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Assessment for the Environmental Impacts of Chemical Constituents' Percentage Variation for Ceramic Manufacturing

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Abstract

Ceramic tile manufacturing process is energy intensive since within several stages the product is subject to thermal treatment. The source of thermal energy used is by combustion of natural gas. Unfortunately, the oxidation of this fossil fuel produces greenhouse gases. The impact severity on environment and humans is influenced by the chemical composition of ceramic. Hence the objective of this research is to study the effect of changing the percentage of seven samples with the most effective composition of ceramic used in many countries. The selected impact categories for the study were global warming, Climate change, acidification, eutrophication, and human toxicity. The constituents' percentages of ceramic manufacturing have been evaluated using GABI vs OpenLCA. It was found that lowering the percentage of Silicon dioxide in the mixture from 51.01% to 87.8 leads to an overall emission reduction of 28% and the differences between the results were close for both software.

Keywords: Life Cycle Assessment; Ceramic Tiles; OpenLCA; GaBi; Climate change; Acidification.

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1. Introduction

The building sector is a considerable contributor to environmental severity influences, such as energy utilization and greenhouse emissions [1,2]. Life cycle Assessment (LCA) technique has been broadly embraced for the construction buildings and is recognized as a precious tool supporting the sustainable design for buildings [3], and it plays a critical part for building certification for many organizations. The environmental impacts of buildings have been more considerable, shown by the growing number of Environmental Product Declarations (EPDs) being released or published [4].The evaluation of life cycle of building materials (in terms of construction) depends on setting standards and specifications for several building materials. That is applied at all stages of construction building materials and during their manufacturing processes as well. This is essential in order to study their impact on the surrounding environment in terms of climate change impact, acidification, eutrophication, human toxicity, and the other aspects that affect the human health and the environment [5,2]. Building materials manufacturing is growing rapidly as its implementations and necessity are dominating the whole world but the majority of construction is primarily focused on the financiall rewarding pursuit of improving the environmental performance of the floor tiles manufacturing sector. It was important to consider the full life cycle of the products, which helped to identify available environmental hotspots at any stagesof the product life cycle [7]. Furthermore, carbon dioxide emissions are monitored and controlled internationally under the the frame of Kyoto Protocol.

In 1970s, the ceramics industry started to expand as a contemporary one using new knowledge and advanced techniques. Since then, it has been developed and become one of the market's most competitive industries, which are using in building construction [8]. Ceramic tile is one of the building materials that considered as inorganic and non-metallic materials which is mostly used as finishing surface and widely used in diffident types of buildings where it can be used in walls, columns, and floors cladding, indoor and outdoor for technical and aesthetic functions [9]. The consumption of ceramic in the building sector is continuously increasing as the rapidly increasing of population and expansion of the construction sector worldwide, especially the residential and infrastructural developments. [9,12]. .

High levels of carbon dioxide, fluoride, methane, and nitrous oxide can be released during the production of ceramic tiles, and these gases are the main cause of the earth's warming trend. While the determination of ceramic process midpoint impact category is 96.77% of the human health endpoint impact. This value was considered the highest midpoint environmental category of building materials like Steel, concrete, wood, Brick, and Glass [13].

The chemical compositions of the ceramic and porcelain are different from country to another and from factory to another at the same country. Porcelain and Ceramic tiles bodies composed basically of blending several raw materials, which have different amounts of 2SiO2, Na_2O, K_2O, AL_2O_3, CaO, etc. fired at very high temperatures ranging from 1200 °C to 1300 °C. The chemical composition is the key to achieve the standard requirement of the ceramic. Kaolinitic clay (AL_2O_3, 2SiO2) are the major compositions of a porcelain product while the higher amount of silica followed by AL_2O_3, then different quantities of Na_2O, K_2O, and some additives with total impurity oxides and loss on ignition [14]. On the other hand, there are a major relationship between the extend of the Chemical composition and the quantity and severity of the emission. Chemical characterization of cement industry and the number of the factories in the industrial zone are considered one of the major influenced parameter for deducting the fingerprint profile of PM2.5 [15].

Miguel Castro and etc. [16] represented the severity of the ceramic manufacturing in Europe where the plant has a significant contribution of the overall production costs. Moreover, they showed several strategies for the improvement of energy efficiency in the industry. The BAT spread around the world to increase the benefits of using these technologies specially in the manufacturing of ceramic.

