A Comparative Life Cycle Assessment Study of Conventional and Best Available Techniques Incorporated Cement Production Processes using midpoint approach.

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Abstract

The construction industry is responsible for several environmental impacts because of various industrial activities. Quantifying these impacts is a major roadmap to reducing them. This study carried out a comparative life cycle assessment (LCA) on two cement plants using the midpoint (problem-oriented approach): Cementos Cosmos S.A. Spanish cement plant (with Best Available Techniques Reference Document –BREF- incorporation) and a typical European plant to quantify the environmental impacts' gains in cement production. The analysis was based on the Functional Unit of 1ton of cement produced in each plant, and the LCA software used was SimaPro 8.2. The result of the analysis showed that the impact categories from Cementos Cosmos S.A. plant had significant reduction when compared with the impact categories from European plant analysis. However, Ozone depletion increased by 5% as a result of high quantity of petroleum coke used in Cementos Cosmos S.A. plant. Also, Climate change has not a great reduction, this is also due to high amount of limestone used in the production process of the cement plant; These however influenced the entire result of the analysis. These results show that the BREF recommendations are very effective as there is great improvement in the environmental performance however, further reduction of fossil fuels (petcoke) and limestone should be considered.

Keywords
Midpoint, Cement, LCA, LCIA, BREF.

1. Introduction
The construction sector is one of the largest industrial sectors as it is one of the highest resource-intensive sectors. These resources range from natural raw materials to industrial energy, which however generate great environmental impact. The construction sector in 2018 account for about 39% of the global CO_2 emissions and 36% of the global energy used (Abergel, Dulac et al. 2019). As at 2017, raw material consumed by this sector was about 90 Gt which will continue to increase as long as there is reproduction of human being (Madlool, Saidur et al. 2011). In 2010, the global cement production was about 310 Mt worldwide and 191 Mt out of it was produced in the European Union (EU-27) (CEMBUREAU 2011). Of this production from the European union, 23.5 Mt was produced in Spain (OFICEMEN 2010a).

The continuous production in the global cement industry is a result of the global population growth. With increment in the population, there is need to build urban landscape and infrastructures to accommodate the increase (Franzoni 2011). The cement industry is of great importance as it is needed by every individual and it is the major constituent of concrete needed in the construction sector. However, the industry is challenged with different impacts that affect the environment. Cement is of great importance as it is needed for continuity of life by building sustainable environment. However, the cement industry is faced with different environmental consequences that does not only affect species but human beings equally. One of these consequences is global warming which brings about changes in the climatic conditions; due to high Greenhouse gas (GHG) emission into the atmosphere. Also, another environmental impact associated with this industry is high energy consumption during production as this can be a source of greenhouse gas and other pollutant and increase the production cost. It is important to conserve energy by improving the energy consumed by this industrial sector. In addition, the cement industry is highly resource-intensive: raw material. With the high usage of resources in this industry, there would be scarcity of raw material if care is not taken, as there are no measures for the preservation of the materials.

In 2016, the construction in Spain stopped evolving positively when compared to the previous year. The global production of gray clinker in Spain reached 17.30 Mt in 2015, this represents about 1.8% increase. However, in 2015, the production of gray cement reduced to 14.15 Mt which represents about 1.2% decrease. Cement consumption presented a negative behavior, losing great part of the increase achieved during 2015, to stand at the end of the year at a figure of 11.08 million tons with a 3.6% decrease but export increased by 4.4%. Foreign trade was the only one whose evolution in the year was reasonably positive, since exports registered an increase of 5.8%, reaching a volume of 9.80 Mt, and imports are reduced by 19.3% with a volume of 0.36 Mt. Table 1represent the production data of gray cement in different region of Spain (OFICEMEN 2016 (In English: Annual report 2016)).

Table 1: Gray cement production in ton in the Spanish cement sector by zones (companies associated with Oficemen) *(OFICEMEN 2016 (In English: Annual report 2016))*

Zonas producción	2014	2015	2016 (1)	Variación 2015 / 2014		Variación 2016 (1) / 2015	
				Absoluta	%	Absoluta	%
Andalucía	2.624.950	2.576.489	2.611.748	-48.461	-1,8%	35.259	1,4%
Cataluña	2.248.186	2.280.328	2.533.402	32.142	1,4%	253.074	11,1%
Centro	3.135.954	3.444.276	3.338.994	308.323	9,8%	-105.282	-3,1%
Norte	1.686.297	1.688.844	1.753.101	2.547	0,2%	64.257	3,8%
Oeste	2.844.100	2.820.494	2.521.605	-23.606	-0,8%	-298.889	-10,6%
Total zonas	12.539.488	12.810.431	12.758.850	270.943	2,2%	-51.581	-0,4%

The European Integrated Pollution Prevention and Control Bureau (EIPPCB) was established in 1997 in the EU to facilitate the exchange of information on Best Available Techniques (BAT) referred to in the Integrated Pollution Prevention and Control Directive (IPPC), associated monitoring, and developments in environmental protection between Member States, industry, and non-governmental organizations. The European IPPC Bureau is a results-driven organization that creates Best Available Techniques reference documents (BREF). BREF are a set of reference documents that cover as many industrial activities as possible. They describe a variety of industrial processes, including their operating parameters and emission rates, among other things. This document is based on information gathered from a variety of sources, via the technical working group (TWG) created under Article 13 of the Directive specifically for exchanging information. The European IPPC Bureau (of the Commission's Joint Research Centre), which heads the team on determining BAT, collects and evaluates the data; technical expertise, transparency, and neutrality are the guiding principles. The European Commission’s latest BREF for cement production was published in 2013.

