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Environmental assessment of different cement manufacturing processes based on Emergy and Ecological Footprint analysis

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A B S T R A C T

Due to its high environmental impact and energy intensive production, the cement industry needs to adopt more energy efficient technologies to reduce its demand for fossil fuels and impact on the environment. Bearing in mind that cement is the most widely used material for housing and modern infrastructure, the aim of this paper is to analyse the Emergy and Ecological Footprint of different cement manufacturing processes for a particular cement plant. There are several mitigation measures that can be incorporated in the cement manufacturing process to reduce the demand for fossil fuels and consequently reduce the CO_2 emissions. The mitigation measures considered in this paper were the use of alternative fuels and a more energy efficient kiln process. In order to estimate the sustainability effect of the aforementioned measures, Emergy and Ecological Footprint were calculated for four different scenarios. The results show that Emergy, due to the high input mass of raw material needed for clinker production, stays at about the same level. However, for the Ecological Footprint, the results show that by combining the use of alternative fuels together with a more energy efficient kiln process, the environmental impact of the cement manufacturing process can be lowered.

1. Introduction

Climate change problems are addressed by two major international agreements: the 1992 United Nations Framework Convention on Climate Change (UNFCCC) and the 1997 Kyoto Protocol (IPCC, 2013). The ultimate objective of these agreements is to stabilise greenhouse gas – GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the global climate system. The latest report from the scientific panel on anthropogenic global warming indicates that substantial and joint global action is required to reduce carbon dioxide – CO_2 emissions. Meaning the longer we wait to address this issue, the more difficult, technologically challenging and expensive it becomes (IPCC, 2014).

It is well known that over 80% of global CO_2 emissions are caused by transport activities and industry due to this reason, there is a need to decarbonize transport and industrial production (Klemeš et al., 2012). In 2008, the electricity and heat generation sector was responsible for 41%, transport sector for 22%, and industry for 20% of anthropogenic CO_2 emissions (Benhelal et al., 2013). From these 20% of global CO_2 emissions related to industry, the cement industry accounts for approximately a quarter of total CO_2 emissions in industry (Marques and Neves-Silva, 2015). This means that cement industry as an energy intensive industrial sector, alone generates approximately 5% of anthropogenic CO_2 in the world, and this figure is given in several studies (Mikulčić et al., 2013a; Usón et al., 2013). Due to its significant environmental impact, over the past decades several CO_2 emissions mitigation measures have appeared. The main objective of these measures is environmental conservation in terms of reducing CO_2 emissions.

In recent years, there have been numerous studies worldwide discussing energy conservation policies, estimating the CO_2 mitigation potential, and considering technology evaluation for the cement industry. Some of these studies investigated the effect of mitigation measures at the global level, such as the study conducted by the International Energy Agency – IEA (IEA, 2009). However, the majority of these studies evaluated the environmental impact of cement production at national and regional levels. The effect of mitigation measures on the regional level, like those in

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the European Union – EU were analyzed in Pardo et al. (2011) and Moya et al. (2011). The United States' cement industry was analysed in the study by Xu et al. (2013). However due to the rapid economic growth and vast urbanization, the majority of the studies related to the cement industry are for the developing countries like China (Li et al., 2014; Wang et al., 2014; Xu et al., 2014), South Africa (Swanepoel et al., 2014), Turkey (Ekincioglu et al., 2013), Iran (Ostad-Ahmad-Ghorabi and Attari, 2013), India (Morrow et al., 2014), Thailand (Hasanbeigi et al., 2010), and Vietnam (Nguyen and Hens, 2015). The reason for these is most easily seen in Table 1 where the global cement production for 2012 is given. Table 1 shows that the vast majority of cement production is located in developing countries, especially in Asia. The importance of cement production in these developing economies can also be observed when comparing the annual CO_2 emissions from cement production in industrialised countries and developing countries. In the EU, the cement industry contributes to about 4.1% of total CO_2 emissions (Mikulčić et al., 2013b). This share varies from one EU country to another, in EU's most developed country Germany, this share is even lower, and the cement industry accounts for 2.9% of Germany's CO_2 emissions (Brunke and Blesl, 2014). This is similar for the cement industry in United States, where cement production is responsible for about 2% of total CO_2 emissions (Worrell and Galitsky, 2008). Whereas in China, the world's largest cement producing country and the world's largest emitter of GHG emissions, 15% of total CO_2 emissions are related to cement production (Chen et al., 2015; Wang et al., 2013). All of these studies stated that there is a great challenge in attempting to approach sustainability in the cement industry. Due to this reason and the increased social awareness in fighting climate changes, eco-labelling of companies, products, lifestyle, services, etc., is becoming an element of decision making (Čuček et al., 2012a).

