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Life Cycle Assessment of *Dachi Appa*: A Traditional Nepali Veneer Brick

By
Diraj Thapa

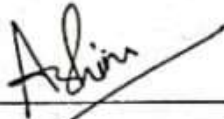
A THESIS
SUBMITTED TO DEPARTMENT OF ARCHITECTURE,
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF MASTER OF SCIENCE IN
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DEPARTMENT OF ARCHITECTURE
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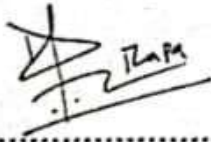


DECLARATION

I hereby declare that the thesis titled “*Life Cycle Assessment of Dachi Appa: A Traditional Nepali Veneer Brick*”, submitted to the Department of Architecture, Institute of Engineering, Pulchowk Campus, in partial fulfillment of the requirements for the degree of Master of Science in Energy-Efficient Building, is a record of original work carried out under the guidance of Associate Professor Dr. Sanjaya Uprety, Institute of Engineering, Pulchowk Campus.

This thesis includes only the work that I have personally conducted, except for referenced and acknowledged materials that were consulted during the course of this research.

I affirm that this thesis has not been submitted to any other institution for the award of any other degree.

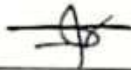


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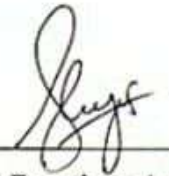


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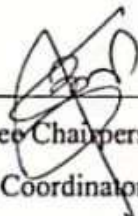
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ABSTRACT

The thesis investigates the life cycle assessment (LCA) of *Dachi Appa*, a traditional veneer brick central to Nepalese heritage architecture, to understand its environmental impact and explore ways to improve its sustainability. The study analyzes the lifecycle of *Dachi Appa* in four phases: cradle-to-gate, transportation, usage, and end-of-life, emphasizing its cultural importance and environmental challenges.

The results reveal that the embodied carbon emission of each *Dachi Appa* brick is 0.65 kgCO₂-eq with distance from factory to site and site to landfill assumed to be 1km. Cradle-to-gate phase accounts for 82.46% of the total carbon footprint of *Dachi Appa*, with the firing process being the most significant contributor due to the use of coal. During the usage phase, the small size and seamless front-face design of *Dachi Appa* require 58.8% more bricks per square meter compared to regular bricks with mortar, leading to higher emissions in this stage.

Scenario analysis shows that replacing coal with wood pellets during the production phase can reduce the overall carbon footprint of *Dachi Appa* by up to 42.9%, making it less emissive than walls built with regular bricks and finishes like plaster or tiles. Furthermore, the end-of-life phase demonstrates the material's environmental advantages, as *Dachi Appa* is durable and often reusable, contributing to reduced waste.

These findings suggest that while *Dachi Appa* has a higher carbon footprint in its current form, optimizing its production and construction practices can make it a sustainable option. By adopting these improvements, *Dachi Appa* can continue to preserve Nepal's cultural heritage while aligning with global sustainability goals.

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Sincerely,

DIRAJ THAPA (079MSEEB008)

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List of Abbreviations

CE- Common Era

CO₂- Carbon Dioxide

DOA- Department of Archeology

DUDBC- Department of Urban Development and Building Construction

EC- Embodied Carbon

GHG- Green House Gases

IOE- Institute of Engineering

ISO- International Organization for Standardization

LCA- Life Cycle Assessment

LCI- Life Cycle Inventory

LCIA- Life Cycle Impact Assessment

OC- Operational Carbon

SDG- Sustainable Development Goal

TU- Tribhuvan University

UHI- Urban Heat Island

UN- United Nation

UNEP- United Nation Environment Program

UNESCO- United Nation Educational, Scientific and Cultural Organization

WLC- Whole Life Carbon

1. INTRODUCTION

1.1 Background

Construction of building is an energy intensive process with significant energy consumption occurring at each stage of the building's lifecycle (Dakwale et al., 2011). The United Nations Environment Program (UNEP) Global Status Report for Buildings and Construction 2024 reported that building and construction sector accounts for 21% of global greenhouse gas emission where in 2022 building were responsible for around 34% of global energy demand and 37% of energy and process-related carbon dioxide (CO₂) emission (UNEP, 2024). The excessive emissions of greenhouse gases have caused significant damage to the economies and societies of various countries, making the tightening of carbon emissions a shared developmental imperative for nations worldwide (Bolea et al., 2020). The impact of buildings on environment has become a pertinent issue and a number of studies have been conducted devising different analysis tools to assess the impacts and explored the ways to reduce the energy consumption and environmental impacts (Singh et al., 2011). Recent research relating to energy use and carbon emissions by buildings has started to move from operational energy carbon impacts to the embodied energy/carbon impacts of buildings, and the methods and approaches used in architectural design to reduce embodied carbon have become more prominent (Arslan et al., 2023).

1.1.1 Brief History of Kathmandu Valley

The history of the Kathmandu valley is mark by rich cultural, architectural and social developments, primarily influenced by the Newar civilization, whose roots trace back to the Licchavi period in the 5th century CE. This valley has been a significant centre for trade, religion, and culture, with various architectural styles and inscriptions that reflects socio-political structure and cultural practices of the time (Parajuli, 2024). Malla period between 12th and 18th centuries were instrumental in construction of temples and palaces, enhancing the valley's architectural landscape with intricate wood work and stone carvings, particularly in Bhaktapur and Patan (Hutt, 1994; Tobias, 1983). The use of traditional bricks like *Dachi Appa*, a veneer brick and *ma Appa*, an structural brick in buildings, temple and monuments also originated in this period (Bonapace & Sestini, 2003; Shrestha, 1981).

The urban landscapes reflect a complex interaction of celestial beliefs and architectural styles, with significant transformations occurring over centuries (Gutschow, 2014). While the Kathmandu valley's heritage is shaped predominantly by its religious architecture and cultural practices, it is also important to consider the impact of modern developments and globalization, which pose challenges to the preservation of this rich historical legacy.

1.1.2 Climate and Climate Change

The elevation of the Kathmandu Valley ranges from approximately 1,200 meters (3,937 feet) to 1,600 meters (5,249 feet) above sea level. The valley climate varies from alpine in the northern part to sub-tropical in the riverbanks of the southern part (Lamichhane et al., 2020). The season vary between dry winter and warm summer with mean annual temperature between 16-20 °C and mean annual precipitation of 1200-1400 mm (Karki et al., 2016).

Climate change in the Kathmandu Valley is characterize by significant temperature increases, altered precipitation patterns, and urbanization impacts. The valley has experienced a rise in both minimum and maximum temperatures, with projections indicating further increases by 0.66°C to 1.21°C by 2050, depending on greenhouse gas scenarios (Lamichhane et al., 2020). Additionally, rainfall trends show an increase during monsoon and winter seasons, while pre-monsoon and post-monsoon periods experience declines (Acharyaa & Devkota, 2023). Urbanization has exacerbated these changes, transforming the valley into an Urban Heat Island (UHI), with built-up areas expanding by 30.7% and green space density declining from 35.59% to 29.17% (Pantha et al., 2024)

1.1.3 Urban Growth and Valley Population

The rate of urban growth in Nepal is significantly high. The 1952/054 census reveals that 2.9 percent population resides in 10 urban areas. After 50 years in 2001, urban population reached up to 13.9% with 6.65 percent urban growth rate during the year. Political decision and reclassification of urban areas increased urban population 27.2% by the year 2014; and 66.2% by the year 2021 with 293 urban area (Joshi, 2023; National Statistics Office, 2021). The built-up area in Kathmandu valley has amplified intensely from 41 km² in 1965 to 177km² in 2018 and is predicted to reach 352 km² by 2050 (Mesta et al., 2022).

According to census report of 2021, Kathmandu district, capital of Nepal and a prime portion of Kathmandu valley has the highest population of 2,041,587 with population density of 5169 people/km² (National Statistics Office, 2021). Though the Newari community has been predominant, the valley is home for at least 67 distinct caste and ethnic groups showcasing a complex social structure (Subedi, 2010). Rapid urban growth in the Kathmandu Valley has significantly threatened its cultural heritage, particularly through the transformation of traditional settlements and the encroachment on historical monuments. This urbanization has led to a disconnection from the valley's rich cultural identity, as modern developments often clash with the vernacular architecture that embodies local traditions (KC et al., 2020). The focus for preservation of endangered tangible heritage (e.g. temples, monuments) and intangible heritage (e.g. rituals, festivals) are vital for cultural continuity (Maharjan & Barata, 2017).

1.1.4 Vernacular Architecture of Kathmandu Valley

Vernacular architecture in Nepal is a reflection of the country's diverse geography, climate, and cultural heritage. It is characterized by the use of locally available materials such as timber, stone, mud, and brick, which are carefully selected based on the region's natural resources. In the hilly region stones and slate are available along with dense vegetation making availability of stone, slate and timber for construction, the mountain region has plentiful possessions of stone and mud with some pine forest, while in the Terai region, mud, bamboo, and thatch are more commonly used to adapt to the warmer climate (Bodach et al., 2014).

The vernacular architecture of the Kathmandu Valley is a unique expression of the region's cultural, historical, and environmental context. This architectural style is primarily characterized using local materials and traditional building techniques, resulting in structures that are not only functional but also aesthetically rich and culturally significant. The Kathmandu Valley's vernacular buildings are deeply influenced by the Newar community, who have inhabited the valley for centuries. The architecture in the valley emphasizes sustainability using local materials and passive design strategies, which enhance thermal comfort and environmental responsiveness (Kandel et al., 2024).

Materials and Construction

Traditional buildings in the Kathmandu Valley are predominantly constructed using locally sourced materials such as brick, timber, stone, and clay. The region's abundant supply of fired brick makes it the primary building material for many structures. The valley is famous for its Newar-style buildings, which feature intricately carved wooden windows, tiered pagoda roofs, and the extensive use of *Dachi Appa* as a face of wall. These buildings often include courtyards, which serve as social spaces and help in ventilation. Timber, often sourced from local forests, is used for structural components like beams, columns, and windows, as well as for intricate carvings (Maharjan & Dongol, 2024). Stone is frequently used in foundations, pathways, and temples, given its durability and availability in the surrounding hills (Hutt, 1994).

Building Typology

Kathmandu Valley's vernacular architecture includes a variety of building typologies, from private residences to temples and public buildings. One of the most iconic elements of Newar architecture is the "*courtyard house*" or "*chhetrapati*" house, which often features a central open courtyard surrounded by living spaces. The design of these houses not only enhances social connectivity but also provides thermal comfort and natural ventilation, making them suitable for the local climate (Sthapak & Bandyopadhyay, 2014).

In the urban core of Kathmandu, one finds the *pagoda-style* architecture, with tiered, multi-roofed structures, often seen in temples and palaces. The pagoda roof is an architectural hallmark of Nepal and is characterized by its upward-curved eaves. This style of architecture has both religious and pragmatic significance, as it allows for better air circulation and rainwater runoff.

Modern Day

Today, while the traditional architecture of the Kathmandu Valley continues to influence new construction, modern development has introduced new materials and building techniques. There is growing interest in preserving the valley's architectural heritage, especially in the wake of the 2015 earthquake, which damaged many of the historic structures. Efforts to restore and protect these buildings are ongoing, with a focus on preserving the valley's architectural uniqueness while integrating modern sustainability practices.

1.1.5 Dachi Aapa and its cultural significance

Dachi Appa is a traditional Nepali brick, characterized by its darker red colour and glossy finish, making it ideal for use as veneer bricks. These bricks are specially fire at very high temperatures to achieve their unique appearance and durability. The brick is available in size of 8”x4”x2” and has a unique trapezoidal shape with perfect rectangular front while side tapers with the width. It is to create smallest possible gap between the bricks for façade with no mortar peeking through the join of the bricks. Traditionally *silay*; a mortar made up of pine resin, mixed with vermilion, were use to make it to match with tone of brick. Currently, cement mortar are used and yellow mud and water are used for pointing brick façade. (Bonapace & Sestini, 2003; Pandé, February 18, 2018)



Figure 1. Close view of *Dachi Appa* wall (Pandé, February 18, 2018)

The process of making *Dachi Appa* begins with the excavation and collection of black clay, which is then transport to the worksite. Traditionally, the bricks were made by mixing clay and water manually using hands and feet. However, this process has now been modernised, with machines being use for mixing. The clay mixture is place into moulds to create the initial rough shape of the brick. The definitive shape is achieved by remoulding the brick using a special pestle. To create a fair-faced surface, additional treatments are carried out. First, the brick is struck with a wooden fillet, then smoothed with a metal knife, and finally

left to sun-dry under mild sunlight for 2–3 weeks. Once dried, the fair-faced surface of the brick is immersed in a semi-liquid red clay mixture. The earth used for fabricating the bricks consists of 37% quartz, 6% feldspar, and 57% clay minerals, while the red earth used for colouring the fair-faced surface comprises 21% quartz, 2% feldspar, and 77% clay minerals. (Bonapace & Sestini, 2003; Pandé, February 18, 2018)



Figure 2. Fair face of brick smoothed with a knife

The use of *Dachi Appa* reflects the rich architectural heritage of Nepal, highlighting the artisanry and local materials that define the region's identity. It has been used for centuries, contributing to the unique aesthetic of Nepali architecture, especially during the Malla Period, which emphasized intricate designs and artistic expression (Shrestha, 1981). The brick is not just a building material; it symbolizes the cultural identity of the Nepali people, representing their connection to history and tradition.

In traditional settings, *Dachi Appa* is prominently used in the construction of temples, palaces, courtyards, and boundary walls. For instance, structures like the Pachpanna Jhyale Durbar in Bhaktapur durbar square and the pagoda-style temples of Kathmandu Durbar Square prominently feature these bricks in their facades and decorative patterns, highlighting their aesthetic appeal and cultural significance. The reddish-brown color and smooth finish perfectly blend with carved wooden doors and windows.

Dachi Appa is also known for its strength and durability, making it suitable for both load-bearing and non-load bearing applications. Their low thermal conductivity provides insulation, keeping interiors cool in summer and warm in winter, making it suitable for the diverse climatic conditions of Nepal (Maharjan & Dongol, 2024). In contemporary architecture, the use of *Dachi Appa* extends to blending traditional and modern styles. Many architects incorporate these bricks into modern homes and commercial buildings to maintain cultural relevance while meeting present-day design standards. Dawarika's Hotel at battisputali, Kathmandu serves as a remarkable example, creating fusion of heritage and modernity.

Furthermore, *Dachi Appa* plays a vital role in the restoration and preservation of UNESCO World Heritage Sites in Nepal. During the post-earthquake restoration efforts, these bricks were extensively used to rebuild damaged heritage structures, maintaining authenticity and adhering to traditional building practices.

1.2 Problem Statement

1.2.1 General Problem: Limited LCA studies on traditional materials

The environmental implications of traditional construction materials like *Dachi Appa* are largely understudy. While the role of traditional materials in preserving cultural heritage is widely acknowledge, there is a significant gap in the LCA of these materials. Most LCA studies focus on modern construction materials, its application to traditional materials remains underexplored (Mazzetto, 2025). This knowledge gap restricts informed decision-making in promoting sustainable construction practices.

1.2.2 Specific Problem: Promotion of traditional materials without understanding environmental implications

Traditional materials, such as *Dachi Appa*, hold significant cultural and architectural value, particularly in preserving local heritage. Thus, government bodies, communities, and local initiatives promoted its usage. However, the environmental implications of its production, use, and disposal remain poorly understood. Without a scientific evaluation of its life cycle impacts, there is a risk of unknowingly exacerbating environmental degradation (e.g., emissions from kilns, energy consumption, and clay mining). Misguided policies

promoting *Dachi Appa* without addressing sustainability concerns could lead to negative ecological consequences.

1.2.3 Topic Significance: Balancing cultural identity and environmental sustainability

The preservation of cultural identity is essential in maintaining the architectural heritage of Nepal, particularly in UNESCO World Heritage sites like Bhaktapur and Patan. However, this preservation must align with global goals for environmental sustainability, such as the United Nations Sustainable Development Goals (SDGs) (UN, 2015). By conducting LCA of *Dachi Appa*, this study aims to bridge the gap between cultural preservation and environmental sustainability, ensuring that traditional materials are promoted responsibly. This research is critical for developing evidence-based policies that minimize environmental impacts while celebrating Nepal's architectural heritage.

1.3 Research Objectives

- To assess the environmental impacts of *Dachi Appa* using a cradle-to-grave LCA approach
- To identify key stages in the lifecycle of *Dachi Appa* that contributes significantly to environmental impacts
- To evaluate the potential for improving the sustainability of *Dachi Appa*

1.4 Scope and Limitations

1.4.1 Scope of the Study

The study focuses on assessing the environmental impacts associated with the life cycle of *Dachi Appa* from cradle to grave. The following boundaries and considerations define the scope:

1. **Functional Unit:** The environmental impacts are analysed for the life cycle of one *Dachi Appa* brick.
2. **System Boundaries:**
 - The study encompasses all life cycle stages, including raw material extraction, production, transportation, use, and disposal.

- The study is confined to a single factory for data collection on the manufacturing process.
3. **Data Source:** Data for the study is derived from field observations, articles and publications, user experiences, and consultations with field workers, factory workers, engineers, architects, and management staff.
4. **Data Applicability:**
- The scenarios and data used are based on the conditions prevailing at the time of the study.
 - Generalized data is used to describe the environmental impacts of energy consumption and transportation.
5. **Assumptions:**
- An average of 5% raw material wastage is assumed during the production of unburnt bricks.
 - A 35% wastage rate is assumed during the burning process, as per the factory's average wastage data.
 - Wastage rate of 1.5% during transportation and stacking inside factory and 2.5% during transportation to site is assumed, based on the experience and observation of drivers and workers that are involved in transportation work in factory.
 - The carbon emission factor for human labour, tile, sand, primer, weather coat paint and silicon paint are not localized to Nepal's conditions and is based on available global standards.
6. **Environmental Focus:**
- The study focuses on environmental impacts and does not consider social or economic dimensions.

1.4.2 Limitations of the Study

The following limitations are inherent to the study due to practical constraints:

1. **Factory-Specific Data:** The manufacturing process data is derived from a single factory and may not fully represent the variability in *Dachi Appa* production across different factories in Nepal.

2. **Provisional Quantitative Data:** Certain quantitative data are provisional and rely on observations, as well as the experience of related users, field workers, factory workers, and management staff.
3. **Generalized Environmental Impact Data:**
 - General datasets are used to estimate the environmental impacts of energy use and transportation, which may not fully account for Nepal's localized conditions.
 - The carbon emission factor for human labour, tile, sand, primer, weather coat paint and silicon paint are not adjusted for Nepal's specific context.
4. **Data on Wastage:** The wastage rates (5% for unburnt bricks and 35% during the burning process) are averages based on the factory's internal records, and they may not reflect broader industry trends.
5. **Excluded Impacts:**
 - The study is confined to the effects on the natural environment and does not account for social, cultural, or economic impacts.
 - The study does not include downstream impacts such as maintenance and reuse potential during the use phase.

By acknowledging these scope boundaries and limitations, the study aims to provide an accurate yet realistic assessment of the environmental impacts of *Dachi Appa* production. Future research can address these limitations by incorporating more localized and comprehensive data.

2. LITERATURE REVIEW

2.1 Overview on Life Cycle Assessment

With the exponential growth in development of cities and increasing demand for construction, which is one of the factors in environmental degradation, the need for CO₂ emissions control is essential (Jahandideh et al., 2020). Buildings have very long-life span and analysis of the life cycle energy use and greenhouse gas emission of a building is a very complex and multifaceted procedure, so it is necessary to understand both embodied and operational energy use and emission and their interlinkage with each other to account the more accurate picture of building's energy use and carbon emissions (Sturgis, 2017). Research by Fařara et al. indicates that 25-30% of CO₂ emissions generated by buildings originate from materials and their manufacturing while 70-75% emission during its operational stage but as the use of building is taken over a longer period of time, the emission at the production stage is fatal (Fařara et al., 2022). Hence, the importance of alternative materials with minimal environmental impact is growing year by year. Life Cycle Assessment (LCA) is a vital tool for evaluating the environmental impact and sustainability of materials. It achieves this by quantifying impacts and identifying trade-offs across the entire supply chain.

Lifecycle Assessment (LCA) is a systematic method for evaluating the environmental impacts associated with all stages of a product's life, from raw material extraction to disposal, often referred to as "cradle to grave." According to the International Organization for Standardization (ISO), "Life Cycle Assessment (LCA) is a technique for assessing the environmental aspects and potential impacts associated with a product, by compiling an inventory of relevant inputs and outputs of a product system, evaluating the potential environmental impacts associated with those inputs and outputs and interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study."(ISO, 1997) This approach enables decision-makers to identify opportunities for reducing environmental burdens and optimizing resource use. LCA emphasizes the need for choosing sustainable materials to reduce environmental impacts throughout a product's life cycle (Rodríguez et al., 2023). The method also supports circular economy principles

by identifying opportunities for reuse and recycling, thus minimizing resource consumption (Ledakowicz & Ziemińska-Stolarska, 2023).

