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Life Cycle Assessment of Cementitious Bricks

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Abstract - The construction sector heavily employs cementitious bricks due to their high durability and versatility. The entire manufacturing process of cementitious bricks and their utilization resulted in severe environmental impacts, including raw material exhaustion, the release of greenhouse gases, and the creation of waste products. This paper evaluates the sustainability implications of cementitious bricks using the Life Cycle Assessment (LCA) method through their entire lifecycle, starting from material extraction and ending at disposal. The analysis showed that the production stage emerges as the most damaging phase because it leads to substantial resource depletion and emission release. The implementation of waste management offers environmental benefits by lowering individual hazards, but it simultaneously produces additional environmental difficulties. Furthermore, visual network diagrams demonstrate that the release of emissions from brick production leads to substantial climate-associated damage and health consequences. A possible sustainable method to overcome waste produced by cementitious bricks is to utilize Waste Tyre Rubber (WTR) as an alternative to the sand component. In summary, this research shows the necessity for improving processes of brick manufacturing, waste management, and ecological alternatives. The study strengthens the movement toward environmentally friendly building materials because it demonstrates their ability to preserve construction standards while decreasing environmental deterioration.

Keywords**:** Life Cycle Assessment, SimaPro, Cementitious bricks, Sustainable construction, Waste management, Ecoinvent database

1. Introduction

LCA is a widely adopted methodology for assessing environmental impacts throughout a product's entire life cycle. [1, 2]. The approach permits the decision-makers to understand the footprint of the chosen product and improve it further by applying better practices to minimize environmental impacts [3]. One of the most utilized products in construction sites is cementitious bricks [4]. While cementitious bricks show high durability and versatility in construction [5], they equally demonstrate significant environmental hazards associated with their production and use [6]. Therefore, this paper aims to conduct a LCA of cementitious bricks to establish their environmental impact at each life cycle stage to provide strategies for future construction activities.

The main stages considered in a general LCA study are extraction of raw materials, production, transportation, use, and waste management [7], as shown in Fig. 1. In each of these stages, there is interaction with the natural environment, leading to several environmental impacts, including consumption of resources or energy, emissions, wastes, or impairment to ecosystems or human health.

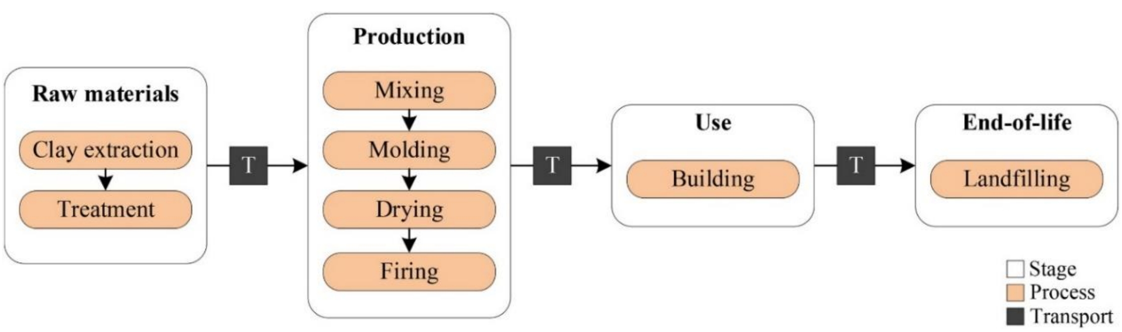

Fig. 1: Stages of Life Cycle Assessment of cementitious bricks [7].

To begin, in the extraction stage, most of the raw materials, like clay, sand, and limestone, are mined, which results in land degradation, air and water pollution, habitat destruction, and high energy use; all these effects can be minimized through sustainable sourcing practices [8]. Moreover, the manufacturing process of cementitious bricks demands substantial energy usage and produces greenhouse gases with multiple pollutants from mixing through firing stages [9]. Similarly, the transportation phase is also environmentally harmful due to the generated gasses from fuel consumption when moving the materials to production, building sites, and waste management plants [10]. Lastly, bricks reach their end of life when they become suitable for either reuse or proper disposal, which is essential to decrease landfill needs, leading to a smaller environmental impact [11].

