ARTICLE TYPE
DOI: XXX-XXX-XXXX
ISSN 2288-6206 (Print) / 2198-0810 (Online)

Influence of the Material Composition on the Environmental Impact of Ceramic Glasses

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KEYWORDS: Ceramic glass, Environmental impact, Life cycle assessment, Material composition

An exhaustive study of the influence of ceramic glass material composition on the environmental impact has been performed. In order to perform a more accurate calculation of the environmental impact a life cycle assessment (LCA) was implemented using real material composition of ceramic glasses. Employing a sequential X-rays Fluorescence spectrometer, the composition of several ceramic glasses were analyzed, as this information is not published by the manufacturers. The environmental impact results of each ceramic glass were surveyed using EcoInvent v3.4 data, and SimaPro 8.4 software, following ReCiPe Endpoint and Carbon Footprint methodologies. The importance of considering the composition on the LCA is shown, establishing significant differences among the analyzed glasses. Few variations in the quantity of material composition generate high differences on the environmental impact values, demonstrating the high influence of the material composition on the environmental impact. Elements such as tin, lithium, and titanium are the ones that generate the highest contribution on the environmental impact. In contrast, silica sand shows the lowest impact in both methodologies despite it *supposes between 58% and 63% of their compositions. Others such as barite and magnesium, together with neodymium emerged in the composition of the studied ceramic glasses as they are considered Critical Raw Materials by the European Union, due to their supply risk and economic importance.*

Manuscript received: March XX, 201X / Revised: August XX, 201X / Accepted: December XX, 201X

NOMENCLATURE

EoL = End of Life
ErP = Energy-Related Products
EU = European Union
EuP = Energy-Using Products
GWP = Global Warming Potential
IPCC = Intergovernmental Panel on Climate Change
ISO = International Organization for Standardization
LCA = Life Cycle Assessment
LREE = Light Rare Earth Element
REACH = Registration, Evaluation, Authorization and restriction of CHemicals
REEs = Rare Earth Elements
RMA = Raw Material Acquisition
RoHS = Restriction of Hazardous Substances

1. Introduction

At the beginning of the 90s, concern about the protection of the environmental arose among society. Even though due to the oil crisis in the 70s, the concern about products' life and energy required for production increased, it was at the end of the 80s when the concept of industrial ecology began to be considered. Ecodesign concept took place at the beginning of the 90s, with the aim of reaching prevention in the design stage, instead of correction in the following stages [1-2], as the material selection at the design stage supposes the main influence for the whole life cycle of the product. [3-5]

Currently, people concern about the protection of the environment is increasing exponentially, mostly because of problems such as climate change or pollution. In the same way, the enterprises have made significant environmental efforts, integrating environmental aspects in the development process, and reducing the amount of impact and generated waste. [6-7] Also, manufacturers need to adopt ecodesign to keep their positions in the market. [8-9] In consequence, sustainability for green manufacturing and design for the environment are both increasingly considered by the manufacturing industry and engineering designers. [10-13]

Many examples of eco-designed products such as computers, electronics or optical products, illustrate this fact. [14-16] When designing environmentally friendly products or considering green and sustainable productions [7,17-19], that suppose several challenges for companies and industries but also entails some benefits [20] like increasing market competitiveness or improving their profits by saving costs. [21-22] In order to promote ecodesign, fulfill environmental design requirements and mitigate impacts on the environment [23-24], several policies have been developed. For example, EuP 2005/32/CE and ErP 2009/125/CE in the European Union (EU). [25-26] Others such as RoHS, 2002/95/CE [27] and REACH, 1907/2006 [28] focus on controlling and reducing the use of toxic substances. Several standards have been developed to introduce the criteria of minimizing the environmental impact on products development (ISO 14006). [29-30]

There is a large number of ecodesign methods and methodologies published and implemented by companies. [31-33] The number of studies about products' environmental impact is continuously increasing.[34] Nevertheless, Life Cycle Assessment (LCA) is the principal methodology to analyze the environmental impact, given that takes into account not only the end of life but also materials, products, processes, and the use or transportations throughout the entire lifecycle. [35-36]

LCA methodology has been applied in many industries and products such as surface-mount device transistors [37] or mobile phones; [38-39] and materials like steel [40,] or plastic injection mould [41], with the purpose of knowing how the environment is affected by them. However, this research focuses on the evaluation of a component included in a household appliance.