Numerous studies and research efforts have been conducted using LCA, demonstrating its significant value and positive applications in various fields. These studies consistently highlight the versatility and importance of LCA in fostering sustainable practices across industries. The summary of the methodology used, and key findings of the different literature is presented in Table 1.

Table 1. Summary of Methodology and Key Findings of literature study

Title	Authors	Methodology	Key Findings
Normalising and assessing carbon emissions in the building sector: A review on the embodied CO2 emissions of residential buildings	(Chastas et al., 2018)	Review of 95 case studies of residential building, as an effort to identify the range of embodied carbon emissions.	The assessment identifies a range of embodied carbon emission between 179.3 kgCO ₂ e/m ² -1050 kgCO ₂ e/m ² (50-year building life span) that reflects a share between 9% and 80% to total lifecycle impact.

Title	Authors	Methodology	Key Findings
<p>GHG emissions and energy consumption of residential buildings—A systematic review and meta-analysis</p>	<p>(Fan & Fang, 2023)</p>	<p>A systematic review and meta-analysis of LCA studies on GHG emissions and energy consumptions in the pre use, use, and demolition stages of residential buildings.</p>	<p>Residential building emits about 2928 Kg GHG emission and consumes about 7430 kWh of energy per m² of gross building area on average throughout the lifecycle. Residential building has an average GHG emission of 84.81% in use phase, followed by pre use and demolition phase.</p>
<p>Modelling of energy consumption and carbon emission from the building construction sector in China, a process-based LCA approach</p>	<p>(Zhang et al., 2019)</p>	<p>Process-based LCA approach</p>	<p>Construction scale, building structure type and material production efficiency are the three important driving factors for energy consumption and emission.</p>

Title	Authors	Methodology	Key Findings
<p>A methodology towards delivery of net zero carbon building in hot arid climate with reference to low residential buildings—the western desert in Egypt</p>	<p>(Fouly & Abdin, 2022)</p>	<p>Experimental methodology for examining LCA for Net Zero Carbon Building (NZCB)</p>	<p>When both passive technique (replacement of conventional construction material) and active technique (application of solar panels) were applied on the experimental models, simulation result shows the reduction of 85% carbon emission through LCA as well as a reduction of 101% in energy consumption.</p>
<p>Setting baselines of the embodied, operational and whole life carbon emissions of the average Spanish residential building</p>	<p>(Izaola et al., 2023)</p>	<p>Scenario based LCA with changing window material, flooring material, and wall insulations</p>	<p>Average multifamily building apartment in Spain, with mean net floor area of 73.1 m², A Whole Life Carbon (WLC) baseline is 1944 kg CO₂e/m² with Embodied carbon of 30.8% (559 Kg CO₂e/m²) and operational carbon of 69.2% (1385 Kg CO₂e/m²) and different comparative scenario shows a reduction on WLC up to 63.4%.</p>

Title	Authors	Methodology	Key Findings
<p>Relationships between embodied, operational, and life cycle carbon in passive house multifamily residential buildings</p>	<p>(Williams, 2023)</p>	<p>Scenario based LCA with case of varying wall and roof assemblies</p>	<p>The material composition of the exterior envelope assemblies can have significant impact on the overall, cumulative carbon impact of a particular building. Moreover, there are clear scenarios in which operational energy efficiency should be sacrificed in favour of reducing upfront embodied carbon emissions, particularly when evaluated over critical time span</p>
<p>Life Cycle Assessment (LCA) and environmental comparison the selected construction methods of residential buildings in traditional and straw cubes technology-a case study</p>	<p>(Fafara et al., 2022)</p>	<p>Scenario based LCA comparing ceramic hollow bricks with different variants of straw bale.</p>	<p>The research indicates that 25-30% of CO₂ emission is generated by building from materials and their manufacturing process and 70-75% emission during operational stage. Despite, the high value of CO₂ in operation stage, the value can be attributed to the use over a longer period and the focus should be on ecofriendly alternative materials with minimal environment impacts.</p>

Title	Authors	Methodology	Key Findings
<p>Life cycle energy consumption and greenhouse gas emissions of urban residential buildings in Guangzhou city</p>	<p>(Zhan et al., 2018)</p>	<p>Hybrid life cycle assessment approach through statistical data collected from studied building and other national statistical data</p>	<p>The CO₂ emission of steel, concrete, bricks and cement together accounted for 76.69% of the total emissions which are related to building materials in preparation stage. The study also found that oil was the largest CO₂ (eq.) emission factor and electricity was the smallest.</p>

Title	Authors	Methodology	Key Findings
<p>Embodied energy and associated carbon emission of key building materials in Nepal</p>	<p>(KC et al., 2025)</p>	<p>LCA framework adopted from ISO 14040:2006 and ISO 14044:2006</p>	<p>The study shows that the production of one ton of cement accounts for 6051.07 MJ energy and emission of 739.49 kgCO₂-eq.; the production of 1000 pieces of standard size burnt brick from fixed chimney bull trench kiln accounts for 4124.56 MJ energy and 502.89 kgCO₂-eq. emission; and the production of one ton of reinforcement steel accounts for 26,033.14 MJ energy and 2565.5 kgCO₂-eq emission with major source of emission being coal. The result also indicates the emission factor of electricity mix of Nepal to be 4.54 kg CO₂-eq/KWh while that of coal, diesel, fuel oil, LPG and firewood to be 3.60 kgCO₂-eq/kg, 3.75 kgCO₂-eq/litre, 4.07 kgCO₂-eq/litre, 2.35 kgCO₂-eq/kg and 1.91 kgCO₂-eq/kg respectively.</p>

Title	Authors	Methodology	Key Findings
<p>Carbon footprint and embodied energy assessment of a civil works program in a residential estate of Western Australia</p>	<p>(Biswas, 2014)</p>	<p>“streamlined” LCA (SLCA) covering material extraction to operation stages for LCA of the building (considering 50 years life) following ISO14040–44 guidelines</p>	<p>The study assessed life cycle GHG emissions and embodied energy of Building 216 in Australia with gross area of 4020 m²., which accounted 14,229 tons CO₂-eq (3.54 tons/m²) and 172 TJ respectively. The ‘use stage’ generated 12,145 tons CO₂-eq and 150 TJ energy, representing about 85% of the total life cycle CO₂-eq emissions.</p>

Title	Authors	Methodology	Key Findings
<p>Life cycle assessment (LCA) in earth construction: a systematic literature review considering five construction techniques</p>	<p>(Arduin et al., 2022)</p>	<p>Systematic review of LCA of Adobe, Cob, Rammed Earth (RE), Compressed Earth Block (CEB), and Light Straw Clay construction.</p>	<p>For stabilized rammed earth wall with lime and cement, the values for A1–A5 go from around 20 kg CO₂-eq/m² to values around 80 CO₂-eq/m². The values for adobes wall are around 100 kg CO₂-eq/m². For CEBs its 20 kg CO₂-eq/m² of which 13.4 kg CO₂-eq/m² is related to raw materials extraction and production.</p> <p>The embodied energy at the product mass (kg), ranges from 0.029 to 0.7 MJ/kg for adobes, CEB, and RE; while at wall scale, from 45 to 395 MJ/m² for all techniques except adobes. Considering the building scale, adobe and CEB techniques presented embodied energy values from 770 to 1300 MJ/m².</p>

Title	Authors	Methodology	Key Findings
<p>Cradle-to-Site Carbon Emissions Assessment of Prefabricated Rebar Cages for High-Rise Buildings in China</p>	<p>(Jiang et al., 2018)</p>	<p>Cradle-to-site LCA approach</p>	<p>This paper investigates the cradle-to-site carbon emissions of Prefabricated Rebar Cage (PRC), and compares the results with those of conventional in-situ rebar construction methods for high-rise buildings. The result shows overall reduction of CO₂ emission by 1.24% by adopting PCR method for high-rise buildings.</p>

2.2 Literature Gaps Identified

From the review of existing literature on traditional materials and life cycle assessments (LCA), several significant gaps have been identified:

1. **Limited LCA Studies on Traditional Materials:** While traditional materials like *Dachi Appa* hold cultural and architectural significance, they have been largely overlooked in LCA studies. Most research focuses on modern materials such as cement and concrete, leaving a significant gap in understanding the environmental implications of traditional alternatives.
2. **Lack of Localized Data:** Existing studies often rely on generalized or international datasets that do not account for local factors, such as Nepal-specific production practices, energy sources, transportation methods, and workforce dynamics. This reliance on non-localized data undermines the accuracy of environmental assessments for *Dachi Appa*.
3. **Lack of Comparative Studies:** There is a dearth of studies that evaluate the relative environmental performance of *Dachi Appa* compared to modern construction materials. This gap hinders a holistic understanding of whether

traditional bricks can provide a sustainable alternative in the context of modern construction practices.

4. **Under exploration of Socio-Cultural and Economic Dimensions:** The role of traditional bricks like *Dachi Appa* in heritage preservation and their socio-cultural significance is not adequately explored in conjunction with environmental assessments. Integrating these aspects into LCA studies could provide a more comprehensive understanding of the material's value beyond its environmental footprint.

These gaps highlight the need for further research to provide localized, comparative, and interdisciplinary insights into the environmental, cultural, and economic implications of *Dachi Appa*.

2.3 Relevance of Literature to Research Topic

The review of existing literature is crucial in providing context and supporting the objectives of this research. The literature is relevant to the research topic for the following reasons:

1. **Foundational Understanding of Environmental Implications:** The literature lays the groundwork for understanding the environmental impacts associated with traditional building materials. It provides the necessary background to assess the life cycle environmental performance of *Dachi Appa*, which is essential for the goal of this research.
2. **Highlighting the Role of Embodied Energy:** A critical insight drawn from the literature is the emphasis on the role of embodied energy in determining the environmental performance of building materials. This concept is vital for evaluating the energy consumption throughout the life cycle of *Dachi Appa*, from raw material extraction to its disposal, which will form a key aspect of the life cycle assessment (LCA) in this research.
3. **Context-Specific Analysis of *Dachi Appa*'s Performance:** Existing studies reinforce the importance of analysing the performance of traditional materials like *Dachi Appa* in different contexts. The literature underscores the need to examine the material's production practices, environmental footprint, and sustainability

across varied production and usage conditions, which aligns with the research's objective to evaluate *Dachi Appa*'s overall performance.

4. **Contribution to Heritage Preservation and Sustainable Usage:** The literature highlights the intersection of environmental sustainability and cultural heritage preservation. This directly supports the research's aim to assess *Dachi Appa*'s environmental impacts while also contributing to its sustainable preservation and continued use in traditional and modern construction practices.

These points underscore the direct relevance of the reviewed literature to the research objectives and strengthen the rationale for conducting a life cycle assessment of *Dachi Appa*.

3. METHODOLOGY

3.1 Research Approach: Cradle-to-Grave LCA

The LCA involves the systematic analysis of product or system’s inputs, outputs, and potential environmental impacts associated across all stages of its lifecycle (López-Aguilar et al., 2016). This research involves a Cradle-to-grave LCA research approach aligning with ISO 14040-44 standards. Cradle-to-grave approach is a comprehensive method for assessing the environmental impact associated with all stage of product’s life cycle from raw material extraction (cradle) to the end-of-life disposal or recycling (grave). The methodology of this research involves four phases: Goal definition and scoping, inventory analysis, impact assessment and interpretation of results. The conceptual framework for LCA of *Dachi Appa* is shown in *figure 3*.

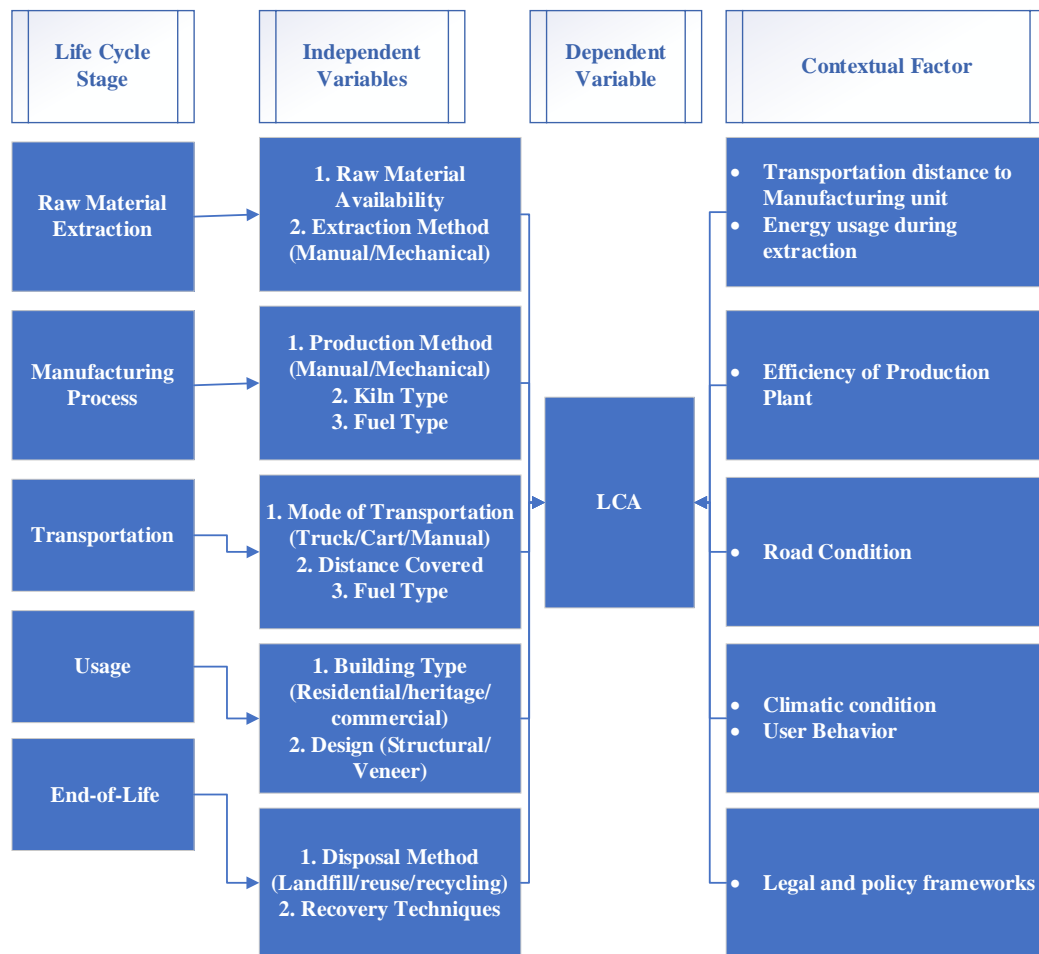


Figure 3. Conceptual framework for LCA of *Dachi Appa*

The framework has four key components: Life cycle stages, Independent Variables, Dependent variable and Contextual factors.

3.1.1 Life Cycle Stage

This component represents different phases of *Dachi Appa*'s life cycle, starting from raw material extraction to its end-of-life. The stage includes:

- **Raw Material Extraction:** It focuses on the sourcing of clay and other raw materials needed for production. This stage examines how materials are obtained and the energy required during extraction
- **Manufacturing Process:** It covers the brick-making process, including shaping, drying, firing in kilns and stacking them in the factory. This is often the most carbon-intensive phase.
- **Transportation:** It includes transportation of finished bricks from factory to construction sites.
- **Usage:** It explores how the bricks are utilized in building construction and their contribution to the overall carbon footprint.
- **End-of-Life:** It involves analyse the disposal, reuse, or recycling of the bricks after their service life.

3.1.2 Independent Variables

This component of framework represents all the factors that vary and can affect the LCA result in each stage of life cycle of *Dachi Appa*. These are the factors within each life cycle stage that directly influence the environmental impact.

- **Raw Material Extraction:** It includes the availability of raw materials and whether the extraction process is manual or mechanical.
- **Manufacturing:** It examines the production method, the type of kiln used, and the fuel burned during the firing process.
- **Transportation:** It focuses on the type of vehicle, distance traveled, and the type of fuel used.
- **Usage:** It considers building typologies (residential, heritage, or commercial) and wall design (structural or veneer).

- **End-of-Life:** It Includes the method of disposal (landfill, reuse, or recycling) and recovery techniques to reduce waste.

3.1.3 Dependent Variable

The dependent variable represents the overall environmental impact, quantified through the LCA. This includes carbon emissions and other ecological effects caused by *Dachi Appa* across their lifecycle.

3.1.4 Contextual Factors

These are external conditions or circumstances that influence the outcomes of the independent variables and ultimately the LCA result. It includes:

- **Raw Material Extraction:** Transportation distance to the manufacturing unit and energy consumed during extraction.
- **Manufacturing:** The operational efficiency of the production plant, which can affect energy use and emissions.
- **Transportation:** Road conditions, including terrain, surface quality, and network efficiency, significantly impact fuel consumption and emissions.
- **Usage:** Climatic conditions and user behavior influence how bricks are utilized and maintained over time.
- **End-of-Life:** Legal and policy frameworks determine how disposal, reuse, or recycling is managed, which can affect sustainability outcomes.

The framework connects all these components to understand how independent variables and contextual factors at each life cycle stage contribute to the overall environmental impact (dependent variable). For example, inefficient kiln technology or poor road conditions can increase emissions significantly. Similarly, better policies for reuse or recycling at the end of life can reduce the overall footprint.

This framework not only helps in analysing the current lifecycle impacts of *Dachi Appa* but also serves as a guide for identifying critical intervention points, such as improving manufacturing efficiency, promoting sustainable transportation, and developing policies for end-of-life management. By systematically addressing each stage, it ensures that both cultural preservation and environmental sustainability are considered.

3.2 Research Method: Quantitative Method

The research employs a quantitative methodology that focuses on numerical data and objective measurements. To gather data for the life cycle stages of *Dachi Appa*, both quantitative and qualitative techniques are utilized, ensuring a comprehensive understanding of each phase—from raw material extraction to disposal after the product's end of life.

Prior to conducting field research, a thorough literature review was undertaken to understand the production process of *Dachi Appa*. This review included journal articles, books, conference papers, and credible online sources to establish a foundational understanding.

The primary field research was carried out at Dakshin Barahi Brick Factory, commonly known as Hira Brick, located in Madhyapur Thimi, Bhaktapur. This site was selected as the case study area due to its reputation and relevance in *Dachi Appa* production.

3.2.1 Data Collection Methods

The following methods were employed for data collection:

1. Field Observation

Field observations were conducted to document processes, practices, and materials used during specific life cycle phases:

- **Raw Material Extraction:** Observations at clay extraction sites provided information about the type and quantity of clay extracted, energy usage for excavation, and any associated environmental impacts.
- **Manufacturing Process:** At Dakshin Barahi Brick Factory (Hira Brick), direct observation of *Dachi Appa* production allowed for data collection on raw material preparation, shaping, drying, and firing processes. Inputs like fuel type, energy consumption, and waste generation were noted.
- **Transportation:** Observations of transportation planning included identifying modes of transport, distances covered, and types of vehicles used to move raw materials to the factory and finished products to distribution sites.

2. Interviews

Structured interviews with stakeholders provided qualitative and quantitative data across all life cycle phases:

- **Workers:** Interviews with workers involved in clay extraction and brick manufacturing helped quantify material usage, working hours, and process efficiency.
- **Management Teams:** Discussions with factory management offered insights into energy use, emissions, production rates, and operational challenges.
- **End Users and Experts:** Interviews with users of *Dachi Appa* and construction professionals helped gather data on the durability, maintenance, and typical lifespan of the bricks in usage phases.

3. Secondary Data Sources

Secondary data were used to complement and validate primary data collected through observations and interviews:

- **Manufacturing and Transportation:** Previous studies on brick production, fuel use, and emissions provided benchmarks for assessing the factory's operations. Transportation data, including average emissions and energy consumption by vehicle type, were referenced from established databases and reports.
- **Usage Phase:** Information on the performance, properties, and lifespan of *Dachi Appa* and its market alternatives were collected from relevant literature, including books, peer-reviewed articles and journal papers.
- **End-of-Life Disposal:** Case studies on traditional brick waste management and recycling practices were consulted to estimate disposal methods, potential reuse, and associated environmental impacts.
- **Emission Factor:** Emission factor data, such as those related to coal, electricity, diesel, and other energy sources, were obtained from relevant literature. Wherever possible, localized data specific to the region were utilized to ensure accuracy and relevance. For instances where localized data were unavailable, globally accepted data were sourced from books, research articles, journals, and recognized manuscripts.

These combined methods ensured the accuracy and reliability of the data used in the life cycle assessment of *Dachi Appa*.

3.2.2 Modelling and Calculation

For the Life Cycle Assessment (LCA) of *Dachi Appa*, modeling and calculations were conducted using a custom-designed spreadsheet instead of specialized LCA software like SimaPro or OpenLCA. The spreadsheet was developed to process the collected data systematically and compute environmental impacts across all lifecycle stages.

The spreadsheet integrated data from phases such as raw material extraction, manufacturing, transportation, usage, and end-of-life. Inputs included resource consumption (e.g., fuel, electricity, water) and emission factors associated with each energy source. Localized emission factors were prioritized, and globally accepted values were used where localized data were unavailable.

