



## Study of the carbon footprint in a ceramic production process in the metropolitan area of Cucuta

Estudio de la huella de carbón en un proceso productivo cerámico en el área metropolitana de Cúcuta

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### ABSTRACT

#### Keywords:

Clay; Ceramic Product, Carbon Footprint, Thermoelectric Ashes, Norte de Santander

The experimental process was proposed in order to establish the viability of substituting part of the mineral fraction used at present (clayey material) by residues of combustion processes (ashes) of coal in thermoelectric, as an element to reduce the carbon footprint of the process of production of ceramic products, without altering the quality, properties and functionality of the final product. The study focuses on the specific case of a brick-making company in the metropolitan area of Cúcuta, and on the substitution of 10% of the raw material (clay) for ashes from the thermoelectric plant, for the production of ceramic blocks. The analyses carried out establish an energy saving derived from the use of 10% fly ash equivalent to 997.12Kg of Norte de Santander coal per burn. The results determine that, in the case of brick production, the annual reduction of emissions associated with the production process, with the use of ashes from the thermoelectric, would be 849.48 tons of CO<sub>2</sub>. Thus, the carbon footprint is reduced by 16.39kgCO<sub>2</sub>equiv/t finished product, which represents a decrease of 5.99% of the carbon footprint compared to the conventional process.

### RESUMEN

#### Palabras clave:

Arcilla; Producto Cerámico, Huella de Carbono, Cenizas de Termoeléctrica, Norte de Santander

El proceso experimental fue propuesto a fin de establecer la viabilidad de sustituir parte de la fracción mineral usada en la actualidad (material arcilloso) por residuos de procesos de combustión (cenizas) de carbón mineral en termoeléctrica, como elemento para reducir la huella de carbono del proceso de producción de productos cerámicos, sin alterar la calidad, propiedades y funcionalidad del producto final. El estudio se centra en el caso concreto de una empresa ladrillera del área metropolitana de Cúcuta, y en la sustitución de un 10% de la materia prima (arcilla) por cenizas procedentes de la central termoeléctrica, para la producción de bloque cerámico. Los análisis realizados establecen un ahorro energético derivado del uso de un 10% de ceniza volante equivalente a 997.12Kg de carbón de Norte de Santander por quema. Los resultados determinan que, para el caso de la producción de la ladrillera, la reducción anual de emisiones asociadas al proceso productivo, con el uso de cenizas de la termoeléctrica, sería de 849.48 toneladas de CO<sub>2</sub>. Así, la huella de carbono se ve reducida en 16.39kgCO<sub>2</sub>equiv/t producto acabado, lo que supone un descenso de un 5,99% de la huella de carbono respecto del proceso convencional.

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## Introduction

At a global level, awareness of the importance of environmental protection is growing. Global warming and high generation of waste from industrial and commercial activity are topics that are the subject of research in different parts of the world. [1], [2], [3], [4].

The circular economy is a reality more and more present, driving the productive sectors to consider alternatives that promote the conservation of the environment, and to face the shortage of productive and energy resources [5]. The circular economy model gives value to waste, regardless of whether it is organic or technological, based on the intelligent reuse of waste in a cyclical model, converting it into raw material for the manufacture of new technological products [6], [7], [8]. The circular economy arises mainly in the literature through two principles called 3R: Reduce, Reuse, and Recycle; and 6R: Reuse, Recycle, Redesign, Remanufacture, Reduce and Recover [9]. The circular economy is considered a solution to harmonize these needs for economic growth and environmental protection

The ceramic industry is a large consumer of energy and natural resources, necessary to produce ceramic construction products, therefore it is also a major generator of greenhouse gases such as carbon dioxide, which is mainly due to the oxidation of fuels in ovens during the firing process [10].

This research has focused on the use of an abundant technological nutrient in the metropolitan area of Cucuta, such as fly ash from thermoelectric plants. A previous study [11] has shown the technical feasibility of replacing 10% of clays with fly ash in the manufacture of ceramic products, giving rise to products with technological properties in accordance with current regulations. The study carried out aims to demonstrate the environmental viability of the use of fly ash. The energetic and environmental effects of technological nutrient (fly ash) presence in the ceramic material are valued through carbon footprint calculation, through a comparative analysis of the conventional product with respect to the new alternative product, which uses 10% by mass of fly

ash as a partial substitute for clay, in order to perform an environmental validation of a product already validated at a technological and functional level.

## Materials and Methods

The calculation of the Carbon Footprint (CF) is done following the methodology described in PAS 2050 [12] and ISO 14067 [13]. Once the process map has been defined (stage 1), the most relevant study parameters are selected within product environmental information. The scope and limits of the system are determined, also setting the parameters to study (stage 2) and proceeds to collect all the necessary information to obtain as much data as possible to achieve the proposed objectives (stage 3).

