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Influence of the Material Composition on the Environmental Impact of SMD Transistors

Patricia Gómez[a], Daniel Elduque[a,1], Judith Sarasa[c], Carmelo Pina[b], Carlos Javierre[a]

[a] *i+, University of Zaragoza, C/ María de Luna,3 - 50018 Zaragoza, Aragón, Spain*

[b] *BSH Electrodomésticos España, S.A., Avda de la Industria, 49 - 50016 Zaragoza, Aragón, Spain*

[c] *Department of Chemical Engineering and Environmental Technologies, University of Zaragoza, C/ María de Luna,3 - 50018 Zaragoza, Aragón, Spain*

Abstract

Purpose. The aim of this study is to better elucidate the influence of surface-mount device (SMD) transistor material composition on the environmental impact of such transistors. A life cycle assessment (LCA) has been performed in which the EcoInvent dataset was updated with material compositions provided by several manufacturers. The influence of the material composition has been studied, providing a more precise understanding of the environmental impact.

The software used to develop the LCA model was SimaPro 8.0.3.14, developed by Pré Consultants. The LCA was calculated with the CML methodology. In addition, a life cycle inventory was developed using EcoInvent v3.

Results. The EcoInvent methodology was used as a comparison tool for information provided by the manufacturers in terms of environmental impact, thus improving transistor selection in electronics design. The environmental impact of an SMD transistor can vary substantially with respect to material composition. Raw material acquisition represent between 20,3% and 99,9% of the total impact in most environmental categories. By contrast, the environmental impact of each transistor created due to part production is usually lower. The lowest environmental impact comes from the end of life treatments, values for which are approximately 0,1%.

Conclusion. This environmental impact study demonstrates the large influence of transistor material composition for those analyzed herein.

Keywords: LCA; transistors; SMD; material composition.

[1] * Corresponding author. Tel.: +34 876555211; fax: +34 976761861

E-mail address: daniel.elduque@gmail.com

List of abbreviations

ETSI	European Telecommunications Standards Institute
GWP100y	Global Warming Potential referred to 100 years
ICT	Information and Communication Technologies
LCA	Life Cycle Assessment
ODP	Ozone layer Depletion
PP	Part Production
RMA	Raw Material Acquisition
SMD	Surface-Mount Device
SMT	Surface Mounting Technology
WEEE	Waste of Electrical and Electronic Equipment

1. Introduction

The concept of ecodesign arose at the beginning of 1990s from the need for reducing environmental impacts of various. This concept is based on the rule of prevention instead of correction and implements creativity, innovation and environmental responsibility in the design stage (Plouffe, et al., 2011) (Aoe, 2007) (E.R. Platcheck, 2008).

In the electronics industry, it is important to measure the environmental performance of a product in order to reduce environmental impact, which also provides another aspect to market competitiveness for manufacturers, i.e., companies look to improve their profits and at the same time save costs (Plouffe, et al., 2011) (Borchardt, et al., 2011).

One of the most important advances in the electronics industry was the invention of the union transistor, which took place in 1951, by William Schockley (Malvino, 1999). The transistor is a semiconductor device mainly used to amplify electronic signals. It can be used for many digital and analogue purposes including amplification, regulation of voltage, switching and signal modulation.

Transistors have had an enormous impact on modern society, as nearly all of the electronic devices we use rely on transistors. As transistors have become an essential component to any electronics device, manufactures continue to try to reduce their size. State-of-the-art transistors are in fact microscopic in size, and their electric power consumption is very low (Hischier, et al., 2007).

There are two main methods of soldering transistors on an electronic circuit board: through-hole mounting technology and surface mounting technology (SMT). Components using the SMT approach are known as surface-mounted devices (SMD) (Sharon Mui Ling, et al., 2014). Through-hole technology requires holding the circuit board to place the components that cross through all layers. In contrast, SMDs are soldered on the circuit board or assembled with a small amount of adhesive on the underside, without the necessity of holding the circuit board (Vianco, 2001) (Liu, 2001).

