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ENVIRONMENTAL LIFE CYCLE ASSESSMENT OF AAC BLOCK: A FACTORY-BASED CASE STUDY IN BANGLADESH

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ABSTRACT

This paper presents environmental assessment of autoclaved aerated concrete (AAC) block made by Eco Friendly Green Bricks Ltd. located at Tangail, Bangladesh. A life-cycle assessment (LCA) methodology was used to express the environmental consequences. The main goal was to assess and quantify the environmental effects of AAC blocks in local conditions. Primary data was directly collected from the production facility and secondary data was taken from the Ecoinvent v3.10 database to define the system boundaries. The assessment was carried out with the help of the openLCA based on ReCiPe 2016 Midpoint (H) methodology according to ISO 14040 and ISO 14044, respectively, and thus ensured transparency and international comparability. The system boundary included cradle to gate stages and two scenarios, one without transportation of materials and one with raw materials transportation. The results showed that while aluminum powder had a very low concentration of 0.3 wt percent of the AAC formulation, it had the greatest of all contributors to impacts on the environment. It was a major driver of climate change potential (0.0728 kg CO2-eq), and terrestrial ecotoxicity (0.233 kg 1,4-DCB-eq). Lime and cement also had substantial impacts on acidification, fossil fuel use and land use intensity, due to themselves being energy intensive in their manufacturing processes. The aggregate impacts of producing one kg of AAC block they found amounted to 0.411 kg CO2-eq for climate change, but other interesting categories included terrestrial ecotoxicity (1.35 kg 1,4-DCB-eq), human non-carcinogenic toxicity (0.0218 kg 1,4-DCB-eq) and formation of particulate matter (0.000303 kg PM2.5-eq). Incorporating transportation increased these impacts slightly, especially those due to ozone depletion, marine eutrophication and photochemical oxidant formation. In summary, this study presents a Bangladesh-specific environmental baseline against which the environmental impacts of AAC blocks production can be compared and lime, cement, and aluminium powder seem to be the most significant contributors to environmental impacts. The results serve as a foundation for further optimizations in sustainable building materials, which in turn can provide decision information to the different stakeholders in the industry and governance structure when aiming for cleaner production routes and material efficiency in the construction industry.

Keywords: *Autoclaved Aerated Concrete (AAC); Life Cycle Assessment (LCA); Environmental Impact*

1. INTRODUCTION

The construction industry is an important driver for climate protection. It has very high consumption of raw materials and energy which results in high levels of pollution. In 2020, the construction sector was responsible for around 37% of global CO2 emissions from the energy sector (*Global Status Report for Buildings and Construction | UNEP - UN Environment Programme*, n.d.). So many countries that are pushing the sector to greener pastures. Bangladesh is doing the same. For Bangladesh, the existence of a national roadmap needs to be supported by practical data at the local levels to help make decisions on materials (*Climate Action Roadmaps for Buildings and Construction Bangladesh | GlobalABC*, n.d.).

Bricks are very commonly used in building industry. Bricks are quite bad for the environment. So we need better options. Autoclaved aerated concrete (AAC) blocks represent a good alternative with obvious advantages (Jerman et al., 2013; Michelini et al., 2023). Still, AAC is not impact-free. Its ingredients do have their own overheads: the production of cement, gypsum, lime and aluminium requires a lot of energy and emits greenhouse gases (Kittipongvises, 2017; Pedreño-Rojas et al., 2020; Soomro et al., 2023; Zhang et al., 2016). Lime production is a direct source of CO2 emission and sand quarrying can destroy land and water systems. Thus we need to examine the contents of AAC more closely, rather than accepting that it is 'green' because it is light and insulating.

Life Cycle Assessment (LCA) is the most suitable analytical tool for evaluating the environmental consequences attached to the production process of aerated autoclaved concrete (AAC) blocks as well as the overall production process. This is better than just guessing from properties like light weight or good insulation. This investigation follows the principles of the ISO 14040 and ISO 14044 standards and limits the boundaries of the investigation to cradle to gate, which covers investigation at the time of primary material extraction through to the factory gate. Impact assessment is carried out based on the methodology ReCiPe 2016 Midpoint (H) which takes into account important indicators such as climate change, ecotoxicity and generation of particulate matter. The model implementation is performed in openLCA, with the selected background datasets based on ecoinvent version 3.10. Ecoinvent version 3.10 is used to model to ensure the reliability, consistency and reproducibility of the model results.

There is a clear research gap for Bangladesh. Many studies use data from other regions that do not match the Bangladesh supply chains. Plant level data on energy sources, materials, water, wastes inside Bangladesh are rare. Transport distances and modes are not well documented, and uncertainty and sensitivity are often missing. This limits fair comparison across plants and reduces confidence for policy.

The present study aims to fill the gap by using primary data collected from Eco Friendly Green Bricks Ltd located in Tangail (Bangladesh) using the cradle to gate approach. The basic data were provided by the firm and then substantiated by engineering personnel. Complementary process parameters were abstracted from the econvent using background datasets retrieved from countries and technologies that are closest to Bangladeshi operational realities. This method ensures greater contextual fidelity in a resultant life-cycle inventory. As a result, the analysis provides a Bangladesh-specific LCA that can be used to inform policy deliberations; the analysis can also be used to support procurement decisions and optimisation of industrial processes.

