# Life Cycle Assessment of Ordinary Portland Cement (OPC) using Problem Oriented (Midpoint) Approach.

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## Abstract

The environmental impact of the cement production has been beckoning for attention in recent time. Different literatures have different things to say on these environmental impacts, at different production phase. This study applied Life cycle assessment (LCA) evaluation tool to evaluate Ordinary Portland Cement (OPC) in establishing the environmental implication of cement production using the midpoint approach of LCIA method. Result of assessment shows that clinker production phase has the highest contribution to global warming which brings about climatic change due to high $CO_2$ emission which affects both human health and ecosystem. Crude oil, coal and natural gas are expended maximally to bring about fossil resource scarcity and terrestrial toxicity, which affects both human and ecosystem because of high copper deposited from the clinker production phase alongside other phases of production.

**Keywords-** Ordinary Portland cement, Environmental impact, LCA, LCIA, Clinker production

## 1. Introduction

The construction sector has in recent time been recorded to produce large environmental impact which is of continuous concern to the society (Moretti & Caro, 2017). Cement is the major constituent of concrete used in the construction sector. Different environmental impacts such as resources scarcity, emissions, and energy consumption spans through its entire production cycle (Miccoli, Finucci, & Murro, 2014a, 2014b). The major constituents of Ordinary Portland cement (OPC) are calcium (limestone, marl or chalk) Silica, alumina and sometimes iron ore. OPC is about 95% clinker and 5% gypsum. These raw materials are placed into the large kiln of over 1400ºC it has been crushed and pulverized. After cooling, the heat is trapped and gypsum is added to improve cement workability (Barcelo, Kline, Walenta, & Gartner, 2014). Different authors have different things to say about the clinker production phase (calcination) i.e. breaking limestone down to give Cao and $CO_2$. Cement industry is said to account for about 12-15% of total industrial energy and 5-7% of total Greenhouse gas (GHG), but literatures have it that a good percentage of this energy is consumed at clinker production phase and also the highest GHG ($CO_2$) is emitted at this phase (Summerbell, Khripko, Barlow, & Hesselbach, 2017) (Hendriks, Worrell, De Jager, Blok, & Riemer, 1998). About a decade ago, over 2.6gigatone of $CO_2$ gas emission was from cement production globally whereas half was from combustion of fuels, the other half was from calcination (Gursel, 2014; Madlool, Saidur, Hossain, & Rahim, 2011; Policy & Policy, 1999).

International Energy Agency's (IEA) Greenhouse Gas R&D Programme documented that over 800g of $CO_2$ is emitted for every 1000g of cement produced (Xu, Fleiter, Fan, & Eichhammer, 2014). Meyer (Meyer, 2009) in his work showed that about 1ton of cement produced emit almost 1ton of CO2 gas. Every human being needs about 1 ton of cement every year (Cembureau, 2012), hence the need for continuous production of cement been its major component (Ali, Saidur, & Hossain, 2011; Van Oss & Padovani, 2003). Seeing that these environmental impacts run through the entire production process, it is therefore important to understand the entire cycle of the cement production and knowing the actual impacts as well as their contribution to the environment changes. Life Cycle Impact Assessment (LCA) is a multiple-issue tool used in evaluating and assessing potential impacts in the entire cycle of a product or process. It is also known as “cradle-grave” i.e. from start of life to end of life (Arvanitoyannis, 2008; Willi Haas, 2013). LCA gives a rounded view of the entire production process. International Standard Organization (ISO) 14040 defines the four stages of LCA as: (i) Goal and Scope definition, (ii) Life cycle inventory (LCI) (iii) Life cycle impact assessment (LCIA) and (iv) Interpretation (Organization, 1997; Standardization, 2006).

Goal and scope definition have to do with objectives for evaluating a product or process alongside functional unit, assumptions, etc. It simply defines the boundaries of the assessment (Marinković, 2013). LCI is all necessary inventory data (technical inputs and outputs) that has to do with the product or process being evaluated. LCIA phase is a multifaceted phase where the actual evaluation takes place showing different environmental impacts categories. Interpretation thereafter present the meaning of the LCIA result based on the LCI (Ormazabal, Jaca, & Puga-Leal, 2014). The remaining of the study is divided into methods in section 2, result and discussion in section 3 and the last section concludes with the findings of the study.

