International Journal on Science and Technology (IJSAT)
E-ISSN: 2229-7677 ● Website: www.ijsat.org ● Email: editor@ijsat.org

Life Cycle Assessment of Construction and Demolition Waste Recycling Plants: Energy Consumption, Greenhouse Gas Emissions, and Economic Viability

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Abstract:
Construction and demolition (C&D) waste constitutes one of the largest waste streams worldwide, placing considerable pressure on landfill capacity and natural resource extraction. Recycling C&D waste has emerged as an effective strategy for promoting circular economy principles by recovering valuable construction materials while reducing environmental impacts. Despite increasing adoption of recycling technologies, limited research has simultaneously evaluated environmental performance, energy requirements, greenhouse gas emissions, and economic feasibility of C&D waste recycling plants within a unified life cycle framework. This conceptual paper synthesizes existing literature on Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) to develop an integrated framework for evaluating the sustainability of construction and demolition waste recycling plants. The framework examines environmental indicators including cumulative energy demand, global warming potential, acidification, eutrophication, photochemical ozone formation, human toxicity, and resource depletion alongside economic indicators such as capital investment, operational costs, maintenance costs, revenue generation, and financial viability. The paper proposes a comprehensive sustainability assessment model that links recycling technologies, operational efficiency, environmental performance, and economic outcomes. It further identifies key research gaps and future research priorities for integrating renewable energy systems, advanced recycling technologies, and circular economy principles into construction waste management. The proposed framework provides guidance for researchers, policymakers, and industry practitioners seeking to improve resource efficiency and achieve sustainable construction practices.

Keywords: Construction and demolition waste, Life Cycle Assessment, Life Cycle Costing, Circular economy, Greenhouse gas emissions, Sustainable construction.

1. Introduction

The construction industry plays a fundamental role in economic development by providing residential buildings, commercial infrastructure, transportation networks, and industrial facilities. However, the sector is also one of the largest consumers of natural resources and one of the major contributors to global waste generation. Rapid urbanization, population growth, infrastructure expansion, and increasing redevelopment activities have significantly increased the volume of construction and demolition (C&D) waste generated worldwide. According to the European Commission (2016), C&D waste accounts for nearly one-third of all waste generated in the European Union, making it the largest waste stream in the region. Similarly, the United States Environmental Protection Agency (2020) reported that approximately 600 million tons of construction and demolition debris were generated in the United States in 2018, exceeding the amount of municipal solid waste produced during the same period. These trends indicate that sustainable management of C&D waste has become a global environmental and economic priority.

Construction and demolition waste comprises a wide variety of materials, including concrete, bricks, asphalt, wood, metals, glass, plastics, gypsum, and excavated soil. Traditionally, much of this waste has been disposed of in landfills, resulting in significant environmental challenges such as land degradation, depletion of landfill capacity, contamination of soil and groundwater, and unnecessary consumption of natural resources. Landfilling also represents a loss of potentially valuable secondary materials that could be recovered and reused within the construction sector. Consequently, governments and international organizations have increasingly emphasized waste prevention, material recovery, and recycling as essential components of sustainable waste management (Bovea & Powell, 2016).

The transition from the traditional linear economy model to a circular economy has received considerable attention as a strategy for improving resource efficiency and minimizing environmental impacts. The circular economy promotes maintaining the value of materials and products for as long as possible through reuse, repair, remanufacturing, and recycling. Within the construction sector, these principles encourage the recovery of valuable materials from demolition waste and their reintegration into new construction projects. Recycled concrete aggregates, reclaimed asphalt, recovered steel, and recycled bricks can replace virgin construction materials, thereby reducing the demand for quarrying, lowering energy consumption, and decreasing greenhouse gas emissions associated with material production (Pomponi & Moncaster, 2017; Ghisellini et al., 2018).

Construction and demolition waste recycling plants play a central role in implementing circular economy principles. These facilities receive mixed construction waste and employ a series of mechanical and physical processes, including sorting, crushing, screening, magnetic separation, and material classification, to recover reusable materials. Modern recycling technologies have substantially improved the quality of recycled aggregates, enabling their use in road construction, pavement bases, drainage systems, and, under appropriate quality standards, structural concrete. Besides reducing landfill disposal, recycling contributes to conserving natural aggregates, lowering extraction activities, and improving overall resource productivity (Silva et al., 2014).