The manufacturing stage of cementitious bricks involves proportioning, mixing, compacting, curing, and drying [12]. Firstly, proportioning must be performed to achieve the correct balance of raw materials necessary for improved concrete quality under specific work conditions. According to Indian standard recommendations, the aggregate should not exceed six parts to one part Portland cement by volume [13]. In addition, for bricks compacted by power-operated machines, lean mixes of up to 1:9 are used, and a water-cement ratio of 0.62 by weight is utilized [13]. Next, aggregates, cement, and water must be thoroughly mixed to ensure a uniform coating, and the mixture must be used within 30 minutes [14]. Furthermore, compaction eliminates air pockets and prevents the free movement of water within the concrete and is usually carried out by semi-automatic vibrating machines [13]. Finally, the process involves at least a 21-day curing period, with water replenished every four days, as longer curing results in better brick quality [13].

The mixing proportions of both plastering and brickmaking have been considered at different rates to suit project requirements. Based on the engineering expertise, the mix for plastering requires 12.5% cement, 75% sand, and 22.5% water, whereas in brickmaking, it includes 12.5% cement, 67.5% sand, 15% aggregate, and 17.5% water. Given the resource-intensive nature of cementitious brick production, optimizing these proportions can contribute to reducing the environmental impact [15].

2. Methodology

2.1. Life Cycle Assessment Setup

The analysis examined the environmental effects of cementitious bricks through a LCA that followed the ISO 14040 procedures. The evaluation process consisted of four sequential phases: goal and scope, life cycle inventory, life cycle impact assessment and terminated with interpretation [16], as shown in Fig. 2. Also, the analysis used SimaPro, Ecoinvent database information, and relevant literature sources to critically conduct the LCA assessment.

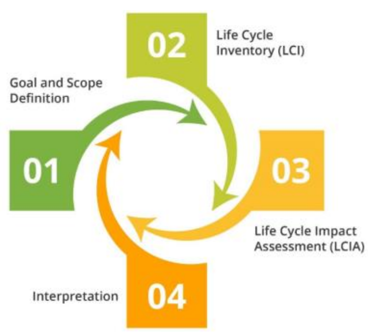

Fig. 2: Phases of Life Cycle Assessment [17].

A functional unit consisting of 1 m^2 cementitious brick wall required 50 bricks weighing 4 kg and totalling 200 kg. The bricks contained 12.5% cement, 67.5% sand, 15% crushed gravel (aggregate), and 17.5% water. The application of a 2 cm thickness of cement plaster required 40 kg of material mixture that contained 12.5% cement, 75% sand, and 22.5% water to achieve a density of 2000 kg/m^3 [18, 19]. The 200 kg of bricks needed 12.4 tonne-kilometers (tkm) freight delivery distance to reach the construction site [15]. The complete 200 kg of material was assumed to enter the waste phase while using the "Waste brick {GLO} | market for | Alloc Def, S" process in SimaPro.

Table 1 shows the life cycle impact assessment methods for brick types. It can be seen that the ReCiPe Midpoint (E) (E) V1.10 / Europe ReCiPe E and ReCiPe Endpoint (E) V1.10 / Europe ReCiPe E/A served as assessment methods to determine environmental impacts from cementitious bricks throughout their life cycle.

Table 1: Type of bricks, country of development, software, database, LCIA method and system boundaries [7].