Over the years, Ecological Footprint has arisen as a simple, yet effective tool that can serve as an indicator of environmental impact, and eco-labelling (Cagiao et al., 2011; Čuček et al., 2012b). However, Huijbregts et al. (2008) in their study show that the usefulness of the Ecological Footprint as a stand-alone indicator for the environmental impact is limited. Based on their observations, they concluded that the Ecological Footprint should be used together with other indicators to estimate in detail the impact of human activities on the environment. This observation was even more highlighted recently by Rugani et al. (2013), where it was concluded that the use of the Carbon Footprint in combination with other single-issue indicators would be recommended to increase transparency and impacts coverage.

As cement manufacturing is an energy intensive process, Emergy was used as an indicator for sustainability in some studies. Pulselli et al. (2008) in their study through an Emergy evaluation assessed the sustainability of building materials, including cement. Zhang et al. (2011) showed that Emergy analysis provides results that measure the resource input in the cement industry. These results can be further used for process performance analysis. Liu et al. (2015) used emergy analysis and evaluated the environmental effect of using sewage sludge as an alternative raw material or fuel in clinker production. The study showed that the use of emergy accounting may provide quantitative metrics of eco-industrial sustainability. In a recent study by Jamali-Zghal et al. (2013), Emergy and Carbon Footprint were used together to study to which extent, replacing fossil fuel with biomass for heating is an environmentally friendly solution. In relation to this study, Andrić et al. (2015) using the same approach for electricity production determined the maximum supply distance of biomass that allows the co-firing of coal and biomass to be more environmentally efficient than the pure coal combustion. The study showed that the Carbon Footprint and Emergy method are used together to cover all, or at least most, of the significant aspects of the electricity production process that may influence the environment.

To date, to the knowledge of the authors, there have been no studies that used the Emergy and Ecological Footprint together as environmental indicators, to investigate the sustainability of cement manufacturing processes. For that reason in this study, in order to help cement manufactures to operate in a more environmental friendly way, and to assess which manufacturing process is more sustainable, the environmental impact of four different cement manufacturing processes is estimated. Actual cement plant data are used in order to correctly study the impact of different processes. The results shown in this study highlight potential modifications and improvements in the manufacturing process, regarding its sustainability.

2. Methodology

Sustainability is essentially about finding ways to meet the material and energy needs of human society within the limits of

Table 1
Global cement production in 2012 (Oh et al., 2014).

Country	Production (million metric tonnes)	Share in the world production
China	2150	58.1%
India	250	6.7%
United States	74	2.0%
Brazil	70	1.9%
Iran	65	1.8%
Vietnam	65	1.8%
Turkey	60	1.6%
Russian Federation	60	1.6%
Japan	52	1.4%
South Korea	49	1.3%
Egypt	44	1.2%
Saudi Arabia	43	1.2%
Mexico	36	1.0%
Germany	34	0.9%
Thailand	33	0.9%
Pakistan	32	0.9%
Italy	32	0.9%
Indonesia	31	0.8%
Spain	20	0.5%
Other (rounded)	500	13.5%
World total (rounded)	3700	–