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Life Cycle Assessment of Ethiopian Cement Manufacturing: A Potential Improvement on the Use of Fossil Fuel in Mugher Cement Factory

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Abstract

The use of imported fuel in the Ethiopian cement industry increased the cost of production and the environmental burden, necessitating intervention. The greenhouse gas (GHG) emission, energy usage intensity, and resource exploitation of Ethiopian cement production were evaluated using the life cycle impact assessment (LCA) tool, aiming to recommend improvements. The LCA study used cumulative energy demand (CED) and Intergovernmental Panel on Climate Change (IPCC) 2006 life cycle impact assessment (LCIA) methods. For the case study of Mugher cement factory (MCF), the results on energy use intensities showed 3.74, 3.67, and 2.64 GJ/ton of clinker, Ordinary Portland cement (OPC), Pozzolana Portland cement (PPC), respectively. The result revealed MCF's energy use intensity was within the global range of 3.32 to 5.11 GJ/ton of cement production using similar kiln technology. The results on the GHG emissions were 0.87, 0.84, and 0.59 tons of CO_2-equivalent/ton of clinker, OPC, and PPC, respectively. Process emissions accounted for 60% of overall CO_2 emissions, with energy-related emissions accounting for the remaining 40%. CO_2 emissions of MCF are below the global limit of 0.9 tons/ton of clinker, where all energy sources are fossil fuels. However, it is higher than the 0.65 ton/ton of clinker from a moderate rotary kiln in China. MCF used 70% of its total energy sources from imported fossil fuels, and transportation of the imported fuel added 1.2% CO_2 to total emissions. A suggested fossil fuel use improvement scenario for MCF, where coffee husk replaces 50% of the imported coal improved the energy intensity, GHG emissions, and total cost of coal in clinker production by 1.2%, 14%, 36%, respectively.

Keywords: Life cycle assessment; Cumulative energy demand; Intergovernmental Panel on Climate Change; Cement production; Greenhouse gas emission

Introduction

As per the world cement report in 2019, China and India are the first and second topmost global cement producers sharing 60% and 7% of the worldwide total cement production. The two countries produced 2,300 and 340 million

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metric tons of cement in the same year, respectively [1]. However, in 2019, the Ethiopian installed capacity was only 17 million metric tons of cement production, using 50% installed capacity. Ethiopian cement production is at a very infant stage with much-anticipated growth, where it grew 50% from 2012 to 2018 [2].

The cement industry is one of the largest CO_2 emitters, contributing up to 8% of total industrial emissions. Despite discrepancies in the raw meal and energy mixes used for cement production, the CO_2 emission is 900 kilograms per ton of cement where fossil fuel is the primary energy source [4–5]. The source of CO_2 emissions in cement manufacturing is the decomposition of calcium carbonate and the combustion of fossil fuels. The calcination process alone accounts for 50% of total cement CO_2 emissions while fossil fuel combustion accounts for 40%. The remaining 10% of CO_2 emissions is from the energy use in the raw meal preparation and finish grinding [6–7].

CO_2 emissions from fossil fuels and the calcination process can be estimated using energy statistics and cement production data [8]. Moreover, cement production data can estimate clinker production in the absence of input carbonate data or national clinker data [9]. Energy use in clinker or cement production varies with the types of technology used, the cement-clinker ratio, and the energy sources used. Heat energy used by wet kilns is higher than the dry kiln; the first has a typical value of 6.0 GJ/ton-clinker and the latter with an average of 4.6 GJ/ton-clinker. Developments in kiln technology have added multi-stage suspension preheaters to reduce the heat required to less than 2.93 GJ/ton-clinker [10–11]. From the total thermal and Electricity use in cement production, the clinker production stage consumes 90% of the total energy uses [12].

Large quantities of mineral resources are also consumed for cement production every year. Limestone takes the largest share of raw material used in cement production, on average, manufacturing 1-ton of cement requires 1.65 tons of limestone, 0.6 tons of clay, and 180–250 kg of coal [13]. In addition, a study on cement production in the US mentioned that manufacturing 56.1 million tons of clinker required 100 million tons of raw materials. And this study pointed out, the raw materials requirement is 170% of the desired clinker production. Besides, a study mentioned 1.5–1.7 tons of raw material is required to manufacture 1-tonne of cement depending on mill type [14].

