 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 one of the most used Life Cycle Inventory databases, developed by Swiss Centre for Life Cycle Inventories. However, these databases provide generic data that is not always adequate for specific products. Our methodology is based on a LCA model, which uses customized datasets to simulate the environmental impact and also quantifies 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 analyzed 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.

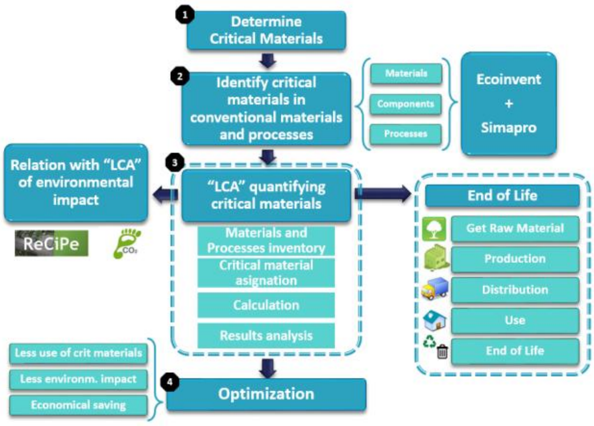


Figure 1: Methodology Diagram

2.1.1. 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. There will be processes that provide more critical materials consumption than others, affecting also the environmental impact simulation results.

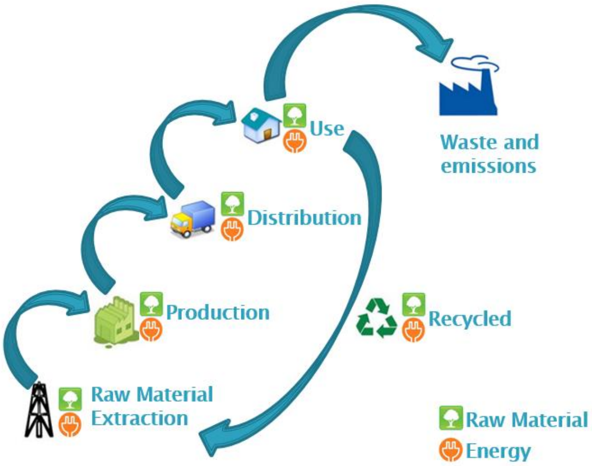


Figure 2: Life Cycle Stages

2.2. Environmental impact

The calculation methodology consist on an improved LCA adapted 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).

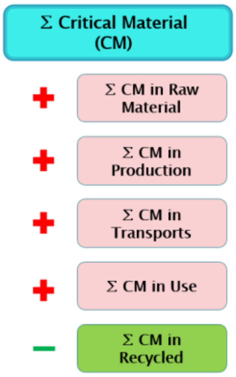


Figure 3: Critical Material Calculation

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

2.3. Results

The methodology can carry out the LCA model calculations and also take into account all the critical and valuable materials consumed in the life cycle.
Results should be clear and concise, in order to the user 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 proper results with this methodology, it is necessary to build a customized database structure that helps calculations. This methodology will be applied to the electrical and electronic field, so these are the components that should be considered for the particularization 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 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.

