

Life Cycle Analysis and Carbon Footprint of Sustainable Bricks Made from Drill Cuttings in Tamaulipas

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ABSTRACT

Deepwater hydrocarbon exploration generates significant volumes of drilling cuttings, which traditionally represent a heavy logistical burden and a severe environmental risk regarding final disposal. However, their specific mineralogical composition and physical properties enable their effective integration as secondary raw materials in the manufacturing of ecological bricks and blocks for the construction sector. This research evaluates the environmental sustainability of producing alternative construction materials derived from drill cuttings recovered directly from the Trion field in the Gulf of Mexico. Following the standardized guidelines of ISO 14040 and ISO 14044, a comprehensive Life Cycle Assessment was conducted under a cradle to gate approach based on a functional unit of one metric ton of finished masonry. Unlike traditional ceramic processes that rely on high temperature thermal firing, this proposal incorporates a zero emission solar drying technique. Two distinct logistical supply routes to the state of Tamaulipas were thoroughly analyzed: the Port of Matamoros and the Altamira Industrial Corridor. The results reveal that the total carbon footprint ranges between 7.17 and 8.17 kg CO₂-eq per ton. These findings highlight that maritime transportation optimization is the critical determining factor ensuring the environmental viability of this circular economy initiative, successfully minimizing both greenhouse gas emissions and local quarry extraction pressures.

Keywords: *Earth architecture, Drill cuttings block, Recycled aggregates, Sustainable building materials*

1. INTRODUCTION

The growing global demand for building materials and sustainability requirements have placed the construction industry at the center of the debate on the transition to a circular economy model. In the field of ceramic materials and masonry, the traditional manufacture of bricks has generally depended on the extraction of virgin mineral resources (such as clays and sands) and the use of intensive processes in thermal consumption that entail high greenhouse gas (GHG) emissions. Faced with this scenario, the recovery of industrial waste for the substitution of raw materials appears as a relevant strategy to mitigate environmental degradation and promote industrial symbiosis (Alfonso González, 2018).

In the extractive industry, deepwater hydrocarbon exploration and production consistently generate considerable volumes of waste known as *drill cuttings* (Ghasemi, Akbari, Jahani, & Kazemzadeh, 2025; Loss et al., 2026). Historically, the management of these materials has represented both a high logistical cost and a potential risk to ecosystems due to the presence of pollutants and the complications associated with their final disposal in landfills or through maritime and terrestrial confinement (Loss et al., 2026; Mejía-Saavedra, Espinosa-Reyes, Ilizaliturri-Hernández, & Chipres de la Fuente, 2014). However, from a materials science perspective, the mineralogical composition and granulometry of certain cuttings allow them to be incorporated as additives or substitute matrices in the formulation of ceramic and construction materials (Alfonso González, 2018; Loss et al., 2026).

In the state of Tamaulipas, Mexico, activity in offshore oil fields such as the Trion field, located in the Lost Fold Belt of the Gulf of Mexico, generates a continuous flow of drilling cuttings that require efficient and sustainable

management schemes (Mejía-Saavedra et al., 2014). The opportunity to integrate these cuttings into the production of sustainable materials in urban and industrial nodes such as Matamoros and Altamira not only reduces the impact derived from waste disposal but also minimizes the pressure on local aggregate extraction quarries (Alfonso González, 2018). Likewise, the implementation of artisanal curing and sun-drying techniques ends the firing stage in wood or hydrocarbon combustion furnaces, drastically reducing direct carbon emissions in the production process (Aranda-Jimenez & Suarez-Dominguez, 2020; Suarez-Dominguez, 2024).

To accurately quantify the environmental performance of these technological alternatives, the Life Cycle Assessment (LCA) methodology, regulated by the international standards ISO 14040 and ISO 14044, is the most robust standardized tool (International Organization for Standardization, 2006a, 2006b; Li, Saboori, & Cao, 2016). LCA makes it possible to account for the flows of matter and energy throughout the life cycle of a product or service, evaluating systematic impact categories such as the Carbon Footprint (HC) in a *cradle-to-gate* approach (Li et al., 2016; Stolarski, Warmiński, Krzyżaniak, Olba-Zięty, & Dudziec, 2025). In the particular case of sustainable materials based on clays and organic or industrial additives, various studies have shown that the carbon footprint depends not only on direct processing emissions, but also preponderantly on the environmental burdens associated with the transport of inputs and the configuration of logistics routes (Aranda-Jimenez & Suarez-Dominguez, 2020).

