

Towards Sustainable Concrete Construction: An Environmental Product Declaration (EPD)  
Roadmap for Bangladesh

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**Abstract**

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Architecture

Climate change represents one of the most pressing global challenges, with the construction industry contributing approximately 40% of worldwide greenhouse gas emissions. Bangladesh, as one of the most climate-vulnerable nations, faces increasing threats from sea level rise and extreme weather events while experiencing rapid infrastructure development. Concrete production generates approximately one ton of CO<sub>2</sub> per ton of cement produced, necessitating careful consideration of the environmental impacts of construction materials. Life Cycle Assessment (LCA) methods enable quantification of the environmental impacts from raw material extraction through manufacturing ("cradle-to-gate"), while Environmental Product Declarations (EPDs) provide standardized, verified LCA results to enable informed material selection. However, in order to obtain LCA and EPD data, developing countries face significant implementation barriers, including limited local data availability, expensive proprietary software, and insufficient technical expertise. Currently, while developed nations possess thousands of EPDs, Bangladesh has only five registered EPDs, with none addressing concrete products. This research addresses the question: How can a comprehensive EPD framework for ready-mix concrete be developed and implemented in Bangladesh despite significant data limitations and regional challenges? The methodology employed primary data collection from the NDE Ready Mix Concrete plant in Dhaka, multi-tool validation using OpenLCA software, spreadsheet calculators, and software in development at the University of Washington, POD|LCA, combined with Ecoinvent database integration. Results demonstrate that accessible, cost-effective approaches utilizing open-source tools and free databases have the potential to effectively overcome traditional barriers to EPD development. This study establishes the first concrete EPD development roadmap for Bangladesh and a draft EPD for concrete mixture, providing a replicable framework for developing countries to advance sustainable construction practices and climate resilience through systematic environmental impact quantification and transparency.

**Keywords:** Environmental Product Declaration, Life Cycle Assessment, Concrete, Embodied Carbon, Developing Countries

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## 1. Introduction

Globally, buildings account for approximately 39% of CO<sub>2</sub> emissions and consume around 40% of total energy. This significant environmental burden arises from energy use during construction and operation, as well as the emissions associated with producing and transporting building materials [1]. This substantial environmental impact is largely influenced by the extensive use of concrete, a widely consumed human-made material due to its durability, affordability, and versatility [2]. While concrete offers excellent properties such as workability, strength, and durability, its production process, particularly the manufacture of cement, is a significant source of GHG emissions and environmental degradation [2,3].

Cement production is responsible for a substantial share of global CO<sub>2</sub> emissions, not only because of the energy required to heat kilns but also due to the chemical decomposition of limestone during clinker production. This process, known as calcination, involves the thermal breakdown of calcium carbonate (CaCO<sub>3</sub>) into calcium oxide (CaO) and carbon dioxide (CO<sub>2</sub>) at temperatures exceeding 1000°C:



These "process emissions" are intrinsic to cement manufacturing and cannot be eliminated through energy efficiency measures alone. They account for approximately 5% of total anthropogenic CO<sub>2</sub> emissions globally, with additional emissions arising from fossil fuel combustion to maintain kiln temperatures, bringing the total contribution of the cement industry to as much as 8% of global emissions [4]. Recognizing the urgency of reducing cement-related emissions, researchers globally are investigating sustainable alternatives that preserve or enhance the engineering performance of concrete. One key strategy is partially replacing Portland cement with supplementary cementitious materials (SCMs) such as ground granulated blast furnace slag (GGBS), fly ash, bagasse ash, and even non-traditional materials like recycled plastic powder. These by-products not only lower embodied carbon but also can improve durability and reduce resource depletion, as discussed in recent studies on material innovation for sustainable infrastructure [5]. These supplementary cementitious materials reduce the environmental impact of concrete production and offer potential economic benefits by lowering construction costs [5]. The construction industry's dependence on natural aggregates, comprising nearly 75% of concrete's total volume, has led to accelerated depletion of non-renewable resources and substantial environmental degradation. This extraction-intensive process not only disrupts ecosystems but also contributes to emissions and land use changes. In response, the integration of Life Cycle Assessment (LCA) methodologies has become essential for evaluating the environmental impacts of construction materials across all stages of their life cycle—from raw material extraction to end-of-life. LCA enables researchers and decision-makers to quantify carbon emissions, energy use, and resource consumption, supporting more sustainable material choices and design strategies. A study from the MIT Concrete Sustainability Hub highlights that adopting life cycle approaches is critical for identifying emissions hotspots and informing mitigation strategies in concrete used for buildings and pavements [6]. By conducting LCAs, researchers and practitioners can quantify the carbon footprint, energy consumption, and other environmental impacts associated with concrete production, enabling informed decision-making and the development of more sustainable practices in the construction industry [7,8].

### **Primary Research Question:**

How can a comprehensive Environmental Product Declaration (EPD) framework for ready-mix concrete

be developed and implemented in a developing country like Bangladesh despite the significant data limitations and regional challenges?

**This investigation is guided by three subsidiary questions:**

- A. What methodological approaches and analysis tools (OpenLCA, spreadsheet calculator, POD|LCA tool) are most appropriate for developing concrete LCAs in Bangladesh, given the scarcity of localized data?
- B. What key data and processes are necessary from Bangladeshi ready-mix concrete plants to create region-specific LCAs that accurately reflect local material sourcing, transportation networks, and manufacturing practices?
- C. How can localized life cycle inventory (LCI) data for concrete production be effectively collected, validated, and applied to meet international EPD standards in a way that establishes a sustainable framework for ongoing EPD development in Bangladesh?

This thesis is organized into six chapters. Chapter 1 introduces the research problem, contextual background, and primary research questions, emphasizing the concrete environmental impacts and the necessity of Environmental Product Declarations (EPDs) in Bangladesh. Chapter 2 presents a detailed literature review, covering the principles and processes of EPDs, the life cycle assessment (LCA) framework, key international standards, embodied carbon reduction strategies, and the current state of LCA and EPD adoption in Bangladesh's construction sector. Chapter 3 outlines the research methodology, including data collection from a Dhaka-based concrete plant, the cradle-to-gate system boundary, and the use of multiple tools—OpenLCA, a spreadsheet calculator, and a tool in development at the University of Washington, POD|LCA—for LCA modeling and cross-validation. Chapter 4 focuses on documentation, quality assurance, and third-party verification procedures essential for EPD preparation. Chapter 5 proposes an EPD roadmap for Bangladesh by analyzing stakeholder roles, registration requirements, and policy recommendations to overcome technical and institutional barriers. Finally, Chapter 6 concludes with a synthesis of findings, practical recommendations for the cement and construction industries, and future research directions to support the development of a scalable, localized EPD framework in Bangladesh.

## **2. Literature Review**

### **2.1. Overview of Environmental Product Declarations**

An Environmental Product Declaration (EPD) is a standardized and verified document that communicates the life-cycle environmental impacts of a product based on a comprehensive Life Cycle Assessment (LCA). It's similar to a nutrition facts label, but one key difference is that an EPD describes emissions that are no longer in the product but have been released into the environment [9,10]. This is why transparency and verification are crucial when using EPDs to make informed sustainability decisions. LCA practice is governed by internationally recognized standards, such as ISO 14025, ISO 14040, ISO 14044, EN 15804, and ISO 21930. EPDs can provide transparent and quantified information about a product's environmental performance throughout its entire life cycle, from raw material extraction and production to use and disposal or recycling [11,12]. They present data on various environmental impact categories, such as global warming potential, acidification, eutrophication, ozone depletion, and resource depletion. The development of an EPD follows a set of rules and guidelines defined in a Product Category Rule (PCR), a standardized document specifying the requirements and methodologies for conducting a life cycle assessment (LCA) and creating an EPD for a specific product category, such as concrete. Concrete EPDs are typically generated by manufacturers, with mix designs often tailored by contractors in collaboration with producers. Industry-specific tools and resources, such as those provided by the National Ready Mixed Concrete

Association (NRMCA), support the creation of mix-specific EPDs. To meet supply chain-specific EPD requirements, such as those defined in Buy Clean Buy Fair Washington, upstream data, particularly from the cement plant(s) supplying the mix, must be included. An example is CalPortland's EPD, which uses manufacturer-specific data representing 100% of the cement in its mixes. This approach improves transparency and aligns with the growing demand for more accurate, traceable embodied carbon reporting in procurement policies [13].

The PCR helps ensure consistency and comparability among EPDs developed within the same product category. These rules apply to EPDs created by individual manufacturers or industry associations. Each EPD must undergo third-party verification by an independent organization to confirm the accuracy and credibility of the information provided. This verification process includes a critical review of the underlying LCA study and the EPD documentation, conducted by qualified experts.

EPDs function as communication tools that allow manufacturers to disclose the environmental performance of their products transparently. They enable architects, engineers, contractors, and consumers to make informed choices based on standardized and comparable data. By fostering transparency, EPDs play a vital role in promoting sustainable practices across industries such as construction, manufacturing, and consumer goods [14–16].

## **2.2. Process of developing Environmental Product Declarations**

Creating an EPD involves several steps, including the development of a Product Category Rule (PCR), conducting an LCA, and distilling the information into an accessible EPD document [15]. **Figure 2-1** illustrates the steps to create EPDs.

### **Step 1: Establishing the Product Category Rule (PCR)**

PCRs lay out the guidelines and methodologies for conducting the LCA that forms the basis of EPDs. These rules are formulated by a committee comprising various stakeholders, assembled by a Program Operator, which can be a company, an industry group, or a trade association. The committee includes representatives from the industry, LCA practitioners, subject matter experts from academia, government agencies, non-governmental organizations, and customers. An independent third-party review panel, typically consisting of at least three members with expertise in LCA and the relevant subject area, evaluates the PCR for its logic and adherence to the ISO 14025 standard. The PCR delineates crucial methodological components pertaining to the EPD, such as product function, goal and scope definition, data aspects, environmental impact categories, and reporting requirements [15].

### **Step 2: Conducting the LCA for the EPD**

To develop an EPD, an LCA is carried out based on the PCR for the specific product or product group. The manufacturer gathers relevant production data (foreground data) such as fuel use, electricity consumption, and raw material sources, which serve as inputs for the LCA. Data outside the manufacturer's control (background data), such as grid electricity, is typically modeled using LCA databases. The LCA can be performed with the assistance of LCA consultants or through software tools designed by manufacturers or Program Operators to streamline the process [12,15].

### **Step 3: Creating the EPD Document**

The third step involves compiling the LCA results into the EPD document, adhering to the format and requirements stipulated in the PCR. This includes reporting additional environmental information, declaring materials and substances, and specifying the validity period. EPDs can be integrated with other

software tools, design tools, and databases to facilitate automation, implementation, and informed decision-making [15].

#### Step 4: Verification and Publication

An independent third party or the Program Operator verifies the EPD's compliance with the PCR. Upon successful completion of the review process, the Program Operator issues the EPD, indicating the name of the verifier and the validity period on the final document. PCRs are typically valid for up to 5 years, and the validity period of the EPD is defined within the PCR. This process is not commonly governed by federal statute or regulation [15,17].

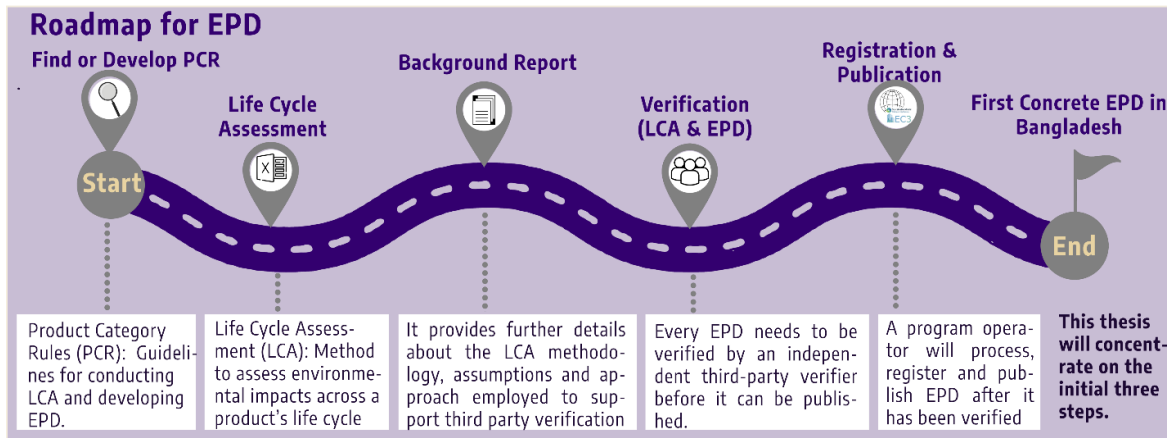


Figure 2-1: Steps of creating an Environmental Product Declaration (EPD).

### 2.3. Types of Environmental Product Declarations

Environmental Product Declarations (EPDs) can be categorized by the specificity of their data and scope of coverage. The classification below aligns with the principles set out in EN 15804:2012+A2:2019 [8], which emphasizes representativeness, transparency, and the use of production-weighted values when aggregating data across facilities.

#### Product- and Facility-Specific EPD:

This EPD type reflects the environmental profile of a single product manufactured at one specific facility. It is based on site-specific primary data for key life cycle stages (A1–A3) and provides the highest level of geographic and technological resolution. These EPDs are often used in procurement processes, as they allow for traceable and accurate environmental comparisons.

#### Product-Specific EPD:

Product-specific EPDs represent a product manufactured at multiple facilities by the same producer. When combining data from more than one facility, the results must be calculated using production-weighted averages, where each plant's environmental data is weighted by its actual annual output [8]. This ensures that the EPD accurately reflects the producer's total environmental performance, rather than a simple arithmetic average. Including production weighting improves data quality and comparability across EPDs and is essential when establishing benchmarks or for policy applications.

#### Regional or Industry-Wide EPD:

These EPDs are developed by industry groups or associations using aggregated data from multiple

manufacturers within a specific sector or region. While less specific than product-level declarations, they offer a broader overview of typical environmental impacts and can guide regional benchmarking or support infrastructure-related LCAs. EN 15804 allows these EPDs as long as data sources and representativeness, including whether production-weighted values were used, are disclosed [8].

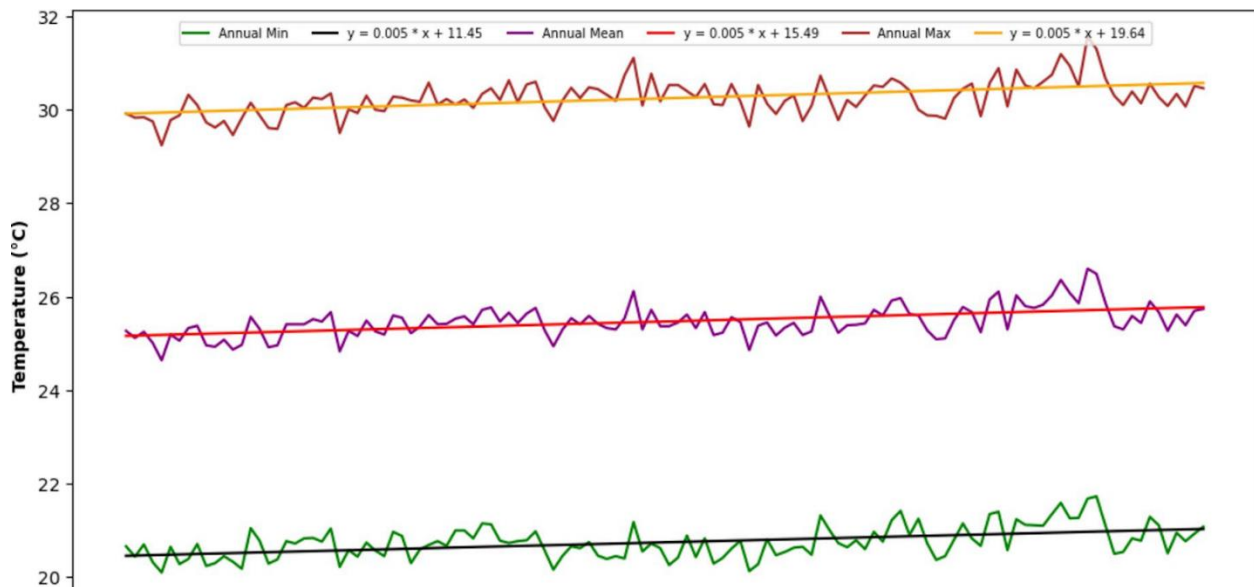
## 2.4. Use of Environmental Product Declarations

EPDs provide vital information for selecting building materials that minimize environmental impacts throughout their life cycle. For architects, engineers, and construction professionals, EPDs can offer transparent data on a product's contributions to global warming, ozone depletion, greenhouse gas emissions, human toxicity, water pollution, and other environmental considerations across manufacturing, use, and end-of-life phases. This data empowers informed product specification and sustainable design choices from the earliest project stages. Designers can evaluate the environmental tradeoffs of different material options and make selections that align with green building certification goals and sustainability mandates. Many rating systems, such as LEED and Green Globes, directly incentivize the use of products with third-party verified EPDs by awarding credits towards certification [17]. Moreover, EPDs enable more precise whole-building life cycle assessment by supplying data inputs that align with the actual product selected rather than industry average data [18]. Manufacturers providing EPD data could gain an advantage as their products can be easily integrated into sustainability modeling for green building projects. [9,15,17].

## 2.5. Current Greenhouse Gas Emission Scenario in Bangladesh

### 2.5.1. Temperature rising

Bangladesh has witnessed a significant warming trend over the past century, with measurable increases in both minimum and maximum temperatures. Historical climate data from 1901 to 2022 show that the annual daily average surface air temperature in Bangladesh has risen from approximately 24.64 °C to 26.60 °C, with consistent increases observed in both minimum and maximum temperatures. This long-term warming trend is visualized in **Figure 2-2**, which illustrates the upward trajectory of surface air temperature over more than a century based on observed records. This sustained rise is attributed to increasing greenhouse gas emissions and is further compounded by rapid urbanization and land use changes [19].



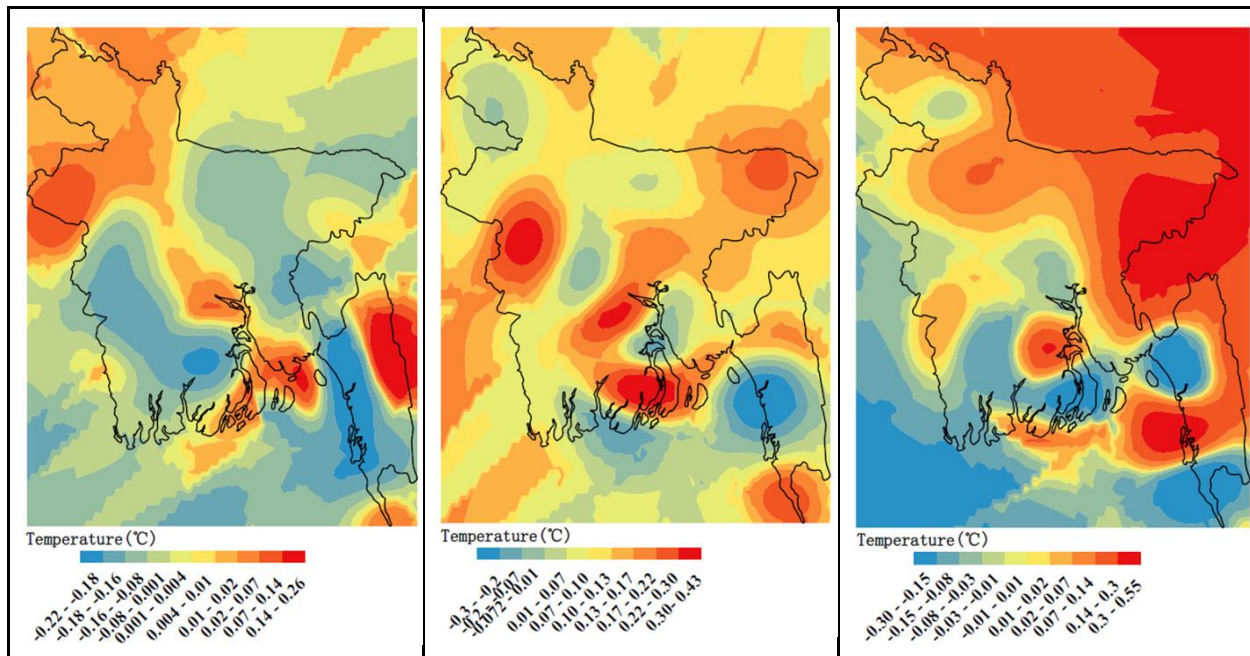
**Figure 2-2:** Observed annual daily average surface air temperature in Bangladesh (1901–2022), showing a clear warming trend over time [19]

Future climate projections using **the Coupled Model Intercomparison Project Phase 6 (CMIP6)**—an advanced global climate modeling framework used by the Intergovernmental Panel on Climate Change (IPCC)—predict that this warming trend will intensify throughout the 21st century. Average annual temperatures in Bangladesh are expected to increase by up to 4.4 °C by 2100. The southeastern and northwestern regions are projected to experience the most pronounced warming. One key projected impact is the substantial rise in the number of tropical nights—nights when temperatures do not fall below 26 °C. Between 2025 and 2035, areas like Sylhet could face over 63 such nights per year, while Dhaka may experience more than 55, most occurring during summer.



**Figure 2-3:** Regional map with 41 meteorological stations in Bangladesh [19]

**Figure 2-3** illustrates the regional map with 41 meteorological stations in Bangladesh [19]. These conditions pose serious threats to public health and urban livability, particularly in densely populated regions. This projected increase in nighttime heat is visually depicted in **Figure 2-4**, which maps the expected number of tropical nights across Bangladesh using high-resolution data-driven modeling techniques [20]. These climatic shifts are expected to exacerbate the intensity and duration of heatwaves, especially when combined with Bangladesh’s high humidity levels. The impacts will likely be disproportionately severe for vulnerable populations in urban and coastal areas, increasing the urgency for localized adaptation and resilience strategies [19,20].