The modeling approach allowed for a detailed evaluation of energy use and emissions at each stage of the lifecycle. By summing the resource use and associated emissions for all stages, the total environmental impact of *Dachi Appa* was calculated. This process ensured flexibility, adaptability, and transparency, enabling a thorough understanding of the lifecycle impacts.

3.2.3 Statistical Analysis

The statistical analysis followed a step-by-step approach, starting with the cradle-to-gate Life Cycle Assessment (LCA) of *Dachi Appa* and progressing to scenario analysis and usage-phase comparisons to address its environmental sustainability. The process involved several key steps:

1. Cradle-to-Gate LCA Phase Analysis

This part of study focuses on quantifying the emissions associated with each sub-stage of the cradle-to-gate life cycle of the Nepali traditional brick, *Dachi Appa*. This section explains the systematic approach used to process, analyse, and interpret data collected from brick manufacturing facilities. The sub-stages analysed include clay extraction, clay transport to factory, stacking, mixing and cake production, brick moulding, preparation of raw bricks, sun drying, stacking in chimney, brick burning, and the stacking of finished bricks in storage for sale. The detail step involved in this phase is shown in flow chart in *figure 4*.

For each sub-stage, emissions were quantified by combining the collected data with established emission factors for the resources and activities involved. The emissions for each sub-stage were then aggregated to calculate the total cradle-to-gate emissions of *Dachi Appa*.

2. **Transportation Phase Analysis**

This phase in the study focuses exclusively on the outbound transportation of finished *Dachi Appa* bricks from the manufacturing site to use sites within Kathmandu Valley. The primary objective is to quantify the emissions associated with delivering bricks to these sites. The analysis considers urban road conditions in Kathmandu Valley while excluding terrain conditions, as the focus is on emissions arising from vehicle use under typical urban settings.

To begin, detailed information about the road network within Kathmandu Valley was collected, including the types of roads, their lengths, and surface conditions. Unlike simplified assumptions of uniformity, this analysis evaluates the actual road surface conditions across different road networks within the valley. The proportions of various road types and surface conditions were determined, and these were used to calculate the average fuel consumption per kilometer based on the weighted impact of each road type on fuel efficiency.

Two types of vehicles commonly used for brick transportation heavy trucks and mini trucks were studied. For each vehicle type, data on load capacity and average fuel consumption under varying urban road conditions were gathered. These factors served as the foundation for estimating fuel usage.

Fuel consumption was calculated based on the distances between manufacturing sites and use sites, combined with the fuel efficiency of each vehicle type under the specific conditions of Kathmandu Valley's Road network. For each round trip, defined as the distance traveled to the use site and back to the manufacturing site, the fuel consumption was estimated in kilometers. Emissions were then determined by multiplying the fuel consumption by standardized emission factors for the specific fuels used by the vehicles.

By analyzing the actual road surface conditions and their proportional contribution to overall transportation impacts, this phase provides a more accurate estimation of emissions associated with the outbound transportation of *Dachi Appa* bricks.

3. Usage Phase Analysis

The cradle-to-gate LCA provided the foundation for calculating carbon emissions associated with *Dachi Appa* production. Using this data, emissions for constructing 1m² of *Dachi Appa* wall were calculated. The analysis begins by calculating the quantities of all materials required to construct 1m² of a *Dachi Appa* wall. This includes the number of bricks, the volume of sand and cement, as well as the manpower and equipment necessary for the construction process. The material specifications and construction methodology followed for this analysis were based on the construction guidelines provided by the Department of Urban Development and Building Construction (DUDBC) and the Department of Archaeology (DOA). The emissions from each material used in building the wall were then individually estimated. This includes emissions from brick production, transportation, and the manufacture of sand and cement, as well as emissions associated with manpower and equipment utilization. The total emissions for constructing 1m² of wall were calculated by summing up the contributions from all these factors.

To estimate the emissions associated with each brick in the use phase, the total emissions for the 1m² wall were divided by the number of bricks required to construct the wall.

The usage of *Dachi Appa* was compared with two alternative use cases:

- **Case 1:** Regular brick wall finished with plaster and paint.
- **Case2:** Regular brick wall with exterior wall tiles.

This analysis enabled the identification of potential areas for improvement in the environmental performance of *Dachi Appa*.

4. End-of-Life Phase Analysis

The End-of-Life phase of the LCA focuses on evaluating the environmental impacts associated with dismantling, transporting, and disposing of *Dachi Appa* walls at the end of their service life. This phase also considers the potential for brick reuse, although reuse and recycling are not within the scope of the current analysis.

The analysis begins with the dismantling of the *Dachi Appa* wall, where the required manpower and equipment are estimated based on the standard specifications provided by the DUDBC. Emissions associated with the dismantling process, including the energy use of tools and equipment, are quantified. The total emissions for dismantling an entire wall are calculated, and emissions per brick are derived for detailed evaluation.

Transportation of dismantled debris is assumed to involve hauling the materials to a landfill site. The transportation emissions are calculated based on the same emission factors established in the transportation phase of the study, ensuring consistency in the analysis. Emissions for transporting each dismantled brick are added to the total End-of-Life emissions.

For disposal, it is assumed that all dismantled debris, including *Dachi Appa* bricks, is disposed of in a landfill site. While reuse and recycling present viable alternatives, these are excluded from the scope of this study.

5. Key Impact Contributor Analysis

To identify the major contributors to the carbon footprint, a detailed statistical analysis of the cradle-to-grave data was conducted. The burning process was found to be a significant contributor due to the use of coal as the primary energy source.

6. Scenario Analysis: Burning Process Optimization

To explore alternative solutions, scenario analysis was conducted by incrementally replacing coal with wood pellets in the burning process. Four scenarios were modeled:

- **Case 1:** 25% of coal replaced with wood pellets.
- **Case 2:** 50% of coal replaced with wood pellets.
- **Case 3:** 75% of coal replaced with wood pellets.
- **Case 4:** 100% of coal replaced with wood pellets.

The emission factors for coal and wood pellets were used to estimate emissions in each scenario.

7. Integration with the Usage Phase

The scenarios were extended to the usage phase to assess their impact on the carbon footprint of 1m² of *Dachi Appa* wall. This analysis evaluated the extent of coal replacement required to make *Dachi Appa* walls more sustainable than the alternative cases.

This structured approach facilitated an understanding of the environmental impacts of *Dachi Appa* and informed strategies to improve its sustainability while maintaining its cultural relevance.

3.3 Phases of LCA of *Dachi Appa*

3.3.1 Goal definition and scoping

This phase consists of defining the purpose of the study and its scope, establishing functional unit and system boundaries of the study. The goal and scope of work for our study is as per *Table 2*.

Table 2. Goal and Scope of the study

Goal	Assess environmental impact of <i>Dachi Appa</i> throughout its life cycle (Cradle-to-grave)
	Identify key impact hotspots
	Evaluate potential sustainability improvements
Scope	Product System: <i>Dachi Appa</i>
	Functional Unit: per brick for calculation (per m ² for comparison)
	Geographic Scope: Kathmandu Valley
	System Boundary: Cradle-to-grave (Raw material extraction, Manufacturing, Transportation, Usage, end-of-life)
	Impact Categories: Carbon emission, Energy use

3.3.2 Inventory Analysis

In this phase, system boundaries are defined, process flow charts are created, and data on production, resource use, energy consumption, emissions, and waste generation are

collected for each subsystem (Jönsson et al., 1997). Each life cycle stage, process, data and methods of data collection are tabulated in *Table 3*.

Table 3. Life Cycle Inventory Analysis of Dachi Appa

A. Cradle-to-Gate (Factory Visit): Dakshin Barahi Brick Factory	Data collection for raw material extraction	Type and quantity of raw material, transportation distance
	Data collection for manufacturing processes	Direct Measurement: Fuel consumption, electricity usage, water consumption, direct emission during production
		Factory Records: Production output, raw material input, energy consumption, waste generation
		Qualitative Data: Interview with factory workers and management
	Data Quality	Document data, assess reliability, completeness and representativeness of data
LCI Modelling	Use Spreadsheets to create an inventory of all inputs (materials, energy) and outputs (emission to air, water and waste)	
B. Transportation	Data Collection	Transportation distances
		Transportation modes: Truck/Cart/Manual
		Road characteristics and Road condition
		Fuel consumption data: literature database, local transport data
	Calculations	Quantify average fuel consumption
Quantify emission from transportation		
C. Use Phase	Data Collection	Usage practices
		Resource requirement
		Alternative practices
		Repair and Maintenance

	Calculation	Quantify emission from Usage
	Comparison	Compare emission with alternative materials (for 1m ² wall)
D. End-of-Life	Data Collection	Demolition process and quantify emission associated with the process
		Disposal methods
		Qualitative data: Interview with local builders and demolition experts to understand common demolition and disposal practice

3.3.3 Impact Assessment

The impact assessment is a quantitative and/or qualitative process to characterize and assess the effects of the environmental burdens quantified in the inventory analysis. A process-based calculation spreadsheet is developed to determine the energy use of materials by summing the energy consumption at each stage of the life cycle, with detailed analysis of individual processes. Emissions at each stage, as well as the total emissions over the entire life cycle of each *Dachi Appa*, are calculated using emission factors for the energy sources involved at each step.

$$CO_2-Eq = \sum_{i=1}^n E_i * EFi$$

Where *i* refers to specific energy source, *E_i* refers to amount of *i* energy used and *EF_i* refers to equivalent emission factor of *i* energy source.

3.3.4 Interpretation of Results

It is the final phase of LCA where meaningful insights are derived by evaluating collected and analysed data from all lifecycle stages. The result from energy use, emission and resource consumption are interpreted to identify the most impactful stages in the lifecycle of *Dachi Appa*. Key contributors to environmental impacts, such as high-emission processes or resource-intensive stages, are highlighted.

The interpretation also involves comparing the calculated emissions and energy usage with benchmarks or standards to assess the environmental performance of *Dachi Appa*. To explore alternative solutions and improve sustainability of *Dachi Appa*, scenario analysis

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was conducted. This phase provides the basis for recommendations on improving the environmental sustainability of *Dachi Appa* by targeting critical stages in its life cycle.

4. CASE STUDY

The case study was conducted in four phases with raw material extraction and manufacturing process studied under first phase Cradle-to-gate followed by transportation and usage phase and last phase of study deals with End-of-life phase.

4.1 Phase 1: Cradle-to-gate

This phase of the study encompasses all processes involved before *Dachi Appa* is transported to its site of use. It includes clay extraction, transportation of the clay to the factory, clay mixing, raw brick formation, the firing process, and finally, stacking the finished bricks for transportation.

The primary field research was carried out at Dakshin Barahi Bricks, popularly recognized as Hira Bricks. It is one of the largest brick manufacturers in Nepal. Located in Madhyapur Thimi, Bhaktapur, the factory produces approximately 8 million bricks annually, despite operating only for five to six months each year due to weather constraints. This site was selected as the case study area due to its reputation and relevance in *Dachi Appa* production. It has been working persistently on preservation of country's culture and tradition as well as unique indigenous building with the historical background of over 3000 years. The factory has given continuation on use of local indigenous building materials following Nepalese tradition and as major contributor on preservation of world heritage both nationally and internationally for 25 years (HiraBricks, 2024).

A flow chart was drawn for the manufacturing procedure of *Dachi Appa* (*Figure 4*) and data on environmental load was gathered for process and transports of the lifecycles. The necessary information and data are gathered from the factory and literature study. Standard values from reputed organizations or journal paper were used for some data. The result of the inventory analysis is calculated for each brick.

4.1.1 General Information about the Factory

- **Electricity Consumption:** The factory is equipped with an 800 KVA transformer dedicated to electricity supply. Currently, they operate at a capacity

of 300 KVA, with a monthly electricity consumption of approximately 30,000 units during the production period.

- **Fuel and Energy Usage:** The factory consumes around 800 tons of coal annually for the brick-firing process. Additionally, they use approximately 7,500 Liters of diesel each month, which includes transportation of finished bricks to their destinations.
- **Water and Waste Management:** Three wells serve as the factory's primary water sources. For solid waste management, the factory utilizes an on-site septic tank system.
- **Raw Material Extraction and Transportation:** The clay required for brick production is sourced from Saraswotikhel, Bhaktapur, located 6.5 kilometres away from the factory. Excavation is performed using a Komatsu PC210 excavator, and the clay is transported to the factory using a Tata 1613 tipper truck.
- **Internal and External Logistics:** For product movement within and outside the factory premises, the factory uses Mahindra Load king trucks.
- **Red Mud and Coal Supply:** Red mud, used for colouring purposes, is sourced from Dakshinkali, approximately 26 kilometres from the factory. The coal used in the brick-firing process is procured from Godawari Commodities, India, and transported via the Birgunj port in Nepal.

4.1.2 Process within Cradle-to-gate of *Dachi Appa*

The cradle-to-gate phase of the case study encompasses all processes involved in the production of *Dachi Appa* bricks, starting from raw material extraction to storage of finished bricks at the inventory. The journey begins with **clay extraction** from the excavation site in Saraswotikhel, Bhaktapur, where an excavator extracts 70 m³ of clay in 30 minutes, consuming 9 liters of diesel. Observations from the factory indicate that 1 m³ of clay produces approximately 500 bricks. Following extraction, the clay is **transported to the factory**, which is located 6.5 km away. Each tripper truck carries 7 m³ of clay per trip, completing a round trip (including 3 minutes for loading) in about 40 minutes.

At the factory, the process proceeds with **stacking**, where manpower is used to stack the wastage generated during raw brick production. A single worker stacks one wheelbarrow (0.08 m³) of waste in 5 minutes. From the stacking area, the clay is **transported to the mixing chamber**, covering a distance of 150 meters. A truck carrying 2.8 m³ of clay requires 2 workers to load and unload the material in a combined time of 25 minutes (15 minutes for loading and 10 minutes for unloading). The next step involves **mixing and cake production**, where 300 brick cakes are produced daily by three workers working an 8-hour shift.

The **transportation of the cakes** to the brick molding site occurs over a distance of 250 meters. Trucks, capable of carrying 2,000 pieces at a time, require four workers who spend 1.5 hours loading and unloading the material. At the molding site, **raw brick production** takes place, with one worker producing 200 bricks during an 8-hour shift. These bricks are then subjected to **sun drying** to remove moisture content.

Once dried, the bricks undergo **red mud coloring**, for which red mud is sourced from Dakshinkali, located 46 km away (round trip). The red mud is transported in trips of 1,000 kg at a time, with 2 kg of mud used for every 600 bricks. One worker travel for 80 minutes per trip and spends an additional 20 minutes loading and unloading the material. Another worker applies the red mud, coloring 600 bricks in an 8-hour shift.

Following this, the bricks are **transported to the chimney and stacked** for firing. The distance between the molding area and the chimney is 500 meters, and trucks carrying 2,000 pieces at a time account for a wastage of 100 bricks per trip. Four workers spend 3 hours loading, unloading, and stacking the bricks in the chimney. **Brick burning**, the most energy-intensive process, involves firing 17,000 bricks at a time in the chimney using 150 tons of coal to burn 1,500,000 bricks. This process employs 18 workers (6 per shift) working 8-hour shifts for 10 days. Burning results in an average wastage of 35% of the total bricks fired.

The final stage involves **transporting the finished bricks to inventory storage and stacking** them. Trucks carry 2,000 pieces at a time over a 100-meter distance, with an average wastage of 30 bricks per trip. Four workers take 2 hours to load, unload, and stack the bricks at the inventory. These steps collectively constitute the cradle-to-gate phase,

offering a detailed breakdown of the production process and associated resource consumption. The flow chart of all the process and resource used within each process is shown in *figure 4*. The data collected and calculations are presented in *Table 7* in ANNEX A.

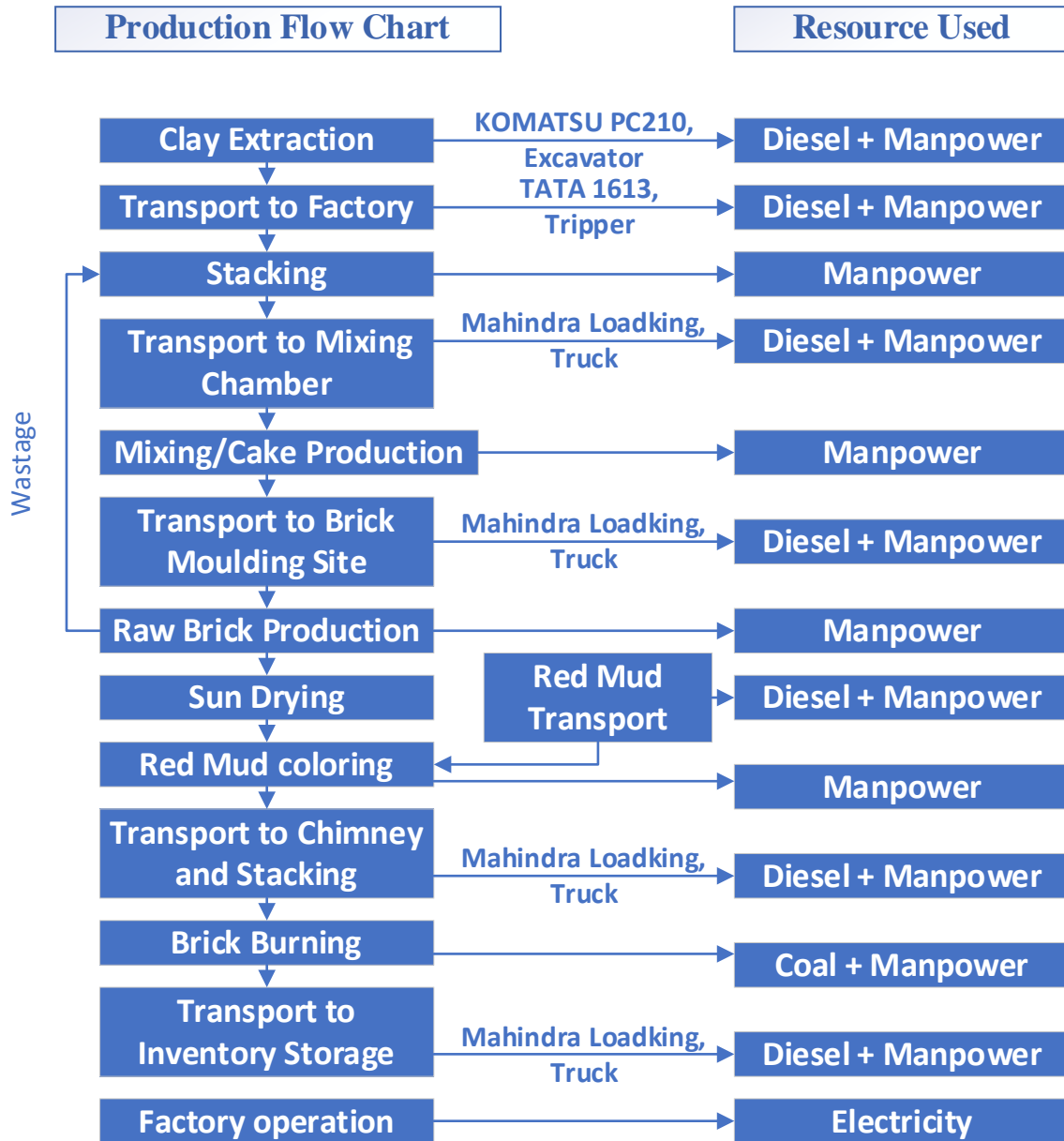


Figure 4. Flow chart showing production stages and associated resource used during production of *Dachi Appa*

4.1 Phase 2: Transportation

This phase involves a detailed analysis of the logistics and environmental impacts of transporting *Dachi Appa* bricks within Kathmandu valley. Vehicle fuel consumption is a complex interplay and depends on several factors such as engine and vehicle technology, road characteristics, environmental condition, traffic conditions, fuel properties, driving style, vehicle load etc. This research limits the vehicle fuel consumption adjustment for road condition including road network type and road surface condition.

The phase started with study of vehicle mileage and road networks. The mileage is then adjusted for road network type and road surface condition to ensure estimate of fuel consumption and emission are more precise. The workflow consisted of the following steps:

1. **Vehicle Mileage Study:** Mini truck like Mahindra super load king is normally used to transport brick within Kathmandu valley. The vehicle carries 2000 brick per trip. The fuel consumption of such vehicles within the Kathmandu Valley is estimated to be 4 km/l (Bajracharya & Bhattarai, 2016). This baseline mileage data served as the starting point for estimating fuel consumption during transportation.
2. **Analysis of Road Network:** A thorough study of the road network within the Kathmandu Valley was conducted to understand the conditions affecting vehicle performance. Study have suggested that two main networks were analyzed:
 - **Strategic Road Network (SRN):** These road network comprises of highways and feeder road, forming the core of the nation's surface transportation and is managed by Department of Roads (DoR) under Ministry of Physical Planning and Works. These roads are wider and managed by traffic police and lights to ensure smooth transition. The total length of SRN is estimated to be 473 KM within Kathmandu valley (Malla, 2014).
 - **Local Road Network (LRN):** These are the roads connecting smaller areas, often with variable conditions. These roads are managed by state and local government bodies. The length of LRN is estimated to be 1746 km inside

Kathmandu valley (Malla, 2014). Due to their complex and segmented geometry, it is estimated that the local road shows 37% less vehicle efficiency compared to highway (Boggio-Marzet et al., 2022).