Therefore, the present work aims to quantitatively evaluate the environmental sustainability and carbon footprint of sustainable bricks manufactured from drilling cuttings from the Trion field, contemplating two logistics reception scenarios on the coast of Tamaulipas (Port of Matamoros and Altamira Industrial Corridor). By applying the Intergovernmental Panel on Climate Change (2021) method on a one-ton functional unit of finished ceramic material, this article identifies the critical stages of the process, determines the feasibility of solar drying, and provides technical foundations for decision-making in the sustainable building sector (Intergovernmental Panel on Climate Change, 2021).

This article presents a detailed analysis of the environmental impact of this process, focusing on the Carbon Footprint (CH) as a sustainability indicator for the state of Tamaulipas.

2. METHOD

To assess the environmental impact of the manufacture of sustainable bricks from industrial waste, this work adopted the standardized method of Life Cycle Assessment (LCA). This method strictly follows the principles, frameworks and requirements specified in the international standards ISO 14040 and ISO 14044, which guarantee the transparency, repeatability and technical rigor of the study. Following these standards, the research was gradually structured in four interconnected phases: the definition of the aim and scope, the analysis of the life cycle inventory (LCI), the environmental impact assessment and the interpretation of the results obtained.

2.1. Definition of Objective and Scope

The purpose of this study is to rigorously quantify the environmental burdens and greenhouse gas (GHG) emissions generated during the process of making ecological artisanal bricks. The limit of the system was found under a "*cradle-to-gate*" approach. This approach covers all production stages from the extraction of the additional raw materials and the maritime-land transport of the drilling cuttings from the oil platforms, to the mixing, molding and final drying of the brick in the manufacturing plant, excluding the subsequent phases of use, maintenance or final disposal of the building parts.

To ensure that all calculations of matter and energy flows are comparable with other research on building materials, a standardized Functional Unit (FU) of 1,000 kg (one ton) of finished bricks was defined. In practical terms, this metric ton corresponds to approximately 595 mechanically stable pieces with standard dimensions of 11.5 cm wide, 23.3 cm long, and 5.3 cm high.

2.2. Life Cycle Inventory (LCI)

The inventory phase collects and quantifies all the resource inputs and emissions outputs associated with the production of the functional unit. For the preparation of a ton of mixture, a formulation previously improved at the laboratory level by Suarez-Dominguez (2024) was used, which balances the mechanical and thermal properties of the part:

- *Drill cuttings*: 500 kg. As they are classified as a waste or industrial by-product free of pre-processing for this purpose, they are assigned a zero environmental load at the start of the system (zero impact at the entrance).
- Local clay soil: 200 kg. The impact derived from its extraction from local quarries is accounted for.
- Fine sand: 300 kg. It considers the impacts associated with its direct mining.
- Water: 150 kg. Used for kneading and homogenizing the mixture.
- Organic aggregate (sorghum straw): 15 kg. It works as a natural reinforcement fiber to prevent cracks during the drying stage.

Unlike traditional brick processes, this proposal replaces firing in high-temperature ovens (which consume firewood, tires or gas) with a natural drying process in the sun, eliminating direct emissions from thermal combustion at the production site.

2.3. Logistics Scenarios and Transportation Modeling

Because drilling cuttings are generated offshore within the Trion oil field (located in the Lost Fold Belt of the Gulf of Mexico), transportation represents the decisive factor in the environmental performance of the product. To evaluate this variable, two logistics distribution scenarios to the state of Tamaulipas were designed and compared:

1. CP-PM Scenario (Matamoros Node): Considers a first maritime stretch of 251 km aboard general cargo ships from the platform to the Port of Matamoros, followed by a short land journey by heavy-duty trucks to the local brick factory.
2. CP-PA Scenario (Altamira Node): It proposes a longer maritime journey of 477 km to the Altamira Industrial Corridor, later articulated with land transport to the processing center.

For the calculation of diesel fuel consumption and associated emissions, standardised emission factors were used for maritime freight transport and heavy trucks with Euro 4/Euro 5 standards.