With the European Commission’s announcement of having EU to be the first carbon-neutral continent by 2050, Spain as a member country have not relented in her effort to reduce emissions from different sectors to bring this ambition into fruition. Therefore, Spain passes a bill to reduce emissions by 39% by 2030; this will require all sectors to sit-up in their CO_2 emissions. A country with an increasing population requires infrastructure to support this growth. The construction industry supports this growth by building necessary structures that will accommodate environmental sustainability. This research therefore aims to compare the environmental impact of a typical Spanish cement industry located in the Autonomous Community of Castilla y León that has incorporated some of the recommendation of Best Available Techniques (BAT) Reference Document for the Production of Cement, (BREF) with the environmental impact of a typical European plant that hasn't incorporated these recommendations so as to quantify the environmental gains of incorporating BREF into a production process.

2. Method

Life cycle assessment (LCA) is a methodology tool used for analyzing the environmental implication of process or product by taking cognizance of the potential effect of the entire cycle chain of such process or product. This assessment is done throughout the cycle of such product or process, i.e., from start to finish. By this, LCA has its other name known as "cradle-to-grave/gate" or "cradle to cradle". LCA was developed over three decades ago primarily to support decision-making (Young, Turnbull et al. 2002, Ailleret 2004). The effective application of LCA is a function of the intended goal of the study. The four stages of LCA recommended by ISO are: Goal and scope definition, Life cycle Inventory Analysis (LCI), ISO - Life Cycle Impact Assessment (LCIA), and Interpretation as represented in figure 1.

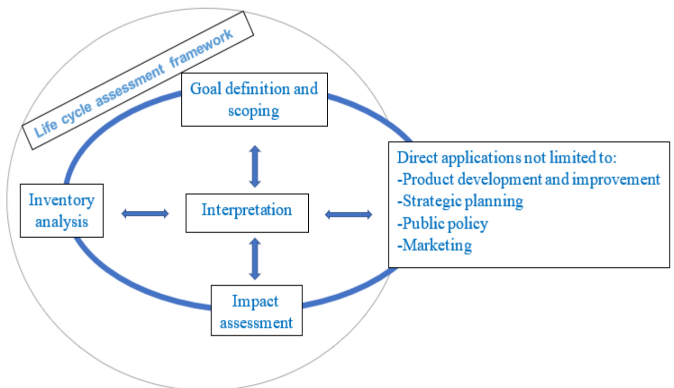


Figure 1: Adapted LCA phases and applications (Standardization 2006)

In LCA analysis, LCIA method presents a broader view of the system understudied as well as the calculations of such systems. This is because these methods make use of specific factors in its analysis. This in turn simplify the analysis carried out (Olagunju and Olanrewaju 2021). ReCiPe is a LCIA method that helps to evaluate the impact category using both endpoint and midpoint approach. The development of ReCiPe was an attempt to harmonize the midpoint and endpoint methods and in so doing eliminate the need to select LCIA method in LCA model (Goedkoop, Heijungs et al. 2013). Midpoint gives a scientific, cause and effect evaluation of wide range of environmental impacts (Bare 2010). In the midpoint approach, flows are categorized into environmental impact to which they contribute. The characterization result of the midpoint approach for a global scale presents 18 impact categories which cover several impacts: Climate change, agricultural land occupation, metal depletion, water depletion, urban land occupation, human toxicity, freshwater ecotoxicity, marine ecotoxicity, particulate matter, terrestrial acidification, ionizing radiation, ozone depletion, photochemical oxidation, marine eutrophication, fossil depletion, freshwater eutrophication, natural land transformation, terrestrial ecotoxicity (Barcelo, Kline et al. 2014, Olagunju and Olanrewaju 2020).

The comparative life cycle assessment in this study will be carried out from the cradle to the grave i.e., from extraction of raw material to production of cement; noise, workers, administration, packaging, recycling or reuse data will not be incorporated into the analysis. Analysis will be carried out based on 1ton of cement produced from both cement plant. The impact assessment method that will be used for this analysis is Europe ReCiPe: midpoint approach for European scale. Further analysis will be done on impact categories with a relatively large value. The characterization and normalization result will be considered in the midpoint approach. Inventory data that is used for this study is primary data from Cementos Cosmos S.A. cement plant, while the dataset for the European cement plant will be taken from Ecoinvent database incorporated into the software used for this analysis. This approach helps to simplify numerous flows by streamlining them into few prevalent environmental impacts. The software used for this assessment is SimaPro 8.2 (Pré Consultants 2016). SimaPro is known to be one of the best software suitable for the cement industry (Olagunju and Olanrewaju 2020). All inventory data used for the assessment is taken from Ecoinvent which is incorporated in the software (Ecoinvent 2019).

3. Results and discussion

The Cementos Cosmos S.A. plant in Toral de los Vados is designed for the production of clinker and different types of gray cement. The BREF recommendation incorporated into the Cementos Cosmos S.A. plant are:

- use of alternative fuel, use of waste as fuel,
- reduction of the use of fossil fuel (coal),
- reduction of the quantity of clinker used in cement production,
- partial replacement of clinker with alternative materials.