Although recycling offers considerable environmental advantages, recycling plants themselves consume substantial amounts of electricity and diesel fuel during waste transportation, crushing, screening, material handling, and aggregate production. These processes generate greenhouse gas emissions and other environmental impacts that should be evaluated throughout the entire recycling chain. Consequently, simply assuming that recycling is environmentally beneficial is insufficient. Comprehensive assessments are required to determine whether the environmental benefits of material recovery outweigh the impacts associated with recycling operations (Butera et al., 2015).

Life Cycle Assessment (LCA) has become the most widely accepted methodology for evaluating environmental impacts associated with products, services, and industrial processes throughout their life cycle. Standardized under ISO 14040 and ISO 14044, LCA considers all significant inputs and outputs, including energy consumption, raw material use, emissions, and waste generation, from raw material acquisition to final disposal. In the context of construction waste management, LCA enables comparisons between landfill disposal and various recycling alternatives while identifying environmental hotspots within recycling operations (ISO, 2006a; ISO, 2006b). Previous studies have consistently demonstrated that recycled construction materials generally result in lower greenhouse gas emissions and reduced resource depletion than virgin materials, although environmental performance varies depending on transportation distance, electricity generation mix, recycling technology, and plant efficiency (Bovea & Powell, 2016; Borghi et al., 2018).

Alongside environmental considerations, the financial viability of recycling plants remains an equally important factor influencing investment decisions. Establishing and operating C&D waste recycling facilities requires significant capital investment in land, machinery, infrastructure, and transportation equipment. Additional operating costs include labour, maintenance, electricity, fuel, and waste handling. These costs must be balanced against revenues generated from recycled aggregate sales, recovered metals, avoided landfill charges, and, where applicable, carbon credit mechanisms. Therefore, Life Cycle Costing (LCC) has increasingly been integrated with Life Cycle Assessment to provide a holistic evaluation of both environmental and economic sustainability (Hunkeler et al., 2008; Di Maria et al., 2018).

Despite the growing body of literature on construction and demolition waste recycling, several important knowledge gaps remain. Existing studies predominantly focus on either environmental assessment through Life Cycle Assessment or financial evaluation through cost analysis. Comparatively few studies integrate environmental and economic perspectives within a single framework. Furthermore, previous reviews indicate considerable variation in functional units, system boundaries, allocation methods, transportation assumptions, and impact assessment methods, making direct comparison among studies difficult (Bayram & Greiff, 2023). In addition, relatively limited attention has been given to examining the combined influence of energy consumption, greenhouse gas emissions, and economic viability on the sustainability of recycling plants from a conceptual perspective.

This paper addresses these gaps by developing a comprehensive conceptual framework that integrates Life Cycle Assessment and Life Cycle Costing for evaluating construction and demolition waste recycling plants. The framework synthesizes current knowledge regarding energy consumption, greenhouse gas emissions, environmental impacts, and economic performance while identifying the key factors influencing sustainable recycling operations. By integrating circular economy principles with environmental and economic assessment approaches, the study provides a structured foundation for future empirical research and offers practical guidance for policymakers, infrastructure planners, and waste management practitioners seeking to improve the sustainability of construction waste management systems.

2. Literature Review

2.1 Construction and Demolition Waste Management

Construction and demolition (C&D) waste is one of the largest solid waste streams worldwide, generated from construction, renovation, maintenance, and demolition activities. It primarily consists of concrete, bricks, metals, wood, asphalt, glass, gypsum, and plastics. Traditionally, a large proportion of this waste has been disposed of in landfills, resulting in resource depletion, land occupation, and environmental pollution. Recent waste management policies encourage recycling and reuse to reduce landfill dependency and promote sustainable resource utilization. Recycling C&D waste conserves natural aggregates, reduces extraction of virgin materials, and supports sustainable construction practices (Bovea & Powell, 2016; Butera et al., 2015; European Commission, 2016).

2.2 Circular Economy in Construction

The circular economy promotes the efficient use of resources by extending material life cycles through reuse, recycling, and recovery. In the construction sector, circular economy principles encourage the recovery of construction materials and their reintegration into new building projects. Recycled aggregates, reclaimed asphalt, and recovered metals reduce dependence on virgin resources while minimizing environmental impacts. Effective implementation of circular economy practices requires efficient recycling technologies, supportive regulations, and markets for recycled construction materials (Pomponi & Moncaster, 2017; Ghisellini et al., 2018).

