



Energy efficiency improvement potentials for the cement industry in Ethiopia



Gudise Tesema^a, Ernst Worrell^{b,*}

^a The Energy and Resource Institute, Africa Programme, Horn of Africa Regional Environmental Centre and Network, Addis Ababa University, College of Natural Sciences Graduate Programme Building, 80773, Addis Ababa, Ethiopia

^b Copernicus Institute of Sustainable Development, Utrecht University, Heidelberglaan 2, 3584, CS, Utrecht, The Netherlands

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ABSTRACT

The cement sector is one of the fast growing economic sectors in Ethiopia. In 2010, it consumed 7 PJ of primary energy. We evaluate the potential for energy savings and CO₂ emission reductions. We start by benchmarking the energy performance of 8 operating plants in 2010, and 12 plants under construction. The benchmarking shows that the energy intensity of local cement facilities is high, when compared to the international best practice, indicating a significant potential for energy efficiency improvement. The average electricity intensity and fuel intensity of the operating plants is 34% and 36% higher. For plants under construction, electricity use is 36% and fuel use 27% higher. We identified 26 energy efficiency measures. By constructing energy conservation supply curves, the energy-efficiency improvement potential is assessed. For the 8 operating plants in 2010, the cost-effective energy savings equal 11 GWh electricity and 1.2 PJ fuel, resulting in 0.1 Mt CO₂ emissions reduction. For the 20 cement plants expected to be in operation by 2020, the cost-effective energy saving potentials is 159 GWh for electricity and 7.2 PJ for fuel, reducing CO₂ emissions by about 0.6 Mt. We discuss key barriers and recommendations to realize energy savings.

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1. Introduction

Cement manufacture is a highly energy-intensive process and total energy consumption of the global cement industry is estimated at 2% of global primary energy use. The production of cement contributes to the emission of CO₂ through the combustion of fossil fuels, as well as through the decarbonisation of limestone, and roughly represents about 5% of anthropogenic global CO₂ emissions [1,2]. The energy costs are a significant part of the total production costs, typically 20–40% of operational costs [1]. The energy efficiency of cement making has direct impact on overall energy consumption, CO₂ emissions, and energy costs, making it the primary strategy to reduce the environmental impact of the globally second largest industrial emission source. Many papers have studied the potentials to reduce energy use and emissions in the cement industry for a number of key producing areas and regions (e.g. China, India, USA, Germany and Europe). For example, energy efficiency potential studies were conducted for the Thai

cement industry [3], the cement industry in Shandong (China) [4,5], for the European [6], US [7], the German cement industry [8]. As the economy develops in Africa and other less-developed countries, cement demand in those countries is rapidly increasing [9]. The newly emerging cement industry offers opportunities to cost-effectively reduce energy use and CO₂ emissions, while meeting local needs for sustainable economic development.

The manufacturing of cement in Ethiopia has shown a steady growth since the country has become one of the fastest-growing African economies in recent years. Massive construction and housing developments, rehabilitation and the upgrade of Ethiopia's roads network and the *Grand Renaissance* hydropower dam construction are the major drives for cement demand [10]. The installed Cement production capacity in Ethiopia has increased at 9%/year between 2008 and 2010, and by 86%/year between 2010 and 2012 [11]. Based on a survey made for this study, Ethiopia's cement production in 2010 consumed around 7 PJ of primary energy and the overall CO₂ emission is estimated at 1.4 Mt CO₂. Cement making in Ethiopia is characterized by high energy costs, exceeding 50% of overall operational costs. As a consequence of rapid growth, energy consumption and emissions are expected to

* Corresponding author. Tel.: +31 30 253 6550

E-mail address: e.worrell@uu.nl (E. Worrell).

Abbreviations

BEST-Cement Benchmarking and Energy Saving Tool For Cement

CAC The Cement Association of Canada

CCE Cost of Conserved Electricity And/or Energy

CCIDI Chemical and Construction Industry Development Institute

HFO Heavy Fuel Oil

CDM Clean Development Mechanism

CO₂ Carbon Dioxide

CSC Conservation Supply Curves

EEl Energy Efficiency Index

EEMS Energy Efficiency Technologies/Measures

ETB Ethiopian Birr

GHG Green House Gases

GEF Grid Emission Factor

GTP Growth and Transformation Plan

IEA International Energy Agency

IPCC Intergovernmental Panel on Climate Change

LHV Lower Heating Value

MBPs Energy Management Best Practices

MOI Ministry of Industry

Mt Million Metric Tons

NSP New Suspension Preheater And Precalciner

OPC Ordinary Portland Cement

PM Particulate Matter

PPC Portland Pozzolana Cement

SI Standard International Units

TBPs Technical Best Practices

TPD Ton per day

VSK Vertical Shaft Kiln

increase significantly in coming years. Part of the production growth is met by imported obsolete technology (i.e. vertical shaft kiln), resulting not only in high energy use and operating costs, but also in low quality products.

The goal of this study is to identify specific EEMs (energy efficiency technology options/measures) and evaluate the potential and economics of energy savings, CO₂ emission reduction for the rapidly developing cement industry in Ethiopia. This helps to develop policy recommendations. Currently, Ethiopian institutions have limited data collection and acquisition capacities and, hence, there are no established production and energy statistics. The study builds on empirical data that was collected from 20 individual facilities, either in operation or under construction. In 2010, 8 cement facilities were in operation, while another 12 facilities were under construction or in planning. Combined, these 20 plants are expected to provide 100% of the cement produced in Ethiopia by the end of 2020. The analysis is based on annual production and energy consumption information of the facilities considering 2010 as a base year and 2020 as a target year. In this study, we determined the energy performance of the Ethiopian cement industry, by benchmarking the 20 facilities. The benchmarking results were also used to estimate the potential for energy efficiency improvement and cost saving opportunities, through determining the potential implementation rate of energy efficient technologies. The economics are analysed by ordering the individual measures in an energy conservation supply curve. Knowledge on energy saving technologies and measures among the Ethiopian cement facilities is quite limited. The Ethiopian government developed the Climate-Resilient Green Economy Strategy that obliges GHG (greenhouse gas) emission reductions in industry, transport, agriculture, power generation and buildings [12]. Nevertheless, there is no sector-specific target or policy to support or enforce the reduction of GHG emissions. Therefore, this study contributes to guiding policy makers to design better sector-specific energy efficiency policy programmes.

