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Analysis of environmental benefits associated with the incorporation of Waelz slag into fired bricks using LCA

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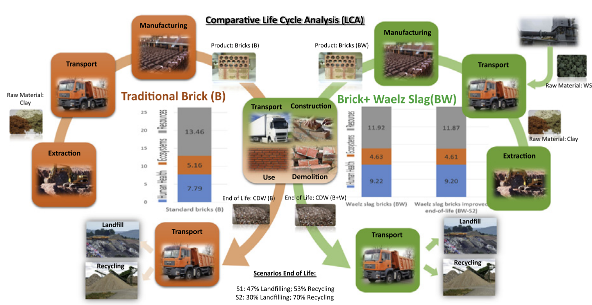
HIGHLIGHTS

- Impact on climate change of bricks incorporating Waelz slag is reduced by 11.8%.
- Waelz slag bricks benefit from impact savings affecting human toxicity category.
- Higher air emissions during firing offset benefits due to soil emission savings.
- Overall environmental benefits of Waelz slag incorporation to bricks is marginal.
- Increased CDW recycling does not improve environmental performance.

GRAPHICAL ABSTRACT



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ABSTRACT

A comparative cradle-to-grave LCA shows that incorporating Waelz slag into ceramic bricks generates lower impact on climate change and reduces the impact on freshwater ecotoxicity and fossil depletion. These benefits are attributable to impact savings due to avoiding the landfilling of the slag and reduced fuel demand during the manufacturing stage. However, due to the higher SO_2 and HF emissions generated in the firing of slag containing bricks, these benefits are offset by higher impacts on human toxicity and terrestrial acidification categories. The aggregated results suggest very limited environmental benefits in this practice even taking into account different end-of-life scenarios.

1. Introduction

The construction sector is increasingly concerned about the application of Industrial Ecology (IE) principles that improve the environmental performance of building materials. The incorporation of industrial residues into construction products is receiving attention as a means to achieve two objectives: first, minimizing the amount of potentially harmful residues destined for disposal; and second, reducing the consumption of natural resources and energy in the manufacturing of the final materials [1–4].

These principles are reflected in the Construction Products Regulation (CPR) 305/2011/EC [5], which lays down harmonised conditions for the marketing of construction products in the European Union (EU). Annex I of this Regulation contains a list of Basic Requirements for Construction Works (BRCW) that must be satisfied by any construction material before it may be granted permission to be used and commercialized in the EU. One of these requirement categories (BRCW 3 – Hygiene, health and the environment) provides conditions to be fulfilled regarding the emission

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of substances that may damage the environment and human health, including greenhouse gas emissions. In this respect, the regulation recognizes the need to minimize the emission of harmful substances to the atmosphere, waters and soil. Another category (BRCW 7 – Sustainable use of natural resources) is dedicated to the use of raw materials in an environmentally conscious manner. This category focuses on the use of materials that are recyclable and compatible with the surrounding environment in terms of degradability and harmlessness at the end of their useful lives. CPR sustains the need to use a life cycle approach to evaluate the environmental performance of construction materials, thus considering impacts attributable to all stages in its value chain from raw material extraction to final disposal. The technical implementation of this life cycle approach is described in *EN 15804 Sustainability of construction works, Environmental product declarations, Core rules for the product category of construction products* [6].

In line with these ideas, experimental results have been particularly promising regarding the incorporation of Waelz slag into fired bricks. This inorganic residue, consisting of a mixture of Fe_2O_3 (56%) and CaO (16%) [7], is generated in large amounts in Waelz plants dedicated to the industrial recovery of ZnO/PbO from Electric Arc Furnace dust [8]. This slag is classified in the European List of Waste [9] as a non-hazardous waste. However, its disposal by landfilling represents a serious environmental risk and involves considerable economic costs for this industrial activity. Experimental investigations have proven the optimum technological properties of ceramic bricks incorporating up to 20% Waelz slag and the reduced energy requirements involved in the firing process [8]. Despite potential benefits, the commercial production of bricks containing waste materials is still very marginal. This has been associated in part to unclear transmission of information to industry and the public in general regarding the environmental soundness of these materials [1] and also the limited amount of work dedicated to evaluate the overall environmental benefits of this approach. However, European strategies, like the Action Plan for Circular Economy [10], can contribute to enhance the benefits of reintroduce waste flows to new production processes. The proposed actions will contribute to "closing the loop" of product lifecycles through greater recycling and re-use, and bring benefits for both the environment and the economy.