As defined in IS0 14040 to 14043 standards, life cycle assessment (LCA) is a tool used for quantifying the environmental burdens of any product or service. LCA helps to compare products and identify the elements of production processes with the highest impact [15]. For example, an LCA study compared the environmental performance of Turkish cement clinker production with conventional and alternative resources. This study used cradle-to-gate LCA and IMPACT 2002 + methods since it combines four methods: IMPACT 2002, Eco-indicator 99, CML, and IPCC. The result of this comparative LCA study showed that the overall environmental impact of clinker production using alternative resources reduced the total effects by almost 12% [17]. Cement industries produce cement with varying grades and strengths. LCA study in China showed that the higher the grade of cement the more significant the environmental impacts [18]. Li [19] compared the ecological burden of China's Portland cement production with that of Japan's using LCA. This study mentioned China's cement production emits less CO_2 than Japan's. A researcher in Zimbabwe used LCA and local cement data to analyze the environmental burdens from selected cement industry [20]. This study showed that clinker production has the highest impact followed by cement milling. LCA study in southern Europe revealed fossil fuel manufacturing contributed most to eutrophication and acidification impacts [21]. The transportation stage and clinker production impacted more in the Brazilian and Spanish cement industries, respectively [22–23].

As per the review, research gaps are identified from the previous studies; most of the LCA studies focused on developed countries, while minimal studies in Africa. The minimal LCA studies in Africa are due to a lack of continent or country-specific databases for cement productions. Even for the limited LCA studies in the African, the inadequate databases forced researchers to use European data, which never represent the reality on the ground leading to unreliable LCA results. Moreover, as noted from previous studies, geographic boundaries and location of the study area affect the results of a regional LCA [16]. Location and geographic boundary affect LCA results mainly due to variations in transportation distances, energy mix, and other study assumptions used in the specific study area. That is why an LCA study on Ethiopian cement production using country-specific data, energy mix, and resource use is proposed.

The LCA study of Ethiopian cement manufacturing answers how much is the effect of using imported fuel and what possible improvement scenario could we apply on the energy uses for better environmental and economic performances. The LCA of Ethiopian cement production aims to assess the environ-mental performance of the cement production process and come up with recommendations on improvements needed.

Method

Analytical research method, LCA is applied using primary input data from Mugher cement factory (MCF) as a case study. MCF is a state-owned cement plant in Ethiopia with three production lines and a total production capacity of 5000 tons of clinker per day. The kiln technology consists of 6 stage preheater and pre-calciner for the new lines. The study applied methodological procedures depicted on the standard for LCA of building materials [24]. This standard consists of modules applied to different stages of building construction, namely: materials production (A1–A3), the construction process (A4–A5), the use stage of building (B1–B7), end of life stage (C1–C4), benefits and loads beyond the system boundary (D). Based on the standard list of modules, the LCA of Ethiopian cement production was analyzed using A1, A2, and A3. These modules contain impact analysis for the extraction of raw materials (A1), transportation (A2), and manufacturing (A3) stages. In addition, the study applied cumulative energy demand (CED) and IPCC 2007 methods for the life cycle impact assessment (LCIA) of cement manufacturing.

1) LCA of Ethiopian cement production

1.1) Goals and scope

This LCA study aims to provide information to the industry managers and policymakers for the improvements needed in the fossil fuel uses of Ethiopian cement manufacturing. The intended audience of this LCA study included but is not limited to managers and professionals in the cement industry, policymakers, academicians, and researchers. The scope of the LCA study is cradle-to-gate as defined in the simplified system boundary for the cement production process. Moreover, based on primary data availability from MCF energy use intensity, GHG emissions, and mineral resource exploitation are selected as environmental aspects in the LCA study. The declared functional units are 1-ton clinker, 1-ton OPC, and 1-ton PPC produced.

1.2) System boundary

System boundary for LCA study of Ethiopian cement production maps the life cycle activities included in the LCA study. The system boundary includes mining and transport of raw materials, raw meal preparation, pyro-processing, finish grinding, and cement packing activities. Besides, it consists of the on-road transport of imported fuel from port Djibouti to MCF. Figure 1 below shows the simplified system boundary for LCA of Ethiopian cement production.

1.3) Life cycle inventory

Life cycle inventory (LCI) is the first stage in LCA which deals with data collection, calculation, and compilation process. LCI shows the details of types and quantities for inputs and outputs in the cement production process. Except for pumice (used in PPC production) and imported fuels, MCF uses all raw materials from nearby open-pit quarries within 7–10 km distances. But quarry for pumice is situated 180 km from MCF in the southern Ethiopian rift valley zone. As per the 2019/20 production data, MCF used imported coal (anthracite), local coal (lignite), heavy fuel oil (HFO), diesel fuel (DF), and Electricity (EE) for cement production processes. In 2019/20 MCF used anthracite, HFO, and DF imported from South Africa and the Arab Emirates through port Djibouti (982 km from MCF). The source of Electricity for MCF is the national grid, and local coal (lignite) is extracted from Kamakshi zone, Beshangul Regional State, Ethiopia (570 km from MCF).