The United Nations Industrial Development Organization (UNIDO) [17] implemented a benchmark study in 2016 of energy efficiency for ceramic tiles industry in Egypt. They mentioned that Egyptian market conducted with 366 x 10^6 m^2 each year of ceramic tiles used in floors and walls from 38 industrial plants. They leaded "Best Available Techniques (BAT) Reference Document from thirteen large productions companies' data base information to save the potentials of the whole ceramic tiles sector in Egypt.

Because of the huge quantities of ceramic production around the world in general and in Egypt in particular moreover the worldwide approaches to decline the negative impact of manufacturing ceramic tiles contributions towards the human and environment contribution, this study was generated to analyze the influence of changing chemical constituent of 1ton ceramic tiles production. All the chemical compositions were considered mainly silicon dioxide that contributes with a large quantity in the composition. Therefore, it was the main driver for selecting the sample to be held in the study and then examine the contribution towards the Environmental consideration such as acidification, climate change, eutrophication, human toxicity. The study was conducted using two different software; GAIB and Open-LCA to revise the differences in the results.

2. Materials & Methods

The constituents of ceramic used were obtained from local manufactures in numerous countries; this included the amount and the chemical composition of the raw material used in the production process of ceramic tiles. There are a lot of software that perform Environmental impact assessment for estimating the contribution of software inputs towards the environmental issues. However, the reliability of the analyses and the results depends on the inserted database and tools used in this software. Therefore, the objective of this article is to develop comparative study between different chemical composition of 1-ton ceramic tiles production used in different countries by two reliable LCA softwares.

The environmental impact assessment was performed using CML (Center of Environmental Science of Leiden University) 2001. It was considered one of the Midpoint based tool that conducts multiple impact categories results that were used in LCA for the project and an operational guide to the ISO Standards in additional to it is available method in the used software [18][19] [20]. Table 1 represents four different impact categories that were chosen for the assessment providing its Environmental indicators. The characterization factors were applied by the CML 2001 method which include the most significant indicators that were evaluated by Cristiane Bueno and his colleagues[21].

Table 1: Impact categories, category indicators and characterization models

Impact categories	Impact Category Abbreviation	Category indicators	Characterization models
Global warming potential	GWP	kg Co_2 eq	CML2001
Acidification potential	AP	kg So_2 eq	CML2001
Eutrophication potential	EP	kg Po_4 eq	CML2001
Human toxicity potential	HTP	kg 1.4–DB eq	CML2001

2.1 Components of Ceramic Tiles

The constituents of ceramic tiles are mainly relying on the used natural elements. The main three formulations are clay, quartz and fluxing agents. Clays are a small particles represent hydrous aluminum phyllosilicate, quartz is the sand or rock forming mineral, and calcium carbonate and feldspars are used as flux agents which has a direct effect on open porosity on the final ceramic product [22]. The quality and durability of ceramics final product vary from country to another depends on the characteristic and quantity of natural raw materials used. These factors influence the degree of severity of the emissions during ceramic manufacturing. Table 2 represents variation of the chemical composition of the different mixtures of ceramic for different countries such as Egypt, Japan, China, Nigeria, and South Africa and the seven samples have Silicon dioxide varies from 51.14% to 79%.

Table 2: Chemical composition of Ceramic tiles used in this study

Raw material	Sample 1 [23]	Sample 2 [24]	Sample 3 [25]	Sample 4 [26]	Sample 5 [23]	Sample 6 [23]	Sample 7 [24]
Silicon dioxide (SiO_2)	51.14	55	60	66.57	70.32	74.7	79
Aluminum oxide (Al_2O_3)	33.87	42.8	26	21.6	17.79	13.52	15.9
Iron oxide (Fe_2O_3)	0.47	0.2	6	1.41	0.11	0.16	0.6
Calcium oxide (CaO)	0.1	0.1	1.5	2.41	0.53	1.06	1.1
Sodium oxide (Na_2O)	0.42	0.4	1	1.41	7.3	2.88	0.2
Potassium oxide (K_2O)	0.7	0.3	3	2.79	2.75	5.94	3.1
Zirconium dioxide (ZrO_2)	0	0	0	1.49	0	0	0
magnesium oxide (MgO)	**0.15**	**0.4**	**1.5**	**0**	**0.15**	**0.47**	**0.1**
Titanium dioxide (TiO_2)	**1**	**0.07**	**0.7**	**0**	**0.02**	**0.02**	**0**

3. Results & Discussion

The Environmental impact results of ceramic tiles using different alternatives of chemical composition and the contribution of the environmental indicators were analyzed. The study identified some parameters that should considered when deciding between the uses of different chemical composition. The outcomes of the result were influenced by many criteria, such as the definition of the functional unit, available data and the model assumptions and specification of system boundaries.

