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A critical analysis of energy efficiency improvement potentials in Taiwan's cement industry

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HIGHLIGHTS

- We analyze energy efficiency improvement potentials in Taiwan's cement industry.
- Eighteen process-specific technologies are analyzed using a bottom-up model.
- Our model systematically reflects the diffusion of technologies over time.
- We find energy-saving potentials of 25% for electricity and 9% for fuels in 2035.
- 91% of the energy-saving potentials can be realized cost-effectively.

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ABSTRACT

The cement industry is the second most energy-intensive sector in Taiwan, which underlines the need to understand its potential for energy efficiency improvement. A bottom-up model-based assessment is utilized to conduct a scenario analysis of energy saving opportunities up to the year 2035. The analysis is supported by detailed expert interviews in all cement plants of Taiwan. The simulation results reveal that by 2035, eighteen energy efficient technologies could result in 25% savings for electricity and 9% savings for fuels under the technical diffusion scenario. This potential totally amounts to about 5000 TJ/year, of which 91% can be implemented cost-effectively assuming a discount rate of 10%. Policy makers should support a fast diffusion of these technologies. Additionally, policy makers can tap further saving potentials. First, by decreasing the clinker share, which is currently regulated to a minimum of 95%. Second, by extending the prohibition to build new cement plants by allowing for replacement of existing capacity with new innovative plants in the coming years. Third, by supporting the use of alternative fuels, which is currently still a niche in Taiwan.

1. Introduction

Global warming and climate change are largely due to greenhouse gas (GHG) emissions associated with the use of energy. The industrial sector accounted for 28.3% of global final energy consumption and 38.5% of CO_2 emissions in 2012 (IEA, 2014). The non-metallic minerals industry is the third-largest industrial energy user, accounting for nearly 12% of global industrial energy use, most of which can be attributed to the cement industry. In 2012, the cement industry consumed approximately 8.5% of total industrial energy consumption and contributed 34% of the industrial direct CO_2 emissions (IEA, 2015).

In 2014, the total cement production in Taiwan was 14.6 million tons, which accounts for 0.35% of the global cement output. Most of the energy used in the manufacturing of cement is derived from coal, electricity, and petroleum products. According to the Energy Balance Sheets (BOE, 2015), the total energy used in the Taiwanese cement industry amounted to 56,900 TJ in 2014, which accounted for 1.8% of total final energy consumption and 3.5% of the total energy consumption of the industrial sector. The cement industry represents one of the most energy-intensive sectors in Taiwan. The

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energy intensity of the non-metallic mineral industry was estimated at 0.88 TJ/million NTD[1] in 2013, second only to the petrochemical sector among all energy-intensive industries. Improving energy efficiency in the cement industry could have a tremendous effect on efforts to reduce energy consumption and mitigate CO_2 emissions. Thus, the objective of this study was to estimate future energy efficiency improvement (EEI) potentials based on current technological practices and possible technology options for Taiwan's cement industry.

A bottom-up model was adopted for scenario analysis related to the availability of energy saving opportunities over the medium- and long-term (i.e., until 2035). We conducted a comprehensive review of the literature as well as interviews with experts on energy efficient technologies (EETs) and their applications in production lines to calibrate the model. We assessed eighteen process-specific EETs, with the energy saving potentials for electricity and fuels estimated under a variety of technology diffusion scenarios.

The remainder of this paper is organized as follows. Section 2 begins with a review of the relevant literature. Section 3 introduces the cement manufacturing process as well as the current status of the cement industry in Taiwan. Section 4 outlines the structure of the model and Section 5 lists our data sources. Section 6 presents our simulation results and the final two sections respectively provide a discussion of the results and our conclusions.

2. Literature review

The importance of energy conservation and efforts to reduce CO_2 emissions have led many researchers to estimate EEI potentials using top-down or bottom-up methodologies. A top-down approach begins with forecasted energy consumption disaggregated by end-use and estimates the percentage savings that EETs could realize during the specified period. A bottom-up approach begins by estimating the number of separate energy-saving implementations that could be deployed over a specified period, and then aggregates the savings of all such EETs.