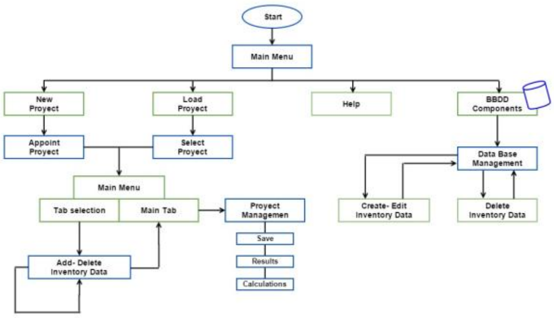


Figure 4: Software Structure

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

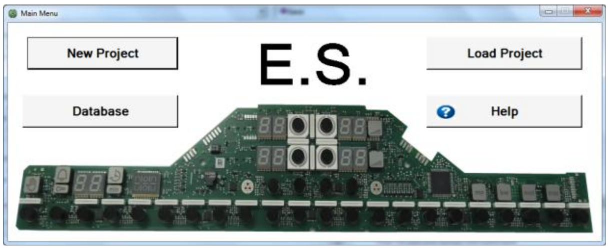
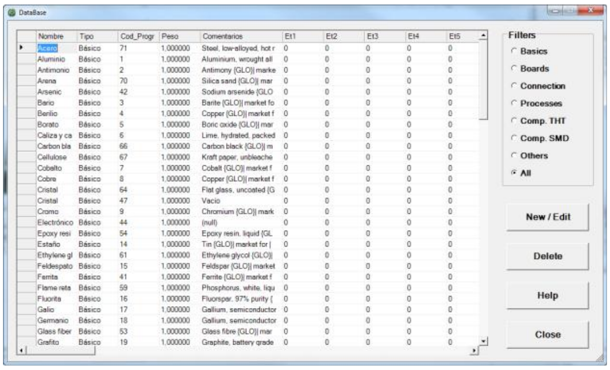


Figure 5: Main Screen of the Software

3.1. Database (LCA model inputs)

Selecting “Database” button from the main screen, the software shows the complete database (Figure 6). Navigating in this screen the user can filter and also manage the database, creating, editing and deleting inventory data.

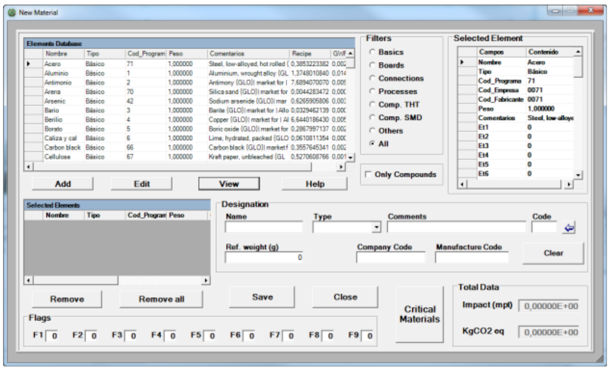


Nombre	Tipo	Cod_Progr	Peso	Comentarios	Et1	Et2	Et3	Et4	Et5
Acero	Básico	71	1,000000	Steel, low-alloyed, hot r	0	0	0	0	0
Aluminio	Básico	1	1,000000	Aluminium, wrought all	0	0	0	0	0
Antimonio	Básico	2	1,000000	Antimony {GLO}| marke	0	0	0	0	0
Arena	Básico	70	1,000000	Silica sand {GLO}| mar	0	0	0	0	0
Arsenic	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

Figure 6: Software Database

After customizing 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.



Elements Database

	Nombre	Tipo	Cod_Program	Peso	Comentarios	Recipe	GWF
▸	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

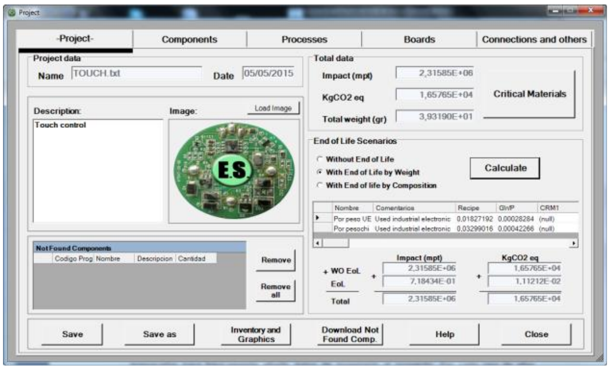
Figure 7: Database Personalization

3.2. Software development

"Sustainable Electronics" software allows researchers and engineers to analyzing 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 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.



