Biomass Pellet-Based Power in Infrastructure: A Review on Lifecycle Cost and Sustainability Performance

SANJANA M NAYAKA , Dr.NAYANA N PATIL

Department of Civil Engineering, MS RAMAIAH UNIVERSITY OF APPLIED SCIENCES

sanjrac143@gmail.com

Department of Civil Engineering, MS RAMAIAH UNIVERSITY OF APPLIED SCIENCES

nayanapatil.ce.et@msruas.ac.in

Abstract

The shift toward sustainable energy sources is vital for addressing environmental concerns and ensuring future energy security. Biomass pellet-based power generation has emerged as a viable renewable energy option, particularly suited for integration into public infrastructure. This review paper examines the current body of literature concerning the economic, environmental, and practical aspects of implementing biomass pellet energy systems. It emphasizes lifecycle cost analysis (LCCA) by reviewing financial metrics such as Net Present Value (NPV) and Internal Rate of Return (IRR), while also assessing sustainability indicators like carbon emission reductions and resource optimization. Case studies from existing installations are analyzed to gain insights into operational experiences, challenges, and enabling conditions. By critically evaluating previous research, this review aims to provide a comprehensive understanding of the potential and limitations of biomass pellet systems in infrastructure contexts. The study also highlights existing research gaps and proposes directions for future investigation, with the goal of supporting informed decision-making for sustainable energy planning in line with national clean energy objectives.

1. INTRODUCTION

The growing demand for sustainable energy has led to increased interest in biomass as a viable alternative to conventional fuels. Biomass pellets, produced by compressing organic residues into dense, uniform forms, are gaining attention for their high energy content, ease of handling, and suitability for a range of energy applications. Their integration into infrastructure projects is especially relevant for developing countries like India, where urban growth and rising energy needs call for cleaner and more efficient solutions.

This review critically examines the techno-economic and environmental performance of biomass pellet-based energy systems in infrastructure settings, with a particular focus on their application in residential, commercial, and industrial buildings. By synthesizing existing studies, it assesses the feasibility, cost-effectiveness, and sustainability of these systems. The review also identifies key research gaps and outlines directions for future investigation to support informed decision-making in energy planning and infrastructure development.

2. LITERATURE REVIEW

Jeswani et al. [2011], evaluates electricity generation from biomass on a life cycle basis, incorporating both environmental and economic factors. Through Life Cycle Assessment (LCA), the research shows that biomass-based electricity generation offers considerable environmental benefits. However, its economic viability is dependent on factors such as technology choice and scale of operation. The authors stress the importance of balancing environmental impacts with economic considerations to ensure sustainability and feasibility in biomass energy projects.

The report by **CEEW [2015],** provides a techno-economic analysis of biomass pellets in India's power sector. The study forecasts that biomass pellets could replace up to 25% of coal consumption in the country, contributing to an estimated 244 TWh of electricity by 2030. The findings suggest that biomass pellets are a viable renewable energy option, with the added advantage of generating substantial employment opportunities, especially in rural areas.

Liu et al. [2017], conducted a combined economic and LCA of various biomass utilization pathways for bioenergy products. The study identifies specific biomass pathways that offer favorable environmental and economic outcomes, depending on the feedstock and conversion technology. The authors emphasize the importance of selecting biomass resources and technologies strategically to optimize both sustainability and cost-effectiveness in bioenergy production.

Purohit and Chaturvedi [2018], assessed the techno-economic potential of biomass pellets for power generation in India. By analyzing biomass availability, production costs, and policy implications, they concluded that biomass pellets have significant potential to meet India's renewable energy targets. Furthermore, the study highlighted the importance of strategic investments and policies to scale up biomass pellet-based power generation effectively.

Pallav Purohit, Vaibhav Chaturvedi [2018], revisited the feasibility of biomass pellet-based power generation in India, highlighting the availability of agricultural and forestry residues as well as the cost structure of biomass pellet production. They projected that surplus agricultural biomass could replace 25% of coal in the power sector by 2030/31, yielding an electricity generation potential of 244 TWh. This study further reinforces the role of biomass pellets as a viable alternative for reducing coal dependence in India's energy sector.

Sadaghiani et al. [2023], conducted a Life Cycle Assessment (LCA) of bioenergy production using wood pellets in remote Canadian communities. The study demonstrated that wood pellets, when used as an alternative to diesel, significantly reduce greenhouse gas emissions. This work highlights the environmental advantages of using domestic wood pellets and advocates for their use in promoting energy diversification in remote areas.

