MITIGATION OF GREENHOUSE GASES EMISSIONS AND REDUCTION OF ENERGY CONSUMPTION IN CEMENT INDUSTRY IN EGYPT

CASE STUDY: ARABIAN CEMENT PLANT

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ABSTRACT

Cement production is an energy intensive industry that generates high CO_2 emissions which is a greenhouse gas (GHG) causing climate change. Although Egypt permitted cement plants to use coal due to the energy shortage, it has also committed to reducing GHGs emissions considering climate change challenges. Therefore, this research focused on studying mitigation measures of GHG emissions and reducing energy consumption in cement production. A case study has been conducted on Arabian cement plant in Egypt. The fossil fuels (coal, pet coke and natural gas) have been partially substituted with the alternative fuels reaching a rate of 13.83% (agricultural wastes 1.46%, refused derived fuel 10.63%, shredded tires 1.32% and sludge 0.42%). The United Nations approved consolidated methodology (ACM0003) was executed. It was found that the use of alternative fuels reduced the GHG emissions by 107,846.89 tons of CO_2e and decreased the consumption of coal by 68,075 tons, and natural gas by 200,120 m^3.

Key words: Cement, mitigation, climate change, energy, alternative fuels.

INTRODUCTION

Cement is an inorganic, non-metallic substance with hydraulic binding properties. It is a key material for infrastructure and building construction (Uwasu *et al.*, 2014). The total volume of cement production worldwide amounted to 4.1 billion tons in 2022 (Statista, 2023a).

Cement production is an energy intensive industry comprising 7% of the global industrial energy use (Zhang *et al.*, 2014). It generates high CO_2 emissions which is a greenhouse gas (GHG) causing climate change. In 2019, CO_2 emissions from cement industry reached 2.4 Gt, accounting for 26% of the total industrial emissions and 6% of the global carbon dioxide emissions (Guo *et al.*, 2023).

CO_2 emissions from the cement industry can be classified into direct and indirect emissions. Direct emissions comprise 90% of emissions divided into 50% from process related emissions due to converting the limestone into clinker and 40% from fuel combustion related emissions (Selim and Salem, 2010). Indirect emissions comprise about 10% of emissions due to electricity consumption (Nie *et al*., 2022).

In 2022, Egypt's cement clinker industry had a capacity of 48 million tons (Statista, 2023b). Cement industry consumes about 5.3% of total national energy. Egypt faces shortage in fossil fuel supply for energy intensive industries mainly cement plants where natural gas and mazut are the main fossil fuels used for cement production in Egypt. Therefore, this crisis led to decreasing the amount of production (Ministry of Environment, 2019).

Considering the energy crisis, Egypt issued a regulation in 2015 allowing the use of coal by cement plants in Egypt. Consequently, it was estimated that the CO_2 emissions from the cement industry will increase by 15% in 2030 from 66 to 76 $MtCO_2$/year. This will put the cement production in Egypt to be among the higher 2% CO_2 intensive globally and decrease the competitiveness (Cement, 2023). In 2018, CO_2 emissions from cement industry represented 60% of the total industrial emissions and 7.2% of the total Egypt’s emissions. As Egypt is one of the most vulnerable countries due to climate change negative impacts, it has committed to set ambitious targets for reducing GHGs emissions and to report progress on achieving that to the United Nations Convention on Climate Change (Statista, 2023c).

Globally, the main mitigation measures of CO_2 emissions from the cement industry includes using alternative fuels, reducing the clinker content, improving energy efficiency, and applying carbon capture and storage (Ishak and Hashim, 2022).

The use of waste derived alternative fuel has been a well-developed practice in some countries for almost 30 years (IEA, 2010). The average substitution rate reached more than 50% for the European cement industry and up to 98% as yearly average for some cement plants. The European Union planned to reach an average rate of 70% by 2040 that would decrease 27% in fuel CO_2 emissions (ECRA, 2017). CEMEX's Costa Rican operations had a 20% alternative fuels substitution rate and reduced 21,000 tons of CO_2 emissions annually. In Japan, where there was a shortage of space for waste, up to 350kg of waste per ton of cement were used as cement alternative fuel. In the developing countries, waste derived fuel projects depend on the financial and regulatory conditions (Askar *et al*., 2010).