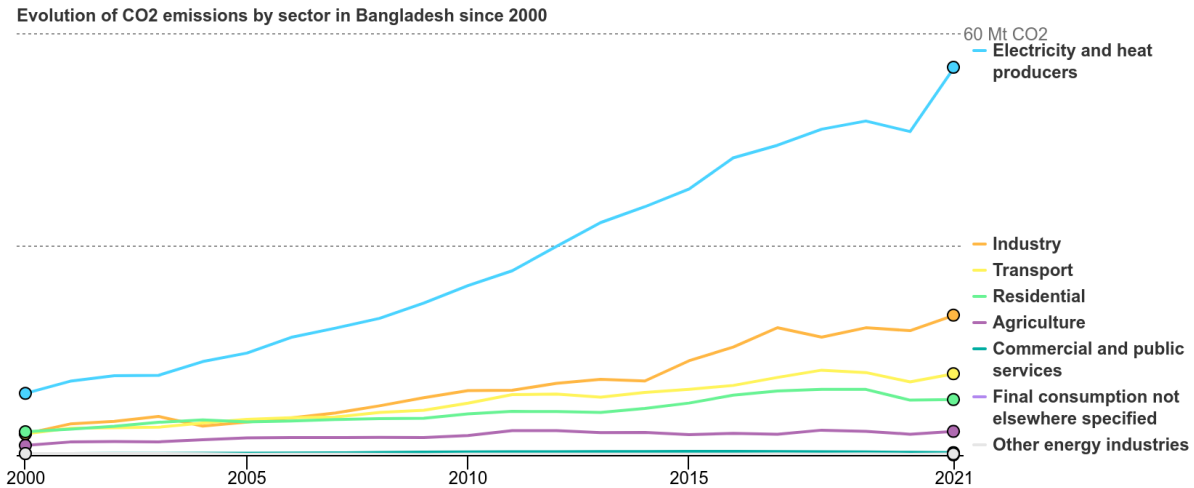
**Figure 2-4:** Projected distribution of tropical nights (minimum temperature > 26 °C) in Bangladesh during 2025–2035. Regions such as Sylhet and Dhaka show significant increases, with over 63 and 55 tropical nights annually [20]

### 2.5.2. Sea Level Rise and Sea Surface Temperature

Global warming significantly impacts Bangladesh's coastal regions through rising sea levels and increasing sea surface temperatures in the Bay of Bengal. Sea levels are projected to rise substantially along Bangladesh's coastlines by 2100, with the central coast around the Meghna Floodplain facing increases of over one meter under a high emissions scenario. This would lead to coastal inundation, loss of land and livelihoods, displacement of populations, and increased vulnerability to storm surges and saltwater intrusion. In the Bay of Bengal, observed sea surface temperatures have already risen around 0.02°C per year in recent decades. Warmer ocean temperatures contribute to more active or intense tropical cyclone activity. After Cyclone Sidr in 2007 caused a 5-meter storm surge and devastating impacts, projections show a similar future storm could produce 53% more inundation by 2100 due to higher sea levels. Limiting global temperature rise through emissions reductions is crucial to averting Bangladesh's most severe sea level rise and coastal hazard risks [21].

### 2.5.3. Energy-related CO<sub>2</sub> emissions by sector

The electricity and heat production sector is by far the largest contributor to energy-related CO<sub>2</sub> emissions in Bangladesh. Emissions from this sector have risen rapidly, increasing from 8.81 Mt CO<sub>2</sub> in 2000 to 55.32 Mt CO<sub>2</sub> in 2021 - an over 6-fold increase. The industry sector is the second largest source, growing from 3.04 Mt CO<sub>2</sub> in 2000 to 19.95 Mt CO<sub>2</sub> in 2021. Transport is the third biggest contributor, with emissions rising from 3.05 Mt CO<sub>2</sub> in 2000 to 11.6 Mt CO<sub>2</sub> in 2021 as vehicle usage has expanded. The residential sector is the fourth largest at 7.92 Mt CO<sub>2</sub> in 2021. Smaller sources include agriculture at 3.37 Mt CO<sub>2</sub> in 2021 and the commercial/public services sector at 0.34 Mt CO<sub>2</sub>. **Figure 2-5** illustrates the CO<sub>2</sub> emissions by sector in Bangladesh [21]. Overall, Bangladesh's energy emissions profile is dominated by the power and industrial sectors, reflecting the energy demands of economic growth and development over the past two decades. Reducing emissions from these key sectors will be crucial for mitigating Bangladesh's climate impacts going forward [21,22]



**Figure 2-5:** CO2 emissions by sector in Bangladesh [21]

## 2.6. History of Concrete in Bangladesh

Reinforced concrete construction began to shape the urban landscape of Dhaka and other major cities during the British colonial period, becoming widespread by the early 20th century. By the 1920s, cement and reinforcing steel were already being manufactured locally, which facilitated the growing use of concrete in structural systems. Before independence in 1947, a common construction technique combined reinforced concrete frames with brick infill walls, typically plastered to create a uniform appearance. This cost-effective method was prevalent in both residential and administrative buildings across cities [23].

Following the creation of East Pakistan, the region saw an influx of modernist architecture that redefined the use of concrete. Foreign-trained architects such as Muzharul Islam, Stanley Tigerman, and notably Louis Kahn introduced new design ideologies that challenged local norms [23]. Kahn's commission for the National Assembly complex in Dhaka, beginning in 1962, marked a pivotal moment in the architectural history of Bangladesh. **Figure 2-6** shows the current state of the National Parliament House in Bangladesh. His vision of concrete was not merely structural but expressive and symbolic. Kahn sought to expose concrete as a monumental and spiritual medium, raw, unadorned, and embedded with meaning. However, this clashed with prevailing local construction practices that favored plastered finishes over exposed surfaces. Ultimately, Kahn negotiated a compromise: he retained the raw concrete aesthetic in key elements while incorporating devices such as marble inserts, recessed brick panels, and a parasol-like roof structure to mediate between his modernist ideals and local technical limitations [24].

As Hashim Sarkis argues, Kahn's intervention represented more than a stylistic imposition; it was a deliberate act of "cultural crossing," where the universal language of modernism was adapted to the specific material, climatic, and cultural context of Bangladesh. His architecture thus contributed not only to a new visual identity for the emerging nation but also to a deeper understanding of concrete as a medium of both structural innovation and cultural negotiation [24]



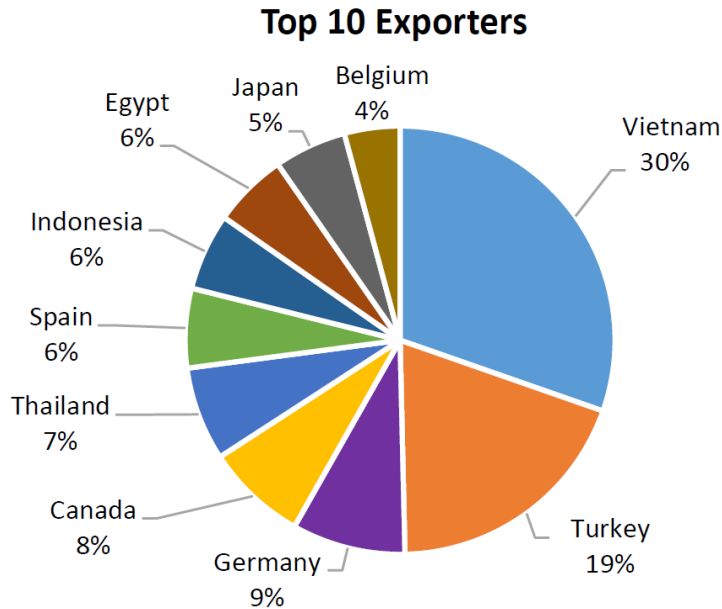
**Figure 2-6:** National Parliament House, Bangladesh [24]

## 2.7. Cement industry in Bangladesh

The cement industry in Bangladesh has experienced significant expansion over the past two decades, largely driven by the country's infrastructure development and urbanization. According to the Bangladesh Cement Manufacturers Association (BCMA), there are currently 42 cement companies operating in the country, with local firms controlling over 80% of the market share. Key industry players include Shah Cement, Bashundhara King Brand Cement, Fresh Cement, Crown Cement, and 7-Rings Cement, together accounting for a major portion of the domestic supply. These firms have a combined annual production capacity of approximately 58 million metric tons, which far exceeds the national demand of 33 million metric tons, resulting in overcapacity and price competition in the market [5,25].

Despite this overcapacity, cement manufacturers continue to invest in capacity expansion, suggesting strong confidence in the sector's long-term prospects. Technological adoption, such as Vertical Roller Mills, has improved energy efficiency and reduced environmental impacts. The industry is expected to benefit from Bangladesh's sustained investment in infrastructure, including mega projects like the Padma Rail Link, Rooppur Nuclear Power Plant, and Matarbari Deep Sea Port. The market structure is relatively concentrated, with leading firms commanding large shares, as illustrated in **Figure 2-7**, which shows the market share distribution among the top manufacturers [25].

A persistent bottleneck, however, is the country's dependency on imported clinker, the key raw material for cement. Due to limited domestic limestone reserves, Bangladesh relies heavily on clinker imports from countries such as Vietnam, Indonesia, Thailand, and Malaysia. Only two domestic manufacturers—LafargeHolcim Bangladesh and Chhatak Cement—produce clinker locally, supplying only about 10% of total demand [5,25]. This dependency subjects the industry to volatility in global prices, foreign exchange fluctuations, and high import duties, adding cost and supply chain risk to cement production.



**Figure 2-7:** Market Share of Major Cement Producers in Bangladesh [25]

## 2.8. How Environmental Product Declarations can help to reduce Embodied Carbon

Embodied carbon refers to the total greenhouse gas (GHG) emissions generated throughout the life cycle of a building material or product, including raw material extraction, processing, manufacturing, transportation, construction, maintenance, and end-of-life disposal or recycling. Studies have shown that embodied carbon can account for up to 50% of a building's total carbon footprint, especially in high-efficiency buildings where operational emissions are minimized [26].

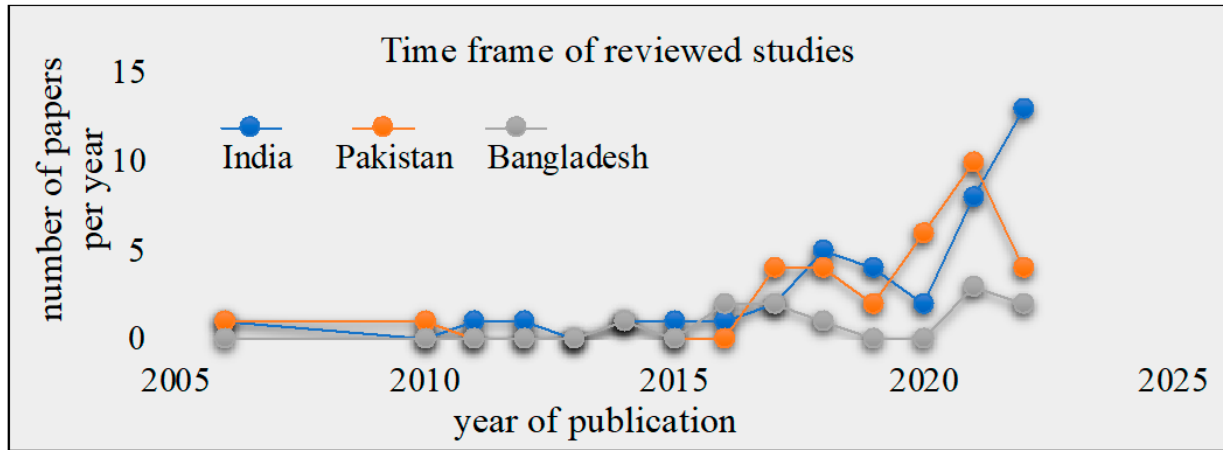
Environmental Product Declarations (EPDs) play a critical role in making embodied carbon visible and manageable by providing standardized, verified data on a product's environmental performance, including its global warming potential (GWP). This transparency allows designers, engineers, contractors, and policymakers to make more informed decisions when specifying materials, encouraging the selection of products with lower embodied emissions. EPDs also create market incentives for manufacturers to invest in lower-carbon technologies, optimize material efficiency, and integrate recycled or renewable content into their production processes [27].

In particular, the use of EPDs enables the incorporation of Life Cycle Assessment (LCA) results into procurement and design practices, which can lead to significant GHG reductions. For example, substituting conventional materials with lower-emission alternatives or reusing existing structures and components can cut emissions by up to 50% in some cases [27]. Furthermore, EPD frameworks promote consistency and comparability through alignment with internationally recognized standards such as ISO 14044, ISO 14025, and EN 15804 [8,11,28].

## 2.9. Current Scenario of Life Cycle Assessment in Bangladesh

Life Cycle Assessment (LCA) has emerged as a vital methodology for evaluating the environmental impacts of construction materials and processes across their life cycle. However, in Bangladesh, the academic and practical application of LCA in the construction sector remains limited and underdeveloped. A comprehensive review by Talpur et al. (2023) analyzed 71 LCA-related publications from South Asia

and found that Bangladesh significantly lags behind regional peers such as India and Pakistan in both the number and scope of published studies [29]. As illustrated in **Figure 2-8** of the review paper, India leads with a steadily increasing volume of LCA research since 2005, whereas Bangladesh shows minimal growth [29]. This gap highlights the nascent stage of LCA integration in Bangladesh’s academic and engineering practice. The limited studies available are typically small in scale, centered on residential or mixed-use buildings, and constrained by a reliance on foreign databases such as Ecoinvent and AusLCI due to the lack of local life cycle inventory (LCI) data. **Table 1** summarizes key LCA studies identified in the review that specifically focus on Bangladesh, offering insights into their methodologies, system boundaries, and major findings. While these studies provide a foundation, they also underscore the critical need for locally contextualized data, comprehensive life cycle modeling, and integration with circular economy goals in the Bangladeshi construction sector [29].



**Figure 2-8:** Number of LCA studies published per year in South Asian countries (2005–2022) [29]

**Table 1.** Summary of Reviewed LCA Studies Focused on Bangladesh from South Asia Review

Study Reference	Building Type	LCA Tool	System Boundary	Functional Unit	Main Findings
Islam & Chowdhury (2021)	Residential	One Click LCA	Cradle-to-Grave	m <sup>2</sup> floor area	Floor slabs, walls, beams, and roofing decks are the main emission contributors.
Shuvo & Sharmin (2021)	Residential, Educational, Office	-	Cradle-to-Grave	m <sup>2</sup> floor area	Operational phase accounts for the majority of emissions; commercial buildings highest.

### **Additional LCA Studies Not Included in the Review:**

There are a few Bangladesh-specific LCA studies that were not included in the review by Talpur et al. (2023), despite their direct relevance to the construction sector [29]. For example, Arenas and Shafique (2024) conducted a comparative LCA of three building types (residential, educational, and commercial) in Bangladesh using a cradle-to-grave boundary [2]. Their study revealed that commercial buildings had the highest embodied carbon emissions—2109.7 kg CO<sub>2</sub>/m<sup>2</sup>—followed by residential and educational buildings. Similarly, Islam et al. (2024) performed a scenario-based LCA using BIM and One Click LCA to evaluate the impact of traditional versus supplementary cementitious material (SCM) concrete [30]. The use of ground granulated blast furnace slag (GGBS) and fly ash led to a 6.72% reduction in total emissions. Mohammed et al. (2014) took a broader material-focused approach, emphasizing the carbon intensity of cement production in Bangladesh and advocating for alternative binders to support sustainable development [31]. These studies extend the existing literature and suggest a growing, though still limited, engagement with LCA tools and sustainability metrics in the country [30].

### **Key Findings Across All Papers**

- **Cement and Concrete as Primary Emission Sources:**  
All studies consistently identify cement and concrete as the largest contributors to embodied carbon emissions of buildings assessed. Concrete accounted for 45% of emissions within the A1–A3 stages in a residential building [32], while cement production was identified as a national-level sustainability challenge [31].
- **Operational Phase Dominates Total Emissions:**  
The operational energy use of buildings contributes nearly 85% of total life cycle emissions, especially in commercial and educational buildings [32].
- **Potential of Supplementary Cementitious Materials (SCMs):**  
The use of GGBS and fly ash in place of traditional cement reduced total CO<sub>2</sub> emissions by 6.72%, highlighting the potential of material substitution strategies [30].
- **Commercial Buildings as Emission Hotspots:**  
Among building types, commercial buildings exhibited the highest embodied emissions—2109.7 kg CO<sub>2</sub>/m<sup>2</sup>—due to their higher structural mass and operational intensity [2].
- **Adoption of ISO-Aligned Methodologies:**  
Most studies apply process-based LCA methodologies aligned with ISO 14044 and use tools such as One Click LCA, often integrating BIM models for energy and material flow simulations [2,30,32].

### **Research Gaps Identified**

- **Critical Research Scarcity:**  
Only 4–5 peer-reviewed studies specifically focus on LCA in construction for Bangladesh, which reflects a major gap in knowledge and research capacity compared to regional neighbors and global standards [29].
- **Methodological Uniformity and Limitations:**  
Most existing studies use cradle-to-gate (A1–A3) or cradle-to-site (A1–A5) system boundaries and depend on foreign datasets such as Ecoinvent and AusLCI, limiting their representativeness [29,30,32].

- **Lack of Local Life Cycle Inventory (LCI):**  
The absence of a national inventory database prevents accurate reflection of local materials, energy mixes, and transportation logistics [29,31].
- **Absence of Environmental Product Declarations (EPDs):**  
Despite aligning with international standards like ISO 14044 and EN 15804, none of the current LCA studies have led to EPD development or publication, reducing their practical and policy utility [2,29,30,32].

## 2.10. Current Scenario of Environmental Product Declarations in Bangladesh

As of June 2025, five Environmental Product Declarations (EPDs) have been published under the International EPD® System [33] for construction products manufactured in Bangladesh. While this represents a step forward in environmental transparency, the scope remains narrow—limited to cement and steel—with no EPDs yet available for concrete, aggregates, or admixtures. Four of the EPDs are for cement products produced by Siam City Cement under the INSEE brand, and one is for steel products from BSRM.

- **INSEE PC:**  
A Portland Cement used in infrastructure projects requiring rapid compressive strength, suitable for bridges and high-rise construction.
- **INSEE PCC:**  
A Portland Composite Cement designed for general structural applications in compliance with BDS EN 197-1.
- **INSEE PPC:**  
A Portland Pozzolana Cement blended with fly ash to enhance sulfate resistance, ideal for marine and industrial structures.
- **INSEE ECO Plus:**  
A premium-grade composite cement (CEM V/A (S-V) 42.5N) made with high-quality clinker. It is especially suited for “Foundation to Roof” applications and offers long-lasting resistance to chlorides and sulfates, making it ideal for coastal, river, and high-durability infrastructure.

All four cement EPDs are compliant with EN 15804 and follow Product Category Rule (PCR) 2019:14, with the PPC variant also referencing c-PCR-001 specific to cement and building lime.

- **BSRM Structural Steel Products:**  
This EPD covers reinforcement bars, epoxy-coated bars, angles, channels, and square bars. These products are suitable for seismic zones, marine structures, and corrosion-prone environments. The EPD is compliant with EN 15804 and developed using PCR 2019:14. It remains valid as of June 2025.

**Figure 2-9** shows the filtered results from the EPD International Library database, confirming the existence of these five valid EPDs under the geographical scope of Bangladesh [33].

**Figure 2-9:** EPD International Library database [33]

### 2.11. Findings from the existing Environmental Product Declarations in Bangladesh

Bangladesh's journey in implementing LCA and EPD represents an emerging transition toward sustainable construction practices. While the country currently faces challenges in comprehensive LCA studies for local building materials, significant progress has been made in establishing EPDs for construction materials. The framework for these implementations is structured around several key components:

- **LCA Standards:**

Bangladesh's LCA practices primarily rely on international standards due to the limited availability of local frameworks. The assessment methodology follows ISO 14040 and ISO 14044, though data collection challenges often necessitate the use of international databases. These standards require comprehensive data across multiple phases, including raw material extraction, manufacturing processes, and waste management systems, presenting unique challenges in the local context.

- **EPD Standards:**

The implementation of EPDs in Bangladesh adheres to a robust framework of international standards. The foundation rests on ISO 14025:2006 for Type III environmental declarations, complemented by EN 15804:2012+A2:2019/AC:2021 for construction products. These are further supported by ISO 14020:2000 for environmental labels and declarations, while maintaining alignment with Bangladesh Standards and Testing Institute (BSTI) guidelines for local compliance.

- **Product Category Rules (PCR):**

Product Category Rules in Bangladesh's EPD system follow PCR 2019:14 V1.3.1 for construction products and c-PCR-001 for cement and building lime (EN 16908). These rules are adapted to integrate with local construction material standards, particularly BDS EN 197-1, ensuring that EPDs reflect both international requirements and local construction practices.

- **Program Operator:**

The International EPD® System, operated by EPD International AB, serves as the primary Program operator for Bangladesh's EPDs. Through this platform, Bangladesh has successfully registered five EPDs.

- **Verification Process:**

The verification system maintains high standards through mandatory independent third-party verification conducted by accredited international verifiers. This process encompasses a thorough review of LCA methodology, calculations, data quality, and documentation. Verified

EPDs maintain a validity period of five years, ensuring regular updates and continued compliance with evolving standards.

- **Publication Process:**

The final stage involves registration through EPD International AB, where each declaration receives a unique EPD registration number. These declarations are made publicly accessible through [environdec.com](http://environdec.com), with requirements for regular updates in cases of significant environmental impact changes (exceeding 10%), production process modifications, or updates to underlying standards or PCRs.

### 3. Methodology

This methodological approach facilitates the development of an EPD for ready-mix concrete in Bangladesh by establishing a comprehensive framework that addresses the significant data limitations and regional challenges facing developing countries in EPD implementation. The research objective is to create Bangladesh's first concrete EPD while providing a replicable roadmap for other developing nations with similar constraints.

The methodology employs a systematic **cradle-to-gate LCA** approach, focusing on the A1-A3 life cycle stages of concrete production. This framework is structured around six key components that collectively enable EPD development despite limited local LCA infrastructure:

#### **Step 1: Primary Data Collection Strategy -**

Direct field investigation at NDE Ready Mix Concrete Ltd. plant in Ashulia, Dhaka (conducted September 2024) to capture local manufacturing practices, material sourcing patterns, and energy consumption data.

#### **Step 2: Multi-Tool Validation Approach -**

Implementation of three complementary analytical methods to overcome data limitations and ensure result reliability:

- **OpenLCA software** with the **Ecoinvent database** for comprehensive impact assessment
- A custom-built spreadsheet calculator specifically designed for Bangladesh's concrete industry
- The **POD|LCA** tool adapted to the Bangladeshi context

#### **Step 3: Local Data Integration -**

Incorporation of existing Bangladesh cement EPDs to ensure alignment with local manufacturing processes and industry standards, specifically targeting **NDE Ready Mix Concrete 3000 psi** as the case study product.