There has been a recent trend toward SMDs rather than through-hole devices due to needs for devices with reduced size and weight, which are thus more compact and portable. Additionally, reducing cost and improving reliability is also important (Koshal, 1993). The smaller size and shorter connections of SMT make it more amenable to these design goals, and the mechanical strength of the assembly is greater as well.

Furthermore, depending on several factors, such as the application requirements of the transistors, there are many types of encapsulation. Once again, due to size constraints, there has been progress in encapsulation of microelectronic devices toward reducing packaging size (Strauss, 1998) (Lau, 2014).

There is an increasing demand for electronic devices due to cheaper, accessible and more efficient products and also to surging data traffic due to cloud services (Concoran & Andrae, 2014). Accordingly, many people can afford to buy new devices, replacing other technologies and generating new waste of electrical and electronic equipment (WEEE). In 2010, European countries produced approximately 6,5 million tons of WEEE, with an estimate 12 million tons for 2015. These figures will increase 16-28% every five years as a result of new cheaper technologies (Ongondo, et al., 2011) (Queiruga, et al., 2012).

Consequently, the European Union has implemented several laws focused on WEEE reduction, such as the WEEE Directive, to improve the recycling of electric and electronic equipment thus reducing the disposal of waste (European Parliament, 2012). As a means to increase energy efficiency, directives related to energy-using products (EuP) (European Parliament, 2005) and energy-related products (ErP) (European Parliament, 2009) were developed to protect the natural environment. This study shows the environmental impact of SMD transistors according to the WEEE Directive, which accounts for the generated waste being treated in a European WEEE treatment plant.

There is also a large concern in society about materials that have substantial environmental impact. These materials are considered critical materials due to shortage or supply risk, economic vulnerability and ecological risk (Commision, 2014). Due to technological change, the demands for particular materials are volatile as one demand for one material may quickly increase while another decreases, which can lead to changes in risk indicators for a particular material. It is necessary to take into account all of these considerations when determining the criticality of a material (Chapman, et al., 2013) (Binnemans, et al., 2013) (Graedel & Nuss, 2014).

Therefore, the main objective of this study is to determine the influence of the material composition on the environmental impact of SMD transistors. To do that, life cycle assessment (LCA) has been used to quantify the environmental impact, identifying the main types of environmental impact along the life cycle.

LCA has been implemented by many industries and businesses to better understand how their products affect the natural environment. Several electrical and electronic products have LCA studies (Andrae, et al., 2004), such as, integrated circuit products (Taiariol, et al., 2001), integrated circuit packaging technologies (Andrae & Andersen, 2011), telecommunications exchange technologies (Andrae, et al., 2000) and optical fiber networks (Andrae, 2012)

Further, several authors analyzed the environmental impact of products from flash memories (Boyd, et al., 2011) to personal computers or mobile phones (Andrae & Andersen, 2010) (Yao, et al., 2010) (Moberg, et al., 2014), including silicon wafer processing for microelectronic chips (Schmidt, et al., 2012), computational logic (Boyd, et al., 2009), smartphones (Andrae & Vaija, 2014) (Andrae, 2015) and FED TVs (Hischier, 2015). Other studies were focused on the environmental impact of information and communication technologies (ICT) (Arushanyan, et al., 2014) (Stiel & Teuteberg, 2014) (Börjesson Rivera, et al., 2014) or domestic induction hobs (Elduque, et al., 2014); also recently, Sikdar published a LCA of electronic components used in Wi-Fi access points and Ethernet switches (Sikdar, 2013) (Sikdar, 2010).

Although other authors wrote studies about semiconductor production processes (Boyd, et al., 2010), this LCA is focused on the material composition of each transistor and the influence they have on the environmental impact. To carry out the LCA, information from several manufacturers has been gathered. Recently, a Technical Specification to carry out LCA of electronic products focused on ICT Equipment, Networks and Services was published by the European Telecommunications Standards Institute (ETSI). This document has been used as a guide in this research (ETSI, 2011).