2.3 Life Cycle Assessment

Life Cycle Assessment (LCA) is an internationally standardized methodology for evaluating the environmental impacts of products and processes throughout their life cycle. According to ISO 14040 and ISO 14044, LCA consists of goal and scope definition, life cycle inventory, impact assessment, and interpretation. In C&D waste management, LCA is widely used to compare recycling and landfill scenarios by assessing energy use, greenhouse gas emissions, resource depletion, and other environmental impacts. It has become an essential decision-support tool for sustainable waste management (ISO, 2006a; ISO, 2006b; Bovea & Powell, 2016).

2.4 Energy Consumption in Recycling Plants

Energy consumption is one of the major environmental concerns in C&D waste recycling plants. Diesel is mainly consumed during waste transportation and material handling, whereas electricity is required for crushing, screening, sorting, and magnetic separation. Previous studies indicate that although recycling operations consume energy, the total energy demand is generally lower than that associated with the extraction and processing of virgin construction materials. Improving equipment efficiency and integrating renewable energy sources can further reduce energy consumption (Butera et al., 2015; Borghi et al., 2018).

2.5 Greenhouse Gas Emissions

Greenhouse gas emissions in recycling plants arise mainly from diesel combustion, electricity consumption, transportation, crushing, and screening activities. Transportation is often the largest contributor because of fuel use during waste collection and aggregate distribution. However, recycling significantly reduces life cycle emissions by replacing virgin aggregate production and diverting waste from landfills. Optimizing transportation routes and using cleaner energy sources can further decrease the carbon footprint of recycling operations (Rosado et al., 2019; Jain et al., 2020).

2.6 Life Cycle Costing

Life Cycle Costing (LCC) evaluates the total economic costs associated with a product or system throughout its life cycle. In construction waste recycling, LCC includes capital investment, operating costs, maintenance, labour, transportation, and energy expenses. Revenue is generated through recycled aggregate sales, recovered metals, avoided landfill fees, and, in some regions, carbon credits. Integrating

LCC with LCA enables decision makers to evaluate both environmental and economic sustainability when selecting waste management strategies (Hunkeler et al., 2008; Di Maria et al., 2018).

2.7 Research Gap

Existing studies have established the environmental benefits of C&D waste recycling; however, several limitations remain. Most research focuses either on Life Cycle Assessment or Life Cycle Costing independently, while relatively few studies integrate both approaches within a comprehensive sustainability framework. Furthermore, variations in system boundaries, functional units, and impact assessment methods limit comparisons across studies. There is also limited conceptual research synthesizing the relationships among energy consumption, greenhouse gas emissions, circular economy practices, and economic viability of recycling plants. This paper addresses these gaps by proposing an integrated conceptual framework that combines environmental and economic perspectives for evaluating the sustainability of construction and demolition waste recycling plants.

3. Methodology

3.1 Research Design

This study adopts a conceptual research design based on an extensive review and synthesis of existing literature on construction and demolition (C&D) waste recycling, Life Cycle Assessment (LCA), Life Cycle Costing (LCC), circular economy, energy consumption, greenhouse gas emissions, and economic viability. Rather than collecting primary data, the study integrates existing theoretical and empirical knowledge to develop a comprehensive framework for evaluating the sustainability of C&D waste recycling plants.

3.2 Literature Search Strategy

A systematic literature search was conducted using internationally recognized scientific databases, including Scopus, Web of Science, ScienceDirect, and SpringerLink. The search focused on peer-reviewed journal articles, review papers, international standards, and reports published primarily between 2005 and 2025.

The following keywords and combinations were used:

- Construction and demolition waste
- C&D waste recycling
- Life Cycle Assessment
- Life Cycle Costing
- Circular economy
- Sustainable construction
- Greenhouse gas emissions
- Energy consumption
- Recycled aggregates
- Environmental sustainability

Only publications written in English and published in peer-reviewed journals were included in the review.

3.3 Literature Selection

The literature selection followed predefined inclusion criteria. Studies were included if they:

focused on construction and demolition waste management;

- applied Life Cycle Assessment or Life Cycle Costing;
- examined energy consumption, greenhouse gas emissions, or economic performance;
- addressed recycling technologies or circular economy practices; and
- were published in reputable Scopus- or Web of Science-indexed journals.
- Publications unrelated to construction waste, conference abstracts, non-peer-reviewed documents, and duplicate studies were excluded.