European cement plant on the other hand represents the production process in a typical European plant. The production data is taken from Ecoinvent database. The midpoint characterization result of 1ton of cement produced from this plant is as presented Table 1. Further analysis was carried out on these impact categories to know the production process that contribute to them. The analysis was carried out based on five production processes are: (1) Clinker production (2) Raw material consumption (3) Electricity usage (4) Fuel consumption (5) Transportation. This is as represented in Figure 2.

Table 2: Midpoint Characterization result of 1 ton of cement in European cement plant.

Impact Category	Unit	Value
Climate change	kg CO_2 eq	870
Ozone depletion	kg CFC-11 eq	2.62E-05
Terrestrial acidification	kg SO_2 eq	2
Freshwater eutrophication	kg P eq	0.074882
Marine eutrophication	kg N eq	0.070968
Human toxicity	kg 1.4-DB eq	82
Photochemical oxidant formation	kg NMVOC	1
Particulate matter formation	kg PM10 eq	0.63616
Terrestrial ecotoxicity	kg 1.4-DB eq	0.014323
Freshwater ecotoxicity	kg 1.4-DB eq	2
Marine ecotoxicity	kg 1.4-DB eq	2
Ionising radiation	kBq U235 eq	30
Agricultural land occupation	m^2a	11
Urban land occupation	m^2a	2
Natural land transformation	m^2	0.052711
Water depletion	m^3	2
Metal depletion	kg Fe eq	8
Fossil depletion	kg oil eq	75

The Clinker production phase has significant impact on climate change (87.1%), photochemical Oxidation (71.9%), terrestrial acidification (60%), marine eutrophication (56.3%), particulate matter (49.3%), Terrestrial ecotoxicity (28.9). This is in line with Güereca *et al.* in their study where they presented that clinkerization have significant contribution to GWP, acidification, eutrophication, and photochemical oxidation (Güereca, Torres et al. 2015). Also, this is in line with Stafford *et al.* in their study concluded that clinkerization yields a high contribution to acidification potential (Stafford, Raupp-Pereira et al. 2016).

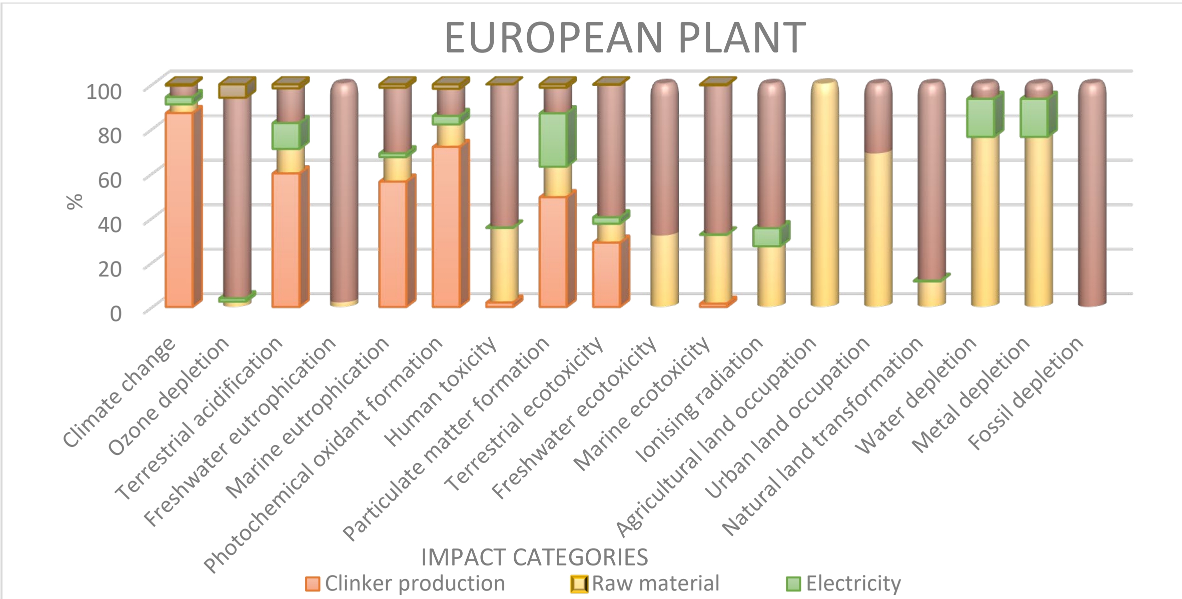


Figure 2: Contribution of five production processes to impact categories (European plant).

We can also see that Raw material consumption contributes significantly to agricultural land occupation (100%), metal depletion (99%), water depletion (76.4%), urban land occupation (68.9%); contribution to other impact categories such as human toxicity (33.5%), fresh water ecotoxicity (32%), marine ecotoxicity (30.9%) are relatively low. Electricity usage had low contribution to these impact categories: particulate matter (24%), water depletion (17.1%), terrestrial acidification (11.6%), ionizing radiation (8.1%). In the same vein, transportation have very low contribution to ozone depletion, photochemical oxidation, terrestrial acidification, marine eutrophication and particulate matter with 6%, 2%, 1.8%.1.5%,1.5% respectively. Fuel consumption has high contribution to fossil depletion (100%), freshwater eutrophication (98%), ozone depletion (90.1%), natural land transformation (88.2%), fresh water ecotoxicity (68%), marine ecotoxicity (67%), human toxicity (64.3%), other relatively low contributions are urban land occupation (31.1%), marine eutrophication (29.5%), terrestrial acidification (15.6%), photochemical oxidation (12.2%).