## 2. Method

LCA is an assessment tool 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. One good posture LCA takes in a system study is to give holistic LCIA method and its calculations (environmental impacts) are based on definite factors. This helps to speed up the analysis as well as simplify the system studied. ReCiPe is a LCIA method that helps to evaluate the impact category using both endpoint and midpoint approach. The process-oriented approach (midpoint) is adopted in this study. 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. This approach contains about 18 impact categories: global warming, stratospheric ozone depletion, ionizing radiation, ozone formation, terrestrial acidification, freshwater eutrophication, marine eutrophication, terrestrial ecotoxicity, freshwater ecotoxicity etc.(Goedkoop, Heijungs, De Schryver, Struijs, & Van Zelm, 2013). This approach helps to simplify numerous flows by streamlining them into few prevalent environmental impacts. The software used for this assessment is SimaPro 9.0.49 (Pré Consultants, 2016). All inventory data used for the assessment is taken from Ecoinvent v3.5which is incorporated in the software (Ecoinvent, 2019).

## 3. Results and discussion

The analysis was run for 1kg of OPC. The environmental impacts are categorized into 18 categories based on their contribution as seen in Table 1. The table gives the values of different impact categories and corresponding units. Impact categories with pronounced value such as Global warming (GW), terrestrial ecotoxicity (TE) and fossil resource scarcity (FRS) and will further be detailed analysis with respect to substance and process will further be carried out.

Table 1: Impact assessment Table of 1kg of OPC

| Se | Impact category | Unit | Cement, Portland {RoW}\| |
|---|---|---|---|
| ☑ | Global warming | kg CO2 eq | 0.911 |
| ☑ | Stratospheric ozone depletion | kg CFC11 eq | 7.84E-8 |
| ☑ | Ionizing radiation | kBq Co-60 eq | 0.00127 |
| ☑ | Ozone formation, Human health | kg NOx eq | 0.00145 |
| ☑ | Fine particulate matter formation | kg PM2.5 eq | 0.000577 |
| ☑ | Ozone formation, Terrestrial ecosy | kg NOx eq | 0.00147 |
| ☑ | Terrestrial acidification | kg SO2 eq | 0.0014 |
| ☑ | Freshwater eutrophication | kg P eq | 1.16E-5 |
| ☑ | Marine eutrophication | kg N eq | 3.56E-7 |
| ☑ | Terrestrial ecotoxicity | kg 1,4-DCB | 0.438 |
| ☑ | Freshwater ecotoxicity | kg 1,4-DCB | 9.92E-5 |
| ☑ | Marine ecotoxicity | kg 1,4-DCB | 0.000383 |
| ☑ | Human carcinogenic toxicity | kg 1,4-DCB | 0.00121 |
| ☑ | Human non-carcinogenic toxicity | kg 1,4-DCB | 0.0153 |
| ☑ | Land use | m2a crop eq | 0.00365 |
| ☑ | Mineral resource scarcity | kg Cu eq | 0.00464 |
| ☑ | Fossil resource scarcity | kg oil eq | 0.0784 |
| ☑ | Water consumption | m3 | 0.00185 |

Table 1 shows that for every 1kg of OPC produced, 0.911kg of $CO_2$ equivalent is emitted during the production process. This implies that there is a very high tendency of global warming when cement quantity as low as 1kg is produced as a result of enormous CO2 that is emitted. This result is further analyzed to know the production process and substances involved.

Table 2: StS of GW

| No | Substance | Compartme | Unit | Cement, Portland |
|---|---|---|---|---|
| | Total of all compartments | | % | 100 |
| | Remaining substances | | % | 0.102 |
| 1 | Carbon dioxide, fossil | Air | % | 97.1 |
| 2 | Methane, fossil | Air | % | 2.61 |
| 3 | Dinitrogen monoxide | Air | % | 0.156 |

The specification to substance (StS) of GW as shown in Table 2 revealed that 97.1% of this impact is as a result of $CO_2$ emission and less than 3% are other gases. Although the Specification to process (StP) of GW shows that 83.2% of the entire impact is from clinker production, StP of carbon dioxide as seen in Table 3 revealed that 85.6% of the 97.1% $CO_2$ gas emitted is from clinker production phase alone.

Table 3: StP of carbon dioxide (fossil) in GW

| No | Process | Project | Unit | Cement, Portland {RoW}\| |
|---|---|---|---|---|
| | Total of all processes | | % | 100 |
| | Remaining processes | | % | 12.1 |
| 1 | Clinker {RoW}\| production \| Cut-off, U | Ecoinvent 3 - allocation, cu | % | 85.6 |
| 2 | Diesel, burned in building machine {GLO}\| processing \| Cut-off, U | Ecoinvent 3 - allocation, cu | % | 0.519 |
| 3 | Electricity, high voltage {CN-NM}\| electricity production, hard coal \| C | Ecoinvent 3 - allocation, cu | % | 0.418 |
| 4 | Heat, district or industrial, natural gas {RoW}\| heat production, natura | Ecoinvent 3 - allocation, cu | % | 0.543 |
| 5 | Heat, district or industrial, other than natural gas {RoW}\| heat product | Ecoinvent 3 - allocation, cu | % | 0.839 |

Terrestrial ecotoxicity is as a result of 0.438kg of 1,4-dichlorobenzene (DCB). The StS in Table 4 show that 61.5% of copper was deposited which brings about the toxicity and StP in Table 5 show that 16.6 % clinker production phase and almost 48% relation with copper brings about 0.438kg of TE for every 1kg of OPC produced.

