Life Cycle Assessment of Biochar as a Partial Replacement to Portland Cement

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Abstract. Biochar also known as ‘biocarbon’ or ‘biocoal’ is a material that has a charcoal similar property. It is obtained from thermolysis (pyrolysis) of biomass feedstocks and plant matters. It can help the process of eliminating carbon dioxide from the atmosphere. The biochar was considered as waste by industrial plants and considered no additional cost except for the transportation. Biochar was tested for its chemical properties in Department of Science and Technology as a parameter for Simapro. Environmental and health impact were analyzed in this study for concrete with biochar as partial replacement for cement. Different mixtures with zero percent to twenty percent biochar replacement was simulated using life cycle assessment with the help of Simapro. Different sources in Luzon island, Philippines were gathered and found out that sources in southern part of Luzon is the best sources for biochar because of its near location that decreases the effect of transportation. Also, concrete with biochar replacement with or without considering the effect of transportation yields greater health and environmental impact compared to mixture without biochar replacement.

1. Introduction

Concrete is one of the world’s leading material for construction and cement, its most important component is accounted for 5-7 percent of the CO₂ emission globally [1]. The cement industry is one of the largest consumers of natural resources such as limestone, clay and gypsum and heated to about 1500 degrees celsius [2]. That heating process is one of the best contributors of CO₂ emission. Global warming is the result of emission of carbon dioxide to the atmosphere. Globally, the construction industry contributes 6% of global greenhouse gas emissions. It is determined that manufacturing of 1 ton of cement produces 1 ton of carbon dioxide. During the manufacturing of cement, different harmful gases like Carbon Dioxide, Sulfur Dioxide and Nitrogen Oxide escape in the atmosphere.

Using of cementitious materials as a partial replacement cement in concrete decreases the amount of cement which in turn reduces the emission of CO₂ [3]. Some supplementary cementitious materials as a partial replacement of cement in concrete have a positive impact when it comes to strength [4]. In line with the effects of these supplementary materials that comes from the cement manufacturing industries on environment, researches on the replacement of cement by using by-products and other material have been done [5]. Using of these products as a binding material has been popular worldwide because of the reduction of many harmful gases in the environment.

Biochar also known as ‘biocarbon’ or ‘biocoal’ is a material that has a charcoal-similar property [6]. It is obtained from thermolysis (pyrolysis) of biomass feedstocks and plant matters. Mainly, biochar is used on the agricultural sectors to improve the quality of soil and increase crop yields [7]. It can help
the process of eliminating carbon dioxide from the atmosphere. It retains about an average of 50 percent of Carbon present in the actual biomass and decelerate the rate of carbon decomposition [8].

Since the Philippines is one an agricultural country that mainly produces crops such as corn, rice, sugarcane, etc., There are a lot of waste materials and its utilization is far too low. Biochar is a new additive being tested for further utilization on concrete structures. Several researches studied its effect to mechanical and physical properties to cement mortar and yields positive results [9][10].

This research is intended to test the environmental impact of using biochar as partial replacement for cement specifically for Philippine setting in Luzon island. Different sources and location were simulated to further analyze the effect of transporting it to the mixing site.

There are 4 types of assessment that can be practiced when using LCA. The first one is Cradle-to-Grave, in this method, all inputs and outputs are to be considered for all the phases of the life cycle [11]. Second is Cradle-to-Gate, in this assessment, the only points to be considered is the partial product life cycle from the manufacture to the factory gate. The use and disposal phase are usually disregarded in order to focus more on the impact of the product. This method is to be used to examine the life cycle of the biochar that is infused with the cement mixture. The third one is the Cradle-to-Cradle, this assessment focuses on the recycling process after the disposal step of the product that is being tested and the last one is Life Cycle Energy Analysis, all energy inputs to a product is to be considered in this type of assessment.

This study used SimaPro as a tool in determining the environmental effect of concrete with biochar replacement to cement. It has been one of the world’s leading LCA software package for more than 20 years [8]. SimaPro has the latest features for addressing the concerns of the product. A wide variety of add-ons can be used in changing the life cycle of a product that can help and improve its positive impact.

2. Materials and Methods

The system boundary that will be considered in this LCA is cradle-to gate. Figure 1 shows the steps on the concrete production being analyze in the study. The first method is to determine the raw materials needed and their method of extraction and transportation. The second method is to identify different processes that each material had gone through ex. (grinding, sieving etc.). The third method is the production of concrete and the last is the transportation to the job site.