A. Input LCI data

All input data used in the case study are primary data obtained from the Ethiopian Mugher cement factory and private transport operators (involved in transporting imported fuel and local materials). Twelve-month energy and raw material consumption data are collected, analyzed, and compiled for the production year 2019/20; those data include quantities and sources of all input resources. In addition to the input energy and raw material data, LCI compiled the quantities of annual production and mix designs for clinker, OPC, and PPC including raw meal: clinker ratio.

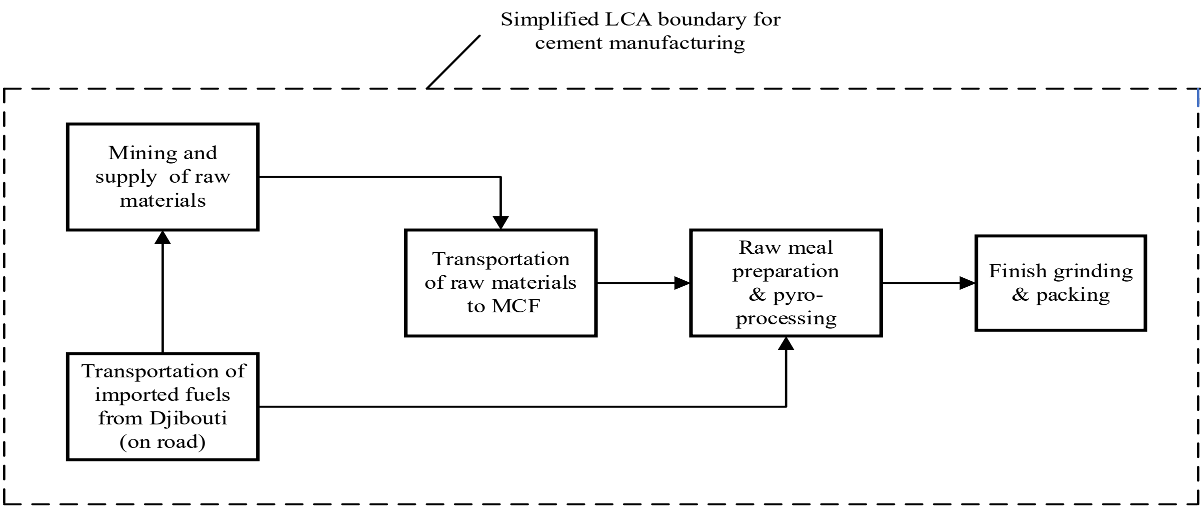

Figure 1 Simplified system boundary for cradle-to-gate LCA of cement production.

The twelve months data for the 2019/20 production year indicated that MCF produced clinker and two types of cement namely OPC and PPC. MCF manufactures OPC as per CEM-I-42.5 grades containing 95% clinker plus 5% gypsum, and PPC is produced as per CEMII - 32.5 grades with 67% clinker, 28% pumice, and 5% gypsum. The mix design for clinker is 89.43% limestone, 7.61% clay, and 2.96% sandstone with the raw meal to clinker ratio of 1.7:1. In the year 2019/20, MCF produced 596,972 ton-clinker where 547,923 ton-clinker was used for the production of 66,112 ton-OPC and 724,055 ton-PPC in MCF. The remaining 49,049 ton-clinker was sent to Tatek clinker grinding plant (owned by MCF, located 90 km from Mugher cement plant).

The primary data for the input raw materials and energy uses were collected, analyzed, and compiled on a modular basis under A1, A2, and A3. As per the energy use data collected from MCF, mining and loading activities use Electricity and diesel fuel which are contained in module A1. Those quarried raw materials are transported to MCF using belt conveyors driven by electricity, and this Electricity consumption is included in module A2. In addition, the diesel fuel consumption for transportation of imported fuels is incorporated under the same module A2 (obtained from transport operators). The last module A3 contained the energy consumption data for raw meal preparation, pyro-processing, finish grinding, and cement packing activities. In MCF, four types of energy sources namely Electricity, imported coal, local coal, and heavy fuel oil were used for activities under module A3.

Data on the types and quantity of energy used for clinker production is compiled as obtained from MCF. However, the energy used for OPC and PPC productions was derived from the energy use of clinker production (based on their clinker consumption), and the additional energy used for clinker grinding. The types and quantities of raw materials consumed for clinker, OPC, and PPC are analyzed and compiled as per their respective mix designs.

Energy consumption data for clinker, OPC, and PPC productions is compiled on a modular basis. Modular energy and raw material use, and their respective intensities are computed and summarized as in Tables 1 and 2 (energy based on the net calorific value).