2. Materials and Methods

2.1. Dataset improvement methodology for electronic components

Most recent LCA studies use generic datasets from databases such as EcoInvent to evaluate electronic products. The EcoInvent database covers several types of parts, including SMD transistors. This database provides a system characterization for transistors produced on a global scale that includes material composition and an estimation of the productions efforts: auxiliaries, energy, emissions, waste, infrastructure, etc. (Hischier, et al., 2007). Manufacturers have started to publish material composition datasheets for electronic components (Technologies, 2014) (Fairchild, 2014), and the aim of this study is to use that information to evaluate the influence of the material composition on the natural environment. Our approach is similar to that of Andrae and Andersen (Andrae & Andersen, 2011), who compared the environmental impacts of integrated circuit packaging technologies based on manufacturer information on the material composition and masses of subparts; however, our study is focused more specifically on analyzing the differences using EcoInvent part data.

Therefore, in this paper, the dataset provided by EcoInvent is updated with material composition provided by manufacturers. To achieve a more precise environmental impact assessment, the production processes and waste generation for each transistor has been analyzed using the EcoInvent methodology and applying it to the information provided by the manufacturers.

For the different construction elements of an SMD transistor (chip, lead frame, encapsulation, etc.), material efficiency and waste generation data provided by EcoInvent for "Transistor, surface-mounted {GLO}| production" have been applied to several SMD transistors. This allows us to estimate the overall raw material acquisition, not only considering the materials present in the final transistors but also the overall material consumption and waste generation. Using the original EcoInvent dataset, the overall amount of non-used raw materials needed for the production processes, which ends up as waste, is also obtained. All of these data are introduced into the EcoInvent dataset, preserving production efforts and updating raw material consumption and waste generation. To improve the comparison between transistors, the EcoInvent dataset has been modified by substituting tin-lead solder for lead-free solder, as most modern transistors are lead-free due to legislation changes (Abtew & Selvaduray, 2000).

This makes possible the use of the information currently supplied by manufacturers of material content and the adaptation of this information to assess the environmental impact while taking into account the system characterization of EcoInvent. Recently, (Zhu & Andrae, 2014) showed a system and methodology for performing cost effective LCA of information and communication technology (ICT) equipment based on material content and in conformance with ETSI TS 103 199. Therefore, the LCAs of different SMD transistors can be performed and compared with the EcoInvent dataset with the objective of evaluating the influence of the material composition on the environmental impact. Doing so enables electronic engineers to choose between different transistors from an environmental point of view.

2.2. LCA Methodology

2.2.1. Goal and scope definition

The aim of this LCA is to analyze the influence of the differences in the material composition on the environmental impact results between different SOT23 SMD transistors. This analysis can be used as a comparison tool to improve transistor selection considering its environmental impact.

2.2.2. Functional Unit

In the developed LCA, the functional unit has been defined as one transistor with a SOT23 package with an NPN structure, with dimensions of 3,0 mm x 1,75 mm x 1,3 mm and power consumption 200-300 mW. Current gains for the transistors studied in this study are between 70 and 160; maximum values for collector currents are between 100 nA and 100 mA. The chosen reference mass flow is 1 g. The LCA accounts for the material composition of the component, waste produced in the production process, energy consumption and end of life. However, in end of life calculations, the transistor is assumed to be integrated into a circuit board, as transistors are manufactured and soldered in integrated circuit boards together with other components, e.g., diodes, resistors and capacitors.

From the information provided by several manufacturers and the commercial database, the environmental impact has been analyzed with respect to SMD transistor material composition.

2.2.3. System boundaries

The main goal of this paper is to study the environmental impact created by different types of transistors, studying and analyzing the variation of the environmental impact caused by their material composition.

To analyze the environmental impact of each transistor and compare them, a LCA model has been developed. It includes the following stages (Figure 1): the production of raw materials and energy consumption (Stage A, following ETSI nomenclature), manufacture and production processes (Stage B1) and finally end-of-life (Stage D2). Distribution to consumers and the use phase are not included in the studied product system, as they are not directly related to material composition of transistors and strongly dependent on the electronic board in which the transistor is used. Other generic processes included in the studied product system are G1 (Transport and Travel), G2 (Electricity), G3 (Fuels) and G5 (Raw Material Acquisition).