The general goal of this work is to create an inventory specific to Bangladesh in the production of AAC blocks and quantify the impact of one kilogram of AAC block using the defined boundary. By reading this paper, policy makers can gain a clear view of the local environmental impacts of AAC blocks. Additionally, the study separates the material constituents that have the greatest influence over the overall impact, thereby providing future engineers with the means of making evidence-based decisions about material substitutions where possible.

2. MATERIALS AND METHODS

To conduct this study, a structured and internationally accepted LCA framework was followed. The overall research process has been summarized in a methodological flowchart, presented in Figure 1.

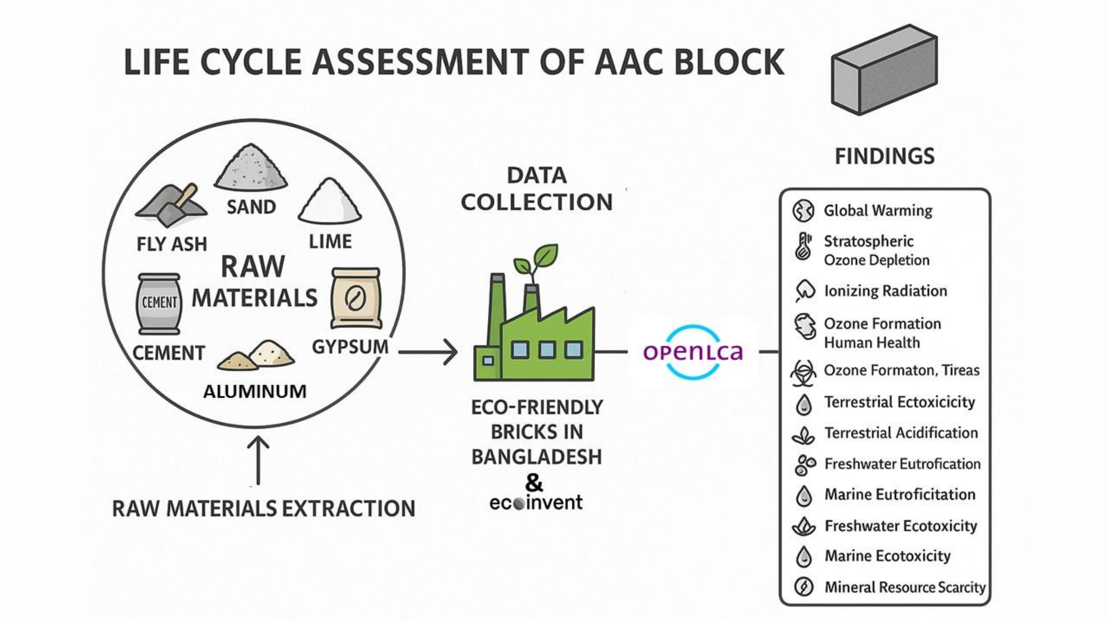


Figure 1: Methodological flowchart of this study.

2.1 Life Cycle Assessment Framework

This study uses Life Cycle Assessment to evaluate the environmental impact of AAC block production at Eco Friendly Green Bricks Ltd., located in Tangail, Bangladesh. A cradle-to-gate LCA approach was selected. The methodological framework closely follows the guidelines of the ISO 14040 and ISO 14044 standards (*ISO 14040:2006 - Environmental Management — Life Cycle Assessment — Principles and Framework*, n.d.), which define four particular phases of a life cycle assessment, such as setting the goal and scope, compiling the inventory data, assessing the environmental impacts, and interpreting the overall results.

2.2 Goal and Scope

The main aim of this research is to quantify the environmental impacts of the production of AAC blocks from cradle to gate (cradle to gate). We look at emissions, material flows, and resource use during manufacturing to build a clear environmental profile for AAC block production in a Bangladeshi plant. The research is motivated by the need for lower-impact building material due to the increased risks to the climate system and the increased need for sustainable infrastructure.

This analysis can be used by manufacturers, engineers, and policymakers to show where the impact of AAC production was largest. The analysis enriches the existing perception regarding the environmental profile of AAC block manufacturing into the construction sector of Bangladesh as a reference point for further research in academia and industry.

2.3 Functional Unit And System Boundary

This study adopts the reference unit to be 1 kilogram (kg) of AAC block and the unit of measure for the environmental impacts of AAC is calculated. This makes it easier and more consistent to make comparisons with other building materials.

The system boundary has been defined as cradle to gate, meaning that it contains everything from the collection of raw materials, to the point at which the finished AAC block leaves the factory. That is, any further activities such as movement to the construction site, use or disposal are excluded from this study.

To gain a better insight as to where environmental impacts are occurring, the study focuses on three different system boundaries, depicted in Figure 1:**:**

- **Case 1**: From the extraction of raw materials to their processing
- **Case 2**: From the extraction of raw materials to their delivery at the AAC block factory
- **Case 3**: From the extraction of raw materials to the finished AAC block leaving the factory

This approach helps identify which part of the process contributes the most to the overall environmental impact.