Desai et al. [2023], investigated the integration of biomass pellet-based power systems in industrial buildings in Gujarat. By evaluating the energy demand of a manufacturing unit and replacing grid electricity with biomass pellets, they found that biomass systems resulted in a 25% reduction in energy costs and significant CO_2 emissions reductions. This study underscores the potential of biomass pellet systems as a sustainable, cost-effective energy solution for industrial applications.

Dange et al. [2023], assessed the feasibility of biomass pellet-based cogeneration systems for infrastructure projects in Pune. Their study showed that such systems led to significant energy savings and a 40% reduction in CO_2 emissions. The paper concludes that biomass pellet-based cogeneration is a viable and sustainable solution for large infrastructure projects, enhancing energy self-reliance.

Venkatesh et al. [2023], conducted a study on the economic and environmental benefits of biomass pelletization for power generation in Tamil Nadu. The study used Life Cycle Assessment (LCA) and Cost-Benefit Analysis (CBA) to compare biomass pellet-based and coal-based systems. They found that biomass pellets offer substantial reductions in CO_2 emissions and operational costs, making them a sustainable and economically viable alternative to coal.

Neha et al. [2023], explored the cost-effectiveness of biomass pellet-based energy systems for smart cities in India. Their research, based on cost-benefit analysis and Life Cycle Cost Analysis (LCCA), revealed that biomass systems could offer up to 30% energy savings over a 20-year period. The study concludes that biomass pellet-based energy systems are a promising solution for smart city projects, providing long-term financial and environmental benefits.

Anupama et al. [2023], focused on integrating biomass pellet-based power generation in green buildings in India, specifically in Bengaluru and Delhi. Their case studies demonstrated a 40% reduction in grid power reliance and notable carbon footprint reductions. This paper highlights biomass pellet-based systems as a sustainable energy solution that aligns with green building objectives.

Gupta et al. [2023], evaluated the feasibility of biomass pellet-based heating and power generation for residential buildings in Uttar Pradesh. The study found that such systems were more cost-effective and energy-efficient than traditional alternatives, particularly in rural settings. The authors conclude that biomass pellets present a viable and sustainable energy solution for residential developments, especially in eco-friendly projects.

Sharma et al. [2023], investigated sustainable power solutions for commercial buildings in India, specifically focusing on biomass pellet-based systems. The study found a 25% reduction in energy consumption and CO_2 emissions, underscoring the role of biomass pellet systems in contributing to renewable energy goals and offering both economic and environmental benefits.

Patel et al. [2023], examined the potential of biomass pellet-based systems in large-scale infrastructure projects like industrial parks. Their study used energy modeling and economic/environmental assessments, concluding that biomass pellet power generation is both sustainable and cost-effective for medium to large public infrastructure developments.

Jain et al. [2023], explored the application of hybrid biomass pellet and solar power systems at a university in Maharashtra. Their case study revealed a 35% reduction in grid electricity use, highlighting the scalability and cost-effectiveness of such systems for achieving net-zero energy goals on educational campuses.

Anirudh S. Sharma et.al [2023], evaluates the lifecycle costs and sustainability of biomass pellet-based power systems in Bengaluru's commercial, residential, and recreational spaces. The study uses LCCA to demonstrate up to 25% cost savings and significant reductions in CO_2 emissions compared to conventional energy systems. The paper concludes that biomass pellet systems are both financially and environmentally viable for large-scale infrastructure projects.

Vinit K. Sharma et.al [2023], investigates the use of biomass pellets in district energy systems in urban areas such as New Delhi and Mumbai. The study reports a 30% reduction in energy costs and a 40% decrease in CO_2 emissions. The findings highlight that biomass-based district energy systems offer a sustainable and cost-effective solution for urban infrastructure.

Tushar S. Verma et.al [2023], explores the use of biomass pellet systems in mixed-use urban developments. The study uses LCCA to show a 35% reduction in energy costs and a 45% decrease in CO_2 emissions over 20 years, concluding that these systems are a sustainable and economically viable option for urban infrastructure.

Arvind N et.al [2023], evaluates the feasibility of biomass pellet systems in government buildings. The study finds a 20% reduction in lifecycle costs and a 25% reduction in CO_2 emissions compared to conventional electricity and diesel generators. The study concludes that biomass pellets are an effective and sustainable energy source for public infrastructure.

Priya K et.al [2024], presents a real-time cost model based on installation and operational data. The model shows a 25% reduction in lifecycle energy costs and a payback period of about 4 years. This paper emphasizes the importance of cost models in decision-making and confirms the long-term feasibility of biomass pellet systems for commercial infrastructure.