Several LCA have been performed over products in the household field: refrigerators [42-44], domestic ovens [45], washing machines [46,] or small household equipment.[47] However, the main contribution of this article is the evaluation of the environmental impact of the ceramic glass, included in induction hobs, considering the composition.

Nowadays ceramic glasses are used in several fields such as optical applications, medical and dental ceramics glass, or induction and radiant hobs. Cooktop panels are the most attractive ceramic glass product nowadays in the market due to its ability to be easily cleaned, and its low coefficient of thermal expansion.[48] The main characteristics of ceramic glasses link together the advantages of glass manufacturing, and the special/unique properties of the ceramics. Features such as hardness, density, thermochromism, and electrical conductivity are directly influenced by manufacturing treatments and material composition. [49]

Several authors have studied the ceramic glass manufacturing process[48] and the influence that modifications in the composition have in their properties. [50-51] Ceramic glasses are designed by choosing and adjusting the composition and the crystallization procedure. However, during the manufacturing of ceramic glass material, the composition must be contemplated not only for their mechanical and optical properties but also due to the influence that its composition supposes on the environmental impact.

In many LCA studies, datasets obtained directly from EcoInvent databases are used to evaluate the environmental impact of glasses, from glass production or waste of glass recycling to glasses used as food packaging. [52-54] There are also some examples of LCA implemented on different types of glasses, such as glass fiber, float glass, or packaging glass. [55-57] However, the type of glass of this study, ceramic glass, is not the same as the ones available in the EcoInvent.

The aforementioned modifications of the composition to improve the properties of the materials and current technological innovation cycles suppose a big challenge for the EU due to the increase of the global demand of certain metals and minerals. [58] In that field, the EU depends on the supply of several minerals and materials required by the industry, in which critical raw materials are included. The methodology for defining the criticality of a material by the EU takes into account two parameters: the importance of reliance, and the supply risk. [59-60] The main purpose of this methodology is to establish or determine the raw materials that entail more supply risk and a higher economic importance. [61-62] Considering previous parameters of the methodology, in 2017, 26 raw materials, including 3 grouped metals, were considered critical raw materials by the EU out of the 78 raw materials analyzed. Candidates to be raw materials are those proposed to be critical but not selected due to their lower values of economic importance or supply risk. [63-64] Industries, businesses, and governments can use LCA to assess supply chains and to analyze the environmental impact of minerals or materials. [65] In many of them, the composition must be analyzed taking into account the presence of critical raw materials, and its inference on the environmental impact. [4]

Critical Raw Materials are a concern for the EU, but also for other countries. It is the case of Australia or China, which promote internal mining activities or Japan and the United States that are focused on development initiatives [66]; proof of this are the Trilateral Conferences on Critical Materials among EU, United States and Japan [67-68].

This article analyzes several ceramic glasses, studying their material compositions. After manufacturing, final glasses are similar; however, as they were manufactured by different suppliers, raw material quantities differ among them. This variation in the material composition influences environmental impact, and also the quantities of critical and candidate raw materials.

This paper is organized following the next structure: first of all, the composition and properties of ceramic glass are presented; then the LCA methodology and Life Cycle inventory are carried out in sections 2.3 and 3 respectively; and, finally, in section 4 results are shown.

2. Materials and Methods

2.1. Composition and Manufacturing Process of Ceramic Glass.

This study has been performed following the EcoInvent methodology, using the customization of the composition for several types of ceramic glass. The purpose of this customization is achieving a more precise environmental impact assessment, showing the influence of material composition on it.

As it will be explained, ceramic glass is manufactured as glass but using a heat treatment, that is, it is crystallized to form polycrystalline materials, improving its mechanical strength and decreasing its coefficients of thermal expansion. Many properties of ceramic glass parts can be modified depending on the composition used. For example, SiO_2 is the main glass-forming component which promotes ceramic glass formation, while TiO_2 and ZrO_2 encourage volume nucleation. Furthermore, ZrO_2 improves mechanical properties such as bending strength or fracture toughness. [69]

Manufacturing process of ceramic glass shown in Fig. 1 consists of several stages: First, in the melting stage (1) raw materials for manufacturing ceramic glass are melted in a tank at around 1500ºC. Then during extrusion (2) the raw liquid glass is pressed and rolled between two rollers into the desired thickness.