The midpoint characterization results of 1ton of cement produced from Cementos Cosmos S.A. cement plant is as presented Table 3. Further analysis was carried out on these impact categories to know the production process that contribute to them. The analysis was carried out based on five production processes are: (1) Clinker production (2) Raw material consumption (3) Electricity usage (4) Fuel consumption (5) Transportation. This is as represented in Figure 3.

Table 3: Midpoint Characterization result of 1 ton of cement in Cementos Cosmos S.A. cement plant.

Impact Category	Unit	Value
Climate change	kg CO_2 eq	685
Ozone depletion	kg CFC-11 eq	2.76E-05
Terrestrial acidification	kg SO_2 eq	0.507591
Freshwater eutrophication	kg P eq	0.018004
Marine eutrophication	kg N eq	0.016632
Human toxicity	kg 1.4-DB eq	25
Photochemical oxidant formation	kg NMVOC	0.393368
Particulate matter formation	kg PM10 eq	0.259943

Terrestrial ecotoxicity	kg 1.4-DB eq	0.0048
Freshwater ecotoxicity	kg 1.4-DB eq	0.451532
Marine ecotoxicity	kg 1.4-DB eq	0.417274
Ionising radiation	kBq U235 eq	26
Agricultural land occupation	m^2a	5
Urban land occupation	m^2a	6.59E-01
Natural land transformation	m^2	0.051224
Water depletion	m^3	0.689655
Metal depletion	kg Fe eq	7
Fossil depletion	kg oil eq	57

As shown in Figure 3, the Clinker production phase has a significant impact on climate change (89.2%), other contributions are: human toxicity (38.7%), terrestrial toxicity (15.2%) photochemical Oxidation (11.1%). The highest contribution of clinker production process to climate change has the same trend with other studies (Huntzinger and Eatmon 2009, Valderrama, Granados et al. 2012, Chen, Hong et al. 2015, Güereca, Torres et al. 2015) (Güereca et al., 2015; Galvez-Martos and Schoenberger, 2014; Valderrama et al., 2012; Chen et al., 2010; Huntzinger and Eatmon, 2009; Stafford et al., 2016a).

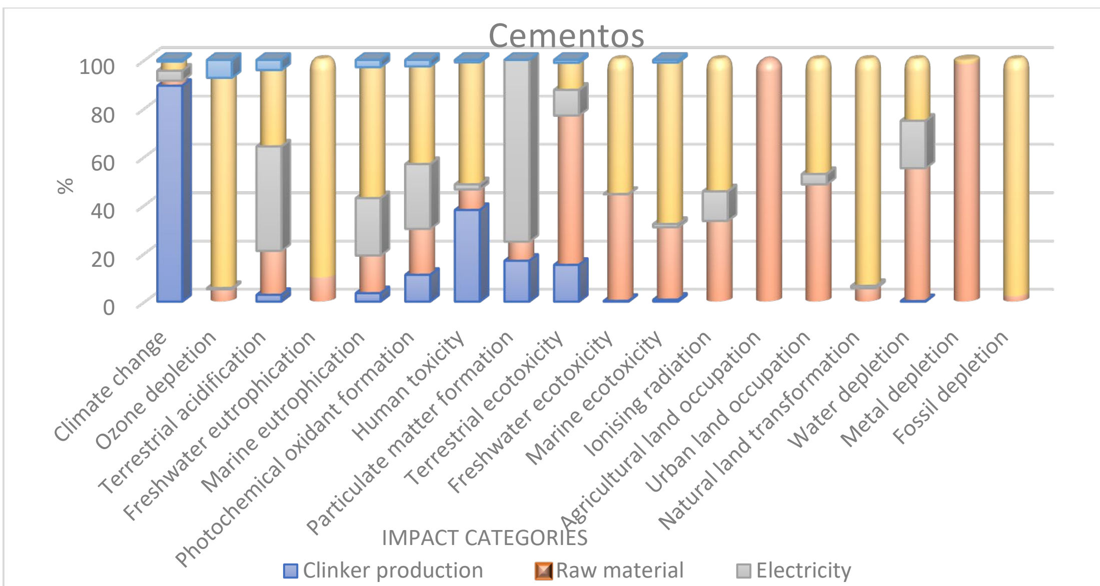


Figure 3: Contribution of five production processes to impact categories (Cementos Cosmos S.A. plant).

Raw material consumption contributes significantly to agricultural land occupation (100%), metal depletion (98.2%), terrestrial ecotoxicity (61.8%), water depletion (55%), urban land occupation (48.5%), freshwater ecotoxicity (44.1%); contribution to other impact categories such as ionizing radiation (33.4%), marine ecotoxicity (30%), particulate matter (19.7%), photochemical oxidation (19%), and terrestrial acidification (18.2%) are relatively low. Electricity usage has relatively low contribution to these impact categories: terrestrial acidification (43.2%), particulate matter (34.4%), photochemical oxidation (26.8%), marine eutrophication (23.7%), water depletion (19.6%), ionizing radiation (12.2%).