2.2.4. Inventory data and cut-off criteria

A life cycle inventory has been developed using EcoInvent v3, one of the most used databases developed by Swiss Centre for life cycle inventories. The inventory data and cut-off criteria are based on EcoInvent.

2.2.5. Assumptions

SimaPro 8.0.3.14, developed by Pré Consultants, was used to develop the LCA model. LCA was implemented with CML – IA baseline V.3.01 methodology. Additionally, the following impact categories have been used to avoid subjectivity: abiotic depletion, abiotic depletion (fossil fuels), acidification, eutrophication, global warming (GWP100y), ozone layer depletion (ODP), human toxicity, fresh water aquatic ecotoxicity, marine aquatic ecotoxicity, terrestrial ecotoxicity and photochemical oxidation.

Disposal of SMD transistors must comply with the WEEE Directive; therefore, they must be collected at the end of their life. It is assumed that the boards where the transistors are soldered are going to be treated in a WEEE treatment plant; thus, the following EcoInvent dataset has been used for all of the transistors: *Used printed wiring boards (waste treatment) {GLO}| treatment of scrap printed wiring boards, shredding and separation*. This dataset has been used as a reasonable proxy for the aim of this study, but if the end-of-life phase were more relevant, it should be analyzed with primary data instead of using this EcoInvent's dataset.

3. Life Cycle Inventory

The aim of this article is to study the environmental impact created by different types of transistors and to examine the influence of their material composition.

To perform this study, the detailed material composition of several transistors have been obtained from manufacturers, including information of their constituent parts. These parts (lead frame, plating, bonding wire, encapsulation, silicon die) are shown in the Figure 2. As shown in the figure, a chip or die is bonded to the lead frame with bonding wires, while this chip is protected from the environment by the epoxy molding or the encapsulation (Vishay Electronic, 2014).

Material content datasheets that have been used to analyze the environmental impact of SMD SOT23 transistors were provided by manufacturers. The SMD type transistor dataset provided by EcoInvent has been analyzed, along with the calculated material composition of 11 different transistors. The results of material composition with respect to 1 g of transistor are shown in Table 1.

Table 1 also shows a detailed inventory of the material composition of each transistor. The quantity of some materials varies considerably from some suppliers to others. This is the case for gold, arsenic, chromium, silicon, titanium and silver. The Ecoinvent transistor dataset does not include these elements despite them being present in most of the studied transistors. Additionally, there are materials that the Ecoinvent dataset include that are not actually found in some of the studied transistors, such as cooper, epoxy resin, aluminum, iron or nickel.

Table 2 shows the studied transistors and the material inputs needed for manufacturing 1 g of each transistor. This allows us to calculate the amount of transistor used, not only considering 1 g of final transistor but also taking into account the complete raw materials inputs and the waste generation. The values have been calculated using the EcoInvent methodology, applying it to every manufacturer dataset. The life cycle inventory for each SMD transistor has been developed to compare these results with EcoInvent. In this way, the influence of the material composition on the environmental impact can be evaluated with more precision. The methodology used to develop the transistor LCAs by EcoInvent considers an input of raw material acquisition (RMA) of 5,80 g for each gram of transistor manufactured (a waste amount of 4,80 g unused raw material). However, transistors such as the SMBTA06 model require 3,35 g, and in BC817#2 transistors, the amount of material is higher, 6,25 g.

Table 3 shows the most relevant EcoInvent datasets that have been used to characterize the inputs of the transistors. These datasets have been selected following the EcoInvent guidelines (Hischier, et al., 2007).

4. Results and Discussion

After introducing the life cycle inventory in SimaPro, several results have been calculated with the aim of analyzing the environmental impact of all of the selected transistors. The influence of the material composition, production processes and end of life have been studied. Finally, a more detailed study of the environmental impact for three particular transistors is shown.

