Effect of Fuel Type on the Life Cycle of Egyptian Cement Industry: Environmental Impact Assessment Approach

Ahmed Abdel Monetleb Mohammed Ali, Egypt-Japan University of Science, Egypt
Abdelazim Mohammed Negm, Egypt-Japan University of Science, Egypt
Mahmoud Farghly Bady, Egypt-Japan University of Science, Egypt
Mona Gamal El-Din Ibrahim, Egypt-Japan University of Science, Egypt

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Abstract
Life cycle assessment (LCA) is a useful tool for assessing the environmental impacts of a system, product or service. Cleaner production and pollution prevention opportunities for the cement sector include: 1) use of alternate fuels in cement kilns; 2) NOX reduction; 3) reduction of dust emissions; 4) reuse of bypass dust; and 5) treatment of hazardous waste. Nowadays, Egypt faced energy scarcity inducing political, social and environmental factors putting pressure on the cement industries to obtain their energy from coal instead of the natural gas, solar and mazzut. Therefore, this paper focuses on assessing the environmental impacts of cement producing facilities in Egypt with regard to their environmental compliance if coal is used compared to other sources by using the LCA tool. A comparative analysis among various fuel types of typical cement plant in Egypt is conducted. Results show that the decision of replacing the existing used fuels in cement industry by coal will carry an additional burden on the environment approximately by 20%. Based on a midpoint method, the global warming potential and respiratory inorganics recorded highly negative impacts of 20% and 25% respectively when using the coal compared with other fuels type. Referring to the endpoint method, the damages to human health (DALY) is dominated when using the coal with a relative contribution of 30%. This increased adverse expected damage must be faced from the Egyptian Environmental Affairs Agency (EEAA) by the limitation and constrains of how to control the output emissions from the plant chimney.

1. Introduction

There are many different procedures and tools used to perform an Environmental Performance Evaluation (EPE) of a material or product such as; the Environmental Indicator Systems (EPIs), the Environmental Management Accounting (EMA), the Environmental Management Systems (EMSs), which performed by *Asdrubali et al.* [1] Furthermore, *Flavin* [2] added the Eco-labeling and Environmental Impact Assessment (EIA) in the EPE.

The study will focus on EIA approach which includes many tools; one of them is the named life cycle assessment (LCA) and life cycle energy analysis (LCEA). [3] LCEA is an approach includes all energy inputs to a product are accounted for, not only direct energy inputs during manufacture, but also all energy inputs needed to produce components, materials and services needed for the manufacturing process. [4] Also life cycle carbon analysis (LCCA) is an increasingly hot topic internationally and domestically associated with certain stages of the life cycle of buildings. Finally, life cycle cost analysis (LCCA) of buildings has been carried out by several researchers. [5] LCCA is a method for assessing the total cost of facility ownership; it takes into account all costs of acquiring, owning, and disposing of a building or building system. [6] This study focuses on the LCA tool. [10]

Omar et al. [8] defined LCA is "a technique for assessing the environmental aspects and potential impacts associated with a product, by: (1) compiling an inventory of relevant inputs and outputs of a product system; (2) evaluating the potential environmental impacts; and (3) interpreting the results of the inventory analysis and impact assessment phases. [9] In literature on life-cycle impact assessment two approaches are proposed; the midpoint and endpoint method. So far, there is no consensus in the research community which assessment method is preferable. Since both methods have their merits and limitations both approaches might be jointly used to provide better insight in environmental impact. [7]

Regarding to the LCA of the cement industry, *Huntzinger et al.* [12] describes that the production of cement involves the consumption of large quantities of raw materials, energy, and heat. Cement production also results in the release of a significant amount of solid waste materials and gaseous emissions. The manufacturing process is very complex, involving a large number of materials (with varying material properties), pyro-processing techniques (e.g., wet and dry kiln, preheating, recirculation), and fuel sources (e.g., coal, fuel oil, natural gas, tires, hazardous wastes, petroleum coke). Thus, inventory analyses and complete LCAs can be quite complicated [13].