The composition of biochar was tested as a requirement for the software to further analyze its environmental and health impact. As shown in Figure 2, the composition of the biochar rice husk that is acquired from the Department of Science and Technology (DOST) is consists of 30.82% Carbon, 51.55% Silicon Dioxide, 1.95% Ferrous Oxide, 1.34% Potassium Oxide, 0.20% Magnesium Oxide, 0.14% Calcium Oxide, 0.11gram of the biochar rice husk, the product is required to have 24.10 kilograms of Silicon, 1.52 kilograms of Iron, 1.34 kilograms of Potassium Oxide, 0.12 kilograms of
Magnesium, 0.10 kilograms of Calcium, 0.09 kilograms of Manganese, 28.02 kilograms of Oxygen, 30.82 kilograms of Carbon, and 13.89 kilograms of ash.

![Figure 2. Composition of biochar](image)

Different cement replacement by biochar (0%, 5%, 10%, 15% and 20%) were tested in the Simapro to analyze what percentage lessen the environmental and health impacts. Table 1 shows the replacement of biochar on the cement content.

| Biochar Replacement | Biochar content (kg) | Cement content (kg) |
|---------------------|----------------------|---------------------|
| 0%                  | 0.00                 | 0.1942              |
| 5%                  | 0.0097               | 0.1845              |
| 10%                 | 0.0194               | 0.1748              |
| 15%                 | 0.0291               | 0.1651              |
| 20%                 | 0.0388               | 0.1554              |

Table 2 and 3 shows the different sources of biochar in Luzon island. Since the location was one of the factors for considering the environmental and health impact of replacing cement by biochar, it was added to the analysis. The location considered to be the job-site were the location of the university, which is in Manila or the capital city of the Philippines. These research did not consider biochar from farmers that burn their rice husk, these locations were chosen based on the availability of industrial plants that uses waste rice husk as their fuel for their production.
Table 2. Data of distance taken from north of Luzon

| Location                  | Distance from FEU-IT (km) |
|---------------------------|---------------------------|
| Sta. Lucia, Ilocos Sur    | 486.2                     |
| Bauang, La Union          | 257.0                     |
| Laoag, Ilocos Norte       | 408.3                     |

Table 3. Data of distance taken from south of Luzon

| Location                  | Distance from FEU-IT (km) |
|---------------------------|---------------------------|
| Malvar, Batangas          | 70.5                      |
| Dasmarinas, Cavite        | 53.0                      |
| Sta. Cruz, Laguna         | 91.4                      |

3. Results and Discussion

Shown in Table 4 are the result of different mixture of concrete with of 0%-20% biochar replacement for cement without considering the additional effect of transporting the biochar rice husk-ash (BRH) to the job-site. As shown on the table, as the biochar replacement increases, the health impact decreases. This is the conventional result of which the cement content of concrete was replaced by a mineral or ash particles. This is because the production of cement due to the fact it uses a lot of energy and heat, it is the main reason high environmental effect of concrete. The replacement of cement by biochar decreases all the categories for environmental and health impact.

One of the parameters that shows significant change is the human toxicity, based on W. Chin et. al (2003) the standardization references for human toxicity through the environment should reflect the total human toxic load caused by human activity in the reference area, i.e. the potential risk associated with environmental exposure (via air, soil, supplies and drinking water) as a result of industrial production, traffic, power plants, etc. emissions to the environment. human toxicity - in LCA context - covers several different effects: acute toxicity, irritation/corrosive effects, allergenic effects, irreversible damage/organ damage, genotoxicity, carcinogenic effects, toxicity to reproductive system/teratogenic effects, and neurotoxicity in a single parameter (toxic equivalency factors, EF). The effect in human in terms of human toxicity in air, was significantly decreases when a portion of cement particles were replaced by biochar.
The result of Table 4 was normalized with respect to the mixture without biochar replacement to further analyze the effect visually. It was shown that all categories of environmental and health impact decreases with respect to the increasing amount of biochar as a replacement. Similar to other additive or replacement to cement such as fly ash, bottom ash, mineral like zeolite, etc., biochar can be considered as a partial replacement to cement that will decrease its environmental impact. This is because that the production of cement is one the leading cause of its high environmental impact due to high temperature needed.