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

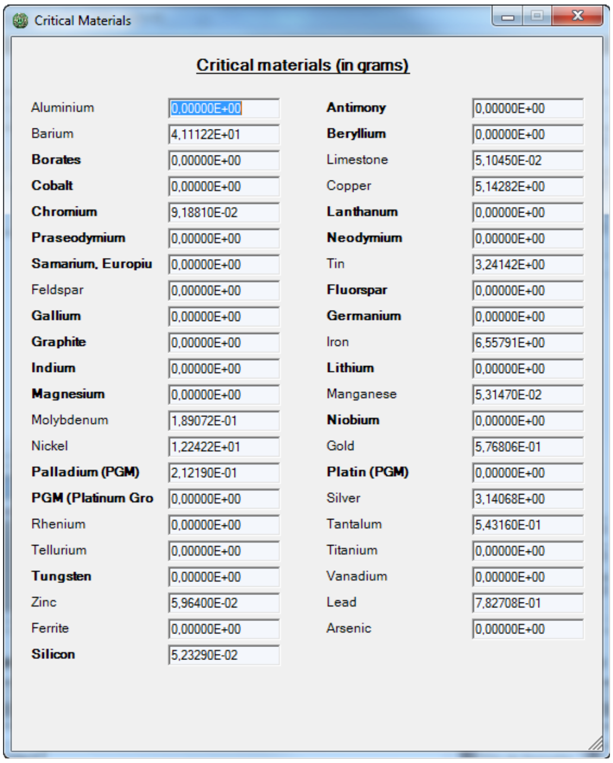
Not Found Components

	Codigo Prog	Nombre	Descripcion	Cantidad

Figure 8: Project Screen

All of these screens are prepared for add easily data from the inventory to the project. Once data is 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" bottom, critical materials window is shown (Figure 9), 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 (Commission 2014).



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		

Figure 9: Critical Materials Screen

4. SOFTWARE APPLICATION

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

4.1. Touch Control

As previously mention, 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 10.

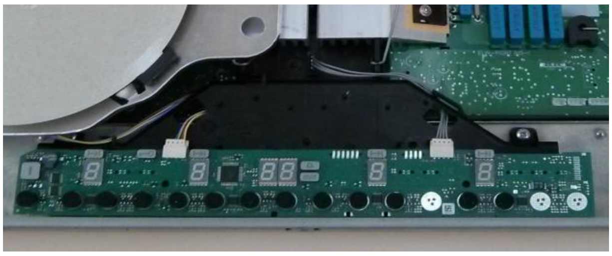


Figure 10: Touch Control

It is an electronic control board, called "Touch Control", used in induction hobs.

4.1.1. Touch Control Inventory

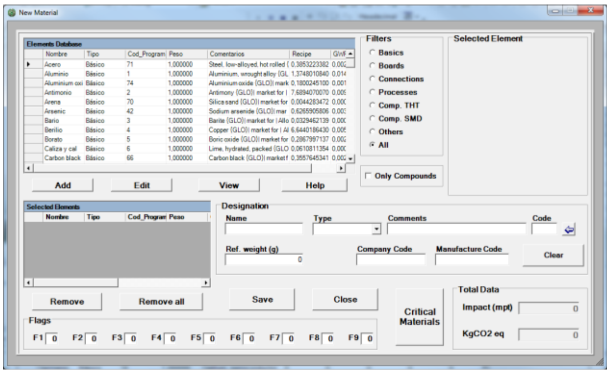
The inventory for this application consists on data related to electronics, such as capacitors, resistors, diodes, transistors and so on, boards and processes as welding SMD technology.

All of the 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).