Therefore, the authors used the LCA tool to assess the environmental impacts of the alternative fuel types in the cement manufacturing process. This paper presents the results of analyzing the environmental impact assessment of the cement producing facilities in Egypt using SimaPro V8.1. The analysis includes the four phases of LCA, namely; goal and scope definition, life cycle inventory, life cycle impact analysis, interpretation of the results, these phases are defined by EN ISO 14040 [19] and EN ISO 14044 [20].

2. Cement manufacturing in Egypt

The Egyptian cement industry increased in size and capacity during the last 30 years. In 1975 the Egyptian Cement Industry was comprised of four factories, which produced 4 Million tons/year. Now there are 16 factories, which produce 46 Million tons cement/year.[14] The government continues to support the expansion of the cement industry because of rapidly increasing demands for cement; consequently, they have approved the construction of an additional six cement factories in 2006-2007 and another 8 factories in 2010.[15] The satellite image in Fig. (1) shows the locations of the 16 cement factories in Egypt.

Fig. 1 Cement factories in Egypt are highlighted with red indicators.

2.1. Cement Production in Egypt

The Egyptian cement industry increased in size and capacity during the last 30 years. In 1975 the Egyptian Cement Industry comprised four factories, which produced 4 million tons/year. Now there are 16 factories, producing 46 million tons/year of clinker primarily from dry kilns with only a small amount from 7 wet kilns in 3 companies. Egypt's production is estimated to be 1.5% of the world production (year 2008). Table (1) shows the production & energy consumption of each of the Egyptian cement producing companies. [14]

Table 1 Cement company's clinker production and energy consumption in Egypt.

No.	Company	Line Clinker	Production
1	Amreya cement (Cimpor group)	Kiln 1, Kiln 2	1,900,483
2	Amreya cimpor (Cimpor group)	Kiln 1	1,352,098
3	Sinai cement (Gray)	Kiln 1, Kiln 2	3,350,221
4	Bani suef cement	Kiln 1	1,573,844
5	Alexandria cement (TITAN)	Kiln 1	1,500,005
6	Misr Qina	Production line	1,859.730
7	National cement	Kiln 1 (wet), Kiln 2 (wet), Kiln 3, Kiln 4	3,031.951
8	Suez cement (Suez plant) (Italcementi group)	Kiln 1, Kiln 2	2,100,710
9	Suez cement (Kattameya plant) (Italcementi group)	Kiln 1	845,810
10	Suez Cement (Torah plant) (Italcementi group)	Kiln 5, Kiln 7, Kiln 8, Kiln 9	2,474,412
No.	**Company**	**Line Clinker**	**Production**
11	Helwan (Italcementi group)	Dry Kiln 1 (plant 2), Dry Kiln 2 (plant 2), wet Kiln 2(plant 1), wet Kiln 3(plant 1),wet Kiln 5(plant 1), wet Kiln 6 (plant 1), wet Kiln 1(plant 3), wet Kiln 2(plant 3)	4,009.340
12	El Minia (Italcementi group)	Kiln 1	287,666
13	El Arabeya cement	Kiln 1	2,030,428
14	CEMEX (Assiut cement)	Kiln 1, Kiln 2, Kiln 3	4,706,112
15	Lavarge Cement	Kiln 1, Kiln 2, Kiln 3, Kiln 4, Kiln 5	8,295,478
16	Misr bani suef (TITAN)	Kiln 1	1,573,844
Total			40,892,132

2.2. Cement manufacturing process

Raw materials should be mixed precisely to manufacture the cement. [16] The cement clinker requires appropriate amount of compositions of the elements calcium, silicon, aluminum and iron. All these raw materials together with the fuel as an energy consumption must be combined to form the typical clinker composition.[17] Fig. (2) shows a comprehensive cement manufacturing process.