The proportion of road types in the total road network was determined, providing insight into the likely routes taken by transporting vehicles.

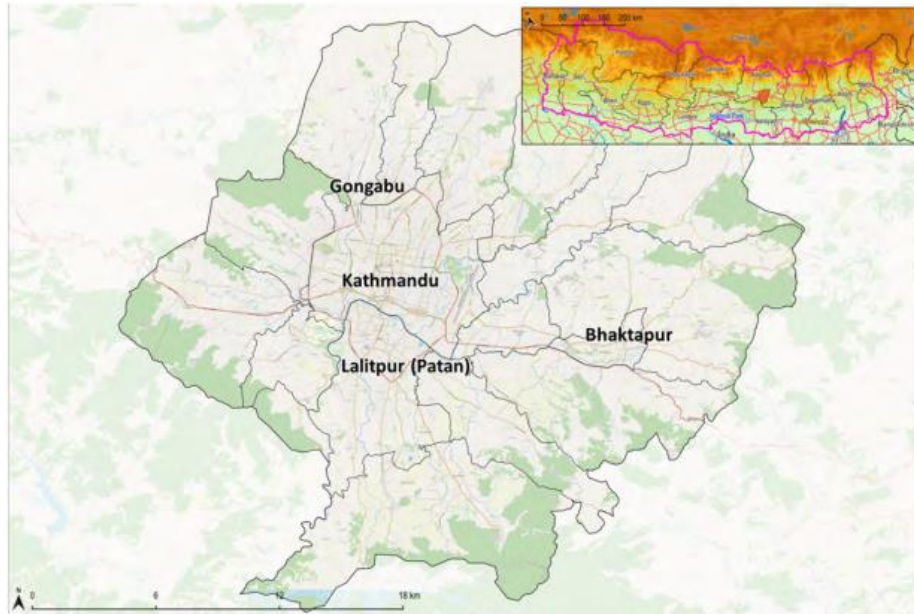


Figure 5. Road network inside Kathmandu Valley (JICA, 2019)

3. **Road Surface Condition Assessment:** The road network was further categorized based on surface conditions:

- **Smooth roads:** Asphalt-paved and well-maintained roads.
- **Graveled roads:** Partially maintained roads with loose gravel.
- **Earthen roads:** Unpaved roads with natural surfaces.

Rough roads are found to add 10% of fuel consumption (Starling, 2001). The proportion of each road type was quantified to assess the impact of road smoothness on vehicle mileage.

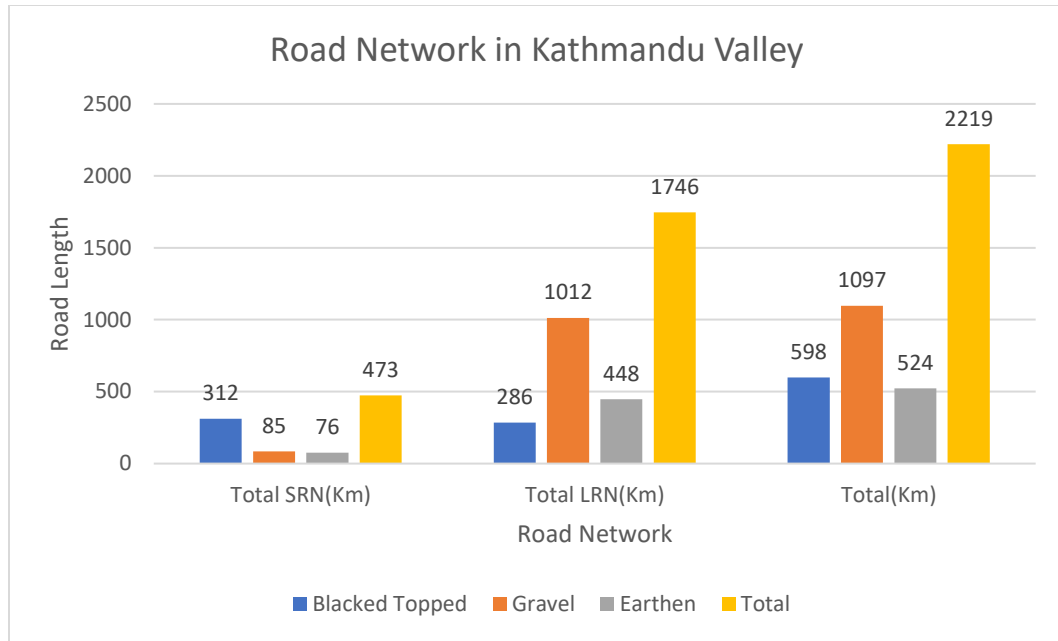


Figure 6. Road network type and surface condition inside Kathmandu Valley (Malla, 2014)

4. **Adjustment for Actual Mileage:** Using the road network and surface condition data, the actual mileage of transporting vehicles was estimated. This involved considering the reduction in mileage due to rougher road types and varying surface conditions. A weighted average approach was applied to calculate the overall mileage for the typical transportation route.
5. **Estimation of Fuel and Manpower Requirements:** The adjusted mileage was used to estimate the amount of fuel consumed per kilometer for transporting bricks. Additionally, the manpower requirements (e.g., drivers or loaders) were calculated based on standard transportation practices for the region. These calculations provided a detailed understanding of the resources required to transport a single brick per kilometer.
6. **Carbon Emission Calculation:** The final step involved calculating the carbon emissions associated with transportation. Emission factors for the fuel type used by the vehicles were applied to the estimated fuel consumption. This enabled a precise calculation of the carbon footprint for transporting a single brick over a given distance.

The transportation phase involves moving the bricks from the inventory to the construction site. The distance is measured per 1,000 meters, with each truck capable of carrying 2,000 pieces of bricks in a single trip. However, there is an estimated wastage of 50 bricks per trip during transportation. Four workers spend 2 hours loading, unloading, and stacking the bricks at the site.

4.2 Phase 3: Usage

In this section, the environmental performance of *Dachi Appa* during the usage phase is assessed and compared with alternative construction practices. The process involves calculating the emissions associated with constructing a 1 m² brick wall, which includes material production, transportation, and labor requirements. Furthermore, scenario analyses are conducted to explore strategies for enhancing the sustainability of *Dachi Appa* walls.

Calculation Process

1. Material and Manpower Requirement:

- The amount of *Dachi Appa* required to construct 1 m² of a brick wall is calculated.
- Additional materials, such as mortar and binding agents, are quantified based on specification established by Department of Urban Development and Building Construction (DUDBC)
- The manpower required to construct the wall is also estimated, considering specification established by DUDBC.

2. Emission Estimation:

- The emissions for each material used in the wall are calculated based on their respective life cycle stages up to the usage phase.
- Emission factors are derived from established databases, literature, or local studies to reflect regional practices and conditions accurately.
- Total emissions for 1 m² of a *Dachi Appa* wall are obtained by summing the contributions of each material and construction activity.

3. Comparative Analysis:

- Two alternative construction cases are modeled:
 - **Case 1:** Regular brick wall finished with plaster and paint.
 - **Case 2:** Regular brick wall with exterior wall tiles.
- Emission calculations for these cases are performed using a similar methodology.
- A comparison is made to determine the carbon emission performance of *Dachi Appa* walls relative to these alternatives.

At the site, the construction of 1 m² of *Dachi Appa* wall in a 1:4 cement-sand mortar mix requires 108 bricks, 12.75 kg of cement, and 0.0322 m³ of sand. For the construction of the wall, 4.72 working hours of workforce are required. Additionally, applying a silicon paint finish with two coats over 1 m² of the *Dachi Appa* wall requires 0.2 kg of paint and 0.4 working hours of workforce. These processes highlight the material, labour, and energy requirements for the effective use of *Dachi Appa* bricks at the construction site.

4.3 Phase 4: End-of-Life

This phase of LCA focuses on evaluating the environmental impacts associated with the dismantling, transportation, and disposal of the brick wall at the end of its service life. The phase also focusses on potential reuse of *Dachi Appa* bricks after the building's lifecycle ends. *Dachi Appa* walls are typically dismantled manually, which allows for careful brick removal and potential reuse, particularly in restoration projects or secondary construction. When reuse is not possible, the bricks are usually disposed of in landfill sites.

One of the key findings in this phase is that *Dachi Appa* bricks highly regarded for its structural durability which make it reusable even after demolition of existing structure, and makes them an environmentally favourable option for disposal compared to conventional bricks. The transportation emissions related to debris disposal are generally like those in the transportation phase. However, while current disposal practices lean towards landfilling, there is considerable opportunity to enhance sustainability by promoting reuse and recycling of the bricks. Developing organized systems for the recovery and reuse of *Dachi Appa* at the end of its lifecycle could significantly reduce waste and extend its utility, reinforcing the material's sustainability credentials. The study involves following key processes:

1. Dismantling

The amount of manpower and equipment required to dismantle the *Dachi Appa* wall is estimated based on standard specification for dismantling wall established by DUDBC. Emissions associated with the dismantling process are quantified, including energy use for tools and equipment. The total emissions are calculated for the dismantling of the entire wall, and the emission per brick is derived for detailed analysis.

2. Transportation of Dismantled Debris

The study is based on assumption that the dismantled debris will be transported to a landfill site. The emission factors for transportation are considered equivalent to those calculated in the transportation phase of the *Dachi Appa* bricks during their initial use. The transportation emissions for each dismantled brick are added to the total emissions for the disposal phase.

3. Disposal

For this study, it is assumed that the dismantled bricks and debris are disposed of in a landfill site. Although alternatives such as reuse and recycling are feasible, these are not considered in the scope of the current analysis. Emissions associated with the disposal process, including transportation and landfill operations, are calculated and added to the total End-of-Life emissions.

The scope of study only accounts deconstruction of the *Dachi Appa* wall at the end of its lifecycle and transportation of disposal to landfill at the end of its lifecycle. For dismantling 1 m² of the wall, it requires 2 working hours of workforce. This process ensures that the bricks can be carefully removed, allowing for potential reuse or appropriate disposal.

5. RESULT AND DISCUSSION

5.1 Result from Phase 1: Cradle-to-gate

Basically, four major source of energy use is seen during production of *Dachi Appa*, i.e. coal, diesel, electricity and workforce. Among the sources, coal account for the most significant proportion of emission share with 90.7%, workforce accounts for 6.1%, electricity accounts for 1.7% while least emission share by diesel accounting 1.5% during production of each brick presented in *figure 7*. The emission factor of electricity mix of Nepal is 0.45 kg CO₂-eq/KWh while that of coal and diesel is 3.6 kg CO₂-eq/Kg and 3.75 kg CO₂-eq/L respectively (KC et al., 2025). Moreover, the average emission factor of human work force working in construction sector is 0.12 kg CO₂-eq/h (0.95 kg CO₂-eq per working day working 8 hour a day) (Jiang et al., 2018). Carbon emission associated with respective resource during manufacturing of *Dachi Appa* is shown in *Table 4*.

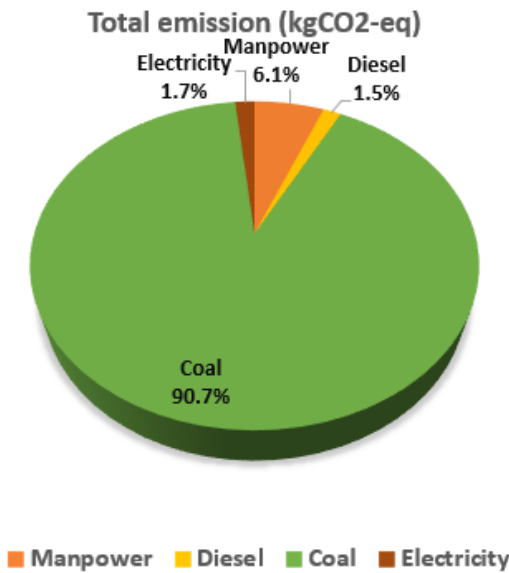


Figure 7. Carbon emission share of energy source during production of *Dachi Appa*

Table 4. Summary of average energy use associated with carbon emission in kgCO₂-eq of per 500 pcs *Dachi Appa*

Resource use	Emission (kgCO ₂ -eq) (Per 500 pcs)

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Workforce	16.26
Diesel	4.15
Coal	243
Electricity	4.5

A process-based study reveals that the brick-burning stage is the most carbon-intensive phase in the lifecycle of *Dachi Appa*, contributing 0.50 kg CO₂-eq per brick (*Table 5*), which accounts for 93.3% of the total carbon emissions during production. The raw brick-making stage contributes 3.2% of the total emissions, while the transportation and stacking stage accounts for 1.7%. Notably, the raw material extraction stage has the least share of emissions, contributing only 0.2% of the total carbon footprint (*figure 8*).

The total carbon emission during production of each *Dachi Appa* account to be 0.53 kg CO₂-eq. The average consumption of electricity during production of 500 bricks is estimated to be 10 KWh while coal for burning 500 bricks is estimated to be 50 Kg as presented in detail calculation in ANNEX A.

Table 5. Summary of lifecycle stage associated with carbon emission in kgCO₂-eq of per 500 pcs Dachi Appa

Process	Emission (kgCO₂-eq) (per 500 pcs)
Extraction	0.51
Transportation and stacking	4.53
Raw brick making	8.50
Burning	249.86
Miscellaneous	4.5
Total Emission per 500 bricks	267.91
Total emission per brick	0.53

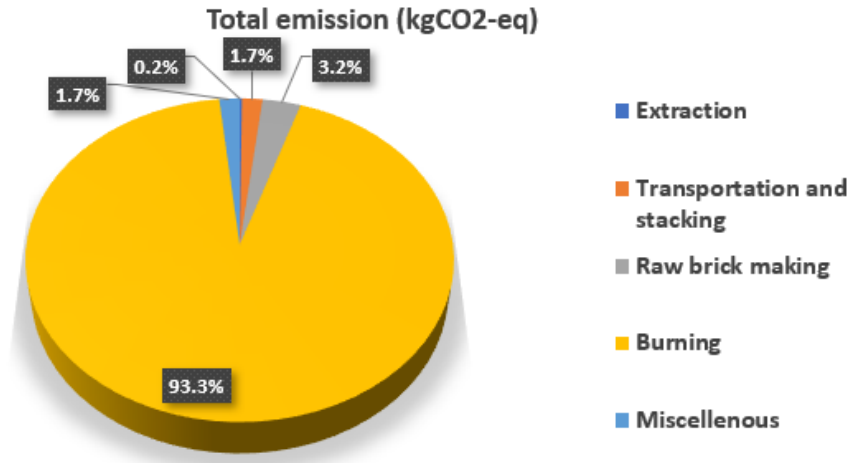


Figure 8. Carbon emission at different stage of production lifecycle of *Dachi Appa*

5.2 Result from Phase 2: Transportation

The study deals with two type of road network i.e. SRN and LRN and two type of road surface i.e. smooth and rough where rough accounts for both earthen and gravel road. The fuel consumption of mini truck and heavy truck is estimated to be 3.5 km/l and 4 km/l respectively in urban road of Nepal in normal condition (Bajracharya & Bhattarai, 2016). The mileage in SRN and LRN is taken considering the proportion of smooth and rough road within the road network with rough road assumed to be 10% more fuel consuming. Similarly, the average mileage is taken considering the proportion of SRN and LRN within the Kathmandu valley with LRN assumed to be 37% more fuel consuming. After consideration of road network and road surface condition the average mileage is taken to be 2.95 km/l for mini truck and 2.58km/l for heavy truck as shown in *figure 9*.

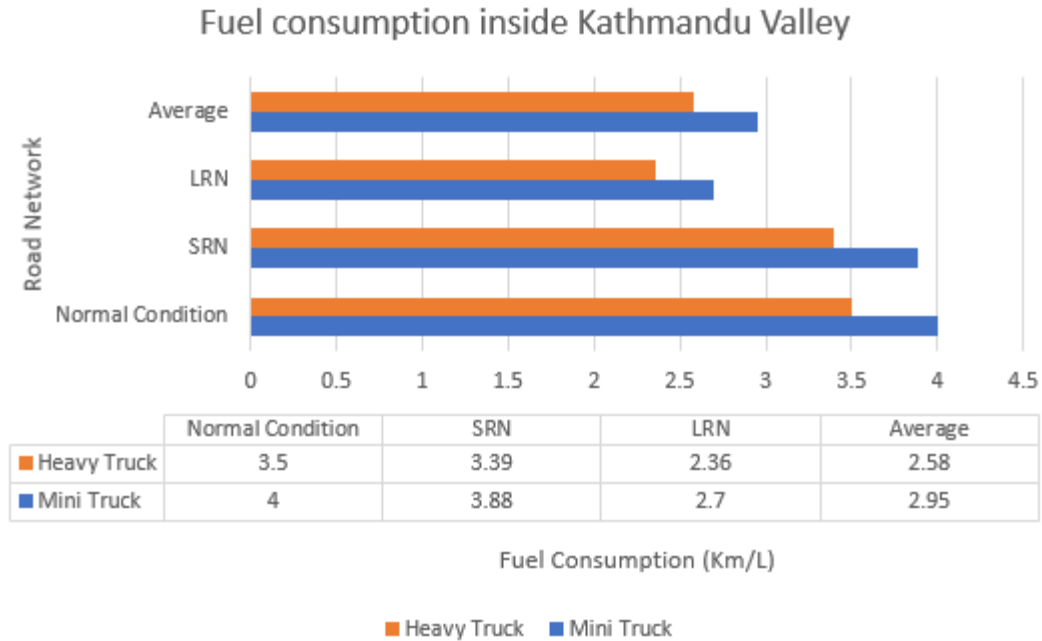


Figure 9. Fuel consumption of vehicle in different road network of Kathmandu Valley

Mini truck is considered for transportation of brick from factory to site. The truck is considered to carry 2000 pcs of brick at a time with 4 people taking 2 hours to load, deliver, unload, and stack the brick at site. This value is taken based on experience of factory worker delivering the bricks. The estimated emission during transportation of each brick is 0.002 kgCo₂-eq/km considering round trip of the vehicle. Detail calculation for emission during transportation is presented in ANNEX A.

5.3 Result from Phase 3: Usage

The result shows usage carbon emission for constructing 1m² of *Dachi Appa* wall. The carbon emission calculation is done for a combination of *Dachi Appa* wall with outer layer covered with two coat of silicon paint. As per the specification proposed by DUDBC and Department of Architecture, for construction of 1m² *Dachi Appa* wall in 1:4 cement sand mortar it requires 108 *Dachi Appa* brick, 12.75 kg cement and 57.6 kg sand (volume of sand=0.032m³, density of sand=1800 kg/m³). Similarly, a total workforce equivalent to 4.72 working hour including both mason and skilled is required for construction 1m² wall. For silicon paint it requires 0.2kg of paint and workforce equivalent to 0.4 working hour is required for two coat silicon paint.

For calculation, the emission factor of dachi brick is taken from the result of cradle-to-gate. The emission factor of cement is taken 0.739 kgCO₂-eq/kg (KC et al., 2025) while emission factor of sand is taken 0.005 kgCO₂-eq/kg (NSSGA, 2021). Similarly, the emission factor for silicon paint is considered 6.31 kgCO₂-eq/kg (Brandt et al., 2013). The result shows an additional emission of 0.108 kgCO₂-eq per brick during the usage phase of *Dachi Appa* with total emission carried to 0.644 kgCO₂-eq per brick up to this phase.

Comparative Analysis:

A base case with combination of 4” *Dachi Appa* exterior wall with silicon paint and 4” regular brick interior wall was compared with two alternative construction cases. Case 1 represent a 9” regular brick wall finished with exterior plaster and paint. Case 2 represent 9” regular brick wall with exterior wall tile. The total emission during construction of 1m² wall from base case was estimated 112.97 kgCO₂-eq. Case 1 was estimated to have the lowest carbon footprint with 89.61 kgCO₂-eq for 1m² wall while Case 2 emerges with carbon footprint of 107.74 kgCO₂-eq closer to base case yet lower footprint than base case.