In the third stage, the resulting glass is cooled down (3) from 900ºC to 100ºC and residual tension is released. In the cutting step (4) glass is cut into sheets and inspected, and then it is ready to send to transformation facilities or storage (5) for processing. Through customization phase (6) glass is cut into required sizes and enamels as well as finishes are applied by means of grinding, drilling and beveling; then, decoration and cooking areas are printed (7) to suit appliance manufacturer needs.

Finally, in the ceramization process (8) final heat treatment at around 900ºC is performed to produce the ceramic glass. After the final quality control inspection, ceramic glass is ready to be shipped (9). [70-71]

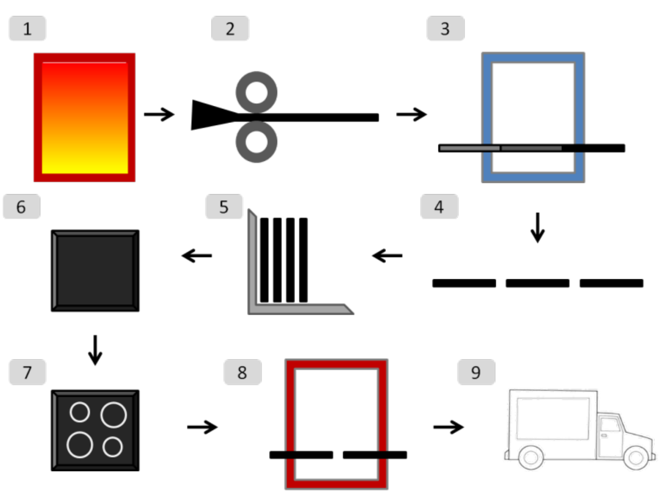

Fig. 1 Ceramic Glass Manufacturing Process

Power consumption was estimated considering previous manufacturing process data of the ceramic glasses. Seven different ceramic glasses (named as Type A … Type G) from different suppliers were selected for this work. As their exact material compositions are not published by the manufacturers, the composition study of each of them was carried out using a sequential spectrometer of X-rays Fluorescence from Thermo Electron, series ARL model ADVANT-XP. [72] The software used for the semiquantitative analysis without patterns was UNIQUANT. [73]

X-rays fluorescence spectroscopy is a technique that requires a source for primary excitation and a device for measuring the response; that allows to identify and to quantify their material composition.

2.2. Dataset Improvement Methodology for Ceramic Glass

The influence of material composition on the environmental impact has been analyzed in several types of ceramic glass. Although some LCA studies are performed using generic datasets as EcoInvent, in this study datasets are created using the exact material composition of each ceramic glass type.

As mentioned before, the exact composition of each ceramic glass has been obtained through a sequential spectrometer of X-rays, except for the materials with lower atomic number, in which a balance composition calculation method has been performed.

Following previous considerations, the LCA was performed, analyzing the influence of the composition on each ceramic glass. Specific manufacturing consumptions are calculated from primary data, based on the specific heat of the glasses materials, and considering all the treatments during ceramic glasses' manufacturing process.

2.3. LCA Methodology

2.3.1. Goal and Scope Definition

The main purpose of this Life Cycle Assessment is to analyze how the material composition influences the environmental impact results of ceramic glasses. The composition characterization has been performed by an X-rays fluorescence spectrometer. ISO 14040, and also 14044 standards of LCA have been applied. [74]

2.3.2. Functional Unit and System Boundaries

The functional unit has been defined as 1 Kilogram of ceramic glass for cooktops, considering Raw Material Acquisition (RMA), Production and End of Life treatments (EoL).

In order to evaluate the environmental impact of each ceramic glass part, an LCA has been developed considering the exact material composition and all the stages shown in Fig. 2.

Following the EcoInvent methodology, market (GLO) and market (RER) datasets have been used to consider the transportation of the raw material. The transportation to the consumer and use stage (cleaning) have been left out of the system boundaries as they are not directly influenced by the composition.