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-segmentos 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

Table 1: Summarized Touch Control Inventory

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



Nombre	Tipo	Cod_Program	Peso	Comentarios	Recipe	GWF
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
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:

Selected Elements: Nombre | Tipo | Cod_Program | Peso

Ref. weight (g): 0

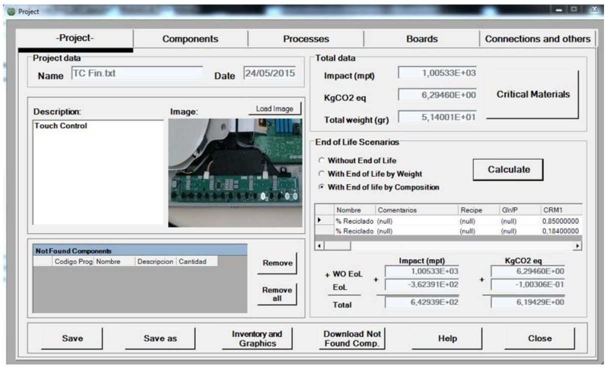
Impact (mpt): 0

KgCO2 eq: 0

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

Figure 11: Add or Create Data Screen

After all the inventory of the project has been created, the next step is create the application case. For that, it is necessary to access to "New Project" (Figure 12), where appears the main menu and it is compulsory named the project.



Name: TC Fin.txt

Date: 24/05/2015

Description: Touch Control

Impact (mpt): 1,00533E+03

KgCO2 eq: 6,29460E+00

Total weight (gr): 5,14001E+01

○ Without End of Life

○ With End of Life by Weight

● With End of life by Composition

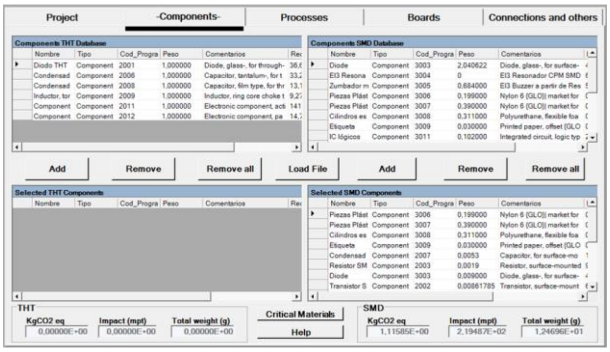
Nombre	Comentarios	Recipe	GWP	CRM1
% Reciclado	(null)	(null)	(null)	0,85000000
% Reciclado	(null)	(null)	(null)	0,18400000

	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

Not Found Components: Codigo Prog | Nombre | Descripcion | Cantidad

Figure 12: Project Screen

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 13).



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	9,2
Component	Component	2011	1,000000	Electronic component, acti	141
Component	Component	2012	1,000000	Electronic component, pa	14,:

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

Figure 13: Components Screen

4.1.2. Touch Control Case Results

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

"Sustainable Electronics" enables apply several end of life scenarios, such as end of life by composition or by weight. 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.

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 shows 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.

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: Overall Material Consumption

Furthermore, there is an option in the software that allows to stand out 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 shows critical and strategic material consumption of SMD components. These are essential because, although SMD components have slight weight, the total consumption of critical and strategic material and the environmental impact is really important.

The value of Copper consumption is the highest in SMD components, followed by Aluminium, Barium and in fourth place Tantalum.

Material	Consumption (g)
Copper	1,427462
Aluminium	0,526671
Barium	0,218226
Tantalum	0,128728
Nickel	0,077808
Iron	0,065517
Tin	0,055989
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

Table 3: SMD Components Material Consumption

After analyzing 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. 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 SE (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.

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 ecodesign 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 modeling and simulation of the environmental impact carried out in this study. This approach will allow companies to reduce supply risk, environmental impact and costs.

ACKNOWLEDGMENTS

We would like to thank Ignacio Alecha for his valuable help.

REFERENCES

Achzet B., Helbig C., 2013. How to evaluate raw material supply risks – an overview. Resources Policy, 38(4), pp. 435-447.