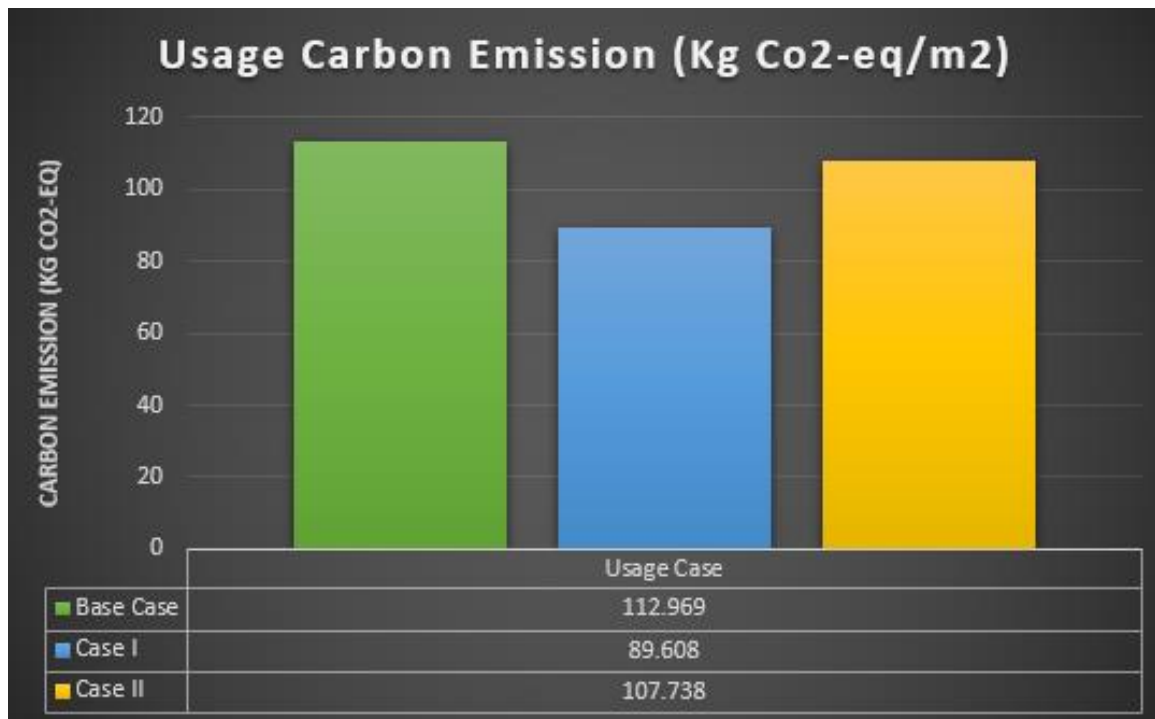


Figure 10. Carbon emission during construction of 1m² wall in different case

5.4 Result from Phase 4: End-of-Life

The study shows a result representing a general practice of dismantling the old structure, transport the brick and debris and dispose it to nearest landfill site. In general, the brick wall is dismantled carefully with human workforce to safeguard reuse potential of brick. The total emission for dismantling each brick is estimated 0.002 kgCO₂-eq. The emission during transportation of dismantled brick and debris is taken 0.002 kgCo₂-eq for round trip, same as the transportation of brick from factory to site.

5.5 Result: Life Cycle Assessment of *Dachi Appa*

With emission calculated for each stage of life including manufacturing of brick, transportation to site, use at site and dismantling and disposal at the end of life, the total carbon emission associated with each *Dachi Appa* is estimated to be 0.65 kgCO₂-eq. The value is estimated on basis that the distance from factory to site and site to landfill is 1km. The LCA study shows the manufacturing stage (Cradle-to-gate) of *Dachi Appa* carries the highest carbon footprint 82.46% of total carbon emission. Usage phase accounts for 16.62% of total emission with transportation and end-of-life stage with lowest carbon footprint account 0.31% and 0.62% of total emission.

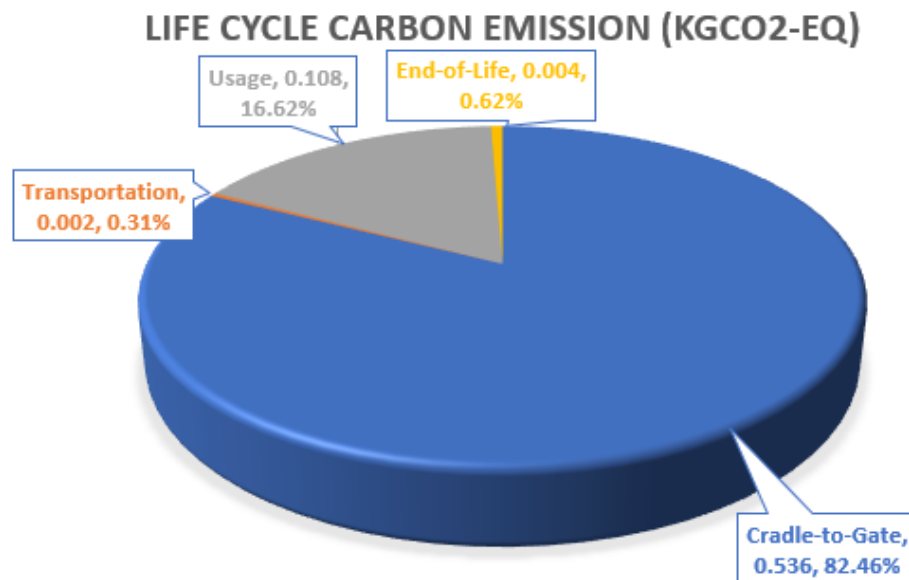


Figure 11. Carbon emission at different stage of lifecycle of *Dachi Appa*

In the overall lifecycle of *Dachi Appa*, four major energy sources contribute to its total carbon footprint: coal, manpower, diesel, and electricity. Among these, coal has the highest carbon emission impact, accounting for 90.12% of the total lifecycle emissions. Manpower contributes 6.44% to the emissions, while diesel and electricity account for 1.78% and 1.67%, respectively.

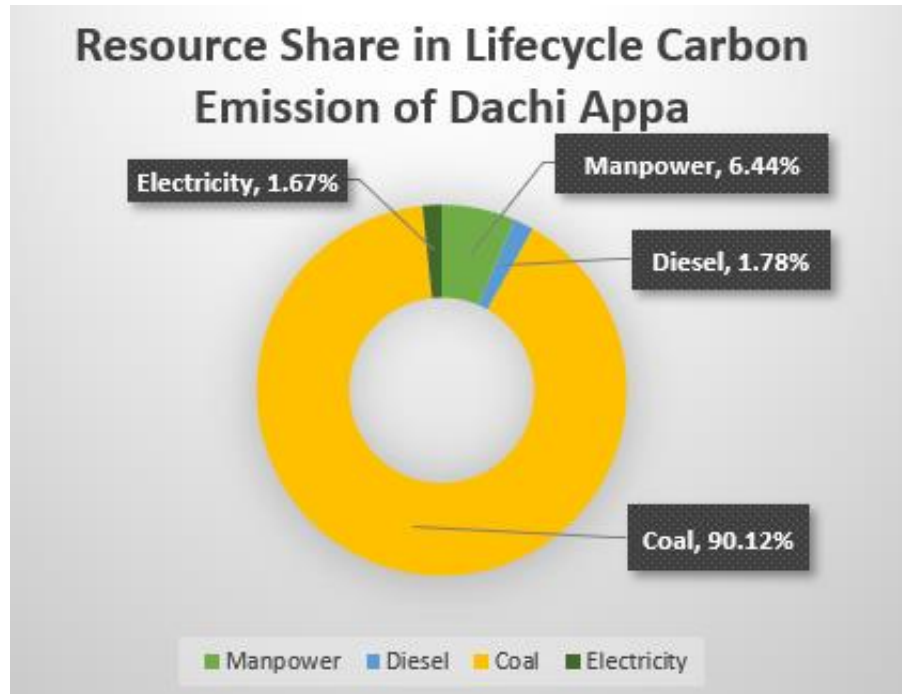


Figure 12. Resource share in lifecycle carbon emission of *Dachi Appa*

5.6 Scenario Analysis

The comparative analysis of *Dachi Appa* shows an environmental and sustainability concern of for using *Dachi Appa* as the case comparison shows a base case with combination of exterior 4” *Dachi Appa* and 4” regular brick wall has more carbon footprint than other two cases. As *Dachi Appa*, hold significant cultural and architectural value, particularly in preserving local heritage we should promote its usage. However, the environmental implications of its production and use shows a negative ecological consequence.

During the study, the product manufacturing stage or cradle-to-gate stage is seen with the most carbon footprint. Within cradle-to-gate stage, brick burning process is encountered to have the most significant impact in carbon footprint with coal being used as a resource for

brick burning. With coal being a non-renewable energy, requires large amount of energy for mining and bought from India, it upholds high embodied emission with it. Coal has an energy value of 25.2 MJ/kg with emission factor being 3.6 kgCO₂-eq/kg (KC et al., 2025; Zheng et al., 2022). Replacing coal with alternatives like biomass and electricity during manufacturing of brick can help to reduce its carbon footprint. Wood pellet, a biomass alternative of coal has an energy value of 17.6 MJ/kg with emission factor of 1.37 kgCO₂-eq/kg (Zheng et al., 2022). The energy of 3.40 MJ is required for burning each brick. The amount of coal equivalent to the energy is 0.135kg with emission equivalent to 0.49 KgCO₂. The same amount of energy can be obtained from burning 0.19kg wood pellet with emission equivalent to 0.26 kgCO₂ only. This shows wood pellet to be a sustainable alternative of coal for brick burning. A scenario analysis with different proportion of wood pellet replacing coal during burning of brick is shown in Table 6.

Furthermore, with wood pellet replacing coal in burning phase, replacement of 25% of coal with wood pellet (Scenario I) made the carbon footprint of base case in comparative analysis lower than Case II while replacement of 100% of coal with wood pellet (Scenario IV) made the base case with the lowest carbon footprint than both comparative cases. It means, if we can replace coal with biomass alternative like wood pellet, we can promote the use of *Dachi Appa* in more sustainable way. This will help to balance both cultural identity and environmental sustainability. The usage phase case after scenario analysis is shown in figure 13.

Table 6. Scenario Analysis of replacing coal with brick and its impact on total emission of brick

Scenario	Description	Emission per Brick for burning (Kg CO ₂ -eq)	Total Emission per brick (Kg Co ₂ -eq)
Base Case	Present scenario with coal used for burning	0.49	0.536
Scenario I	Examine the CO ₂ -eq emission from the material production after replacing 25% of energy generated from coal by biomass	0.4325	0.4785

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Scenario II	Examine the CO ₂ -eq emission from the material production after replacing 50% of energy generated from coal by biomass	0.375	0.421
Scenario III	Examine the CO ₂ -eq emission from the material production after replacing 75% of energy generated from coal by biomass	0.3175	0.3635
Scenario IV	Examine the CO ₂ -eq emission from the material production after replacing 100% of energy generated from coal by biomass	0.26	0.306

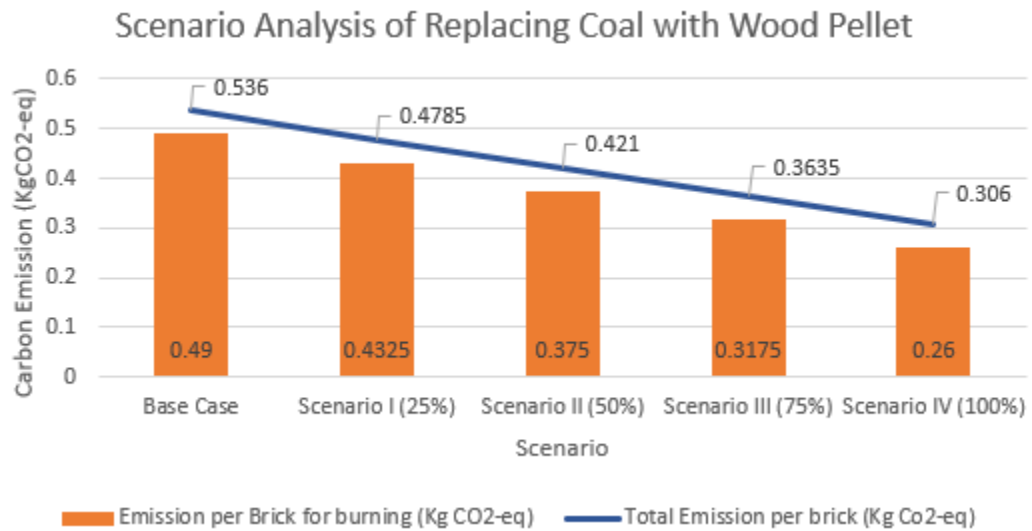


Figure 13. Scenario analysis of replacing coal with wood pellet during burning of *Dachi Appa*

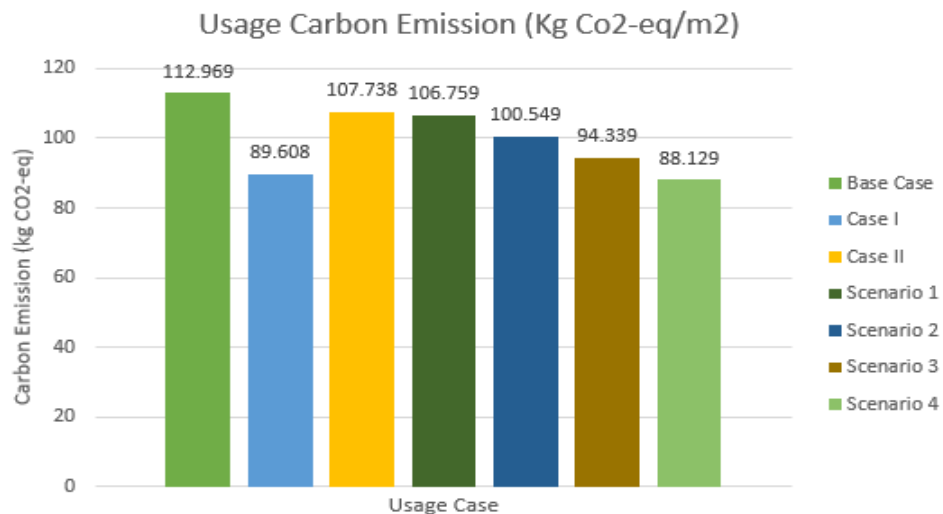


Figure 14. Usage carbon emission after replacing coal with wood pellet during burning of *Dachi Appa*

Replacing coal with electricity would also be another good option. The electricity mix of Nepal consist of 82.51% electricity from hydropower and 17.49% imported from India with overall transmission and distribution loss accounting to 17.18% (NEA, 2022). The energy value of electricity is 3.6 MJ/KWh. This indicates that for burning a brick an electricity equivalent to 0.95 KWh is required leading to an equivalent emission of 0.43 kgCO₂. With the value of emission our electricity mix have, using *Dachi Appa* (base case) cannot be as sustainable as regular brick wall with plaster and paint (Case I) in carbon footprint despite replacing 100% coal with electricity.

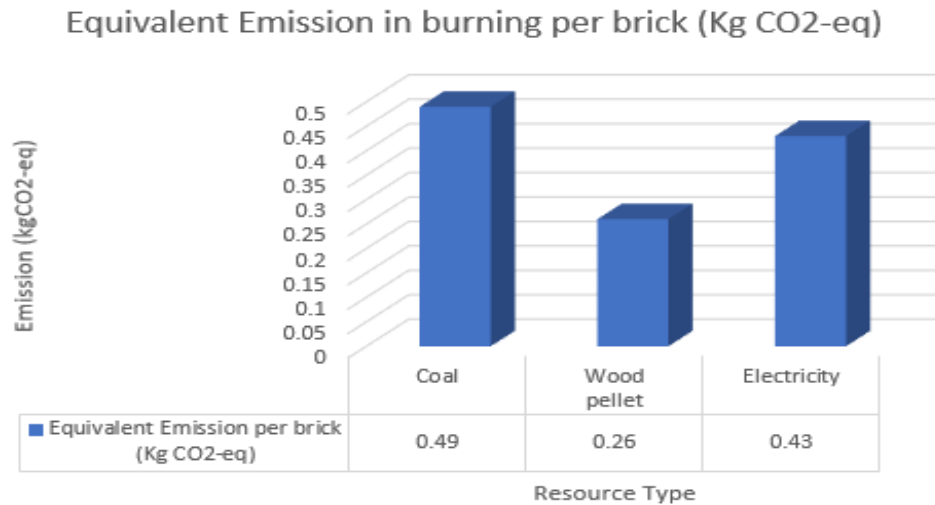


Figure 15. Equivalent emission for burning each *Dachi Appa* using different resource

5.7 Discussion

This study aimed to assess the environmental impact of *Dachi Appa* bricks using a cradle-to-grave LCA framework, focusing on raw material extraction, production, transportation, use, and end-of-life phases. The study reveals the embodied carbon emission of each *Dachi Appa* during its lifecycle stage with brick manufacturing stage to be the most carbon-intensive stage, with coal being the primary contributor to emission.

The carbon emissions associated with the manufacturing of each *Dachi Appa* brick are calculated to be 0.53 kg CO₂-eq. A recent study on the embodied carbon emissions of regular bricks, based on energy audit data from 27 brick industries across Nepal, reports an

average value of 0.502 kg CO₂-eq per brick (KC et al., 2025). This indicates that the embodied emissions of *Dachi Appa* bricks are nearly equivalent to those of regular bricks, which can be attributed to the similarity in their production processes.

One notable distinction in this study is the inclusion of manpower as an energy source, contributing 6.1% to the total carbon emissions during the manufacturing stage of *Dachi Appa*. This factor is often excluded in other studies on embodied energy, which may explain why the emissions of *Dachi Appa* bricks are calculated to be 5.5% higher than those of regular bricks. The slightly higher emissions for *Dachi Appa* may therefore be attributed to this broader accounting approach.

The transportation emissions for each *Dachi Appa* brick, calculated at 0.002 kg CO₂-eq per kilometer, may appear to have a minimal impact on the overall lifecycle emissions of the brick. However, as the transportation distance increases, coupled with the inefficiencies in road networks, poor road surface conditions, and challenging terrain across Nepal, this factor can substantially affect the embodied carbon footprint. This impact is particularly significant for regions where long-distance transportation is required, not only for delivering finished bricks to construction sites but also for sourcing raw materials and transporting waste to disposal sites. The compounded effect of inefficient transportation infrastructure amplifies the carbon emissions associated with each stage of the brick's lifecycle. Furthermore, transportation emissions can vary widely based on the type of vehicle used, its load capacity, and fuel efficiency. Heavy reliance on diesel-powered vehicles, common in Nepal, further exacerbates emissions. Transitioning to more efficient or alternative fuel vehicles, optimizing logistics, and improving road infrastructure can help mitigate these emissions. Addressing transportation-related emissions is essential for reducing the overall embodied carbon of bricks and enhancing the sustainability of traditional materials like *Dachi Appa*. Incorporating transportation considerations into policy planning and infrastructure development, such as improving rural road conditions and encouraging regional sourcing of materials, can significantly reduce emissions while supporting local economies.

The standard size of *Dachi Appa* (8"x4"x2") is only one inch shorter in length compared to the regular brick (9"x4"x2") commonly available in the market. However, its unique

trapezoidal design allows for a seamless veneer face without visible mortar joints on the front and a thin layer of mortar joints at the back. To construct a 1 m² wall, *Dachi Appa* requires 108 bricks, whereas a wall built with regular bricks, which features thicker mortar joints between layers, requires only 68 bricks for the same area.

Since bricks are a dominant factor influencing the environmental impact of a brick wall, the higher number of bricks needed for *Dachi Appa* walls results in a higher overall carbon footprint. This difference is further justified by the current usage practices of *Dachi Appa*, as its unique design and construction requirements contribute to a higher carbon footprint in the use phase compared to conventional wall systems.

While *Dachi Appa* holds significant cultural and architectural value, its current production methods result in a high carbon footprint, primarily due to the reliance on coal. Wood pellets are found to be more sustainable than coal despite their potentially higher emissions during combustion due to several key factors related to their lifecycle, renewability, and environmental impact.

Wood pellets are derived from biomass, a renewable resource. The carbon dioxide released during the combustion of wood pellets is part of the natural carbon cycle. The trees or plants that serve as biomass sources absorb carbon dioxide from the atmosphere during their growth, offsetting the emissions released during burning. This creates a near net-zero carbon footprint over the lifecycle of wood pellets, assuming sustainable forestry practices. Coal, on the other hand, is a fossil fuel. Its carbon emissions are "new" additions to the atmosphere, accumulated over millions of years and not part of the current carbon cycle. Burning coal contributes to a net increase in atmospheric CO₂, driving climate change. While wood pellets may emit more CO₂ during combustion per unit of energy, their lifecycle emissions (from production, processing, transportation, and end use) are significantly lower than those of coal. The production and transport of coal involve energy-intensive processes and result in substantial emissions from mining.

Scenario analysis of the study has shown that replacing coal with biomass, such as wood pellets, during burning of *Dachi Appa* can significantly reduce emissions, making the brick more sustainable. Their use not only reduce emission but also aligns with global climate goals and the transition towards, renewable energy systems.

The comparative analysis highlights that the *Dachi Appa* walls currently have higher carbon footprint than conventional wall systems but can achieve a competitive footprint with cleaner production methods. The finding emphasizes the importance of balancing cultural preservation with environmental sustainability through policy support, technological innovation, and industry collaboration. Transition to cleaner energy sources in *Dachi Appa* production is crucial for aligning its use with global sustainability goals.

The study also displayed that transitioning from coal to electricity in brick production, given Nepal's current electricity mix, offers only limited emission reductions compared to the use of biomass. This limited impact is attributed to several factors. Firstly, Nepal's electricity mix partially relies on imports from India, where fossil fuels constitute a significant share of energy generation. Secondly, the conventional methods used for the transmission and distribution of electricity across the country result in substantial energy losses. These transmission and distribution losses increase the overall carbon footprint per kWh of electricity, diminishing its effectiveness as a low-carbon alternative. In contrast, wood pellets, as a renewable biomass fuel, have demonstrated greater potential for reducing emissions compared to electricity in the current energy scenario.