#### **Step 4: International Standards Compliance -**

Adherence to **ISO 14044** and **ISO 14025 standards** to ensure the methodology meets global EPD requirements while accommodating local data constraints.

#### **Step 5: Cross-Validation Protocol -**

Triangulation of results across the three analytical approaches to validate findings and establish confidence in the EPD outcomes.

## **Step 6: Framework Documentation -**

Development of a replicable methodology that can be adapted by other developing countries facing similar data availability challenges.

### **3.1. Product Identification and Usage**

Ready-mix concrete is a composite material of cement, coarse and fine aggregates, water, and admixtures, engineered to meet specific performance and durability requirements. This Environmental Product Declaration (EPD) covers a 3000 psi (20.69 MPa) concrete mix designed and produced by NDE Ready Mix Concrete Ltd. in Dhaka, Bangladesh. The mix was formulated using the ACI method and is optimized for workability, pumpability, and structural performance, with a target slump of  $160 \pm 25$  mm at the batching plant and  $100 \pm 25$  mm at placement.

The 3000-psi mix is widely used in structural and general-purpose concrete applications. It is typically employed in residential and commercial construction for elements such as:

- Reinforced beams and girders
- Slabs-on-grade and elevated slabs
- Footings, columns, and walls
- Driveways, walkways, and pavements

During casting, this mix becomes physically integrated with the building structure, forming monolithic components that gain strength through hydration and hardening. The mix is compatible with both cast-in-place and precast construction methods, supporting a broad range of structural and architectural concrete applications across Bangladesh's growing infrastructure and urban development sectors.

### **3.2. Standards Review & Selection**

To ensure methodological rigor and international credibility, this Environmental Product Declaration (EPD) is developed in accordance with globally recognized standards for life cycle assessment (LCA) and EPD development. The selected standards are aligned with practices observed in countries such as India and Thailand, which are regionally relevant and have existing construction EPDs verified under similar frameworks.

#### **Core Standards Adopted**

- **ISO 14025:2006 – Type III Environmental Declarations:**  
This standard governs the format, verification, and publication of Type III EPDs. It allows for EPDs that are modular in nature, such as those covering only cradle-to-gate stages (A1–A3), as long as the scope is transparently declared and based on a valid Product Category Rule (PCR) [28].
- **ISO 14044:2006 – Life Cycle Assessment (LCA) Requirements:**  
Provides detailed requirements for conducting LCA, including system boundary selection, allocation procedures, impact assessment methods, and interpretation. It supports partial system boundaries when aligned with the study's objective and a corresponding PCR [11].
- **EN 15804:2012+A2:2019 – Sustainability of Construction Works:**  
This is the principal European standard for EPDs in the construction sector. It defines the required

environmental indicators, modular structure (A1–C4, D), and modeling rules. It explicitly recognizes Type D EPDs, covering only A1–A3, as valid for construction products where specific conditions are met [8].

- **PCR 2019:14 v1.3.4 – Construction Products (The International EPD System):**

This is the Product Category Rule applied in this study. It sets the EPD scope, declared unit (1 m<sup>3</sup>), and mandatory modules (A1–A3 for Type D). While there is no sub-PCR for concrete under this version, it allows adaptation using general construction rules and EN 15804 alignment [12,33]. This ensures compatibility with international publication platforms such as EPD International AB [33].

### **Regional Benchmarking: India & Thailand:**

In Thailand, concrete EPDs (e.g., by Siam Industrial Wire) follow the same ISO and EN standards, published under the International EPD System. Similarly, India has issued EPDs for construction materials using the same PCR 2019:14 and EN 15804 guidance, in the absence of country-specific PCRs. These precedents confirm that the selected standards offer appropriate technical grounding for Bangladesh as well.

### **Bangladesh Context:**

Currently, there is no official mandate from the Government of Bangladesh requiring the development or publication of EPDs for construction materials. The Bangladesh Standards and Testing Institution (BSTI) governs certification for 273 products, but none relate to EPDs [34]. Moreover, no directive exists that designates EPD International AB as a government-appointed program operator [33]. Instead, the use of ISO and EN standards in the country's few existing EPDs appears to be a voluntary decision, motivated by access to LEED certification, international green building markets, and alignment with regional practices.

## **3.3. System Boundary**

This Environmental Product Declaration adopts a Type D format, which limits the system boundary to the product stage—Modules A1 to A3—covering raw material extraction, inbound transportation, and manufacturing at the ready-mix concrete plant [12]. **Figure 3-1** illustrates the Life Cycle Stages and system boundary of the study [35].

### **Raw Material Extraction (A1):**

Data on the sourcing of cement, aggregates, sand, and admixtures were collected directly from NDE's procurement records. For instance, the aggregates are sourced from Sylhet, and cement is procured from local suppliers in Dhaka.

### **Transportation (A2):**

Transportation data was gathered for all raw materials, detailing modes of transport, distances traveled, and fuel types used. The survey revealed the use of bulk carriers, lighter vessels, and trucks, with transportation distances varying significantly (e.g., stone aggregates transported over 7,000 km from Dubai to Chittagong Port).

### **Manufacturing (A3):**

The data collected covered energy consumption (electricity and diesel), water usage, and emissions during the concrete mixing process. Observations of batching operations and equipment use were documented to assess their environmental impacts.

This scope reflects a cradle-to-gate analysis for 1 m<sup>3</sup> of 3000 psi ready-mix concrete produced in Dhaka, Bangladesh. According to PCR 2019:14 v1.3.4, EPDs of Type D (and Type E) shall only be used if the following three conditions are valid [12]:

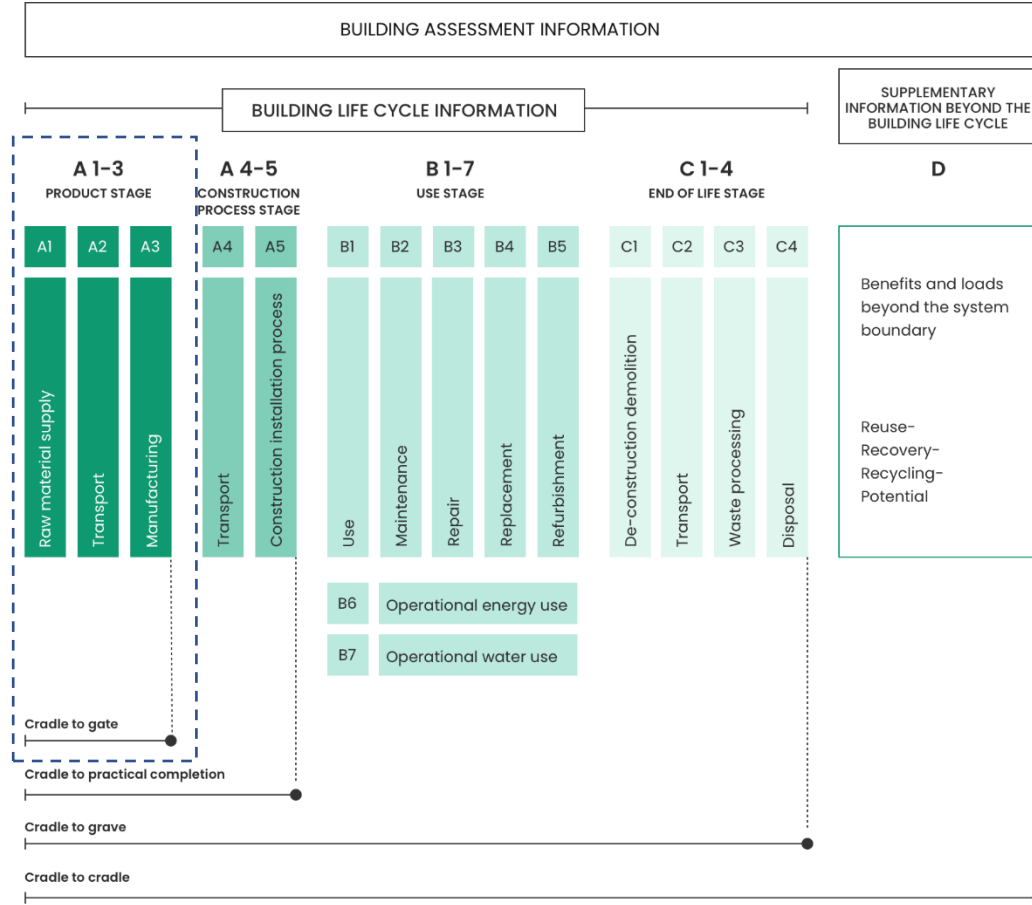
1. The product or material is physically integrated with other products during installation, so it cannot be physically separated from them at the end of life;
2. The product or material is no longer identifiable at the end of life as a result of a physical or chemical transformation process;
3. The product or material does not contain biogenic carbon.

*Note: If the packaging contains more than 5% biogenic carbon, Module A5 must be included to balance biogenic carbon emissions [12].*

Arguably, this 3000-psi concrete mix meets all three conditions, as outlined below:

- **Condition 1** is satisfied because ready-mix concrete becomes physically integrated with the building structure during placement and curing. It bonds with embedded reinforcement and forms monolithic structural elements that cannot be separated without total demolition. The hydration process forms a hardened calcium silicate hydrate (C-S-H) gel matrix that fuses all components [36]. Separation of hardened concrete from reinforcement has only been demonstrated under controlled laboratory conditions using experimental techniques such as microwave-induced heating [37].
- **Condition 2** is met through the irreversible chemical transformation of concrete during hydration. The mix undergoes exothermic reactions between cement, water, and aggregates, forming a new solid-phase matrix where original constituents are no longer distinguishable. Hydration involves proton transfer in calcium silicate phases, producing new materials that define the concrete's structural integrity [38]. The dominant hydration peak corresponds to the growth of C-S-H needles, solidifying the chemical change [39].
- **Condition 3** is fulfilled because the 3000-psi mix does not contain biogenic carbon. It consists of Portland cement (derived from geological limestone), mineral aggregates, water, and chemical admixtures. Limestone used in Portland cement production originates from non-biogenic sedimentary formations, with over 60% globally formed through chemical precipitation, not biological processes [40,41].

Provided the program operator assesses that all required conditions are met, the use of a Type D EPD format is fully justified and compliant with the selected PCR 2019:14 v1.3.4 and international standards (EN 15804+A2, ISO 14025, ISO 14044). If not, additional LCA work would be required to develop use and end-of-life data.



**Figure 3-1:** Life Cycle Stages and system boundary of the study [35]

### 3.4. Data Collection and Sources

Primary data was collected through a field survey at the NDE Ready Mix Concrete plant. This survey was conducted to gather comprehensive information on raw material sourcing, transportation logistics, and manufacturing processes, which are crucial for the cradle-to-gate LCA. The data collection methods included:

- Direct Observations:**  
 Detailed observations of the batching plant operations, including aggregate handling, mixing processes, and quality control measures. **Figure 3-2** illustrates the NDE Concrete Plant.
- Interviews with Plant Personnel:**  
 Structured interviews with plant managers and technical staff to gather insights into material sourcing, energy use, and operational efficiencies. **Figure 3-3** illustrates the Interviews with Plant Personnel.

- **Document Analysis:**

Collection of operational records, such as electricity bills, fuel consumption logs, material quantity, and sourcing documentation (**Figure 3-4** and **Figure 3-5**) to quantify environmental impacts.



**Figure 3-2:** NDE Concrete Plant (Source: NDE)



**Figure 3-3:** Interviews with Plant Personnel

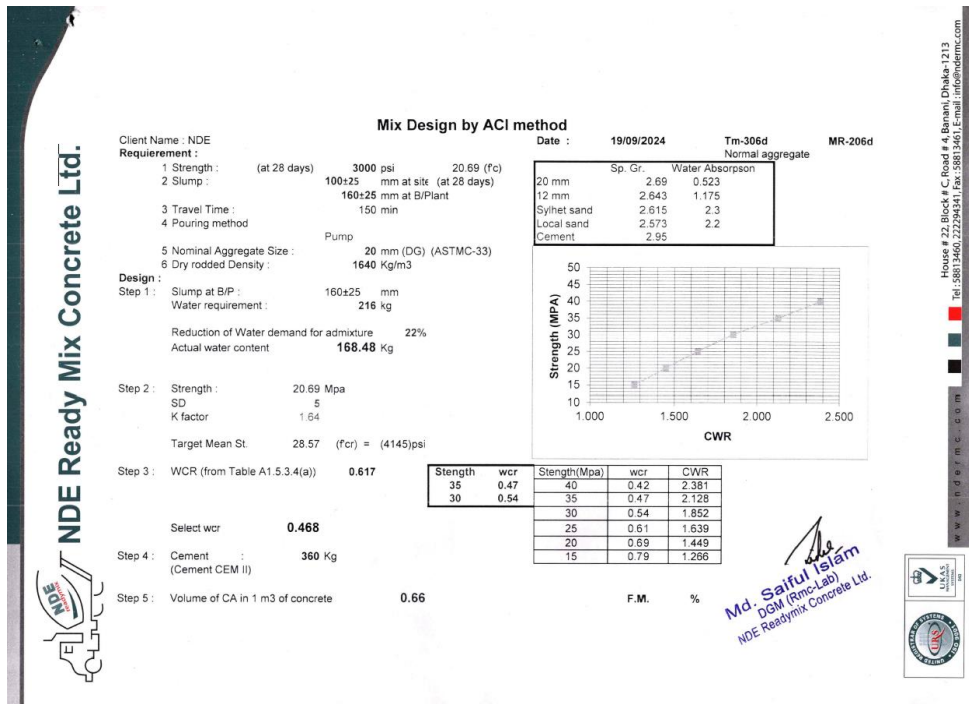


Figure 3-4: 3000 psi (28 days) mix design specification for NDE Ready Mix Concrete (Image Credit: NDE)

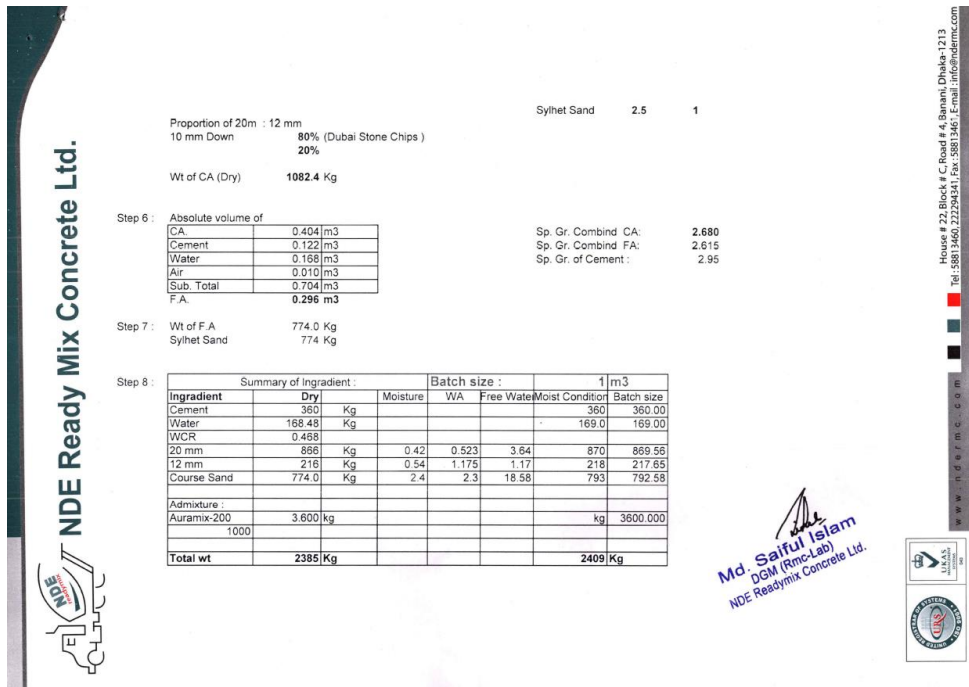


Figure 3-5: 3000 psi (28 days) mix design material quantity for NDE Ready Mix Concrete (Image Credit: NDE)

### 3.5. Manufacturing process

The construction process at **NDE Ready Mix Concrete Ltd.** involves a highly organized sequence of activities designed to ensure the efficient production and delivery of high-quality ready-mix concrete. **Figure 3-6** illustrates the manufacturing Process of the NDE plant.

- **Raw Material Handling:**

NDE's manufacturing process begins with careful storage and management of raw materials at its Ashulia plant. Cement, available in both OPC and PPC varieties, is stored in dedicated silos equipped with weighing scales for precise measurement. Coarse aggregates, consisting of both 12mm and 20mm sizes, are stored in designated areas that protect them from contamination. Fine aggregates, primarily sand sourced from Sylhet, are maintained in separate storage zones to prevent mixing. The facility maintains two on-site potable water tanks, each with a 10,000L capacity, ensuring a consistent water supply for the mixing process. Admixtures, which are crucial for enhancing concrete properties, are kept in a specialized storage area.

- **Batching Process:**

The batching stage represents the heart of NDE's concrete production. Heavy-duty payloaders systematically transfer materials from storage areas to the hopper system. A conveyor belt network then transports these materials to the batching plant. Here, the advanced batching system precisely combines ingredients according to specific mix designs. Each component is individually weighed using calibrated weighing scales to ensure exact proportions. The entire batching process is automated and monitored through a computerized control system, allowing for precise adjustments and quality control.

- **Mixing Operation:**

During the mixing phase, all measured materials converge in the central mixer where they are thoroughly combined. Water and admixtures are introduced at carefully controlled rates to achieve the desired consistency. The entire mixing operation is overseen from a central control room, where operators monitor key parameters like mixing time, material flow, and consistency. This sophisticated control system allows NDE to produce concrete with compressive strengths ranging from 2000 to 5500 psi, meeting various construction requirements.

- **Quality Control System:**

Quality assurance is integral to NDE's manufacturing process. Each batch undergoes rigorous testing in the on-site testing facility. Technicians perform slump tests to verify concrete consistency and workability. The testing room is equipped with advanced equipment for conducting sieve analyses and other quality control measures. These tests ensure that every batch meets the specified requirements before leaving the plant. The quality control process is continuous and documented, maintaining NDE's high standards of production.

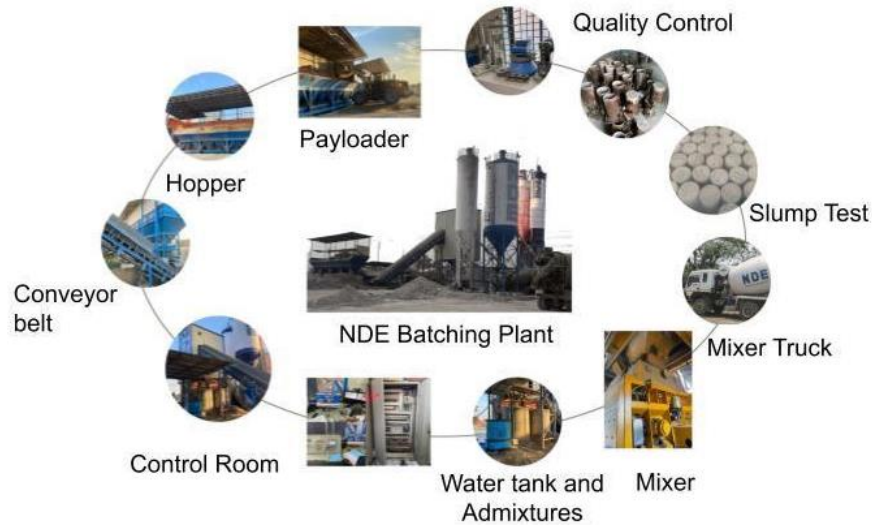
- **Transportation System:**

The final stage involves transferring the mixed concrete into the delivery system. NDE employs a fleet of transit mixers, each with a 17-ton capacity, to transport the concrete to construction sites. The facility is equipped with concrete pumps capable of handling between 39 m<sup>3</sup>/hr and 137 m<sup>3</sup>/hr, allowing for efficient delivery and placement.

- **Control and Monitoring System:**

The entire manufacturing process is centrally monitored and controlled through an advanced control room. This nerve center houses the automated control panel system that oversees every aspect of production. Operators can monitor real-time data on material flow, mixing parameters, and quality metrics. The control system allows for immediate adjustments to maintain product consistency and respond to any process variations. This comprehensive monitoring ensures that

NDE can consistently produce high-quality ready-mix concrete that meets the demanding requirements of Bangladesh's growing infrastructure development projects.



**Figure 3-6:** Manufacturing Process of NDE

### 3.6. Declared Unit

The declared unit for this study is one cubic meter (m<sup>3</sup>) of concrete.

### 3.7. Impact Category

The selection of impact categories for this Environmental Product Declaration (EPD) follows established international standards to ensure consistency, comparability, and scientific rigor. Specifically, the categories are aligned with **ISO 14044**, **ISO 14025**, and **EN 15804:2012+A2**—the core European standard for EPDs of construction products. EN 15804 A2 mandates the inclusion of **19 environmental impact indicators**, including various subcategories of Global Warming Potential (fossil, biogenic, and land use and land use change), acidification, eutrophication (terrestrial, freshwater, and marine), ozone depletion, resource use, and waste generation. It also prescribes the modular reporting structure across life cycle stages **A1–C4**, with optional inclusion of **Module D** for benefits beyond the system boundary.

- **Global Warming Potential (GWP):**

Measures the potential contribution to climate change due to the emission of greenhouse gases, expressed in kilograms of CO<sub>2</sub> equivalents. It is divided into different categories:

- **GWP Total:**

This category measures the overall potential contribution to climate change from all greenhouse gases emitted throughout the cement production process. It is expressed in kilograms of CO<sub>2</sub> equivalents.

- **GWP Fossil:**

Focuses specifically on emissions arising from the combustion of fossil fuels, such as coal, oil, and natural gas, used in the production process. These emissions are also expressed in kilograms of CO<sub>2</sub> equivalents.

- **GWP Biogenic:**

This category captures the emissions related to biogenic (biological origin) carbon sources, primarily focusing on the release or sequestration of carbon dioxide from organic materials.

It's measured in kilograms of CO<sub>2</sub> equivalents, but typically reflects lower values due to the short carbon cycle of biogenic sources.