A comparison also was made between different proportions of silicon dioxide in different countries including Egypt to obtain the limitation that could adversely affect the environment and contribute to global warming and hence climatic changes. As mentioned before GaBi and Open-LCA simulating tools were used for comparison to study the different scenarios performed for acidification, climate change, global warming, eutrophication and human toxicity as demonstrated in the coming subsections.

The results show the basic seven raw materials samples of ceramic, which include silicon dioxide, aluminum oxide, iron oxide, calcium oxide, sodium oxide, potassium oxide, zirconium oxide, magnesium oxide and titanium dioxide. The obtained values showed that silicon dioxide turns out to be the raw material with the highest percentage of contribution to the formation of all samples, followed by aluminum oxide and then iron oxide and the percentages varies according to the sample chosen.

Figure 1 demonstrates the **Acidification** impact of manufacturing 1 ton of ceramic for the seven samples using Open-LCA and Gabi software. The most influencing chemical combinations on the results are silicon dioxide and aluminum oxide. Sample 1 had the lowest acidification due to lack of contribution of raw materials in general and the basic raw material (silicon dioxide) in particular in the mixture and sample 7 had the highest acidification due to the increase of contribution of raw materials in general and the basic raw material (silicon dioxide) in particular in the mixture. On the other hand, Aluminum oxide percentage differs randomly for the samples.

For sample 1: total acidification was 86.71 kg SO_2 and silicon dioxide had the highest participation in total acidification followed by aluminum oxide where acidification of silicon dioxide = 51.01 kg SO_2 and acidification of aluminum oxide = 33.78 kg SO_2.

For sample 7: total acidification was 99.755 kg SO_2 and silicon dioxide had the highest participation in total acidification followed by aluminum oxide where acidification of silicon dioxide = 78.8 kg SO_2 and acidification of aluminum oxide was 15.86 kg SO_2. The increase of silicon dioxide for sample 1 and sample 7 was about 35.3%. The silicon dioxide increased gradually for the other samples.