4.1. Analysis of the environmental impact of all transistors.

Table 4 shows the calculations of the environmental impacts of each transistor in relation to the different categories of impact. The presented results are the percentage of impact with respect to the values of the EcoInvent methodology, considering EcoInvent results as the benchmark 100%. In general, it can be said that the highest environmental impact is observed for the transistor ZSOT23. It can be seen that in all environmental categories, it creates the highest environmental impact, mainly because of its higher gold percentage in its material composition (see Tables 1 and 2). The large relevance of the use of gold is in line with the results of other studies about electronic products (Andrae & Andersen, 2011) (Nordelöf, et al., 2014) (Whitehead, et al., 2015). The impact of gold is mainly caused by the disposal of mine tailings containing sulfides. Gold is usually used in transistors when other materials can cause problems by current-induced ion migration (Industry, 2014). On the other hand, there is one transistor without gold content (BC817#2) that in some categories creates a lower environmental impact than the one calculated with the Ecoinvent dataset.

The environmental impact created by the studied transistors in each environmental category is summarized as follows.

- The highest environmental impact for *abiotic depletion* is produced by the ZSOT23 transistor, almost 170 times higher than the EcoInvent dataset. The most significant impacts in this category are created by gold consumption; therefore the BC817#2 transistor has the lowest environmental impact investigated due to low gold consumption. In spite of that, its impact is 2,8 times higher than the EcoInvent dataset.
- *Abiotic depletion (fossil fuels) and global warming (GWP100y)* impacts are also higher in ZSOT23, followed by BCR533 and SMBTA06; all of them between 1,5 and 4,1 times higher than the EcoInvent transistor. These impacts are primarily a result of gold content and electricity consumption. Accordingly, BC817#2 has the low environmental impact in this category, similar to that of the EcoInvent dataset
- In the case of *ODP,* gold and electricity consumption generate the highest impact. The impact of transistor ZSOT23 is almost 3,9 times higher than the environmental impact provided by EcoInvent. Conversely, BC817#2 generates only 73,2% of the impact as that of the EcoInvent dataset.
- *Human toxicity* impact is mainly caused by gold, silver and electricity consumption. The ZSOT23 transistor relies heavily on all three and thus has a high environmental impact. In contrast, BC817#2 has the lowest value for this category, even lower than that of EcoInvent.
- For *fresh water aquatic ecotoxicity and marine aquatic ecotoxicity*, gold generates most of the environmental impact in both categories. As BC817#2 contains no gold, its environmental impact in these categories is the lowest of all, approximately 55% of the EcoInvent environmental impact.
- *Terrestrial ecotoxicity* once again is mainly caused by gold and electricity consumption. All of the transistors have higher values than EcoInvent in this category, from 113% for transistor BC817#2 up to 503% for transistor ZSOT23.

- *Photochemical oxidation and acidification* are mostly caused by gold, nickel and electricity consumption; in these categories, transistors BCR108 and ZSOT23 have the highest values of environmental impact.
- *Eutrophication effects* are mainly produced by the consumption of gold and nickel, and in this category BCR533 and SMBTA06 create an impact more than 13,5 times higher than EcoInvent but still lower than that of ZSOT23, which is 51,9 times higher.

After updating the EcoInvent data with manufacturers' information, Monte Carlo simulations were carried out. Although the absolute uncertainty of these results remains relatively high, due to the uncertainty in the original EcoInvent data, this relatively high uncertainty of LCA of integrated circuit packaging technologies was also shown by Andrae and Andersen. (Andrae & Andersen, 2011). The people behind EcoInvent have been working on improving their uncertainty calculations and it will be updated with a refined empirical pedigree matrix in the following versions. (Muller, et al., 2014) (Ciroth, et al., 2013).

4.2. Study of the Life Cycle Stages of each transistor.

To further analyze the environmental impact, the environmental impact of the three life cycle stages: A (Materials), B1 (Production) and D2 (End of Life) over the whole life cycle are shown in this subsection.

4.2.1. Environmental impact of Raw Materials Acquisition

The importance of the material composition of each transistor in the environmental impact varies considerably. Table 5 presents the percentages of the environmental impacts of the input of materials (Stage A) over the whole life cycle (100%).