The reduction of clinker content could reduce CO_2 emission depending on the availability of blending materials such as fly ash and pozzolana (Worrell *et al.*, 2001). For example, despite the blended cements were commonly applied in Europe, they were less common in North America (Hendriks *et al*., 1998), while it accounted for 73% of 2022 total cement production in India (Cemnet, 2022). The improvement of energy efficiency in Indian cement industry was estimated to achieve energy savings of 48%, and reduce 27% of CO_2 emissions (Worrell *et al*., 2001). Most CO_2 removal techniques are still under research to decrease the cost of these technologies to be economically viable and safer option for cement plants (Plaza *et al*., 2020).

Despite the energy crisis in Egypt, there are non-conventional energy sources which are not properly utilized, such as municipal solid wastes, sewage sludge, and agricultural wastes that are disposed in an uncontrolled manner (Ministry of Environment, 2023).

Therefore, this research focused on studying mitigation measures of GHG emissions and reducing energy consumption in the cement industry in Egypt based on the international practices. A case study has been conducted on Arabian cement plant in Egypt on the partial substitution of fossil fuels with alternative fuels as a measure for mitigating GHGs emissions, decreasing energy consumption, and avoiding the uncontrolled burning of wastes.

MATERIALS AND METHODS

Applied methodology:

We applied the United Nations approved consolidated methodology ACM0003 entitled "Partial substitution of fossil fuels in cement or quicklime manufacture", Version 9.0, under the Intergovernmental Panel on Climate Change (IPCC) calculation protocols. We compared the GHGs emissions and energy consumption when using alternative fuels with the business-as-usual situation when using only fossil fuels.

Preparation of alternative fuels

In Arabian cement plant, the fossil fuels (coal, pet coke and natural gas) used in clinker production have been partially replaced by alternative fuels (agricultural wastes, refused derived fuel (RDF), sewage sludge and shredded tires). The application of alternative fuels required the application of new equipment and facilities to enable the cement production combustion system to adapt to the new alternative fuels. The following steps were applied:

a) The alternative fuels arrived by trucks, then weighed. A sample was taken from the fuel to be checked at the cement plant laboratory to ensure that sulfur and silica amount were very low.
b) The alternative fuels were unloaded using the truck belt at the receiving storage area in separate piles with spaces between them to allow handling and passage of equipment and to decrease the risk of fires. This area was shed with adequate openings to keep the biomass under aerobic conditions.
c) Then the alternative fuels were loaded on the factory trucks using loaders to be transported to the feeding system area.
d) The loading of alternative fuels differed between the two production lines in the cement plant. They were loaded directly into the first line (hot disc) that allowed

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the application of large sizes of alternative fuels to the main calciner at 800 ^oC. The second line, which is a regular line, required shredding of the alternative fuels into smaller sizes before feeding into the precalciner at 400 ^oC for heating until reaching the main calciner at 800 ^oC). Then they were loaded into the shredder to be around 50 mm, then transported to the overhead reclaimer storage system. The alternative fuels were discharged by a drag chain conveyor to an overhead reclaimer storage whose capacity is 1000 m^3 which gave a buffer time of approximately 25 hours only to avoid the anaerobic fermentation for the biomass fuel. Finally, they were extracted with dosing screws integrated into the storage, where transferred to the burner section by pipe conveyors.

Applied substitution rate

In the study situation, we identified the substitution rate of fossil fuels with alternative fuels based on the required thermal energy to produce certain amount of clinker according to the production plan of the cement plant.

In the business-as-usual situation (using only fossil fuels), we identified the required amount of fossil fuels mix to produce the same amount of clinker to be compared with the study situation.

Estimation of emissions and energy consumption

The research was applied for 12 months (from 1 September 2021 to 31 August 2022) where emissions were calculated using the following equation:

$$\mathbf{E}_{(K)} = \sum_k \mathbf{FC}_{(Ton)} \times \mathbf{NCV}_{(TJ/Ton)} \times \mathbf{EF}_{(TCO2/TJ)}$$

Where:

$E_{(K)}$: Emissions from combustion of fuel type k (TCO_2)

$FC_{(Ton)}$: Quantity of fuel type k used in the cement plant,

$NCV_{(TJ/Ton)}$: Net calorific value of the alternative fuel type k,

$EF_{(TCO2/TJ)}$: CO_2 emission factor for fuel type k, and

K: Fuel types used in the cement plant.