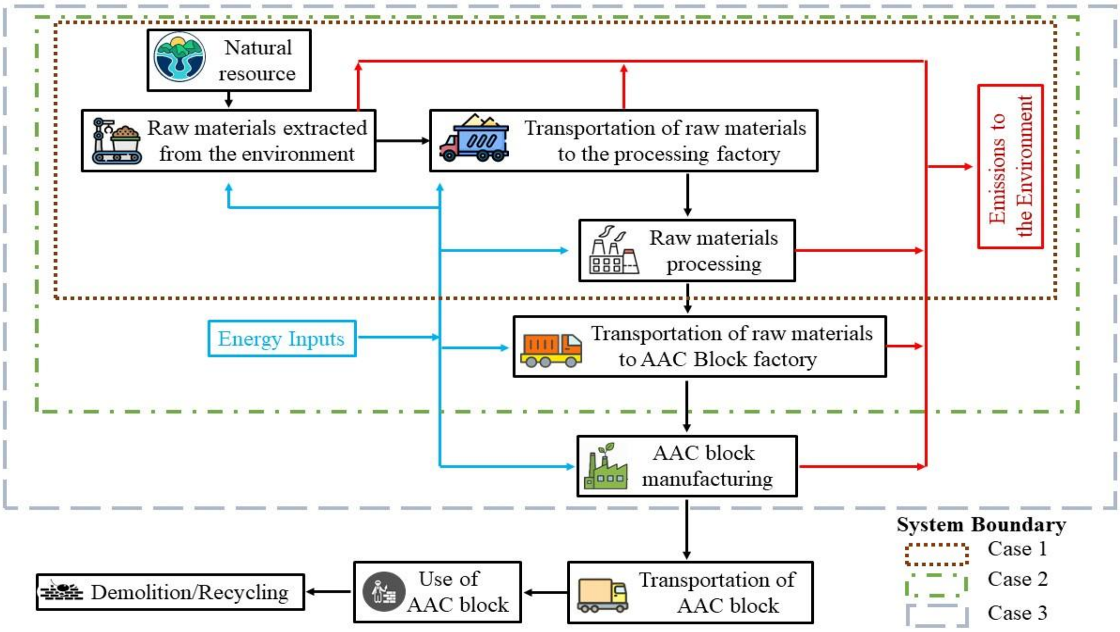


Figure 2: System boundary of this study.

2.4 LIFE CYCLE INVENTORY (LCI)

This phase collected both primary and secondary data to map all key inputs and outputs of AAC block production. Primary data came directly from the factory during site visits in 2024 and 2025. We recorded raw material quantities, energy use, and direct emissions, using plant records and discussions with technical staff.

Secondary data were taken from the ecoinvent v3.10 database, a widely used, ISO-aligned source (Wernet et al., 2016). All data were processed and modeled in openLCA, which supports transparent, ISO-consistent LCA work (*OpenLCA.Org | OpenLCA Is a Free, Professional Life Cycle Assessment (LCA) and Footprint Software with a Broad Range of Features and Many Available Databases, Created by GreenDelta since 2006*, n.d.)

Background data were taken from the ecoinvent v3.10 database and modelled in openLCA. For some materials and processes, Bangladesh-specific background datasets were not available. In these cases, proxy datasets were used. The selection of proxies was based on similarity of production technology and the closest available geographic representation, following common practice in life cycle assessment studies.

Using proxy datasets introduces uncertainty because upstream energy systems, emission levels, and supply chains may differ from local conditions in Bangladesh. This mainly affects the absolute values of the results. However, the approach is suitable for identifying the main contributing materials and processes and for comparing their relative importance. The results should therefore be interpreted as a Bangladesh-relevant baseline rather than exact national values. A detailed quantitative uncertainty analysis was not performed in this study and is recommended for future work.

Transportation distances for raw materials were estimated using geographic mapping tools and cross-checked through interviews with factory engineers.

Table 1: LCA inventory data for AAC block production (per kg)

Material	Amount (kg)	Transport Distance (km)	Transport Mode (Truck-Equivalent, km)	Source of Data
Cement	0.1300	134	Truck	Factory Records (Verified by Engineers)
Quicklime	0.1600	360	Truck	Factory Records (Verified by Engineers)
Gypsum	0.0800	350	Truck	Factory Records (Verified by Engineers)
Aluminum Powder	0.0030	350	Truck	Factory Records (Verified by Engineers)
Sand	0.6270	41	Truck	Factory Records (Verified by Engineers)
Electricity (kWh)	0.0675	–	–	Factory Records (Verified by Engineers)
Water	0.1840	–	–	Factory Records (Verified by Engineers)

2.5 LIFE CYCLE IMPACT ASSESSMENT (LCIA)

The life cycle impact assessment (LCIA) in this study was done using the ReCiPe 2016 Midpoint (H) method, a popular tool in construction research because it covers a wide range of environmental impacts and follows global standards (Huijbregts et al., 2017). The key indicators assessed include climate change (global warming potential), acidification, various ecotoxicity categories (terrestrial, freshwater, and marine), human toxicity (both carcinogenic and non-carcinogenic), resource depletion (energy and material resources), particulate matter formation, photochemical oxidant formation, eutrophication, ozone depletion, land use, ionising radiation, and water use. ReCiPe's compatibility with the openLCA platform and its ability to provide both midpoint and endpoint-level results made it a strong fit for the analysis.

