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Life Cycle Assessment of Traditional Clay Bricks and Autoclaved Aerated Concrete (AAC) Blocks: A Comparative Study in Environmental Sustainability

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Abstract

In today's construction industry, the imperative to merge quality with environmental responsibility has prompted a profound paradigm shift towards eco-friendly construction materials. This study conducts a comprehensive examination of the environmental impacts associated with traditional bricks and Autoclaved Aerated Concrete (AAC) blocks, with a specific focus on Life Cycle Assessment (LCA). While traditional bricks, steeped in historical significance, offer durability and high thermal mass, their kilning process raises significant environmental concerns due to high energy consumption and greenhouse gas emissions. Conversely, AAC, derived from waste materials such as fly ash, presents a viable alternative with a substantially reduced environmental footprint. Utilizing SimaPro software and the CML 2 method, this study meticulously evaluates the environmental burdens of AAC blocks and bricks. Findings reveal that AAC blocks exhibit higher environmental impacts per unit mass compared to traditional bricks. However, due to their lower density, fewer AAC blocks are required in construction, resulting in an overall reduced environmental impact throughout the lifecycle. Major contributors to environmental burdens include energy consumption, emissions, and resource extraction. Key considerations for environmentally friendly decision-making encompass ozone layer depletion, global warming, and acidification. Although AAC blocks demonstrate higher global warming potential per kilogram, their lower density mitigates overall environmental harm compared to traditional bricks. Additionally, factors such as usability, economy, and accessibility play pivotal roles in material selection, influencing the overall sustainability of construction projects. In conclusion, AAC blocks present promising prospects for sustainable construction practices. Their utilization offers a pathway to reconcile the construction industry's quest for quality with a steadfast commitment to environmental sustainability. By leveraging LCA methodologies, this study provides valuable insights into the comparative environmental impacts of AAC blocks and traditional bricks, contributing to informed decision-making in the construction sector. Furthermore, it highlights the importance of considering not only the environmental impact but also factors like usability and economy in material selection processes. This holistic approach is crucial for fostering a greener and more sustainable construction industry, aligned with global initiatives to address climate change and reduce ecological footprints.

Keywords: Life cycle assessment, environmental sustainability, construction materials, simapro

INTRODUCTION

In the realm of modern construction, a paradigm shift is underway, compelling the industry to reconcile quality with a commitment to environmental sustainability. The quest for eco-friendly construction materials has intensified,

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fuelled by a global initiative to address climate concerns and reduce ecological footprints without compromising structural integrity [1]. A collection of studies has emerged, exploring alternative construction materials like AAC blocks, concrete blocks, Wood-Crete etc. creating potential pathways towards a greener construction future.

Against this backdrop, this study embarks on a comprehensive exploration of the environmental impacts associated with traditional bricks and AAC blocks, with an explicit focus on Life Cycle Assessment [2, 3]. Traditional brick masonry, steeped in historical significance offers—proffering durability and high thermal mass while entailing an environmentally taxing kilning process. On the other hand, AAC emerges as a promising alternative, derived from waste materials offering comparable strength to traditional bricks with a significantly reduced environmental footprint [4].

Life cycle assessment is a tool that has been used to determine the impact of building material on environment [3]. In this study AAC and Bricks are analysed using SimaPro (Version 7). The life cycle inventory analysis is done using, CML 2 (Centre for Environmental Studies, University of Leiden) baseline (2000) method and Eco-invent database has been used for the analysis. Results from the study would be helpful in assessment of environmental burden of the two materials which can be used in decision making process. Although, social and economic impact of the materials are also important but the study is limited to the environmental impact assessment.

LITERATURE REVIEW

In the modern construction industry, it's becoming increasingly crucial to develop and use eco-friendly construction materials without sacrificing quality. There have been studies comparing life cycle performance of the varied building construction material.

"A Comparative Cradle-To-Gate Life Cycle Assessment of Three Concrete Mix Designs" looked at different ways to make concrete more environmentally friendly. They used a 'cradle-to-gate' approach, examining three types of concrete mixes: one with 100% Portland cement, another with 65% Portland cement and 35% Fly Ash, and a third with 30% Portland cement and 70% ground granulated blast furnace slag (GGBS). They were primarily interested in how these mixes affected carbon dioxide (CO_2) emissions. Their findings suggested that using alternative materials, especially GGBS, could reduce the environmental impact of concrete production while keeping performance intact. This reflects the construction industry's growing commitment to sustainability.