We start with a brief literature review, followed by a short introduction of the cement sector in Ethiopia. Next the methodology for the study is presented including a description of data collection efforts and assumptions, the benchmarking method, and determining an energy conservation supply curve to estimate the cost-effectiveness and technical potentials of efficiency improvements and CO₂ emission reduction. Following this, key findings are discussed and the paper concludes by providing firm and government level policy recommendations to help realizing energy savings.

2. Literature review

Various studies have analysed the energy efficiency of cement making and available EEMs for the cement industry. Energy benchmarking can provide valuable insights regarding energy efficiency potentials of cement industries. Based on cement production in 2007, Saygin et al. analysed the energy efficiency performance of 2000 large cement kiln plants [13]. Cement production and energy information is collected from statistics and various studies. Benchmarking is used to compare the performance of individual cement plants with the most energy efficient cement plant. The result is shown on a benchmark curve in which the energy use of individual plants is plotted from the most efficient to the least efficient plant, as a function of cumulative clinker or cement production. It demonstrates the value of benchmarking as a basis for estimating improvement potentials and provides valuable information on the global cement industry's energy use. Using benchmarking, researchers analysed energy efficiency of 15 Portland cement producing plants in Canada. The cement plants are members of the CAC (Cement Association of Canada) and accounted for 98% of the national cement production in 2007. Survey instruments were developed to collect production and energy information of the plants. Then energy efficiency performances of the cement plants were evaluated against a best-practices facility. The study also analysed existing energy MBP (management practices) and the implementation of TBPs (technical best practices) in production processes, systems, activities and equipment that can contribute to improvements in plant energy efficiency. The results from the MBP and TBP evaluations were integrated with the results of energy efficiency benchmarking and helped to develop and implement a comprehensive action plan to improve energy performance in the Canadian cement sector [14].

Several papers have studied the potentials of reducing energy use and emissions in cement plants for India [15], Europe [16], or the U.S. [7]. Worrell et al. [7] study the historical energy use and energy intensity trends of the US cement industry between 1970 and 1999, and then estimate the 1999 U.S. baseline energy consumption by cement process. The study identifies EEMs and estimated energy savings, investment costs, and operation and maintenance costs for each of the measures. Another study identified energy savings potentials for the 16 cement plants in Shandong province, China [4]. The plants energy use data was collected and used to benchmark the energy efficiency of individual plants to both domestic (Chinese) and international best practice using the Benchmarking and Energy Saving Tool for Cement (BEST-Cement).

32 EEMs suitable for the 16 Chinese cement plants were identified and an energy conservation supply curve was developed to evaluate the potential for energy efficiency for the year 2008.

3. Overview of The Ethiopian cement industry

In 2012, there were 25 cement producing establishments in Ethiopia, consisting of facilities that produce clinker only, integrated clinker and cement plants, or stand-alone grinding plants that process purchased clinker. This paper focuses on the 20 key clinker and cement plants. OPC (Ordinary portland cement) and PPC (portland pozzolans cement) are the only hydraulic cement types that are produced in Ethiopia. In 2010, 8 cement plants operated in Ethiopia, while 12 cement facilities were under construction. The new plants are expected to become operational during the period 2012–2016. Based on the survey, the actual 2010 cement and clinker production was estimated at 2.0 Mt and 1.7 Mt, resulting in a clinker-cement-ratio (expressed as clinker production divided by cement production) of 0.85.

In the same year, one third of the local cement demand is met by imported cement due to local supply shortages [17]. According to MOI (2010), local demand is expected to be met by local capacity and cement import was banned by 2012. In the GTP (*Growth and transformation plan*) of the government, the cement production is expected to grow further. By 2015, the total national cement production capacity is expected to be 27 Mt and 60% of produced cement is planned to be exported to the region. This plan can be considered as ambitious. In our survey, only 16 Mt installed production capacity is likely to be installed and operating by 2015 and it is unlikely that the remaining 11 Mt is realized. Cement is a heavy bulk product and the transport costs would be relatively high for a land-locked country like Ethiopia, limiting export over long distances. The Chemical and Construction Input Industry Development Institute estimated that Ethiopia in the 2012/2013 fiscal year earned 9.0 million US\$ from export of cement [18]. Currently only three cement plants export cement by truck to neighbouring countries, i.e. Somalia, Djibouti, Kenya and south Sudan.

Clinker is the key input, and most energy intensive production step, in cement making. In Ethiopia, two clinker kiln types are used; i.e. VSKs (Vertical shaft kilns) and rotary Kilns. Most of the rotary kiln technologies are adopted from Germany and Denmark, and the VSKs mainly from China and India. In 2010, nearly 78% of Ethiopia's cement was produced in three rotary kiln cement plants, and the remainder from recently established VSK. Of the 8 operating cement plants in 2010, only three are rotary kilns (one with a NSP (new suspension pre-heater and pre-calciner) kiln, and the other two having multi-stage pre-heaters). The number of VSK-plants is higher than that of the rotary kiln plants, but represents only 19% of total clinker production capacity in the years 2008–2012. Table 1 shows the cement and clinker production by technology type. The (2012) clinker making capacity of rotary kiln plants ranged from 860 to 5600 t/d and that of VSK plants ranged from 100 to 1000 t/d.

Fig. 1 shows the rapid increase in cement production from VSKs in recent years, from 0 Mt in 2006 to 0.56 Mt in 2010. This can be

explained by the GTP plan that allows for the installation of small scale plants (VSKs) as a short term intervention to tackle local cement supply constraints [19]. However, VSK is an obsolete technology and no longer used in Europe for reasons of high fuel consumption, low productivity and an inconsistent cement quality [20]. The Chinese government also makes an aggressive policy to phase out VSK during the five year period 2011–2016. Recently, the phase out of VSK capacity exceeded the policy target and in turn, production from rotary kilns grew rapidly [5]. In other words, current policy in Ethiopia allows the import of technology that is considered obsolete in the exporting country itself. This may pose risks for the economics and energy use of the future Ethiopian cement industry. To reduce these risks, a policy revision regarding new establishments may be needed to ban new (and existing) VSKs in Ethiopia.