3.4 Literature Synthesis

The selected studies were critically reviewed and grouped into six major themes:

- Construction and demolition waste management.
- Circular economy in construction.
- Life Cycle Assessment applications.
- Energy consumption in recycling plants.
- Greenhouse gas emissions.
- Life Cycle Costing and economic viability.

The findings from these themes were synthesized to identify common conclusions, research trends, methodological approaches, and existing knowledge gaps.

3.5 Development of the Conceptual Framework

Based on the synthesized literature, a conceptual framework was developed to illustrate the relationships among recycling operations, energy consumption, environmental impacts, and economic performance. The framework integrates the principles of Life Cycle Assessment and Life Cycle Costing to provide a holistic approach for evaluating the sustainability of C&D waste recycling plants. The framework also highlights the role of circular economy practices in improving material recovery, reducing greenhouse gas emissions, and enhancing economic viability.

3.6 Conceptual Framework

The proposed framework consists of four interconnected components:

- Input variables: mixed C&D waste, transportation, electricity, diesel, water, and recycling technology.
- Recycling processes: sorting, crushing, screening, magnetic separation, and aggregate production.
- Assessment dimensions: environmental performance (LCA) and economic performance (LCC).
- Sustainability outcomes: reduced energy consumption, lower greenhouse gas emissions, improved resource efficiency, enhanced profitability, and circular economy implementation.

The framework provides a theoretical basis for future empirical studies using operational data from construction and demolition waste recycling plants.

4. Proposed Conceptual Framework

4.1 Integrated Framework for Sustainable Construction and Demolition Waste Recycling

Based on the synthesis of the existing literature, this study proposes an integrated conceptual framework that combines Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) to evaluate the sustainability of construction and demolition (C&D) waste recycling plants. The framework links recycling operations with environmental and economic assessment methods to provide a comprehensive evaluation of recycling performance. It also incorporates circular economy principles to demonstrate how efficient resource recovery contributes to environmental protection and long-term economic viability.

The framework begins with the generation of mixed construction and demolition waste from building construction, renovation, and demolition activities. The collected waste is transported to recycling plants, where it undergoes a sequence of operations including sorting, crushing, screening, magnetic separation, and aggregate production. These activities require energy, water, labour, and equipment, which constitute the primary operational inputs of the recycling process.

The environmental performance of the recycling system is assessed using Life Cycle Assessment. This component evaluates cumulative energy demand, greenhouse gas emissions, acidification, eutrophication, photochemical ozone formation, human toxicity, and resource depletion associated with recycling operations. Through these indicators, environmental hotspots can be identified and opportunities for improving resource efficiency can be recognized.

The economic dimension of the framework is evaluated using Life Cycle Costing. The analysis considers capital investment, equipment costs, labour, maintenance, fuel, electricity, transportation, and other operational expenditures. The economic benefits include revenue generated from recycled aggregate sales, recovered metals, avoided landfill disposal costs, and potential carbon credits. Financial performance can be evaluated using indicators such as Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period, and Benefit-Cost Ratio.

The integration of LCA and LCC enables simultaneous evaluation of environmental and economic sustainability. Rather than focusing on environmental impacts alone, the proposed framework demonstrates that sustainable waste management decisions should also consider financial feasibility. This integrated perspective supports policymakers, recycling plant operators, and construction companies in selecting waste management strategies that maximize resource recovery while minimizing environmental impacts and operational costs.

The framework further recognizes the importance of circular economy principles in improving sustainability. Efficient recycling technologies reduce landfill disposal, conserve natural aggregates, decrease greenhouse gas emissions, and promote the continuous circulation of construction materials within the economy. Consequently, the framework establishes a direct relationship between recycling efficiency, environmental performance, economic viability, and circular economy implementation.

Hence, the proposed conceptual framework provides a theoretical foundation for future empirical studies that may apply Life Cycle Assessment software and Life Cycle Costing models using operational data from recycling facilities. It also offers practical guidance for improving the sustainability of construction and demolition waste management systems.