Also, transportation has very low contribution to ozone depletion, terrestrial acidification, marine eutrophication, photochemical oxidation, and particulate matter with 7.5%, 4.2%, 3%, 2.7%, 2.2% respectively. Fuel consumptions have high contribution to fossil depletion (97.8%), natural land transformation (93.5%), freshwater eutrophication (90.1%), ozone depletion (87%), marine ecotoxicity (66.8%), freshwater ecotoxicity (55.5%), ionizing radiation

(54.5%), human toxicity (50.3%), urban land occupation (47.2%), particulate matter (42%), photochemical oxidation (40.4%), other relatively low contributions are terrestrial acidification (31.6%), water depletion (25%), terrestrial ecotoxicity (11.2%). This result is in line with one of the findings of F. N. Stafford *et al*. in their study the evaluation of the environmental impact of cement when waste is used as a partial substitution for fossil fuel in a cement plant in Southern Europe (Stafford, Dias et al. 2016).

The characterizations result of the two plants is comparatively presented in Table 4. As seen in Table 4, all impact categories reduced, except for Ozone depletion. Marine ecotoxicity (-79.1%), Freshwater ecotoxicity (-77.4%), Marine eutrophication (-76.6%), Freshwater eutrophication (-75.8%), Terrestrial acidification (-75%), Human toxicity (-69.5%), Urban land occupation (-67.1%), Terrestrial ecotoxicity (-66.5%), water depletion (-65.5%), Photochemical oxidant formation (-60.7%), Particulate matter formation (-59.1), Agricultural land occupation (-54.4%) and decreased significantly.

Table 4: Comparison of the Characterization result of the midpoint analysis of the two cement plants

Impact Category	Unit	EUROPEAN PLANT Value	CEMENTOS COSMOS Value	Change (%)
Climate change	kg CO_2 eq	870	685	- 21.3
Ozone depletion	kg CFC-11 eq	2.62E-05	2.76E-05	+5
Terrestrial acidification	kg SO_2 eq	2	0.507591	-75
Freshwater eutrophication	kg P eq	0.074882	0.018004	-75.8
Marine eutrophication	kg N eq	0.070968	0.016632	76.6
Human toxicity	kg 1.4-DB eq	82	25	-69.5
Photochemical oxidant formation	kg NMVOC	1	0.393368	-60.7
Particulate matter formation	kg PM10 eq	0.63616	0.259943	-59.1
Terrestrial ecotoxicity	kg 1.4-DB eq	0.014323	0.0048	-66.5
Freshwater ecotoxicity	kg 1.4-DB eq	2	0.451532	-77.4
Marine ecotoxicity	kg 1.4-DB eq	2	0.417274	-79.1
Ionising radiation	kBq U235 eq	30	26	-13.3
Agricultural land occupation	m^2a	11	5	-54.4
Urban land occupation	m^2a	2	6.59E-01	-67.1
Natural land transformation	m^2	0.052711	0.051224	-2.8
Water depletion	m^3	2	0.689655	-65.5
Metal depletion	kg Fe eq	8	7	-12.5
Fossil depletion	kg oil eq	75	57	-24

From the analysis represented in Figure 3, we see that the major production processes associated with the above-mentioned impact categories are raw material consumption and fuel consumption. According to the process contribution analysis in SimaPro, these two processes involve mining and extraction of resources alongside production and processing of such resources, i.e., getting the extracted material ready to be used in the cement production processes (Çankaya and Pekey 2019). Therefore, this reduction is due to a reduction in the resources mined and extracted, compared to the resources used in a typical European plant. Therefore, adopting some of the BREF recommendation results into significant reduction in various impact categories. Reduction in the use of fossils will reduce the level of mining impact, which will consequently reduce the above-mentioned impact categories that are affected by mining and extraction processes.

Notice that Ozone depletion is also associated with raw material consumption and majorly with fuel consumption; however, it increased slightly by 5%. Ozone depletion occurs when a high concentration of anthropogenic emissions of chemicals with high chlorine or bromine content is released into de air; notice its unit is in Trichlorofluoromethane equivalent (CFC-11 eq). Güereca *et al*., in their work, stated the process of producing petroleum coke from crude oil emits chlorofluorocarbons (CFC). In the LCI analysis, petroleum coke has the highest value of all the fossil fuels used though the value of ozone depletion obtained from this analysis and is still within the range 5.11E-04 CFC-11 eq to 6.40E-08 CFC-11 eq opined in previous studies (Usón, Ferreira et al. 2012, Valderrama, Granados et al. 2012, Saade, da Silva et al. 2015, Georgiopoulou and Lyberatos 2018). As shown in table 4, climate change reduced by 21%. The reduction is not significant because more amount of limestone is still used for the production process. As earlier seen in the analysis in figure 3, the clinker production process has the highest contribution to this impact category. The clinker production phase is where the clinker is produced in the kiln, also known as clinkerization. This phase involves the chemical decomposition of limestone ($CaCO_3$) to give quick lime (CaO) and carbon dioxide (CO_2).

Further analysis was carried on four top impact categories with the highest value to know the substances emitted and the medium to which they were emitted. In both cement plants, climate change, human toxicity, ionizing radiation and fossil depletion impact categories were further analyzed and compared.