Type	Author (Year)	Country	Software	Database	LCIA method	System boundaries	Considerations for the choice of system boundaries
CB	Koroneos and Dompros (2007)	Greece	SimaPro	No one	EcoIndicator 95	Cradle-to-grave	U.I.
	Wei et al. (2008)	China	U.I.	U.I.	U.I.[a]	Cradle-to-use	U.I.
	Yahya and Boussabaine (2010)	UK	SimaPro	Ecoinvent	EcoIndicator 95	Only EoL	The study aims to assess three options of final disposal of brick wastes
	Kua and Kamath (2014)	Singapore	U.I.	Ecoinvent	U.I.	Cradle-to-grave	U.I.
	Condeixa et al. (2014)	Brazil	SimaPro	Ecoinvent	CML 2001	Cradle-to-grave	The study aims to assess a use stage of 50 years
	Almeida et al. (2015)	Portugal	SimaPro	Ecoinvent	CML 2001/ Impact 2002+	Cradle-to-grave	U.I.
	Giama and Papadopoulos (2015)	Greece	SimaPro	Ecoinvent	CML 2001	Cradle-to-gate	Quality and reliability of initial data used to make the life cycle inventory
	Souza et al. (2016)	Brazil	SimaPro	Ecoinvent	Impact 2002+/ ReCiPe	Cradle-to-grave	U.I.
	Christoforou et al. (2016)	Cyprus	GaBi	GaBi database	CML 2001	Cradle-to-site	Difficulty to assess the use and final disposal
	Talang et al. (2017)	Thailand	U.I.	Ecoinvent/ TH LCI	Stepwise2006/ ReCiPe	Cradle-to-gate	Facility to compare with other studies
	López-Aguilar et al. (2019)	Mexico	SimaPro	Ecoinvent	EcoIndicator 99/ Impact 2002+/ CML 2001/ ReCiPe	Cradle-to-gate	U.I.
ABO	Bories et al. (2016)	France	SimaPro	Ecoinvent	ReCiPe	Cradle-to-gate	U.I.
	Galan-Marin et al. (2016)	Spain	U.I.	Ecoinvent	CML 2001	Cradle-to-grave	U.I.
	Joglekar et al. (2018)	India	GaBi	Indian database	CML 2001/ ReCiPe	Cradle-to-use	U.I.
	Lozano-Miralles et al. (2018)	Spain	SimaPro	U.I.	Impact 2002+/ ReCiPe	Cradle-to-gate	The study only aims to assess new samples production
	Mohajerani et al. (2018)	Australia	SimaPro	AusLCI	ReCiPe	Cradle-to-gate	U.I.
ABI	Salman et al. (2016)	Belgium	SimaPro	Ecoinvent	ReCiPe	Cradle-to-gate	The study aims to compare the proposed bricks with a conventional one only until the productive processes
	López-Aguilar et al. (2016)	Mexico	SimaPro	Ecoinvent	EcoIndicator 99	Cradle-to-gate	U.I.
	Marcelino-Sadaba et al. (2017)	Spain/UK	OpenLCA	ELCD	CML 2001	Cradle-to-gate	To avoid complications of recycling an already recycled product
	Robayo-Salazar et al. (2017)	Colombia	OpenLCA	Ecoinvent	IPCC 2013	Cradle-to-gate	U.I.
	Huang et al. (2017)	Taiwan	SimaPro	U.I.	Impact 2002+	Cradle-to-grave	The study aims to compare different scenarios of reuse of fly ashes
	Muñoz et al. (2018)	Spain	SimaPro	Ecoinvent	ReCiPe	Cradle-to-grave	U.I.
	Seco et al. (2018)	Spain	OpenLCA	ELCD	CML 2001	Cradle-to-gate	U.I.
	Poinot et al. (2018)	India	U.I.	Ecoinvent	Impact 2002+	Cradle-to-gate	Lack of data for the use stage of alkali-activated bricks
OB	Özkan et al. (2016)	Turkey	SimaPro	U.I.	CML 2001	Cradle-to-gate	U.I.
	An et al. (2018)	China	U.I.	Ecoinvent	U.I.	Cradle-to-gate	U.I.
	Yuan et al. (2018)	China	SimaPro	Ecoinvent	ReCiPe	Cradle-to-gate	Both types of bricks do not present outputs of pollutants materials during the use and have a same EoL
	Boenzi et al. (2019)	Spain	OpenLCA	Ecoinvent	ReCiPe	Cradle-to-gate	U.I.

ABI: Alternative brick with inorganic additives. ABO: Alternative brick with organic additives. CB: Conventional brick. EoL: End-of-life. LCIA: Life cycle impact assessment. OB: Other types of bricks. U.I.: Unknown information.

[a] The authors made an Intensity Analysis of material, energy and pollutant based in a LCA inventory.

2.2. Impacts of the Life Cycle Assessment

In the LCA carried out on cementitious bricks, both Midpoint and Endpoint impact indicators were used to evaluate environmental impacts. The CML-IA baseline V3.01 and Eco-indicator 99 (E) V2.09 methods were utilized in the study; they were selected since they are widely used in the literature related to LCAs of construction materials.

Midpoint analysis addressed impact categories like climate change, ozone depletion, human toxicity, freshwater ecotoxicity, agricultural land occupation, natural land transformation, and water depletion. On the other hand, Endpoint analysis addressed damage assessment to human health, ecosystem quality, and resources.

The methodology followed guarantees an exhaustive assessment of the environmental impacts of the lifecycle of cementitious bricks using fixed procedures and addressing a wide variety of impact categories.