2.4. Environmental Impact Assessment

The inventory data were processed in SimaPro environmental analysis software. The characterization of the impacts was conducted following the guidelines of the [Intergovernmental Panel on Climate Change \(2021\)](#) method (developed by the Intergovernmental Panel on Climate Change), quantifying the Global Warming Potential (GWP) in kilograms of carbon dioxide equivalent ($kg\ CO_2\text{-eq}$). The analysis broke down the total impact into three key categories: the fossil carbon footprint (transport fuels), the biogenic carbon footprint (natural decomposition of straw) and soil transformation (clay and sand extraction).

3. RESULTS

The results of the calculation of the Carbon Footprint (CH) obtained using the SimaPro v.9 software and the [Intergovernmental Panel on Climate Change \(2021\)](#) methodology (GTP100) for the functional unit of 1,000 kg (1 ton, equivalent to 595 pieces) of sun-dried bricks are presented broken down into three main environmental categories: Fossil HC, Biogenic HC and Soil Transformation. [Figure 1](#) shows the location of the drilling cut obtention from well perforation.

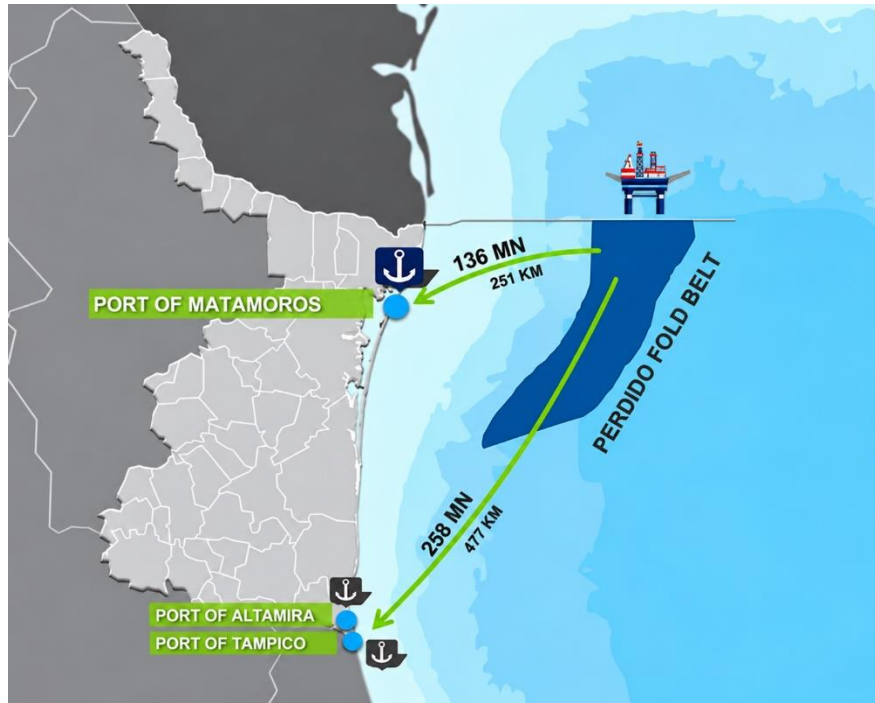


Figure 1. Geographical location of the lost folded belt.

3.1. Impact Assessment by Logistics Scenario

Table 1 summarizes the absolute values of environmental impact for each category for the two reception nodes analyzed: Port of Altamira (CP-PA) and Port of Matamoros (CP-PM).

Table 1. Carbon footprint by impact category for 1 tons of sun-dried bricks (kg CO₂-eq).

Impact Category	Altamira Scenario (CP-PA)	Matamoros Stage (CP-PM)
Fossil	8.17	7.16
Biogenic	1.22×10^{-4}	1.10×10^{-4}
Soil Transformation	1.89×10^{-3}	1.90×10^{-3}
Total Carbon Footprint	8.17	7.17

The characterization analysis reveals that the Fossil CH is the dominant category in both scenarios, being more than 99.9% of the global impact of the product. The contributions of the Biogenic CH (associated with the decomposition of sorghum straw) and the Soil Transformation (associated with the mining of sand and clay) are marginal, standing at 10^{-4} orders of magnitude of and 10^{-3} kg CO₂-eq, respectively.