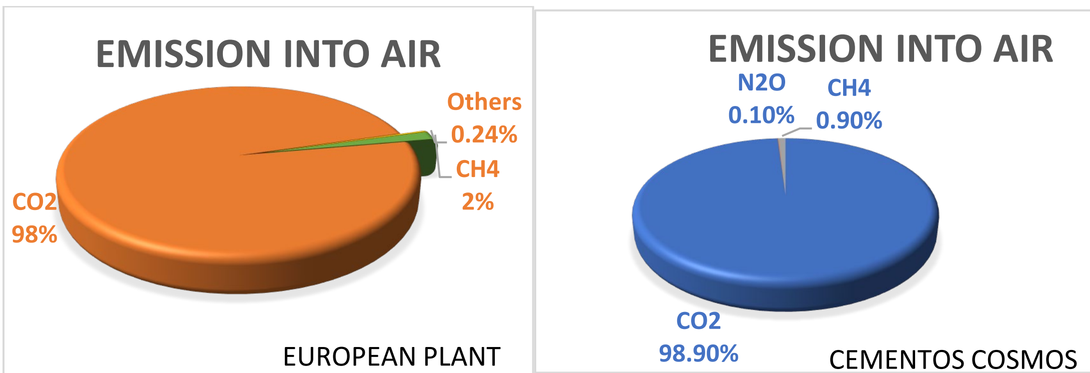
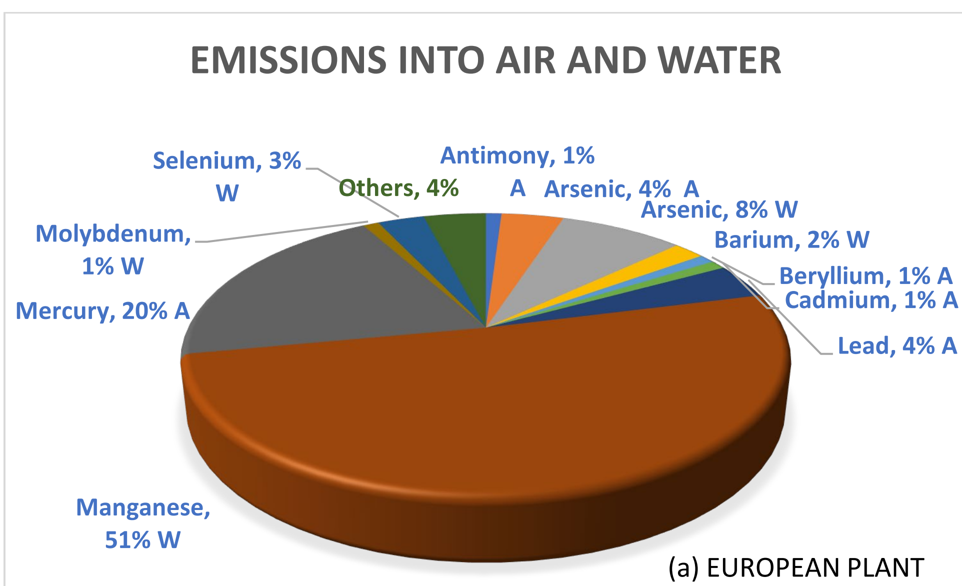


Figure 4: Analysis on Climate Change in the cement plants.

From tables 2 and 3, climate change has a value of 870 kg CO_2 eq and 685 kg CO_2 eq for European plant and Cementos Cosmos S.A. respectively. From figure 4, we see that for the European plant 98% of CO_2 is emitted into the air which means that for every 1ton cement produced in this plant, 852.6kg of CO_2 is emitted into the air while in Cementos Cosmos S.A. cement plant, 677.5kg of CO_2 is emitted. This shows that there is a reduction of about 175kg of CO_2 emitted into the atmosphere when some BREF recommendations are incorporated into the production process as in the case of Cementos Cosmos S.A. cement plant.



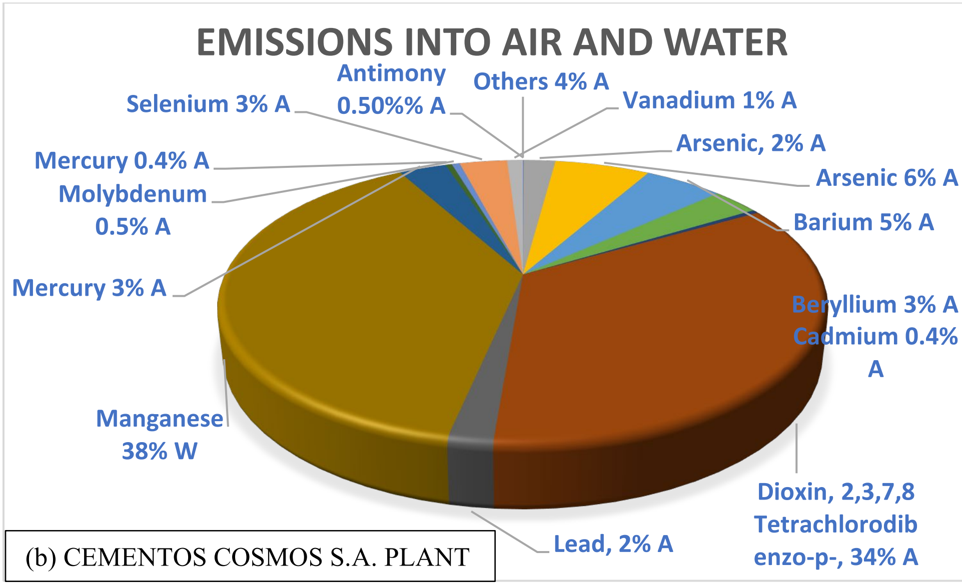


Figure 5: Analysis on Human toxicity in (a) European plant and (b) Cementos Cosmos SA plants.