The nutrient free production process is compared when 10% fly ash is included in the process [14].

### *Construction of the map of processes*

The processes of the cycle of life, with generic character, of the ceramic product object of the present investigation, can be summarized in the following: Extraction of raw materials (A1), Transport of raw materials to plant (A2), Grinding (A3a), Molding (A3b), Drying (A3c), Firing (A3d), Classification and packaging (A3a), Transport to final destination, Commissioning, Maintenance of the building, Demolition of the building (end of life), and Treatment of the waste at the end of the useful life. In accordance with the requirements of the regulations applied in this study, when making the calculation of the Carbon Footprint it is necessary to follow certain rules, requirements, and specific guidelines, compiled in the Product Category Rules (PCR) [15]. The European Association of Manufacturers of Ceramic Products "TBE", has published the document "TBE PCR for clay construction products: A Guidance document for developing an EPD [16]". In the absence of specific CPR for structural ceramic products in Colombia, (beyond the indications of the Colombian environmental seal) [17], the rules set out in Standard EN-15084 are followed in the present comparative analysis [18]. Similarly, the PCR developed by TBE and the PCR developed internationally for ceramic products are taken as reference.

Based on these indications, the declared unit is referred to as “ton of manufactured ceramic product”, in this specific case, refers to a ton of ceramic block produced in brickwork.

### ***Inventory analysis***

#### ***Clay extraction data (A1)***

This stage only considers the impact associated with fuel consumption used by the extraction machinery (petrodiesel), leaving the rest of the elements out of the study, interpreting a priori, that the impact produced by them will be minimal in relation to the total load of the product studied (e.g. maintenance oils for machinery or tires). The most relevant consumption data collected, in the clay extraction plant, related to the extraction of clays as raw material for the manufacture of ceramic products are the following: Extraction machinery, consumptions (petrodiesel) and yields: Excavator: 6.6gal/h (24.98 l/h) and 66Ton/h; Bulldozer: 4.8gal/h (18.16l/h) and 66Ton/h; Loader: 2.04gal/h (7.72l/h) and 144Ton/h; Caterpillar: 3.6gal/h (13.63l/h) and 36Ton/h.

#### ***Data of fly ash generating plant (A1)***

For the comparative study, the most relevant consumption data collected in this plant, related to the technological nutrient, are those related to the process of loading the product in trucks for transport to the ceramic production plant of the brickyard. Machinery of load, consumptions (petrodiesel) and efficiencies: loaders: 2.04gal/h (7.72l/h) and 144.00Ton/h

#### ***Transport of raw materials to production plant (A2).***

According to the information collected, and in order to compare both the clay taken from the mine and the ashes collected from the thermoelectric plant, a dump truck is considered, with the following technical characteristics: Volume: 18.00m<sup>3</sup>, Maximum payload: 2.00t, Maximum engine power: 240.00Kw, Average displacement speed: 40km/h, Average consumption 100km: 10.30gal (38.99l), Distance (mine - brickyard): 22km. The round trip is considered since the return route cannot be used by

trucks to load another type of product.

### ***Ceramic production (A3).***

The data collected in the brickyard, for each of the stages of the production process, are the following:

- ***Storage, loading, and grinding.*** Corresponding to the consumption of the loaders, which is 2.04gal/h (7.72 l/h) and a yield of 144 Ton/h. In the milling process, hammer mills and conveyor belts are used. The energy consumed in this stage is of electrical origin, being the consumption of 10800 kW/h, with a yield of 4.13 kWh/t..
- ***Molding and extrusion.*** The machinery used in this phase are mixers, laminators, extruders, and cutters. The electric power consumed in this stage is 6.92 kWh/t.
- ***Dried.*** The energy consumed in this stage, of electrical origin, is 180 Kwh/t.
- ***Firing.*** In the firing operation, flame-type beehive ovens with a capacity of 180.00 tons of product fired by burning are used. The electricity consumption is 10.80 kWh/t
- ***Classification and packaging.*** The machinery used in this stage is a heat shrinkable packaging tunnels, with an electrical consumption of 2.82 kWh/t.

### ***Results and discussions***

#### ***Impact evaluation Calculation of the carbon footprint***

For impacts evaluation, the following operation conditions facilitated by the brickwork have been taken into account: Firing at 900 °C, 30,000 blocks loaded to a hive type oven, Approximate weight of a fired block 6.0 kg, 15 ton of mineral coal used for the firing Energy saving derived from the use of 10% flying ash: 997.12 Kg of coal per burning [1]. The inputs obtained in the inventory phase are converted into environmental charges (CO<sub>2</sub>equiv), making the corresponding mass balances for each phase of the process, and applying the corresponding internationally accepted emission factors.