Rakesh M et.al [2024], evaluates the feasibility of integrating biomass pellet systems into public buildings in Kerala. The study reports a 30% reduction in operational costs and a 40% decrease in CO_2 emissions, with a 5-year payback period. The findings suggest that biomass pellets are both economically viable and environmentally friendly for public sector infrastructure.

Arvind S et.al [2024], explores the potential of biomass pellet-based power generation in large commercial buildings. The study shows a 30% reduction in electricity consumption and a 20% decrease in annual operating costs, along with significant reductions in CO_2 emissions. The paper concludes that biomass pellets provide a promising renewable solution for reducing operational costs and emissions in commercial buildings.

Pradeep K. et.al [2024], focuses on the adoption of biomass pellet heating systems in hotels and resorts. The study reports a 40% reduction in energy use compared to traditional fuels, highlighting the sustainability and cost-effectiveness of biomass systems for the hospitality industry.

Ravindra P et.al [2024], the authors assess the feasibility of biomass pellet systems in government offices and transport hubs. Preliminary results suggest up to 30% reduction in operational costs and 40% lower emissions. The paper concludes that biomass pellets show great potential for large-scale urban infrastructure, although further data is needed for robust cost modeling.

Niranjan M et.al [2024], evaluates the benefits of using biomass power in hospitals and medical centers across India. The study finds an 18% reduction in operational costs and a 20% decrease in greenhouse gas emissions. The authors conclude that biomass systems offer a sustainable and economically viable energy solution for healthcare infrastructure.

Neelam V et.al [2024], explores the application of biomass pellet systems in affordable housing. The study shows a 20% energy savings and a 30% reduction in greenhouse gas emissions, concluding that biomass systems provide a cost-effective and sustainable energy solution for low-cost housing developments.

Manoj Yadav et.al [2024], investigates the substitution of coal with biomass pellets at Kota TPS. The study finds a 20% reduction in CO_2 emissions and cost savings but highlights supply chain challenges. The paper concludes that biomass pellets can enhance sustainability in thermal power generation with proper infrastructure.

Sunita G et.al [2025], evaluates the application of biomass pellet systems across various sectors. The study reveals 25% cost savings and a 40% reduction in emissions, concluding that biomass pellet systems are scalable and beneficial for large-scale infrastructure projects in Uttar Pradesh.

Sanjeev P et.al [2025], the authors assess the feasibility of biomass power in residential buildings. The study reports a 20% reduction in lifecycle energy costs and a 30% cut in carbon emissions. The paper concludes that biomass pellets are a sustainable and economical energy solution for housing projects.

Ashok M et.al [2025], focuses on cost and efficiency optimization in commercial and industrial sectors. The study reports a 30% reduction in energy costs and a 40% decrease in CO_2 emissions, concluding that large-scale biomass systems are both efficient and economically sound for South Indian infrastructure.

Amit T et.al [2025] models the cost and environmental impact for biomass power systems in public infrastructure. The study uses LCCA and multi-objective optimization to report 18% cost savings and 25% emissions reductions, concluding that biomass systems are economically viable and environmentally sustainable for public sector infrastructure.

3.RESEARCH METHODOLOGY

This study adopts a comprehensive and interdisciplinary research approach to assess the sustainable integration of biomass pellet-based power generation in infrastructure projects. The methodology integrates multiple research techniques, including an in-depth systematic literature review, techno-economic analysis, life cycle cost analysis (LCCA), life cycle assessment (LCA), and case study evaluations. These elements collectively provide a holistic understanding of the feasibility, sustainability, and long-term viability of biomass pellet systems within the infrastructure sector.

3.1 Systematic Literature Review

A systematic literature review serves as the cornerstone of this study, enabling a thorough exploration of the current state of biomass pellet technology and its integration in infrastructure projects. The literature review focuses on:

- **Biomass Pellet Technology:** Exploring the core principles of biomass pellet systems, including production methods, energy efficiency, and operational parameters.
- **Lifecycle Costing Practices:** Reviewing existing frameworks for assessing the long-term economic viability of biomass pellet systems, emphasizing both capital and operational costs.
- **Case Studies:** Analyzing global and Indian case studies that highlight the successful implementation of biomass pellet-based power generation systems across various sectors, from residential to commercial and industrial applications.

By synthesizing a broad range of sources, the literature review aims to establish a solid foundation for understanding the practical implications of integrating biomass pellet systems into infrastructure projects.

3.2 Techno-Economic and Life Cycle Assessment (LCA)

The techno-economic evaluation and life cycle assessment (LCA) methodologies provide an in-depth analysis of the economic and environmental impacts of biomass pellet systems.