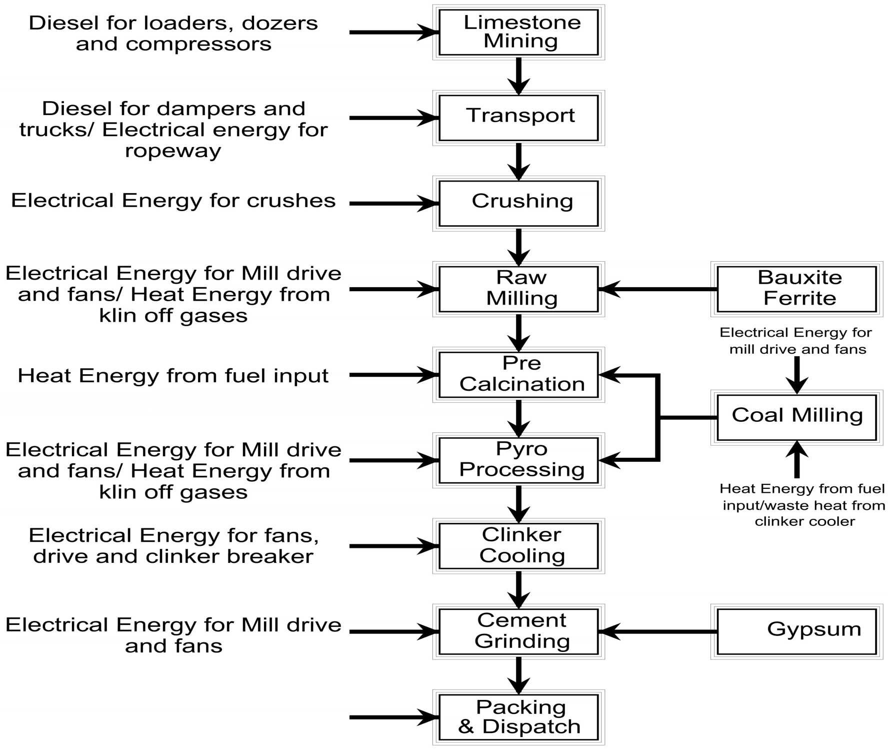


Fig. 2 The life cycle of the cement production
(raw material and the consumed Energy)

2.3. The Environmental Status of Cement Companies in Egypt

In 1994, the Egyptian Environmental Affairs Agency (EEAA) issued the Egyptian Environmental Protection Law number (4) and their executive regulation was issued for protection of the Egyptian environment. Limits for dust emissions from cement plants were 300 mg/m^3 for plants established before 1995, 200mg/m^3 for plants installed after 1995 and before issuance of the new amendments and 100 mg/m^3 for new plants. Nitrogen oxides (NO_x) and Sulfur oxides (SO_x) emission limits were set at 300 mg/m^3 and 4000 mg/m^3 respectively. Following ratification of Law 9 for the environment in 2009 the Ministry of State for Environmental Affairs and the EEAA developed new air emission standards, which are expected to be ratified by Parliament towards the end of 2010. The new standards for cement plant's dust emissions will thereby be more in line with international standards with 100 mg/ m^3 for old plants and 50 mg/ m^3 for new plants, SO_x is 400 mg/ m^3 and 600 mg/ $m^3$for NO_x. [14]

2.4. Cement Process Emissions

Cement is made from a mixture of calcium carbonate (generally limestone), silica, iron oxide and alumina. A high temperature kiln fuelled by natural gas or heavy fuel oil heats the raw materials to a partial melt at 1450º C, transforming them chemically and physically into clinker. Clinker is then ground with gypsum, flue ash and/or sand to make cement. Figure (3) shows the main sources of pollutants from cement production using the dry process. [14]