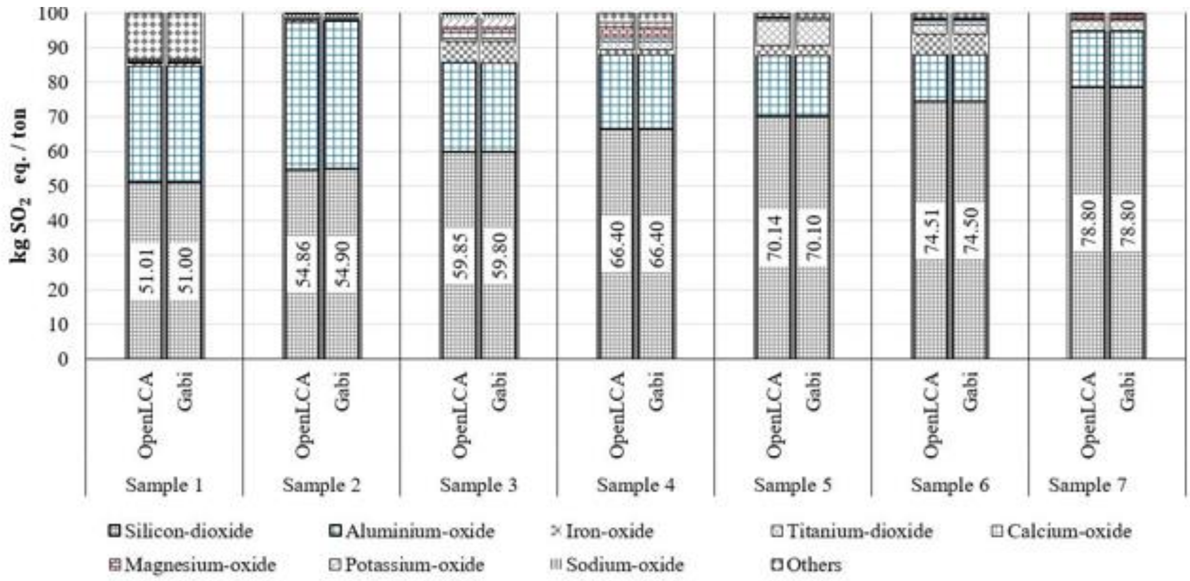

Figure 1: Acidification results for 1-ton manufacturing using OPENLCA and GABI

As for the impact of ceramic manufacturing of climatic change and global warming, ***Figure 2*** demonstrates the results simulated of Global Warming by Open-LCA and Climate change by GABI. Sample 1 had the lowest climate change due to lack of contribution of raw materials in general and the basic raw material (silicon dioxide) in particular in the mixture and sample 7 had the highest climate change due to the increase of contribution of raw materials in general and the basic raw material (silicon dioxide) in particular in the mixture.

For sample 1: total global warming was 867.1 kg CO_2 and silicon dioxide had the highest participation in total climate change followed by aluminum oxide where climate change of silicon dioxide = 510.05 kg CO_2 and global warming of aluminum oxide was 337.8 kg CO_2. The results using Gabi were differ where the results concerning the climate change. The participation of the climate change for the first sample was 1668.62 kg CO_2.

For sample 7: total global warming was 997.55 kg CO_2 and silicon dioxide had the highest participation in total climate change followed by aluminum oxide where climate change of silicon dioxide was 787.95 kg CO_2 and climate change of aluminum oxide = 158.6 kg CO_2. The participation of the climate change for the first sample was 1922.86 kg CO_2 which increased by 13.2 percent.

There was a difference between the results of the two different software because Open-LCA produces global warming, while GABI attains climate change. This difference between climate change and global warming is due to the fact that global warming is basically part of the drivers of the climate change, so it is always the value of global warming is higher than the value of climate change. According to Environmental Protection Agency, the two terms are used interchangeably [27].

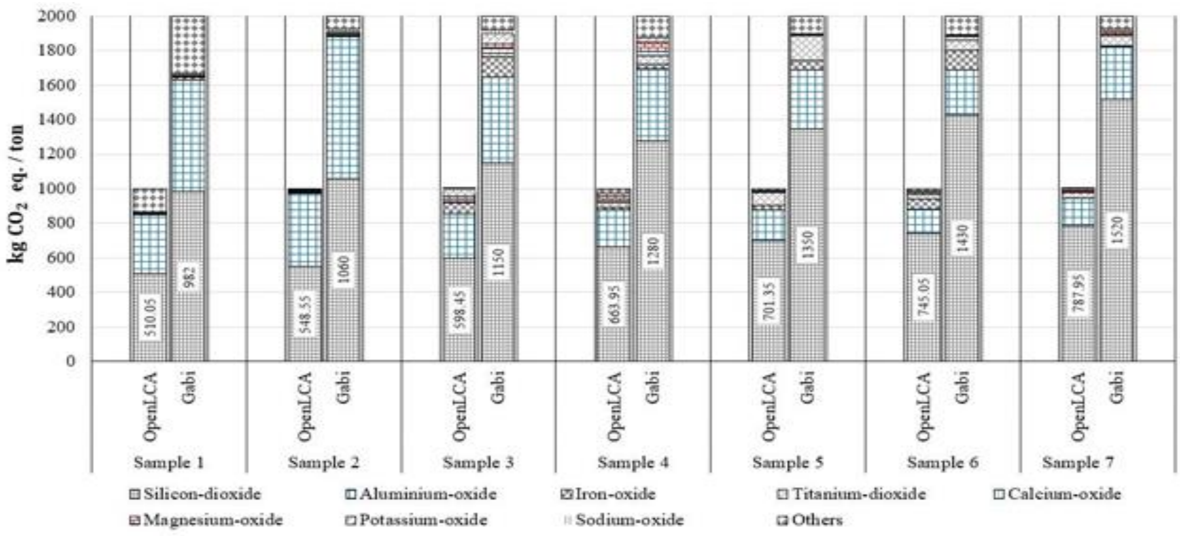

Figure 2: Climatic change and Global Warming results for 1-ton manufacturing using OPENLCA and GABI