- **GWP Land Use and Land Use Change:**  
Evaluates the impact of land use and land use changes associated with sourcing raw materials. This includes the carbon emissions from activities like deforestation or land conversion, which can affect carbon storage. It is expressed in kilograms of CO<sub>2</sub> equivalents.
- **Acidification Potential:**  
Assesses the impact of emissions like sulfur oxides (SO<sub>x</sub>) and nitrogen oxides (NO<sub>x</sub>) that contribute to acid rain, which can harm ecosystems, soil, and water bodies. It is expressed in moles of H<sup>+</sup> equivalents.
- **Eutrophication Potential:**  
Evaluates the potential for nutrient enrichment (mainly nitrogen and phosphorus) in aquatic environments, which can lead to excessive algae growth, depleting oxygen in water bodies. This category is measured in terms of nitrogen and phosphorus equivalents.
- **Ozone Depletion Potential:**  
Assesses the potential impact on the depletion of the ozone layer caused by the release of substances like chlorofluorocarbons (CFCs), measured in kilograms of CFC-11 equivalents.
- **Photochemical Ozone Creation Potential (Smog Formation):**  
Evaluates the formation of ground-level ozone (smog) due to the reaction of volatile organic compounds (VOCs) and nitrogen oxides (NO<sub>x</sub>) under sunlight. It is expressed in kilograms of NMVOC (Non-Methane Volatile Organic Compounds) equivalents.
- **Abiotic Depletion Potential (ADP): Divided into two categories:**
  - **ADP for fossil resources:**  
Measures the depletion of non-renewable fossil resources like coal, oil, and natural gas, expressed in megajoules (MJ).
  - **ADP for elements:**  
Assesses the depletion of non-fossil resources like metals, measured in kilograms of antimony (Sb) equivalents.
- **Water Deprivation Potential:**  
Examines the potential impact on water scarcity due to the consumption of water resources, expressed in cubic meters of water deprived.

Both the OpenLCA software and the spreadsheet calculator cover all of these impact categories. However, the POD|LCA tool provides results for a more limited set, addressing Global Warming Potential (GWP), Acidification Potential, Eutrophication Potential, Ozone Depletion Potential, and Photochemical Ozone Creation Potential (Smog Formation).

### 3.8. Inventory Inputs

#### 3.8.1. A1- Raw Material

The material name and quantity are for ready-mix concrete with a strength of 3000 psi, which has been sourced from the NDE plant. **Table 2** shows the material name and quantity.

**Table 2.** Concrete Material Inputs (per 1 m3 concrete)

Material	Quantity	Unit
Portland Cement	360	kg
Water	168.48	kg
20 mm stone	866	kg
12 mm stone	216	kg
Sand	774	kg
Admixture	3.6	kg

### 3.8.2. A2-Transport Modeling and Treatment of Return Trips in Life Cycle Assessment

The transportation model developed for this study includes key data for each raw material used in the 3000-psi concrete mix. **Table 3** outlines material types, transport modes, travel distances, transported mass, and total tonne-kilometers (tkm). A critical element in this model is determining whether vehicles and vessels return empty, as these influences emissions attributed to the A2 module in the LCA.

#### Standards Referenced for Return Trip Inclusion

This modeling approach aligns with major LCA and EPD standards. ISO 14044:2006 explicitly lists "Empty return (Yes/No)" as a data point for transport. EN 15804:2012+A2:2019 requires transport modeling to reflect real-world conditions, including vehicle load factors and return trips. While PCR 2019:14 v1.3.4 does not define return trip handling explicitly, it references EN 15804, making its guidance applicable and enforceable for this study [8,11,12,16,28].

**Table 3.** Transportation modes and distances.

Material	Mode	Distance	Unit	Material mass [kg]	Empty return (Yes/NO)	Multiplier	Adjusted Distance	Transport [tkm]
Portland cement	Cement Bulk Carrier (12 Wheel)	16.8	km	360	Yes	1.48	24.864	8.95
	20 mm stone & 12 mm stone	Mother Vessel	5556	km	1082	Yes	1.5–1.6 (est.)	8889.6
		Lighter Vessel	300	km	1082	No	-	300
Sand	Lighter Vessel	350	km	774	No	-	350	270.9
Admixture	Truck	40	km	3.6	Yes	1.48	59.2	0.21

## Assumptions and Multipliers Applied

- **Short-haul Truck Transport** (e.g., Portland cement at 16.8 km and admixture at 40 km): These deliveries are modeled with **empty returns**. According to NSF PCR, short-haul trucks should assume **empty return** and multiply distance by  $2 / 1.35 \approx 1.48$ , which adjusts for the 35% additional distance often embedded in U.S. datasets. Although NSF is not the primary reference, its logic is declared transparently and applied for methodological robustness [16].
- **Long-haul Ocean Freight** (e.g., stone aggregates from Dubai to Chittagong, 5556 km): In the absence of known return cargo, the vessel is assumed to **return empty**. A **1.5 multiplier** is used instead of doubling the emissions, reflecting reduced fuel consumption during unloaded return trips while maintaining a conservative estimate.
- **Inland Waterway Transport** (e.g., lighter vessels from Chittagong Port to the concrete plant): **No empty return** was assumed. These barges typically operate in continuous cycles or shared logistics routes and are unlikely to return completely empty.

### 3.8.3. A3-Manufacturing Energy Consumption

The energy consumption for the A3 module was determined based on primary data collected from the NDE Ready-Mix Concrete plant. Monthly electricity usage and diesel fuel consumption were obtained directly from utility bills and internal fuel records spanning eight months. The total production volume during this period was reported in cubic feet and converted into cubic meters using the standard conversion factor ( $1 \text{ m}^3 = 35.3147 \text{ cft}$ ), resulting in an average monthly production of approximately  $9,174.3 \text{ m}^3$ .

Electricity consumption data showed a total monthly usage of 40,200 kWh. Dividing this value by the average monthly production volume yielded a unit electricity consumption of **4.38 kWh/m<sup>3</sup>**. For diesel, the plant consumed 32,788.63 liters, which was converted to **8,661.9 gallons** using a conversion factor of 1 gallon = 3.78541 liters. This value was then normalized by monthly production volume, resulting in a diesel consumption of **0.944 gallons/m<sup>3</sup>**. These unit values were then used as inputs in the life cycle inventory model, which is shown in **Table 4**.

**Table 4.** Energy consumption during the manufacturing process

Energy Type	Quantity	Unit
Electricity	4.38	kWh
Diesel	0.944	gal

## 3.9. Interpretation

The interpretation phase employs contribution analysis to identify the key processes and materials driving environmental impacts across different categories. Special attention is given to understanding the relationship between material composition, transportation distances, and manufacturing practices specific to the Bangladeshi context. The interpretation also includes a comparative analysis of results obtained from the three methodological approaches (OpenLCA, spreadsheet calculator, and POD|LCA tool), examining consistency across methods and investigating the sources of any significant variations. This comparison

provides valuable insights into methodological robustness and helps identify the most appropriate approach for the Bangladeshi context, where localized LCI data is limited.

### 3.10. LCA Modeling Approaches

This research employs three complementary approaches to model the life cycle assessment of ready-mix concrete in Bangladesh, addressing challenges related to limited local data availability. The first approach utilizes **OpenLCA software** with the **Ecoinvent database**, incorporating field data from the NDE plant while using Ecoinvent's global datasets for background processes. The second employs a **custom-built spreadsheet calculator** that integrates existing Bangladeshi EPDs (particularly for cement) with Ecoinvent impact factors for other materials, creating an accessible tool for local manufacturers. The third applies the **POD/LCA tool** adapted to Bangladesh, offering specialized concrete modules with standardized methodologies and visualization capabilities, while still utilizing Ecoinvent background data. This comparative analysis provides insights into which approach offers the optimal balance of accessibility, accuracy, and adaptability for the Bangladeshi construction sector, while identifying specific data gaps and methodological considerations for future EPD development in the region.

#### 3.10.1. OpenLCA Model Development

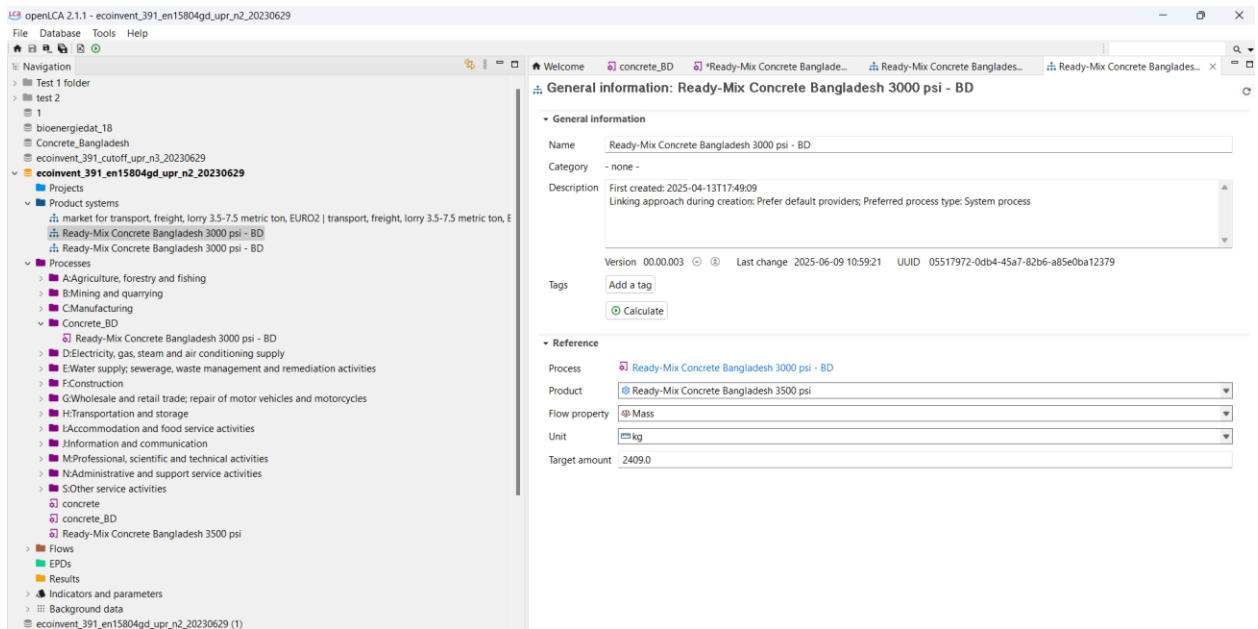
OpenLCA is a leading open-source software for Life Cycle Assessment (LCA), providing a comprehensive platform for evaluating environmental impacts across product lifecycles. This professional-grade tool enables practitioners to conduct detailed cradle-to-gate or cradle-to-grave analyses while offering flexibility in modeling approaches. **Figure 3-7** illustrates the OpenLCA software interface. The software supports multiple impact assessment methods, including EN 15804+A2 and TRACI, and allows users to work with various LCI databases such as Ecoinvent. OpenLCA facilitates the creation of complex process models with detailed supply chains, supports visualization through Sankey diagrams, and enables contribution analysis to identify environmental hotspots. Its user-friendly interface makes it accessible to researchers, industry professionals, and academics while maintaining the technical depth required for robust environmental impact assessment. As a free alternative to expensive commercial LCA software, OpenLCA has become increasingly popular for developing Environmental Product Declarations (EPDs) worldwide [42].

#### **OpenLCA Modeling Steps:**

The OpenLCA software has been used to develop a comprehensive model for this ready-mix concrete study. The following steps outline the process of creating the model and extracting environmental impact results.

#### **Process Creation:**

A process for "Ready-Mix Concrete Bangladesh 3000 psi" was established to model the concrete production system, with Bangladesh specified as the geographical location to ensure regional relevance.



**Figure 3-7:** OpenLCA software interface

### **Material Inputs (A1):**

Raw materials were incorporated into the model based on the mix design data collected from NDE, including Portland cement (360 kg), aggregates (866 kg of 20mm stone and 216 kg of 12mm stone), sand (774 kg), water (168.48 kg), and admixtures (3.6 kg).

### **Transportation Modeling (A2):**

Transportation processes were modeled using ton-kilometers (tkm), accounting for the various modes of transport, including cement delivery by truck, stone transportation by sea and inland waterway, and sand delivery by inland waterway.

### **Manufacturing Inputs (A3):**

Energy consumption during the manufacturing process was integrated into the model, including 4.38 kWh of electricity and 3.02 kg of diesel, representing the energy requirements for concrete production. **Figure 3-8** illustrates the Processes, Inputs/Outputs in the OpenLCA software.

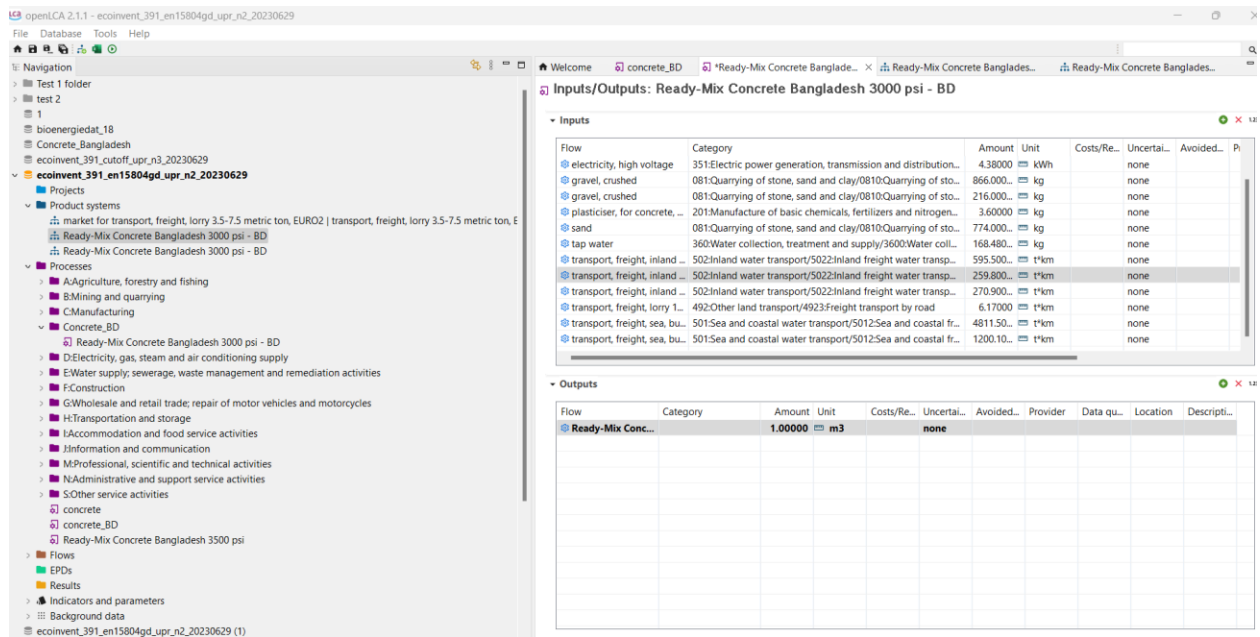


Figure 3-8: OpenLCA software (Processes, Inputs/Outputs)

### Output Definition:

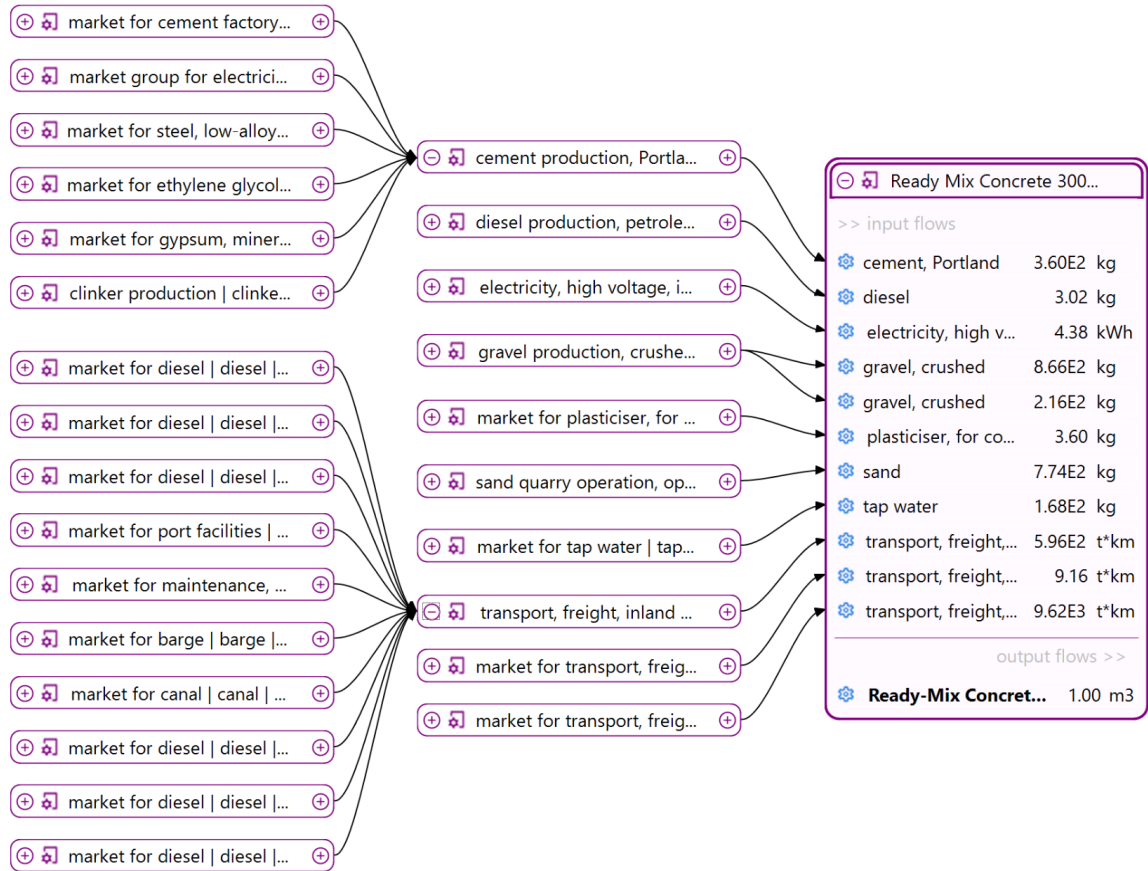
The reference output was defined as "Ready-Mix Concrete 3000 psi" with a mass of 2409 kg representing 1 m<sup>3</sup>, based on density data from the concrete plant.

### Product System Creation:

A product system was created based on the process with auto-linking of processes enabled, allowing for a complete supply chain analysis with defined system boundaries.

### Model Graph Generation:

The model graph in OpenLCA provided a visual representation of the entire supply chain network for concrete production. This graph illustrates all interconnections between processes, from raw material extraction to final product, with nodes representing processes and edges representing material and energy flows. The graph facilitated the identification of critical pathways and dependencies in the production system, enhancing the transparency and comprehensibility of the model structure. **Figure 3-9** illustrates the Model Graph of Inputs/Outputs in the OpenLCA software. **Table 5** shows the Ecoinvent inventories and geographical scope.



**Figure 3-9:** OpenLCA software (Model Graph of Inputs/Outputs)

**Table 5.** Input flows and Ecoinvent processes showing geographical scope

Flows	Ecoinvent processes	Location
Portland cement	cement production, Portland   cement, Portland   EN15804, U - IN	India
20 mm stone & 12 mm stone	gravel production, crushed   gravel, crushed   Cutoff, U-IN	India
Sand	market for sand   sand   EN15804, U-IN	India
Admixture	plasticiser production for concrete, based on sulfonated melamine formaldehyde	Global
Water	market for tap water   tap water   EN15804, U - IN	India
Cement Bulk Carrier (12 Wheel)	transport, freight, conveyor belt   transport, freight, conveyor belt   EN15804, U	Global
Mother Vessel for stone	market for transport, freight, sea, bulk carrier for dry goods   transport, freight, sea, bulk carrier for dry goods	Global

	EN15804, U market for transport, freight, inland waterways, barge tanker   transport, freight, inland waterways, barge tanker	
Lighter vessel for stone	EN15804, U	Global
	market for transport, freight, inland waterways, barge tanker   transport, freight, inland waterways, barge tanker	
Lighter Vessel for Sand	EN15804, U	Global
	transport, freight, conveyor belt   transport, freight, conveyor belt   EN15804, U	
Truck for admixture		Global
	electricity, high voltage, production mix   electricity, high voltage   EN15804, U	
Electricity		Bangladesh
	diesel production, low-sulfur, petroleum refinery operation   diesel, low-sulfur   EN15804, U	
Diesel		India

---

### Impact Assessment:

The EN 15804+A2 LCIA method was selected to calculate environmental impacts across various categories, providing standardized results compatible with international EPD requirements.

### Visualization:

The most comprehensive visualization was a Sankey diagram that depicted the flow of environmental impacts through the product system. In this diagram, the thickness of flow lines was proportional to their contribution to the overall impact, providing an intuitive visual representation of hotspots. **Figure 3-10** the Sankey Diagram in the OpenLCA software clearly illustrates cement's outsized impact compared to other materials and processes, accounting for over three-quarters of the total carbon footprint. This visualization was instrumental in identifying the critical pathways for potential improvements in the concrete production system.