Adibi N., Lafhaj Z., Gemechu E.D., Sonnemann G., Payet J., 2014. Introducing a multi-criteria indicator to better evaluate impacts of rare earth materials production and consumption in life cycle assessment. Journal of Rare Earths,32(3), pp.288-292

Binnemans K., Jones P.T., Blanpain B., Van Gervenc T., Yang Y., Walton A. & Buchert M., 2013. Recycling of rare earths: a critical review. Journal of Cleaner Production, Volumen 51, pp. 1-22

Chapman A., Arendorf J., Castella T., Thompson P. & Willis P., 2013. Study on Critical Raw Materials at EU Level, Buckinghamshire: OAKDENE HOLLINS

Dewulf J., Benini L., Mancini L., Sala S. Blengini G.A., Ardenete F., Recchioni M., Maes J., Pant R., Pennington D., 2015. Environmental Science & Technology, 49, pp. 5310-5317

Dhammika Bandara H.M., Darcy J.W., Apelian D., Emmert M.H., 2014. Value Analysis of Neodymium Content in Shredder Feed: Toward Enabling the Feasibility of Rare Earth Magnet Recycling. Environmental Science & Technology, 48, pp. 6553-6560

Eckelman M.J., Ciacci L., Kavlak G., Nuss P., Reck B.K., Graedel T.E., 2014. Life cycle carbon benefits of aerospace alloy recycling. Journal of Cleaner Production, 80, pp. 38-45

Elduque D., Javierre C., Pina C., Martínez E. & Jiménez E., 2014. Life cycle assessment of a domestic induction hob: electronic boards. Journal of Cleaner Production, 76, pp. 74-84

European Commission, 2010. Report of the Ad-hoc Working Group on defining critical raw materials. Enterprise and Industry Directorate General website.

European Commission, 2014. Report on Critical Raw Materials for the EU. Critical Raw Materials Profiles, European Union: DG Enterprise and Industry.

European Parliament, 2003. Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS). EU Publications Office, Luxembourg. Official Journal of the European Union.

European Parliament, 2005. Directive 2005/32/EC of the European Parliament and of the Council of 6 July 2005 Establishing a Framework for the Setting of Ecodesign Requirements for Energy-Using Products, EU Publications Office, Luxembourg: Official Journal of the European Union.

European Parliament, 2006. Regulation (Ec) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency. Official Journal of the European Union. EU Publications Office, Luxembourg.

European Parliament, 2009. Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 Establishing a Framework for the Setting of Ecodesign Requirements for Energy-Related Products, EU Publications Office, Luxembourg: Official Journal of the European Union.

Fernández A., Javierre C., González J. & Elduque D., 2013. Development of thermoplastic material food packaging considering technical, economic and environmental criteria. Journal of Biobased Materials and Bioenergy, 7(2), pp. 176-183.

Funari V., Braga R., Nadeem S., Bokhari H., Dinelli E., Meisel T., 2014. Solid residues from Italian municipal solid waste incinerators: A source for ‘‘critical’’ raw materials. Waste Management (article in press)

Glöser S., Espinoza L.T., Gandenberger C., Faulstich M., 2015. Raw material criticality in the context of classical risk assessment. Resources Policy, 44, pp. 35-46

Goe M and Gaustad G., 2014. Identifying critical materials for photovoltaics in the US: A multi-metric approach. Applied Energy 123, pp. 387-396

Gómez P., Elduque D., Sarasa J., Pina C.,Javierre C., 2015. Influence of the material composition on the environmental impact of surface-mount device (SMD) transistors. Journal of Cleaner Production.

Graedel T.E., Nuss P., 2014. Employing Considerations of Criticality in Product Design. JOM, 66(11), pp. 2360-2366.

Gutierrez-Gutierrez S., Coulon F., Jiang Y., Wagland S., 2015. Rare earth elements and critical metal content of extracted landfilled material and potential recovery opportunities. Waste Management, 42, pp.128-136

Hennebel T., Boon N., MaesS., Lenz M., 2015. Biotechnologies for critical raw material recovery from primary and secondary sources: R&D priorities and future perspectives. New Biotechnology, 32 (1), pp. 121-127

Jiménez E., Martínez E., Blanco J., Pérez M., Graciano C., 2014. Methodological approach towards sustainability by integration of environmental impact in production system models through life cycle analysis: Application to the Rioja wine sector. SIMULATION, 90(2), pp. 143-161.