3. RESULTS AND DISCUSSION

The life cycle impact assessment of AAC block production reveals that there are a number of categories that are much more important than others. The overall results are shown in Figure 4, in which the terrestrial ecotoxicity, climate change, and fossil fuel use stand out as the main contributors. The other categories like eutrophication, particulate matter, and ozone depletion are way less in comparison. Because of the very wide ranges of the results, the results including both sets of indicators were presented on a log scale in Figure 4 for clarity.

When acidification is included in the calculation, Figure 3a illustrates that aluminium contributes the most to the calculation, with a value of 3.1×10^{-4} kg SO_2-eq per kilogram AAC block. Cement follows at 2.2×10^{-4} and lime at 1.7×10^{-4}, while electricity, gypsum, and sand remain much smaller. Climate change impacts follow a different pattern. As shown in Figure 3b, the most dominant contribution is lime with 0.20 kg CO2-eq followed by cement with 0.12 kg CO2-eq and aluminium which contributes

0.10 kg CO2-eq. Phenomena of calcination are therefore of extreme importance for lime and cement manufacturing.

Freshwater ecotoxicity is determined by a combined action of production and transport. Figure 3c shows that lime is the most impactful location with 4.6×10^{-5} kg 1,4-DCB-eq, almost half of which is due to transport. Sand and gypsum increase strongly after transport is taken into account, aluminium and cement become important. In the case of marine ecotoxicity, shown in Figure 3d, the lime is again in the control position with 4.8×10^{-4} kg 1,4-DCB-eq, followed by cement and aluminium. The influence of supply chain logistics is also visible in the fact that transport increases gypsum and sand loading.

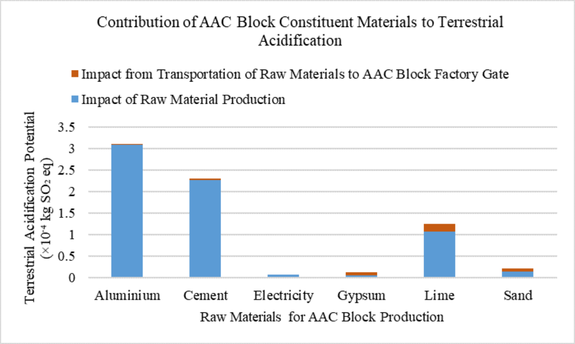
The most striking result comes from terrestrial ecotoxicity. Figure 3e shows lime contributing 4.7×10^{-3} kg 1,4-DCB-eq, far higher than in any other category. Cement and aluminium also add large shares, and transport raises the totals further. This confirms that terrestrial ecosystems are highly sensitive to AAC raw material supply chains. A similar dominance of lime, cement, and aluminium appears in fossil fuel use. Figure 3f shows values of 2.0×10^{-2}, 1.5×10^{-2}, and 1.4×10^{-2} kg oil-eq for these three materials, while electricity, gypsum, and sand remain very small.

Nutrient-related indicators shift the focus slightly. Freshwater eutrophication, shown in Figure 3g, is mainly driven by cement at 3.0×10^{-6} kg P-eq, followed by aluminium at 1.5×10^{-6}. Marine eutrophication, presented in Figure 3h, is dominated by lime at 6.7×10^{-7} kg N-eq and electricity at 5.0×10^{-7}, while gypsum and sand rise modestly when transport is added.

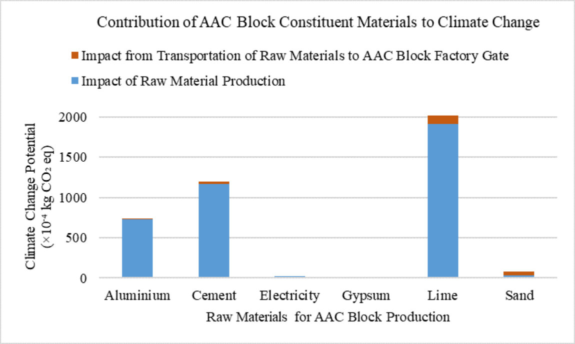
Human toxicity is clearly controlled by aluminium. Figure 3i shows aluminium contributing 2.5×10^{-4} kg 1,4-DCB-eq to carcinogenic effects, while cement and lime remain much smaller. In non-carcinogenic toxicity, illustrated in Figure 3j, aluminium contributes more than 1.4×10^{-6} kg 1,4-DCB-eq, with all other materials nearly negligible. This means that even though aluminium is used in small amounts, its upstream production causes large emissions that dominate toxicity impacts.