Components of the Proposed Framework

Inputs

- Mixed construction and demolition waste
- Transportation
- Electricity
- Diesel fuel
- Water

- Recycling technology
- Plant equipment

Recycling Operations

- Waste collection
- Sorting
- Crushing
- Screening
- Magnetic separation
- Aggregate production
- Residual waste management

Environmental Assessment (LCA)

- Energy demand
- Greenhouse gas emissions
- Acidification
- Eutrophication
- Human toxicity
- Resource depletion

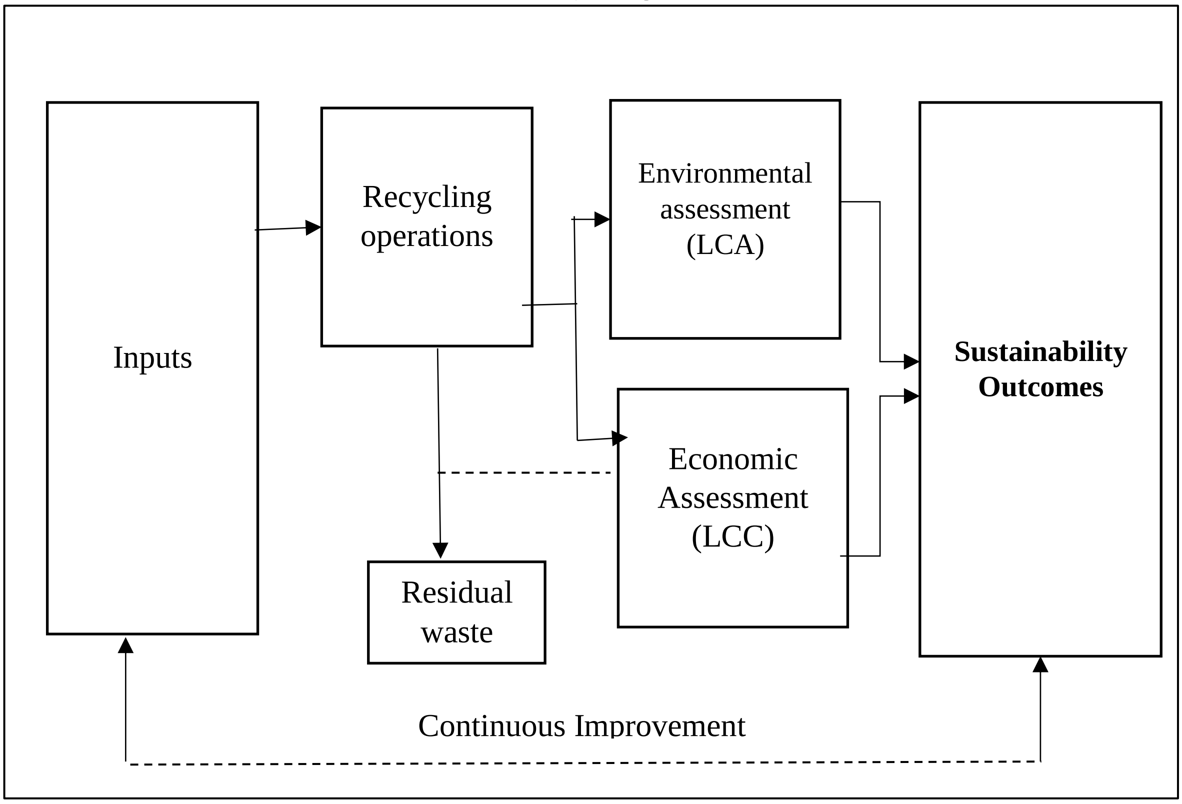
Economic Assessment (LCC)

- Capital investment
- Operating costs
- Maintenance costs
- Labour costs
- Transportation costs
- Revenue from recycled aggregates
- Revenue from recovered metals
- Carbon credit benefits

Sustainability Outcomes

- Reduced landfill disposal
- Lower greenhouse gas emissions
- Reduced energy consumption
- Conservation of natural resources
- Higher material recovery
- Improved economic viability
- Circular economy implementation

Figure 1: Integrated Conceptual Framework for Sustainable Construction and Demolition Waste Recycling.



Source: Authors own work

5. Discussion

The proposed conceptual framework highlights the importance of integrating environmental and economic perspectives when evaluating construction and demolition (C&D) waste recycling plants. Previous research has consistently demonstrated that recycling construction waste reduces landfill disposal, conserves natural resources, and lowers greenhouse gas emissions compared with conventional disposal methods (Butera et al., 2015; Bovea & Powell, 2016). However, environmental performance alone is insufficient for determining the long-term sustainability of recycling facilities. Financial feasibility, operational efficiency, and market demand for recycled materials are equally important factors that influence the successful implementation of recycling systems.