Another significant issue identified during the study of *Dachi Appa* production is the inefficiency of the brick-burning process, with an average wastage rate of approximately 35%. Given that the burning process is the most carbon-intensive phase of brick production, this high level of wastage exacerbates the environmental impact. The inefficient burning not only increases fuel consumption but also leads to unnecessary emissions, compounding the overall carbon footprint of each brick. This inefficiency underscores the urgent need for improvements in brick-burning techniques. Addressing this issue requires not only a shift to cleaner and more efficient kiln technologies but also better process management to minimize wastage. Techniques such as improving kiln insulation, optimizing firing cycles, and adopting advanced monitoring systems could significantly reduce both fuel use and material loss.

Traditional materials like *Dachi Appa* play a vital role in preserving cultural and architectural heritage, particularly in the context of Nepal's vernacular architecture. The promotion of such materials by government bodies, local communities, and preservation

initiatives reflects their commitment to safeguarding national identity and historical legacy. However, the findings of this study highlight a critical oversight: the environmental implications of *Dachi Appa*'s production, use, and disposal are not adequately understood or addressed. There is little to no government focus on addressing the environmental sustainability of *Dachi Appa*. Policies promoting its use often emphasize cultural preservation without considering the associated ecological consequences, such as emissions from traditional kilns, excessive energy consumption, and the environmental impacts of clay mining.

Misguided policies that encourage the use of *Dachi Appa* without addressing its environmental implications could inadvertently lead to environmental degradation. For instance, the continued use of nonrenewable resources like coal and inefficient kiln technologies not only exacerbates greenhouse gas emissions but also contributes to air pollution, which has direct implications for public health and the environment. Similarly, unsustainable clay extraction practices can lead to soil erosion and habitat destruction. Lack of reuse and recycle policy by government has ended up landfills with huge pile of production, construction and dismantled building wastage including wastage from *Dachi Appa*. Hence government must create a framework where traditional materials like *Dachi Appa* are not only preserved for their cultural significance but also contribute to the broader goals of environmental sustainability and climate resilience.

6. CONCLUSION

The study explores the Life Cycle Assessment (LCA) of *Dachi Appa*, a Traditional Nepali Veneer Brick, with the aim of evaluating its environmental impacts across its cradle-to-grave journey and proposing strategies to enhance its sustainability. While *Dachi Appa* holds immense historical and cultural significance, embodying centuries of architectural tradition, the study also highlights the environmental challenges associated with its production and use in modern construction.

The research revealed that the cradle-to-gate phase contributes the most to the carbon footprint of *Dachi Appa*, with the firing process being the most significant emitter. Traditional kilns, which often use coal as fuel, are a major source of emissions, necessitating the exploration of alternative, low-carbon fuels.

The transportation phase of *Dachi Appa* was found to have moderate emissions due to the localized production and distribution of the material. However, inefficiencies in logistics and the reliance on outdated vehicles present opportunities for optimization.

The usage phase revealed a notable challenge: the smaller size of *Dachi Appa* and its seamless front-face design require a higher number of bricks per square meter compared to regular bricks. This increases the material requirement and consequently results in higher emissions for the construction of a *Dachi Appa* wall under current practices. When compared to regular brick walls with plaster (Case 1) and with exterior tiles (Case 2), the carbon footprint of *Dachi Appa* walls was found to be higher. This finding emphasizes the urgent need to explore sustainable alternatives to reduce the environmental impact of *Dachi Appa* without compromising its cultural and historical value.

Scenario analysis demonstrated that replacing coal with wood pellets substantially reduces emissions, making *Dachi Appa* more environmentally competitive. Though achieving a 100% replacement of coal with wood pellets might be challenging in practice, adopting a regulated mix of these fuels can result in significant emission reductions.

The end-of-life phase revealed that *Dachi Appa* is a durable brick, offering advantages of reuse even after demolition of old structure. While current practices predominantly involve

landfilling, systematic reuse and recycling of the bricks could further enhance their sustainability and reduce waste.

As Nepal strives to achieve its net-zero targets and align with global sustainable development goals, it is critical to strike a balance between preserving traditional materials like *Dachi Appa* and addressing their environmental impacts. This study underscores the need for innovation in production processes, such as optimizing kiln technology and exploring alternative fuels, to minimize emissions while retaining the cultural essence of *Dachi Appa*.

The findings of this research not only contribute to the broader discourse on sustainable construction but also provide actionable insights for integrating traditional materials into modern sustainability frameworks. By making *Dachi Appa* more environmentally sustainable, we can preserve its cultural heritage for future generations while contributing to a greener future for Nepal.

7. RECOMMENDATION

Based on the findings of this study, the following recommendations are proposed to improve the sustainability of *Dachi Appa* production and to balance cultural preservation with environmental stewardship:

1. Adoption of Regulated Fuel Mix

The study suggests the adoption of a regulated mix of coal and biomass pellets as a transitional solution to reduce emissions during the brick-burning process. Biomass pellets, being a renewable energy source, can help offset the carbon footprint of coal while maintaining the energy requirements for efficient firing.

2. Exploration of Efficient Burning Techniques

Given the inefficiency of the current burning process, with an average wastage of 35%, there is a pressing need to explore and implement advanced and efficient burning techniques. Innovations in kiln technology, optimization of firing cycles, and enhanced process management should be prioritized to minimize fuel consumption and material loss.

3. Government Intervention and Regulation

Effective government intervention is critical to addressing the environmental challenges associated with *Dachi Appa* production. This includes formulating strict regulations for sustainable clay extraction, emissions from kilns, and waste management. Additionally, providing financial and technical incentives for adopting cleaner technologies and sustainable practices will ensure better compliance and environmental outcomes.

4. Informed Promotion of Traditional Materials

While *Dachi Appa* holds significant cultural and architectural value, its promotion should be based on a thorough understanding of its environmental implications. Policies should integrate scientific evaluations, such as life cycle assessments, to ensure that the material's use aligns with sustainability goals without compromising cultural heritage.

5. Future Research Directions

To build upon this study, further research is recommended in the following areas:

- **Social, Cultural, and Economic Impacts:** Evaluating the broader implications of *Dachi Appa* production and use on communities, livelihoods, and cultural preservation.
- **Variability in Production:** Addressing inconsistencies in production practices across different factories to standardize and improve sustainability.
- **Operational Carbon Emissions:** Assessing the emissions associated with the operational emission of *Dachi Appa*, including its thermal performance and durability, to provide an understanding of its environmental impact and benefits over regular burnt brick.

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ANNEX A: DATA COLLECTION AND CALCULATION

Table 7. Cradle-to-Gate Carbon Emission Calculation (for 500 bricks)

S. N.	Process	Description	Equipment Use	Resources Use	Quantity	Unit	Emission Factor	Unit	Total emission (kgCO ₂ -eq)
1	Clay Extraction	Clay excavation site is located in sarashwotikhel, Bhaktapur. The excavator excavates 70m ³ of clay in 30-minute consuming 9liter of diesel. Observation data from factory shows 1m ³ of clay can produce 500 pieces of brick. *	Excavator,	Diesel	0.128	L	3.75	kgCO ₂ -eq/L	0.48
			Komatsu PC210 (Diesel use: 18 ltr/hr) *	Manpower	0.05	hour	0.12	KgCO ₂ -eq/hr	0.006
2	Transport to factory	The distance between excavation site and factory is around 6.5km. The tripper carries 7m ³ of clay in one trip. *	Tripper,	Diesel	0.72	L	3.75	kgCO ₂ -eq/L	2.7
		The travel time is taken 40 minutes for round trip and 3 minutes for loading. *	Tata 1613 (Mileage: 2.58 Km/ltr) **	Manpower	0.102	hour	0.12	KgCO ₂ -eq/hr	0.012

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S. N.	Process	Description	Equipment Use	Resources Use	Quantity	Unit	Emission Factor	Unit	Total emission (kgCO ₂ -eq)
3	Stacking	Energy use is quantified for manpower use for staking wastage from raw brick production to stacking site. One man stack one wheel barrow (0.08m ³) wastage in 5minute. *		Manpower	1.042	hour	0.12	KgCO ₂ -eq/hr	0.125
4	Transport to mixing chamber	The distance between mixing area and stacking area is 150m. Truck carry 2.8 m ³ clay. *	Truck, Mahindra Load	Diesel	0.036	L	3.75	kgCO ₂ -eq/L	0.135
		2 person takes 15 minute to load and 10 minute to unload the material*	king, (Mileage: 2.95 km/tr)	Manpower	0.298	hour	0.12	KgCO ₂ -eq/hr	0.036
5	Mixing/Cake Production	300 brick cake is produced by 3 people working 8 hour a day*		Manpower	40	hour	0.12	KgCO ₂ -eq/hr	4.8

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S. N.	Process	Description	Equipment Use	Resources Use	Quantity	Unit	Emission Factor	Unit	Total emission (kgCO ₂ -eq)
6	Cake Transport to brick moulding site	The distance between mixing area and Moulding area is 250m. The truck carry 2000 pcs at a time.	Truck , Mahindra Load king,	Diesel	0.042	L	3.75	kgCO ₂ -eq/L	0.158
		4 person takes 1.5 hour to load and unload the material	(Mileage: 2.95 km/lt r) **	Man power	1.5	hour	0.12	KgCO ₂ -eq/hr	0.18
7	Raw Brick Production	1 person produces 200 bricks working 8 hours		Man power	20	hour	0.12	KgCO ₂ -eq/hr	2.4
8	Sun Drying								0
9	Red Mud Coloring	Red Mud carried from dakshinkali (46 Km round trip) 1000 kg at a time. 2 Kg red mud is used for 600 bricks*	Truck , Mahindra Load king,	Diesel	0.026	L	3.75	kgCO ₂ -eq/L	0.098

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S. N.	Process	Description	Equipment Use	Resources Use	Quantity	Unit	Emission Factor	Unit	Total emission (kgCO ₂ -eq)
		1 person travel 80 minute and take 20 minute to load and unload the material*	(Mileage: 2.95 km/lt r) **	Manpower	0.003	hour	0.12	KgCO ₂ -eq/hr	0
		1-person colour 600 bricks working 8 hours*		Manpower	6.667	hour	0.12	KgCO ₂ -eq/hr	0.8
10	Transport to Chimney and Stacking	The distance between Moulding area and chimney is 500m. The truck carry 2000 pcs at a time, wastage accounts for 100 bricks in each trip.*	Truck, Mahindra Load king, (Mileage: 2.95 km/lt r) **	Diesel	0.085	L	3.75	kgCO ₂ -eq/L	0.319
		4 person takes 3 hours to load, unload and stack the dried brick in chimney*		Manpower	3	hour	0.12	KgCO ₂ -eq/hr	0.36
Total Emission before brick burning(kgCO ₂ -eq)									12.609
Estimated wastage upto this phase (5%)(kgCO ₂ -eq)									0.63
Total Emission before burning including wastage(kgCO₂-eq)									13.239

Life Cycle Assessment of *Dachi Appa*: A Traditional Nepali Veneer Brick

S. N.	Process	Description	Equipment Use	Resources Use	Quantity	Unit	Emission Factor	Unit	Total emission (kgCO ₂ -eq)
11	Brick Burning	17000 bricks are burnt at a time in chimney. 150-ton coal is used to burn 1500000 bricks.		Coal	50	kg	3.6	kgCO ₂ -eq/kg	180
		18 person (6 person in each shift) working 8 hour for 10 days		Man power	42.353	hour	0.12	KgCO ₂ -eq/hr	5.082
		Wastage in burning accounts to 30-40% (Avg-35%) of total burnt brick							
Total Emission during brick burning(kgCO ₂ -eq)									185.082
Estimated wastage in this phase (35%)(kgCO ₂ -eq)									64.779
Total Emission in burning including wastage(kgCO₂-eq)									249.861
12	Transport to inventory storage and stacking	The distance between chimney and inventory storage is 100m. The truck carry 2000 pcs at a time, wastage accounts for 30 bricks in each trip. *	Truck, Mahindra Load king, (Mile age: 2.95	Diesel	0.017	L	3.75	kgCO ₂ -eq/L	0.064

Life Cycle Assessment of *Dachi Appa*: A Traditional Nepali Veneer Brick

S. N.	Process	Description	Equipment Use	Resources Use	Quantity	Unit	Emission Factor	Unit	Total emission (kgCO ₂ -eq)
		4 person takes 2 hours to load, unload and stack the dried brick in inventory storage*	km/lt r) **	Man power	2	hour	0.12	KgCO ₂ -eq/hr	0.24
Total Emission during brick transport(kgCO ₂ -eq)									0.304
Estimated wastage in this phase (1.5%) (kgCO ₂ -eq)									0.005
Total Emission in transport including wastage(kgCO₂-eq)									0.309
13	Factory Electricity Use	The Factory produces 1500000 bricks in one month. An average electricity consumption of the factory is 30000 units per month. *		Electricity	10	KWh	0.45	kgCO ₂ -eq/KWh	4.5
Total Emission during production of 500 brick including wastage(kgCO₂-eq)									267.909
Total Emission during production of each brick(kgCO₂-eq)									0.536

Table 8. Transportation Carbon Emission Calculation (for 500 bricks)

S. N.	Process	Description	Equipment Use	Resources Use	Quantity	Unit	Emission Factor	Unit	Total emission (kgCO ₂ -eq)
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14	Transport to site	The distance is taken per 1000m. The truck carry 2000 pcs at a time, wastage accounts for 50 bricks in each trip. *	Truck, Mahindra Load king, (Mile	Diesel	0.085	L	3.75	kgCO ₂ -eq/L	0.319
		4 person takes 2 hours to load, unload and stack the brick*	age: 2.95 km/lt r) **	Manpower	2	hour	0.12	KgCO ₂ -eq/hr	0.24
Total Emission during brick transport(kgCO ₂ -eq)									0.559
Estimated wastage in this phase (2.5%) (kgCO ₂ -eq)									0.014
Total Emission during transportation of 500 brick including wastage(kgCO₂-eq)									0.573
Total Emission during transportation of each brick per Km one way(kgCO₂-eq)									0.001
Total Emission during transportation of each brick per Km round trip(kgCO₂-eq)									0.002

Table 9. Usage Carbon Emission Calculation (for 1m² brick wall)

S.N	Processes	Description	Equipment Use	Resources Use	Quantity	Unit	Emission Factor	Unit	Total emission (kgCO ₂ -eq)
15	Usage at site	For 1m ² <i>Dachi Appa</i> in 1:4		<i>Dachi Appa</i>	108	nos	0.536	kgCO ₂ -eq/nos	57.888

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<p>cement sand mortar it requires 108 nos dachi brick, 12.75 kg cement and 0.0322m3 sand</p> <p>4.72 working hour of a manpower is required for 1m2 wall</p> <p>for 1m2 silicon paint 2 coats over <i>Dachi Appa</i> requires 0.2 kg paint</p> <p>0.4 working hour of a manpower is required for painting 1m2 wall</p>	Cement	12.75	kg	0.73949	kgC O2- eq/kg	9.428
	sand	57.60 0	kg	0.00551	kgC O2- eq/kg	0.317
	Manpower	4.72	hour	0.12	KgC O2- eq/hr	0.566
	silicon paint	0.200	kg	6.31	KgC O2- eq/kg	1.262
<p>Total Emission during construction of 1m2 dachi brick wall(kgCO2-eq)</p>						69.509
<p>Total Emission during usage of each dachi brick in wall(kgCO2-eq)</p>						0.644
<p>Additional Emission during usage of each dachi brick in wall(kgCO2-eq)</p>						0.108

Table 10. Dismantling Carbon Emission Calculation (for 1m² brick wall)

S. N.	Process	Description	Equipment Use	Resources Use	Quantity	Unit	Emission Factor	Unit	Total emission (kgCO ₂ -eq)
16	Dismantling	2 working hour of a manpower is required for dismantling 1m ² wall		Manpower	2	hour	0.12	KgCO ₂ -eq/hr	0.24
Total Emission during dismantling of 1m² dachi brick wall(kgCO₂-eq)									0.24
Total Emission during dismantling of each dachi brick in wall(kgCO₂-eq)									0.002

* Refers to data obtained based on observation and experience of associated stakeholders

** data from calculation

Table 11. Life Cycle Carbon Emission of *Dachi Appa* brick

Life-cycle Stage	Life cycle Carbon Emission (KgCo ₂ -eq)
Cradle-to-Gate	0.536
Transportation (per Km)	0.002
Usage	0.108
End-of-Life (per km for disposal)	0.004
Total	0.65

Table 12. Resource share in life cycle carbon emission of Dachi Appa

Resource use	Emission (kgCO ₂ -eq)	Emission Share (%)
Manpower	17.36	6.44
Diesel	4.80	1.78
Coal	243.00	1.67
Electricity	4.50	90.12

Table 13. Length of road in road network with road surface characteristics in Kathmandu valley

Road Network	Total SRN(Km)	Proportion (%)	Total LRN (Km)	Proportion (%)	Total (Km)	Proportion (%)
Blacked						
Topped	312	65.96	286	16.38	598	27
Gravel	85	17.97	1012	57.96	1097	49.4
Earthen	76	16.07	448	25.66	524	23.6
Total	473		1746		2219	

Table 14. Vehicle type and fuel consumption in different road network inside Kathmandu valley

Vehicle Type	Fuel Consumption (Km/L)			
	Normal Condition	SRN	LRN	Average
Mini Truck	4	3.88	2.7	2.95
Heavy Truck	3.5	3.39	2.36	2.58

Table 15. Estimation of material and manpower (As per specification of DUDBC and Department of Archaeology)

For 1m² wall of 9" thickness with cement sand mortar 1:4			
Skilled	0.322	person	

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unskilled	0.644	person	
Brick	128.8	nos	
cement	22.08	kg	
Sand	0.0621	m ³	
For 1m² wall of 4" thickness with cement sand mortar 1:4			
Skilled	0.168	person	
unskilled	0.336	person	
Brick	67.2	nos	
cement	11.52	kg	
Sand	0.0324	m ³	
For 1m² <i>Dachi Appa</i> wall with cement sand mortar 1:4			
Skilled	0.45	person	
unskilled	0.14	person	
Dachi	107.6	nos	
cement	12.75	kg	
Sand	0.0322	m ³	
For 1m² outer plaster 20mm with cement sand mortar 1:4			
Skilled	0.14	person	
unskilled	0.19	person	
cement	8.1	kg	
Sand	0.022	m ³	
for 1m² wall tile with cement sand mortar 1:4			
Skilled	1.3	person	
unskilled	0.45	person	
cement	5.6	kg	
Sand	0.0152	kg	Density of sand: 1800 kg/m ³
Tile	1.1	m ²	
For 1m² weather coat paint 2 coats over 1 coat primer			
Skilled	0.058	person	
unskilled	0.058	person	

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Primer	0.08	Liter	
Paint	0.16	liter	
For 1m2 silicon paint 2 coats			
Skilled	0.03	person	
unskilled	0.02	person	
Paint	0.2	liter	
For dismantling 1m2 wall			
manpower	0.2544	person	

Table 16. Usage carbon emission calculation (for 1m2 wall)

Usage Carbon Emission per m2 of dachi brick wall (4")									
S. N.	Processes	Description	Equipment Use	Resources Use	Quantity	Unit	Emission Factor	Unit	Total emission (kgCO ₂ -eq)
15	Usage at site	For 1m2 <i>Dachi Appa</i> in 1:4 cement sand mortar it requires 108 nos dachi brick, 12.75 kg cement and 0.0322m3 sand		<i>Dachi Appa</i>	108	nos	0.536	kgCO ₂ -eq/nos	57.888
				Cement	12.75	kg	0.73949	kgCO ₂ -eq/kg	9.428
				sand	57.600	kg	0.00551	kgCO ₂ -eq/kg	0.317
		Manpower		4.72	hour	0.12	KgCO ₂ -eq/hr	0.566	
		4.72 working hour of a manpower is required for 1m2 wall							

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		for 1m ² silicon paint 2 coats over <i>Dachi Appa</i> requires 0.2 kg paint		silicon paint	0.200	kg	6.31	KgC O ₂ -eq/kg	1.262
		0.4 working hour of a manpower is required for painting 1m ² wall		Manpower	0.4	hour	0.12	KgC O ₂ -eq/hr	0.048
69.50									
Total Emission during construction of 1m² dachi brick wall(kgCO₂-eq)									
9									
Usage Carbon Emission per m² of regular brick wall (4")									
S. N.	Processes	Description	Equipment Use	Resources Use	Quantity	Unit	Emission Factor	Unit	Total emission (kgCO ₂ -eq)
15	Usage at site	For 1m ² brick wall in 1:4 cement sand mortar it requires 68 nos brick, 11.52 kg cement and 0.0324m ³ sand		brick	68	nos	0.502	kgCO ₂ -eq/nos	34.136
				Cement	11.52	kg	0.73949	kgCO ₂ -eq/kg	8.519
				sand	58.320	kg	0.00551	kgCO ₂ -eq/kg	0.321
		Manpower		4.03	hour	0.12	KgC O ₂ -eq/hr	0.484	