A bottom-up method means that the energy savings achieved using one EET is added to the energy savings achieved using other EETs. The main advantage of the bottom-up method (as compared to the top-down method) is the fact that it allows for the direct monitoring of energy savings attributable to specific EETs. Thus, this approach enhances the accuracy of estimation and enables the establishment of benchmarks and effective program control.[2] It can also facilitate improvements in the design and implementation of EEI and shine light on how and why particular results are achieved (EMEEES website). Therefore, this study applied a process-specific bottom-up model for the analysis of EEI potential in the cement industry in Taiwan.

Some of previous bottom-up studies estimated energy-saving potentials based on assessments using the best available technology (BAT) or best practice technology (BPT). In other words, energy-saving potential was estimated under the assumption that BAT or BPT were applied to the industrial processes. This approach has been applied in a variety of industries for the estimation of EEI potentials, such as the petrochemical industry (Neelis et al., 2007; Saygin and Patel, 2009; Saygin et al., 2011a), the cement industry (Xu et al., 2012; Xu et al., 2014), iron and steel (Flues et al., 2015), plastics (Worrell et al., 1994), paper and board (De Beer et al., 1998) and the industrial sector overall (Lu et al., 2013; UNIDO, 2010; Saygin et al., 2011b). However, these studies based on the BAT approach did not investigate the effects of technology diffusion on energy-saving potential. In other words, they did not consider developments over time and could therefore draw no conclusions related to the timeframe required for the unfolding of the potentials. Our study provides a consistent and systematic reflection of the diffusion of technologies over time, which provides important insight into the degree of maturity of the various technologies. Its results therefore are more applicable to policy decision-making.

On the other hand, some bottom-up models have explicitly taken the influence of technology diffusion into consideration (Fleiter et al., 2012; Karali et al., 2014; Li et al., 2014; Wen et al., 2015; Xu et al., 2016). New technologies change the technical system over time, resulting in changing energy demand. The advantage of these studies is the transparency of the underlying technology development, which ensures a realistic development path. In these models, some important parameters (e.g. production output) should be forecasted exogenously prior to model simulation. These exogenous parameters are usually obtained through statistical methods (e.g. econometric or time series models). However, statistical methods based on historical data are unable to catch the external factors or changes in a dynamic environment, and may lack fidelity. Thus, a significant difference between previous bottom-up models and our works is that the previous work merely forecasted exogenous parameters through statistical methods, while our study applies Bayesian integration to combine statistical methods with expert opinions in order to obtain a more realistic estimation of exogenous parameters.

Several studies on the cement industry in Taiwan have been conducted over the past decade; however, they differ in their focus and the dimensions they address. These include models for the forecasting of demand for cement (Wu and Chen, 2009), the status of energy conservation (Su et al., 2013), the forces driving CO_2 emissions (Huang and Wu, 2013), the factors affecting changes in cement industry's profit (Liu, 2006), the establishment of GHG Protocol calculation tools (Su et al., 2005) and energy efficiency benchmarking (Chan et al., 2014). Few studies have evaluated long-term EEI potentials in the cement industry, particularly with regard to the assessment of process-specific technology. Lu et al. (2013) applied the BAT approach to the assessment of energy-saving potentials; however, they disregarded the applicability of technologies in individual cement plants. This study fills this gap in the literature by using a process-specific bottom-up model for the analysis of long-term EEI potential in the cement industry of Taiwan.

3. Overview of the cement manufacturing process and industry status in Taiwan

3.1. Cement manufacturing processes

The cement-making process can be divided into three major stages: raw material preparation, clinker production, and cement grinding (Su et al., 2013). The first stage is mining, grinding and homogenization of raw materials. Then, the calcination of the raw materials takes place in the kiln to obtain calcium oxide ($CaCO_3 \rightarrow CaO + CO_2$), which together with silica, alumina and ferrous oxide forms clinker. Finally, the clinker is ground together with gypsum and other additives to produce the cement (IEA, 2009).

3.2. Production and consumption

According to the Taiwan Cement Industry Review 2015 (Taiwan

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[1] NTD stands for New Taiwan Dollar; 1 USD is approximately equivalent to 30 NTD.

[2] However, some weaknesses associated with use of the bottom-up approach should be acknowledged. A potential drawback of bottom-up evaluation is the potentially high costs of data collection, if a high level of accuracy is deemed necessary.