3. Results and Discussion

3.1. Comparison of Life Cycle Assessment Results: ReCiPe Midpoint & Endpoint

Fig. 3 shows the environmental impact of cementitious bricks across different impact categories through ReCiPe Midpoint indicators. The production stage stands as the main contributing factor through all examined categories. Although the impact of brick waste extends most heavily into natural land transformation, it shows positive effects on the rest of the categories. Additionally, transportation and installation, though less influential, still contribute to environmental degradation across all categories.

Fig. 3: ReCiPe Midpoint (E) V1.10 / Europe Recipe E.

Fig. 4 compares the ReCiPe Midpoint results with and without waste management. Waste management lowers land use impact from 75% to 45% by reducing raw material use. It also cuts freshwater ecotoxicity, human toxicity, and agricultural land occupation, showing clear environmental benefits. However, it is essential to note that waste management integration introduces additional impacts on natural land transformation throughout the production, transportation, and installation stages, producing around 40% of waste, possibly due to the need for land acquisition for waste management facilities and infrastructure.

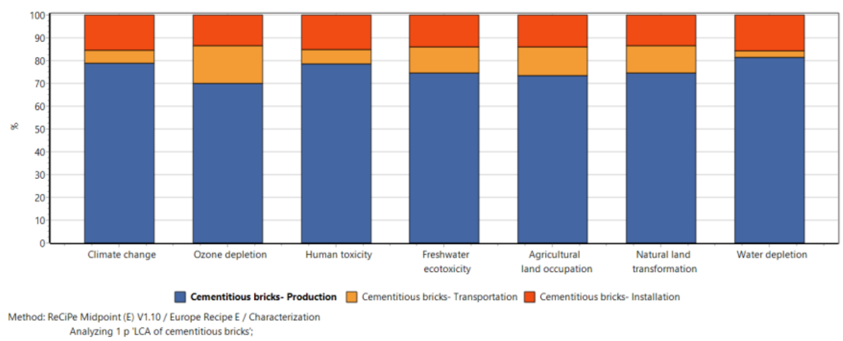

Fig. 4: ReCiPe Midpoint (E) V1.10 / Europe Recipe E (excluding waste).

Fig. 5 shows the ReCiPe Endpoint results, which are similar to the Midpoint assessment, indicating that the production stage is the main cause of environmental damage in all categories. Likewise, transportation and installation do not contribute much to environmental damage, but they still have some noticeable effects. However, the Endpoint assessment shows that brick waste has a positive impact in all categories, unlike what was discussed in the Midpoint assessment.

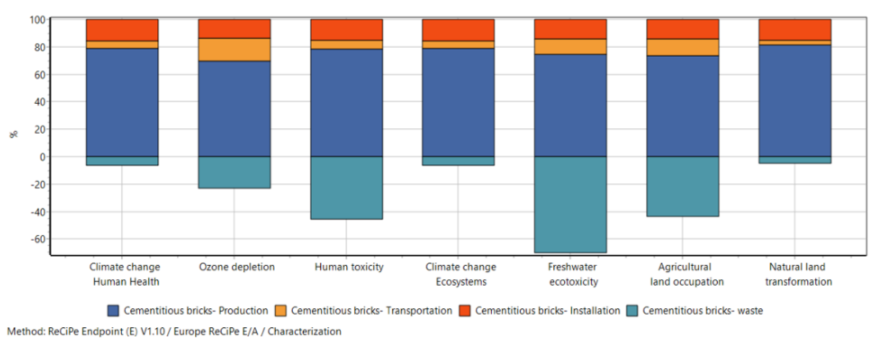

Fig. 5: ReCiPe Endpoint (E) V1.10 / Europe ReCiPe E/A.

The results reveal that cementitious bricks inflict substantial environmental damage during their manufacturing and disposal processes. Environmental concerns related to waste management decrease toxicities, and land use problems yet introduce new environmental challenges. The Midpoint method provides detailed information about individual stages, yet the Endpoint method collects comprehensive data to demonstrate human health system degradation, ecosystem disruption, and resource exhaustion. Furthermore, waste management strategies have a negligible impact on both water depletion and climate change, although they achieve some environmental benefits.