Table 4: StS of TE

| No | Substance | Compartme | Unit | Cement, Portland {RoW}\| |
|---|---|---|---|---|
| | Total of all compartments | | % | 100 |
| | Remaining substances | | % | 0.083 |
| 1 | Beryllium | Air | % | 0.222 |
| 2 | Cadmium | Air | % | 1.06 |
| 3 | Chromium VI | Air | % | 0.208 |
| 4 | Cobalt | Air | % | 0.149 |
| 5 | Copper | Air | % | 61.5 |
| 6 | Lead | Air | % | 2.56 |
| 7 | Mercury | Air | % | 11 |
| 8 | Nickel | Air | % | 7.53 |
| 9 | Selenium | Air | % | 0.34 |
| 10 | Thallium | Air | % | 0.158 |
| 11 | Tin | Air | % | 0.301 |
| 12 | Vanadium | Air | % | 7.06 |
| 13 | Zinc | Air | % | 7.77 |

Table 5: StP of TE

| No | Process | Project | Unit | Cement, Portland {RoW}\| |
|---|---|---|---|---|
| | Total of all processes | | % | 100 |
| | Remaining processes | | % | 15.6 |
| 1 | Ammonia, liquid {RoW}\| ammonia production, steam reforming, liqu | Ecoinvent 3 - allocation, cu | % | 0.949 |
| 2 | Brake wear emissions, lorry {RER}\| treatment of \| Cut-off, U | Ecoinvent 3 - allocation, cu | % | 4.77 |
| 3 | Brake wear emissions, lorry {RoW}\| treatment of \| Cut-off, U | Ecoinvent 3 - allocation, cu | % | 11.7 |
| 4 | Clinker {RoW}\| production \| Cut-off, U | Ecoinvent 3 - allocation, cu | % | 16.6 |
| 5 | Copper {AU}\| production, primary \| Cut-off, U | Ecoinvent 3 - allocation, cu | % | 1.92 |
| 6 | Copper {RAS}\| production, primary \| Cut-off, U | Ecoinvent 3 - allocation, cu | % | 13.4 |
| 7 | Copper {RLA}\| production, primary \| Cut-off, U | Ecoinvent 3 - allocation, cu | % | 11.2 |
| 8 | Copper {RoW}\| production, primary \| Cut-off, U | Ecoinvent 3 - allocation, cu | % | 12.2 |
| 9 | Diesel, burned in building machine {GLO}\| processing \| Cut-off, U | Ecoinvent 3 - allocation, cu | % | 0.742 |
| 10 | Electricity, high voltage {RoW}\| electricity production, oil \| Cut-off, U | Ecoinvent 3 - allocation, cu | % | 1.96 |
| 11 | Electricity, high voltage {SA}\| electricity production, oil \| Cut-off, U | Ecoinvent 3 - allocation, cu | % | 0.943 |
| 12 | Ferronickel, 25% Ni {GLO}\| production \| Cut-off, U | Ecoinvent 3 - allocation, cu | % | 2.92 |
| 13 | Heat, district or industrial, other than natural gas {RoW}\| heat product | Ecoinvent 3 - allocation, cu | % | 0.752 |
| 14 | Heat, district or industrial, other than natural gas {RoW}\| heat product | Ecoinvent 3 - allocation, cu | % | 1.73 |
| 15 | Heavy fuel oil, burned in refinery furnace {RoW}\| processing \| Cut-off, | Ecoinvent 3 - allocation, cu | % | 1.44 |
| 16 | Zinc {RoW}\| primary production from concentrate \| Cut-off, U | Ecoinvent 3 - allocation, cu | % | 1.13 |

FFS impact is as a result of 0.078kg of oil used in producing 1kg of OPC. The StS in Table 6 shows that crude oil, coal and natural gas are substances that are used up that result into scarcity; the StP in Table 7 show the same result.