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Table 1: Sources of GHGs emissions included in the study boundary.

	SOURCE	GAS
Business as Usual Emissions (in case of the combustion of fossil fuels only)	Emissions from the fossil fuel combusted in the cement plant	CO_2
	Emissions of Methane avoided from preventing the disposal or avoided from burning the biomass residues in an uncontrolled manner	CH_4 (emission source from the municipal solid waste disposed as well as emissions from decay, dumping or burning of agricultural residues)
	Emissions from the electricity consumption as a result of coal/ pet coke preparation	CO_2
	Emissions from combustion of fossil fuels for transportation of fossil fuels	CO_2
Study Emissions (in case of including the alternative fuels in the fuel mix)	Emissions from the use of the alternative fuels' sources	CO_2
	Emissions from the fossil fuel combustion for clinker production	CO_2
	Emissions from the electricity and/or fossil fuel consumption because of the study for preparation of alternative fuels and fossil fuels	CO_2
	Emissions from combustion of fossil fuels for transportation of alternative fuels	CO_2
	Emissions from combustion of fossil fuels for transportation of fossil fuels	CO_2

According to the applied methodology (ACM0003), the reduction in emissions was calculated by comparing the emissions in case of the study situation with the business-as-usual situation. The reduction in energy consumption was calculated by identifying the reduction in fossil fuel consumption in case of applying the alternative fuels within the fuel mix.

RESULTS

a) Energy consumption and emissions in case of using alternative fuels

We reached a substitution rate of 13.83% for alternative fuels within the total energy mix (coal 16.27%, pet coke 45.14%, natural gas 24.76%, agricultural wastes 1.46%, refused derived fuel 10.63%, shredded tires 1.32% and sludge 0.42%) as indicated in Table (2). The applied energy mix has produced a thermal energy of 13,541 Tera Joules with a fuel efficiency of 3.63 Giga Joules/ ton clinker which were required to produce 3,727,504 tons of clinker.

Table (2): Energy consumption in case of using alternative fuels.

FUEL	DATA / UNIT	VALUE	REFERENCE / APPLIED EQUATIONS FOR CALCULATIONS
Coal	Quantity of fuel (FC) (ton)	80,085	Arabian Cement Plant
	Net Calorific Value (NCV) (TJ/t)	0.0275	Lab analysis by Egyptian Petroleum Research Institute (EPRI)
	Thermal Energy (TJ)	2203.1207	Thermal Energy (TJ) = FC (Tons) × NCV (TJ/Ton)
	Thermal Percentage	16.27%	Thermal energy of coal / Total Thermal energy of fuels
Petroleum Coke	Quantity of fuel (FC) (ton)	198,438	Arabian Cement Plant
	Net Calorific Value (NCV) (TJ/t)	0.0308	Lab analysis by Egyptian Petroleum Research Institute (EPRI)
	Thermal Energy (TJ)	6112.4074	Thermal Energy (TJ) = FC (Tons) × NCV (TJ/Ton)
	Thermal Percentage	45.14%	Thermal energy of petroleum coke / Total Thermal energy of fuels
Natural Gas	Quantity of fuel (m3)	123,875,268	Arabian Cement Plant
	Quantity of fuel (ton)	93,069	1 ton natural gas (density) =1331 m3
	Net Calorific Value (NCV) (TJ/t)	0.0360	Lab analysis by Egyptian Petroleum Research Institute (EPRI)
	Thermal energy (TJ)	3,352.7516	Thermal Energy (TJ) = FC (Tons) × NCV (TJ/Ton)
	Thermal Percentage	24.76%	Thermal energy of natural gas / Total Thermal energy of fuels

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Cont. Table (2):