From tables 2 and 3, human toxicity has a value of 82 kg 1.4-DB eq and 25 kg 1.4-DB eq for European plant and Cementos Cosmos S.A. respectively. From figure 5, we see that for the European plant 51% of manganese is emitted into the waterbody, which means that for every 1ton cement produced in this plant, 41.8 kg of manganese is emitted into the air while in Cementos Cosmos S.A. cement plant, 9.5 kg of manganese is emitted. This shows that there is a reduction of about 32.3 kg manganese emitted into the waterbody.

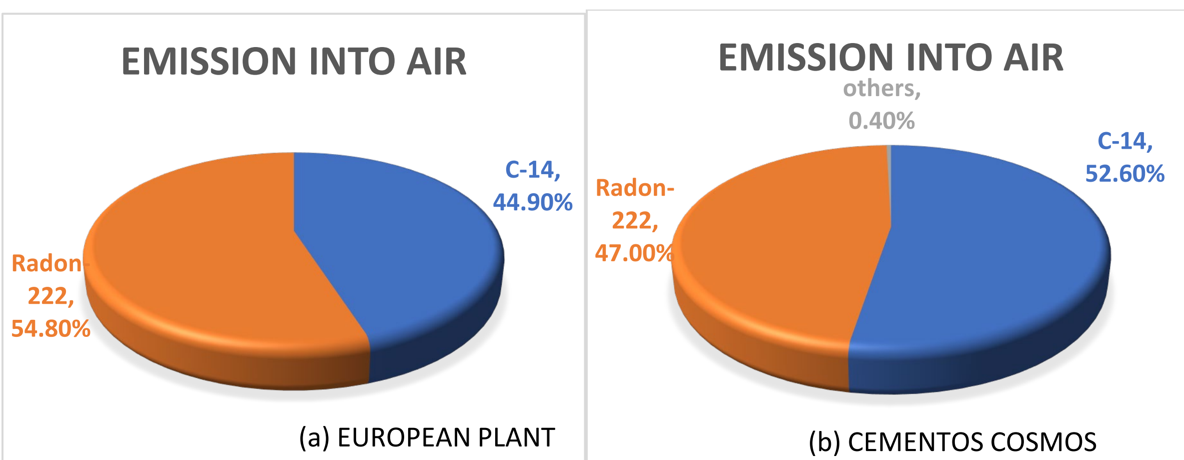


Figure 6: Analysis on Ionizing radiation in (a) European plant and (b) Cementos Cosmos plant

As presented in table 2 and 3, 9onizing radiation has a value of 30 kBq U235 eq and 26 kBq U235 eq for European plant and Cementos Cosmos S.A. respectively. From figure 6, we see that for the European plant 54.8% of radon-222 and 44.9% of C-14 is emitted into air which means that for every 1ton cement produced in this plant, 16.4 kBq of radon-222 and 13.5 kg of C-14 is emitted into the air while in Cementos Cosmos S.A. cement plant, 11.8kBq of radon-222 and 13.2 kBq of C-14 is emitted. This shows that there is a reduction of about 4.6 kBq of radon-222 and 0.3 kBq of C-14 emitted into the air. This is because of the reduction in extraction and mining processes.

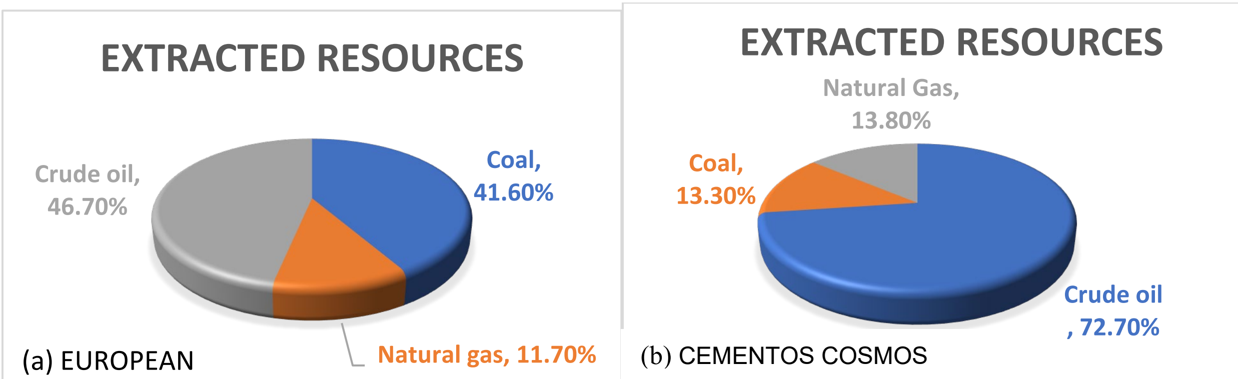


Figure 7: Analysis on Fossil depletion in (a) European plant and (b) Cementos Cosmos plant