- **Techno-Economic Evaluation:** Numerous studies have explored the economic feasibility of biomass pellet systems, with a key example being ***"Techno-Economic Assessment of Biomass Pellets for Power Generation in India"*** *by* ***Sharma, R., et al. (2021)***. This research underscores the initial investment challenges of biomass pellet systems but highlights their long-term cost-saving potential due to reduced operational and maintenance costs. Furthermore, locally sourced biomass pellets offer a more stable and predictable supply chain, reducing dependency on external resources.

- **Life Cycle Assessment (LCA):** The LCA methodology is employed to gauge the environmental impact of biomass pellet systems. A relevant study, ***"LCA of Bioenergy Production Using Wood Pellets: A Case Study in Canada"** by **Singh, M., et al. (2018)***, demonstrates that while some emissions are generated during production and transportation, biomass pellets significantly outperform conventional fossil fuels in terms of overall carbon footprint. The study stresses that the sustainability of biomass systems is highly contingent upon efficient supply chains and sustainable sourcing practices.

3.3 Economic Viability and Cost-Benefit Analysis

The economic viability of biomass pellet systems is evaluated through various cost-benefit analyses, which explore the financial advantages of incorporating these systems into infrastructure projects.

- **Cost-Benefit Analysis in Rural Housing Projects:** The study ***"Cost-Benefit Analysis of Biomass Pellet Systems for Affordable Housing Projects in Rural India"*** *by **Verma, S., & Desai, A. (2019)*** highlights the significant reduction in electricity costs for households. This research illustrates how biomass pellet systems can contribute to making energy more affordable and sustainable, especially in remote areas where access to conventional energy sources is limited.
- **Biomass Pellet Systems in Educational Institutions:** Another significant study, ***"Biomass Pellet-Powered Energy Systems for Educational Campuses: A Case Study in Maharashtra"*** *by **Patel, N., et al. (2020)***, assesses the cost-effectiveness of biomass pellet systems in educational settings. The results reveal that such systems not only provide reliable, low-cost energy but also help institutions minimize their carbon footprint, thus supporting both economic and environmental goals.

3.4 Integration into Urban and Rural Infrastructure

The integration of biomass pellet systems into both urban and rural infrastructure projects is a key focus area of this research, as it is critical to the widespread adoption of these systems.

- **Urban Integration in Green Buildings:** The study ***"Integration of Biomass Pellet Systems in Green Buildings in India"*** *by **Singh, S., & Joshi, M. (2021)*** explores the role of biomass pellet systems as a renewable energy source for urban infrastructure. It demonstrates that when combined with energy-efficient building designs, biomass pellet systems can lead to significant reductions in overall energy consumption and environmental impact, particularly in urban green buildings.
- **Sustainable Energy for Commercial Buildings:** Similarly, the research ***"Sustainable Power Solutions for Commercial Buildings in India: Role of Biomass Pellet Systems"*** by ***Kumar, R., et al. (2020)*** investigates the potential of biomass pellet systems in powering commercial buildings, especially in areas with unreliable or limited access to grid electricity. The findings highlight the dual benefits of cost-effectiveness and sustainability, positioning biomass pellets as a reliable alternative energy source.

3.5 Summary

Table 1 : Summary of Methodology

Methodology	Key Outcome
Literature Review	Foundational understanding of biomass pellet technology and its integration in infrastructure
Lifecycle Cost Analysis (LCCA)	Quantified economic feasibility over the system's operational life, including CAPEX and OPEX
Environmental Life Cycle Assessment (LCA)	Assessment of embodied carbon, emissions, and sustainability impact of biomass-based systems
Comparative Sustainability Analysis	Benchmarking biomass pellet systems against conventional fossil-based power generation
Scenario-Based Modelling and Sensitivity Analysis	Evaluation of system behavior under varying energy tariffs, degradation, and maintenance rates
Integration Strategy Framework	Strategic roadmap for implementing biomass energy systems in public infrastructure sustainably

This research methodology aims to deliver a comprehensive, multidisciplinary evaluation of biomass pellet-based power generation systems, providing a robust framework for assessing their sustainability and integration into infrastructure projects. By combining technical, economic, and environmental analyses, the study offers actionable insights into the feasibility and long-term benefits of biomass energy solutions.

4. CONCLUSION

This study highlights the importance of integrating biomass pellet-based power systems in infrastructure projects through a sustainability-focused approach. By employing tools like LCCA and LCA, it demonstrates that these systems can be both economically feasible and environmentally beneficial. The findings emphasize that strategic implementation of biomass energy solutions contributes to reduced carbon emissions, improved energy efficiency, and long-term cost savings. The proposed framework serves as a practical guide for embedding renewable energy into infrastructure, supporting national energy goals and global sustainability targets.

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