Leiva-Lázaro F.J., Blanco J., Martínez, E., Jiménez E., 2014. Production of compost for mushroom cultivation: A life cycle assessment study 26th European. Modeling and Simulation Symposium, EMSS 2014; Bordeaux; France; pp 620-625.

Lim S.R., Kang D., Ogunseitan O.A., Schoenung J.M., 2013. Potential Environmental Impacts from the

Metals in Incandescent, Compact Fluorescent Lamp (CFL), and Light-Emitting Diode (LED) Bulbs. Environmental Science & Technology, 47, pp. 1040-1047

Mancini L., Sala S., Recchioni M., Benini L., Goralczyk M., Pennington D., 2015. Potential of life cycle assessment for supporting the management of critical raw materials. International Journal of Life Cycle Assessment (20), pp.100-116

Martínez, E., Blanco J., Jiménez, E., Saenz-Díez J.C., Sanz F., 2015. Comparative evaluation of life cycle impact assessment software tools through a wind turbine case study. Renewable Energy, 74, pp- 237-246.

Martínez E., Sanz F., Pellegrini S., Jiménez E., Blanco J., 2009. Life cycle assessment of a multi-megawatt wind turbine. Renewable Energy, 34(3), pp. 667-673.

Mcguiness P., Akdogan O., Asali A., Bance S., Bittner F., Coey J. M. D.,. Dempsey N. M, Fidler J., Givord D Gutfleisch., O., Katter M., Le Roy D., Sanvito S., Schrefl T., Schultz L., Schwöbl C., Soderžnik M., Šturm S., Tozman P., Üstüner K., Venkatesan M., Woodcock T. G., Žagar K., Kobe S., 2015. Replacement and Original Magnet Engineering Options (ROMEOs): A European Seventh Framework Project to Develop Advanced Permanent Magnets Without, or with Reduced Use of, Critical Raw Materials. The Journal of The Minerals, Metals & Materials Society (TMS), 67 (6), pp. 1306-1317

Nuss P., Harper E.M., Nassar N.T., Reck B.K., Graedel T.E., 2014. Criticality of Iron and Its Principal Alloying Elements. Environmental Science & Technology, 48, pp. 4171-4177

Pina C., Elduque D., Javierre C., Martínez E., Jiménez E., 2015. Influence of mechanical design on the evolution of the environmental impact of an induction hob. International Journal of Life Cycle Assessment, 20(7), pp. 937-946.

Peck D., Kandachar P., Tempelman E., 2015. Critical materials from a product design prespective. Materials and Design, 65, pp.147-153.

Rademaker J.H., Kleijn R., Yang Y., 2013. Recycling as a Strategy against Rare Earth Element Criticality: A Systemic Evaluation of the Potential Yield of NdFeB Magnet Recycling. Environmental Science & Technology, 47, pp. 10129-10136

Rorbech J., Vadenbo C., Hellweg S., Astrup T.F., 2014. Impact Assessment of Abiotic Resources in LCA: Quantitative Comparison of Selected Characterization Models. Environmental Science & Technology, 48, pp. 11072-11081

Sonnemann G., Gemechu E.D., Adibi N., Bruille V.D., Bulle C., 2015. From a critical review to a conceptual framework for integrating the criticality of resources into Life Cycle Sustainability Assessment. Journal of Cleaner Production, 94, pp 20-34

Sprecher B., Daigo I., Murakami S., Klejin R., Vos M., Kramer G.J., 2015. Framework for Resilience in Material Supply Chains, With a Case Study from the 2010 Rare Earth Crisis. Environmental Science & Technology, 49, pp. 6740-6750