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	required for 1m ² wall					
	for 1m ² plaster 20mm thick in 1:4 cement sand mortar requires 8.1kg cement and 0.022m ³ sand	cement	8.100	kg	0.73949	KgC O ₂ -eq/kg 5.99
	2.64 working hour of a manpower is required for plastering 1m ² wall	sand	39.600	kg	0.00551	kgCO ₂ -eq/kg 0.218
	for 1m ² weather coat paint 2 coat over one coat primer requires 0.08 ltr primer and 0.16 ltr paint	Manpower	2.64	hour	0.12	KgC O ₂ -eq/hr 0.317
	0.93 working hour of a manpower is required for painting 1m ² wall	Primer	0.08	ltr	0.659	KgC O ₂ -eq/ltr 0.053
		paint	0.16	ltr	1.81	KgC O ₂ -eq/ltr 0.29
		Manpower	0.93	hour	0.12	KgC O ₂ -eq/hr 0.112
Total Emission during construction of 1m² brick wall(kgCO₂-eq)						50.44
Usage Carbon Emission per m² of wall tile						

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S. N.	Process	Description	Equipment Use	Resources Use	Quantity	Unit	Emission Factor	Unit	Total emission (kgCO ₂ -eq)
15	Usage at site	For 1m ² wall tile in 1:4 cement sand mortar it requires 1.1m ² of tiles nos brick, 5.6 kg cement and 0.015m ³ sand		Tile	1.1	m ²	11.42	kgCO ₂ -eq/m ²	12.562
				Cement	5.60	kg	0.73949	kgCO ₂ -eq/kg	4.141
				sand	27.000	kg	0.00551	kgCO ₂ -eq/kg	0.149
				Manpower	14	hour	0.12	KgCO ₂ -eq/hr	1.68
18.532									
Total Emission during construction of 1m² wall tile(kgCO₂-eq)									
Usage Carbon Emission per m ² of dachi brick wall (Dachi Burnt using 50% coal and 50% wood Pellet)									
S. N.	Process	Description	Equipment Use	Resources Use	Quantity	Unit	Emission Factor	Unit	Total emission (kgCO ₂ -eq)
15	Usage at site	For 1m ² <i>Dachi Appa</i> in 1:4 cement		<i>Dachi Appa</i>	108	nos	0.421	kgCO ₂ -eq/nos	45.468

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		sand mortar it requires 108 nos dachi brick, 12.75 kg cement and 0.0322m ³ sand		Cement	12.75	kg	0.7394	kgCO ₂ -eq/kg	9.428
				sand	57.600	kg	0.0055	kgCO ₂ -eq/kg	0.317
				Manpower	4.72	hour	0.12	KgC O ₂ -eq/hr	0.566
				silicon paint	0.200	kg	6.31	KgC O ₂ -eq/kg	1.262
				Manpower	0.4	hour	0.12	KgC O ₂ -eq/hr	0.048
		4.72 working hour of a manpower is required for 1m ² wall							
		for 1m ² silicon paint 2 coats over <i>Dachi Appa</i> requires 0.2 kg paint							
		0.4 working hour of a manpower is required for painting 1m ² wall							
Total Emission during construction of 1m² dachi brick wall(kgCO₂-eq)								57.08	9
Usage Carbon Emission per m ² of dachi brick wall (Dachi Burnt using 75% coal and 25% wood Pellet)									
S. N.	Processes	Description	Equipment Use	Resources Use	Quantity	Unit	Emission Factor	Unit	Total emission (kgCO ₂ -eq)

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15	Usage at site	For 1m2 <i>Dachi Appa</i> in 1:4 cement sand mortar it requires 108 nos dachi brick, 12.75 kg cement and 0.0322m3 sand	<i>Dachi Appa</i>	108	nos	0.4785	kgCO ₂ -eq/nos	51.678
		4.72 working hour of a manpower is required for 1m2 wall	Cement	12.75	kg	0.73949	kgCO ₂ -eq/kg	9.428
		for 1m2 silicon paint 2 coats over <i>Dachi Appa</i> requires 0.2 kg paint	sand	57.600	kg	0.00551	kgCO ₂ -eq/kg	0.317
		0.4 working hour of a manpower is required for painting 1m2 wall	Manpower	4.72	hour	0.12	KgC O ₂ -eq/hr	0.566
			silicon paint	0.200	kg	6.31	KgC O ₂ -eq/kg	1.262
			Manpower	0.4	hour	0.12	KgC O ₂ -eq/hr	0.048
Total Emission during construction of 1m2 dachi brick wall(kgCO₂-eq)								63.299

Usage Carbon Emission per m2 of dachi brick wall (Dachi Burnt using 25% coal and 75% wood Pellet)

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S. N.	Processes	Description	Equipment Use	Resources Use	Quantity	Unit	Emission Factor	Unit	Total emission (kgCO ₂ -eq)
15	Usage at site	For 1m ² <i>Dachi Appa</i> in 1:4 cement sand mortar it requires 108 nos dachi brick, 12.75 kg cement and 0.0322m ³ sand		<i>Dachi Appa</i>	108	nos	0.3635	kgCO ₂ -eq/nos	39.258
				Cement	12.75	kg	0.73949	kgCO ₂ -eq/kg	9.428
				sand	57.600	kg	0.00551	kgCO ₂ -eq/kg	0.317
				Manpower	4.72	hour	0.12	KgCO ₂ -eq/hr	0.566
		for 1m ² silicon paint 2 coats over <i>Dachi Appa</i> requires 0.2 kg paint		silicon paint	0.200	kg	6.31	KgCO ₂ -eq/kg	1.262
0.4 working hour of a manpower is required for painting 1m ² wall		Manpower	0.4	hour	0.12	KgCO ₂ -eq/hr	0.048		

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<p align="right">50.87</p> <p align="center">Total Emission during construction of 1m2 dachi brick wall(kgCO2-eq)</p> <p align="right">9</p>									
<p>Usage Carbon Emission per m2 of dachi brick wall (Dachi Burnt using 0% Coal and 100% wood Pellet)</p>									
S. N.	Processes	Description	Equipment Use	Resources Use	Quantity	Unit	Emission Factor	Unit	Total emission (kgCO2-eq)
15	Usage at site	For 1m2 <i>Dachi Appa</i> in 1:4 cement sand mortar it requires 108 nos dachi brick, 12.75 kg cement and 0.0322m3 sand		<i>Dachi Appa</i>	108	nos	0.306	kgCO2-eq/nos	33.048
				Cement	12.75	kg	0.73949	kgCO2-eq/kg	9.428
				sand	57.600	kg	0.00551	kgCO2-eq/kg	0.317
				Manpower	4.72	hour	0.12	KgCO2-eq/hr	0.566
		for 1m2 silicon paint 2 coats over <i>Dachi Appa</i> requires 0.2 kg paint	silicon paint	0.200	kg	6.31	KgCO2-eq/kg	1.262	
0.4 working hour of a manpower is	Manpower	0.4	hour	0.12	KgCO2-eq/hr	0.048			

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		required for painting 1m2 wall							
Total Emission during construction of 1m2 dachi brick wall(kgCO2-eq)									44.669
Usage Carbon Emission per m2 of regular brick wall (9")									
S. N.	Processes	Description	Equipment Use	Resources Use	Quantity	Unit	Emission Factor	Unit	Total emission (kgCO2-eq)
15	Usage at site	For 1m2 brick wall in 1:4 cement sand mortar it requires 129 nos brick, 22.08 kg cement and 0.0621m3 sand		brick	129	nos	0.502	kgCO2-eq/nos	64.758
				Cement	22.08	kg	0.73949	kgCO2-eq/kg	16.328
				sand	111.780	kg	0.00551	kgCO2-eq/kg	0.616
		Manpower		7.72	hour	0.12	KgCO2-eq/hr	0.926	
		cement		8.100	kg	0.73949	KgCO2-eq/kg	5.99	
		sand		39.600	kg	0.00551	kgCO2-eq/kg	0.218	
		7.72 working hour of a manpower is required for 1m2 wall							
		for 1m2 plaster 20mm thick in 1:4 cement sand mortar requires 8.1kg							

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		cement and 0.022m ³ sand							
		2.64 working hour of a manpower is required for plastering 1m ² wall		Manpower	2.64	hour	0.12	KgC O ₂ -eq/hr	0.317
		for 1m ² weather coat paint 2 coat over one coat primer requires 0.08 ltr primer and 0.16 ltr paint		Primer	0.08	ltr	0.659	KgC O ₂ -eq/ltr	0.053
		0.93 working hour of a manpower is required for painting 1m ² wall		paint	0.16	ltr	1.81	KgC O ₂ -eq/ltr	0.29
				Manpower	0.93	hour	0.12	KgC O ₂ -eq/hr	0.112
Total Emission during construction of 1m² brick wall(kgCO₂-eq)									89.60
8									
Usage Carbon Emission per m ² of regular brick wall (4" wall only)									
S. N.	Process	Description	Equipment Use	Resources Use	Quantity	Unit	Emission Factor	Unit	Total emission (kgCO ₂ -eq)
15	Usage at site	For 1m ² brick wall in 1:4		brick	68	nos	0.502	kgCO ₂ -eq	34.136

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	cement sand mortar it requires 68 nos brick, 11.52 kg cement and 0.0324m3 sand	4.03 working hour of a manpower is required for 1m2 wall					eq/nos		
			Cement	11.52	kg	9	0.7394	kgCO ₂ -eq/kg	8.519
			sand	58.320	kg	1	0.0055	kgCO ₂ -eq/kg	0.321
			Manpower	4.03	hour	0.12		KgC O ₂ -eq/hr	0.484
Total Emission during construction of 1m2 brick wall(kgCO₂-eq)								43.46	

Table 17. Scenario analysis (Replacement of Coal by wood pellets) (for 1 brick)

Scenario	Description	Emission per Brick for burning (Kg CO ₂ -eq)	Total Emission per brick (Kg Co ₂ -eq)
Base Case	Present scenario with coal used for burning	0.49	0.536
Scenario I (25%)	Examin the CO ₂ -eq emission from the material production after replacing 25% of energy generated from coal by biomass	0.4325	0.4785
Scenario II (50%)	Examin the CO ₂ -eq emission from the material production after replacing 50% of energy generated from coal by biomass	0.375	0.421

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Scenario	Description	Emission per Brick for burning (Kg CO2-eq)	Total Emission per brick (Kg Co2-eq)
Scenario III (75%)	Examin the CO2-eq emission from the material production after replacing 75% of energy generated from coal by biomass	0.3175	0.3635
Scenario IV (100%)	Examin the CO2-eq emission from the material production after replacing 100% of energy generated from coal by biomass	0.26	0.306

Table 18. Carbon emission calculation for different Usage case alternatives (for 1m2 wall)

Usage Case	Wall Type	Combination	Carbon Emission (Kg Co2-eq/m2)
Base Case	Exterior: 4" <i>Dachi Appa</i> , Interior: 4" regular brickwall	4" inner brick wall+4" <i>Dachi Appa</i> exterior with 2 coat silicon paint	112.969
Case I	Exterior: Paint over plaster, Interior: 9" regular brickwall	9" brick wall with 20mm plaster, one coat primer and 2 coat weathercoat paint	89.608
Case II	Exterior: Tile, Interior: 4" regular brickwall	9" brick wall with ceramic wall tile	107.738
Scenario 1	Exterior: 4" <i>Dachi Appa</i> , Interior: 4" regular brickwall	4" inner brick wall+4" <i>Dachi Appa</i> exterior with 2 coat silicon	106.759

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Usage Case	Wall Type	Combination	Carbon Emission (Kg Co2-eq/m2)
		paint (Dachi burnt using 75% coal and 25% wood pellet)	
Scenario 2	Exterior: 4" <i>Dachi Appa</i> , Interior: 4" regular brickwall	4" inner brick wall+4" <i>Dachi Appa</i> exterior with 2 coat silicon paint (Dachi burnt using 50% coal and 50% wood pellet)	100.549
Scenario 3	Exterior: 4" <i>Dachi Appa</i> , Interior: 4" regular brickwall	4" inner brick wall+4" <i>Dachi Appa</i> exterior with 2 coat silicon paint (Dachi burnt using 25% coal and 75% wood pellet)	94.339
Scenario 4	Exterior: 4" <i>Dachi Appa</i> , Interior: 4" regular brickwall	4" inner brick wall+4" <i>Dachi Appa</i> exterior with 2 coat silicon paint (Dachi burnt using 0% coal and 100% wood pellet)	88.129

Table 19. Energy value and emission of Coal, Wood pellet and Electricity (for 1m² wall)

Resource use	Coal	Wood pellet	Electricity
Energy Value	25.2	17.6	3.6
Energy Unit	MJ/Kg	MJ/kg	Mj/KWh
Equivalent Emission (Kg CO2-eq/kg)	3.6	1.37	0.45
Emission Unit	Kg CO2-eq/Kg	Kg CO2-eq/Kg	Kg CO2-eq/KWh
Total Energy required for burning each brick (MJ)	3.402		
Resource equivalent amount	0.135	0.19	0.95

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Unit	Kg	Kg	Kwh
Equivalent Emission per brick (Kg CO ₂ -eq)		0.49	0.26
			0.43

Table 20. Transportation emission calculation for tile transport (for 1m² Tile)

Process	Description	Equipment Use	Resources Use	Quantity	Unit	Emission Factor	Unit	Total emission (kgCO ₂ -eq)
Transport of tile to site	The distance of Nepovit tile factory situated at jitpur, simara to Kathmandu is 159km. The heavy truck carry 4000 box (9 Sq. Ft. in each box) of 12"x18" tile at a time with wastage accounting to 5% on an average.	Heavy load Truck (Mile age: 2.58 km/lt r) *	Diese	107.	L	3.75	kgCO ₂ -eq/L	404.239
	Man power		24	hour	0.12	KgCO ₂ -eq/hr	2.88	
Total Emission during tile transport (36000 sq.ft. tile) (kgCO ₂ -eq)								407.119
Estimated wastage in this phase (5%) (kgCO ₂ -eq)								20.356
Total Emission in transport including wastage(kgCO₂-eq)								427.475
Total Emission in transport of 1m² tile including wastage(kgCO₂-eq)								0.13

ANNEX B: PHOTOGRAPHS



Figure 16. Clay extraction site at Sarashwotikhel, Bhaktapur

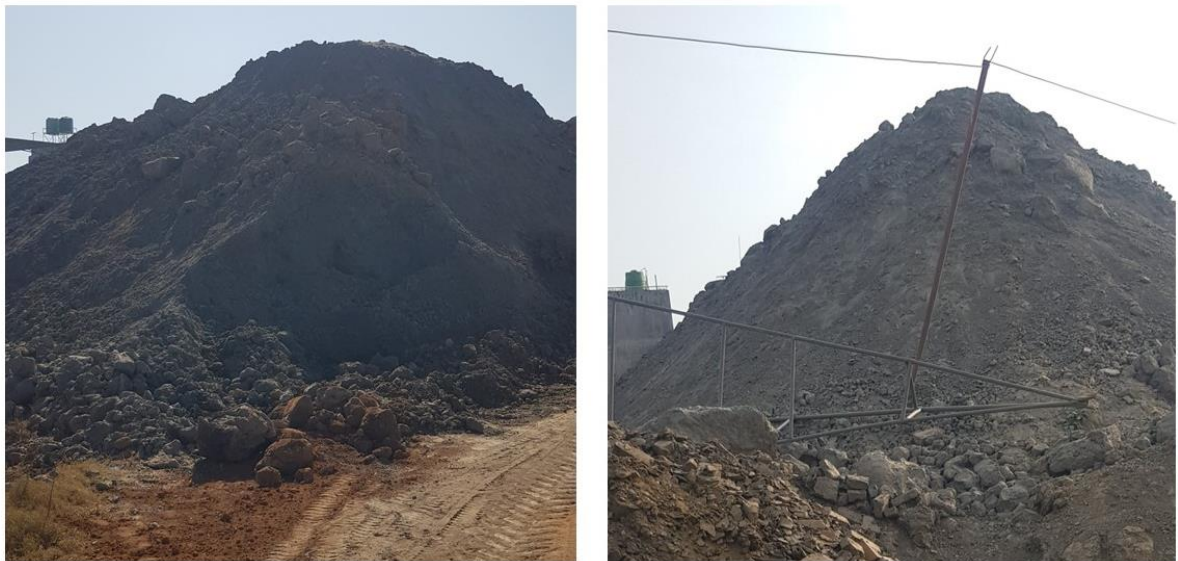


Figure 17. Clay Stacking in Dakshin Barahi bricks factory at Madhyapur Thimi, Bhaktapur



Figure 18. Dakshin Barahi bricks factory at Madhyapur Thimi, Bhaktapur



Figure 19. Unmoulded raw brick

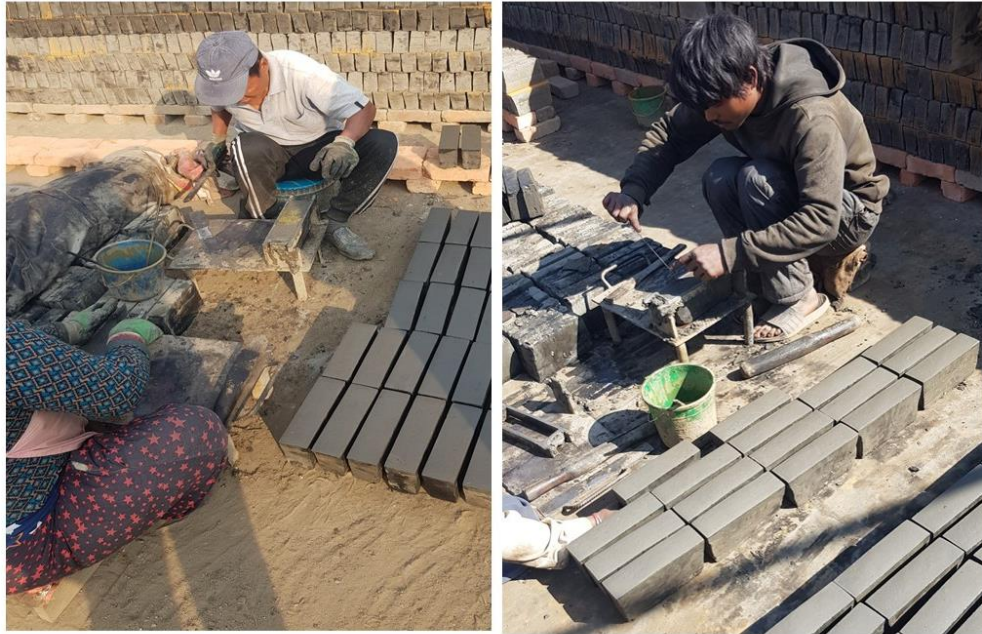


Figure 20. Making of raw Dachi brick



Figure 21. Stacking raw Dachi brick for sun drying



Figure 22. Wastage from moulding process stacked for reuse

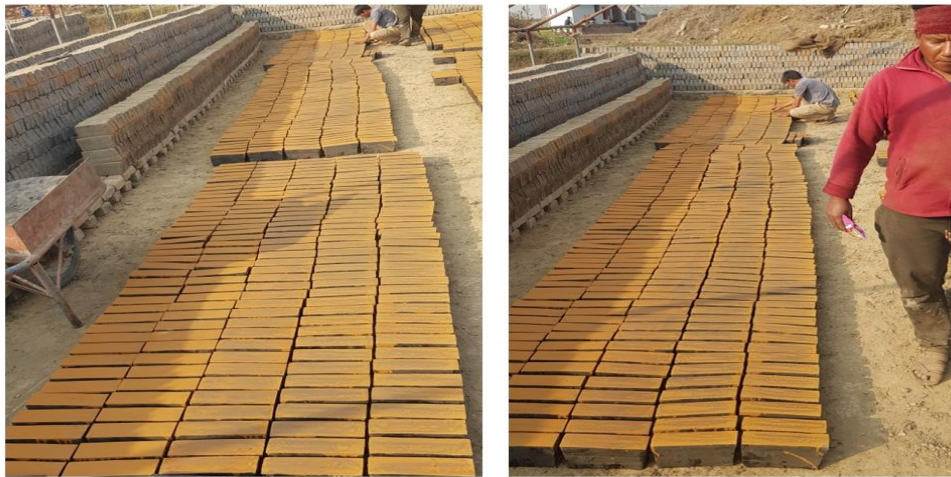


Figure 23. Red mud colouring of raw brick before burning



Figure 24. Sun dried brick stacked for burning



Figure 25. Brick burning inside kiln



Figure 26. Taking out burnt brick from kiln



Figure 27. Brick stacked at factory for selling

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Figure 28. Vehicle used for transportation in and outside factory



Figure 29. Newly built office building of Balaju industrial area

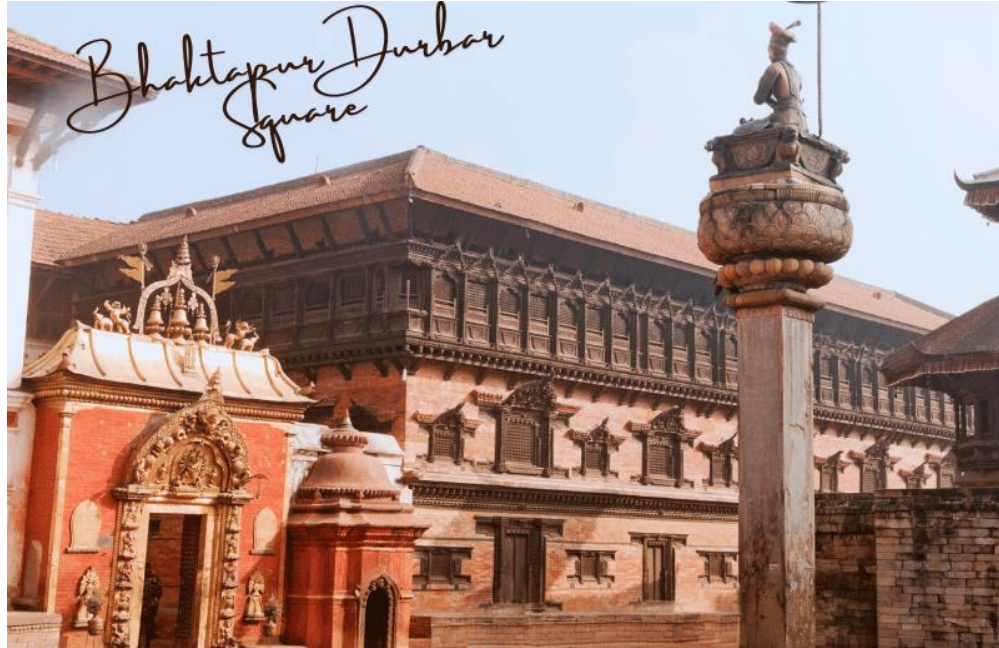


Figure 30. Fifty-five window palace at Bhaktapur Durbar Square (Source: <https://www.altitudehimalaya.com/blog/bhaktapur-durbar-square>)



Figure 31. Newly built building of Chandragiri Municipality (Source: https://www.chandragirimun.gov.np/sites/chandragirimun.gov.np/files/field/image/viber_image_2022-02-07_20-08-22-779.jpg)



Figure 32. Residential building made in traditional style at Raniban, Kathmandu



Figure 33. Dwarika's Hotel, the heritage hotel made in traditional style at old baneshwor, Kathmandu
(Source: <https://www.dwarikas.com/wp-content/uploads/2021/12/home-banne-1536x774.jpg>)

ANNEX C: CONFERENCE PAPER

IOE Graduate Conference
[Placeholder for
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Cradle-to-gate life cycle assessment of *Dachi Appa*: A traditional Nepali veneer brick

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Abstract

This study performs a cradle-to-gate Life Cycle Assessment (LCA) of dachi appa, a traditional Nepali veneer brick renowned for its cultural and architectural significance. Field research at Dakshin Barahi Brick Factory in Bhaktapur, combined with literature reviews and interviews, evaluates energy consumption and carbon emissions during production.