"Life Cycle Assessment of Autoclaved Aerated Fly Ash and Concrete Block Production: A Study in China" delved into the production of aerated autoclaved fly ash and concrete blocks (AAFACB), focusing on the entire process from the beginning to the finished product. This study, conducted in China, found that AAFACB, as a green building material, has advantages in heat insulation, soundproofing, and fire resistance [5, 6]. They used a specific model to evaluate environmental impacts and identified major concerns such as marine pollution, freshwater pollution, and human toxicity [7, 8]. They also pinpointed critical stages in the production process and materials like cement, lime, and natural gas as significant contributors to environmental issues. The study recommended optimizing certain processes and reducing the use of key materials to improve sustainability. Additionally, they assessed the economic side of production and found opportunities for cost reduction.

"Life Cycle Assessment of Traditional and Alternative Bricks: A Review" expanded its focus to include both traditional bricks and alternative bricks with organic or inorganic additives [9, 10]. It explored the environmental impact of these bricks, highlighting the potential for alternative bricks to reduce environmental impact by avoiding the traditional firing process. This aligns with the growing interest in environmentally friendly construction materials [11]. The study also emphasized the importance of considering impact categories, system boundaries, and the tools used in life cycle assessments when evaluating these building materials. While there are studies on comparison of different alternative materials. This study aims to conducting life cycle assessments (LCA) for two fundamental building materials: traditional brick and aerated autoclaved concrete (AAC).

The Life cycle assessment is an apparatus for evaluating the different phases of a product from the acquisition of raw materials, their refinement, production, shipping, usage, and final scrapping. LCA, therefore, gauges the cost and effects of a product on the society and environment. The method first requires to define the scope and system boundaries, followed by Life cycle inventory analysis, life cycle Impact assessment and interpretation of the results.

The system boundaries are important to define what all needs to be assessed in the model. The cradle to grave system is the most extensive type of assessment that includes the whole life cycle of the product. This system comprises the life of a product from the extraction of resources to its production in the factory. The Cradle-to-cradle is a type of system in which a product at the end of its life is recycled. The Gate-to-gate is a technique that evaluates a single value-added process in the complete production chain.

Life cycle assessment (LCA) can be used to assess the potential environmental impacts of construction industry and its processes, this paper will be exploring the life cycle of clay brick, along with alternative materials like AAC blocks.

MATERIALS AND METHODS

Brick masonry has been a primary and one of the oldest construction technologies in common uses. Due to extensive availability of clay and ease of brick manufacturing, it still continues to be a desirable, construction technology in many locations. Since circa 5000 BCE, bricks have been produced in numerous materials, types, and sizes which vary with region and time period. There are two basic categories of brick, fired bricks and non-fired bricks but, but due to its longevity and strength, the clay fired bricks are most commonly used type of brick [12–14].

While clay bricks have properties such as durability, high thermal mass, and are considered sustainable due to their local extraction and production [15]. The kilning process used for its production has raised some environmental concerns because the kilning process in brick manufacturing has a high energy consumption and greenhouse gas (GHG) emissions.

Due to an arising need for development of green Infrastructure, the industry of green materials, products and services and is also rising. One of those green materials is autoclaved aerated concrete which is considered to be efficient construction materials as it is produced by using waste materials like fly ash while providing the same strength as clay bricks. In 1924, a Swedish architect developed AAC to get a material like wood having good thermal insulation, adequate strength, and ease of use but without the limitations of wood i.e., combustibility, decay and termite damage.

The main objective of developing AAC was to replace energy intensive clay brick with a material of adequate load-bearing and well insulating properties while also reducing the energy in production process and at the building operation level.

However, it is important to evaluate the eco-efficiency of both clay bricks and AAC blocks, in order to know whether AAC blocks are really more environment friendly than clay bricks. In that sense, Life Cycle Assessment (LCA) is a powerful tool to measure all the potential environmental impacts, inputs and outputs of these construction materials along their whole life-cycle.