In the *abiotic depletion* category, the percentage of environmental impact created by materials is approximately 99.7%. However, in *abiotic depletion (fossil fuels)*, *global warming* and *terrestrial ecotoxicity,* the percentages are lower: they vary from almost 17,7% up to approximately 58,5%; remarkably, the value for transistor ZSOT23 exceeds 83,9%.

For *ODP*, *photochemical oxidation* and *acidification* the percentages of environmental impact created by the use of materials are lower than *abiotic depletion*, but higher than *abiotic depletion (fossil fuels)* or *global warming*. In *ODP* these values are between 27,2% for BC817#2 and 86,3% for ZSOT23. In *photochemical oxidation*, the percentages vary from 53,9% for the EcoInvent dataset up to 84,9% for the ZSOT23 dataset. The *acidification* category has similar values; they are between 58,3% for the EcoInvent dataset and 90,3% for the ZSOT23 dataset.

As previously mentioned, *human toxicity* is mainly caused by gold. Thus, transistors which contain gold (all the studied ones except EcoInvent and BC817#2) have high percentages, approximately 98,5% of the environmental impact of each transistor. In transistors without gold, these percentages are lower, such as that for transistor BC817#2, in which the environmental impact of materials is 54,8% of the total. Values for *fresh water aquatic ecotoxicity* and *marine ecotoxicity* categories are similar to *human toxicity*, as gold consumption generates most of the environmental impact in both categories.

Finally, the last environmental impact category *eutrophication*, also shows low percentages in BC817#2 and EcoInvent datasets due to the low consumption of gold and nickel, 44,6% and 69,6%, respectively.

4.2.2. Environmental impact of part production

Table 6 shows the results (as a percentage of the total impact) due to part production processes (Stage B1). The environmental impacts are usually lower than those due to material composition.

In *abiotic depletion*, the percentage of environmental impact created by processes are the lowest of all categories: less than 2,2% of environmental impact. The highest value comes from the EcoInvent dataset. In contrast, *abiotic depletion (fossil fuels), global warming and terrestrial ecotoxicity* have higher values; they are between 16,1% in ZSOT23 and 82,0% in the EcoInvent dataset.

For *ODP, photochemical oxidation* and *acidification* the percentages of environmental impact are approximately 20-50% of the environmental impact; the values were also lower for the ZSOT23 transistor.

Human toxicity, fresh water aquatic ecotoxicity, marine ecotoxicity have low values of percentage of environmental impact from 0,4% up to 4,1% in all categories, except for the EcoInvent dataset and BC817#2, where environmental impact due to processing are higher: approximately 20% and 50%, respectively.

Eutrophication values are low. Most of the transistors have values of environmental impact lower than 3,6%. However, the EcoInvent dataset and transistor BC817#2 generate higher environmental impacts, 30,4% and 55,4%, respectively.

4.2.3. Environmental impact of end of life

The environmental impacts caused due to end of life treatments (Stage D2) are especially low, between 0% to 1,5% of the total environmental impact of all categories (data not shown). The contribution percentage of the end of life phase can be obtained subtracting to 100% the percentages of the other two LCA phases (RMA and PP). Additionally, typical values of the impacts of end of life in most categories calculated in this study are lower than 0,1%. Therefore, the EcoInvent dataset proxy used for the end of life has a low influence on the overall results.

4.3. Study of the environmental impact generation of three selected transistors

After analyzing the overall impact and the influence of each life cycle stage (A, B1 and D2), the impact generation of several transistors was analyzed and is detailed in this section. The results allow one to perform a sensitivity analysis on how material composition modifies the environmental impact.

Three different transistors have been selected: the ZSOT23, which has the highest gold content of the 12 analyzed transistors; the BC817-25, which has a material composition closest to the average material composition of all of the studied transistors; and the BC817#2, which is the transistor with an environmental impact closest to EcoInvent dataset, as it does not contain gold in its material composition.