Regarding the emission factors, within the framework of the project Mechanism of Voluntary Mitigation of Greenhouse Gases Colombia -MVC-, carried out by Fundación Natura, La Bolsa Mercantil, and La Corporación Ambiental Empresarial, with the accompaniment and coordination of Colombian UPME and MADS, a technical consultancy was developed to update the database of the Emission Factors of Colombian Fuels -FECOC [13]. The emission factors used in the present study are the following: ACPM (petrodiesel): 10.28 kgCO<sub>2</sub>/gallon (2.95 kgCO<sub>2</sub>/t), Thermal coal from Norte de Santander: 2812.75 kgCO<sub>2</sub>/ton.

For the calculation of the emissions derived from the production, transport, and consumption of electric power, in 2016 the indicator of CO<sub>2</sub>equiv emissions per kWh of electrical energy consumed was 120 grams of CO<sub>2</sub> per kWh consumed.

### ***Carbon footprint (CF) in the conventional manufacturing process.***

The total CF for the conventional manufacturing process is defined by the following formula and applies to clay as a technological nutrient:

$$CF(total)=CF(A1)+CF(A2)+CF(A3a)+CF(A3b)+CF(A3c)+CF(A3d)+CF(A3e)$$

Where: CF (total) is the total carbon footprint of the product (kgCO<sub>2</sub>equiv/t finished product), the addendums being the CF of each of the stages: CF (A1) refers to the extraction of raw materials (clay in mines and technological nutrient in thermoelectric); CF (A2) transporting raw materials to plant; CF (A3a) storage, loading and grinding; CF (A3b) Molding; CF (A3c) Drying; CF (A3d) Firing; CF (A3e) Classification and packaging.

Calculating CF of each of the sub stages:

- ***Extraction of raw materials. Mines (A1).*** Calculated from the consumptions of the extraction machinery, and yields of them, obtained in the inventory phase: Excavator: 0.1000 gal/ton (0.3785 l/t), Bulldozer: 0.0727 gal/t (0.2752 l/t), Loader: 0.0142 gal/t (0.0536 l/t), Dump truck: 0.1000 gal/t (0.3785 l/t).

A total unit consumption of 0.29 gal/t (1.09 l/t) of extracted clay is obtained: CF A1 = unit consumption \* emission factor = 2.95 kg CO<sub>2</sub>equiv/t. Referred to ton of clay (raw material) extracted.

- ***Transport of raw materials to production plant (A2).***

$$Unit\ Consumption\ \left(\frac{l}{t}\right) = \frac{Cv * D}{2 * Ct}$$

Where: Cv = Transport vehicle consumption (l/km), Ct = Transport vehicle load (t), D = Distance traveled from the quarry to the plant, 2 = Fixed factor (when considering the round trip).

For the precise calculation for each case, the three indicated variables should be considered. Therefore: CF A2 = consumption (l/ton \* km) \* (distance (km) \* 2) \* emission factor (kg CO<sub>2</sub>equiv/l) = 1.94 kgCO<sub>2</sub>equiv/t. Referred to ton of clay (raw material) transported

- ***Product manufacturing (A3)***

- ***Storage, loading and grinding (A3a).***

$$CF\ A3a = (Ce * Fee) + (Cc * Fec)$$

Where: Ce: Unit electricity consumption, Fee: Electricity emission factor (kgCO<sub>2</sub>/kWh), Cc: Fuel unit consumption, Fec: Fuel emission factor. CF A3a = (4.13 \* 0.120) + (0.01416 \* 10.277) = 0.64 kg CO<sub>2</sub>equiv/t

- ***Molding (A3b).***

$$CF\ A3b = (Ce * Fee)$$

Where. Ce: Unit electricity consumption, Fee: Electricity emission factor (kgCO<sub>2</sub>/kWh). CF A3b = (6.92 \* 0.120) = 0.83 CO<sub>2</sub>equiv/t

The results obtained refer to ton of product for its loading in the dryer.

- ***Drying (A3c).***

$$CF\ A3b = (Ce * Fee)$$

Where: Ce: Unit electricity consumption, Fee: Electricity emission factor (kgCO<sub>2</sub>/kWh). Therefore, CF A3c = (180.00 \* 0.120) = 21.60 kgCO<sub>2</sub>equiv/t



The results refer to ton of dry product.