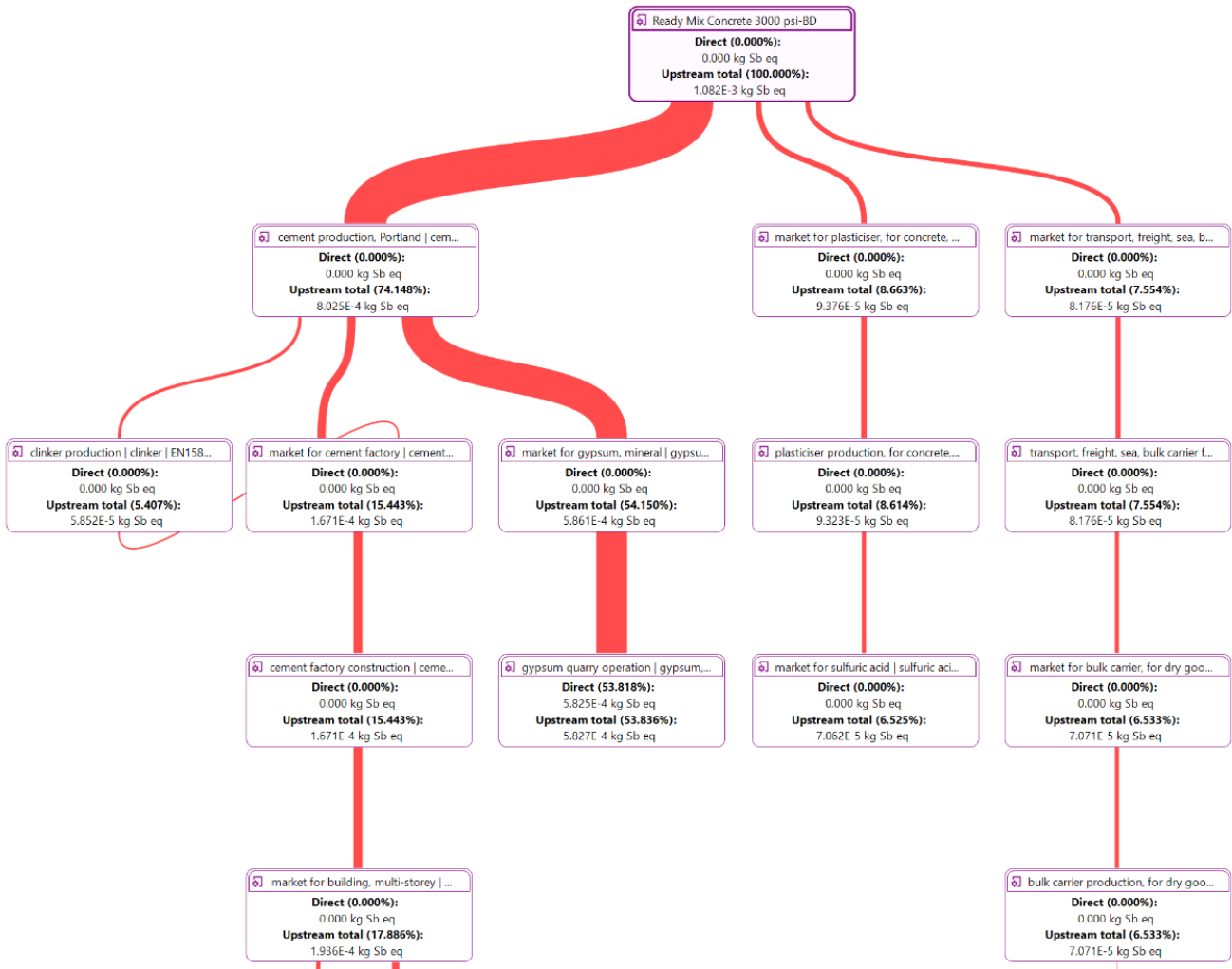
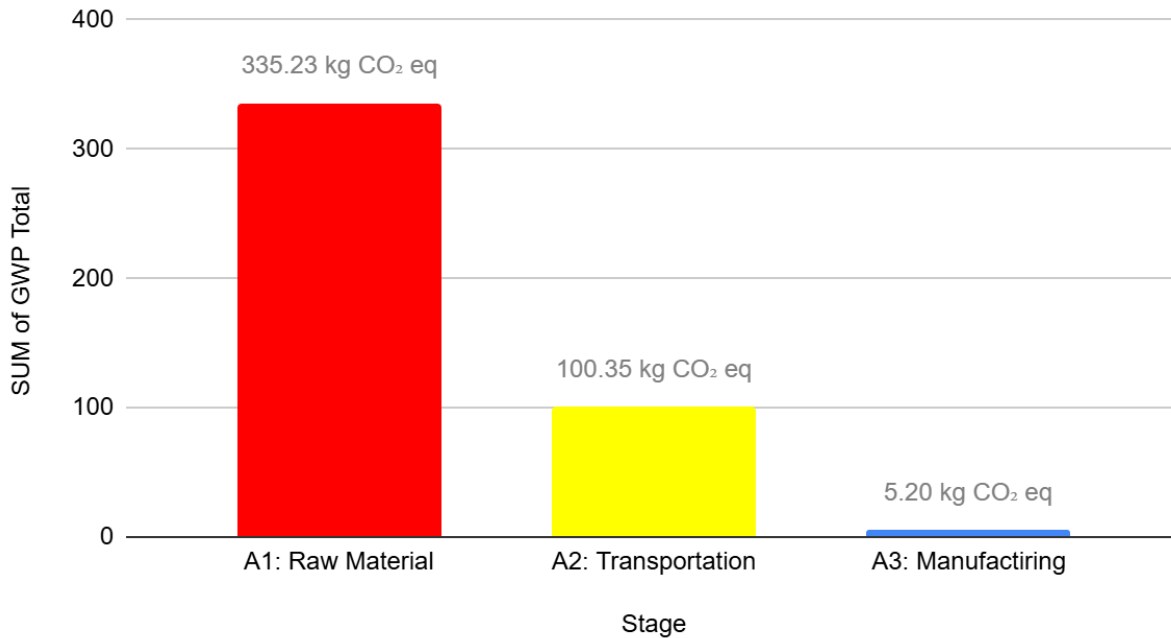


Figure 3-10: OpenLCA software (Sankey Diagram)

### Global Warming Potential by Life Cycle Stage:

Figure 3-11 illustrates the distribution of Global Warming Potential (GWP) across the three key life cycle stages of concrete production. Stage A1 (Raw Material Extraction) is the dominant contributor, accounting for 335.23 kg CO<sub>2</sub> eq, which constitutes approximately 75.6% of the total emissions. This is followed by Stage A2 (Transportation), contributing 100.35 kg CO<sub>2</sub> eq or 22.6%, and Stage A3 (Manufacturing), which emits 5.20 kg CO<sub>2</sub> eq, representing only 1.2% of the total. These results highlight that raw material sourcing is the most carbon-intensive phase, offering the most impactful opportunity for emission reductions through material substitutions, sourcing changes, or the use of supplementary cementitious materials.

## SUM of GWP Total vs. Life Cycle Stages

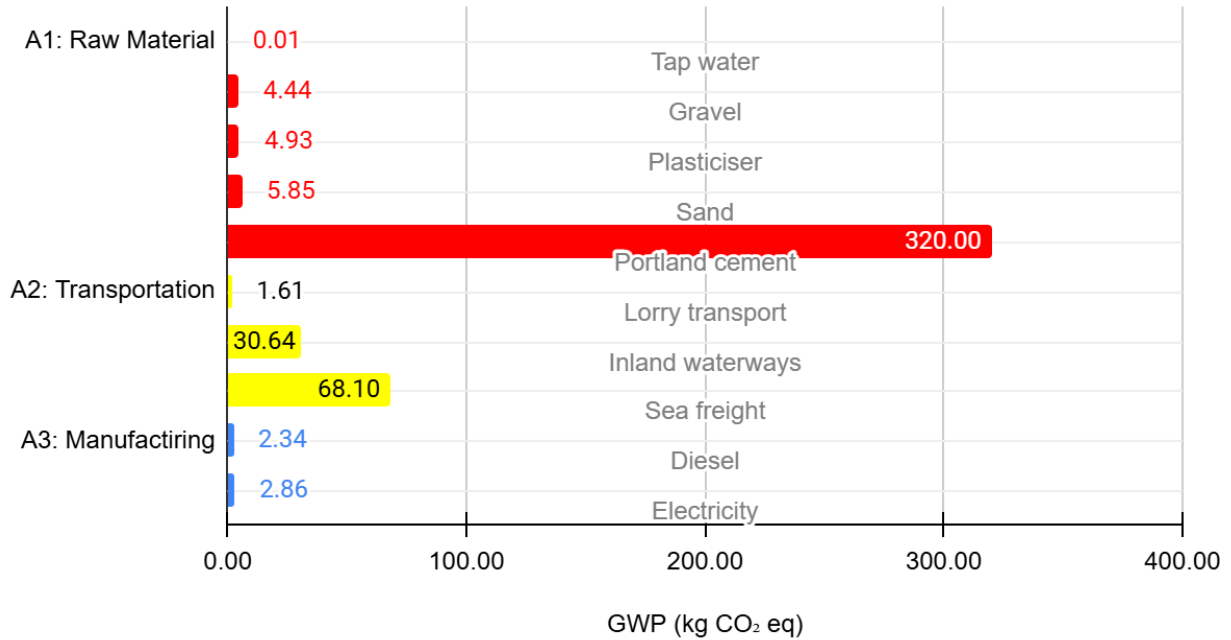


**Figure 3-11:** Sum of Global Warming Potential by Life Cycle Stage

### **Process Contribution to Global Warming Potential:**

**Figure 3-12** presents a detailed breakdown of the Global Warming Potential (GWP) across individual processes within each life cycle stage of concrete production. In Stage A1 (Raw Material Extraction), Portland cement overwhelmingly dominates, contributing 320.00 kg CO<sub>2</sub> eq, which represents the vast majority of emissions in this stage. Other materials, such as sand (5.85 kg CO<sub>2</sub> eq), plasticiser (4.44 kg CO<sub>2</sub> eq), and gravel (4.93 kg CO<sub>2</sub> eq), contribute only marginally. In Stage A2 (Transportation), inland waterways account for 68.10 kg CO<sub>2</sub> eq, followed by sea freight (30.64 kg CO<sub>2</sub> eq) and lorry transport (1.61 kg CO<sub>2</sub> eq). Stage A3 (Manufacturing) exhibits minimal impact, with electricity contributing 2.86 kg CO<sub>2</sub> eq and diesel contributing 2.34 kg CO<sub>2</sub> eq. This granular process-level analysis reinforces that cement production is the primary hotspot, responsible for the largest share of embodied carbon in the concrete's life cycle.

## GWP Total for different processes

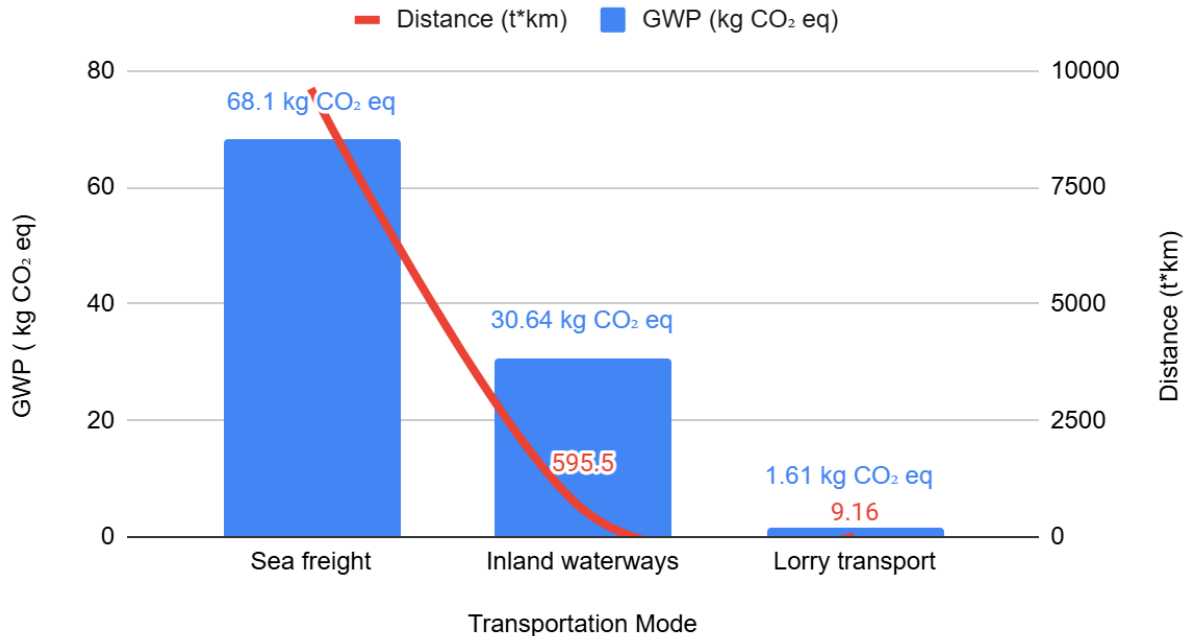


**Figure 3-12:** Different Process Contributions to Total Global Warming Potential

### Transportation Modes Analysis:

**Figure 3-13** examines the relationship between transportation distance (in ton-kilometers, shown by the red line) and associated Global Warming Potential (GWP, shown by blue bars) for three transportation modes used in concrete production. Sea freight results in the highest impact at 68.1 kg CO<sub>2</sub> eq, primarily due to the long transport distance of approximately 9,168 tkm, despite its relative efficiency per kilometer. Inland waterways contribute 30.64 kg CO<sub>2</sub> eq over a distance of 595.5 tkm, and lorry transport accounts for just 1.61 kg CO<sub>2</sub> eq across 9.16 tkm. This visualization emphasizes how Bangladesh's dependence on imported aggregates transported via maritime routes significantly increases the embodied carbon of concrete, even though sea freight is more carbon-efficient on a per-kilometer basis.

## Different modes of Transportation VS Distance



**Figure 3-13:** Relationship of GWP emissions from different transportation modes and distance

### 3.10.2. Spreadsheet Calculator Development

A customized spreadsheet calculator was explicitly developed for the Bangladesh context to provide a more accessible and user-friendly tool for concrete manufacturers to assess the environmental impacts of their products. While OpenLCA offers comprehensive analysis capabilities, it requires specialized knowledge and training. The spreadsheet calculator bridges this gap by providing a simplified yet robust approach to environmental impact assessment that aligns with international standards while incorporating regional specificity. Ecoinvent data sets were utilized for the analysis used in this report.

The open access calculator uses **placeholder (dummy) factors** for impact categories due to licensing restrictions on redistributing proprietary data from the Ecoinvent database. Users with valid access to the Ecoinvent database can manually replace these dummy values with official impact factors to generate accurate impact results, provided they are aligned with the Ecoinvent licensing terms. The spreadsheet is publicly available via Google Drive [[Concrete Spreadsheet Calculator.xlsx](#)], allowing researchers, manufacturers, and educators to explore and adapt the tool for context-specific applications.

#### **Purpose and Advantages of Spreadsheet Calculator:**

The primary motivation for developing this spreadsheet calculator was to create a localized tool that addresses the specific challenges of the Bangladeshi concrete industry. This calculator offers several distinct advantages:

- **Bangladesh-Specific Impact Database:**

The calculator incorporates a customized impact database derived from Ecoinvent but adapted specifically for the South Asian region, with particular focus on Bangladesh, where available. This

regional specificity improves the accuracy of environmental impact assessments compared to using global default values.

- **Integration of Local EPDs:**

The calculator directly incorporates data from existing Bangladeshi EPDs, particularly the INSEE cement EPDs, ensuring that the most significant component of concrete's environmental impact is represented by locally verified data rather than international approximations.

- **Accessibility and Transparency:**

Unlike complex LCA software, the spreadsheet format makes the assessment process transparent and accessible to stakeholders without specialized LCA knowledge, enabling broader adoption within the Bangladeshi construction industry.

- **Customizability:**

The calculator is designed to be easily modified by users to reflect their specific concrete mix designs, material sourcing, and manufacturing processes, making it adaptable to various contexts within Bangladesh.

- **Comprehensive Impact Assessment:**

Despite its simplified interface, the calculator provides a comprehensive assessment across all impact categories required for EPD development according to EN 15804+A2 standards.

## Calculator Structure and Components:

The spreadsheet calculator is organized into four main sections:

1. **Explanations (Sheet 1):**

This introductory sheet provides an overview of the calculator's purpose, methodology, and instructions for use. It explains that the environmental impact data is based on a combination of Ecoinvent database values adapted for Bangladesh and local EPD information, where available. The sheet outlines key concepts such as system boundaries, declared units, and impact categories to guide users through the assessment process. **Figure 3-14** illustrates the interface of the Spreadsheet Calculator.

2. **LCA Model Working (Sheet 2):**

The core calculation engine of the spreadsheet is contained in this comprehensive sheet. It is structured to follow the A1-A3 life cycle stages:

- **Product Definition Section:**

Defines the concrete product (3000 psi NDE Ready-Mix Concrete) and establishes the declared unit (1 m<sup>3</sup>).

- **A1 Raw Materials Section:**

Includes input fields for concrete constituents (cement, aggregates, sand, water, admixtures) with corresponding quantities and environmental impact factors.

- **A2 Transportation Section:**

Incorporates transportation modes, distances, and associated emissions factors specific to Bangladesh's transportation infrastructure and material sourcing patterns.

- **A3 Manufacturing Section:**

Accounts for energy consumption (electricity, diesel) during the concrete production process, with emissions factors reflecting Bangladesh's energy grid composition.

- **Results Visualization:**

Provides automatically generated charts showing the contribution of different materials and processes to various environmental impact categories.

3. **Concrete Impact Database (Sheet 3):**

This sheet serves as the repository for environmental impact factors needed for the calculations. This sheet contains **placeholder (dummy) factors** for impact categories due to licensing restrictions on redistributing proprietary data from the Ecoinvent database. The database includes impact factors for various materials and processes across multiple environmental indicators.

4. **Collected EPD (Sheet 4):**

Contains data extracted from existing EPDs published in Bangladesh, particularly the INSEE cement products. This integration of locally produced EPD data significantly improves the accuracy of the cement-related impacts, which typically account for the majority of concrete's environmental footprint. Users can utilize their EPD data in this sheet.

5. **LCA Model\_Concrete\_Example (Sheet 5)** This sheet presents an example LCA of 3000 psi ready-mix concrete in Bangladesh using placeholder (dummy) data, along with visualizations of the results. Users can begin a new LCA in Sheet 2 or modify the material types and quantities in Sheet 5 to conduct their own analysis.

A1: Raw material Extraction						LCI process impacts evaluated					
No	Material	Quantity	Unit	LCI process	Notes	Global Warming Potential, total kg CO <sub>2</sub> eq.	Global Warming Potential, fossil fuels, kg CO <sub>2</sub> eq.	Global Warming Potential, biogenic, kg CO <sub>2</sub> eq.	Global Warming Potential, land use and change, kg CO <sub>2</sub> eq.	Depletion potential of the stratospheric ozone layer, kg CFC 11 eq.	Acidification potential, Accumulated Exceedance, mol H <sup>+</sup> eq.
1	Portland Cement	360	kg	EPD: INSEE PC produced in Bangladesh by Siam City Cement	Data collection: 2022 data from INSEE Cement	0.9616	0.9614	0.0001398	0.0000893	0.000000015	0.003722
2	Water	168.48	kg	Ecoinvent: market for tap water   tap water   EN15804, U	Both India and the rest of the world have in	0.0012	0.0012	8.80E-06	2.00E-06	9.80E-12	5.90E-06
3	20 mm stone	866	kg	Ecoinvent: gravel production, crushed   gravel, crushed	Both India and the rest of the world have in	0.0076	0.0072	2.10E-05	7.90E-06	6.20E-11	4.80E-05
4	12 mm stone	216	kg	Ecoinvent: gravel production, crushed   gravel, crushed	Both India and the rest of the world have in	0.0076	0.0073	2.10E-05	7.90E-06	6.20E-11	4.80E-05
5	Sand	774	kg	Ecoinvent: market for sand   sand   EN15804, U-IN	Both India and the rest of the world have in	0.033	0.033	1.05E-05	1.60E-05	5.20E-10	1.80E-04
6	Admixture	3.6	kg	Ecoinvent: plasticiser production for concrete, based on su	Only Global impact available	1.28	1.27	0.0027	0.0012	1.30E-07	0.0087
<b>Total</b>											

Figure 3-14: Spreadsheet Calculator Interface

**Calculation Methodology:**

The calculator employs a straightforward but rigorous calculation methodology:

1. **Material Inputs:**

Users enter the concrete mix design specifications in terms of kg per m<sup>3</sup> for each constituent.

2. **Impact Calculation:**

Each material input is multiplied by its corresponding impact factor from the Concrete Impact Database to determine its contribution to each environmental impact category.

3. **Transportation Impact:**

Transportation impacts are calculated using a ton-kilometer (tkm) approach, where the mass of each material is multiplied by the transportation distance and then by the appropriate emissions factor for the transport mode.

4. **Manufacturing Impact:**

Energy consumption during production is converted to environmental impacts using factors that reflect Bangladesh's specific energy production profile, which differs significantly from global averages.

5. **Aggregation:**

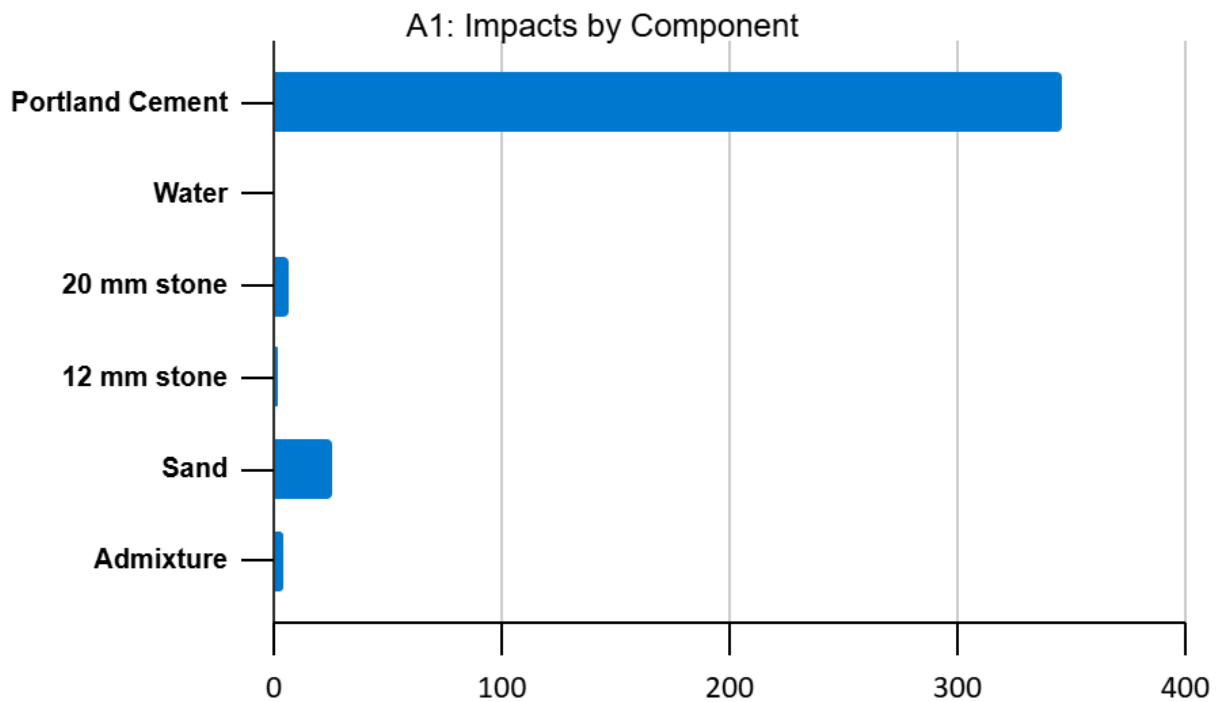
Impacts from all three life cycle stages (A1-A3) are aggregated to provide comprehensive results across all required impact categories.

