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Cement industry greenhouse gas emissions – management options and abatement cost

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ABSTRACT

Growing anthropogenic greenhouse gas emissions and increasing global demand for cement are general drivers for managing greenhouse gas emissions (GHG) in the cement industry. Overall CO_2 dominates cement sector GHG emissions. The aim was to study how the management of GHG emissions in the cement production chain is related to (1) clinker substitutes, (2) primary source of energy, (3) electricity emissions, (4) technology in use and (5) geographic location. Therefore regional CO_2 emissions in the cement industry were analyzed by applying a climate impact management matrix on a cradle-to-gate basis. The use of clinker substitutes in cement varied from 3% to 36.4%. The results show that the variation of process technology and thermal energy use related CO_2 emissions is more significant than that of electricity emissions. The highest near term potential to avoid emissions is replacing clinker with mineral components (MIC). Increasing the global use of MIC to a level of 34.2%in cement would save 312 Mt CO_2 with the 2013 level of annual cement production. Similarly, a 2.7% reduction in thermal energy use would save 28 Mt CO_2 annually, and a 10% decrease of emissions from electricity use would save 26 Mt CO_2. The best long term options from 2030 onwards are different carbon capture technologies and MgO and geopolymer cements. In addition, the CO_2 abatement costs of different investment projects were compared by using a uniform capital recovery factor. The abatement cost of avoided emissions varied from US$4 to US$ 448 per ton of CO_2 depending on the technology, geographical location and initial level of CO_2 emissions.

1. Introduction

Since 1950 the production of cement has gone up by a factor of 25, and China used more cement in 2011–2013 than the USA during the entire 20th century (Smil, 2013). Consequently, in 2010 the cement sector was responsible for 2823 million metric tons (Mt) of CO_2 emissions (OECD, 2012). This corresponded to almost 9% of global CO_2 emissions from burning of fossil fuels that year. In total, cement production accounts for roughly 5–8% of global CO_2 emissions. Thus growing anthropogenic greenhouse gas emissions and increasing global demand for cement are general drivers that motivate finding solutions for managing greenhouse gas emissions (GHG) in the cement industry and comparing the abatement cost of different technological or technical solutions. The United Nations Intergovernmental Panel for Climate Change (IPCC) and the International Energy Agency (IEA) estimate that the annual mitigation potential of GHG emissions in the cement industry will vary between 480 and 1700 million metric tons in 2030 (IPCC, 2007; IEA, 2006).

Global reporting on cement industries is, however, not complete: available statistics on cement industry production volumes and GHG emissions do not fully cover global emissions and vary in different sources of information. The large amount of CO_2 emissions, considerable use of energy, and depleting resources has pushed the cement industry to implement commitments like the Cement Sustainability Initiative (CSI, 2011; WBCSD, 2012). A roadmap for reducing the climate impact of cement industries gives the general framework (IEA, 2009) that is supported by other organizations (Gupta, 2011). Global cement production grew by over 73% between 2005 and 2013 from 2310 Mt to 4000 Mt (Cembureau, 2014), highlighting the importance of reducing CO_2 emissions of cement production.

Research on the management of cement industry GHG emissions and, in particular, those of CO_2 has received considerable interest worldwide. The cement production process, energy use and related CO_2 emissions are known from previous research

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(Usón et al., 2013; Benhelal et al., 2012; Mikulcic et al., 2012). Traditional pathways to decrease cement production emissions are improved energy efficiency through improved technology, better process integration together with the use of clinker substitutes like waste fly ash and slags from power production and minerals processing (Ishak and Hashim, 2014; Worrell et al., 2008), and fuel switching and alternative fuels (McLellan et al., 2012; Rahman et al., 2015). Ash from agricultural wastes which constitute pozzolanic materials can be used as a replacement for cement (Aprianti et al., 2015). Hasanbeigi et al. (2012) reviewed eighteen emerging technologies and their benefits for the cement industry. One of the conclusions was that information is still scarce and scattered regarding energy-efficiency and low-carbon technologies. Also most of the technologies have an energy penalty associated with their operation. Considerable research effort is dedicated to reducing the cement production emissions in China, and accompanying investments in new kiln technologies have considerably reduced the CO_2 emissions per ton of cement from 2006 onwards (Xu et al., 2014; Wang et al., 2014, 2013; Wen et al., 2015; Hasanbeigi et al., 2013).