The impact was also studies for eutrophication as presented in ***Figure 3*** below. Sample 1 had the lowest eutrophication due to lack of contribution of raw materials in general and the basic raw material (silicon dioxide) in particular in the mixture and sample 7 had the highest eutrophication due to the increase of contribution of raw materials in general and the basic raw material (silicon dioxide) in particular in the mixture.For sample 1: total eutrophication was 22.5446 kg PO_4 and silicon dioxide had the highest participation in total eutrophication followed by aluminum oxide where eutrophication of silicon dioxide was13.26 kg PO_4 and eutrophication of aluminum oxide was 8.78 kg PO_4.For sample 7: total eutrophication was 25.9363 kg PO4 and silicon dioxide had the highest participation in total eutrophication followed by aluminum oxide where eutrophication of silicon dioxide = 20.49 kg PO_4 and eutrophication of aluminum oxide was 4.12 kg PO_4.

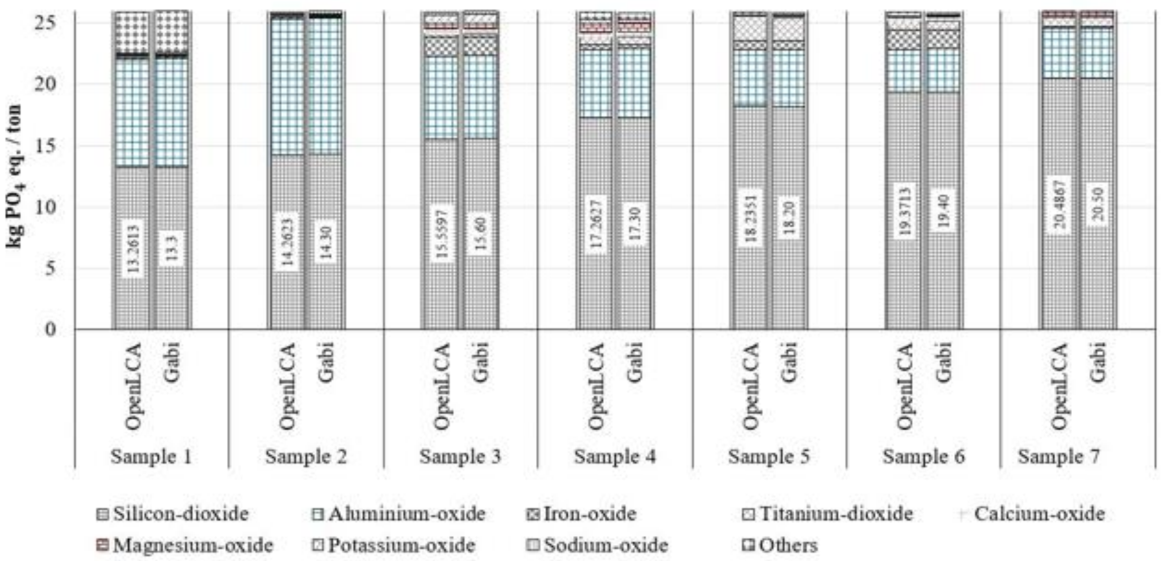

Figure 3: Eutrophication results for 1-ton manufacturing using OPENLCA and GABI

Then **Figure 4** demonstrated the impacts of Ceramic manufacturing on Human toxicity. Sample 1 had the lowest human toxicity due to lack of contribution of raw materials in general and the basic raw material (silicon dioxide) in particular in the mixture and sample 7 had the highest human toxicity due to the increase of contribution of raw materials in general and the basic raw material (silicon dioxide) in particular in the mixture.

For sample 1: total human toxicity was 208.104 kg 1,4-DB and silicon dioxide had the highest participation in total human toxicity followed by aluminum oxide where human toxicity of silicon dioxide was 122.41 kg 1,4-DB and human toxicity of aluminum oxide was 81.07 kg 1,4-DB.

For sample 7: total human toxicity was 239.412 kg 1,4-DB and silicon dioxide had the highest participation in total human toxicity followed by aluminum oxide where human toxicity of silicon dioxide was 189.11 kg 1,4-DB and human toxicity of aluminum oxide was 38.06 kg 1,4-DB. The differences in results were almost non-existent as shown in the results between Open-LCA and GABI simulation.

The value of global warming is greater than climate change because global warming refers to the rise in the Earth's surface temperature due to increased concentrations of carbon dioxide and other greenhouse gases due to people burning coal and oil, while climate change also includes global warming and its side effects such as melting Glaciers and rainstorms, and thus the temperature decreases, which leads to climate change, so the value of global warming is greater than the value of climate change.