As presented in tables 2 and 3, fossil depletion has a value of 75 kg oil eq and 57 kg oil eq for European plants and Cementos Cosmos S.A., respectively. From figure 7, we see that for the European plant 46.7% of crude oil and 41.6% of coal is extracted, which means that for every 1ton cement produced in this plant, 35 kg of crude oil and 31.2 kg of coal is emitted into the air while in Cementos Cosmos S.A. cement plant, 41.4kg of crude oil and 7.6 kg of coal is emitted. This shows that there is a reduction of about 23.6 kg of coal was reduced in terms of coal extraction while 6.4kg more of crude oil was used. This is because of more petroleum coke used in the production process of the Cementos Cosmos S.A. plant; this also shows why there is an increment in the value of the ozone depletion impact category and a number of other variations. However, the incorporation of some BREF has reduced the extraction of coal by 23.6kg. Table 5 represents the normalization result of the two cement plants. Normalization involves the evaluation of the environmental impacts within the characterization process by the weighting of each impact category. It helps to get rid of the units, and thus it is useful in order know the most prominent impact category. As presented in table 5, the major impact categories in the Cementos Cosmos S.A. cement plant were observed to be Natural land transformation, Climate change, Marine ecotoxicity, Freshwater eutrophication, Freshwater ecotoxicity, Human toxicity and Fossil depletion while those of European cement plant were observed to be Natural land transformation, Marine ecotoxicity, Freshwater eutrophication, Freshwater ecotoxicity, Human toxicity, Climate change, and Fossil depletion.

Table 5: Normalization results of the two plants (midpoint)

Impact category	CEMENTOS COSMOS	EUROPEAN PLANT
Climate change	0.061081	0.077622
Ozone depletion	0.001251	0.00119
Terrestrial acidification	1.48E-02	0.044525
Freshwater eutrophication	4.34E-02	0.180465
Marine eutrophication	0.001643	0.007012
Human toxicity	0.04022	0.130135
Photochemical oxidant formation	0.006923	0.026253
Particulate matter formation	0.017442	0.042686
Terrestrial ecotoxicity	0.000581	0.001733
Freshwater ecotoxicity	0.041044	0.159963
Marine ecotoxicity	0.047987	0.196094
Ionising radiation	0.004199	0.004852
Agricultural land occupation	0.001019	0.002474
Urban land occupation	0.001621	0.005348
Natural land transformation	0.317075	0.326282

Water depletion	0	0
Metal depletion	0.010415	0.011721
Fossil depletion	0.036596	0.048325

4. Conclusion

It was carried out a comparative life cycle assessment study on two cement plants: Cementos Cosmos S.A. cement plant and a typical European plant using mid-point (problem-oriented) approach of LCIA method. Cementos Cosmos S.A. plant located in Spain has incorporated some BREF recommendations into her production processes. These recommendations are use of alternative fuel, use of waste as fuel, reduction of the use of fossil fuel (coal), reduction of the quantity of clinker used in cement production, partial replacement of clinker with alternative materials. The characterization result of both plants was compared, and the result showed that all impact categories from the Cementos Cosmos S.A. plant reduced greatly except for ozone depletion, which increased by 5%. Tracing back to the LCI analysis, petroleum coke has the highest impact of all the fossil fuel used. The amount of petroleum coke used in the Cementos Cosmos S.A. plant is higher than the value used in the European cement plant, hence the increase.

Most of the impact categories with significant reduction were associated with two major production processes: raw material consumption and fuel consumption. These two processes involve mining and extraction of resources as well as the processing of these resources. Therefore, this reduction is due to a reduction in the resources mined and extracted, compared to the resources used in a typical European plant. This shows that the use of alternative fuel and material, waste, reduction of coal thus reduces the environmental impact of a cement production process. Climate change also has 21% reduction. From the LCI analysis, it was observed that a higher quantity of limestone was used in the production of clinker. Hence significant reduction was not experienced though the quantity of clinker used was reduced.

Further analysis was carried out on the top four impact categories with the highest value in both plants. These impacts are climate change, human toxicity, ionizing radiation and fossil depletion. Comparative analysis between both plants showed that when the above-listed BREF recommendations are incorporated into the production process, there is a reduction of about 0.175t of CO_2 emitted into the atmosphere for every 1 ton of cement produced. Also, there is a reduction of about 0.0323t manganese emitted into the waterbody for every 1 ton of cement produced. In addition, there is a reduction of about 4.6kBq of radon-222 and 0.3 kBq of carbon-14 emitted into the atmosphere for every 1 ton of cement produced. Finally, there is a reduction of about 0.0236t of coal in terms of coal extraction for every 1 ton of cement produced. However, crude oil usage increases by 0.0064t; this is due to more petroleum coke used in the production process of Cementos Cosmos S.A. plant.

The midpoint normalized values of both plants showed that the major impact categories in Cementos Cosmos S.A. are: Natural land transformation, Climate change, Marine ecotoxicity, Freshwater eutrophication, Freshwater ecotoxicity, Human toxicity and Fossil depletion, while those of European cement plant are Natural land transformation, Marine ecotoxicity, Freshwater eutrophication, Freshwater ecotoxicity, Human toxicity, Climate change, and Fossil depletion. The production processes with the highest contribution to these impacts are clinker production, fossil fuel consumption, and raw material consumption. The results in this study are compatible with those in the literature with minimal variation.

Acknowledgment

The authors gratefully acknowledge Durban University of Technology for an enabling environment and NRF for the financial support during the study.

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