3.2. Damage Assessment Using the ReCiPe Endpoint Method

The ReCiPe Endpoint method evaluated cementitious brick environmental impacts across three fundamental areas: human health, ecosystems, and resources. The evaluation method considers the complete lifecycle of cementitious bricks, beginning with their production and ending at their disposal stage. A wide range of health effects are included in the Endpoint assessment, such as the incidence of cancer, respiratory problems, and the influence of climate change on human health.

Fig. 6 demonstrates the proportionate influence of diverse stages across the lifecycle that generate these environmental consequences. The production stage drives most environmental damage between the three lifecycle phases; the environment faces maximum damage through emissions and pollutants, which collectively account for 50-80% of total impacts. Consequently, transportation and installation operations also result in measurable effects throughout the assessment, reaching up to 30% of the total impacts. Lastly, a positive impact of waste management was posed throughout the phases of the experiment.

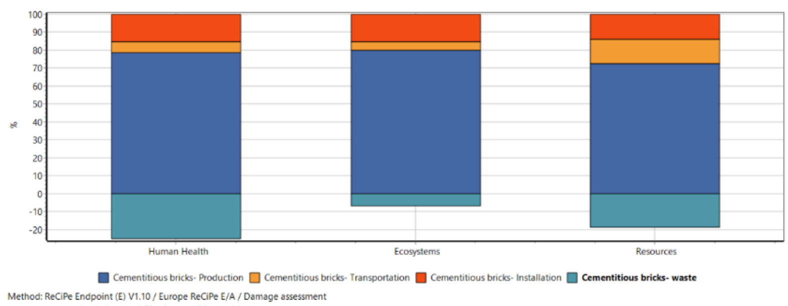

Fig. 6: ReCiPe Endpoint (E) V1.10 / Europe ReCiPe E/A (damage assessment).

3.3. Network Diagrams Using the ReCiPe Midpoint Method

Network diagrams illustrate the interconnections between processes which contribute to environmental effects from the inception to the termination of cementitious brick life cycles. These diagrams reveal crucial impact zones while simultaneously showing essential stages that need focused monitoring.

Fig. 7 shows the Climate Change Network Diagram evaluated through Midpoint analysis. Notably, the operational phase of brick use in buildings produces 97% of the total global warming potential as greenhouse gasses from brick materials.
Furthermore, the impact of heating and cooling buildings makes the situation worse because it results in additional energy consumption.

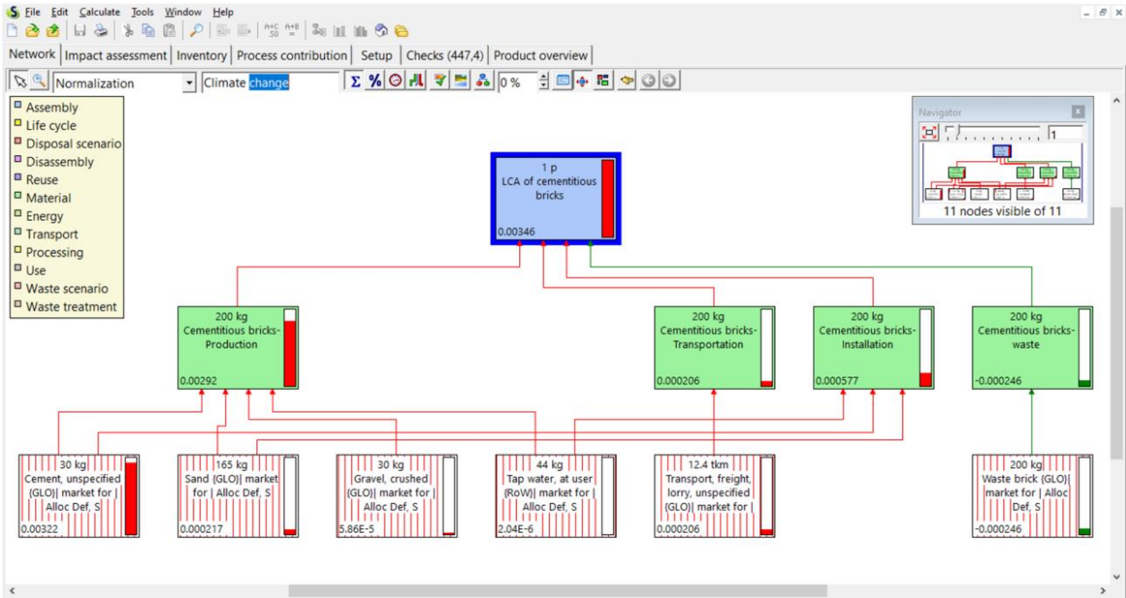

Fig. 7: Network of climate change using ReCiPe Midpoint method.