AIM AND SCOPE

The aim of this study is to perform life cycle analysis of AAC blocks and Bricks using eco-invent 2.0 database from SimaPro (version 7). The life cycle inventory analysis is done using CML 2 (Centre for Environmental Studies, University of Leiden) baseline (2000) method taken from Ecoinvent 2.0 and extended with most important missing substances.

Materials are analysed based on ten different impact categories as described in CML 2 (Centre for Environmental Studies, University of Leiden) baseline (2000) method taken from Ecoinvent 2.0.

As AAC block and bricks have different densities 600kg/m3 and 1800m3 respectively. Functional unit has been decided based on the mass of AAC and brick used in 1m3 of masonry work. The data for the material in eco invent is based on production of brick and AAC blocks in Europe (RER). The system boundary accounts for inputs of energy requisites, transportation, and natural resources, as well as the outputs comprising of emissions released into soil, water, and air. Emissions from infrastructure processes are also included.

LIFE CYCLE INVENTORY AND DATA ANALYSIS

Life cycle inventory of the LCA model has been made primarily based on Ecoinvent data c2.0 final reports. In LCA model of AAC- Brick, the input data have been taken as resource (Kg), energy (electricity kWh/kg), Transportation (tkm) emission (kg/kg) to air. The input material data for the production of 1 kg of AAC block and Brick is shown in the following Table 1 and Table 3, Table 4. The emissions are shown in Table 2 and Table 5 Respectively.

Table 1. Inputs from Technosphere.

Known Inputs from Technosphere (material/fuels)		
Name	***Amount***	***Unit***
Aluminium, secondary, from new scrap, at plant/RER U	0.0007	kg
Anhydrite, at plant/CH U	0.044	kg
Diesel, burned in building machine/GLO U	0.0252	MJ
Electricity, medium voltage, production UCTE, at grid/UCTE U	0.0575	kwh
Heat, natural gas, at industrial furnace >100kW/RER U	0.646	MJ
Mine, clay/CH/IU	1.67E-10	p
Packing, clay products/CH U	1	kg
Portland cement, strength class Z 42.5, at plant/CH U	0.26	kg
Quicklime, milled, packed, at plant/CH U	0.104	kg
Sand, at mine/CH U	0.504	kg
Tap water, at user/RER U	0.648	kg
Transport, lorry >16t, fleet average/RER U	0.0381	t-km

Adapted from ecoinvent Centre, 2007.Database.

Table 2. Emissions to Air.

Emissions to air		
Name	***Amount***	***Unit***
Heat, waste	0.207	MJ

Adapted from ecoinvent Centre, 2007.Database.

Table 3. Inputs from Nature.

Known inputs from nature (resources)			
Name	**Sub-compartment**	**Amount**	**Unit**
Water, well, in ground	In water	7.36 E-5	M3

Adapted from ecoinvent Centre, 2007.Database.

LIFE CYCLE IMPACT ASSESSMENT (LCIA)

The CML 2 baseline (2000) tool has been used for the Life cycle impact evaluation of the manufacturing process of brick and AAC block. Characterization values of each impact categories are analysed; Normalization of the impact categories is done based on global - World 1995 values in the LCA model and values are given in Table 6 and units are given in Table 7.

RESULTS AND DISCUSSIONS

The comparative analysis was done using the models from ecoinvent data. Emission from transportation from gate to gate, further Processing of material and additional materials used for masonry work like mortar are not included in the model. The AAC block has higher environmental impact per unit mass (Kg) compared to the per unit mass (Kg) of brick as shown in Figure 1 and Figure 2 but as the density of the two material varies, 600 kg/m3 for AAC block and 1800 kg/m3 for Bricks, the total mass of AAC blocks used in construction of 1m3 of brick masonry is less than that of bricks. from this comparative study where, functional unit is taken as the mass of material used for construction of 1m3 of masonry work.

Table 4. Inputs from Technosphere.

