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Life cycle assessment of renewable energy alternatives for replacement of natural gas in building material industry

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Abstract

Due to environmental and geopolitical reasons, the need for substitution of fossil fuels with renewable alternatives in industry is augmenting. The main objective was to assess environmental impacts of "cradle-to-gate" brick production stages and to evaluate the effect of fuel substitution and variation of electricity mix on the impact. Scenarios with natural gas, bio-methane, first and second generation bio-fuels used as the fuels in industrial furnace were studied. Scenarios were analyzed using "*ReCiPe*" and "*EcoIndicator'99*" impact assessment methods. Results show that environmental impact can be reduced by circa 50 % when natural gas is substituted with bio-methane or second generation bio-fuel.

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Keywords: Bio-methane; Brick production; Building industry; Cradle-to-gate; Eco-design; Life cycle assessment; Renewable energy; Sustainable construction; System innovation

1. Introduction

Production sector of ceramic construction materials is energy-intensive due to operation of high-temperature kilns for long periods [1, 2]. Due to the energy consumption of machinery, the manufacturing stage of these materials contributes significantly to global warming by emissions of greenhouse gases (GHG). The construction sector consumes approximately 40 % of raw materials used globally every year [3] and bricks are among the major materials used for building construction [4]. Substantial amounts of energy are needed to fire bricks and tiles as well

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as melt, shape, and harden ceramics. Although the production phase of construction materials has large environmental impact, the materials have a long life-time and reduce energy consumption of buildings. Therefore, life cycle assessment data are needed for comparison of various alternatives for selection of construction materials.

Various studies have been conducted to optimize kilns and plants [5–7], to study the effects of additives on fuel consumption and on mechanical-physical properties of bricks [8–10], to develop sustainable construction materials via waste recycling [11, 12], and to assess life cycle of buildings or building construction systems [13, 14]. Notwithstanding, less attention seems to be paid to the evaluation of environmental impact caused by the production of certain types of construction materials, or to rate changes of environmental impact caused by the substitution of fuel.

As to the first, only a few studies are published which show evaluation of the environmental impact of ceramic building materials. The study of environmental assessment of brick production in Greece [4] used the method *EcoIndicator'95* to quantify impact. This method is a predecessor of the *EcoIndicator'99* method. But currently even more recently developed methods such as the *ReCiPe* [15], which is used to evaluate environmental aspects of brick production in Latvia in the present study, are available.

There are studies related to energy efficiency improvements or use of renewable energy sources [16, 17] for reduction of GHG emissions per unit of production. However, it is expected that the energy "embodied" in the construction materials will become more critical in the future as the energy efficiency of buildings will increase. In the Reference Document on best available technologies (BAT) in the Ceramic Manufacturing Industry (issued by the European Commission) it is mentioned that mostly natural gas, liquefied petroleum gas and extra light fuel oil are used for brick firing at the present time. Other energy sources, e.g. liquefied natural gas, biogas, biomass, electricity, heavy fuel oil and solid fuels (e.g. coal, petroleum coke) are used in burners of furnaces [1]. In the Reference Document it is declared that environmental benefits could be achieved by switching from heavy fuel oils or solid fuels to natural gas (also liquefied petroleum gas and liquefied natural gas). It is also noted that renewable energy sources could play a role as energy sources for burners, but information gaps still exist– lack of emission and consumption data [1].

Studies based on life cycle inventory data [18, 19] show that if bio-methane is substituted for natural gas, GHG emissions can be reduced by nearly 80 %. It can be claimed that substitution of fuels in this type of industry can give more substantial environmental benefits than gradual improvements of equipment efficiencies. Recently Ellersdorfer and Weiβ have described integration of biogas plants in the cement industry from the energy and economic point of view [17]. However, a more detailed study based on life cycle assessment and considering other alternatives, e.g. bio-fuels is needed. Therefore, in this research three different renewable energy sources, i.e. bio-methane, as well as 1st and 2nd generation bio-fuels, for use in the Latvian ceramic brick industry are compared on the basis of environmental impact.

The research questions for this study are the following: how large are environmental impacts created by processes of brick production in Latvia and how these impacts change if energy sources used for the production, i.e. fuel for heat supply and electricity mix, are varied? The main goal of this study was to characterize environmental impacts of brick production stages ("cradle-to-gate") at midpoint and endpoint impact category level (1), to evaluate the effect of fuel substitution and variation of electricity mix on the environmental impact (2). The results were primarily targeted for the purpose of ecodesign applied to the building sector as well as to reduce the environmental impact of the brick production industry. Results of the study are important for building design and construction material industry as well as for planning future energy supply systems. Bricks manufactured in Latvia are exported to many countries and therefore the results are relevant for a wider region. This study continues the previous research [18–20] where the environmental impact of building materials for the purpose of ecodesign were characterized, environmental aspects of substitution of the natural gas by bio-synthetic natural gas were analyzed, and life cycle assessment of biomethane supply system was carried out, by considering more fuel alternatives for brick firing and using LCA methodology with two impact assessment methods.