The rapid growth of production by rotary kilns over the years 2010 and 2011 is due to the start-up of the largest cement plant in Ethiopia, which accounted for 23% of national capacity. Table 2 also shows that the kiln technology of plants under construction in the period 2012–2016 is dominated by rotary kilns. Due to the lack of energy statistics on the Ethiopian cement industry, historical energy consumption data cannot be presented. Based on a survey of cement plants in Ethiopia in 2010, it is estimated that the cement sector consumed 7046 TJ of primary energy. All cement plants depend on foreign fuel supply and on the national grid for electricity. HFO (Heavy fuel oil), petroleum coke and coal are the major kiln fuels with shares of 41%, 26% and 23% of the 2010 primary energy consumption, respectively. Biomass (solid wood) fuel has a share of less than 1%. Electricity accounts for 10% of the total primary energy. The notion of using alternative/waste-derived fuels is introduced to the sector and some rotary kiln plants are conducting tests [21]. In 2010, the cement sector spent about US\$89.05 Million to purchase energy; around US\$5.5 Million for electricity and US\$83.5 Million for fuels. The cost of electricity is minimal because power supply in Ethiopia is regulated by the government and heavily subsidized. It is estimated that 54% of power production costs are covered by subsidies [22].

The use of energy in the cement manufacturing process produces large amounts of CO₂, SO₂ and particulate matter (PM) emissions. The 2010 CO₂ emissions from fuel, electricity use and process emissions (calcination of limestone) are estimated at 513 kt CO₂, 1.1 kt CO₂, 853 kt CO₂, resulting in an annual emission of 1.4 Mt CO₂ (2010).

4. Methodology

As national data on energy use in the cement industry is very limited, we collected this information through a survey of existing plants and plants under construction (step 1). The collected data is

Table 1
Installed cement and clinker production capacity in Ethiopia, 2008–2012 [4].

	2008	2009	2010	2011	2012
Cement production (Mt)	2.1	2.3	2.6	4.8	9.2
Vertical Shaft kilns (Mt)	0.3	0.3	0.6	1.3	1.5
Rotary (NSP + other) kilns (Mt)	1.8	2.0	2.0	3.4	7.7
Clinker Production (Mt)			2.1	3.8	6.9
Clinker-Cement Ratio			0.8	0.8	0.7

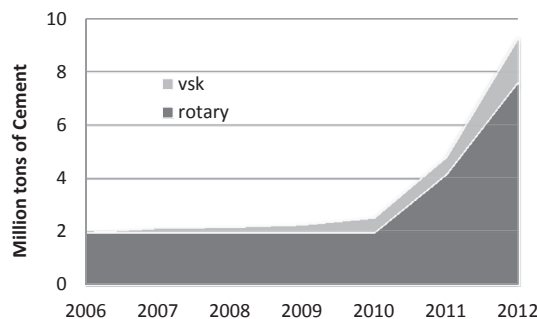


Fig. 1. Installed cement production capacity in Ethiopia by major kiln type, 2006–2012 (Expressed in Mt per year) [11].

Table 2

Cement plants in Ethiopia: production capacity and kiln technology (survey results).

No	Plant Name	Year of Operation	Address	Clinker capacity t/d	Kiln technology
Operating plants (2010)					
1	Muger Cement Enterprise	1984	Oromia	2000	5 stage pre-heater (3-stage cyclone pre-heaters and shaft pre-heater) and planetary cooler rotary kiln
2	Mesebo Cement Factory	2001	Mekelle	2330	5 stage pre-heater, pre-calciner& grate cooler rotary kiln
3	Huan Shang P.L.C	2010	Oromia	860	mechanized VSK
4	National Cement S.C	old plant 1936/renovated 2005	Dire Dawa	960	5 stage pre-heater rotary kiln
5	Abyssinia Cement P.L.C	2007	Oromia	288	mechanized VSK
6	Jema Cement P.L.C	2008	Oromia	100	ordinary VSK
7	DebresinaBussiness industries P.L.C	2009	Oromia	288	mechanized VSK
8	Dejen Mini Cement Plant	2007	Amhara	288	mechanized VSK
Plants under construction (2012–2016)					
9	Mugher Cement Expansion project	2012	Oromia	3000	6 stage pre-heater, pre-calciner kiln
10	Messobo Cement Expansion Project	2011	Mekelle	3300	6 stage pre-heater, pre-calciner& grate cooler
11	National Cement S.C (new)	2014	Dire Dawa	2880	5 stage pre-heater
12	Derbadashen Cement Plant	2011	Oromia	288	mechanized VSK
13	Jema Cement Plc.	2014	Oromia	100	mechanized VSK
14	Derba MIDROC Main Cement Plant Project	2012	Oromia	5600	5 stage pre-heater, pre-calciner& grate cooler
15	Dangote Industries P.L.C	2015	Oromia	4800	6 stage pre-heater, pre-calciner& grate cooler
16	Habesha cement sh.company	2016	Oromia	3000	5 stage pre-heater, pre-calciner& grate cooler
17	Ethio-Cement Plc.	2014	Oromia	1340	5 stage pre-heater, pre-calciner& grate cooler
18	East Cement Plc.	2011	Oromia	1675	5 stage pre-heater rotary kiln
19	Pioneer Cement Plc.	2012	DereDawa	1000	mechanized VSK
20	EnchiniBedroc Cement Plc.	2012	Oromia	667	mechanized VSK

used to benchmark the energy efficiency of the individual plants (step 2). Using a menu of energy efficient technologies, the survey results are used to develop an energy conservation supply curve to evaluate the potential for energy efficiency improvement for 2010 and 2020 (step 3). The results are used to estimate the potentials for energy efficiency improvement and CO₂ emission reduction, and to come to policy recommendations.

4.1. Data collection, conversion factors and assumptions

Detailed data collection forms were developed and dispatched to the 25 cement plants of Ethiopia. These forms requested specific information on 1) technology configuration (VSK vs. rotary kilns); 2) annual raw material and additive consumption; 3) electricity and fuel consumption; 4) annual cost of energy and maintenance; 5) installed clinker and cement-making capacity; 6) actual clinker and cement production; and 7) detailed plant process and equipment information. For cement plants planned or under construction during the 2010–2016-period, planned production capacity, technology configuration and prospective energy use data were requested.