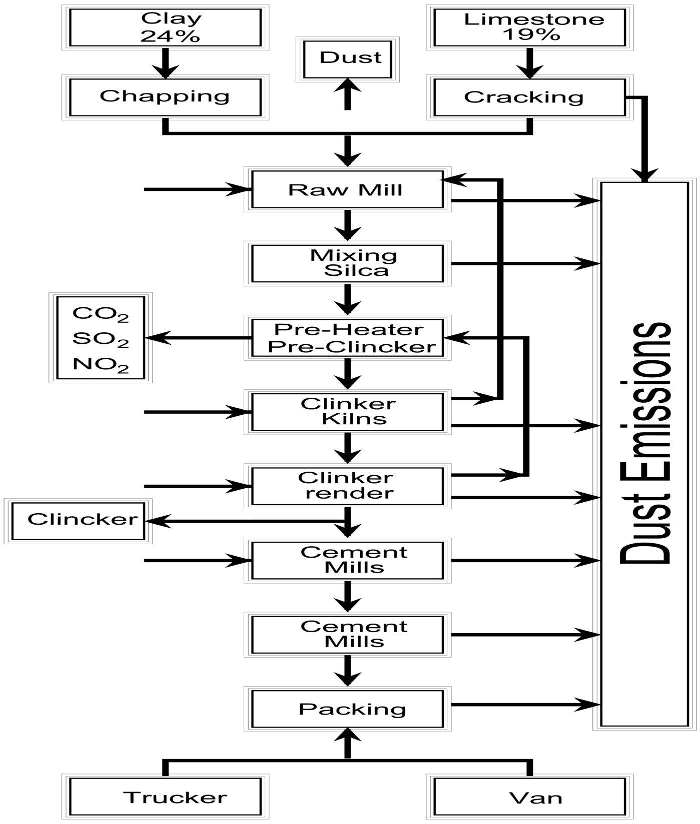


Fig. 3 Pollutions from Cement manufacturing - dry process

2.5. Cement plants in Egypt (case study)

The main components in the manufacture of cement are not different from the factory to another but differ in the amounts of these materials in factories, these material are lime stone,(Adobe Clay) sand ,slagand g gypsum, which called raw materials. Referring to the other materials such as energy and resources, consist of mazzut, natural gas, solar (diesel), water and electricity. Eventually, the emissions from the cement manufacturing are include dust emissions and gasses emissions (CO, SO_2 and NO_2).

2.6. The collected data form cement factories

To the best of the authors knowledge and from previous authors literature which published in [18], Egypt suffered from shortage of life cycle inventory database, thus, the researchers suggest collected the (input-output) database of Egyptian plant from the field visits. Table (2) shows the collected data during field visits & survey of the cement plants.

Table 2 Cement manufacturing data which collected from Egyptian cement plant

Consumption of raw materials By ton/year	Lime Stone	5978720
	Clay	528719
	Sand	0
	Slag/Iron Ore	624946
	Gypsum	207410
Consumptions	Electrical (MwH/Year)	641526
	Natural Gas (Ton/Year)	0
	Mazut (Ton/Year)	399790
	Solar (Diesel) (Ton/Year)	7984325
Emissions Mg/m^3	Dust	23648
	CO	512.48
	SO_2	25.27
	NO_2	130.69

- Solar (diesel) used in transportation of the materials in each stage by heavy trucks and the excavators in the raw material excavation stage.
- Natural Gas and Mazzut used in mechanical machines and other used Electrical power. (Which shown in figure (2)).

3. Assess the environmental impacts of cement industry

SimaPro V8.1 was used in the analysis of the two types of cement industry plant using the above inventory databases. SimaPro is a dedicated LCA software tool for undertaking LCA studies according to EN ISO 14040 [19] and EN ISO 14044 [20].

3.1. Goal and Scope

The main objective of this study is to contribute to the Environmental Impact Assessment of the cement industry in Egypt, by means of the adaptation of the LCA methodological process, in order to ease the stakeholders, decision makers and building material manufacturers, through the knowledge of the environmental impacts caused by technologies, procedures or materials used in cement industry. Therefore, a comparison has been performed between two different systems of the same cement plant in Egypt; regarding to the alternate fuel types. One of them is using electricity, natural gas, solar and mazzut as energy consumption and the second is a hypothetical plant operating using electricity and coal. Purpose of this study is for academic only but the outcomes and conclusions will be beneficial for Egyptian cement industry so as to tackle with environmental impacts and energy consumption. To make a fair comparison between the two systems, all of the inputs of life cycle inventory database are the same quantities in the two case studies in Egypt, because the second case study is still under development and thus it is hypothetical, taking into account, the minimal error rates of the results between the two Egyptian cement plants. Referring to the scope of the study focuses on the consumed fuels in these process; raw material acquisition, processing, and product manufacturing which are shown in Fig. (2). As for the functional unit; as cement industry is a manufacturer industry all the data collection and calculations in this study have been converted to be for 1 Kg basis.

3.2. Life Cycle Inventory database

Involves data collection and calculation procedures to quantify relevant inputs and outputs of a product system, such as; raw material from mines: lime stone, gypsum, clay, slag/ iron ore and Additions, Water use, Diesel use and Emissions; Dust emissions, Particulate matter emissions, gaseous emissions and heavy metals emissions. This study used the inventory data which collected from Egyptian cement plant as a case study and any missing data will take it from literature review, international papers, assumptions and Ecoinvent V.3 Database.