FUEL	DATA / UNIT	VALUE	REFERENCE / APPLIED EQUATIONS FOR CALCULATIONS	
Agricultural waste	Quantity of fuel (ton)	15,579	Arabian Cement Plant	
	Net Calorific Value (NCV) (TJ/t)	0.0127	Lab analysis by Egyptian Petroleum Research Institute (EPRI)	
	Thermal Energy (TJ)	197.6986	Thermal Energy (TJ) = FC (Tons) × NCV (TJ/Ton)	
	Thermal Percentage	1.46%	Thermal energy of solar / Total Thermal energy of fuels	
Refused Derived Fuel (RDF)	Quantity of fuel (ton)	120,796	Arabian Cement Plant	
	Net Calorific Value (NCV) (TJ/t)	0.0119	Lab analysis by Egyptian Petroleum Research Institute (EPRI)	
	Thermal Energy (TJ)	1439.4083	Thermal Energy (TJ) = FC (Tons) × NCV (TJ/Ton)	
	Thermal Percentage	10.63%	Thermal energy of solar / Total Thermal energy of fuels	
Shredded tires	Quantity of fuel (ton)	5,581	Arabian Cement Plant	
	Net Calorific Value (NCV) (TJ/t)	0.0320	Lab analysis by Egyptian Petroleum Research Institute (EPRI)	
	Thermal Energy (TJ)	178.7412	Thermal Energy (TJ) = FC (Tons) × NCV (TJ/Ton)	
	Thermal Percentage	1.32%	Thermal energy of solar / Total Thermal energy of fuels	
Sludge	Quantity of fuel (ton)	5,740	Arabian Cement Plant	
	Net Calorific Value (NCV) (TJ/t)	0.0099	Lab analysis by Egyptian Petroleum Research Institute (EPRI)	
	Thermal Energy (TJ)	56.8722	Thermal Energy (TJ) = FC (Tons) × NCV (TJ/Ton)	
	Thermal Percentage	0.42%	Thermal energy of solar / Total Thermal energy of fuels	
Amount of clinker Produced Quantity (ton)		3,727,504	Arabian Cement Plant	
Total Thermal Energy Produced (TJ)		13,541	Summation of the thermal Energy of consumed fuels	
Fuel Efficiency		TJ/Ton Clinker	0.003632726	Total Thermal Energy (TJ) / Amount of clinker Produced Quantity (ton)
		GJ/Ton Clinker	3.632725813	1 GJ = 1 TJ × 1000

The total GHGs emissions in the study situation were 1,055,642.24 tCO_2e as indicated in Table (3). The GHGs emissions from the preparation and use of alternative fuels represented 6.6% of the total emissions, while the remaining amount (93.4%) resulted from the fossil fuel component in the energy mix.

Table (3): Emissions in case of using alternative fuels.

ACTIVITY	**EMISSIONS (TCO_2E)**
Emissions from the combustion of alternative fuels	63,528.931
Emissions from the combustion of fossil fuel for clinker production	979,330.076
Emissions from additional electricity and onsite fossil fuel consumption for preparation and application of alternative fuels	4,289.967
Emissions from used fossil fuels for offsite transportation of alternative fuels	1,744.796
Emissions from onsite electricity, and onsite and offsite fossil fuel consumption because of the use of fossil fuels (mainly for coal preparations)	6,748.5037
Total study emissions using alternative fuels	1,055,642.274

b) Energy consumption and emissions in case of business-as-usual situation

In the business-as-usual situation, we identified the percentages of each fuel type in the fossil fuel mix (30.1 % coal, 45.1% petroleum coke and 24.8% natural gas) as indicated in Table (4). This energy mix produced the required thermal energy of 13,541 Tera Joules to produce the same amount of clinker 3,727,504 tons to be compared with the study situation.

Table (4): Energy consumption in case of using fossil fuels.