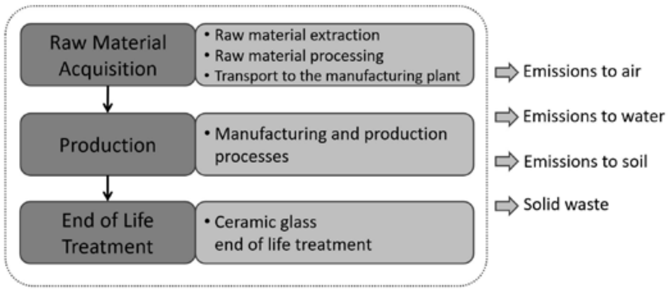

Fig. 2 Ceramic Glass Manufacturing Process

2.3.3. Inventory Data and Assumptions

The EcoInvent v3.4 database was selected to develop the life cycle inventory. It is one of the most important databases, developed by the Swiss Centre for Life Cycle Inventories. [75] The approach "Allocation at the point of substitution" used in this study, is a system model in which products of treatment processes are considered as part of the waste production system and are allocated together.

The LCA model has been performed using SimaPro 8.4, developed by Pré Consultants. [76] It has been carried out through ReCiPe Endpoint (H/A) and IPCC 2013 Carbon Footprint (GWP100y) methodologies. The ReCiPe methodology was developed to combine midpoint and endpoint methods; it allows creating easier comparison among materials and its easy of interpretation supposes an improvement from an engineering and design point of view [77-78]. While Carbon Footprint IPCC 2013 GWP 100y establishes the equivalence between the emissions of a gas that generates greenhouse effect and the quantity of CO_2 with the same effect. This methodology is selected due to its current social relevance. [79-81]

3. Life Cycle Inventory

In Table 1 all the compositions of the seven ceramic glasses analyzed are included, and all the materials presented are shown concerning 1 kg of ceramic glass. As it can be seen in Table 1, the quantities of the elements vary considerably from one to another.

As it is shown, some oxide elements of neodymium, arsenide, iron, or strontium are not present in all the studied ceramic glasses. For example, neodymium is only included in Type G ceramic glass. Elements such as arsenide, iron, and strontium are present only in specific types of ceramic glass. Arsenide is just included in ceramic glasses Type C and Type F. Only ceramic glasses of types A, B, and E contain iron. Finally, in the case of strontium, it appears only in types E and G.

In contrast, there are several types of ceramic glass which do not contain certain elements. It is the case with magnesium, not included in the Type D ceramic glass; sodium, not included in ceramic glass types C and F, or tin, not included neither in the Type C nor Type F.

Table 1 Material composition of ceramic glass (Kg)

Material	Type A	Type B	Type C	Type D	Type E	Type F	Type G
Al_2O_3	0.1905	0.1886	0.1863	0.1932	0.1933	0.1849	0.1938
As_2O_3	-	-	0.0163	-	-	0.0176	-
BaO	0.0642	0.0673	0.0217	0.0472	0.0589	0.0241	0.0162
CaO	0.0073	0.0063	-	0.0078	0.0074	-	0.0039
Fe_2O_3	0.0017	0.0019	-	-	0.0012	-	-
K_2O	0.0074	0.0047	0.0072	0.0075	0.0057	0.0074	0.0030
Li_2O	0.0350	0.0320	0.0250	0.0285	0.0285	0.0350	0.0350
MgO	0.0018	0.0019	0.0054	-	0.0021	0.0054	0.0043
Na_2O	0.0135	0.0051	-	0.0121	0.0103	0.0013	0.0094
Nd_2O_3	-	-	-	-	-	-	0.0015
SiO_2	0.5684	0.5818	0.6277	0.5897	0.5782	0.6137	0.6043
SnO_2	0.0069	0.0074	-	0.0057	0.0068	-	0.0028
SrO	-	-	-	-	0.0015	-	0.0137
TiO_2	0.0403	0.0401	0.0362	0.0424	0.0394	0.0322	0.0303
ZnO	0.0316	0.0312	0.0326	0.0335	0.0334	0.0345	0.0377
ZrO_2	0.0314	0.0317	0.0416	0.0323	0.0333	0.0438	0.0441
Total	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