Cement is one of the key components in concrete. Several studies concentrate on the possibility to replace cement in concrete or mortar with recycled materials like porcelain polishing residues (Jacoby and Pelisser, 2015), glass (de Castro and de Brito, 2013), recycled tyre rubber (Usón et al., 2013), basalt aggregates (Ingrao et al., 2014), ceramic aggregates (Medina et al., 2013) or other aggregates (Mutuk and Mesci, 2014). Research on alternative binders to Portland cement that reduce the CO_2 emission is progressing (Ponikiewski and Gołaszewski, 2014; Juenger et al., 2011), and e.g. the use of alkali-activated (AA) binder instead of ground granulated blast-furnace slag (GGBS) cement in concrete or in ordinary Portland cement (OPC)-based concrete reduces the CO_2 emission of concrete by between 55 and 75% (Yang et al., 2013). GGBS can also be used as a soil stabilizer instead of cement in non-fired clay mixes (Kinuthia and Oti, 2012). Composite masonry bricks without Portland cement have been successfully tested (Turgut, 2012), and the latest news report on compostable bricks grown on agricultural waste frames with the help of fungi for short life time constructions (NS, 2014). Carbon capture technologies are also one of the future options to reduce the CO_2 emission of cement production leading to life cycle GHG emission reductions of 39–78% for cement production (Volkart et al., 2013; Hasanbeigi et al., 2012). Simulation models for oxy-combustion, calcium looping and amine scrubbing reduced the flue gas CO_2 content by 63–85% but increased the specific energy consumption (Vatopoulos and Tzimas, 2012). A scenario analysis for Spain forecasts a 45% emission reduction from the 2010 level in 2030 (García-Gusano et al., 2015). The promising different options to reduce the GHG of cement production and partially incomplete and scattered data motivated us to study how the overall management of GHG emissions in the cement production chain is related to clinker substitutes, technology in use, primary source of energy, electricity emissions and geographic location. In addition, we compared the abatement costs of reducing the GHG of cement production by using a uniform capital recovery factor. Our focus in this paper is on managing GHG emissions in cement production chains. Other environmental burdens like particulate matter formation, terrestrial acidification and freshwater eutrophication are excluded. Methods are described in Section 2, and Section 3 presents the results of our study. The conclusions are highlighted in Section 4.

2. Methods

The system boundary for a single plant GHG management was selected on a cradle-to-gate basis and is described in Figs. 1 and 2. For analyzing regional differences, data on cement production GHG emissions collected from several sources were grouped by geographic region. GHG emissions in the cement industry were analyzed and calculated in uniform unit (kg CO_2/t cement) as shown in the resulting datasets (Table 2). The consistency and accuracy of contributors to the overall CO_2 emissions in the cement industry in the datasets – clinker baseline, positive impact of

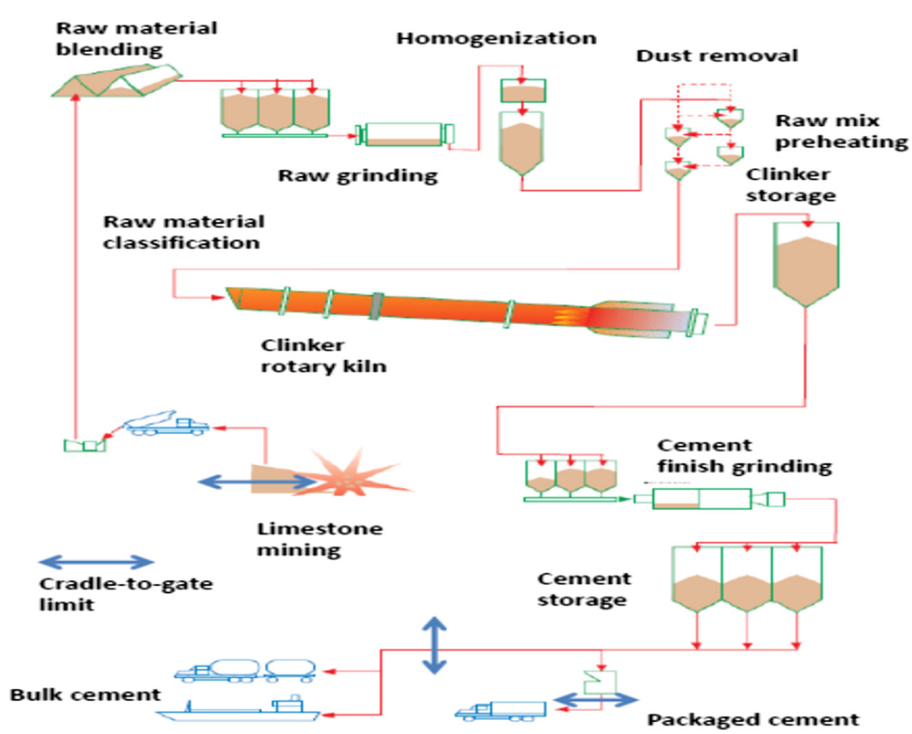

Fig. 1. System boundary for a cradle-to-gate LCA of a cement plant. Adapted from Finnsementti (2007).