4.3.1. Environmental impact of the ZSOT23 transistor

Table 7 shows how the environmental impact is generated for each category. Gold created between 53,8% of the impact in *photochemical oxidation* up to 98,9% in *human toxicity* thus producing most of the environmental impact of this transistor. The presence of nickel is especially relevant for *photochemical oxidation* and *acidification*. The following materials in terms of importance are tin, silver, and copper, but each has a minor (<2,7% each) influence on the overall results.

The contribution of the electricity consumption of the production processes achieves between 8,6 and 18,5% in *abiotic depletion (fossil fuels), global warming potential, ODP, terrestrial ecotoxicity, photochemical oxidation* and *acidification*. EcoInvent's assumption of an electronic component factory creates impact between 0,01% for *abiotic depletion* and up to 1,4% in *photochemical oxidation*.

4.3.2. Environmental impact of the BC 817-25 transistor

The environmental impact generation for the BC 817-25 transistors is shown in Table 8. In this case, gold generates between 18,3% of the impact in *photochemical oxidation* up to 96,2% in *human toxicity*. As with the previous transistor, the presence of nickel and tin is especially relevant for *photochemical oxidation* and *acidification*. Silver and copper have a minor influence on the results (<4,8% each).

The electricity consumption in the production processes creates between 18,9 and 46,1% in *abiotic depletion (fossil fuels), global warming potential, ODP, terrestrial ecotoxicity, photochemical oxidation* and *acidification*. EcoInvent's assumption of the electronic component factory generates between 0,05% *for abiotic depletion* and up to 3,0% in *ODP*.

4.3.3. Environmental impact of the BC 817#2 transistor

Finally, the BC817#2 is analyzed, which is the one transistor in this study that does not contain gold in its material composition. As shown in Table 9, in this case, the electricity consumption of the production processes creates more than 60% of the environmental impact in four out of eleven categories and between 25% and 50% in the other six. As in other transistors, the consumption of nickel is relevant for *photochemical oxidation* and *acidification*; in this case creating 50% of the impact of these two categories. Silver and tin create a noteworthy impact in *abiotic depletion*, with values of 60,7% and 36,6%, respectively. The electronic component factory assumption and copper consumption also each generate nearly 10% of the total impact in *human toxicity, fresh water* and *marine aquatic ecotoxicity* and *eutrophication*.

5. Conclusions

The influence of the material composition on the environmental impact of different SMD SOT23 transistors has been analyzed. It has been found that the presence of some precious metals, especially gold, highly increases the environmental burden in most impact categories.

Using the EcoInvent SMD transistor as a reference, the overall impacts of the transistors vary from 0,48 times up to 167 times to that of the reference, primarily depending on the amount of gold content.

The consumption of gold and electricity generate most of the environmental impact in all of the studied categories. Although most transistors contain materials such as cobalt, chromium or silicon, which are considered as critical raw materials for the European Union, those do not create relevant environmental impacts for the studied transistors.

In general, RMA creates a higher impact than part production processes in most transistors and impact categories. Although this conclusion can also be obtained from the EcoInvent dataset, the relevance of RMA for the studied transistors is much higher, especially in abiotic depletion (fossil fuels), global warming (GWP100y) and terrestrial ecotoxicity environmental impact categories.

The assumed end-of-life treatments (Stage D2 according to ETSI TS 103 199 (ETSI, 2011)) create low environmental impacts (0-1,5% of the total impact) compared with the raw materials consumption (Stage A) and the production processes (Stage B1).

6. Outlook

This study has been performed with the information that is currently being made public by the manufacturers; therefore, the data that are available to analyze the impact of these electronic components. To further improve these comparisons, manufacturers should provide information about their production processes and waste generation.

To further improve the accuracy and robustness of these types of studies, the following future lines of research could be pursued.

- Recycling of raw material could be considered by the authors as a way to reduce the share of RMA, e.g., gold, in the life cycle.
- Including market data changes for materials to further improve the precision by means of the advanced attributional LCA method proposed by Andrae (Andrae, 2015). This method improves comparative LCA as real or future market changes can be taken into account and be used as a sensitivity check.

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Figure captions

Figure 1 System boundaries
Figure 2 Schematic view of the parts of a transistor SMD SOT23

Tables

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