Table 2 shows the most significant EcoInvent datasets that have been applied in order to characterize the inputs of all the ceramic glass types analyzed. They were selected following the EcoInvent guidelines. [82]

Table 2 EcoInvent dataset selection

Material	Dataset
Al_2O_3	Aluminium oxide {GLO}| market for
As_2O_3	Sodium arsenide {GLO}| market for
BaO	Barite {GLO}| market for
CaO	Quicklime, milled, packed {GLO}| market for
Fe_2O_3	Pig iron {GLO}| market for
K_2O	Potassium hydroxide {GLO}| market for
Li_2O	Lithium hydroxide {GLO}| market for
MgO	Magnesium oxide {GLO}| market for
Na_2O	Sodium oxide {GLO}| market for
Nd_2O_3	Neodymium oxide {GLO}| market for
SiO_2	Silica sand {GLO}| market for
SnO_2	Tin dioxide {GLO}| market for
SrO	Strontium carbonate {GLO}| market for
TiO_2	Titanium dioxide {RER}| market for
ZnO	Zinc oxide {GLO}| market for
ZrO_2	Zirconium oxide {GLO}| market for

Environmental impact calculations of ceramic glass production have been achieved using the manufacturing process impacts previously explained in subsection 2.1. Also, the end of life has been estimated as the worst-case scenario of landfill treatment using EcoInvent v3.4 data.

4. Results

As previously explained, life cycle inventories were introduced in SimaPro. Inventory data was obtained by a sequential X-rays Fluorescence spectrometer that allows to identify the composition of the ceramic glasses. After that, the environmental impacts of each type of ceramic glass were calculated by the use of the ReCiPe methodology, and the Global Warming Potential (GWP). First, results of the Raw Material Acquisition are shown to better illustrate the influence of the composition on the environmental impact; after that, in the next subsections, the impact of the complete studied life cycle is shown, including, also, the production and end of life environmental impacts.

4.1. Analysis of the Environmental Impact of the Raw Material Acquisition (ReCiPe methodology)

With the purpose of analyzing the environmental impact of the seven types of ceramic glass, Table 3 shows the impact the ReCiPe methodology (points) has for the RMA of 1 kg of ceramic glass.

As it can be seen in Table 3, the highest environmental impact is produced by ceramic glass type B with 0.5475 points per kilogram, followed by ceramic glass type A with 0.5254. On the other hand, the minimum environmental impact is produced by ceramic glass type C with 0.1075 points per kilogram, around 80.4% less than the maximum.

Table 3 Environmental impact of RMA of 1 kg of ceramic glass (Points, ReCiPe)

Material	Type A	Type B	Type C	Type D	Type E	Type F	Type G
Al_2O_3	0.0279	0.0277	0.0273	0.0283	0.0283	0.0271	0.0284
As_2O_3	-	-	0.0084	-	-	0.0091	-
BaO	0.0008	0.0008	0.0003	0.0006	0.0007	0.0003	0.0002
CaO	0.0006	0.0005	-	0.0006	0.0006	-	0.0003
Fe_2O_3	0.0004	0.0004	-	-	0.0003	-	-
K_2O	0.0017	0.0011	0.0017	0.0018	0.0014	0.0018	0.0007
Li_2O	0.0228	0.0208	0.0163	0.0185	0.0185	0.0228	0.0228
MgO	0.0002	0.0002	0.0005	-	0.0002	0.0005	0.0004
Na_2O	0.0051	0.0019	-	0.0045	0.0039	0.0005	0.0035
Nd_2O_3	-	-	-	-	-	-	0.0060
SiO_2	0.0027	0.0027	0.0029	0.0028	0.0027	0.0029	0.0028
SnO_2	0.4160	0.4440	-	0.3450	0.4110	-	0.1713
SrO	-	-	-	-	0.0002	-	0.0023
TiO_2	0.0276	0.0275	0.0248	0.0290	0.0270	0.0220	0.0207
ZnO	0.0031	0.0031	0.0032	0.0033	0.0033	0.0034	0.0037
ZrO_2	0.0166	0.0168	0.0220	0.0171	0.0176	0.0232	0.0233
Total	0.5254	0.5475	0.1075	0.4516	0.5157	0.1136	0.2866