**Visualization Features:**

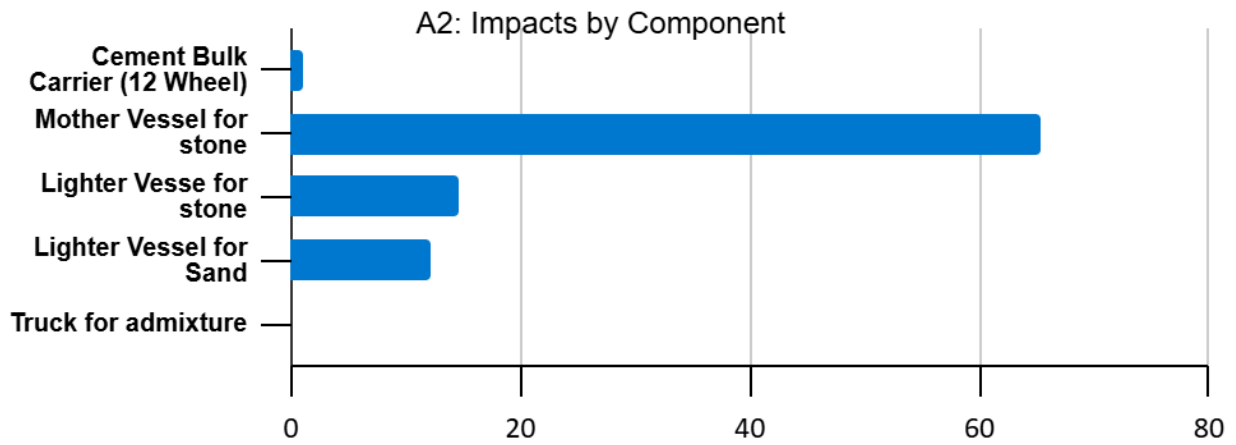
The calculator includes several visualization features to help users interpret the results:

- **Material Contribution Charts:**

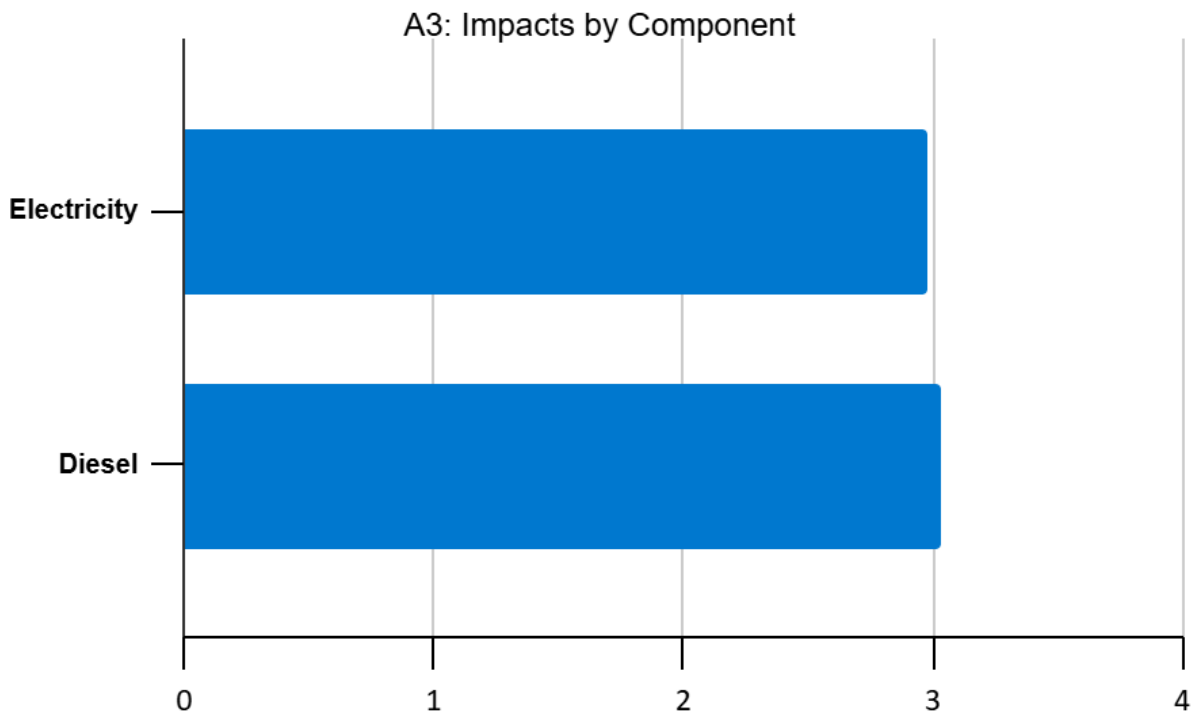
Display the relative contribution of each material to different environmental impact categories, highlighting hotspots in the concrete production process. **Figure 3-15** depicts the contribution of each material to GWP. **Figure 3-16** and **Figure 3-17** illustrate the contribution of different transportation modes and energy consumption to global warming potential



**Figure 3-15:** The contribution of each material to global warming potential (GWP)



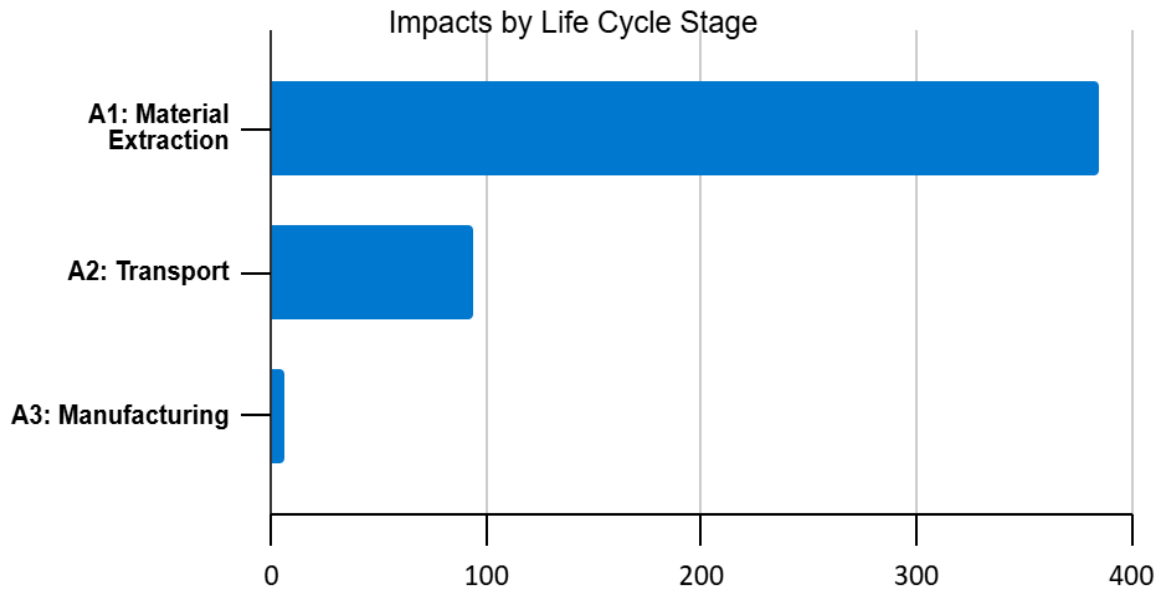
**Figure 3-16:** The contribution of different transportation modes to global warming potential (GWP)



**Figure 3-17:** The contribution of different energy consumption to global warming potential (GWP)

- **Life Cycle Stage Comparison:**

**Figure 3-18** visualizes the distribution of impacts across the A1-A3 stages, typically showing the dominance of the A1 (raw materials) stage.



**Figure 3-18:** The distribution of global warming potential (GWP) impacts across the A1-A3 stages

#### **Implementation and Customization Guide:**

The calculator is designed to be user-friendly while maintaining technical rigor. To implement the calculator for a specific concrete product, users should:

1. **Input Product Information:**  
Define the concrete type, strength class, and declared unit.
2. **Enter Mix Design:**  
Input the quantities of each concrete constituent based on actual mix designs.
3. **Specify Transportation:**  
Enter the transportation modes, distances, and quantities for each material.
4. **Add Manufacturing Data:**  
Input plant-specific energy consumption data for the concrete production process.

The calculator automatically generates results once all inputs are provided, impacts are selected from the impact database sheet, and visualizations update accordingly. Users can modify any aspect of the calculator to better reflect their specific circumstances, including adding new materials or updating impact factors when more localized data becomes available.

#### **3.10.3. POD|LCA Tool Application**

The Parametric Open Data Life Cycle Assessment (POD|LCA) Tool, currently in development by an interdisciplinary team at the University of Washington, provides a flexible object-oriented approach to life cycle assessment specifically designed for the construction industry [43].

#### **Purpose and Advantages of POD|LCA Tool:**

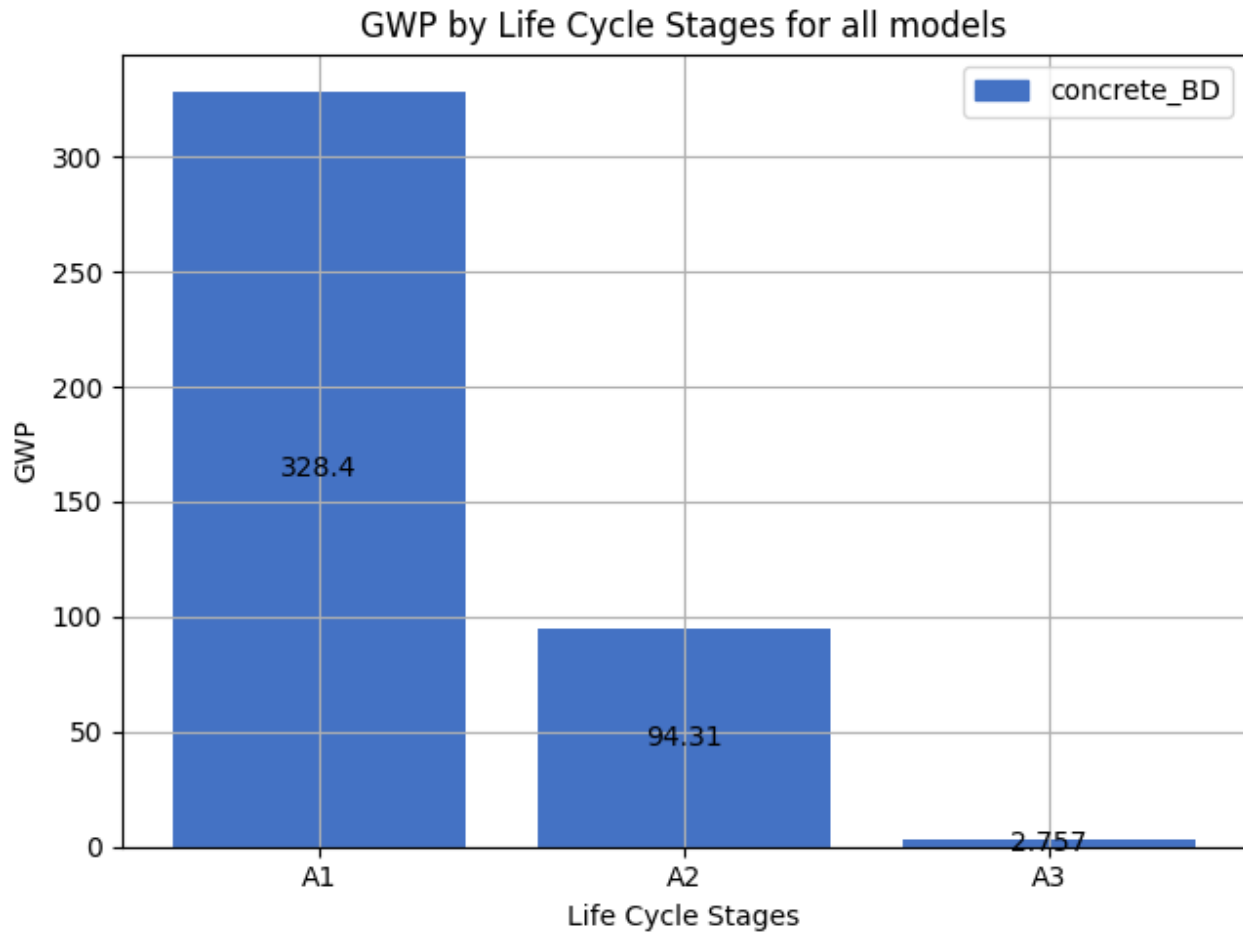
The POD|LCA Tool provides several distinct advantages for concrete LCA assessment in Bangladesh:

- **Object-Oriented Framework:**  
Unlike spreadsheet calculators, POD|LCA employs an object-oriented programming approach that creates robust data structures representing materials, locations, and processes, enabling more sophisticated modeling capabilities.
- **Dynamic Analysis Capability:**  
The tool supports parametric and sensitivity analysis through its modular programming structure, allowing researchers to efficiently test multiple scenarios and material variations.
- **Customizable Impact Database:**  
POD|LCA can integrate region-specific impact factors for Bangladesh, overcoming the limitations of Western-centric databases and improving assessment accuracy for local conditions.
- **Specialized Visualization:**  
The tool includes built-in visualization modules that generate standardized environmental impact charts, making results more accessible to stakeholders without deep LCA expertise. **Figure 3-19** illustrates the contribution of different (A1-A3) life cycle stages to GWP.

### **Tool Structure and Components:**

The POD|LCA tool is structured around a modular architecture comprising several key components:

1. **Location Module:**  
The POD|LCA tool has a customizable impact data option that allows users to conduct LCAs globally. However, it does not provide integrated global energy data. Instead, users have the option to manually input energy-related data from external sources, such as Ecoinvent's global datasets
2. **Materials and Project Manager:**  
Manages the definition of concrete mix designs, material quantities, and relationships between components, creating a structured hierarchy of the assessment scope.
3. **Impacts Database:**  
Incorporates customized impact factors specifically adapted for Bangladeshi concrete production, including locally sourced materials and energy profiles.
4. **Calculator Module:**  
Processes the inputs to generate comprehensive impact assessments across multiple environmental indicators, including GWP, AP, EP, ODP, and SFP.
5. **Visualization Module:**  
Generates standardized charts and graphs that clearly communicate results across life cycle stages and material contributions.



**Figure 3-19:** The contribution of different (A1-A3) life cycle stages to GWP

#### **Implementation for Bangladesh Concrete Assessment:**

For this research, the POD|LCA tool was adapted to the Bangladeshi context through several customizations:

- The geographical system was set to "Asia" to better reflect regional production processes and energy systems. The POD|LCA tool is in the development stage and is currently focused on the North American context.
- A custom impact database was integrated, incorporating Bangladesh-specific data where available, supplemented with regional proxies when necessary.
- The concrete model was configured to match the exact specifications of the NDE Ready Mix 3000 psi concrete, including precise material quantities and transportation scenarios.
- Transportation processes were modeled with particular attention to the long-distance aggregate transportation by sea and inland waterways, which significantly impacts the overall environmental footprint.

## **4. Result**

### **4.1. Comparative Analysis of Life Cycle Assessment Methods**

The comparison of results from the three methodological approaches reveals both consistency and variation in the environmental impact assessment of concrete in Bangladesh. As illustrated in the comparative charts,

all three methods—OpenLCA, POD|LCA, and the Spreadsheet Calculator—show similar overall patterns in their assessment of Global Warming Potential (GWP), though with notable differences in specific values and distributions.

**Figure 4-1** shows a detailed breakdown of GWP contributions by material and process across all three methods. Several key observations can be made:

- **Portland Cement Dominance:**

All three methods identify Portland cement as the primary contributor to GWP, consistently accounting for approximately 75–80% of the total carbon footprint. OpenLCA and POD|LCA report cement-related emissions in the range of **330–340 kg CO<sub>2</sub> eq**, while the Spreadsheet Calculator shows a slightly higher value, just under **350 kg CO<sub>2</sub> eq**.

- **Transportation Impacts:**

Transportation is the second most significant contributor, with OpenLCA estimating the highest emissions for this category, followed closely by the Spreadsheet Calculator and then POD|LCA. Differences may arise due to how each tool handles transport modes and distances, particularly maritime and inland logistics.

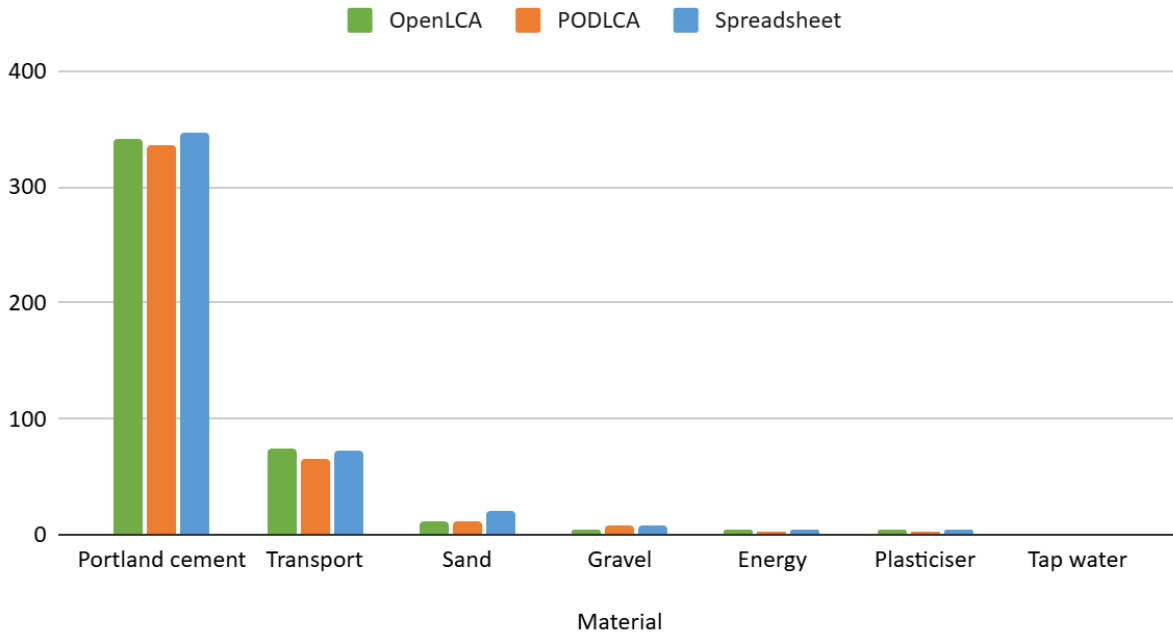
- **Manufacturing Energy:**

All three methods attribute relatively minor GWP contributions to electricity and diesel used in manufacturing. The results are closely aligned, with only small variations that reflect the tools' differing assumptions or emission factor databases.

- **Minor Constituents:**

Materials such as sand, gravel, plasticiser, and tap water consistently show minimal GWP contributions across all three tools. Their impact is small relative to the dominant contributors and shows strong consistency, affirming that all tools follow a similar hierarchy of process impact.

## OpenLCA, PODLCA and Spreadsheet Results Comparison

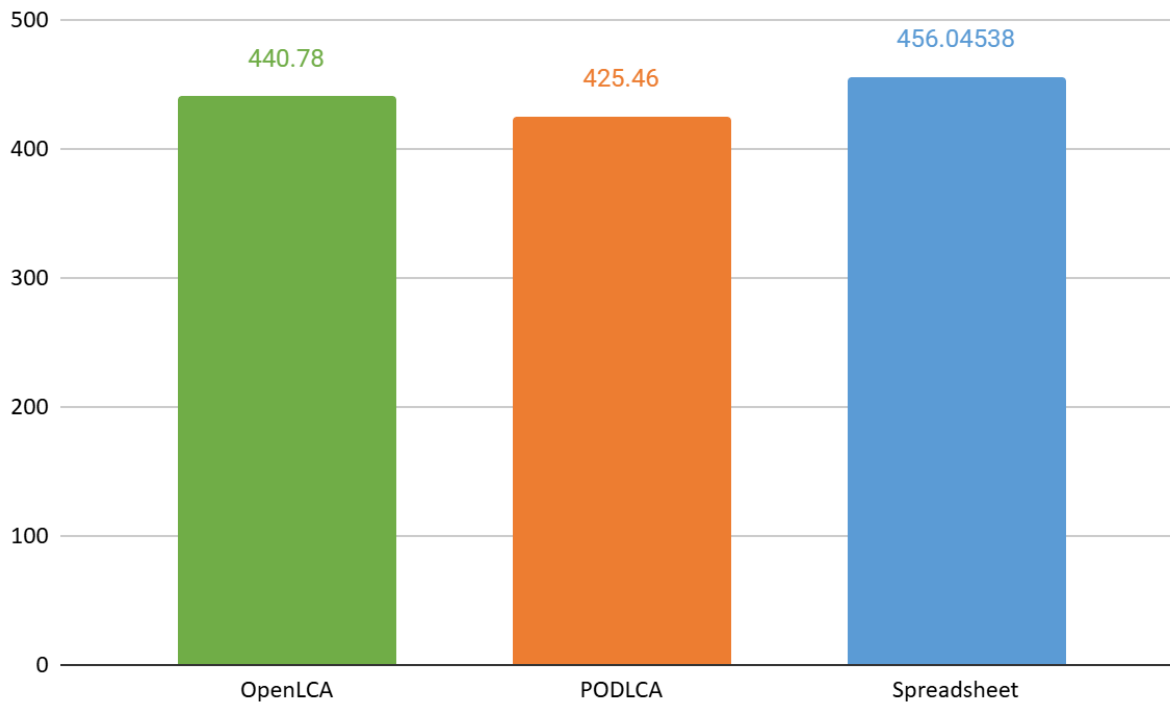


**Figure 4-1:** Comparison of GWP from OpenLCA, PODLCA Tool, and Spreadsheet Calculator from different processes

**Figure 4-2** compares the total GWP per cubic meter of concrete across the three methods:

- **OpenLCA:** 440.78 kg CO<sub>2</sub> eq
- **PODLCA:** 425.46 kg CO<sub>2</sub> eq
- **Spreadsheet Calculator:** 456.05 kg CO<sub>2</sub> eq

These values reveal a **maximum difference of around 7%**, indicating a strong degree of methodological consistency. Notably, the **Spreadsheet Calculator** produced the highest GWP estimate. This higher value results from its use of more **region-specific emission factors**, such as the integration of a **Bangladesh-specific cement EPD**, making it more reflective of local conditions and potentially more conservative in areas with limited data availability.