Table 6: StS of FRS

| No | Substance | Compartme | Unit | Cement, Portland {RoW}\| |
|---|---|---|---|---|
| | Total of all compartments | | % | 100 |
| 1 | Coal, brown | Raw | % | 1.81 |
| 2 | Coal, hard | Raw | % | 41.4 |
| 3 | Gas, natural/m3 | Raw | % | 13.1 |
| 4 | Oil, crude | Raw | % | 43.7 |
| 5 | Peat | Raw | % | 0.00681 |

Table 7: StP of FRS

| No | Process | Project | Unit | Cement, Portland {RoW}\| |
|---|---|---|---|---|
| | Total of all processes | | % | 100 |
| | Remaining processes | | % | 11.6 |
| 1 | Hard coal {AU}\| hard coal mine operation and hard coal preparation \| | Ecoinvent 3 - allocation, cu | % | 3.97 |
| 2 | Hard coal {CN}\| hard coal mine operation and hard coal preparation \| | Ecoinvent 3 - allocation, cu | % | 21.8 |
| 3 | Hard coal {ID}\| hard coal mine operation and hard coal preparation \| C | Ecoinvent 3 - allocation, cu | % | 3.06 |
| 4 | Hard coal {RU}\| hard coal mine operation and hard coal preparation \| | Ecoinvent 3 - allocation, cu | % | 2.15 |
| 5 | Hard coal, run-of-mine {IN}\| hard coal mine operation \| Cut-off, U | Ecoinvent 3 - allocation, cu | % | 6.03 |
| 6 | Lignite {RoW}\| mine operation \| Cut-off, U | Ecoinvent 3 - allocation, cu | % | 1.6 |
| 7 | Natural gas, high pressure {DZ}\| natural gas production \| Cut-off, U | Ecoinvent 3 - allocation, cu | % | 2.12 |
| 8 | Natural gas, high pressure {RoW}\| natural gas production \| Cut-off, U | Ecoinvent 3 - allocation, cu | % | 1.95 |
| 9 | Natural gas, high pressure {RU}\| natural gas production \| Cut-off, U | Ecoinvent 3 - allocation, cu | % | 2.43 |
| 10 | Natural gas, unprocessed, at extraction {GLO}\| production \| Cut-off, U | Ecoinvent 3 - allocation, cu | % | 1.72 |
| 11 | Petroleum {RAF}\| production, onshore \| Cut-off, U | Ecoinvent 3 - allocation, cu | % | 1.29 |
| 12 | Petroleum {RME}\| production, onshore \| Cut-off, U | Ecoinvent 3 - allocation, cu | % | 12.7 |
| 13 | Petroleum {RoW}\| petroleum and gas production, off-shore \| Cut-off, | Ecoinvent 3 - allocation, cu | % | 6.75 |
| 14 | Petroleum {RoW}\| petroleum and gas production, on-shore \| Cut-off, | Ecoinvent 3 - allocation, cu | % | 13.6 |
| 15 | Petroleum {RoW}\| production, onshore \| Cut-off, U | Ecoinvent 3 - allocation, cu | % | 1.68 |
| 16 | Petroleum {RU}\| production, onshore \| Cut-off, U | Ecoinvent 3 - allocation, cu | % | 5.55 |

## 4. Conclusion

The analysis was done on 1kg of OPC. Global Warming brings about climate change, which affects both human health and ecosystem. Note that whatsoever affects ecosystem will of surety affect human beings general. The effect of global warming therefore has major effect on human being. GW is as a result of 97.1% of $CO_2$ emission and 85.6% or this emission is from the clinker production stage. This is in-line with literature and particularly with Meyer's submission in his work that almost 1ton of cement produced emits almost 1 ton of $CO_2$. However, kilogram is the unit of measure used in this study. As seen above, Fossil resource scarcity results to unavailability of fuel resources such as crude oil (43.7%), coal energy (43.21%) and natural gas (13.1%) of 0.083kg (mineral resource scarcity and fossil resource scarcity) for every 1kg of OPC produced. The unavailability of resources thereby increases the cost of the available ones. In addition, Terrestrial ecotoxicity affects both human health and ecosystem as 61.5% of 0.438kg of this impact is from copper deposited at clinker production phase and other phases. This study concluded that 0.91kg of $CO_2$ is emitted for every 1kg of OPC produced and 0.756kg of this 0.91kg is from the calcination process alone. Global warming has the highest impact and makes the most prominent environmental impact of the cement industry. This therefore calls for attention as the effect of impact is seen in changes in climatic condition which affects both human and ecosystem. The calcination phase is the highest contributor because of the chemical decomposition of $CaCO_3$. One of the ways to reduce $CO_2$ emission in this phase is to reduce the amount of clinker and replace it with other supplementary cement materials like natural pozzolana: fly ash, slag, etc.

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