|                     | Unit       | BRH 0%          | BRH 5%          | BRH 10%         | BRH 15%         | BRH 20%         |
|---------------------|------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Ozone Depletion     | Kg CFC11 eq| 0.00000032      | 3.09E-07        | 0.000000298     | 0.000000288     | 0.000000277     |
| Ozone Formation     | Person.ppm.| 0.000018        | 0.0000174       | 0.0000167       | 0.0000161       | 0.0000154       |
| (human)             | Person     |                 |                 |                 |                 |                 |
| Human Toxicity air  | m3         | 0.00000261      | 2.53E-06        | 0.00000245      | 0.00000237      | 0.00000229      |
| Human Toxicity water| m3         | 0.0000428       | 0.0000412       | 0.0000397       | 0.0000381       | 0.0000365       |
| Human Toxicity soil | kg         | 6.34E-08        | 6.18E-08        | 6.02E-08        | 5.86E-08        | 5.69E-08        |
| Hazardous Waste     |            |                 |                 |                 |                 |                 |

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Figure 3. Normalized value of environmental effect of biochar replacement to cement without considering the effect of transportation

Biochar in the Philippines can be acquired through industrial plants near the rice fields that utilized it as fuel. Most of the rice fields in Luzon island is on the northern part but it yields higher impact compared to areas in the south because of the additional effect of the transportation.
As shown in Table 5, the assumption of the author is the biochar is transported to the concrete production. In the case of Luzon island in the Philippines, Concrete batching plant is near the plant of cement manufacturers, but for the case of Biochar, it was assumed at different location in the Luzon area were rice fields are located. The farthest location which is the northern Luzon gave the highest environmental impact due to the additional transportation needed in order to bring it to the batching plants. Comparing the result of concrete batch without the effect of transporting biochar from different sources, it shows significant increase.

Table 5. Characterization result of 5% biochar concrete mix with transportation.

| Category                        | Unit       | BRH 5% Northern Luzon | BRH 5% Southern Luzon |
|---------------------------------|------------|------------------------|------------------------|
| Ozone Depletion                 | Kg CFC11 eq| 0.0000025              | 0.000000649            |
| Ozone Formation (human)         | Person.ppm.h| 0.0000612              | 0.0000251              |
| Human Toxicity air              | Person     | 0.000114               | 0.000054               |
| Human Toxicity water            | m³         | 0.0000121              | 0.0000322              |
| Human Toxicity soil             | m³         | 0.0000458              | 0.0000193              |
| Hazardous Waste                 | kg         | 0.00000019             | 8.43E-08               |

Other impact categories as shown in Table 6 were calculated using Simapro and shows the same results in which higher replacement of cement by Biochar leads to lower impact. Biochar can be a good replacement to other mineral replacement like fly ash to cement due to the fact that it lowers all the environmental and health impacts of the cement production. This is because cement production is one of the leading environmental hazards. There is none existing product that can be utilized to replace concrete or cement in particular, with its unprecedented characteristics and lower cost, it is the most practical material in the construction industry, and one way to reduce its impact is to find materials such as biochar if it can utilized to at least partially used as a substitute to cement [12].

Table 6. Characterization Result of 0%-20% biochar concrete mix without transportation

| Impact Category | Unit | BRH 0% | BRH 5% | BRH 10% | BRH 15% | BRH 20% |
|-----------------|------|--------|--------|---------|---------|---------|

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| Global Warming Ozone Formation (Vegetation) | Kg Co2 eq | 0.0000251 | 0.0000241 | 0.0000230 | 0.0000220 | 0.0000210 |
|------------------------------------------|-----------------|-------------|-------------|-------------|-------------|-------------|
| Acidification Terrestrial Eutrophication | Kg Co2 eq | 0.0000192 | 0.0000185 | 0.0000178 | 0.0000171 | 0.0000164 |
| Aquatic eutrophication EP(N) | Kg N | 0.0000045 | 0.00000433 | 0.00000417 | 0.00000401 | 0.00000385 |
| Aquatic eutrophication EP(P) | Kg P | 0.0000584 | 0.0000563 | 0.0000543 | 0.0000523 | 0.0000502 |
| Ecotoxicity water chronic Ecotoxicity | m3 | 0.00000141 | 0.00000136 | 0.00000131 | 0.00000127 | 0.00000122 |
| water acute Ecotoxicity | m3 | 0.00000136 | 0.00000131 | 0.00000127 | 0.00000122 | 0.00000118 |
| soil chronic | m3 | 0.00000194 | 0.00000189 | 0.00000184 | 0.00000179 | 0.00000174 |