3.3. LCA Impact Assessment

The use of impact categories gives the ability to compare the environmental impacts of the different options. Characterization factors, or equivalency factors, describe the relative impact of the different environmental flows (ISO 2006). [21] A larger characterization factor means a larger impact for that flow. Characterization factors are multiplied by each of the environmental flows to convert all them into an equivalent amount of the category indicator. The category indicator is the flow that is usually associated with that particular impact category (CO_2 for global warming) [22] Table (3) describes the environmental impact categories which required for LCI inventory which involved in SimaPro V. 8.1; this study used the IMPACT 2002+ category to assess the environmental impacts from cement industry in Egypt.

Table 3 Sources for characterization factors and damage units of IMPACT 2002+(version Q2.2) [23]

[source]	Midpoint category	Midpoint reference substance	Damage category	Damage unit	Normalized damage unit
[a]	Human toxicity (carcinogens + non-carcinogens)	kg Chloroethylene into air-eq	Human health	DALY	Point
[b]	Respiratory (inorganics)	kg PM 2.5 into air-eq	Human health		
[b]	Ionizing radiations	Bq Carbon-14 into air-eq	Human health		
[b]	Ozone layer depletion	kg CFC-11 into air-eq	Human health		
[b]	Photochemical oxidation (= Respiratory (organics) for human health)	kg Ethylene into air-eq	Human health Ecosystem quality	n/a	n/a
[a]	Aquatic eco-toxicity	kg Triethylene glycol into water-eq	Ecosystem quality	PDF·m^2·y	Point
[a]	Terrestrial ecotoxicity	kg Triethylene glycol into soil-eq	Ecosystem quality		
[b]	Terrestrial acidification/nutrificati	kg SO^2 into air-eq	Ecosystem quality		

[source]	Midpoint category	Midpoint reference substance	Damage category	Damage unit	Normalized damage unit
	on				
[c]	Aquatic acidification	kg SO^2 into air-eq	Ecosystem quality		
[c]	Aquatic eutrophication	kg PO43- into water -eq	Ecosystem quality		
[b]	Land occupation	m^2 Organic arable land-eq · y	Ecosystem quality		
	Water turbined	inventory in m^3	Ecosystem quality		
[IPCC]	Global warming	kg CO^2 into air-eq	Climate change (life support system)	kg CO_2 into air-eq	Point
[d]	Non-renewable energy	MJ or kg Crude oil-eq (860 kg/m^3)	Resources	MJ	Point
[b]	Mineral extraction	MJ or kg Iron-eq (in ore)	Resources		
	Water withdrawal	inventory in m^3	n/a		
	Water consumption	inventory in m^3	Human health Ecosystem quality Resources		

[a]IMPACT 2002, [b]Eco-indicator 99, [c]CML 2002, [d] Ecoinvent, [IPCC] (IPCC AR5 Report), and [USEPA] (EPA). DALY= Disability-Adjusted Life Years; PDF= Potentially Disappeared Fraction of species; -eq= equivalents; y= year.

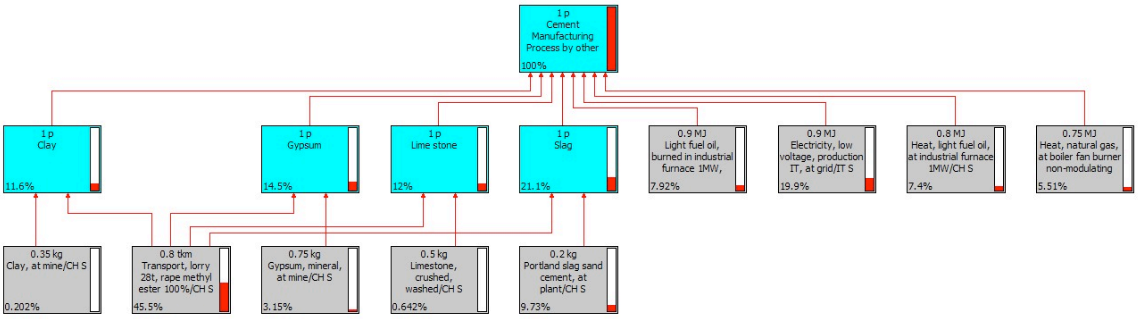
In LCA-type models, two main methods in describing impacts can be distinguished [7]: the first is at the level of midpoint impacts, covering issues such as climate change, abiotic resource depletion and others. The second include the study used the endpoint impacts, covering issues such as [1]:

- Human health damage, expressed as the number of years of human life lost or in suffering from disease, which expressed in Disability Adjusted Life Years (DALY).
- Quality of ecosystems, expressed as the loss of living species in a certain area over a time.
- Natural resources, expressed as the surplus of energy necessary for further extracting minerals and fossil fuels.