Known Inputs from Technosphere (material/fuels)		
Name	***Amount***	***Unit***
Electricity, medium voltage, production UCTE, at grid/UCTE U	0.0394	kWh
Transport, lorry >28t, fleet average/CH	0.014	t-km
Transport, freight, rail/RER U	9.0E-5	t-km
Natural gas, high pressure, at consumer/RER U	1.24	MJ
Limestone, milled, packed, at plant/CH U	0.0239	kg
Diesel, burned in building machine/GLO U	0.0297	MJ
Lubricating oil, at plant/RER U	1.32E-5	kg
Steel, low-alloyed, at plant/RER U	3.06E-5	kg
Transport, lorry 20-28t, fleet average/CH U	0.00468	t-km
Tap water, at user/RER U	0.0272	kg
Clay, mine/CH U	1.35	kg
Mine, clay/CH/I U	2.0E-10	p
Sand, at mine/CH U	0.0147	kg
Limestone, crushed, for mill/CH U	0.000396	kg
Pulverised lignite, at plant/DE U	0.0245	MJ
Sheet rolling, chromium steel/RER U	1.57E-7	kg
Sheet rolling, steel/RER U	1.57E-5	kg
Heavy fuel oil, at regional storage/RER U	0.000381	kg
Light fuel oil, at regional storage/RER U	0.00541	kg
Polyethylene, HDPE, granulate, at plant/RER U	8.58E-7	kg
Polystyrene, expandable, at plant/RER U	0.000352	kg
Packaging film, LDPE, at plant/RER U	0.000542	kg
Transport, passenger car/RER U	0.0166	Person-km
Wood chips, mixed, from industry, u=40% at plant/RER U	5.3E-5	m3
EUR-flat pallet/RER U	1.61E-5	p

Adapted from ecoinvent Centre, 2007.Database.

Table 5. Emissions to Air.

Emissions to air		
Name	***Amount***	***Unit***
Carbon dioxide, fossil	0.18	kg
Carbon monoxide, fossil	0.000391	kg
Heat, waste	0.142	MJ
Hydrogen chloride	1.22E-5	kg
Hydrogen fluoride	1.06E-5	kg
Nitrogen oxides	0.00026	kg
Particulates, < 2.5 um	1.4E-5	kg
Sulfur dioxide	9.98E-5	kg
Particulates, > 10 um	4.68E-6	kg
Benzene	2.96E-6	kg
Formaldehyde	1.64E-5	kg
NMVOC, non-methane volatile organic compounds, unspecified origin	7.63E-5	kg
Phenol	1.3E-7	kg

Adapted from ecoinvent Centre, 2007.Database.

Table 6. Unit of impact categories.

Impact category	**Unit**
Abiotic depletion	kg Sb eq
Acidification	kg S02 eq
Eutrophication	kg PO4 eq
Global warming (GWP100)	kg CO2 eq
Ozone layer depletion (ODP)	kg CFC-11 eq
Human toxicity	kg 1,4-DB eq
Fresh water aquatic ecotoxicity	kg 1,4-DB eq
Marine aquatic ecotoxicity	kg 1,4-DB eq

Table 6. Normalization values of Impact categories.

Impact category	**Normalization**
Abiotic depletion	6.39E-12
Acidification	3.11E-12
Eutrophication	7.56E-12
Global warming (GWP100)	2.41E-14
Ozone layer depletion (ODP)	1.94E-9
Human toxicity	1.75E-14
Fresh water aquatic ecotoxicity	4.90E-13
Marine aquatic ecotoxicity	1.95E-15
Terrestrial ecotoxicity	3.72E-12
Photochemical oxidation	1.04E-11

Adapted from Pré Consultants, 2007

Brick has greater environmental bearing as compared to AAC block in all the sections mentioned in CML 2 baseline (2000) method. Figure 3 and Table 8 shows the characterization graph of the comparative LCA model.

Normalization graph (Figure 4) shows that marine aquatic ecotoxicity is the most significant impact categories for both the materials, followed by abiotic depletion and global warming potential while ozone depletion potential is the least significant impact category considering regional impact values. Normalization values shows that Brick has the environmental impact in marine aquatic ecotoxicity with very high margin and terrestrial ecotoxicity with very low margin compared to AAC block.