Other categories are driven by individual processes. Ionising radiation, shown in Figure 3k, is almost completely linked to electricity production, reaching 7.8×10^{-4} kBq Co-60-eq. Mineral resource use, illustrated in Figure 3l, is dominated by aluminium at 7.5×10^{-4} kg Cu-eq, reflecting the intensity of bauxite mining. Ozone depletion, in Figure 3m, is highest for aluminium at 1.3×10^{-3} kg CFC-11-eq, with cement, electricity, and lime also contributing smaller amounts. Particulate matter formation, shown in Figure 3n, is led by aluminium and cement, which together exceed 2.3×10^{-4} kg $PM_{2.5}$-eq. Photochemical oxidant formation, illustrated in Figure 3o and Figure 3p, is dominated by cement, followed by aluminium and lime, while transport adds small shares for gypsum and sand. Finally, water use is shown in Figure 3q to be largely from electricity, with a value of 7.0×10^{-3} m^3, while aluminium and lime add secondary contributions.

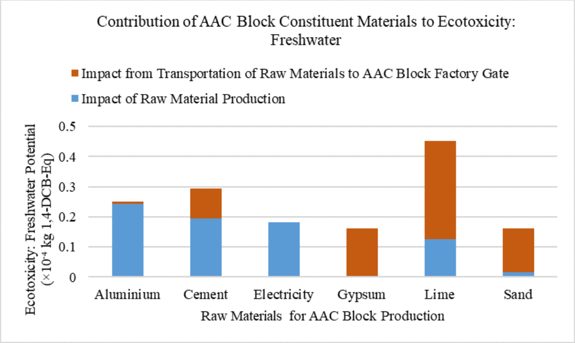
The combined impacts for the AAC block are summarised in Figure 4. This figure makes it clear that lime, cement, and aluminium together account for most of the burdens across categories. Electricity dominates in ionising radiation and water use, while gypsum and sand become relevant mainly through transport. Overall, binder production and aluminium dosing are the key hotspots, while electricity plays a major role in some categories, and transport acts as a secondary but visible factor.


Contribution of AAC Block Constituent Materials to Terrestrial Acidification
Impact from Transportation of Raw Materials to AAC Block Factory Gate
Impact of Raw Material Production
Terrestrial Acidification Potential (×10^{-4} kg SO$_2$ eq)
3.5
3
2.5
2
1.5
1
0.5
0
Aluminium
Cement
Electricity
Gypsum
Lime
Sand
Raw Materials for AAC Block Production

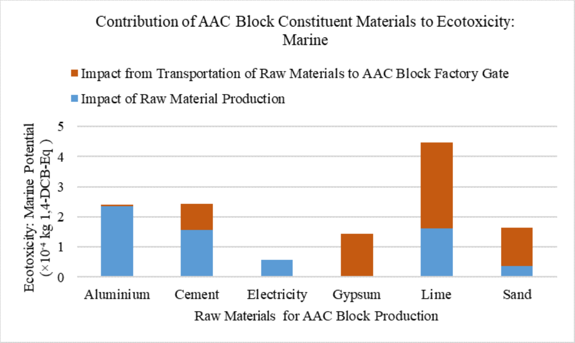
(a)


Contribution of AAC Block Constituent Materials to Climate Change
Impact from Transportation of Raw Materials to AAC Block Factory Gate
Impact of Raw Material Production
Climate Change Potential (×10^{-4} kg CO$_2$ eq)
2000
1500
1000
500
0
Aluminium
Cement
Electricity
Gypsum
Lime
Sand
Raw Materials for AAC Block Production

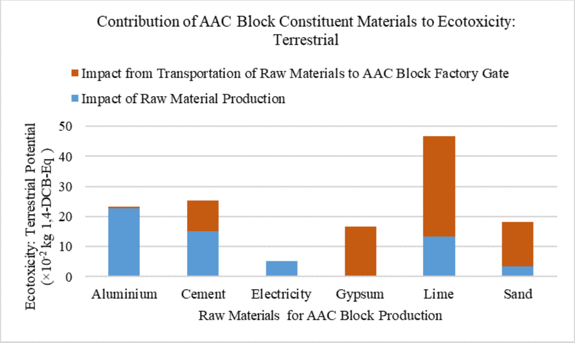
(b)


Contribution of AAC Block Constituent Materials to Ecotoxicity: Freshwater
Impact from Transportation of Raw Materials to AAC Block Factory Gate
Impact of Raw Material Production
Ecotoxicity: Freshwater Potential (×10^{-4} kg 1,4-DCB-Eq)
0.5
0.4
0.3
0.2
0.1
0
Aluminium
Cement
Electricity
Gypsum
Lime
Sand
Raw Materials for AAC Block Production

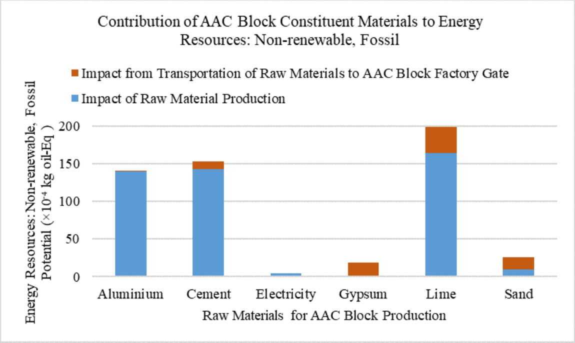
(c)