All cement plants in Ethiopia are connected to the national power grid for electricity supply. The national grid relies almost completely on hydropower. Using the IEA definitions the average national efficiency is estimated at 98% and a conversion factor of 1.02 is used to convert electricity to primary energy, including transmission and distribution losses [23,24]. For fuels the LHV (Lower Heating Value) is used to convert the fuels (i.e. heavy fuel oil, petroleum coke, coal and biomass) to energy values. Energy use and all other values are expressed in SI units (Standard International), e.g. metric tons, joules. The conversion factors to calculate CO₂ emissions from energy consumption are taken from the 2006 Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas Inventories [25]. The combined marginal emission factor of Ethiopia's grid electricity is calculated according to the UNFCCC methodological tool used to calculate the emission factor for an electrical system and assumed to be 0.006 tCO₂/MWh (0.006 kg CO₂/kWh) [24]. Costs are reported as U.S. dollars (US\$).

4.2. Energy benchmarking

In this analysis, the energy consumption of a cement facility is compared with an identical hypothetical cement facility that uses commercially-available “best practice” technologies in the major process steps; i.e. raw material preparation, clinker making, and finish grinding. The analysis is done using the BEST-Cement benchmarking and Energy Saving Tool [26]. The tool enables to compare cement plants with international “best practice” in terms of energy efficiency both at the plant level and process level. Some of the technical parameters and factors (e.g. grid electricity CO₂ emission factors, currency conversions and calorific values of fuels) were adapted to make the tool usable for the situation in Ethiopia. The benchmarking analysis is done for base year cement facilities (2010), as well as for new installations under construction and expected to start up in the period 2010–2016. The energy efficiency benchmarking tool calculates energy performance indicators as total energy intensity (expressed in the BEST-tool in coal equivalent kgce/t cement); fuel intensity (kgce/t cement or clinker); electricity intensity (kWh/t cement); and an EEI (energy efficiency index). A conversion factor of 0.0293 of GJ/kgce is used to convert coal equivalent (commonly used in china) to GJ. The EEI allows a meaningful comparison between plants with significant structural differences (e.g. wet kiln and dry kiln processes). EEI is a measurement of the total production energy intensity of a cement facility compared to the benchmark energy intensity (see Eq. (1)):

$$EEI = 100 * \frac{\sum_{i=1}^n P_i * EI_i}{\sum_{i=1}^n P_i * EI_{i,BP}} = 100 * \frac{E_{tot}}{\sum_{i=1}^n P_i * EI_{i,BP}} \quad (1)$$

Where:

EEI = energy efficiency index

n = number of products to be aggregated

EI_i = actual energy intensity for product i

EI_{i,BP} = best practice energy intensity for product i

P_i = production quantity for product i.

E_{tot} = total actual energy consumption for all products

By definition (see Eq. (1)), a plant that uses the benchmark or reference technology will have an EEI of 100. In practice, cement plants will have an EEI greater than 100. The gap between actual energy intensity and the reference level energy consumption can be viewed as the technical energy efficiency potential of a plant.

4.3. Construction of conservation supply curves

A CSCs (conservation supply curve) is developed to evaluate the economics and potential for energy efficiency improvements and CO₂ emission reduction in cement plants of Ethiopia. In the 1980's, CSCs were developed by energy analysts to rank energy conservation investments alongside investments in energy supply to assess the least cost approach to meeting energy service needs. The curve shows the energy conservation potential as a function of the marginal cost of conserved energy.

To construct the CSC, energy conservation technologies and measures can be ranked by calculating the CCE (Cost of Conserved Energy), which accounts for the costs (and benefits) associated with implementing and maintaining an EEM (energy efficiency measure), and the energy savings [27,1]. All costs and benefits are annualized (see Eq. (2)).

The CCE of a particular measure is calculated as:

$$CCE = \frac{\text{Annualized capital cost} + \text{annual change in O\&M Costs}}{\text{Annual Energy savings}} \quad (2)$$

The annualized capital cost is a function of the discount rate (d) and life time (n) of the technology. It is calculated according to Eq. (3):

$$\text{Annualized capital cost} = \text{Capital cost} * \frac{d}{1 - (1 + d)^{-n}} \quad (3)$$

To calculate the annualized capital costs it is required to define a discount rate and a life time period. The technical life time depends on the characteristics of the technologies. The discount rate is supposed to reflect the (risk) preference of the investor and the cost of capital. Discount rates vary strongly among the different studies assessing the costs and potentials of energy conservation investments [27]. It ranges from low discount rates (4%–8%), also called social discount rates, to high discount rates up to 30%, also called private or real discount rates. For this analysis, a 30% real discount rate is used, also reflecting the existing inflation rates in Ethiopia.

After calculating the CCE for all EEMs, the measures were ranked in ascending order of their CCE whose shapes looks like a ladder. In CSCs, an energy price line is determined that reflects the current cost of energy. All measures that fall below the energy price line are considered "cost-effective". On the curve, the width of each measure (plotted on the horizontal axis) represents the energy saved by that measure. The height (plotted on the vertical axis) shows the measure's CCE per unit energy saved. A CSC gives a snap shot of possible savings. Actual energy savings are also dependent on opportunity costs related to implementation, plant specific conditions such as raw material quality (e.g. moisture content of raw materials and hardness of the limestone), and future fuel mixes. Note that some EEMs also provide additional productivity and environmental benefits which are difficult and sometimes impossible to quantify economically. Including quantified estimates of other benefits could significantly reduce the CCE for the energy-efficiency measures [5,28,29].

Various studies over the past years have characterized and analysed the energy efficiency measures in the cement industry.

The studies identified over 70 energy-EEMs that are applicable to the cement sector. The EEMS are commercially available. Of the 70 EEMs, 26 EEMS are selected (see Table 3) that are applicable to the cement industry in Ethiopia based on the survey results and expert consultation. Potential implementation rates for the EEMs are based on the survey of the individual plants and production capacities.

5. Results and discussion

5.1. Energy benchmarking

Table 4 provides data on the average energy use of the various types of cement kilns found in Ethiopia in 2010, based on the detailed survey of this study. VSKs are more energy-intensive than rotary kilns. On average, 16% fuel savings and 4% electricity savings could be achieved if all clinker would be manufactured in rotary kilns instead of VSKs.