FUEL	DATA / UNIT	VALUE	REFERENCE / APPLIED EQUATIONS FOR CALCULATIONS
Coal	Quantity of fuel (FC) (ton)	148,159.6	Fuel Quantity (ton) = Thermal Energy/NCV
	Net Calorific Value (NCV) (TJ/t)	0.0275	Lab analysis by Egyptian Petroleum Research Institute (EPRI)
	Thermal Energy (TJ)	4,075.841	Thermal Energy (TJ) = FC (Tons) × NCV (TJ/Ton)
	Thermal Percentage	30.1%	Arabian Cement Plant Thermal energy of coal / Total Thermal energy of fuels
Petroleum Coke	Quantity of fuel (FC) (ton)	198,262	Fuel Quantity (ton) = Thermal Energy/NCV
	Net Calorific Value (NCV) (TJ/t)	0.0308	Lab analysis by Egyptian Petroleum Research Institute (EPRI)
	Thermal Energy (TJ)	6,106.991	Thermal Energy (TJ) = FC (Tons) × NCV (TJ/Ton)
	Thermal Percentage	45.1%	Arabian Cement Plant Thermal energy of petroleum coke / Total Thermal energy of fuels
Natural Gas	Quantity of fuel (m3)	124,075,389.5	Fuel Quantity (ton) = Thermal Energy/NCV
	Quantity of fuel (ton)	93,220	1 ton natural gas (density) =1331 m3
	Net Calorific Value (NCV) (TJ/t)	0.0360	Lab analysis by Egyptian Petroleum Research Institute (EPRI)
	Thermal energy (TJ)	3,358.168	Thermal Energy (TJ) = FC (Tons) × NCV (TJ/Ton)
	Thermal Percentage	24.8%	Arabian Cement Plant Thermal energy of natural gas / Total Thermal energy of fuels
Amount of clinker Produced Quantity (ton)		3,727,504	Arabian Cement Plant
Total Thermal Energy Produced (TJ)		13,541	Summation of the thermal Energy of consumed fuels
Fuel Efficiency	TJ/Ton Clinker	0.003632726	Total Thermal Energy (TJ) / Amount of clinker Produced Quantity (ton)
	GJ/Ton Clinker	3.632725813	1 GJ = 1 TJ × 1000

Based on applying this fossil fuel mix, the total resulted GHGs emissions in the business-as-usual situation were 1,163,489.17 tCO_2e as indicated in Table (5). The emissions from fossil fuel preparation and combustion represented 99.8% of the total

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emissions, where the remaining amount (0.2%) resulted from methane emissions in case of the uncontrolled disposal of wastes under the business-as-usual situation.

Table (5): Business as usual emissions results

ACTIVITY	EMISSIONS (TCO_2E)
Emissions from combustion of fossil fuel for clinker production	1,152,902.41
Methane emissions that result from the uncontrolled burning or disposal of biomass residues under the business-as-usual situation	2,545.013
Emissions from onsite electricity, and onsite and offsite fossil fuel consumption because of the use of fossil fuels (mainly for coal preparations)	8,041.7540
Total business-as-usual emissions	1,163,489.17

c) The achieved emission reduction

The application of alternative fuels has resulted in achieving emission reduction of 107,846.89 TCO_2e, as indicted in table (6), where it was calculated using the following equation:

Emission Reduction = Business-as-usual Emissions – Study Emissions

Table (6): Achieved emission reduction.

ITEM	RESULT (TCO_2E)
Business-as-usual Emissions	1,163,489.17
Study Emissions	1,055,642.27
Emission Reduction	107,846.89

d) The achieved savings in energy consumption

The application of alternative fuels in the fuel mix resulted in reducing the amount of consumed coal by 68,075 tons, and natural gas by 200,120 m3, which resulted in energy savings by 1878.17 TJ, as indicated in Table (7).

Table (7): Achieved savings in energy consumption.

FUEL TYPE (UNIT)	CONSUMED AMOUNT IN THE STUDY SITUATION	CONSUMED AMOUNT IN BUSINESS-AS-USUAL SITUATION	SAVINGS (AMOUNT)	SAVINGS (TJ)
Coal (ton)	80,085	148,159.6	68,075 tons	1,872.73
Natural gas (m^3)	123,875,268	124,075,389.5	200,120 m^3	5.42

DISCUSSION & CONCLUSION

This research focused on studying mitigation measures of GHG emissions and reducing energy consumption, where a case study of using alternative fuels as a mitigation measure has been conducted on Arabian cement plant in Egypt.