B. Output LCI

Cement production is a linear process where there is no byproduct at all; hence, all emissions from cement production are associated with cement only, and there is no allocation at all. As per the defined scope of the LCA study, the output LCI analysis for cement production is limited to GHG emissions to the air. Emission to air from cement production is grouped into direct and indirect emissions. Direct emissions (DE) are those caused and controlled by the cement factory (in this case MCF). The DE includes emissions from the calcination process, kiln fossil fuel use, and non-kiln fossil fuel use (fuels used by plant vehicles and quarry machines). The indirect emissions are those emitted as a result of activities not controlled by the cement factory, such as emissions from the Electricity supplying company (in this case Ethiopian Electric Power Corporation, EEPCO) and vehicles owned by transport operators. The GHG emissions were computed by the Intergovernmental Panel for Climate Change (IPCC) method, and it includes $C0_2$, CH_4, and N_2O emissions. Cement kiln dust (CKD) has been recycled in MCF with no wastage or disposal; hence, no additional emission from CKD. Complete oxidation was assumed both in the calcination process and fossil fuel uses at all stages of production. Emission was calculated using IPCC tier equations and default emission factors as presented in Table 3.

Based on ISO 14044 requirements for data quality assessment, quality is measured in terms of technology, time, and geographical coverages. The data used in the LCA study of Ethiopian cement production covers dry processing cement plants with preheater and precalciner technology. The study used recent input data for a case study in the production year 2019/20, with 100% representativeness of input raw materials and energy use data. The quantities of input data such as raw material and fuel uses are complete and were used to calculate the output LCI results within the system boundary.

Table 1 Modular input LCI for energy uses in the total clinker, OPC, and PPC productions

Product type	Energy sources	Modular LCI for total energy uses in clinker, OPC, and PPC production (MJ)		
		A1	**A2**	**A3**
Clinker	Electricity	8,651,271.6	2,091,898.8	126,650,268
	Diesel fuel	24,075,581.75	81,157,739.47	-
	Heavy fuel oil	-	-	16,789,011.84
	Imported coal	-	-	1,440,491,700
	Local coal			530,371,100
OPC	Electricity	908,383.68	219,649.32	21,714,410.8
	Diesel fuel	2,527,936.98	8,521,558.54	-
	Heavy fuel oil	-	-	1,762,845.52
	Imported coal	-	-	151,252,830
	Local coal	-	-	55,688,430
PPC	Electricity	7,033,483.8	1,700,713.8	160,249,285.8
	Diesel fuel	24,059,539.1	103,244,706.5	-
	Heavy fuel oil	-	-	13,649,467.64
	Imported coal	-	-	1,171,120,740
	Local coal	-	-	431,189,360

Table 2 Summary of computed input raw materials and energy use intensities for

Input item	Intensity for clinker production	Intensity for OPC production	Intensity for PPC production
Input raw material intensity (kg/ ton-clinker)			
Lime stone	1,520	1,440	1,020
Clay	130	120	90
Sand stone	50	50	30
Gypsum	-	70	50
Pumice	-	-	280
Input Energy intensity (MJ/ ton-clinker)			
Electricity	230.15	345.51	233.38
Diesel fuel	176.28	167.13	175.82
Heavy fuel oil	28.12	26.66	18.85
Imported coal (Anthracite)	2,413	2,287.83	1,617.45
Local coal (Lignite)	888.44	842.33	595.52

1.4) Life cycle impact assessment (LCIA)

The LCIA is a very crucial step in LCA; it is a step where the LCI results are classified, characterized, normalized, and weighed. At this step, the inventory items are assigned to specific impacts categories, the impacts are quantified, and weighed for their relative significance. Among the available life cycle impact assessment methods, the cumulative energy demand (CED) and IPCC 2007 methods were applied for LCIA of Ethiopian cement production. As per the defined scope of the LCA study, the selected impact categories included global warming potential (GWP), abiotic depletion of fossil fuels, renewable energy exploitation (hydro, wind, and solar), mineral resources, and freshwater exploitation. The selected parameters under each impact category describe GHG emissions, exploitation of renewable and non-renewable mineral resources, renewable and non-renewable primary energy, and freshwater resources. The water use data of MCF shows the specific water consumption is 0.357 m^3/ton-clinker.

As per IPCC 2007, Global Warming Potential (GWP100) was expressed as Global Warming Potential for a time horizon of 100 years. The 100-years global warming effects of each GHG were computed and presented as equivalent kg-CO_2. The conversion factor used for CO_2 equivalent calculation is 1, 25, and 300 for CO_2, CH_4 N_2O, respectively. Besides, the primary energy consumptions were compiled as per the cumulative energy demand model (CED).

The LCIA results per declared units for clinker, OPC, and PPC productions are summarized in Table 5.