Contribution of AAC Block Constituent Materials to Ecotoxicity: Marine
Impact from Transportation of Raw Materials to AAC Block Factory Gate
Impact of Raw Material Production
Ecotoxicity: Marine Potential (×10^{-4} kg 1,4-DCB-Eq)
5
4
3
2
1
0
Aluminium
Cement
Electricity
Gypsum
Lime
Sand
Raw Materials for AAC Block Production

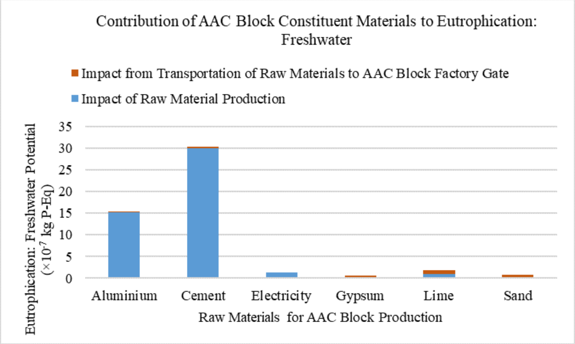
(d)


Contribution of AAC Block Constituent Materials to Ecotoxicity: Terrestrial
Impact from Transportation of Raw Materials to AAC Block Factory Gate
Impact of Raw Material Production
Ecotoxicity: Terrestrial Potential (×10^{-2} kg 1,4-DCB-Eq)
50
40
30
20
10
0
Aluminium
Cement
Electricity
Gypsum
Lime
Sand
Raw Materials for AAC Block Production

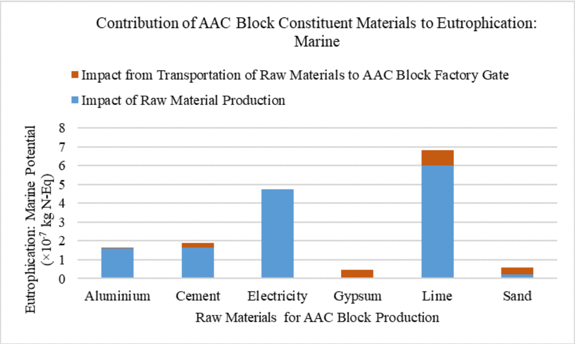
(e)


Contribution of AAC Block Constituent Materials to Energy Resources: Non-renewable, Fossil
Impact from Transportation of Raw Materials to AAC Block Factory Gate
Impact of Raw Material Production
Energy Resources: Non-renewable, Fossil Potential (×10^{-4} kg oil-Eq)
200
150
100
50
0
Aluminium
Cement
Electricity
Gypsum
Lime
Sand
Raw Materials for AAC Block Production

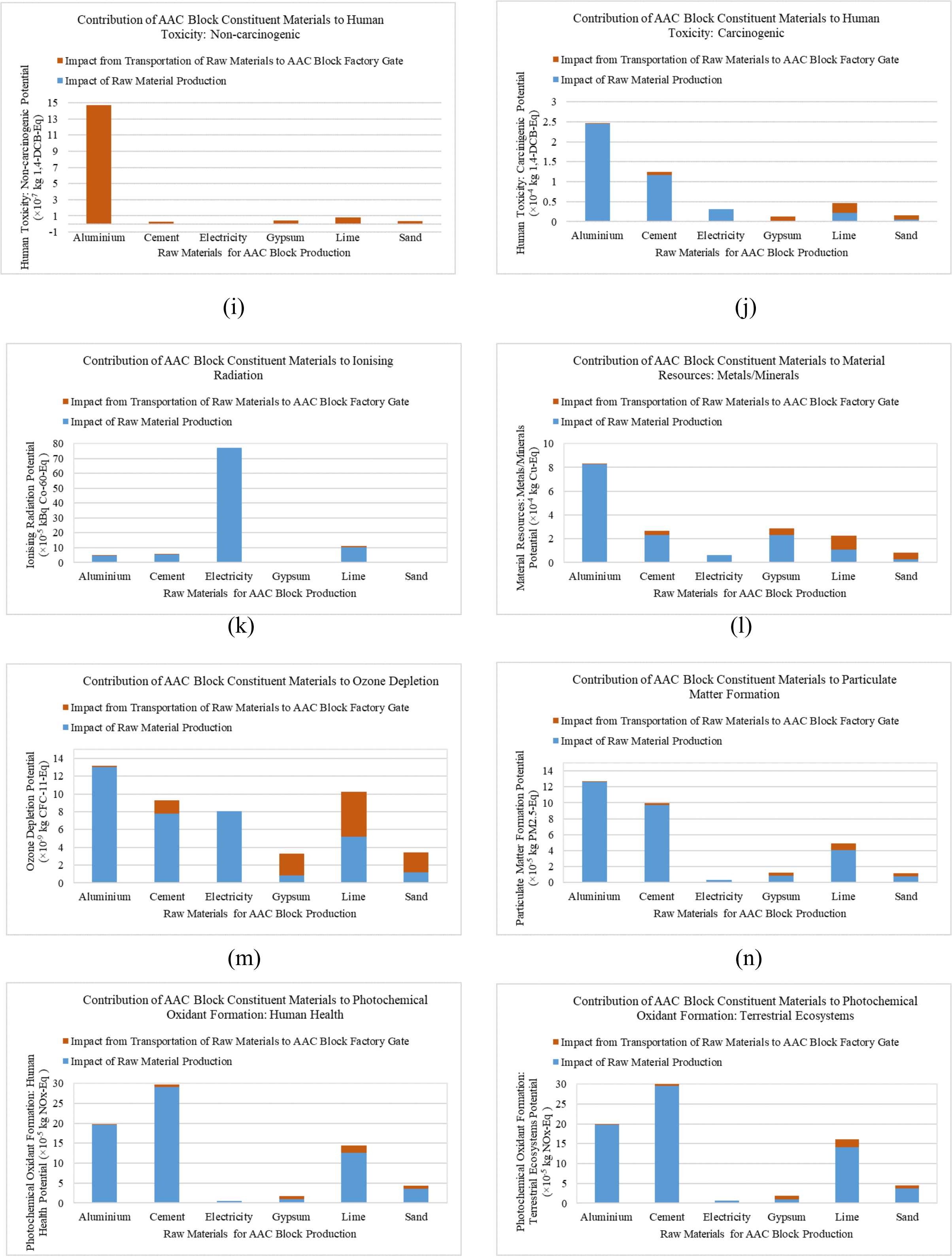
(f)