The fossil fuels mix (coal, pet coke and natural gas) was partially substituted with the alternative fuel mix (agricultural wastes, refused derived fuel, shredded tires, and sludge) reaching a rate of 13.83% during the study period of one year (1 September 2021 - 31 August 2022), that resulted in reducing GHGs emissions by 107,846.89 tons CO_2e, and reduced the consumed amount of coal by 68,075 tons, and natural gas by 200,120 m^3.

Thus, the study has contributed to the achievement of sustainable development in its 3 pillars as follows:

a. Environmental: through reducing emissions from fossil fuels combustion and the uncontrolled disposal of waste.
b. Social: through reducing the air pollutants to avoid negative health impacts, and the opportunity for training and getting expertise in this emerging field for creating job opportunities.
c. Economic: through reducing the consumption of non-renewable sources and saving the foreign currency needed for importing fossil fuels and the subsidy burden by the government and opening a promising investment market for the preparation and use of alternative fuels.

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In comparison with the common practice, the use of waste derived alternative fuel has been a well-developed practice in some countries for almost 30 years (IEA, 2010). In some European countries, the average substitution rate reached more than 50% for the cement industry and up to 98% as yearly average for some cement plants. The EU planned to reach an average rate of 70% by 2040 that would decrease 27% in fuel CO_2 emissions (ECRA, 2017). CEMEX's Costa Rican operations had a 20% alternative fuels substitution rate and reduced 21,000 tons of CO_2 emissions annually. In Japan, where there was a shortage of space for waste, up to 350kg of waste per ton of cement were used as cement alternative fuel (Askar *et al.,* 2010).

Considering the applied case study in the Arabian cement plant, the main challenges that need to be addressed include:

a. The lack of a stable supply of alternative fuels.
b. The variable prices of alternative fuels, as there is no set standard for pricing, and it depends mainly on the supplier.
c. The variable quality level of the supplied alternative fuel types has a negative impact on the production process.

Therefore, it is recommended to set an integrated alternative fuel management system indicating the role of each actor in the cycle of generation, collection, sorting, preparation according to a set of quality standards and transportation until the use at cement plants. It is also recommended to establish a monitoring, reporting and verification system to provide accurate database for cement plants including number of kilns, production capacity, fuel consumption and a national inventory for CO_2 emissions that links with all cement plants to get emissions related data and meet mitigation targets, where this might require revising the current law to set limits for the GHGs emissions.

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التخفيف من انبعاثات غازات الاحتباس الحراري والحد من استهلاك الطاقة في صناعة الأسمنت في مصر
دراسة حالة: مصنع العربية للأسمنت

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المستخلص

يعد إنتاج الأسمنت صناعة كثيفة الاستخدام للطاقة وتولد انبعاثات عالية من ثاني أكسيد الكربون وهو غاز احتباس حراري يسبب تغير المناخ. وعلى الرغم من أن مصر سمحت لمصانع الأسمنت باستخدام الفحم بسبب نقص إمدادات الطاقة، إلا أنها التزمت أيضًا بخفض انبعاثات غازات الاحتباس الحراري في ضوء تحديات تغير المناخ. ولذلك ركز هذا البحث على دراسة تدابير الحد من انبعاثات غازات الاحتباس الحراري واستهلاك الطاقة في إنتاج الأسمنت في مصر، حيث تم إجراء دراسة حالة على مصنع العربية للأسمنت في مصر، تضمنت استبدال جزئي للوقود الأحفوري (الفحم الحجري، الفحم البترولي والغاز الطبيعي) بالوقود البديل بنسبة 13,83٪ (المخلفات الزراعية 1,46%، الوقود المشتق من المخلفات البلدية 10,63%، الإطارات المقطعة 1,32%، الحمأة 0,42%). تم تنفيذ المنهجية المعتمدة من الأمم المتحدة (ACM0003). أوضحت النتائج أن استخدام الوقود البديل قد حقق خفض في الانبعاثات بمقدار 107846,89 طن ثاني أكسيد الكربون المكافئ كما أدى لتقليل استهلاك الفحم الحجري بمقدار 68075 طن، والغاز الطبيعي بمقدار 200120 متر مكعب.

الكلمات الدالة: الأسمنت، التخفيف، تغير المناخ، الطاقة، الوقود البديل.