1.5) Interpretation

As observed from the energy mix data for OPC production in MCF, the energy sources were about: 64% anthracite, 24% lignite, 6% electricity, 1% heavy fuel oil, and 5% diesel fuel oil. Out of the total energy uses in MCF, 70% of the energy sources were from imported fuels. As per the LCIA results, the energy intensities of MCF were found to be 3.74, 3.67, and 2.64 GJ/ton clinker, OPC, and PPC, respectively. For clinker production, the emission analysis had shown that 93.3% of CO_2 was contributed by coal (both anthracite and lignite) having an 88% share of the total energy mix. Moreover, from the total clinker production, about 60% of the total CO_2 emission was contributed by the calcination process, while the remaining 40% was from the energy uses. Clinker manufacturing consumed 94.8% of the total energy contributing 98.4% of the total CO_2 emissions. Both the energy use intensity and GHG emission per ton of clinker production are higher than the corresponding values for OPC and PPC productions. Besides, due to its lower clinker content, the production of 1 ton - PPC consumes less energy and emits less GHG than the production of 1 ton - OPC. Table 6 summarizes the energy mix and emission contribution from each type of energy used for clinker production.

Table 3 Summary on emission types, the process responsible, and methods of calculation

Type of emission	Process responsible for the emission		Source of pollutant	Type of pollutant emitted	IPCC method used	Emission factor used (EF)
Direct emission	Calcination process		Decomposition of $CaCO_3$	CO_2	Tier 2	520 kg CO_2/t clinker, from Cement Sustainability Initiative [25]
	Fossil fuel use	Kiln fossil fuel use	Burning: coal and heavy fuel oil	CO_2 CH_4 N_2O	Tier 1	IPCC default emission factor for stationary combustion, Table 2.3
		Non-kiln fossil fuel use	Burning diesel oil	CO_2 CH_4 N_2O	Tier 1	IPCC default emission factors for mobile source Table 3.3.1
Indirect emission	Electricity consumption		Use of electricity	CO_2 CH_4 N_2O	Tier 1	Country specific electricity generation emission factors [26].
	Fossil fuel use for transportation of imported fossil fuels		Burning diesel oil	CO_2 CH_4 N_2O	Tier 1	IPCC fuel-based emission factors for vehicle types in road transport Tables 3.2.1 and 3.2.2

Table 4 Output LCI for GHG emissions from clinker, OPC, and PPC productions

Product type	Type of GHG	GHG missions in clinker, OPC, and PPC production (kg / ton-product)			
		A1	**A2**	**A3**	**Total**
Clinker	CO_2	3.468	10.189	849.525	863.182
	CH_4	1.868-E04	5.349-E04	3.3-E02	3.345-E02
	N_2O	1.157-E03	5.311-E04	4.928-E03	6.616-E03
OPC	CO_2	2.509	9.657	826.751	838.917
	CH_4	1.769-E04	5.069-E04	3.236-E02	3.304-E02
	N_2O	1.096-E03	5.034-E04	4.854-E03	6.453-E03
PPC	CO_2	2.781	10.649	574.748	588.178
	CH_4	1.507-E04	5.596-E04	2.195-E02	2.266-E02
	N_2O	9.519-E04	5.573-E04	3.296-E03	4.805-E03

Table 5 Summary of LCIA results for clinker, OPC, and PPC productions

Impact Category	Impact indicators	Unit	LCIA result for each product		
			Clinker	**OPC**	**PPC**
Global warming potential	CO_2 CH_4 N_20	kg CO_2 eq / ton-product	866.00	841.68	590.19
Abiotic fossil fuel depletion	Anthracite Lignite Heavy fuel oil Diesel fuel	MJ / ton-product	3,505.84	3,323.95	2,407.64
Renewable Energy exploitation	Electricity	MJ / ton-product	230.15	345.51	233.38
Abiotic mineral resources depletion,	Limestone Sandstone Clay Gypsum Pumice-aggregate	ton / ton-product	1.70	1.68	1.47
Water resources exploitation	Freshwater use	m^3/ ton-product	0.357	0.339	0.239

As per the modular LCA results of cement production in MCF, A3 used the lion share of energy and mineral resources having the highest contribution for the global warming and resources exploitation impacts. The energy use for mining (A1) and transportation (A2) of inputs to MCF accounted for 1.5% and 3.7% of the total energy, respectively. In addition, the LCA result had shown the GHG emissions from A1 and A2 were 3.5% and 0.2%. Moreover, the transportation of imported fuel consumed 3.7% of the total energy with an emission contribution of 1.2% of CO_2 in clinker production. Figures 2, 3, and 4 show emission contributions by modules for clinker, OPC, and PPC productions respectively.