Benchmarking the energy efficiency of individual plants is based on data collected by the survey, and using the BEST Cement tool. In addition to the operating facilities, 12 cement plants were under construction. Prospective energy use and production capacity data was collected from these plants. By 2012, 7 new facilities had already started production and the other 5 were under construction. New projects or installations that could come online in the period 2015–2020 are not included in the analysis. Based on the interviews with cement plant representatives and survey results, certain assumptions were made for expected raw material consumption, production, and energy use:

- Average 75% capacity utilization (due to supply constraints and maintenance stops);
- Production of 20% of OPC and 80% PPC (based on historical production);
- For this analysis 1.7 t raw material to 1 t clinker (based on average of survey results);
- Primary energy mix is assumed to be 76% coal, 6% HFO, 5% pet coke, and 13% electricity (based on survey results);
- No captive electricity generation as all cement plants will use power from the national grid (2010 situation for operating plants and survey data).

New rotary kiln plants will increase cement production with 14% compared to 2010. The average clinker-to-cement ratio of new plants is expected to be 0.76 (see Table 5), which could be improved by using more additives.

The results from the best cement tool analysis shows that all operating cement facilities are relatively less efficient compared to the international best practice plant. Fig. 2 shows that all 8 plants (P_1 – P_8) score above 100, indicating none of them are considered to be at the international best practice level. The EEI of the 8 operating plants ranges from a low of 117 to a high of 186, indicating a large potential for energy efficiency improvement. The average electricity intensity and fuel intensity of cement facilities is higher than international best practice facilities by 34% and 36%, respectively. The average technical primary energy savings potential of these 8 plants is 36%.

Benchmarking the 12 new cement facilities (P_9 – P_{20}) to international best practice, demonstrates that the new plants have higher energy intensities (see Fig. 2). The EEI of the 12 new plants ranges from a low of 123 to a high of 162. The average electricity intensity and fuel intensity of the new cement facilities is higher than international best practice facilities by 36% and 27%, respectively. The average technical primary energy savings potential for

Table 3

Common fuel and electricity savings, capital costs and annual operation and maintenance (O&M) costs for selected energy-efficiency measures [4,26,33,42,47].

No	Energy-efficiency measures/Technologies	Capital cost (US\$/t output)	Annual additional O&M cost (US\$/t output)	Fuel savings (GJ/t output)	Electricity savings (kWh/t output)
Raw materials preparation					
t output = t raw material					
1	High-efficiency Classifiers/Separators (Dry Process)	2.20	0.00	—	3.25
2	Raw Meal Process Control for Vertical Mills (Dry process)	0.30	0.00	—	0.90
3	Use of Roller Mills (Dry Process)	5.50	0.00	—	5.00
4	Efficient Transport Systems for Raw Materials Preparation (Dry Process)	0.55	−0.10	—	1.00
5	Raw Meal Blending (Homogenizing) Systems (Dry Process)	1.80	0.01	0.01	0.73
Fuels preparation					
t output = t clinker					
6	New Efficient Coal Separator for Fuel Preparation	0.01	0.00	—	0.26
7	Roller Mills for Fuel Preparation	0.05	0.00	—	1.47
Clinker making					
t output = t clinker					
<i>Clinker Making – All Kilns</i>					
8	Improved Refractories for Clinker Making in All Kilns	0.25	0.00	0.26	0.00
9	Energy Management and Process Control Systems for Clinker Making in All Kilns	0.35	0.00	0.11	0.45
10	Adjustable Speed Drive for Kiln Fan for Clinker Making in All Kilns	0.23	0.00	0.00	6.10
<i>Clinker Making –Rotary Kilns</i>					
11	Optimize Heat Recovery/Upgrade Clinker Cooler for Clinker Making in Rotary Kilns	0.20	0.00	0.11	−2.00
12	Kiln Combustion System Improvements for Clinker Making in Rotary Kilns	1.00	0.00	0.18	0.00
13	Conversion to Reciprocating Grate Cooler for Clinker Making in Rotary Kilns	5.00	0.11	0.18	−4.00
14	Increasing Number of Pre-heater Stages in Rotary Kilns from 5 to 6 stage	2.79	0.00	0.11	−1.17
15	Efficient Kiln Drives for Clinker Making in Rotary Kilns	0.22	0.00	0.00	0.55
16	Installation or Upgrading of a Pre-heater to a Pre-heater/Pre-calciner Kiln for Clinker Making in Rotary Kilns	18.70	1.10	0.40	0.00
<i>Clinker Making –Vertical Shaft Kilns</i>					
17	Kiln Combustion System Improvements for Clinker Making in Vertical Shaft Kilns	1.00	0.00	0.18	0.00
18	Replacing Vertical Shaft Kilns with New Pre-heater/Pre-calciner Kilns	18.70	1.10	2.40	0.00
Finish/Cement grinding					
t output = t cement					
19	Vertical Roller Mill for Cement Grinding	7.86	0.00	0.00	16.9
20	High Pressure (Hydraulic) Roller Press for Cement Grinding	5.25	0.00	0.00	24.41
21	Improved grinding media (for ball mills)	1.10	0.00	0.00	4.00
22	High Efficiency Classifiers for Finish Grinding	0.33	0.00	0.00	4.58
Product & Feedstock changes					
t output = t cement					
23	Changing Product and Feedstock: Blended Cements	0.72	−0.04	1.19	−14.00
24	Changing Product and Feedstock: Use of Waste-Derived Fuels	1.65	−3.75	0.00	−1.35
25	Changing Product and Feedstock: Limestone Portland Cement	0.72	−0.04	0.21	3.00
Utility system measures					
t output = t cement					
26	Adjustable or Variable Speed Drives	1.41	0.00	0.00	9.15

these 12 new plants is 28%, compared to international best practices.

5.2. Energy efficiency improvement potentials

For the base year actual production of the surveyed 8 cement plants is used, while the results are also presented including the 12 new facilities under construction (for assumptions see section 5.1).

For the target period production at 75% capacity is considered for the 20 cement plants (new plants in the target period plus current production levels of the 8 plants operating in the base year). The CO₂ emission reduction potentials and the net annual cost savings are calculated based on the energy savings that can be attained by implementing the selected 26 EEMs. Due to the low carbon intensity of power generation in Ethiopia, electricity savings do not contribute significantly to the CO₂ emission reduction potential.

Table 4

Total energy cost, intensity and consumption by Kiln type In Ethiopia for 2010 (Own calculation based on survey results).

