Journal of Cleaner Production 82 (2014) 94–111

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Energy conservation measures for the German cement industry and their ability to compensate for rising energy-related production costs

Jean-Christian Brunke [a, b, *], Markus Blesl [b]

[a] Graduate and Research School Efficient Use of Energy Stuttgart (GREES), University of Stuttgart, DE-70565 Stuttgart, Germany
[b] Institute for Energy Economics and The Rational Use of Energy (IER), University of Stuttgart, DE-70565 Stuttgart, Germany

A R T I C L E I N F O

Article history:
Received 30 December 2013
Received in revised form
8 May 2014
Accepted 25 June 2014
Available online 2 July 2014

Keywords:
Industrial energy efficiency
Cement industry
Energy-efficient technologies
Bottom-up
Cost of energy saving

A B S T R A C T

Cement is a bulk commodity that is correlated with the population growth. While the world-wide sales are continuously increasing, the demand for cement in Germany is stagnating. Nevertheless, cement production accounts for 3.8% of Germany's industrial final energy consumption and 2.9% of Germany's total CO_2 emissions in 2012. We assessed the energy conservation and CO_2 abatement potential of 21 identified measures by deriving fuel, electricity conservation and CO_2 abatement cost curves. In our bottom-up investigation, we account for the current efficiency of plants and use two different system boundaries: a process boundary for benchmarking measures and a facility boundary for calculating the total potential. We identified economical conservation and abatement potentials for the year 2013 of 4% for fuel, 0.7% for electricity and 3.4% fuel and process-related CO_2 emissions in relation to 2012. The results of the subsequent sensitivity analysis showed that electricity conservation measures in cement grinding can compensate for higher electricity prices in the amount of the German electricity tax. In contrast, the sector's energy-related productions costs showed a high sensitivity against rising CO_2 prices. Without radical process innovations such as low carbon cements, CO_2 prices until 2035 accounted in average for more than 40% of the gross value-added which indicates, according to the EU ETS directive, the carbon leakage risk of the cement sector.

1. Introduction

Cement is with a world-wide annual production of 3.3 Gt a bulk commodity that is correlated with the population growth, as in consequence, new houses and infrastructure need to be built. Unsurprisingly, over 57% of the world production is accounted by China, while Europe holds a 5.7% share (Weiß et al., 2012). Germany in particular has with 1% an even smaller share of 1% with 32.5 Mt in 2012 (VDZ, 2013). Nevertheless, the production of clinker, an intermediate product for cement, is with 3300 MJ/t clinker and 0.816 t CO_2/t clinker, whereof 0.421 t CO_2/t clinker are process-related emissions, energy- and CO_2-intensive (Ecofys et al., 2009). In total, the cement industry is according to DESTATIS (2014) responsible for 3.8% of Germany's industry final energy consumption and 2.9% of Germany's total CO_2 emissions in 2012 (VDZ, 2013).

While carbon capture and storage (CCS) is an effective way to lower direct CO_2 emissions (Li et al., 2013), energy conservation can be a more cost-effective point of attack to lower fossil-fuel related CO_2 emissions. The importance of energy efficiency was accordingly identified by policy-makers (e.g. EIPPCB, 2009). As a consequence, policies, such as the 20–20–20 targets, which demand, among others, a reduction of the primary energy consumption of the industry by 19% until 2020, have been put in place. Besides, with energy costs accounting for 30–40% of total production costs, plant operators have been traditionally concerned with energy efficiency, but more from an economic point of view. In this context, we understand energy efficiency as the reduction of energy-related production costs, whereby external costs (e.g. air pollution, anthropogenic climate change) are included. Thus, energy conservation (EC), i.e. the reduction of the specific energy consumption, might lead to, but does not imply, an improvement in energy efficiency.

Since the two oil price shocks in the 1970s, EC cost curves (ECCC) and greenhouse gas (GHG) abatement cost curves are commonly used to disseminate the results of identified measure-specific potentials and their costs (Wächter, 2013). With publication of global GHG abatement cost curves by McKinsey (2009), this concept has

* Corresponding author. Institute for Energy Economics and The Rational Use of Energy (IER), University of Stuttgart, DE-70565 Stuttgart, Germany. Tel.: +49 711 685 87838; fax: +49 711 685 87883.
E-mail addresses: jean-christian.brunke@ier.uni-stuttgart.de, jb@ier.uni-stuttgart.de (J.-C. Brunke), markus.blesl@ier.uni-stuttgart.de (M. Blesl).