Table 6 Summary of energy share in the mix and emission contribution for clinker production

Type of energy in the mix	Energy share in the mix (%)	Contribution of emission by energy sources in clinker production (%)		
		CO_2	CH_4	N_2O
Electricity	6	2.2	0.9	0.9
Diesel fuel oil	5	3.8	2	25.4
Heavy fuel oil	1	0.7	0.4	0.3
Anthracite	64	68.8	71.8	54.5
Lignite	24	24.5	24.9	18.9

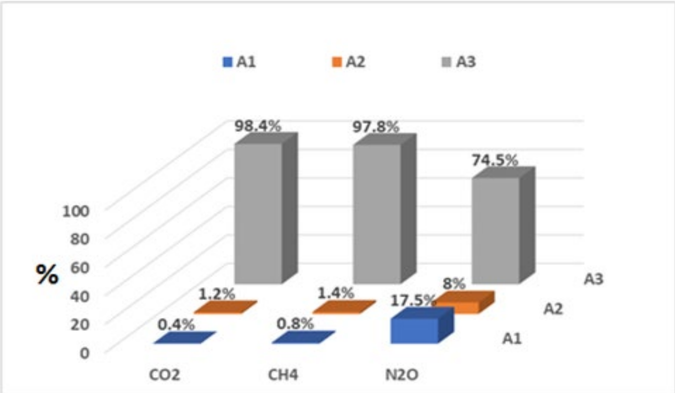

Figure 2 Emission contribution by modules per 1-ton of clinker production.

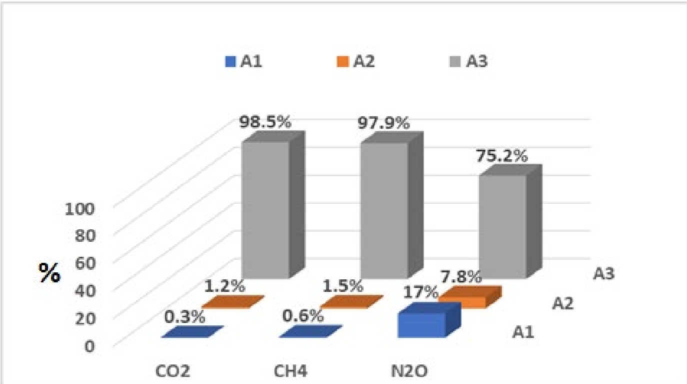

Figure 3 Emission contribution by modules per 1-ton of OPC production.

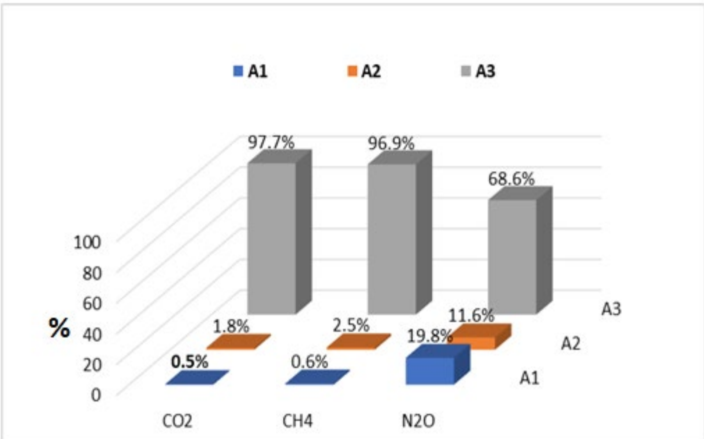

Figure 4 Emission contribution by modules per 1-ton of PPC production.

The LCIA results revealed that the use of coal as a source of energy in clinker production contributed to the majority of CO_2 emissions which is mentioned as 93.3%. This clearly shows the necessity of replacing coal with alternative energy sources such as bio-mass with zero emissions values. Accordingly, the study proposed an improvement scenario on the fossil fuel use where imported coal is to be partially replaced by bio-mass; the impact of the replacement is analyzed in section below.

Recommended improvement scenario on fossil fuel use

Based on the LCIA results of clinker production in MCF, the input energy is dominated by imported coal from South Africa. As per a study report in Ethiopia, the price of imported coal was in the range of 160-180 USD /ton-coal, even some industries mentioned a price of 200 USD/ton-coal [27]. However, studies in Ethiopia indicated the untapped potentials of alternative energy sources for the Ethiopian cement industry. According to availability, source proximity, and technical evaluations, coffee husk was proposed as a viable alternative energy source for MCF; besides, the average cost of biofuel to the gate of MCF was reported as equivalent to 29 USD / ton-biofuel [28]. Moreover, an experimental study [29] determined the calorific value of Ethiopian coffee husk, as per this study the higher heat value (HHV) of coffee husk is 18.6 MJ kg^{-1}.