Life Cycle Assessment (LCA) is a methodology widely used to quantify potential impacts and damage to the environment associated with process and products, including the value chain of construction materials [11,12]. LCA conducted on standard products from the brick manufacturing industry [13–16] have shown that environmental impacts are primarily associated with energy consumption in the firing process. Impact on climate change reported in the literature for fired clay bricks usually range between 132 and 295 kg of CO_2 eq./tonne of brick [15,17,18], depending primarily on the scope of the LCA, characteristics of the firing process and brick quality. The use of LCA to investigate the benefits of waste incorporation into fired bricks is very limited. Bories et al. [19] applied a cradle to gate approach to demonstrate the improved performance of fired clay bricks when incorporating agricultural wastes as pore forming agent.

The aim of this investigation is to provide additional information about the environmental consequences of incorporating Waelz slag into fired bricks. The analysis has been performed using LCA methodology and a cradle to grave approach. The analyses have been carried out using primary inventory data obtained experimentally for the emission of air pollutants during the firing process and for the leaching of potentially toxic inorganic species in landfill sites at the end of the useful lives of the ceramic bricks. Impact savings due to avoiding the landfilling of the Waelz slag were also considered. A series of scenarios have been defined describing the transport of raw materials and residues, processing and manufacturing of fired clay bricks, and the end-of-life of the construction products. The analysis also covers the effect of alternative waste management scenarios regarding the landfilling and recycling of Construction and Demolition Waste (CDW).

2. Methodology

2.1. Life cycle assessment of fired clay bricks containing Waelz slag

2.1.1. Goal and scope definition

The main goal of this investigation is to quantify the environmental benefits associated with the incorporation of Waelz slag into fired clay bricks, as an alternative to the final disposal of this residue by landfilling. In addition, a secondary goal has also been set involving the analysis of environmental benefits resulting from meeting the recycling objectives for Construction and Demolition Waste (CDW) set under the EU Waste Framework Directive for 2020. This investigation has been carried out using Life Cycle Assessment (LCA) methodology according to standard procedures described under ISO 14040 and ISO 14044 [20,21].

This LCA has been based on an earlier experimental work carried out by authors of the same research group describing the characteristics of ceramic bricks incorporating different proportions of this non-hazardous residue. This investigation proved that fired clay bricks containing up to 20 wt% Waelz slag complied with all the technological specifications and also with the environmental requirements regarding the leaching of potentially hazardous components when disposed of by landfilling [8]. Inventory data for air emissions during the firing process and the leaching of toxic compounds during landfilling derive from this preceding investigation [8,22]. Since both products, the conventional bricks and the waste incorporating bricks, are capable of accomplishing the same functional requirements, the functional unit for this investigation was selected on a product mass basis as "*1 tonne of bricks*".

The LCA has been performed following a cradle-to-grave approach and considering the following four life cycle phases:

- RAW MATERIALS: including extraction of raw materials (natural clay and/or Waelz slag) and transportation to the brick manufacturing plant,
- MANUFACTURING: including the fabrication of the standard or Waelz slag containing ceramic bricks,
- RECYCLING: transport of bricks to the recycling facility at the end of their useful lives, shorting of raw materials and processing for aggregate production.
- LANDFILLING: transport of used bricks from construction site to disposal facility, construction and operation of landfill site, and leaching of toxic inorganics.

Owing to their limited contribution, and also due to the fact that they have a similar contribution in all the scenarios considered, the following processes were left out of the boundaries of the analysis: machinery and equipment at brick manufacturing plant, landfill site and CDW recycling plant; and brick utilization phase (including transport to the construction site, construction activities and demolition of building at the end of its useful life).

2.1.2. System boundaries and scenarios

Fig. 1 shows the life cycle diagram and system boundaries of the three analysis scenarios considered in this investigation:

i) **Standard brick (B-S1) scenario** describes conventional bricks produced from 100 wt% clay. The system boundaries cover the extraction from the quarry of 1.25 tonnes of natural clay, its transportation to the brick factory, the