Results indicate the total carbon emission during production of each brick accounts to 0.53 KgCO₂-eq with the brick-burning stage, reliant on coal, as the most carbon-intensive stage, accounting for 93.8% of total emissions. Other stages, including raw brick-making, transportation, and material extraction, contribute minimal emissions. Coal is the dominant energy source, responsible for 91.2% of total emissions.

The study emphasizes the need for efficient burning techniques like replacing coal with renewable alternatives such as wood pellets. Government and associated authorities should impose stricter energy regulations to improve the sustainability of Dachi Appa, preserving its cultural heritage while reducing environmental impact.

Keywords

Lifecycle assesment, dachi appa, environmental impact, carbon emission sustainability

1. INTRODUCTION

Building construction is an energy-intensive process with significant energy consumption occurring at each stage of the building lifecycle [1]. At the world level, building construction consumes 24% of the raw materials extracted from the lithosphere [2]. The exponential growth of the global population has further fueled construction activities to meet the needs of the growing population. These activities have significantly impacted the environment, including, but not limited to, the depletion of natural resources, increased pollution, global warming, and climate change.

In the trade-off between aesthetic preference and environmental impact, modern architectural trends prioritize aesthetics. Clean and standardized outer appearances are highly favored, often achieved using veneer materials such as marble, fair-faced brick, tiles, and similar elements. However, these materials typically have high embodied energy, significantly contributing to environmental degradation. Although prioritizing aesthetics is a necessity, it is equally important to select materials that combine aesthetic appeal with low embodied energy to achieve a balance between visual appeal and environmental responsibility.

Nepal's rich architectural heritage, characterized by intricate designs and the use of traditional materials, has long been a center of attraction. Among these materials, dachi appa veneer bricks have remained a priority in building construction, not only for their aesthetic value but also for their historical and cultural significance. Recognizing the importance of preserving this heritage, the government has actively promoted the use of dachi appa and similar materials on building façades, reviving traditional practices and fostering a sense of cultural pride.

Life Cycle Assessment (LCA) emerges as a powerful tool to assess the environmental benefits and impacts of traditional materials like dachi appa. By analyzing the material's entire life cycle—from raw material extraction to disposal—LCA provides insights into its environmental footprint. This paper deals with a cradle-to-gate LCA of dachi appa focusing on calculation of its embodied energy during its production.

1.1 Objective of the study

- To assess the carbon emission of Dachi appa up to its manufacturing stage using a cradle-to-gate LCA approach.
- To identify key stages in the manufacturing of Dachi appa that contributes significantly to environmental impact.
- To evaluate the potential for improving the sustainability of Dachi Appa production.

2. MATERIAL AND METHODS

2.1 Dachi Appa

Dachi Appa is a traditional Nepali brick, characterized by its darker red color and glossy finish, making it ideal for use as veneer bricks. These bricks are specially fired at very high temperatures to achieve their unique appearance and durability. The brick is available in size of 8"x4"x2" and has a unique trapezoidal shape with perfect rectangular front while side tapers with the width. It is to create smallest possible gap between the bricks for façade with no mortar peeking through the join of the bricks. Traditionally silay; a mortar made up of pine resin, mixed with vermilion, were used to make it to match with tone of brick. Currently, cement mortar are used

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and yellow mud and water are used for pointing brick façade [3, 4].

2.2 Making of Dachi Appa

The process of making Dachi Appa begins with the excavation and collection of black clay, which is then transported to the worksite. Traditionally, the bricks were made by manually mixing clay and water using hands and feet. However, this process has now been modernized, with machines being used for mixing. The clay mixture is placed into molds to create the initial rough shape of the brick. The definitive shape is achieved by remolding the brick using a special pestle. To create a fair-faced surface, additional treatments are carried out. First, the brick is struck with a wooden fillet, then smoothed with a metal knife (Figure 1), and finally left to sun-dry under mild sunlight for 2–3 weeks. Once dried, the fair-faced surface of the brick is colored with a layer of semi-liquid red clay mixture. The earth used for fabricating the bricks consists of 37% quartz, 6% feldspar, and 57% clay minerals, while the red earth used for coloring the fair-faced surface comprises 21% quartz, 2% feldspar, and 77% clay minerals [3, 4].



Figure 1: Fair face of brick is smoothed with a knife

2.3 Use of Dachi Appa

The use of Dachi Appa reflects the rich architectural heritage of Nepal, showcasing the craftsmanship and local materials that define the region's identity. It has been used for centuries, contributing to the unique aesthetic of Nepali architecture, especially during the Malla Period, which emphasized intricate designs and artistic expression [5]. The brick is not just a building material; it symbolizes the cultural identity of the Nepali people, representing their connection to history and tradition.

In traditional settings, Dachi Appa is prominently used in the construction of temples, palaces, courtyards, and boundary walls. For instance, structures like the Pachpanna Jhyale Durbar in Bhaktapur durbar square and the pagoda-style

temples of Kathmandu Durbar Square prominently feature these bricks in their facades and decorative patterns, highlighting their aesthetic appeal and cultural significance. The reddish-brown color and smooth finish perfectly blend with carved wooden doors and windows.

Dachi Appa is also known for its strength and durability, making it suitable for both load-bearing and non-load bearing applications. Their low thermal conductivity provides insulation, keeping interiors cool in summer and warm in winter, making it suitable for the diverse climatic conditions of Nepal [6]. In contemporary architecture, the use of Dachi Appa extends to blending traditional and modern styles. Many architects incorporate these bricks into modern homes and commercial buildings to maintain cultural relevance while meeting present-day design standards. Dwarika's Hotel at battispatali, Kathmandu serves as a remarkable example, creating fusion of heritage and modernity.

Furthermore, Dachi Appa plays a vital role in the restoration and preservation of UNESCO World Heritage Sites in Nepal. During the post-earthquake restoration efforts, these bricks were extensively used to rebuild damaged heritage structures, maintaining authenticity and adhering to traditional building practices.



Figure 2: Dwarika's Hotel, the heritage hotel made in traditional style at Battispatali, Kathmandu (source: <https://www.dwarikas.com/wp-content/uploads/2021/12/home-banne-1536x774.jpg>)

2.4 Life Cycle Assessment (LCA) Methodology

The LCA involves the systematic analysis of product or system's inputs, outputs, and potential environmental impacts associated across all stages of its lifecycle [7]. The methodology of this research involves four phases: Goal definition and scoping, inventory analysis, impact assessment and interpretation of results.

The field research is carried out with a quantitative method following both quantitative and qualitative technique to obtain a quantitative data relating to production of dachi appa. A thorough literature study is done to understand the production procedure beforehand the actual factory visit. Dakshin Barahi Brick factory, popularly known as Hira Brick situated at madhyapur thimi, Bhaktapur is chosen as the case study area. The field data is collected from observation of making of dachi inside the factory, interview with workers, and management team. Some necessary data were taken with reference from various journal articles, books, conference papers and websites.

2.4.1 Goal Definition and Scoping:

The main purpose of the study is to assess the environmental impact from cradle to gate for dachi appa. The manufacturing of one brick is taken as the functional unit. The study is delimited to following respect:

- Manufacturing procedure of only one factory is taken in account.
- Scenarios and data are applicable to the situation prevailing today.
- Some quantitative data are provisional and are taken based on the observation and experience of related factory workers and management staff.
- Carbon emission factor of human work force is not localized to Nepal's condition.
- An average of 5% wastage of raw material is assumed for the production of unburnt bricks, while an average of 35% wastage is assumed during the burning process, based on the factory's average wastage data.
- The study is confined to effects on the natural environment only.
- General data were used to describe the environmental impact of energy use and transportation.

2.4.2 Inventory analysis

A flow chart was drawn for the manufacturing procedure of dachi appa (Figure 3) and data on environmental load was gathered for process and transports of the lifecycles. The necessary information and data are gathered from the factory and literature study. Standard values from reputed organizations or journal paper were used for some data. The result of the inventory analysis is calculated for each brick.

2.4.3 Impact Assessment

A process-based calculation spreadsheet (Figure 4) is created and energy use of material is determined by adding energy use at each stage of production lifecycle. The emission at each stage and total emission during production of each dachi appa is established using emission factor from each energy source in each step of production process. $CO_2-Eq = \sum E_i \cdot EF_i$ Where i refers to specific energy source, E_i refers to amount of i energy used and EF_i refers to equivalent emission factor of i energy source.

2.4.4 Interpretation of Result

The inventory analysis and impact assessment provided insights that were analyzed to evaluate the environmental performance of Dachi Appa and its production process.

2.5 CASE STUDY AREA

Dakshin Barahi Bricks, popularly recognized as Hira Bricks, is one of the largest brick manufacturers in Nepal. Located in Madhyapur Thimi, Bhaktapur, the factory produces approximately 8 million bricks annually, despite operating only for five to six months each year due to weather constraints. The factory consumes 800 tons of coal annually for the brick firing process which is procured from Godawari Commodities, India, and transported via the Birgunj port in Nepal. Additionally, they use approximately 7,500 liters of diesel each month, which includes transportation of finished bricks to their destinations. The factory has monthly electricity consumption of 30,000 units of electricity per month during its production period. Three wells serve as the factory's primary water sources. For solid waste management, the factory utilizes an on-site septic tank system.

The clay required for brick production is sourced from Saraswotikhel, Bhaktapur, located 6.5 kilometers away from the factory while red mud, used for coloring purposes, is sourced from Dakshinkali, approximately 26 kilometers from the factory. For product movement within and outside the factory premises, the factory owns four minitrucks.

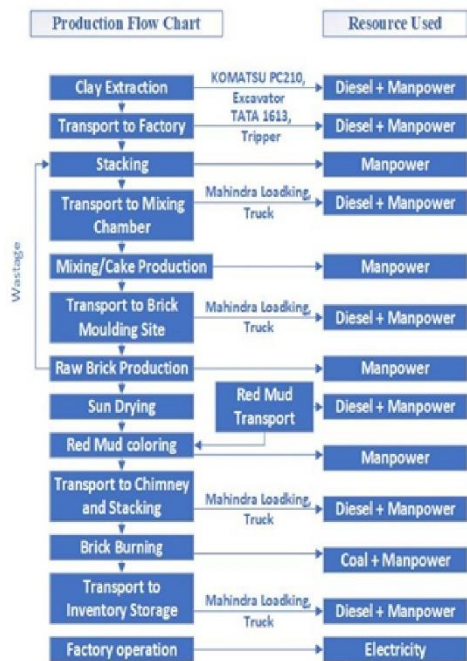


Figure 3: Flow chart showing production stages and associated resource used during production of Dachi Appa

3. RESULT AND DISCUSSION

3.1 CARBON EMISSION

The total carbon emission during production of each Dachi Appa brick account to be 0.53 kg CO₂-eq.

3.2 HOTSPOT IN MANUFACTURING

A process-based study reveals that the brick-burning stage is a key stage in lifecycle of dachi appa with the most carbon-

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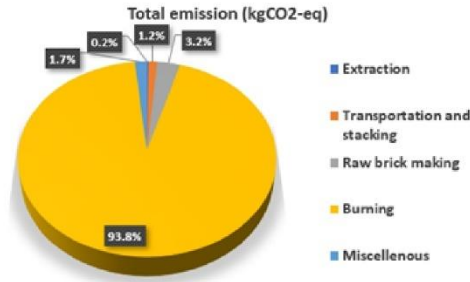


Figure 4: Carbon emission at different stage of production lifecycle of *Dachi Appa*

intensive phase in the lifecycle of *dachi appa*, contributing 0.50 kg CO₂-eq per brick (Table 1), which accounts for 93.8% of the total carbon emissions during production. The raw brick-making stage contributes 3.2% of the total emissions, while the transportation and stacking stage accounts for 1.2%. Notably, the raw material extraction stage has the least share of emissions, contributing only 0.2% of the total carbon footprint (figure 4).

Table 1: Process and its associated emission during manufacturing of *dachi appa*

Process	Emission(kgCO ₂ -eq/500pcs)
Extraction	0.51
Transportation and stacking	3.14
Raw brick making	8.44
Burning	249.86
Miscellaneous	4.5
Emission per 500 bricks	266.54
Total emission per brick	0.53

3.3 DOMINANT IMPACT FACTOR

Basically, four major source of energy use is seen during production of *dachi appa*, i.e. coal, diesel, electricity and manpower. The average consumption of electricity during production of 500 bricks is estimated to be 10 KWh while coal for burning 500 bricks is estimated at 50 kg. Among the sources, coal emerges as dominant impact factor with the most significant proportion of emission share with 91.2%. Manpower accounts for 6.1%, electricity accounts for 1.7% while least emission share by diesel accounting 1.0% during production of each brick presented in figure 5. The emission factor of electricity mix of Nepal is 0.45 kg CO₂-eq/KWh while that of coal and diesel is 3.6 kg CO₂-eq/Kg and 3.75 kg CO₂-eq/L respectively [8]. Moreover, the average emission factor of human work force working in construction sector is 0.12 kg CO₂-eq/h (0.95 kg CO₂-eq per working day working 8 hour a day) [9].

3.4 DISCUSSION

Brick burning process is encountered to have the most significant impact in carbon footprint with coal being used as

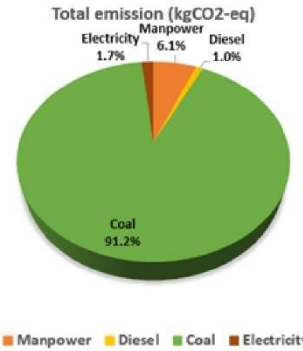


Figure 5: Carbon emission share of energy source during production of *Dachi Appa*

Table 2: Resource used and associated with carbon emission in kgCO₂-eq of per 500 pcs *dachi appa*

Resource use	Emission (kgCO ₂ -eq/500pcs)
Manpower	16.27
Diesel	2.69
Coal	243
Electricity	4.5

a resource for brick burning emerges as a dominant impact factor. With coal being a non-renewable energy, requires large amount of energy for mining and bought from India, it upholds high embodied emission with it. Coal has an energy value of 25.2 MJ/kg with emission factor being 3.6 kgCO₂-eq/kg [8, 10]. Replacing coal with alternatives like biomass and electricity during manufacturing of brick can help to reduce its carbon footprint. Wood pellet, a biomass alternative of coal has an energy value of 17.6 MJ/kg with emission factor of 1.37 kgCO₂-eq/kg [10]. The energy of 3.40 MJ is required for burning each brick. The amount of coal equivalent to the energy is 0.135kg with emission equivalent to 0.49 KgCO₂. The same amount of energy can be obtained from burning 0.19kg wood pellet with emission equivalent to 0.26 kgCO₂ only. This shows wood pellet to be a sustainable alternative of coal for brick burning. A scenario analysis with different proportion of wood pellet replacing coal during burning of brick is shown in Figure 6.

4. CONCLUSION

The study highlights the carbon emission during cradle-to-gate lifecycle stage of *Dachi Appa*. The brick-burning process, primarily fueled by coal, is a key stage in manufacturing process of the brick with the most significant contribution to carbon emissions. To enhance the sustainability of *dachi appa*, it is crucial to adopt more efficient burning techniques.

Scenario analysis demonstrated that replacing coal with wood pellets substantially reduces emissions, making *dachi appa* more environmentally competitive. Though achieving a 100% replacement of coal with wood pellets might be challenging in

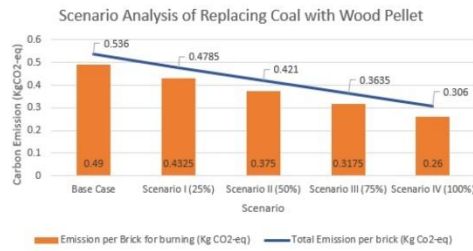


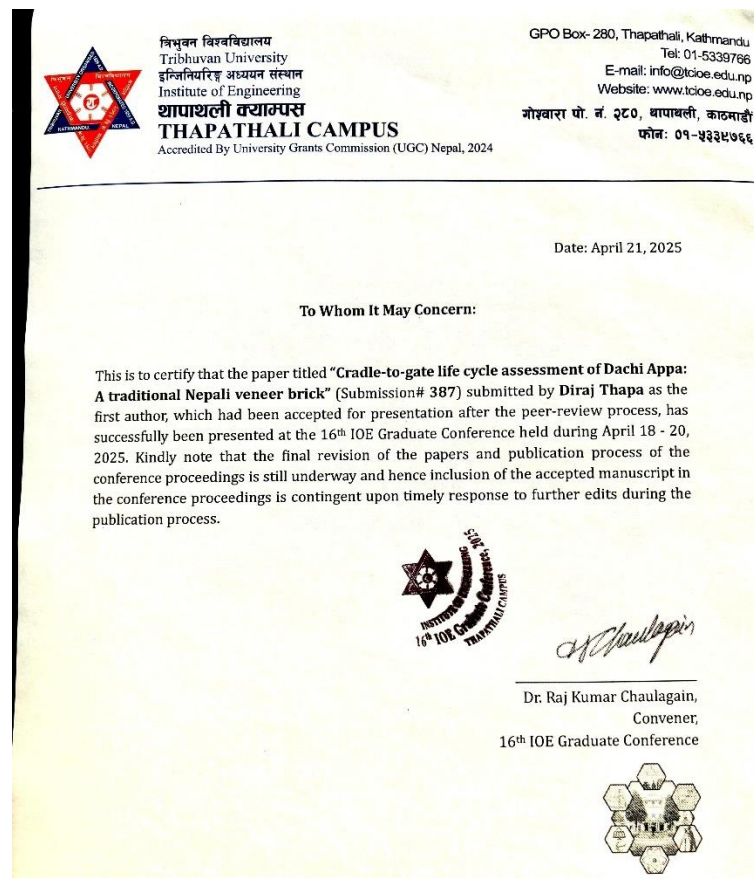
Figure 6: Scenario analysis of replacing coal with wood pellet during burning of Dachi Appa

practice, adopting a regulated mix of these fuels can result in significant emission reductions. Furthermore, the government should establish and enforce stringent policies to regulate energy consumption and emissions. Additional measures should also be implemented to mitigate CO₂-eq emissions during the production of such construction materials.

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ANNEX D: CONFERENCE CERTIFICATE AND LETTER OF ACCEPTANCE



ANNEX E: PLAGIARISM REPORT

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