**Figure 4-2:** Simplified comparison of the total GWP across OpenLCA, Spreadsheet Calculator, and PODLCA Tool

#### 4.2. Methodological Differences and Implications

The variations in results across the three methods can be attributed to several key methodological differences:

1. **Background Data Sources:**

OpenLCA primarily relies on the Ecoinvent database with global or Rest of World (RoW) processes, while the Spreadsheet Calculator incorporates Bangladesh-specific EPD data for cement and regional proxies for other materials. In the PODLCA tool, a customized impact database derived from Ecoinvent, with a focus on global data, has been used. These differences in background data are particularly influential for materials like cement and transportation processes.

2. **System Boundary Implementation:**

While all three methods follow the same declared A1-A3 system boundary, there are subtle differences in how each tool implements cutoff criteria and handles minor inputs and outputs. OpenLCA typically includes a more comprehensive set of background processes, potentially capturing impacts that might be simplified in the other approaches.

3. **Transportation Modeling:**

A significant difference appears in how transportation impacts are calculated. OpenLCA uses detailed transport modeling with specific emission factors for different vehicle types and fuels, while the Spreadsheet Calculator employs a more streamlined approach based on standard ton-kilometer factors. The PODLCA tool's object-oriented approach follows a project-specific method

of estimating transportation impacts built from US transportation data, resulting in values that sometimes fall between the other two methods.

#### 4. **Impact Assessment Methods:**

While all three approaches use impact assessment methods aligned with EN 15804+A2, there may be slight variations in the characterization factors applied, particularly for processes specific to Bangladesh or the Asian region.

These methodological differences have important implications for EPD development in Bangladesh:

- **Data Quality Tradeoffs:**

The choice of method involves balancing the comprehensiveness of OpenLCA against the accessibility and regional specificity of the Spreadsheet Calculator and POD|LCA tool. For contexts with limited local data, like Bangladesh, the ability to incorporate regional proxies and custom data becomes particularly important.

- **Verification Considerations:**

The variations across methods highlight the importance of transparent documentation in EPD verification processes. For Bangladesh's emerging EPD landscape, establishing clear guidelines on acceptable methodological approaches and data sources will be crucial.

- **Stakeholder Communication:**

The consistency in identifying key hotspots (cement and transportation) across all methods provides confidence in communicating priority areas for environmental improvement to stakeholders, even if absolute values vary somewhat.

- **Future Refinement:**

The comparison suggests that future efforts should focus on improving transportation data and regional characterization factors for Asian contexts, as these show the most variation across methods.

This comparative analysis demonstrates that while each method has its strengths and limitations, they collectively provide a robust foundation for EPD development in Bangladesh. The **Spreadsheet Calculator** emerges as particularly effective for the Bangladeshi context, offering exceptional accessibility to local manufacturers, straightforward adaptability to regional materials and practices, and a transparent calculation process that aligns with the technical capacity of the local construction industry. While OpenLCA provides comprehensive analysis capabilities and alignment with international standards, and the POD|LCA tool offers enhanced visualization and parametric analysis features, the Spreadsheet Calculator's simplicity and direct relevance to Bangladesh's construction sector make it the most practical immediate solution. As Bangladesh transitions toward more transparent and sustainable concrete production practices, this accessible tool can serve as an entry point for widespread adoption of environmental assessment practices, while the other methods can supplement analysis when greater complexity is required.

## 5. **Discussion & Findings**

Following the methodological evaluation in Chapter 4, it is essential to interpret the broader implications of the environmental assessment. The analysis of 3000 psi ready-mix concrete produced in Bangladesh offers key insights into both technical performance and strategic pathways for sustainability integration in the local construction sector.

One of the most significant takeaways is the environmental cost associated with cement consumption and the use of imported aggregates. These materials drive up the global warming potential of the concrete mix and point to a critical area for intervention: material optimization and localization.

The successful application of accessible, locally adapted tools alongside established software solutions further validates that credible environmental assessments do not require high-cost platforms. This promotes a more democratic approach to LCA adoption, empowering a wider range of stakeholders, including smaller manufacturers and public agencies, to participate in environmental product declaration initiatives.

By moving beyond technical calculation and demonstrating the operational feasibility of contextualized tools, the research contributes a replicable approach that could be adopted across similar economies aiming to bridge the LCA capacity gap.

### 5.1. Limitations of the Conventional EPD Pathway

The conventional method of developing EPDs, although internationally standardized, presents several key challenges in the context of Bangladesh. These limitations hinder widespread adoption and create barriers to sustainability transparency in the local concrete sector.

- **Lack of Local Expertise:**  
Bangladesh currently lacks a robust network of trained professionals in Life Cycle Assessment. This expertise gap limits the capacity to develop EPDs that meet international verification and reporting standards.
- **Scarcity of Local LCI Data:**  
Reliable, region-specific life cycle inventory data is not readily available. As a result, practitioners often rely on foreign databases that may not reflect local conditions, leading to less accurate assessments.
- **High Cost of Tools and Databases:**  
Proprietary LCA software and access to global databases like Ecoinvent come with substantial costs. For small and medium enterprises, these expenses create a significant entry barrier.
- **Limited Verification Infrastructure:**  
The absence of locally based, recognized EPD program operators means that third-party verification and publication must be sought internationally, an expensive and time-consuming process.

These challenges emphasize the need for a context-sensitive EPD framework tailored to the capacities and constraints of Bangladesh.

### 5.2. The Bangladesh EPD Pathway: A Contextual Solution

To overcome these challenges, a localized and simplified EPD pathway is proposed. This “Bangladesh Way” reframes the conventional roadmap to suit national conditions while upholding international credibility. Key elements include:

- **Local Training:**  
University partnerships and technical institutes can offer LCA and EPD training to build a domestic expert base.

- **Open-Source Tools:**  
Use of accessible, spreadsheet-based carbon calculator tools to reduce expensive and technically critical software dependency.
- **Local Verifiers:**  
Train local professionals to perform EPD verification, reducing reliance on costly international consultants.
- **Regional Program Operator:**  
Establish or partner with a South Asian EPD program operator to streamline documentation and publication.

These steps can enable an affordable, scalable, and context-sensitive EPD ecosystem, beginning with ready-mix concrete.

### 5.3. Policy Framework Recommendations

To support this system, a supportive policy environment is essential. A Bangladesh-specific EPD policy framework should include:

- **Funding Support:**  
Government subsidies and licensing assistance for small manufacturers can play a pivotal role in encouraging EPD adoption. Specific funding mechanisms could include grants for EPD development projects, financial support for database access and software procurement, and subsidized costs for third-party verification. This support would especially benefit small and medium-sized concrete producers, who often lack the capital to participate in rigorous environmental assessments.
- **Procurement Leverage:**  
Preference for EPD-labeled products in public infrastructure projects can create a significant demand-side pull for sustainable materials. Government procurement policies could mandate the inclusion of EPDs as a criterion in tender evaluations for large-scale projects such as roads, bridges, and public buildings. By requiring EPDs to set minimum sustainability benchmarks, public agencies can lead by example, encouraging the private sector to invest in EPD development and material optimization. Additionally, pilot programs could demonstrate the feasibility and benefits of low-carbon concrete procurement to build momentum.
- **Education Framework:**  
Inclusion of LCA and EPD topics in engineering and architecture curricula is crucial to fostering a culture of sustainability within the construction and materials sectors. Academic institutions should integrate life cycle thinking into undergraduate and graduate programs to ensure that future professionals are equipped with the knowledge and tools to assess environmental impacts. Short courses, workshops, and certificate programs could further support continuing education for current industry practitioners and public officials. Establishing partnerships between universities, industry, and government can also help tailor educational content to local needs and promote applied research in this area.
- **Inclusive Outreach for Non-Technical Stakeholders:**  
To ensure widespread adoption and awareness, it is essential to engage manufacturers, laborers, and others without technical backgrounds. Technical terms related to carbon emissions, global warming, and sustainability should be translated into the local language and presented in an accessible manner. Interactive workshops and awareness campaigns can be organized to explain the importance of understanding the carbon footprint of construction materials. By building

environmental literacy across all levels of the construction value chain, this approach can foster collective responsibility and more informed decision-making.

- **Market Incentives:**

Tax benefits, green building credits, and streamlined permitting processes can incentivize producers to pursue EPD development. For example, manufacturers that achieve verified EPDs could qualify for reduced corporate taxes or import duties on eco-efficient equipment. In addition to these financial benefits, EPDs serve as a public and credible advertisement for product sustainability. Since EPDs are published and accessible, they enhance market visibility, helping manufacturers stand out in competitive bidding processes and appeal to environmentally conscious clients. These market-based tools can reduce the perceived burden of sustainability and make environmental transparency a strategic advantage.

- **Design and Construction Sector Engagement:**

Architects, developers, and contractors play a crucial role in mainstreaming low-carbon materials into the built environment. Promoting awareness of green building standards, such as the Leadership in Energy and Environmental Design (LEED) certification, can encourage design teams and clients to prioritize products with verified EPDs. LEED and similar programs reward the selection of low-embodied carbon materials, creating an incentive for sustainable procurement. Educational outreach and case studies demonstrating EPD-based decisions can further influence industry practices, helping align design aspirations with measurable environmental performance.

- **International Integration:**

Compatibility with global systems like the EC3 database enhances the international credibility and accessibility of Bangladeshi EPDs. Participation in established global platforms not only increases visibility but also aligns national sustainability reporting with global best practices. This integration enables benchmarking, facilitates exports, and positions Bangladeshi manufacturers as competitive players in international green procurement markets. Encouraging cross-border collaboration on EPD verification and mutual recognition agreements can further strengthen global integration.

## 6. Conclusion and Future Vision

This thesis demonstrates that developing an Environmental Product Declaration (EPD) framework for ready-mix concrete in Bangladesh is not only feasible but necessary for climate-resilient infrastructure planning. Through fieldwork, data modeling, and tool validation, it reveals that current barriers—technical, economic, and institutional—can be addressed through context-specific innovations.

The methodology used here resulted in Bangladesh's first (unverified) concrete EPD, showing how local materials and practices can be integrated with global sustainability frameworks. The findings affirm that the greatest environmental impacts lie in cement production and long-distance material transport—insights that can guide national mitigation strategies.

While this study has laid the foundation for the development of an Environmental Product Declaration (EPD) framework in Bangladesh, further efforts are needed to scale its impact and institutionalize environmental transparency across the construction sector. The scope of EPDs must grow beyond individual case studies and evolve into a national system supported by academic, industrial, and governmental collaboration. Addressing the environmental impacts of concrete production demands sustained investment in data infrastructure, human capacity, and policy alignment. Furthermore, as the urgency of the climate crisis grows, the importance of knowledge-sharing and regional partnerships becomes ever more critical.

The next steps extend beyond this single case study. A broader vision includes:

- **Scaling Nationwide:**  
Expand EPD development to cover a variety of concrete mixes, other construction materials, and plants across the country. This would involve building a repository of EPDs representing regional production practices and material variations. Such an effort would provide benchmarking opportunities and help policymakers and practitioners compare environmental performance across different regions and technologies.
- **LCA Hubs:**  
Establish regional centers of excellence for LCA education, training, and tool development. These hubs could be embedded within universities or research institutions and serve as innovation incubators that support academic, industry, and government collaboration. They would offer hands-on training, host certification programs, and drive the creation of localized LCI datasets.
- **Digital EPD Infrastructure:**  
Create a national open-access EPD registry integrated with international platforms. This digital platform would ensure transparency and accessibility of verified environmental information for materials. Features could include searchable databases, export-friendly formats, and links to tools like EC3, EPD portal, and others. A robust digital backbone would facilitate monitoring, policy implementation, and private-sector innovation.
- **Developing Country Collaboration:**  
Share tools and best practices with other developing countries to create a network of climate-conscious construction actors. This includes developing joint guidance documents, mutual recognition frameworks for EPD verification, and cooperative regional databases. Bangladesh can play a leading role in forming a South Asian alliance to collectively accelerate sustainable construction transitions.

In conclusion, this study has taken an initial step toward establishing a nationally relevant Environmental Product Declaration (EPD) framework tailored for the ready-mix concrete industry in Bangladesh. By identifying key barriers in the conventional system and proposing locally appropriate solutions—grounded in field data, tool comparisons, and policy recommendations—it has laid the groundwork for a more inclusive and scalable approach to environmental transparency in construction. This research not only produced the first draft Environmental Product Declaration (EPD) for ready-mix concrete in Bangladesh (**Appendix 1**) but also developed a comprehensive EPD Roadmap guideline (**Appendix 2**) to support future stakeholders in establishing a sustainable EPD system across the country. These findings demonstrate how developing countries can innovate within global frameworks to meet local sustainability goals. The outputs of this study are expected to guide future academic inquiry, government policymaking, and industry practices in advancing low-carbon infrastructure solutions.

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## **Appendix**

## Appendix 1

# Draft Environmental Product Declaration (EPD)

Ready-Mix Concrete – 3000 psi

Prepared for Academic Purposes Only

This document is a **draft example** of an Environmental Product Declaration (EPD) prepared for the Master's thesis:

**"Towards Sustainable Concrete Construction: An EPD Roadmap for Bangladesh"**

by **Azeezah Sultana Priyota**

University of Washington, 2025

### Next Steps for Finalization:

- **Verification:** This EPD has not undergone third-party verification as required under ISO 14025.
- **Data Substitution:** Substitution of all placeholder/dummy LCI data with verified datasets.
- **Registration:** For this document to become an official EPD, it must be reviewed, verified, and registered through a recognized Program Operator such as EPD International AB ([www.environdec.com](http://www.environdec.com)).

# Environmental Product Declaration

In accordance with ISO 14025:2006 and EN 15804:2012+A2:2019/AC:2021 for:

## **1 m<sup>3</sup> of Ready-Mix Concrete**

from

**NDE Ready Mix Concrete**



Programme:

Programme operator:

EPD registration number:

Publication date:

Valid until:

The International EPD<sup>®</sup> System, [www.environdec.com](http://www.environdec.com)

EPD International AB

**THIS IS A DRAFT EXAMPLE OF AN UNVERIFIED EPD**

**PREPARED AS PART OF A Master's THESIS**

**NOT VALID FOR USE**

*An EPD should provide current information and may be updated if conditions change. The stated validity is therefore subject to the continued registration and publication at [www.environdec.com](http://www.environdec.com)*



## General information

### Programme information

<b>Programme:</b>	The International EPD® System <b>PROPOSED EPD PROGRAM OPERATOR</b>
<b>Address:</b>	EPD International AB Box 210 60 SE-100 31 Stockholm Sweden
<b>Website:</b>	<a href="http://www.environdec.com">www.environdec.com</a>
<b>E-mail:</b>	<a href="mailto:info@environdec.com">info@environdec.com</a>

<b>Accountabilities for PCR, LCA, and independent, third-party verification</b>
<b>Product Category Rules (PCR)</b>
CEN standard EN 15804 + A2 serves as the Core Product Category Rules (PCR)
Product Category Rules (PCR): PCR 2019:14 – Construction Products (EN 15804+A2) – version 1.3.2 PCR 2019:14-c-PCR-003 c-PCR-003 Concrete and concrete elements (EN 16757) (2023-01-02)
PCR review was conducted by: <b>NOT COMPLETED</b>
<b>Life Cycle Assessment (LCA)</b>
LCA accountability: Azeezah Sultana Priyota
<b>Third-party verification</b>
Independent third-party verification of the declaration and data, according to ISO 14025:2006, via:  Third-party verifier: <b>NOT COMPLETED</b> Approved by:
Procedure for follow-up of data during EPD validity involves third-party verifier: <input type="checkbox"/> Yes <input type="checkbox"/> No

The EPD owner has the sole ownership, liability, and responsibility for the EPD.

EPDs within the same product category but registered in different EPD programmes, or not compliant with EN 15804, may not be comparable. For two EPDs to be comparable, they must be based on the same PCR (including the same version number) or be based on fully-aligned PCRs or versions of PCRs; cover products with identical functions, technical performances and use (e.g. identical declared/functional units); have equivalent system boundaries and descriptions of data; apply equivalent data quality requirements, methods of data collection, and allocation methods; apply identical cut-off rules and impact assessment methods (including the same version of characterisation factors); have equivalent content declarations; and be valid at the time of comparison. For further information about comparability, see EN 15804 and ISO 14025.

## Company information

**Owner of the EPD:** NDE Ready Mix Concrete

**Contact:** MD Saiful Islam

**Description of the organization:**

NDE Ready Mix Concrete Ltd., established in 2009, is the largest ready-mix concrete manufacturing company in Bangladesh. Over the years, it has evolved into one of the most reputed brands in Dhaka's construction industry. The company supplies a wide range of concrete mixes and is affiliated with top international cement brands like Lafarge, Heidelberg, and Holcim, as well as prominent local producers.

NDE RMC operates an extensive network of production facilities across key regions, including Dhaka, Chattogram, Gazipur, Mymensingh, and more. These units are equipped with advanced batching plants, with individual capacities ranging up to 330 m<sup>3</sup>/hr, enabling the company to meet high-volume demands efficiently.

In 2014, the company expanded into asphalt production through its state-of-the-art plants in Ashulia and Rupgonj. In addition to concrete and asphalt, NDE RMC utilizes a large fleet of transit mixers, concrete pumps, and other heavy machinery to ensure consistent quality and timely delivery.

With over 2,400 employees—including engineers, technical staff, and support personnel—NDE Ready Mix Concrete Ltd. is committed to delivering engineering excellence and sustainable construction solutions throughout Bangladesh.

**Product-related or management system-related certifications:** As a **draft EPD** and no formal certifications (like ISO 9001 or ISO 14001) have been obtained yet

**Name and location of production site(s):** NDE Ready Mix Concrete Ltd., Ashulia Batching Plant Ashulia, Savar, Dhaka, Bangladesh

## Product information

**Product name:** NDE Ready Mix Concrete – 3000 psi (20.7 MPa) Mix

**Density (kg/m<sup>3</sup>):** 2409

**Product identification:**

Concrete mix designed and batched by NDE Ready Mix Concrete Ltd. using the ACI method. Conforms to ASTM C94/C94M for ready-mixed concrete. Compressive strength: 3000 psi (20.69 MPa) at 28 days. Nominal maximum aggregate size: 20 mm.

Product Category	Product performance and application
<b>3000 psi (20.69 MPa) Ready-Mix Concrete (NDE Ashulia Plant)</b>	<p>This general-purpose concrete is suitable for a wide range of applications, including foundations, slabs, beams, columns, and pavements in residential and commercial buildings. Designed using the ACI method, it offers balanced workability and strength, making it ideal for conventional and pump placements. The mix achieves its target strength of 3000 psi at 28 days with a water-cement ratio of 0.468. Admixtures such as Auramix-200 enhance workability while maintaining slump retention (160±25 mm at plant, 100±25 mm at site).</p>

**Geographical scope:** Bangladesh

**UN CPC code:** 375 Articles of concrete, cement, and plaster

## LCA information

**Functional unit / declared unit:** 1 m<sup>3</sup> average ready-mix concrete.

**Reference service life:** 50 years

**Time representativeness:** 2025

**Database(s) and LCA software used:** OpenLCA v1.11 and Ecoinvent database (v.3.9.1).

**Description of system boundaries:**

Cradle to gate (Modules A1–A3). This EPD includes raw material extraction (A1), transport to the batching plant (A2), and manufacturing processes (A3). These modules are excluded in accordance with the Type D EPD definition per PCR 2019:14.

**System diagram:**

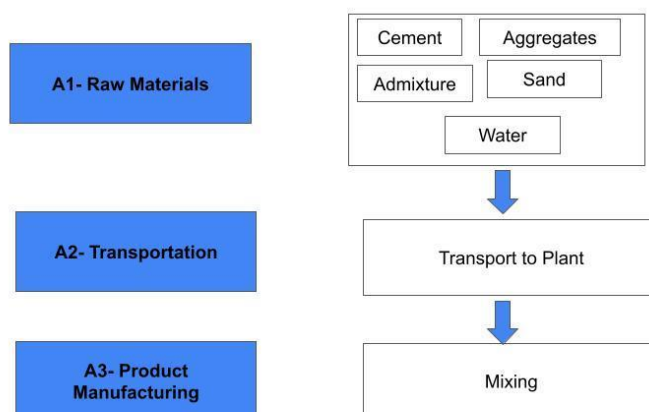


Figure: System Boundary for LCA Study

## Modules A1-A3 Manufacturing

**Raw Material Extraction (A1):** Data on the sourcing of cement, aggregates, sand, and admixtures were collected directly from NDE's procurement records. For instance, the aggregates are sourced from Sylhet, and cement is procured from local suppliers in Dhaka.

**Transportation (A2):** Transportation data was gathered for all raw materials, detailing modes of transport, distances traveled, and fuel types used. The survey revealed the use of bulk carriers, lighter vessels, and trucks, with transportation distances varying significantly (e.g., stone aggregates transported over 7,000 km from Dubai to Chittagong Port).

**Manufacturing (A3):** The data collected covered energy consumption (electricity and diesel), water usage, and emissions during the concrete mixing. Observations of batching operations and equipment use were documented to assess their environmental impacts.