	Fuel intensity (GJ/t clinker)	Electricity intensity (kWh/t cement)	Fuel use (TJ)	Electricity use (GWh)	Final energy (TJ)	Primary energy (TJ)	Annual energy costs (10 ⁶ US\$)
Vertical Shaft Kiln – Ordinary	4.63	80	80	1	85	85	1
Vertical Shaft Kiln – Mechanical	4.62	100	1333	31	1445	1448	8
Rotary Kiln – Pre-heater	4.44	90	2618	66	2857	2861	44
Rotary Kiln – NSP 2000–4000 t/day	3.43	93	2337	86	2645	2652	36
Total			6368	184	7032	7046	89

Table 5

Expected production capacity of new plants in Ethiopia under construction and operation by 2015.

	Annual production
Cement production (Mt)	8.16
Vertical Shaft kilns (Mt)	0.65
Rotary (NSP + other) kilns (Mt)	7.51
Clinker Production (Mt)	6.22
Clinker-Cement Ratio	0.76

This is also the result of the low (subsidized) power prices. The UNFCCC tool that is used to calculate emission factors for hydro-dominated power systems in developing countries was revised in 2013. Based on the revision the grid carbon emission intensity for Ethiopia is calculated to be 0.1538 tCO₂/MWh [30]. However, in this study we still assume an average emission factor of 0.006 tCO₂/MWh, following IPCC guidelines as cement plants typically use baseload power (see also in the discussion section).

The result from the operating 8 plants shows that the cost-effective energy saving potentials is 11 GWh for electricity and 1.2 PJ for fuel. The CO₂ emissions reduction potential associated with cost-effective electricity and fuel is 66 tCO₂ and 0.1 Mt CO₂, respectively. The technical energy saving potential is 66 GWh for electricity and 1.3 PJ for fuel. The CO₂ emissions reduction potential associated with technical electricity and fuel is 0.3 kt CO₂ and 0.12 Mt CO₂, respectively.

Fig. 3 depicts the electricity CSC for the 20 cement plants for the year 2020. The cost-effective potential reflects those EEMs which have a CCE lower than the average electricity price in 2020 (US\$ 10/MWh). The cost-effective and technical electricity saving potentials are 159 GWh and 304 GWh respectively. The cost-effective electricity saving potentials accounts to 16% of the 2020 estimated electricity consumption based on survey results.

The CO₂ emission reduction potentials is estimated at 1.82 kt, of which 0.96 kt CO₂ is from cost-effective options. The implementation of the vertical roller mill for Cement Grinding (No.19 in Fig. 3) gives the highest technical saving potential, accounting for 33% of the overall electricity saving potential. Table 6 lists the electricity saving measures ranked by their cost of conserved

electricity (CCE), and gives associated CO₂ emissions reductions and net annual cost savings calculated based on an average electricity price of US\$ 10/MWh.

Fig. 4 shows the fuel-related CSC for the 20 cement plants for the year 2020. The cost-effective potential reflects those EEMs which have a CCE lower than the weighted average fuel price for cement plants in 2020 (US\$ 5/GJ). The cost-effective fuel savings potential is equal to the technical fuel savings potential and calculated to be 7151 TJ, or 24% of the estimated 2020 fuel consumption.

The CO₂ emission reduction potentials associated with the implementation of all identified fuel saving options is estimated to be 586 kt CO₂. Table 7 lists the fuel saving measures ranked by their cost of conserved energy, and provides associated CO₂ emissions reductions and net cost savings based on a weighted average fuel price of US\$ 5/GJ.

5.3. Discussion

In the year 2020, the cumulative energy saving potentials of 8 base year plants and 12 new cement plants differences are large. Also the CO₂ emission reduction potentials and the net annual cost savings varies significantly (see Table 8). This is mainly due to variation in production capacity and the degree of implementation of the selected 26 EEMs. Some of the newly constructed cement plants are equipped with modern rotary kilns with lower energy intensity than the base year plants. As explained in section 5.1, compared to international best practices, the technical primary energy savings potential of 8 existing plants equals 36% and 28% for the 12 new plants. Out of the 20 cement plants expected to be in operation by 2020, the share of cost-effective electricity saving potential is 35% for the 8 existing plants and 65% for the 12 new plants. The share of cost-effective fuel saving potential for 8 existing plants is 43% and 57% for the 12 new plants.

A sensitivity analysis is conducted for different discount rates of 10%, 20% and 25%, while keeping the other parameters constant (i.e. electricity and fuel prices, investment cost of the measures, and energy saving of the measures). It shows that lowering the discount rate from 30% to 10%, increases the cost-effective electricity saving potentials and the associated CO₂ emission reductions. Due to high

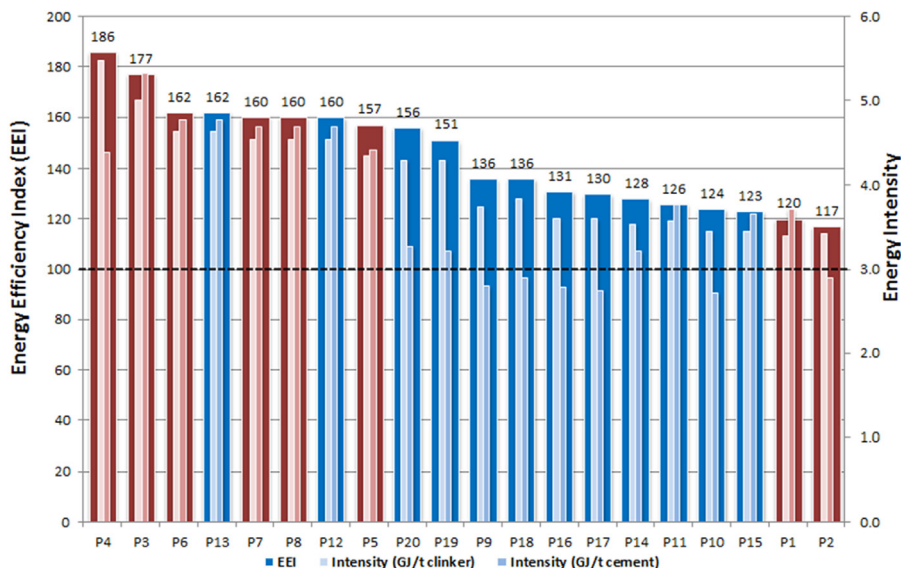


Fig. 2. International best practice comparison for 20 cement plants in Ethiopia, expressed as Energy Efficiency Index (EEI) (best practice = 100). Benchmarking results are based on primary energy consumption.