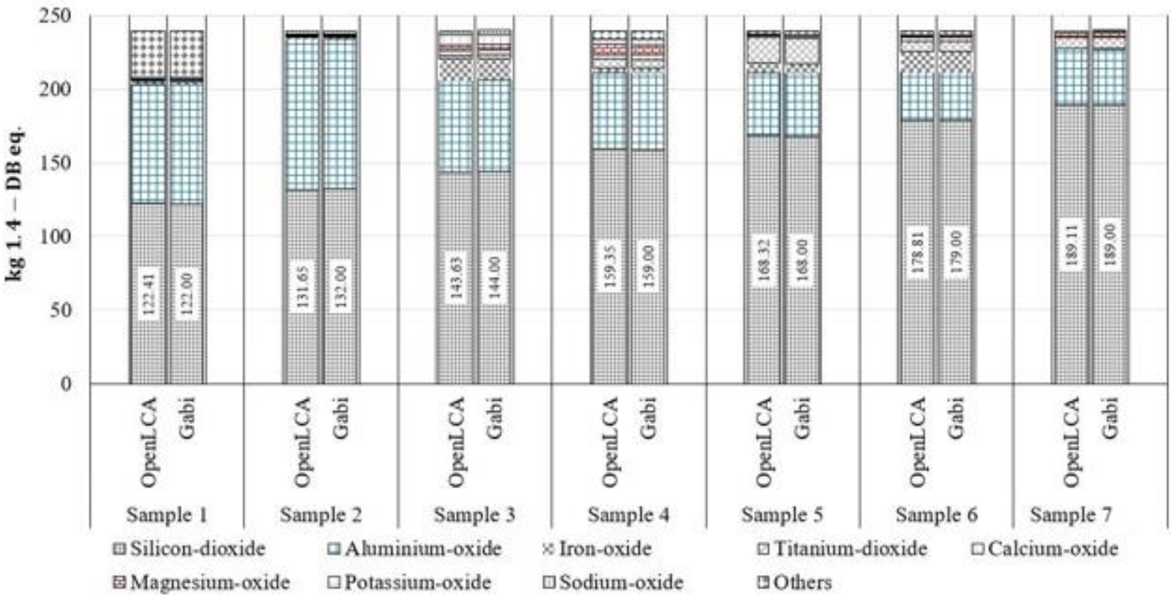

Figure 4: Human Toxicity results for 1-ton manufacturing using Open-LCA and GABI

4. Conclusion

The ceramic industry is known as one of the largest consumer of energy and natural resources manufacturing. Internationally, millions of metric squares of ceramic are required yearly especially with the rise in population seeking shelter and facilities being constructed worldwide. Open-LCA and GABI are two simulating tools widely used for evaluating the environmental impacts of construction material and studying their life cycle assessment. Both tools were used to evaluate the impact of ceramic constituent testing different percentages of the chemical composition to produce 1-ton ceramic tiles.

The selection of ceramic mixtures in this study is based on two antagonistic axes: structural quality and environmental quality, so that the final product fits the structural and environmental specifications together, and this represents the biggest points that deserve attention, which are the limits of the specifications.The biggest obstacle in this study is the presence of some mixtures that cause a very small environmental impact, but at the same time the mixture does not suit the targeted construction quality of ceramics. Among the obstacles is the different weather conditions in each country in which ceramics are manufactured compared to another.Results showed that Silicon dioxide was the driver of the fluctuation of the outcomes. The lowest combination of ceramic constituents would be sample 1 with 51.14 percent of Silicon dioxide gives the lowest Environmental contribution and the highest value for contribution was Sample 7 that contain 79 percent of Silicon dioxide leads to the highest values for the Environmental indicators. Reducing Silicon dioxide in the mixture from 51.01% to 54.86, 59.85, 66.4, 70.14, 74.5, and 87.8 leads to reduction in the selected environmental indicator by 4%, 9%, 17%, 20%, 25%, 28% respectively. These results drive to pay the attention to attempt decreasing Silicon dioxide in the mixture during the production of ceramics tiles in order to preserve the environment.Finally, the results appeared to a large extent very similar for both Open-LCA and GABI software in all the studied effects categories: acidification, eutrophication, and human toxicity, while the difference appeared only in the following effects categories: climate change for the Open-LCA program and global warming for the program GABI.

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