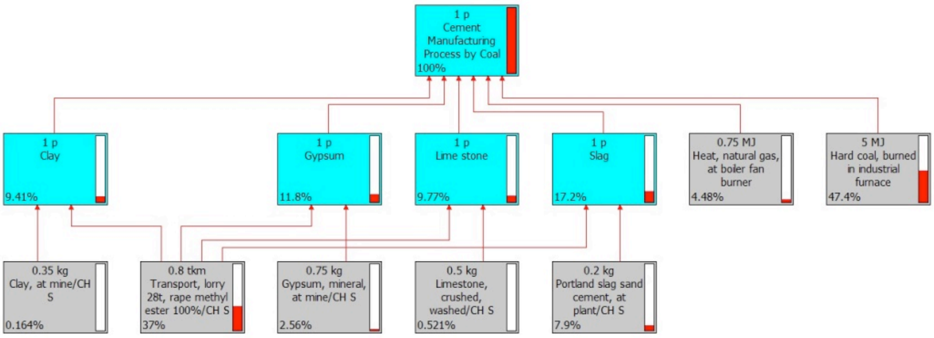
3.4. Result, Discussion and Interpretation

It should be highlighted that the assembly of cement industry links to the processes, which describe the materials, production, transport and energy processes that are needed to produce the reference flow of 1 KG cement defined in section 2.6.

At this stage the basic model of the cement production cycle is built by creating the unit processes identified in section 2.6 and interconnecting them into an assembly network through "known outputs to technosphere (products and co-products)". A list with the processes used in the model is provided in Fig. (2), whereas the model networks of the two cases created are shown in Fig. (4). In this case the classification into categories was based on the unit, with which the product output is defined.



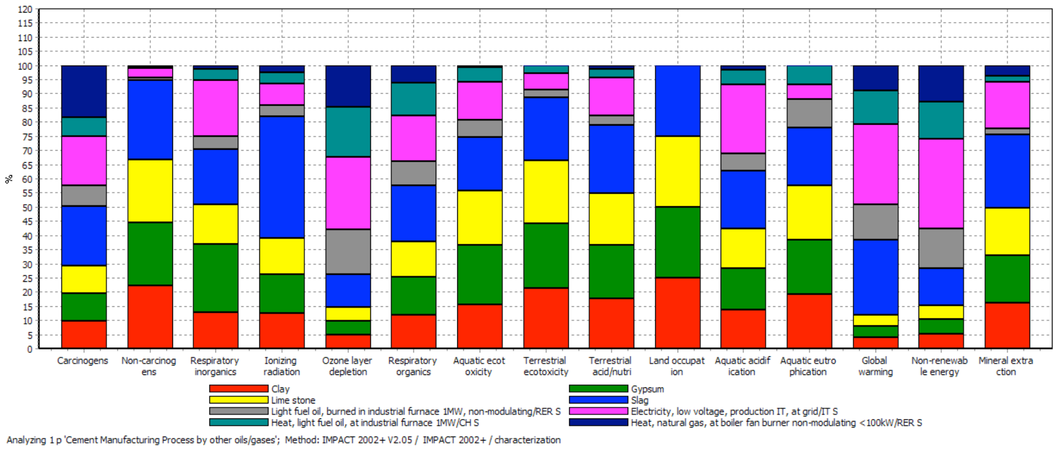
(a) Energy consumption in cement industry plant based on electricity, natural gas, solar and mazzut as Energy sources.