http://dx.doi.org/10.1016/j.jclepro.2014.06.074
0959-6526/

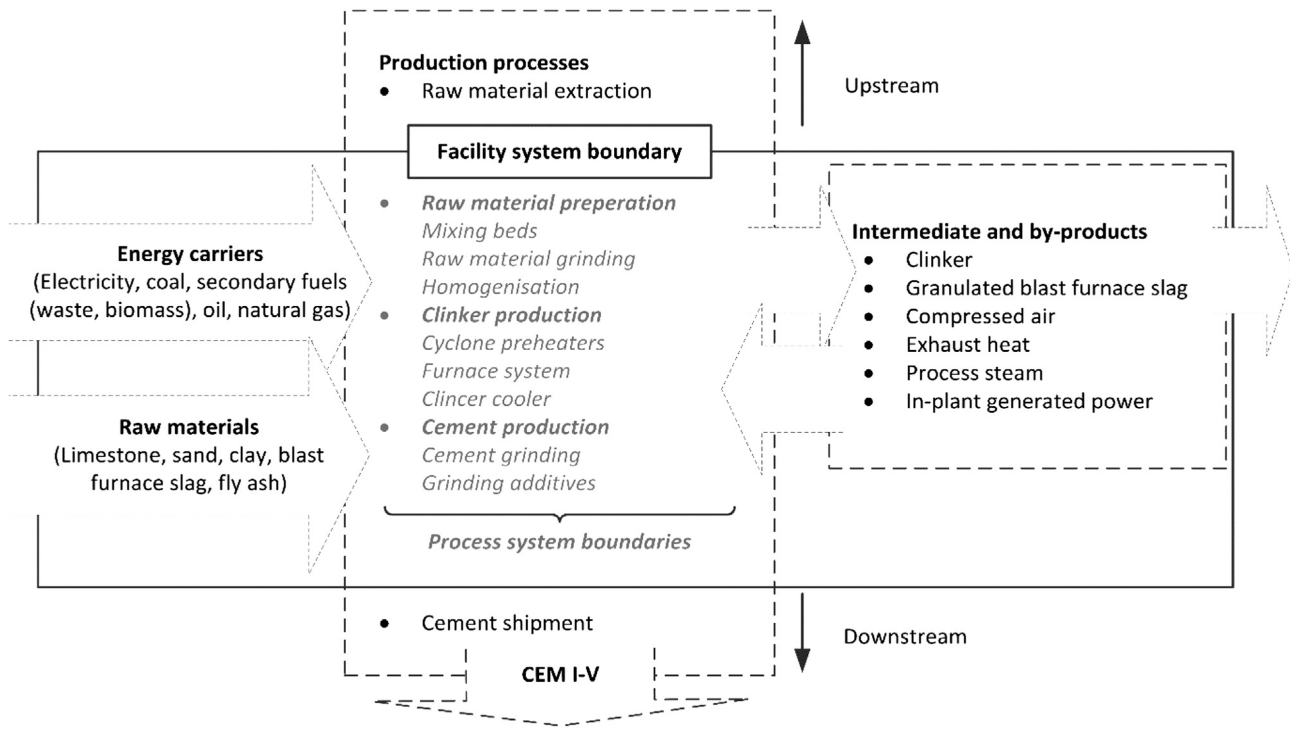

Fig. 1. Typical production processes of an integrated cement facility and the system boundaries respected in the investigation. The process system boundaries (in grey italic font) cover each of the production processes and the respective energy conservation measure. They are used for benchmarking measures. The facility boundary covers the raw material preparation, clinker and cement production processes. It is used to calculate the total energy conservation potential.

reached a wide public and is increasingly used to inform policy-makers (Vogt-Schilb and Hallegatte, 2013). The ranking of EC and abatement measures according to their cost-effectiveness gives policy-makers a least cost pathway to fulfil certain reduction targets. Using technological EC or CO_2 abatement (CA) measures in a bottom-up approach is one common method to develop ECCC or CO_2 abatement cost curves (CACC) (Wächter, 2013). For the production of cement, ECCCs and CACCs have been developed for China (Hasanbeigi et al., 2013b), India (Morrow et al., 2013), Thailand (Hasanbeigi et al., 2010a,b), USA (Sathaye et al., 2010) and on a global level for GHG abatements of 21 selected world regions (McKinsey, 2009). Detailed knowledge of available and prospective EC measures is needed for the development of cost curves. Madlool et al. (2013) reviews previous studies on EC and CA technologies applicable to the cement industry. Benhelal et al. (2013) provides a good overview of CA potentials of recent studies. We add three selected recent case studies to these two reviews: First, Feiz et al. (2014) researched with the cooperation of the company CEMEX (see Table 2) ways to improve the CO_2 performance of cement and present a framework for assessing CA measures including corresponding results for CEMEX. Second, Castañón et al. (2014) performed a case study at a cement plant in Spain with the aim to achieve ECs and CAs via optimisation of the production process. Third, Xi et al. (2013) quantified the co-benefits and abatement costs for 18 CA measures.

The aim of this paper is to determine the cost-effective EC potential for the production of cement in Germany with the help of ECCCs and to investigate its sensitivity and its impact towards energy-related production costs. Therefore, we identify 21 EC measures and apply them to German cement plants individually to derive EC potentials. We use a plant-specific bottom-up approach which is explained in Section 2. The measure-specific electricity, fossil fuel and CO_2 conservation and abatement potentials are displayed in ECCCs and CACCs in Section 3. Subsequently, we perform a sensitivity analysis of the cost-effective EC and CA potentials as well as the energy-related production costs in the period 2013–2035 with varying interest rates, electricity and CO_2 prices.

2. Method

2.1. The process and facility system boundaries

The definition of the system boundary has an important impact on the results. Comparison of studies addressing energy efficiency in the iron and steel industry (Siitonen et al., 2010) and in the aluminium industry (Liu and Müller, 2012) unveiled significant differing results regarding energy- and CO_2-equivalent intensities which can be, to some extent, explained by the use of different system boundaries. We therefore define our system boundaries in this section (see Fig. 1).

The smallest boundary is the process boundary. It covers the inputs and outputs of the respective process. The process level is

Table 1
Comparison of our number and capacity of plants for clinker production in Germany in 2012 (IER, see also Table 2) with the numbers of the German cement association (VDZ, 2013).

Type	Number		Daily capacity [t/d]	
	VDZ	IER	VDZ	IER
Kilns with cyclone preheaters	39	38	100,460	89,500
Kiln with grate preheater	6	6	5050	7050
Total	45	44	105,510	96,550
			Average daily capacity [t/d]	
Kilns with cyclone preheaters			2355	2355
Kiln with grate preheater			917	1175