Contribution of AAC Block Constituent Materials to Eutrophication: Freshwater
Impact from Transportation of Raw Materials to AAC Block Factory Gate
Impact of Raw Material Production
Eutrophication: Freshwater Potential (×10^{-7} kg P-Eq)
35
30
25
20
15
10
5
0
Aluminium
Cement
Electricity
Gypsum
Lime
Sand
Raw Materials for AAC Block Production

(g)


Contribution of AAC Block Constituent Materials to Eutrophication: Marine
Impact from Transportation of Raw Materials to AAC Block Factory Gate
Impact of Raw Material Production
Eutrophication: Marine Potential (×10^{-7} kg N-Eq)
8
7
6
5
4
3
2
1
0
Aluminium
Cement
Electricity
Gypsum
Lime
Sand
Raw Materials for AAC Block Production

(h)



Contribution of AAC Block Constituent Materials to Human Toxicity: Non-carcinogenic

(i)

Contribution of AAC Block Constituent Materials to Human Toxicity: Carcinogenic

(j)

Contribution of AAC Block Constituent Materials to Ionising Radiation

(k)

Contribution of AAC Block Constituent Materials to Material Resources: Metals/Minerals

(l)

Contribution of AAC Block Constituent Materials to Ozone Depletion

(m)

Contribution of AAC Block Constituent Materials to Particulate Matter Formation

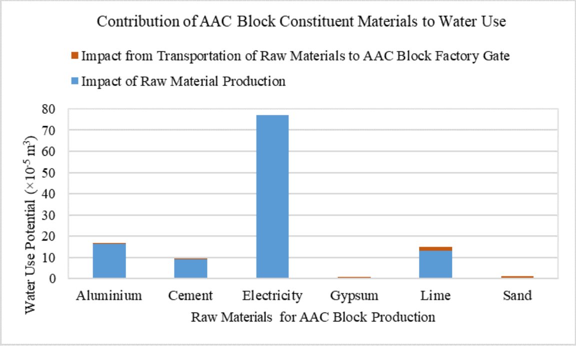
(n)

Contribution of AAC Block Constituent Materials to Photochemical Oxidant Formation: Human Health

(o)

Contribution of AAC Block Constituent Materials to Photochemical Oxidant Formation: Terrestrial Ecosystems

(p)



(q)

Figure 3: Contribution of AAC block constituent materials to a) terrestrial acidification b) climate change c) ecotoxicity: freshwater d) ecotoxicity: marine e) ecotoxicity: terrestrial f) energy resource: nonrenewable, fossil g) eutrophication: fresh water h) eutrophication: marine i) human toxicity: non carcinogenic j) human toxicity: carcinogenic k) ionising radiation l) material resources: metals/ minerals m) ozone depletion n) particle matter formation o) photochemical oxidant formation: human health p) photochemical oxidant formation: terrestrial ecosystem q) water use