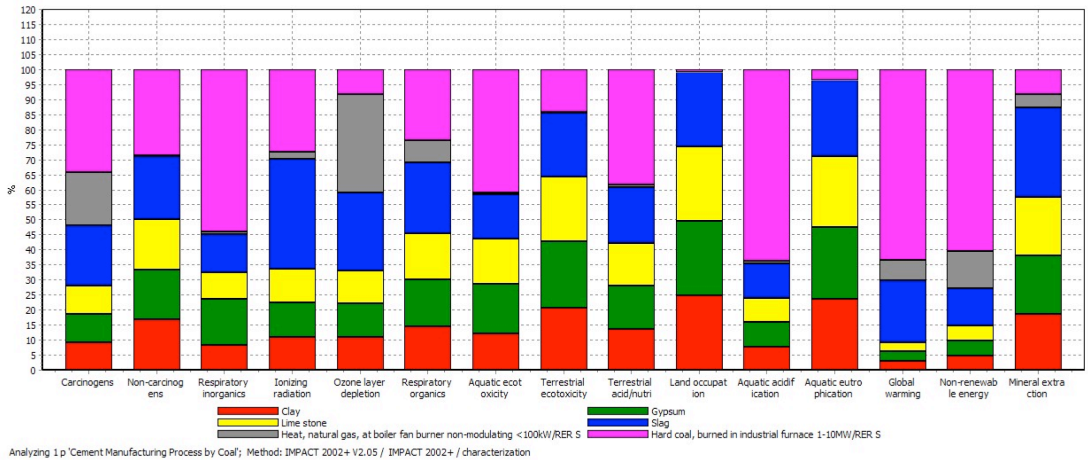
(b) Energy consumption in cement industry plant based on electricity and coal as Energy sources.

Fig. (4) The network flow diagram of the two cases studies based on SimaPro.

Figure (5) presents the relative impacts produced by each energy sources in each phase of the Egyptian cement plant. It is observed that the respiratory organics, aquatic acidification, global warming (climate change) and the non-renewable energy have higher impact than the ordinary process by 35, 60, 35 and 35% respectively. Consequently, the main high bad effect resulting from the use of coal is the SO_2 compound that is produced from the plant chimney during the oven stage. To get rid from the SO_2 emissions we should use the technology which used in the European plant such as the scrubbers which removes, or "scrubs," the SO_2 emissions from the exhaust of coal-fired kiln.



(a) The life cycle impact assessment of the Egyptian Cement Plant by using electricity, natural gas, solar and mazzut.



(b) The life cycle impact assessment of the Egyptian Cement Plant by using electricity and coal.

Fig. (5) Environmental impact assessment of the two Egyptian cement plants

Figure (6) shows the comparison of Life Cycle Environmental Impact between the two analyzed case studies, based on the Midpoint method; the overall impact of coal is higher. The main contributing categories to this higher impact are global warming potential and respiratory inorganics (see Table 3 the identification of these impacts in the IMPACT 2002+ category) where they represent 20% and 25% from the overall 100% impact respectively. This mainly attributed to the difference of the chemical composition of the coal and the other fuels which are used in the oven process. Furthermore, using coal in the cement plant has high adverse environmental impacts by 20% in total (60 Ecopoint), this percentage is not ineffective, we can reducing it by using European technology such as the scrubbers and reach to the ordinary case.