Fig. 8 shows the Human Health Network Diagram appears. Specifically, the recovery process depends heavily on polyethylene incineration due to its intense energy output capability. Consequently, the toxic pollutants generated from this phase contribute to cancer development and respiratory health problems. Therefore, targeted mitigation strategies become possible through the identification of important stages.

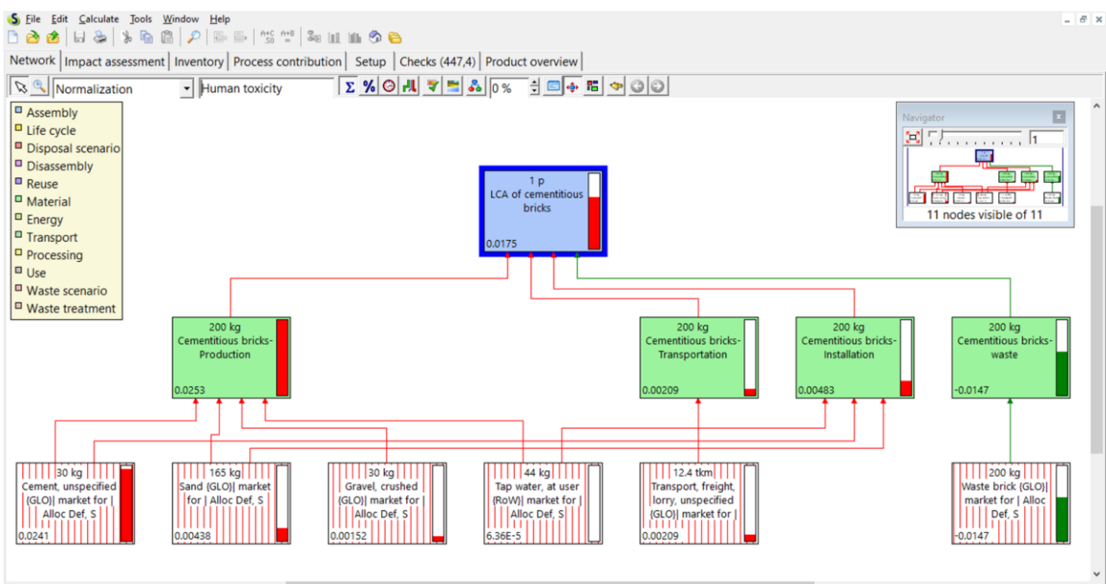

Fig. 8: Network of human toxicity using ReCiPe Midpoint method.

Through network diagrams, stakeholders can easily comprehend complex environmental information that was previously difficult to understand. The diagrams assist with improved decision processes while facilitating strategy development to minimize cementitious brick-related health and environmental damage.

3.4. An alternative to Cementitious Bricks

Cementitious bricks initiate environmental effects during their entire life cycle, starting from manufacturing and continuing through the disposal stages. The development of eco-friendly brick solutions presents an urgent need since organizations must find ways to reduce these effects. Research results show that bricks with partially replaced sand by WTR have achieved high compressive strength levels after 28 days of curing, making them suitable for building structures [20]. WTR substitution between 10-30% successfully resulted in bricks that fulfilled the minimum requirement of 3.5 MPa set by IS 1077 standard [20]. The process of replacing standard sand with WTR has produced a valuable decrease in thermal conductivity, according to published data [20]. Using WTR waste materials in brick production reveals an opportunity to develop environmentally friendly bricks suitable for construction work. The application of WTR has the potential to serve as an environmentally friendly alternative to typical brick production if it fulfils required building standards.

4. Conclusion

This research performed a LCA on cementitious bricks to determine their environmental effects throughout their entire production and disposal cycle. The assessment based on the ISO 14040 LCA framework and ReCiPe methodologies revealed production as the main source of impact due to significant resource consumption and emission generation. Network diagrams displayed how operational emissions during different stages affect climate change by producing the most significant environmental impact.

It is suggested that future research on construction sustainability to expand its examination of larger system scopes while using improved analysis techniques and developing new alternative materials. The implementation of recycled materials, such as WTR in brick manufacturing, represents an effective route to constructing environmentally sustainable buildings.

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