3.2. Contribution of System Processes

The breakdown of the individual processes within the system shows marked differences associated with maritime logistics:

1. Altamira Scenario (CP-PA): Reaches a total impact of 8.17 kg CO₂-eq per tonne. In this scenario, maritime transport from the Cinturón Plegado Perdido (477 km) gives 2.1 kg CO₂-eq (25.7% total fossil). Land Transport (25 km) contributes 3.6 kg CO₂-eq (44.0%), while the acquisition of mineral inputs (clay and sand) generates 1.96 kg CO₂-eq (24.0%).
2. Matamoros Scenario (CP-PM): The total footprint is reduced to 7.17 kg CO₂-eq per tonne. Due to the shorter maritime distance (251 km), the emissions associated with the ship journey decrease to 1.1 kg CO₂-eq (15.3% total fossil fuel), reducing the global CH by approximately 1.0 kg CO₂-eq compared to the Altamira scenario.

The relative contributions of raw materials such as water (0.057 kg CO₂-eq) and straw (0.44 kg CO₂-eq) remained constant between both scenarios.

4. DISCUSSION

The results obtained allow us to evaluate the sustainability of the use of oil drilling cuttings as secondary raw material in construction, highlighting the following key aspects:

4.1. Logistical Sensitivity and Location of the Plant

The determining factor in the variation of the Carbon Footprint among the options evaluated lies in the distance of maritime transport of the waste raw material from the maritime deposit to the coast. The 226 km reduction in the maritime journey by selecting the Port of Matamoros instead of the Port of Altamira generates 12.2% direct savings in global emissions per ton produced. This shows that the environmental viability of the circular economy with offshore waste is conditioned by the proximity of the receiving planning node.

4.2. Benefits of Raw Material Substitution and Solar Curing

The entry of the drill cutting, with a zero-input environmental impact (as it is classified as industrial waste), avoids the extraction of virgin clay per ton of product. 500 kg

In addition, the elimination of the firing process by implementing solar drying is the greatest environmental benefit of the proposed design. In the traditional production of ceramic bricks fired using rustic masonry or wood kilns, thermal emissions typically range from 200 and 350 kg CO₂-eq per ton of fired brick due to combustion. As it does not require fossil or biomass thermal input in the curing stage, the value achieved in this study (7.17 a 8.17 kg CO₂-eq/t) is a reduction greater than the 95% compared to traditional baked masonry.

4.3. Implications for the Construction Industry

The low emissions of the Soil Transformation category (< 0.002 kg CO₂-eq) reaffirm that the recovery of waste from the oil industry does not transfer environmental burdens to other terrestrial ecosystems, positioning these sustainable bricks as a competitive alternative in terms of decarbonization of materials for the state of Tamaulipas.

5. CONCLUSIONS

The manufacture of sustainable bricks by incorporating 50% oil drilling cuttings and a solar curing/drying process proves to be a technically workable and environmentally superior alternative to traditional masonry. With a total Carbon Footprint (HC) ranging from 7.17 and 8.17 kg CO₂-eq/t of finished material, the system achieves a reduction in emissions greater than 95% compared to conventional firing processes in rustic thermal ovens.

The evaluation by Life Cycle Assessment (LCA) under the *cradle-to-gate approach* confirms that the fossil transport phase is the critical factor that conditions the environmental performance of the product, being more than 99.9% of the total footprint. The selection of the Port of Matamoros (CP-PM scenario) as a reception node reduces the maritime journey in 226 km with respect to the Altamira Industrial Corridor (CP-PA scenario), which translates into a direct decrease in the 12.2% in the impact of global warming potential (GWP-100).

The entry of drill cuttings with zero environmental load at the beginning of the system boundary allows the extraction of 500 kg first raw material (clay/sand) for each ton of brick produced. This not only mitigates the extractive pressure on local aggregate banks and minimizes the impact of soil transformation (< 0.002 kg CO₂-eq/t) but also transforms an environmental and logistical liability of the *offshore* industry of the Gulf of Mexico into a value-added input for sustainable construction in Tamaulipas.

Finally, it is recommended to install processors and manufacturing infrastructures in the northern coastal area of the state (Matamoros) to improve the maritime-terrestrial supply chain. Likewise, it is suggested to continue with the mechanical characterization, durability and modeling of the variants subjected to heat treatment in rustic kilns to complete the comparative matrix of environmental and structural performance.

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INSTITUTIONAL REVIEW BOARD STATEMENT

Not applicable.

TRANSPARENCY

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

COMPETING INTERESTS

The authors declares that there are no conflicts of interests regarding the publication of this paper

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