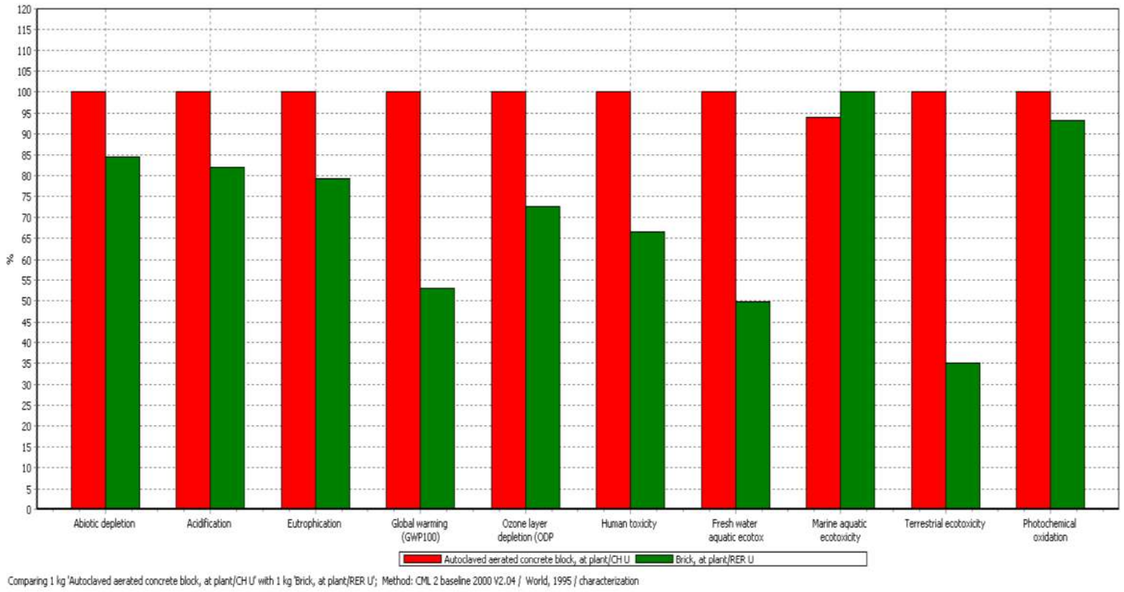

Figure 1. Characterization chart comparing 1 kg AAC block with 1 kg Brick (Ecoinvent Centre, 2007).

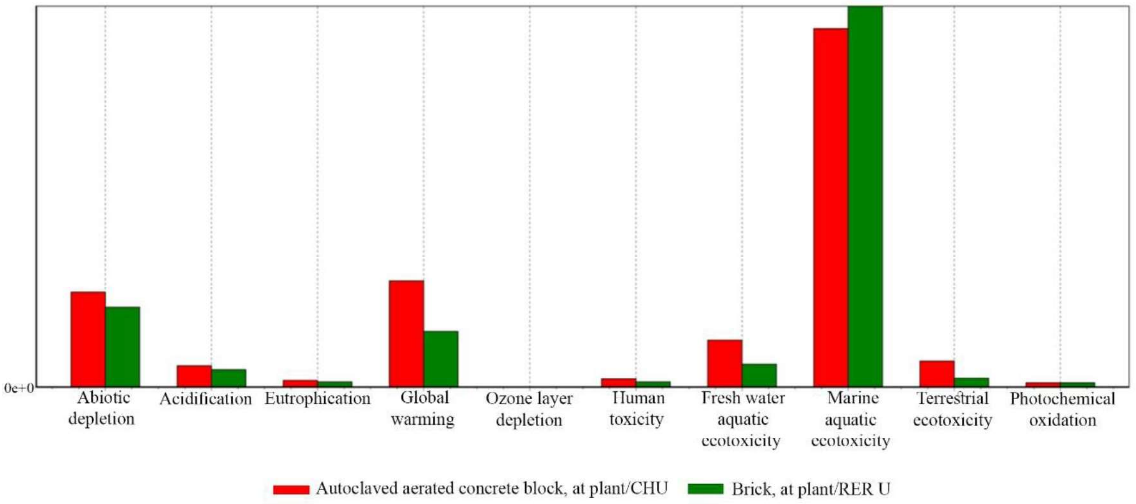

Figure 2. Normalization chart comparing 1 kg AAC block with 1 kg Brick (Ecoinvent Centre, 2007).

Table 7. Characterization table comparing 600 kg AAC block with 1800 kg Brick.