As shown in Figure 4, cement account for 82.7 percent of the total environmental impact of the concrete mixture. The added biochar only accounts for 0.584% since it was a waste material. Burning rice husk is not intended for concrete use, and therefore should not be considered as environmental impact to the concrete. Bichar can be an alternative to other cement replacement like fly ash that can reduce the impact of cement production and cost [13].

**Figure 4.** LCA Using Simapro of concrete with 5% biochar replacement

4. Conclusion
Since the Philippines is an agrarian country where rice, corn and any other crops were grown, there is an abundant source of Biochar. Biochar can be derived by burning the husk of crops, but it is not advisable to burn these crops for the purpose of using it as a replacement to cement. It can be utilized as substitute to coal or charcoal for a heat source of different production plant like sugarcane. The resulting ash form this production plant can be used to substitute for a portion of cement to lower its environmental impact.

Cement is the leading cause of environmental impact in the constituents of concrete. Replacing cement by biochar even considering the additional environmental impact due to transportation, it shows decreasing impact when the replacement of cement increases. Biochar is a good substitute to fly ash because of its positive effect to the physical strength of concrete and also it can lower the environmental impact due to the fact that Biochar is just a waste product of burning rice husk.

The southern part of Luzon is the most viable source of biochar because of its strategic location and near Metro Manila. But since the northern Luzon mostly produces rice and other biomass, it can be also considered as a source of biochar to be utilized by concrete batching plants. Considering the distance of sources in northern Luzon, concrete without biochar yields higher environmental and health impact compared to concrete with biochar considering the added effect of transportation.

Reference

[1] Chen, C., Habert, G., Bouzidi, Y., Jullien, A., 2010. Environmental impact of cement production: detail of the different processes and cement plant variability evaluation. Journal of Cleaner Production. 18, 478-485.
[2] L. Berntsson and S. Chandra, “Lightweight Aggregate Concrete-Science, Technology, and Applications”, Noyes Publications, Norwich, NY, 2014, page 430.
[3] M. Kachan et al., “Effect of Relative Levels of Mineral Admixtures on Strength of Concrete with Ternary Cement Blend”, 2013
[4] EcoSmart, “Environmental Impact: Cement Production and the CO2 Challenge”, 2012.
[5] A. Khan and B. Khan, “Effect of Partial Replacement of Cement by Mixture of Glass Powder and Silica Fume Upon Concrete Strength” in International Journal of Engineering Works, Kambohwell Publisher Enterprises, 4 (7), 2017), pp.124-135.
[6] M. Khokhar et al., “Cement & Concrete Composites”, 2010, pp.32-377
[7] B. Zbigniew et al., “Biochar – Potential tool to combat climate change”, 2018.
[8] F. Fuchs et al, “Biochar: Background & Early Steps to Market Development” in Biochar Industry Opportunities in the Pacific Northwest, 2012.
[9] Muthukrishnan, S., Gupta, S., & Kua, H. W. (2019). Application of rice husk biochar and thermally treated low silica rice husk ash to improve physical properties of cement mortar. *Theoretical and Applied Fracture Mechanics, 104*, 102376.
[10] Cuthbertson, D., Berardi, U., Briens, C., & Berruti, F. (2019). Biochar from residual biomass as a concrete filler for improved thermal and acoustic properties. *Biomass and bioenergy, 120*, 77-83.
[11] I. Muralikrishna and V. Manickam, “Life Cycle Assessment” in Environmental Management Butterworth-Heinemann, 2017, page 57-75.
[12] Huntzinger, D. N., & Eatmon, T. D. (2009). A life-cycle assessment of Portland cement manufacturing: comparing the traditional process with alternative technologies. *Journal of Cleaner Production, 17(7)*, 668-675.
[13] Gupta, S., & Kua, H. W. (2019). Combination of Biochar and Silica Fume as Partial Cement Replacement in Mortar: Performance Evaluation Under Normal and Elevated Temperature. *Waste and Biomass Valorization, 1*-18.