Besides, some elements some elements contribute to higher values of environmental impact. It is the case of neodymium, considered as a critical raw material by the EU or tin and titanium, candidates to be critical raw materials in the last 2017 EU report. Ceramic glass types with the highest values of environmental impact are those with higher quantities of tin and titanium. In ceramic glass type B, the contribution of those materials are 81.1% and 5% of the total impact respectively. Following the same criteria, ceramic glass type F, the second one with less environmental impact, includes a low content of titanium and no presence of tin or neodymium in its composition. In contrast, ceramic glass type C generates the lowest environmental impact, with no content of tin or neodymium. From the total environmental impact, 23% is created by titanium; and there is also a high content of silica sand, which produces a low contribution to the environmental impact.

Ceramic glass type G produces an intermediate value of the environmental impact of the seven ceramic glasses analyzed: 0.26 points per kilogram less than the maximum, and 0.18 more than the minimum. Also, the quantity of tin is integrated between the maximum and the minimum of all analyzed types.

Furthermore, focusing on ceramic glass type B, tin represents only 0.74% of the composition, but it generates 81.1% of its total environmental impact.

Elements as barite and magnesium are included in all of the ceramic glass types analyzed in this paper; and, although, their environmental impact does not show high values, the EU considers them critical raw materials. Neodymium, as previously mentioned, is also considered a critical one. Nevertheless, it is only included in one of the ceramic glasses analyzed, ceramic glass type G. Barite is an inert element, used as an additive in the manufacturing of industrial products like ceramic glasses. In the case of magnesium, it is commonly used in the manufacturing industry due to its lightness and its contribution to mechanical strength properties. Finally, neodymium, is included in the Rare Earth Elements (REEs), as a Light Rare Earth Element (LREE), and its primary application is focused on glasses due to their optical properties.[83]

There are also candidate raw materials included in the composition of the ceramic glasses analyzed. It is the case of aluminium, lithium, titanium, and zinc, present in all the studied ceramic glasses or tin, which is included in almost all ceramic glasses except type C and type F.

4.2. Analysis of the Environmental Impact of the Raw Material Acquisition (IPCC 2013 GWP 100y).

As in the previous subsection, Table 4 shows the magnitude of the Raw Material Acquisition environmental impact in Global Warming Potential of the seven types of ceramic glass expressed in kg CO_2 eq. for 1 kg of ceramic glass.

Table 4 Environmental impact of RMA of 1 kg of ceramic glass (kg CO_2 eq., GWP 100y)

Material	Type A	Type B	Type C	Type D	Type E	Type F	Type G
Al_2O_3	0.2613	0.2587	0.2556	0.2650	0.2651	0.2536	0.2658
As_2O_3	-	-	0.0597	-	-	0.0646	-
BaO	0.0066	0.0069	0.0022	0.0049	0.0061	0.0025	0.0017
CaO	0.0091	0.0078	-	0.0097	0.0092	-	0.0048
Fe_2O_3	0.0038	0.0042	-	-	0.0027	-	-
K_2O	0.0173	0.0111	0.0169	0.0176	0.0134	0.0174	0.0070
Li_2O	0.2246	0.2054	0.1604	0.1829	0.1829	0.2246	0.2246
MgO	0.0022	0.0023	0.0066	-	0.0025	0.0065	0.0053
Na_2O	0.0487	0.0183	-	0.0437	0.0370	0.0048	0.0338
Nd_2O_3	-	-	-	-	-	-	0.0420
SiO_2	0.0264	0.0270	0.0291	0.0274	0.0268	0.0285	0.0280
SnO_2	0.1289	0.1376	-	0.1069	0.1273	-	0.0531
SrO	-	-	-	-	0.0023	-	0.0213
TiO_2	0.2347	0.2338	0.2107	0.2471	0.2295	0.1876	0.1763
ZnO	0.0281	0.0277	0.0289	0.0298	0.0296	0.0307	0.0335
ZrO_2	0.1552	0.1567	0.2055	0.1593	0.1645	0.2161	0.2176
Total	1.1467	1.0974	0.9756	1.0942	1.0990	1.0370	1.1147