Modules declared, geographical scope, share of specific data (in GWP-GHG results) and data variation (in GWP-GHG results): (X= Declared Module; MND = Module not declared)

	Product stage			Construction process stage		Use stage							End of life stage				Resource recovery stage
	Raw material supply	Transport	Manufacturing	Transport	Construction installation	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction demolition	Transport	Waste processing	Disposal	Reuse-Recovery-Recycling-potential
Module	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
Modules declared	X	X	X	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND

## Content information for reference product - 1 m<sup>3</sup> of Ready-Mix Concrete

Product components	Weight, %	Post-consumer material, weight-%	Biogenic material, weight-% and kg C/functional or declared unit
Portland cement	14.90%	0	0
Water	7.00%	0	0
20 mm stone	36.00%	0	0
12 mm stone	9.00%	0	0
Sand	32.10%	0	0
Admixture	0.15%	0	0
Packaging materials	Weight, kg	Weight-% (versus the product)	Weight biogenic carbon, kg C/functional or declared unit
None (delivered by mixer truck)	0	0	0
<b>TOTAL</b>	<b>0</b>	<b>0</b>	<b>0</b>

Dangerous substances from the candidate list of SVHC for Authorisation	EC No.	CAS No.	Weight-% per functional or declared unit
No Presence in the product	ND	ND	0

## Mandatory impact category indicators according to EN 15804

Indicator	A1-A3 (Total)	Unit
Global Warming Potential, total	470	kg CO <sub>2</sub> eq.
Global Warming Potential, fossil fuels	460	kg CO <sub>2</sub> eq.
Global Warming Potential, biogenic	0.11	kg CO <sub>2</sub> eq.
Global Warming Potential, land use and land use change	0.18	kg CO <sub>2</sub> eq.
Depletion potential of the stratospheric ozone layer	0.0000079	kg CFC 11 eq.
Acidification potential, Accumulated Exceedance	3.0	mol H+ eq.
Eutrophication potential, fraction of nutrients reaching freshwater end compartment	0.077	kg P eq.
Eutrophication potential, fraction of nutrients reaching marine end compartment	0.47	kg N eq.
Eutrophication potential, Accumulated Exceedance	7.8	mol N eq.
Formation potential of tropospheric ozone	2.1	kg NMVOC eq.
Abiotic depletion potential for non- fossil resources	0.00038	kg Sb eq.
Abiotic depletion potential for fossil resources potential	3600	MJ, net calorific value
Water (user) deprivation potential, deprivation-weighted water consumption	49	m <sup>3</sup> world eq. deprived

## Additional environmental impact indicators

Indicator	A1-A3 (Total)	Unit
Global Warming Potential, GHG	470	kg CO <sub>2</sub> eq.
Environment: Human toxicity (carcinogenic)   HTC	1.2E-07	CTUh
Environment: Human toxicity (non-carcinogenic)   HTNC	3.2E-06	CTUh
Environment: Ionising radiation (human health)   IRH	3.6	kBq U235 eq
Environment: Land use and land use change   LULUC	2600	dimensionless
Environment: Particulate matter formation   PMF	1.0E-05	disease incidence
Environment: Human toxicity (carcinogenic)   HTC	1.2E-07	CTUh

## Parameters describing resource use

Indicator	A1-A3 (Total)	Unit
Primary energy: Non-renewable (energy use)   PENRE	3200	MJ (PENRE)
Primary energy: Non-renewable (material use)   PENRM	200	MJ (PENRM)
Primary energy: Non-renewable (total)   PENRT	3400	MJ (PENRT)
Primary energy: Renewable (energy use)   PERE	105	MJ (PERE)
Primary energy: Renewable (material use)   PERM	0	MJ (PERM)
Primary energy: Renewable (total)   PERT	106	MJ (PERT)
Resource: Net use of fresh water   FW	1.25	m <sup>3</sup> (FW)
Resource: Non-renewable secondary fuels   NRSF	0.90	MJ (NRSF)
Resource: Renewable secondary fuels   RSF	0.40	MJ (RSF)
Resource: Secondary materials   SM	2.9	kg (SM)

### Other environmental information describing waste categories

Indicator	A1-A3 (Total)	Unit
<b>Hazardous waste disposed</b>	0.00	kg
<b>Non-hazardous waste disposed</b>	0.00	kg
<b>Radioactive waste disposed</b>	0.00	kg

### Environmental information describing output flows

Indicator	A1-A3 (Total)	Unit
<b>Components for re-use</b>	0.00	kg
<b>Materials for recycling</b>	1.83	kg
<b>Materials for energy recovery</b>	0.00	kg
<b>Exported energy</b>	0.00	MJ per energy carrier

Note: All environmental impact results are rounded to two significant figures. These results are derived using LCI data from the Ecoinvent database (v3.9.1) accessed under academic license terms. Redistribution of full-resolution data is restricted. Users should consult the original database for verified values if conducting official assessments or publications.

### Differences versus previous versions

This is the first draft EPD version – No previous versions.

## References

- GPI v.4.0:2021-03-29 General Program Instructions of the International EPD® System
- PCR 2019:14 v.1.3.2 Product Category rules | Construction products | The International EPD® System
- EN 15804:2012+A2:2019/AC:2021 Sustainability of construction works - Environmental Product Declarations -  
Core rules for the product category of construction products
- ISO 14025:2006 Environmental labels and declarations - Type III environmental declarations - Principles and procedures
- ISO 14040:2006 Environmental management - Life Cycle Assessment - Principles and framework
- ISO 14044:2006 Environmental management - Life Cycle Assessment - Requirements and guidelines
- OpenLCA Tool OpenLCA Model Manual, (n.d.). [https://greendelta.github.io/openLCA2-manual/introduction/openLCA\\_now.html](https://greendelta.github.io/openLCA2-manual/introduction/openLCA_now.html).
- *General Programme Instructions and Templates | EPD International.* (n.d.). Retrieved June 12, 2025, from <https://environdec.com/resources/documentation#epddevelopmentandverificationtemplates>

EXAMPLE ONLY

## Appendix 2

# EPD Roadmap for Bangladesh

This document presents a roadmap for Environmental Product Declarations (EPDs) specifically designed for the context of Bangladesh. EPDs are essential for promoting low-carbon construction and are becoming increasingly important for transparent procurement and sustainable development. This roadmap provides a practical and accessible method for developing countries to implement EPDs, utilizing localized data, simplified tools, and international standards to support the entire industry.



# ENVIRONMENTAL PRODUCT DECLARATIONS for Ready-Mix Concrete

*A Framework for Advancing Low-Carbon Construction in  
Developing Countries*

A Case Study from Bangladesh



NDE READY MIX CONCRETE (IMAGE CREDIT: NDE)

## Content

1. Introduction
2. What is an EPD?
3. Why are EPDs important for Bangladesh?
4. LCA and PCRs
5. Program Operators, EPD Systems & Databases
6. Roles of Verification Bodies and Program Operators
7. Tools for EPD Development
8. Conventional EPD Framework
9. Recommended EPD Roadmap for Bangladesh



BANGLADESH NATIONAL PARLIAMENT HOUSE (IMAGE CREDIT: CEMAL EMDEN)

# 1. Introduction

As Bangladesh experiences rapid urbanization and infrastructure growth, the environmental burden from construction materials, particularly concrete, is increasing. Concrete's widespread use and its high embodied carbon make it a critical focus for climate action. This roadmap provides a national framework for implementing Environmental Product Declarations (EPDs) for ready-mix concrete in Bangladesh. It outlines the technical, institutional, and policy steps necessary to support transparent environmental reporting and low-carbon procurement.

**Summary:**

This document outlines a roadmap for Environmental Product Declarations (EPDs) tailored to the context of Bangladesh. EPDs play a critical role in enabling low-carbon construction and are increasingly important for transparent procurement and sustainable development. This roadmap offers a practical and accessible approach for developing countries to implement EPDs, using localized data, simplified tools, and international standards to support industry-wide adoption.





### 3. Why are EPDs important for Bangladesh?

The publishing of a third-party verified EPD is a transformative step for Bangladesh's construction industry, enabling robust, transparent, and science-based environmental accountability.

In a country facing climate vulnerability, rising emissions, and rapid urban growth, EPDs offer a credible pathway to align infrastructure development with sustainable, low-carbon goals.

**Climate Action:** Cement contributes 8–9% of global CO<sub>2</sub> emissions. EPDs foster transparency, enabling stakeholders to make emissions-conscious choices.

**Sustainable Procurement:** EPDs support growing public and private demand for verified low-carbon materials, guiding greener procurement policies.

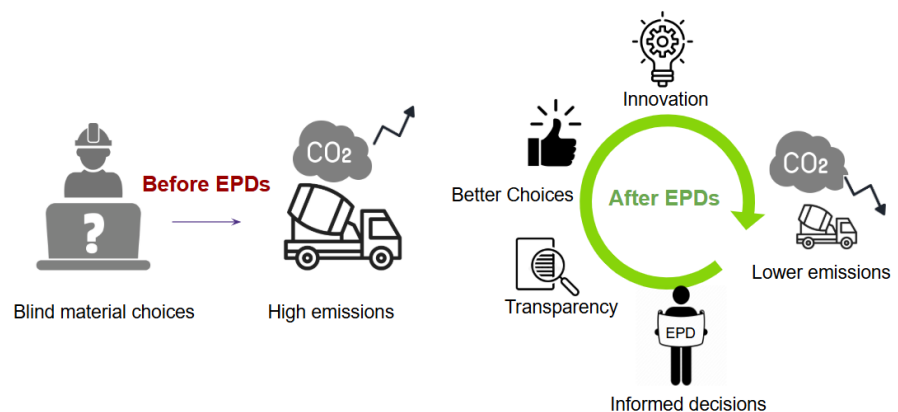
**Market Access:** Verified EPDs position Bangladeshi manufacturers to compete in global green building markets and meet certification requirements like LEED or EDGE.

**Design Optimization:** Architects and engineers can use EPD data to evaluate material options and optimize for embodied carbon from the early design phase.

**Informed Decisions:** EPDs replace blind material choices with data-backed insights, leading to more sustainable decisions.

**Transparency & Accountability:** Verified EPDs increase visibility of carbon impacts across the supply chain, enabling consistent monitoring and improvement.

**Innovation Driver:** Public access to environmental data motivates manufacturers to develop lower-carbon alternatives and innovate to stay competitive.



## 4. LCA and PCRs

### Standards

#### Example:

##### ISO 14040:

Principles and framework for conducting LCA

##### ISO 14044:

Requirements and guidelines for LCA methodology

##### ISO 14025:

Guidelines for creating **Type III environmental declarations**, such as EPDs

A Life Cycle Assessment (LCA) evaluates the environmental impacts associated with all stages of a product's life—from raw material extraction and manufacturing to transport, use, and end-of-life. It quantifies impacts like energy consumption, greenhouse gas emissions, and resource depletion, helping decision-makers choose more sustainable materials and processes. To ensure consistency and comparability, LCA for EPDs is conducted in accordance with **Product Category Rules (PCRs)**. PCRs define how LCAs should be carried out for specific product types and set requirements including:

- **System Boundaries:** Identifying which life cycle stages and processes (e.g., raw material supply, manufacturing, transport) should be included

- **Declared or Functional Unit:** Specifying the quantity or function that serves as the basis for assessment (e.g., 1 m<sup>3</sup> of concrete)

- **Use Phase and End-of-Life Scenarios:** Describing expected service life, disposal, and recycling options

- **Impact Categories:** Determining what types of environmental impacts must be reported (e.g., Global Warming Potential, acidification)

## 5. Program Operators, EPD Systems & Databases

### Program Operators

Example:

Europe:



THE INTERNATIONAL EPD® SYSTEM

GlobalEPD

A VERIFIED ENVIRONMENTAL DECLARATION

North America:



ASTM INTERNATIONAL



NATIONAL READY MIXED  
CONCRETE ASSOCIATION

A **program operator** is the organization responsible for overseeing the development, verification, and publication of Environmental Product Declarations (EPDs). This can include companies, industry associations, government agencies, or independent scientific bodies. Program operators play a critical role in ensuring the credibility and standardization of EPDs.

They are responsible for:

- Verifying the accuracy and compliance of the EPD
- Managing the platform on which the EPD is published
- Developing Product Category Rules (PCRs)
- Administering General Program Instructions (GPIs) that guide the EPD process

Program operators may function nationally or internationally, and manufacturers are not limited to working with an operator from their own country. The most important criterion is ensuring that the selected program operator aligns with the target market and complies with relevant standards

## 6. Roles of Verification Bodies and Program Operators

While Bangladesh does not yet have a national EPD program operator, the following steps can be considered:

- **Short-term:** Use of recognized international program operators for EPD verification and publication.
- **Mid-term:** Designation of a regional partner to support Bangladeshi manufacturers.
- **Long-term:** Establishment of a local program operator affiliated with BSTI\*, BUET\*, or a public-private entity.

Verifiers should be trained and certified to review LCA models, EPD documents, and background data.

BSTI- Bangladesh Standards and Testing Institution

BUET- Bangladesh University of Engineering and Technology

## 7. Tools for EPD Development

### Spreadsheet Calculator

A customized, open-access **Spreadsheet Calculator** was developed to support ready-mix concrete manufacturers in Bangladesh by offering a simplified, transparent, and regionally adapted tool for conducting cradle-to-gate environmental impact assessments. Designed to overcome barriers related to software cost and technical expertise, the tool aligns with EN 15804+A2 standards and accommodates both placeholder (dummy) impact factors. A calculator with specific data could be developed under license from Ecoinvent or through the development of regionally specific datasets for emissions related to electricity and fuel use, and relevant manufacturing processes such as aggregate production, etc.

**Accessibility:** Free and openly available for download and use

**Customization:** Inputs can be tailored to plant-specific data, transport distances, and mix designs

**Educational Value:** Ideal for capacity-building and initial training on EPD methodology

➔ [Spreadsheet Calculator link](#)

This calculator serves as a foundational resource for Bangladeshi producers to begin quantifying environmental impacts and preparing EPDs without the need for advanced LCA software.

## 8. Conventional EPD Framework

### 1. Find or Develop Product Category Rules (PCR)

The process begins by identifying the applicable Product Category Rules (PCR). These documents define the rules, requirements, and guidelines for conducting a Life Cycle Assessment (LCA) and reporting the results for a specific product category—such as ready-mix concrete.

### 2. Conduct Life Cycle Assessment (LCA)

An LCA is carried out to quantify the environmental impacts of the product from cradle to gate (or beyond). This step involves collecting primary and secondary data on materials, transport, energy use, and emissions, and modeling them using a recognized method such as ISO 14040/14044. In this thesis, three different tools—OpenLCA, POD|LCA, and a spreadsheet calculator—were applied to perform LCA for a typical Bangladeshi concrete mix.

### 3. Prepare the Background Report

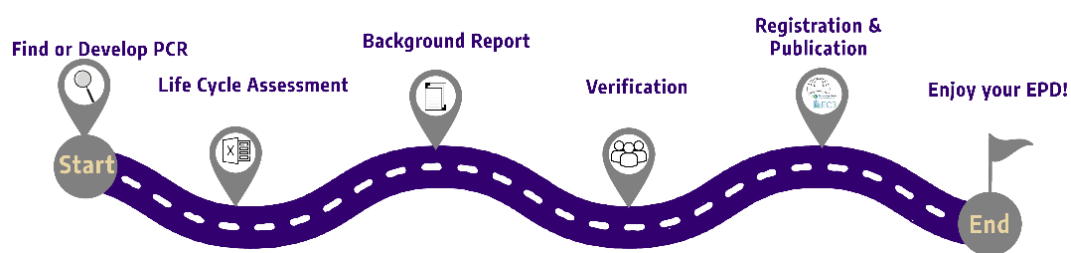
The background report documents the entire LCA process, including data sources, modeling assumptions, impact categories, and system boundaries. It serves as the technical foundation for verification and supports the credibility of the published EPD. It must be detailed and transparent enough to allow third-party reviewers to validate the results.

### 4. Verification (LCA & EPD)

Before an EPD can be published, it must undergo independent third-party verification. The verifier ensures that the LCA and background report comply with the selected PCR and international standards such as ISO 14025. Verification adds credibility and integrity to the EPD.

### 5. Registration & Publication

After verification, the EPD is submitted to a program operator, who reviews, registers, and publishes it on an official platform. Examples of recognized program operators include The International EPD System, the National Ready Mixed Concrete Association (U.S. with global reach) and regional bodies under the Eco Platform.



EPD Roadmap

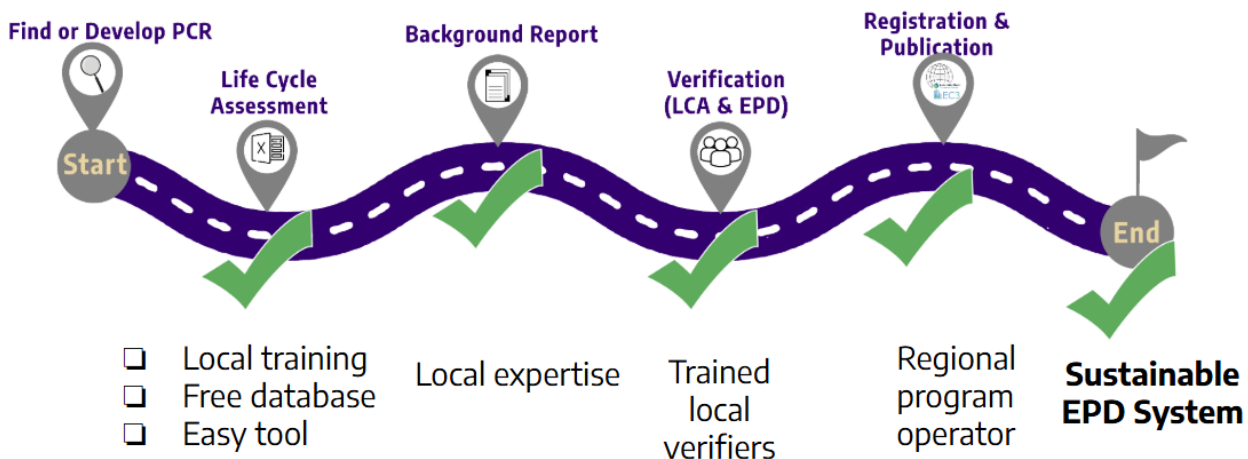
## 9. Recommended EPD Roadmap for Bangladesh

To overcome barriers and enable localized EPD development, a tailored roadmap for Bangladesh is proposed. This framework follows the conventional EPD process but adapts each phase to regional capacity and context:

- 1. Find or Develop PCR**  
Build capacity through local training initiatives and adopt open-access or existing international PCRs to reduce entry barriers.
- 2. Life Cycle Assessment (LCA)**  
Promote free or low-cost tools (e.g., spreadsheet calculators) and accessible databases to support LCA modeling, particularly for small manufacturers.
- 3. Prepare Background Report**  
Develop local expertise to ensure that background documentation is complete, transparent, and verifiable.
- 4. Verification (LCA & EPD)**  
Train independent local verifiers to reduce dependency on international experts and lower the cost of verification.
- 5. Registration & Publication**  
Establish or collaborate with a regional program operator to facilitate the official registration and publication of EPDs.

This localized roadmap lays the foundation for a sustainable EPD system in Bangladesh—one that is accessible, affordable, and aligned with national climate and construction priorities.

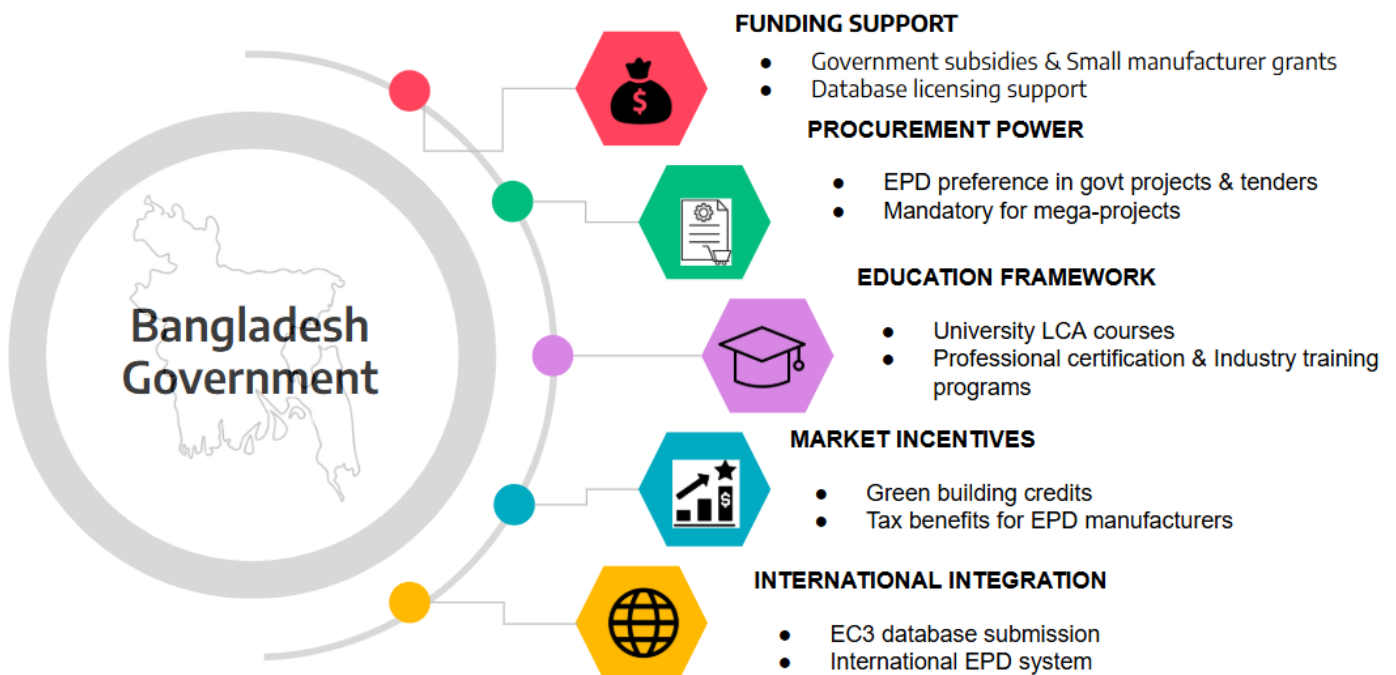
### THE EPD ROADMAP: Solution for Bangladesh



## 10. Policy Recommendations

To enable wide-scale EPD adoption, the following actions can be followed:

- **Training & Education**
  - Integrate LCA and EPD training into university curricula and professional development programs
  - Certify local verifiers and LCA practitioners
- **Incentives**
  - Provide tax benefits or green credits for verified EPDs
  - Prioritize EPD-backed materials in government tenders and mega-projects
- **Financial Support**
  - Offer grants or subsidies for SME (Small and Medium-sized Enterprises) manufacturers to cover verification and data costs
  - Fund national database and tool development
- **Institutional Development**
  - Develop a national EPD registry
  - Establish a formal program operator under the Ministry of Environment or BSTI



## 11. The Vision Forward

This roadmap aims to transform Bangladesh into a regional leader in life cycle transparency for construction. By enabling cost-effective EPD development, building institutional capacity, and embedding environmental performance into public procurement, Bangladesh can unlock a pathway toward sustainable infrastructure and climate resilience.