In the year 2019/20, the energy use data for MCF showed that 53,951 t of anthracite (imported coal) was consumed for clinker production. Assuming an improvement scenario of replacing 50% of anthracite with coffee husk, we can compute the equivalent mass of coffee husk required to replace 50% of imported coal (26,975.5 ton-anthracite). Using the IPCC HHV of anthracite (32.2 MJ/kg-anthracite), the equivalent mass of coffee husk required to replace 50% of anthracite is 46,699.5 t.

As per the result of direct emissions analysis from the kiln fossil fuels use (discussed in section 2.1.3 B), the specific GHG emission from burning 53,951 tons of anthracite is found 237.91 kg CO_2 eq/ton-clinker (A3). Moreover, there is an emission from the transportation of anthracite from port Djibouti to MCF (A2). The total diesel fuel consumed for the transportation of 53,951 t of anthracite was 1,514,674 liter or 54,058,715 MJ of energy with a total emission of 6.83 kg CO_2 eq/ton-clinker. Accordingly, the total GHG from transport and use of anthracite amounted to 244.74 kg CO_2 eq/ton-clinker. However, according to the cement sustainability initiative (CSI) guideline, CO_2 emission from the use of biofuels in the cement industry is reported as zero since it can be compensated by the regrowth of biomass in the short term [25]. In addition, replacing 50% of anthracite with coffee husk saves 3,501,304.5 USD from the total cost of 9,711,180 USD paid for the import of 53,951 tons of anthracite. Hence, for the proposed improvement scenario: a saving of 27,029,357.53 MJ of energy, a reduction of 122.37 kg CO_2 eq/ton-clinker GHG emission, and a saving of 3,501,304.5 USD from the total cost of anthracite is achieved. Accordingly, the proposed improvement scenario results in a reduction of energy intensity, GHG emissions, and cost of coal by 1.2%, 14%, 36%, respectively.

Results and discussion

The environmental performance of Ethiopian cement production was assessed using LCA. The study used actual input data from MCF as a case study for the Ethiopian cement plant producing two types of cement (OPC and PPC). The study showed the energy use per ton of clinker as 3.74 GJ/ton-clinker, which is found to be within the global range of energy use by cement plants having similar kiln technology. However, GHG emission of 0. 87 ton CO_2 eq./ ton-clinker is found to be 34% higher than emissions from a moderate rotary kiln in China. The study also identified cement manufacturing stage (A3) scored the highest in energy use and GHG emissions. MCF used 70% of its energy sources from imported fossil fuel which is dominated by coal. The use of coal as a source of energy contributed the largest share (93.3%) of CO_2 emissions. In addition, the transportation of imported fuels from port Djibouti to MCF added 1.2% of the gross CO_2 emission. This reveals that the use of imported fuel not only adds the economic burden on the Ethiopian cement production but also adds to the emissions per ton of clinker productions. Hence, there is a need for substitution of an imported fossil by alternative fossil sources which can improve both the environmental and economic performances of cement production. Based on availability, economic and technical evaluations, coffee husk was proposed as an alternative source of energy for MCF. Accordingly, a fossil fuel use improvement scenario is suggested for MCF where 50% of the imported coal is replaced by the coffee husk. As per the recommended fossil fuel use improvement scenario discussed in section 3, replacing 50% of imported coal with the coffee husk improved the energy intensity, GHG emissions, and cost of coal by 1.2%, 14%, 36%, respectively.

Conclusion

The use of imported fossil fuel by MCF increased the environmental and economic burdens of cement production in Ethiopia. These burdens can be mitigated by replacing imported fossil fuels with alternative energy sources. As per a study report, coffee husk was mentioned as the appropriate alternative energy source for MCF. The result of impact analysis for the substitution of 50% of anthracite by coffee husk also confirmed a significant improvement in the energy intensity, GHG emission, and cost of cement production. Hence, MCF managers need to work on the implementation plan of imported fossil fuel substitution by the coffee husk. In addition, an intervention is also required from the policy-makers and industry drivers in supporting the cement industry to develop effective and efficient energy management schemes. Those schemes include waste heat recovery and substitution of fossil fuel by local alternative energy sources; both schemes reduce the GHG emissions and enhances the overall environmental and economic performance of the Ethiopian cement industry.