In general, it is shown that the highest environmental impact is created by ceramic glasses type A with 1.1467 kg CO_2 eq., followed by type G with 1.1147 kg CO_2 eq. In contrast, those ceramic glasses with less environmental impact are type C and type F; whose values of GWP methodology are 0.9756 kg CO_2 eq., and 1.0370 kg CO_2 eq., respectively. The difference between the maximum and minimum environmental impacts is 0.1711 kg CO_2 eq., 14.92% less than the maximum, a much lower difference than under the ReCiPe methodology. As in the previous subsection, the presence of elements such as neodymium, tin or lithium highly contributes to the increment of environmental impact values in the GWP methodology. Nevertheless, ceramic glasses with higher values of environmental impact (type A and type G) are, primarily, the result of aluminum, lithium, titanium, zirconium, and tin content, due to the high impact produced by these materials.

Tin, neodymium, and lithium elements are the main contributors to the increase of the environmental impact: neodymium contributes with 27.2 kg CO_2 eq. per kilogram, tin supposes 18.7 kg CO_2 eq. per kg, and lithium 6.4 kg CO_2 eq. per kg. Tin and lithium are present in most of the ceramic glass analyzed, while neodymium is only included in one of them (ceramic glass type G).

Ceramic glass type A, with the highest environmental impact in GWP, includes only 0.69% of tin in its composition. However its environmental impact generates 11.24% of the total environmental impact of type A ceramic glass. It also includes barite and magnesium, critical raw materials that involve a risk of lack of supply and comprise a substantial economic importance.

Finally, it is remarkable that the analysis of the environmental impact of each type of ceramic glass in previous subsections shows that type C, and type F are the lowest in both methodologies, ReCiPe and GWP; mainly because there is no presence of tin neither in type C nor in type F. The high presence of silica sand in these ceramic glasses also contribute to lower their values of impact. Although the content of it is 63% of the total composition in ceramic glass type C and the 60% in type F, it supposes the lowest contribution to the environmental impact in the GWP methodology.

4.3. Environmental Impact of the Ceramic Glass Types Life Cycle (ReCiPe).

In this subsection, the environmental impact in the ReCiPe methodology created by the seven types of ceramic glass is analyzed taking into consideration the complete life cycle stages included in the system boundaries. Therefore, Table 5 shows the results and the percentages of each phase (raw material acquisition, production, and end of life).

Table 5 Environmental impact of ceramic glass life cycle (ReCiPe).

Phases	Type A	Type B	Type C	Type D	Type E	Type F	Type G
RMA	89,6%	90,1%	63,5%	88,0%	89,5%	64,7%	82,1%
Production	9,6%	9,2%	34,0%	11,1%	9,8%	32,8%	16,6%
EoL	0,7%	0,7%	2,6%	0,8%	0,8%	2,5%	1,2%
Total (Points)	0.5862	0.6079	0.1693	0.5129	0.5763	0.1755	0.3489

Most of the environmental impact is created by the material composition, followed by the manufacturing processes and, finally, the lower contribution is produced by the end of life stage.

Nowadays ceramic glasses are not usually recycled due to their wide range of compositions. Therefore, a landfilling option has been calculated, as explained in section 3.

Table 5 shows that higher percentages of environmental impact due to production are created in Type C and Type F with 34% and 32.8% respectively. These values are mainly created by the absence of tin in the composition, which reduces the RMA environmental impact, increasing, consequently, the production processes percentage.

On the other hand, the lowest percentages of environmental impact production are created in Type A and Type B with 9.6% and 9.2% of the total impact, due to their higher whole impact.

The lowest environmental impact is created by the end of life treatments, from 0.7% to 2.5% of the total of all categories.

4.4. Environmental Impact of the Ceramic Glass Types Life Cycle (IPCC 2013 GWP 100y).

The environmental impacts analyzed by Global Warming Potential methodology and calculated in kg CO_2 eq., and the percentages of each phase of the life cycle (raw material acquisition, production, and end of life) are shown in Table 6.

Table 6 Environmental impact of ceramic glass life cycle (GWP 100y).