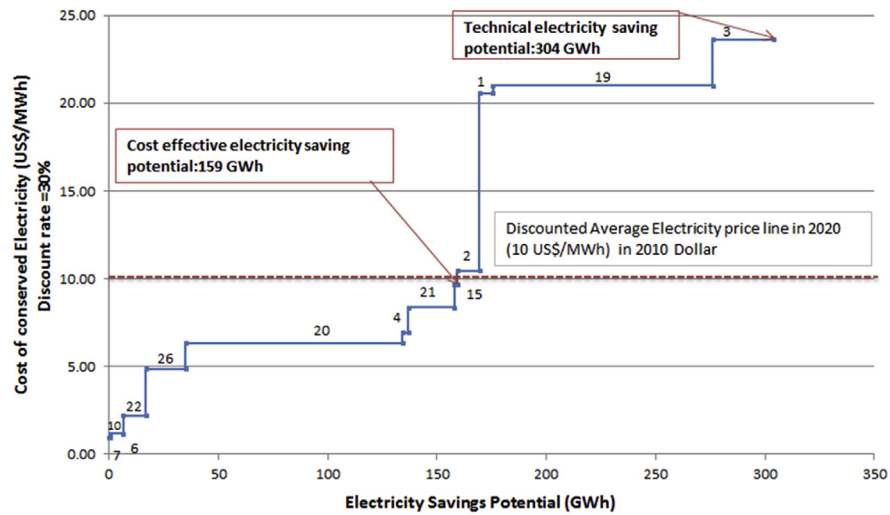


Fig. 3. Electricity conservation supply curve for 20 cement plants in Ethiopia in 2020, using a discount rate of 30% and expected 2020 electricity prices.

Table 6

Electricity efficiency measures ranked by the cost of conserved electricity (CCE), the CO₂ emission reduction and net cost savings for the Cement Plants in the year 2020.

Measures	Production at 75% capacity (Mt/year)	Electricity Savings (GWh)	Cost of conserved energy (CCE) (US\$/MWh)	CO ₂ emission reduction (t CO ₂)	Net annual cost saving (10 ³ US\$)	Application share of capacity (%)
7 Roller Mills for Fuel Preparation	7.82	1	0.9	4	2	6%
6 New Efficient Coal Separator for Fuel Preparation	7.82	0	1.2	1	0	5%
10 Adjustable Speed Drive for Kiln Fan for Clinker Making in All Kilns	7.82	6	1.2	35	14	12%
22 High Efficiency Classifiers for Finish Grinding	10.08	10	2.2	62	23	22%
26 Adjustable or Variable Speed Drives	10.08	18	4.9	110	37	19%
20 High Pressure (Hydraulic) Roller Press for Cement Grinding	10.08	99	6.3	595	193	40%
4 Efficient Transport Systems for Raw Materials Preparation	15.11	3	6.9	15	5	17%
21 Improved grinding media (for ball mills)	10.08	21	8.4	127	38	52%
15 Efficient Kiln Drives for Clinker Making in Rotary Kilns	7.82	1	9.7	8	2	31%
2 Raw Meal Process Control for Vertical Mills (Dry process)	15.11	10	10.5	61	17	73%
1 High-efficiency Classifiers/Separators	15.11	6	20.6	36	6	12%
19 Vertical Roller Mill for Cement Grinding	10.08	100	21.0	603	88	89%
3 Use of Roller Mills	15.11	28	23.6	166	19	36%

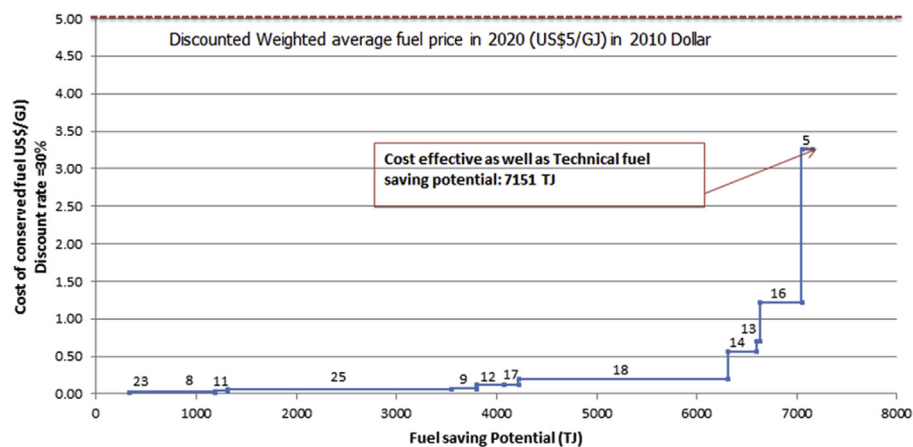


Fig. 4. Fuel conservation supply curve for 20 cement plants in Ethiopia in 2020. A discount rate of 30%, and expected fuel prices for 2020 are used.

Table 7Fuel efficiency measures ranked by cost of conserved fuel (CCF), the CO₂ emission reductions and net cost savings for the cement plants in the target year 2020.

EEM no	Measures	Production at 75% capacity (Mt/year)	Fuel savings (TJ)	Cost of conserved energy (CCE) (US\$/GJ)	CO ₂ emission reductions (kt CO ₂)	Annual net cost savings (10 ³ US\$)	Application Share (%)
23	Changing Product and Feedstock: Blended Cements	10.08	323	0.02	35	542	5%
8	Improved Refractories for Clinker Making in All Kilns	7.82	855	0.02	70	1429	42%
11	Optimize Heat Recovery/Upgrade Clinker Cooler	6.60	135	0.04	12	222	17%
25	for Clinker Making in Rotary Kilns						
25	Changing Product and Feedstock: Limestone Portland Cement	10.08	2237	0.06	174	3653	19%
9	Energy Management and Process Control Systems	7.82	241	0.07	20	391	28%
12	for Clinker Making in All Kilns						
12	Kiln Combustion System Improvements for Clinker Making in Rotary Kilns	7.82	282	0.12	23	444	20%
17	Kiln Combustion System Improvements for Clinker Making in Vertical Shaft Kilns	7.82	141	0.13	12	222	10%
18	Replacing Vertical Shaft Kilns with New Suspension	7.82	2095	0.20	172	3122	11%
14	Pre-heater/Pre-calciner Kilns						
14	Increasing Number of Pre-heater Stages in Rotary Kilns from 5 to 6 stages	7.82	285	0.57	24	320	34%
13	Conversion to Reciprocating Grate Cooler for Clinker Making in Rotary Kilns	7.82	36	0.71	3	35	3%
16	Installation or Upgrading of a Pre-heater to a	7.82	417	1.22	34	199	13%
	Pre-heater/Pre-calciner Kiln for Clinker Making in Rotary Kilns						
5	Raw Meal Blending (Homogenizing) Systems (Dry Process)	15.11	103	3.26	7	–162	54%