Impact category	**Unit /**	**Autoclaved aerated concrete block, at plant/CHU**	**Brick, at plant/RER U**
Human toxicity	kg 1,4-DB eq	26.8	53.5
Fresh water aquatic ecotoxicity	kg 1,4-DB eq	5.49	8.2
Marine aquatic ecotoxicity	kg 1,4-DB eq	1.04E4	3.31E4
Terrestrial ecotoxicity	kg 1,4-DB eq	0.404	0.425
Photochemical oxidation	kg C2H4	0.0257	0.072
Ozone layer depletion (ODP)	kg CFC-11 eq	1.31E-5	2.85E-5
Global warming (GWP100)	kg CO2 eq	249	396
Eutrophication	kg PO4--- eq	0.0508	0.121
Abiotic depletion	kg Sb eq	0.84	2.13
Acidification	kg S02 eq	0.401	0.986

Adapted from ecoinvent Centre, 2007.Database.

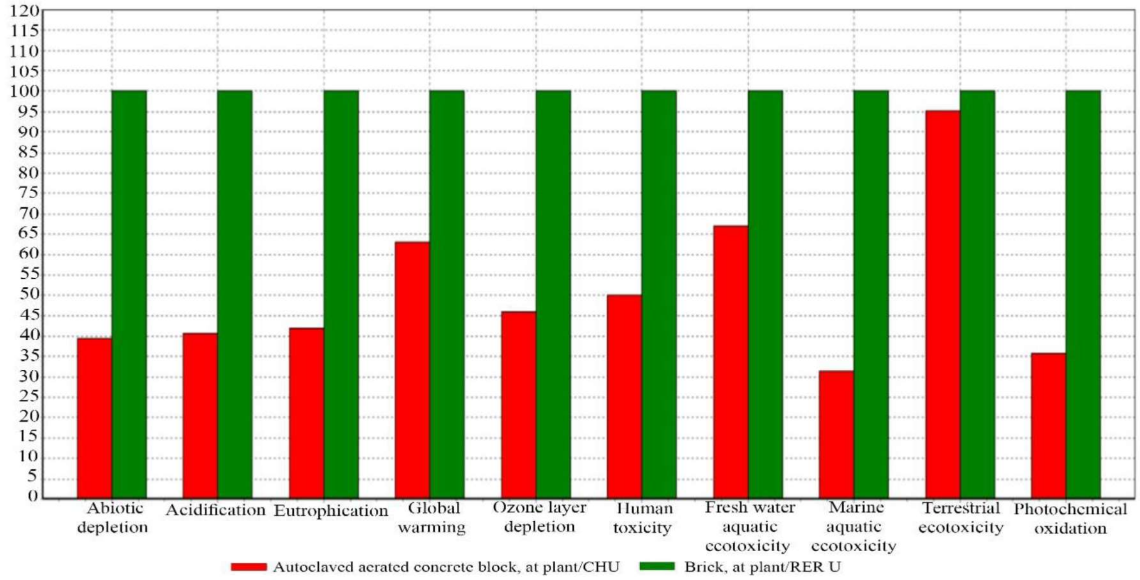

Figure 3. Characterization chart comparing 600 kg AAC block with 1800 kg Brick (Ecoinvent Centre, 2007).

An inventory analysis of the sections in the CML method reveals that the major factors in abiotic depletion are gypsum, crude oil, coal, and natural gas. Acidification of air is caused by the release of ammonia, nitrogen oxides, and Sulphur oxides. Mercury, vanadium released into air and chromium into soil are the leading pollutants causing the terrestrial ecotoxicity. Nickel, vanadium, cobalt and beryllium are the leading pollutant which mainly pollutes ground water and cause fresh and marine aquatic depletion. Carbon dioxide and methane released have the global warming potentials while carbon monoxide and sulphur dioxide cause photochemical oxidation. Polycyclic aromatic hydrocarbons, arsenic and barite are the primary substances released into air causing human toxicity while nitrogen oxide, ammonia released in air and phosphate released in water causes eutrophication.

Table 8. Normalization table comparing 600 kg AAC block with 1800 kg Brick.