➤ **Firing (A3d).**

$$CF A3d = (Ct * fc) + (Ce * fe)$$

Where: Ct = Thermal unit consumption (kg coal/product ton), fc = fuel emission factor, Ce = Electric unit consumption, fe = Electric emission factor

$$CF A3d = (83.33 * 2.81) + (10.80 * 0.12) = 235.63 \text{ kgCO}_2\text{equiv/t}$$

➤ **Classification and packaging (A3e).**

$$CF A3e = (Ce * Fee)$$

In which, Ce: Unitary electricity consumption, Fee: Electricity emission factor (kgCO<sub>2</sub>/kWh). Therefore, CF A3e = (1.92 \* 0.120) = 0.23 kgCO<sub>2</sub>equiv/t

**Carbon footprint of the manufacturing process with technological nutrient**

➤ **Storage, loading and grinding (A3a).** CF A3a = 0.64kg CO<sub>2</sub>equiv /t

➤ **Molding (A3b).** CF A3b = 0.83 CO<sub>2</sub>equiv /t

➤ **Drying (A3c).** CF A3c = 21.60 kgCO<sub>2</sub>equiv /t

➤ **Firing (A3d).** In the case of firing, the results obtained in the study of energy consumption of the mixture of 90% clay and 10% fly ash, compared to the conventional process of manufacturing ceramic products (100% clay).

CF A3d = 220.05 kgCO<sub>2</sub>equiv /t. The results refer to ton of fired product.

➤ **Classification and packaging (A3e).** CF A3e = (1.92 \* 0.120) = 0.23kgCO<sub>2</sub>equiv /t

**Global Results**

**Table I.** Results obtained for HdC

PROCESS TYPE	CF (kg CO2equiv/t)							TOTAL
	A1	A2	A3					
			A3a	A3b	A3c	A3d	A3e	
Conventional (100% clay)	2.95	1.94	0.64	0.83	21.60	235.63	0.23	263.82
New alternative (90% clay + 10% nutrient)	2.67	1.91	0.64	0.83	21.600	220.05	0.23	247.93

It was applied in the same way as for clay, so the corresponding equations did not undergo any significant modification, except for the firing equation.

- **Extraction (A1).** CF A1 = 2.67 kg CO<sub>2</sub>equiv /t
- **Transport of raw materials to plant (A2).** CF A2 = 1.91kg CO<sub>2</sub>equiv /t

**Product manufacturing (A3)**

**Assignment to declared unit**

To obtain the global value, each Carbon Footprint value has to be associated with the declared unit defined in the present investigation of “ton of finished product” (ceramic block manufactured in the brickyard). Therefore, the equivalence between the declared unit and the units to which the values of each of the studied phases are referred must be found. It is explained as follows:

**Table II.** Assignment of values to declared unit

PROCESS TYPE	CF (kg CO2equiv/t)							TOTAL
	A1	A2	A3					
			A3a	A3b	A3c	A3d	A3e	
Conventional (100% clay)	4.62	2.85	0.76	1.1280	23.52	240.44	0.23	273.54
New alternative (90% clay + 10% nutrient)	4.18	2.80	0.76	1.12	23.52	224.54	0.23	257.16

## Results and Discussion

The results, shown in the previous section, show that the environmental consequences of the addition of 10% of fly ash as a raw material in the manufacturing process of ceramic products are clearly positive.

Thus, the carbon footprint is reduced by 16.39 kgCO<sub>2</sub>equiv/t finished product, which implies a decrease of 5.99% of the carbon footprint with respect to the conventional process. Extrapolating this reduction of carbon footprint to the ceramic production in the metropolitan area of Cucuta and considering a monthly production in the metropolitan area of Cucuta of 125750 tons of product/month, an emission savings of 2061.04 tons of CO<sub>2</sub> would be obtained, and 24732.48 tons per year.

This saving is equivalent to the annual emissions of 2248.41 medium-sized homes that emit 11 tons of CO<sub>2</sub> (according to data from the European Environment Agency), this value provides a good approximation of the environmental benefit of the new alternative process.

## Conclusions

The results of the investigation show the environmental viability for the use of fly ash in the manufacture of ceramic products in the metropolitan area of Cucuta, as it reveals a reduction in the Carbon Footprint of the production process.

The firing stage of the product is the one that represents a greater decrease of Carbon Footprint. Other production stages do not suffer an alteration in terms of values. The drying stage is the one that presents a greater environmental impact, this is due to firing mass losses of the mixture with ashes with respect to the conventional mixture, which has their repercussion in the “upstream” stages, although the overall result is clearly favorable to the new alternative process.

Economically, the use of technological nutrient supposes an economic saving, from lower use of fuel, in the process of ceramic products manufacture.

The improvement implied by the new alternative process in the use of the technological nutrient as

a raw material in the manufacture of ceramics contributes positively to the fulfillment of the sustainable development objectives of Colombia.

It is considered as a general conclusion, that the results are a contribution to identify and reduce the environmental impact the construction sector, from the perspective that the environmental impact of a building begins from the moment in which raw materials are extracted for the manufacture of construction products.

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