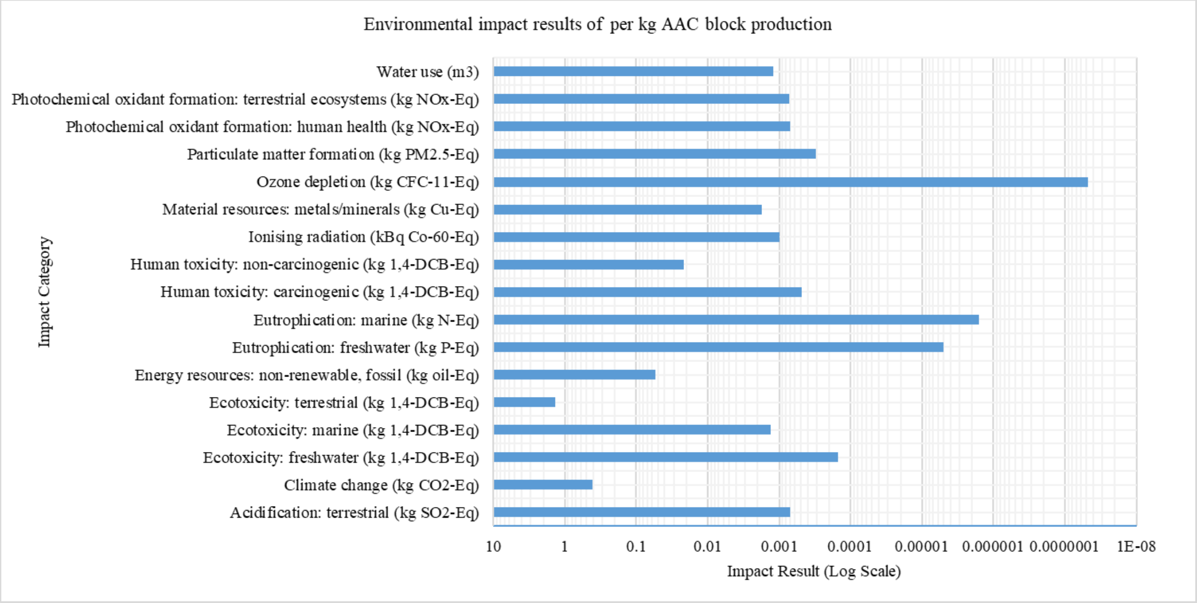


Figure 4: Environmental impact results of per kg AAC block production

4. CONCLUSION

This research achieved its main goal, which was to measure the environmental impact of AAC block production in Bangladesh using real factory data. By collecting data from Eco Friendly Green Bricks Ltd. and combining it with ecoinvent datasets, this study created a local life cycle picture that better represents Bangladesh than studies based only on foreign data. The results show clear patterns that help us understand where the biggest impacts come from and how to reduce them.

The results of these tests prove that the largest effects come from lime, cement, and aluminum powder. Lime and cement make most of the emissions associated with climate change and acidification because the production requirements a lot of heat and fuel. Although used in a small amount, aluminum imposes a huge burden in toxicity and use of resources due to its very energy intensive production. Electricity consumed in the factory impacts fields of consideration like ionizing radiation and usage of water. When the transport is included, the effect is increased for heavy materials like sand and gypsum. These results explain the impact of the individual raw materials and processes on the environment in a comprehensible and measurable manner.

The results are sensitive to aluminium dosage and electricity use. Although aluminium powder is used in a very small amount, it contributes strongly to several impact categories, especially toxicity and resource use. A small change in aluminium dosage or the use of recycled aluminium could therefore reduce overall impacts noticeably. Electricity use mainly affects ionising radiation and water use. Using a cleaner electricity mix would lower these impacts without changing the production process.

This outcome is a match for the objective of the study. The research enabled building a full inventory for AAC block production in Bangladesh and calculating impact per kg and identifying the main hotspots in the process. It fills the data gap by offering a real picture of AAC manufacturing under local conditions. For policy and engineering practice, this work gives a base to make decisions about cleaner production methods and better material selection in future projects.

The study's strength is that it connects local factory data with an international LCA method, producing reliable and transparent results. The key message is simple: cleaner binders, efficient use of aluminum, and better energy management can greatly reduce the total footprint of AAC production. Replacing part of clinker and lime with materials like fly ash or slag, using recycled aluminum, and improving autoclave efficiency are practical next steps. Cleaner electricity from renewable sources would also reduce several impact categories at once. Transport improvements, though smaller, still help by cutting fuel use and emissions.

The findings are relevant for both industry and policy in Bangladesh. The results show that reducing lime and cement content, improving aluminium efficiency, and using cleaner electricity can significantly lower environmental impacts. These measures align with national goals for greener construction and reduced emissions in the building sector. The study provides local evidence that can support material selection, factory improvement, and policy decisions related to sustainable construction materials.

For future research, the LCA boundary can be extended to include the use and end-of-life stages. Studying how AAC performs during building use will show its real long-term benefit. Sensitivity tests on aluminum dosage, binder ratio, and energy mix would also make the results stronger. This work can guide other researchers and local industries to develop a cleaner and more sustainable AAC production process in Bangladesh.

Declaration of Use of AI

The authors declare that ChatGPT (version 5.2), an AI-based language model developed by OpenAI, was used during the preparation of this manuscript for the purpose of improving grammar, language clarity, and overall readability. The AI tool was not used in the research design, data collection, analysis, interpretation of results, or generation of scientific content.

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