Impact category Unit	**Autoclaved aerated concrete block, at plant /CH U**	**Brick, at plant /RER U**
Abiotic depletion	5.37E-12	1.36E-11
Acidification	1.25E-12	3.07E-12
Eutrophication	3.84E-13	9.13E-13
Global warming (GWP100)	6E-12	9.53E-12
Ozone layer depletion (ODP)	2.54E-14	5.53E-14
Human toxicity	4.7E-13	9.37E-13
Fresh water aquatic ecotoxicity	2.69E-12	4.02E-12
Marine aquatic ecotoxicity	2.02E-11	6.45E-11
Terrestrial ecotoxicity	1.5E-12	1.58E-12
Photochemical oxidation	2.68E-13	7.49E-13

Adapted from ecoinvent Centre, 2007.Database.

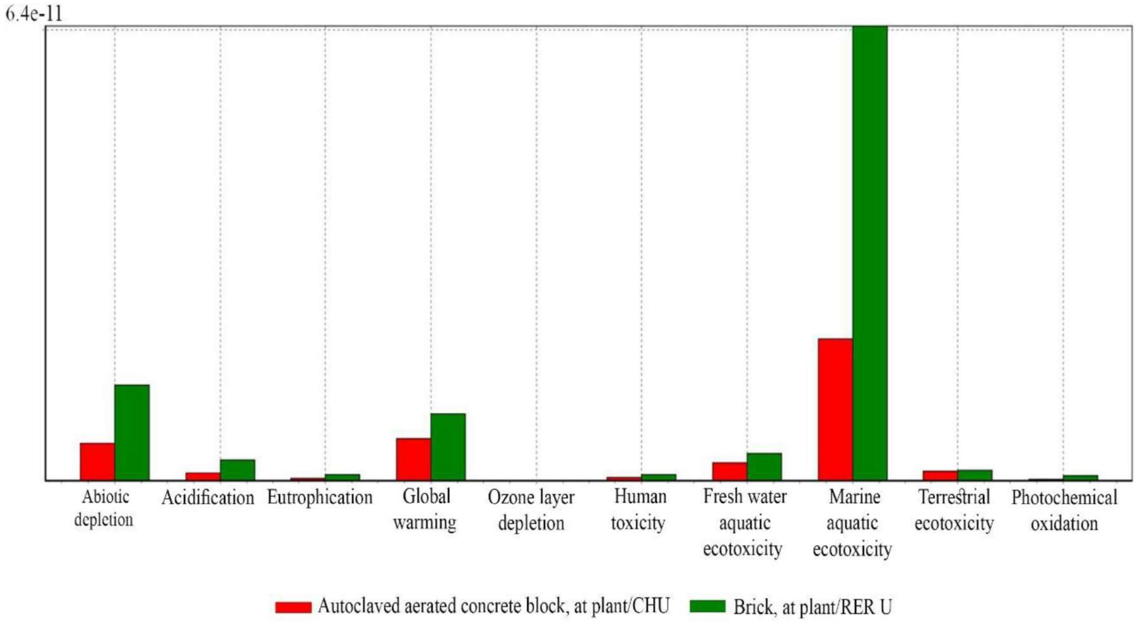

Figure 4. Normalization chart comparing 600 kg AAC block with 1800 kg Brick (Ecoinvent Centre, 2007).

The primary considerations for environment-friendly decision making should be based on factors causing ozone layer depletion, global warming, and acidification. While AAC blocks have high global warming potential per kg, brick comes out to cause more harm as number of AAC blocks used for masonry construction are 3 times less than that of brick due to low density. When assessing the life cycle of these building materials, one must look at the usability, economy, and accessibility of these materials. AAC block also comes with a property of reduced heat gain in the building. While it costs same as the brick the number of blocks, amount of cement, sand and water required for AAC block masonry construction is substantially less than brick masonry making it a popular material in many large projects. The factors previously delineated are crucial in choosing the building materials.

CONCLUSION

In conclusion, the life cycle assessment (LCA) comparing autoclaved aerated concrete (AAC) blocks and traditional clay bricks underscores the significance of environmental considerations in construction materials. AAC blocks exhibit overall lower environmental burdens than clay bricks when considering their lower density. The normalization analysis highlights marine aquatic ecotoxicity as a crucial impact category for both materials, emphasizing the importance of addressing this environmental concern. As sustainable decision-making becomes increasingly crucial in the construction industry, this LCA contributes valuable insights for informed material selection, promoting a balance between structural integrity and environmental responsibility in the pursuit of a greener future.

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