References

[1] Thomas, A. A review of global cement industry trends. Concreatech, New Delhi, 2018.
[2] Gemechu, W., Teshome, A., Khalid, A., Daniel, B., Elias, H., Aderajew, S. Ethiopian Cement Industry Development Strategy 2015–2025. Project report to FDRE Ministry of Industry, 2015.
[3] Glob bulk Technologies S.L. World cement statistics booklet with Country-level data, 2020. [Online] Available from: http://www.globbulk.com/.
[4] Mahasenan, N., Steve, S., Kenneth, H., Kaya, Y. The cement industry and global climate change: Current and potential future cement industry CO_2 emissions. Greenhouse Gas Control Technologies–6th International Conference. Oxford: Pergamon, 2003, 995–1000.
[5] Justnes, H. How to make concrete more sustainable. Journal of advanced concrete technology, 2015, 13(3), 147–154.
[6] United Nations Environment Program. The 2020 global status report for buildings and construction: Towards a zero-emission, efficient and resilient buildings and construction sector, Nairobi, 2020.
[7] Farfan, J., Fasihi, M., Breyer, C. Trends in the global cement industry and opportunities for long-term sustainable CCU potential for Power-to-X. Journal of Cleaner Production, 2019, 217, 821–835.

[8] Quéré, C.L., Andrew, R.M., Friedlingstein, P., Sitch, S., Pongratz, J., Manning, A.C., ..., Zhu, D. Global carbon budget 2017. Earth System Science Data, 2018, 10(1), 405–448.

[9] Andrew, R.M. Global CO_2 emissions from cement production. Earth System Science Data, 2018, 10(1), 195–217.

[10] International Finance Corporation. Improving thermal and electric energy efficiency at cement plants: International Best Practice, World Bank, 2017.

[11] Madlool, N.A., Saidur, R., Hossain, M. S., Rahim, N.A. A critical review on energy use and savings in the cement industries. Renewable and Sustainable Energy Reviews, 2011, 15(4), 2042–2060.

[12] Worrell, E., Kermeli, K., Galitsky, C. Energy efficiency improvement and cost-saving opportunities for cement making an ENERGY STAR® guide for energy and plant managers. The EPA-United States Environmental Protection Agency, 2013.

[13] British Geology Survey Mineral profile. Cement raw materials. British Geology Survey Natural Environment Research Council, 2005.

[14] Golewski, G.L. Energy savings associated with the use of fly ash and nano additives in the cement composition. Energies, 2020, 13(9), 2184.

[15] Standardization, I. Environmental management: Life cycle assessment: Principles and Framework, 1997.

[16] Yazdanbakhsh, A., Lagouin, M. The effect of geographic boundaries on the results of a regional life cycle assessment of using recycled aggregate in concrete. Resources, Conservation and Recycling, 2019, 143, 201–209.

[17] Çankaya, S., Pekey, B. A comparative life cycle assessment for sustainable cement production in Turkey. Journal of environmental management, 2019, 249, 109362.

[18] Yang, D., Fan, L., Shi, F., Liu, Q., Wang, Y. Comparative study of cement manufacturing with different strength grades using the coupled LCA and partial LCC method-A case study in China. Resources, Conservation and Recycling, 2017,119, 60–68.

[19] Li, C., Cui, S., Nie, Z., Gong, X., Wang, Z., Itsubo, N. The LCA of Portland cement production in China. The International Journal of Life Cycle Assessment, 2015, 20(1), 117–127.

[20] Mbohwa, C., Moyo, S. Life cycle assessment of the cement industry in Zimbabwe, 2008.

[21] Stafford, F.N., Dias, A.C., Arroja, L., Labrincha, J.A., Hotza, D. Life cycle assessment of the production of Portland cement: A Southern Europe case study. Journal of Cleaner Production, 2016, 126, 159–165.

[22] Stafford, F.N., Raupp-Pereira, F., Labrincha, J.A., Hotza, D. Life cycle assessment of the production of cement: A Brazilian case study. Journal of Cleaner Production, 2016,137, 1293–1299.

[23] García-Gusano, D., Herrera, I., Garraín, D., Lechón, Y., Cabal, H. Life cycle assessment of the Spanish cement industry: implementation of environmental-friendly solutions. Clean Technologies and Environmental Policy, 2015, 17(1), 59–73.

[24] International Organization for Standardization. Environmental management: Life cycle assessment; Principles and framework, 2006, Vol.14044 ISO.

[25] The Cement Sustainability Initiative: Our agenda for action, World Business Council for Sustainable Development, 2002, pp 20.

[26] Brander, M., Sood, A., Wylie, C., Haughton, A., Lovell, J. Technical paper| Electricity-

specific emission factors for grid electricity. Ecometrica, Emission factors.com, 2011.

[27] International Finance Corporation. Use of alternative fuels in the cement sector in Ethiopia: Opportunities, challenges and solutions, 2017, World Bank.

[28] Seboka, Y., Getahun, M.A., Haile-Meskel, Y. Biomass energy for cement production: Opportunities in Ethiopia.

[29] Wondemagegnehu, E.B., Gupta, N.K., Habtu, E. Coffee parchment as potential biofuel for cement industries of Ethiopia. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 2019, 1–12.