Phases	Type A	Type B	Type C	Type D	Type E	Type F	Type G
RMA	65.9%	65.0%	61.7%	64.6%	65.0%	63.1%	64.6%
Production	32.3%	33.1%	36.2%	33.5%	33.1%	34.9%	33.5%
EoL	1.9%	1.9%	2.1%	1.9%	1.9%	2.0%	1.9%
Total (Kg CO_2 eq)	1.7413	1.6888	1.5812	1.6948	1.6920	1.6437	1.7258

Higher percentages of environmental impact are created by material acquisition., where the higher values are created by Type A and Type B with 65.9% and 65% of the total environmental impact. On the contrary, the lowest environmental impact percentage of RMA is achieved on ceramic glass Type C, with 61.7% of the total.

Environmental impact due to production supposes from 32.3% to 36.2% of the total. The highest percentage is created by Type C, whereas 32.6% corresponds to ceramic glass Type A.

Finally, the end of life treatments generate the lowest environmental impact of the three stages (material acquisition, production process, and end of life), being between 1.9% and 2.1% of the total impact of all categories.

Under the Carbon Footprint methodology, production processes generate a higher contribution to the environmental impact, due to energy consuming processes that, in many cases, increase directly the Carbon Footprint emissions.

5. Conclusions

This article highlights the importance of considering the exact material composition of a component when calculating its environmental impact. Thus, the influence of material composition on the environmental impact of several types of ceramic glass has been analyzed in order to perform a more accurate calculation, and to identify the materials that mainly affect the total impact of the ceramic glasses under study.

In order to achieve a more precise calculation, the ceramic glasses were analyzed using a sequential X-rays Fluorescence spectrometer to analyze their composition, as this information is not published by the manufacturers. Critical raw materials were found among the components in the ceramic glasses analyzed. It is the case of barite or magnesium, both incorporated in the composition of most of the ceramic glasses analyzed due to their optical properties and mechanical improvements during production.

Other materials found in the composition are candidates to be critical raw materials by the EU: aluminum, lithium, tin, titanium, and zinc; whose presence highly contributes to increasing the environmental impact values.

The inventory data and cut-off criteria are based on EcoInvent, one of the most used databases that have been developed by the Swiss Centre for Life Cycle Inventories. Also, SimaPro 8.4., developed by Pré Consultants, is the software used to achieve the LCA, in which the main target of this paper is to evaluate the environmental impact of ceramic glasses considering the exact composition and its influence on the overall environmental impact values.

Also, manufacturing consumptions and glass treatments during the manufacturing processes were considered to assess the environmental impact. LCA results have been obtained through the ReCiPe Endpoint (H/A) and IPCC 2013 Carbon Footprint GWP100y methodologies.

Tin is the material that to a large extent contributes to increasing the environmental values of the analyzed ceramic glasses using the ReCiPe methodology. It can be shown in ceramic glass type B, in which the highest environmental impact is achieved: 0.5475 points per kilogram. However 0.74% of ceramic glass type B composition generates just a mere 81.1% of its environmental impact. In contrast, the absence of tin in ceramic glass type C generates around 80% less environmental impact than in ceramic glass type B considering the ReCiPe methodology.

Through the GWP methodology, elements that highly contribute to increasing the environmental impact are neodymium, tin, and lithium. Nevertheless, materials such as aluminum, titanium or zirconium also contribute to reach higher values of environmental impact under this methodology. It is shown in ceramic glasses type A and G, in which the highest values of environmental impact appear mostly due to the presence of aluminum, lithium, and titanium. In both, the content of lithium is the 3.5% of the total composition, generating 19.6% of the total environmental impact under the GWP methodology in ceramic glass type A and 20.15% in ceramic glass type G.

Silica sand is the material with the lowest contribution to the environmental impact in both methodologies, ReCiPe, and GWP. Although it is included in all ceramic glasses analyzed and supposes between 58% and 63% of their compositions, it is almost irrelevant for the environmental impact.

ACKNOWLEDGMENT

The study presented in this paper has been partially supported by the Spanish MINECO under Project RETO RTC-2014-1847-6, and has been performed by members of the I+AITIIP (DGA-T08_17R) research group of the FEDER 2014-2020 "Construyendo Europa desde Aragón" program, recognized by the Regional Government of Aragon.

CONFLICT OF INTEREST STATEMENT

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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