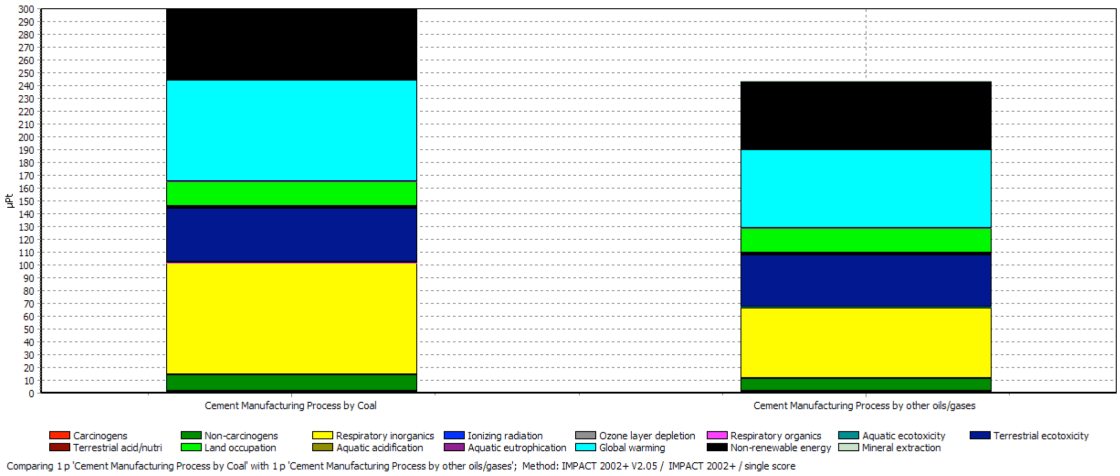


Fig. (6) The comparison of Environmental Impact Categories of the two Egyptian cement plant (Midpoint Method)

On the other hand, the damage assessment (been mentioned in the section 3.3) based on the endpoint method indicates that both of the human health damage (DALY) and climate change damages are higher in case of using coal in cement industry as clear from Figure (7). Their relative contributions are 30% and 25% respectively.

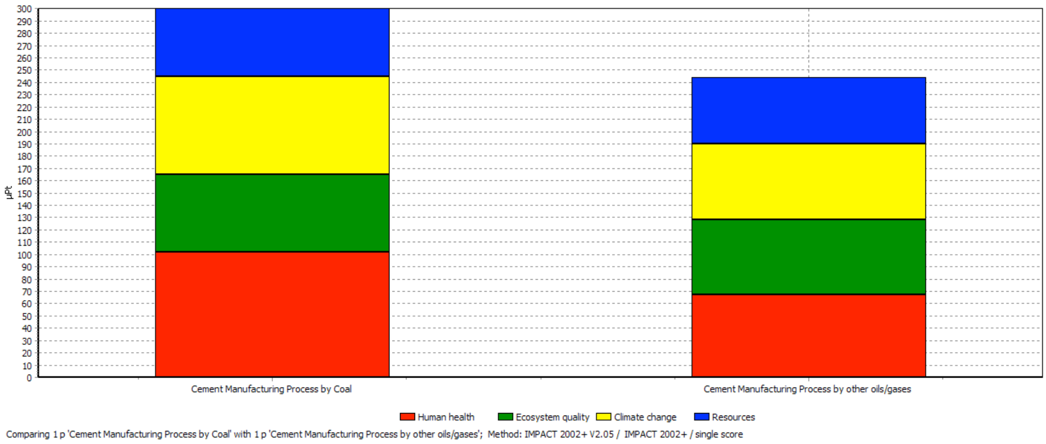


Fig. (7) The damage assessment of the two Egyptian cement plants (Endpoint Method)

4. Conclusion

This paper compares the environmental impacts of a typical cement industry in Egypt considering different sources of energy compared to coal. Discussion of results revealed that using coal in cement industry produce 20% adverse environmental impact (global worming) and 25% respiratory inorganics compared to other sources based on the midpoint impact method. From the endpoint method point of view, the expected damages are higher in both of the human health damage (DALY) and climate change categories where their relative contribution are 30% and 25% respectively if cement is used coal compared to other sources. However, the adverse environmental impacts of coal can be minimized by activating the environmental laws through the Egyptian Environmental Affairs Agency (EEAA) and encouraging cement industry to utilize new technologies through set of incentive policies and using the European technology such as the scrubbers.

5. Recommendations

The authors highlight the following suggestions which if implemented might be highly contributed in reducing the environmental impacts associated with coal-based-cement industry:

- Developing national policy to systemize supply on long term basis for consistent quality waste derived fuel.
- The difference of the coal chemical composition which used has a significant environmental impact positively and negatively.
- Clean coal technology is a collection of technologies being developed to mitigate the environmental impact of coal burning such as the scrubbers, must have an important role in Egyptian cement plants.
- Encouraging production of low energy cement and incentivizing the use of wastes as raw materials / fuels.
- Using sustainable fuels and raw materials to reduce the environmental impact from the quarrying and the grinding process.
- Developing and applying comprehensive norms for cement industry (covering all pollutants, when coal and/or alternate fuels are used.)
- Involving reliable and acceptable LCA for cement industries as well other industry based on Egyptian conditions and encouraging cement plants to take up LCA studies voluntarily for continual improvement

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