inflation rates and higher risks of investments in developing countries like Ethiopia, it is unlikely that cement plants will use low discount rates for their investment decision making. Note that cost-effective fuel savings will not change by changes in the discount rate in the range of 10–25%. The reason for this is that the total fuel saving potential in fuel CSC is by far cost-effective and changes in the discount rate in the range of 10–25% will not affect this.

Using higher grid emission factors significantly affects the economic and technical emission reduction potentials. Table 9 compares the CO₂ emission reduction potentials considering 0.006 tCO₂/MWh (2008) and 0.1538 tCO₂/MWh (2013) grid emission factors.

Various other factors may affect the 2020 energy saving potentials of the Ethiopian cement industry. Data for benchmarking and the baseline energy consumption are based on reported data by

the individual cement plants. Typical errors in energy use data for cement plants can be around 5–10%. Fuel and electricity price lines may vary from our assumed 2020 energy prices. Furthermore, most of the rotary kiln plants could shift from HFO to Pet coke or coal due to HFO price hikes. This will affect the primary energy mix estimated in section 5.1 of this study and the resulting CO₂ emission reductions. It is also noted that the actual capacity utilization could be greater or less than 75% of the installed cement capacity, resulting in different energy saving potentials.

6. Conclusion & recommendations

We analysed energy use of cement plants in Ethiopia operating in 2010 and new plants under construction using energy efficiency benchmarking. Data was based on a detailed survey of all operating

Table 8Electricity and fuel saving potentials, CO₂ emission reductions, and net annual savings for Ethiopian cement plants in 2020.

Electricity	Electricity savings (GWh)			CO ₂ emission reductions (kt CO ₂)			Annual net cost saving (1000 US\$)		
	8 plants	12 new plants	20 plants	8 plants	12 new plants	20 plants	8 plants	12 new plants	20 Plants
Cost-Effective	56	104	159	0.33	0.62	0.96	111	204	314
Technical	94	209	304	0.57	1.25	1.82	146	296	444
% share (Cost-Effective)	35%	65%	100%	35%	65%	100%	35%	65%	100%
% share (Technical)	31%	69%	100%	31%	69%	100%	33%	67%	100%
Fuel	Fuel savings (TJ)			CO ₂ emission reductions (kt CO ₂)			Net cost saving (10 ³ US\$)		
	8 plants	12 new plants	20 plants	8 plants	12 new plants	20 plants	8 plants	12 new plants	20 plants
Cost-Effective	3053	4097	7151	250	336	586	4403	5623	10,417
Technical	3053	4097	7151	250	336	586	4403	5623	10,417
% share	43%	57%	100%	43%	57%	100%	42%	54%	100%

Table 9Comparison of CO₂ emission reductions potentials at low and high grid emission intensities for Ethiopian cement plants in 2020.

Electricity	CO ₂ emission reductions (kt CO ₂)			CO ₂ emission reductions (kt CO ₂)		
	8 plants	12 new plants	20 plants	8 plants	12 new plants	20 plants
Cost-Effective	0.33	0.62	0.96	8.56	15.85	24.52
Technical	0.57	1.25	1.82	14.52	32.09	46.72
% share (Cost-Effective)	35%	65%	100%	35%	65%	100%
% share (Technical)	31%	69%	100%	31%	69%	100%

plants and those under construction. The results of the benchmarked and surveyed plants are used to make a robust economic assessment of the energy-efficiency potential in the Ethiopian cement industry. The overall benchmarking results show that the energy intensity of local cement facilities is high compared to international best practices. For the operating plants, the average electricity intensity is 34% higher and the fuel intensity 36% higher. Remarkably, this is not much lower for plants currently under construction. For these plants the potential improvements are 36% for electricity and 27% for fuel.

Adoption of EEMs will enable the Ethiopian cement facilities to reduce the identified energy efficiency performance gap. By constructing conservation supply curves for electricity and fuel, the energy-efficiency improvement potential is assessed economically. For 20 cement plants expected to be in operation by 2020, the cost-effective energy saving potentials is 159 GWh for electricity and 7.2 PJ for fuel. This saving potential accounts 24% of fuel and 16% of electricity consumption estimated for 2020. The CO₂ emissions reduction potential associated with cost-effective electricity and fuel is 0.96 kt CO₂ and 0.6 Mt CO₂, respectively. The annual net cost saving associated with cost-effective electricity and fuel is 0.3 Million US\$ and 10.4 Million US\$, respectively.

Based on our survey, the key barriers to adoption of EEMs in Ethiopia are: subsidised power supply, capital constraints, lack of sector targets, energy supply constraints, lack of information on opportunities, lack of an infrastructure for alternative fuels, and limited coordination between government and cement plants. Hence, capacity building is necessary, both at the cement plants and with the government. Selecting EEMs that qualify for CDM (Clean Development Mechanism) projects could be an option to alleviate the capital constraints of cement plants of Ethiopia. Provision of support and facilitating logistics services for blending cement and alternative fuels (e.g. biomass residues and others) could reduce the use of (imported) fossil fuels in cement kilns. VSKs are considered an obsolete technology in most countries of the world [37]. Yet, new VSKs are still built in Ethiopia, especially due to the low capital requirements and lack of infrastructure in some areas limiting distribution of products. This can have serious long-term consequences for Ethiopia, resulting in low quality cement, increased use of energy and higher environmental impacts. A critical assessment of the policy on VSKs in Ethiopia is needed. Future research should include the co-benefits (including air quality) of energy efficiency measures to provide an integrated analysis of all private and public benefits of an active industrial energy policy.

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