The integration of Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) provides a comprehensive decision-making framework by evaluating both environmental impacts and economic performance. While LCA identifies environmental hotspots such as transportation, crushing, and electricity consumption, LCC determines whether investments in recycling infrastructure generate acceptable financial returns. This integrated approach enables decision-makers to identify strategies that simultaneously minimize environmental impacts and maximize economic benefits (Di Maria et al., 2018).

The framework also emphasizes the role of energy consumption as a key determinant of environmental performance. Transportation, crushing, screening, and material handling require significant quantities of diesel fuel and electricity. Improving equipment efficiency, optimizing transportation routes, and adopting renewable electricity sources can substantially reduce cumulative energy demand and greenhouse gas emissions. Previous studies indicate that transportation distance and electricity generation mix are among the most influential factors affecting the environmental performance of recycling plants (Rosado et al., 2019; Jain et al., 2020).

Another important contribution of the framework is its emphasis on circular economy principles. Recycling construction materials extends the useful life of resources by recovering concrete, metals, asphalt, bricks, and other materials for reuse in new construction projects. This reduces dependence on virgin aggregates, minimizes extraction of natural resources, and supports sustainable production and consumption. The framework therefore demonstrates that effective recycling systems contribute not only to waste reduction but also to broader circular economy objectives (Pomponi & Moncaster, 2017; Ghisellini et al., 2018).

The proposed framework also identifies several operational factors that influence the sustainability of C&D waste recycling plants. These include recycling technology, material recovery efficiency, transportation logistics, energy source, equipment maintenance, and market demand for recycled products. Improvements in these areas can enhance both environmental and economic performance. In particular, advanced sorting technologies and renewable-energy-powered recycling plants offer considerable opportunities for reducing environmental impacts while improving operational efficiency.

Finally, the study addresses an important gap in the existing literature by integrating Life Cycle Assessment and Life Cycle Costing into a single conceptual framework. Previous studies have generally examined environmental or economic performance independently, whereas the present framework recognizes that sustainable waste management requires simultaneous consideration of both dimensions. The framework therefore provides a useful theoretical foundation for future empirical studies and offers practical guidance for policymakers, recycling plant operators, and construction companies seeking to implement sustainable construction waste management practices.

6. Practical Implications

The proposed integrated framework has important implications for policymakers, construction companies, recycling plant operators, researchers, and investors. By combining Life Cycle Assessment (LCA) and Life Cycle Costing (LCC), the framework provides a comprehensive approach for evaluating both the environmental and economic performance of construction and demolition (C&D) waste recycling plants. The findings can support informed decision-making and contribute to the transition toward a circular economy in the construction sector.

6.1 Policy Implications

Governments play a critical role in promoting sustainable construction waste management. The proposed framework highlights the need for policies that encourage waste segregation at the source, increase recycling rates, and reduce landfill disposal. Regulatory agencies should establish quality standards for recycled construction materials and introduce incentives such as tax benefits, landfill taxes, and subsidies for recycling facilities. Public procurement policies should also encourage the use of recycled aggregates in infrastructure projects to strengthen market demand and support circular economy objectives.

6.2 Industrial Implications

Construction companies and recycling plant operators can use the proposed framework to improve operational efficiency and environmental performance. Investments in advanced crushing, screening, and sorting technologies can increase material recovery rates while reducing energy consumption. Optimizing transportation routes and adopting preventive equipment maintenance can further reduce operational costs and greenhouse gas emissions. In addition, integrating renewable energy sources, such as solar and wind power, into recycling plants can significantly improve sustainability performance.

6.3 Environmental Implications

The framework demonstrates that efficient recycling systems contribute to environmental sustainability by reducing landfill dependency, conserving natural resources, and decreasing greenhouse gas emissions. Increased utilization of recycled aggregates reduces the extraction of virgin materials and lowers the environmental burden associated with quarrying and material processing. Adoption of Life Cycle Assessment as a routine decision-support tool can help identify environmental hotspots and prioritize strategies for continuous improvement.

6.4 Economic Implications

Life Cycle Costing enables organizations to evaluate the long-term financial viability of recycling facilities. The proposed framework assists investors and plant managers in assessing capital investment requirements, operating costs, maintenance expenses, and potential revenue from recycled materials. A balanced evaluation of environmental and economic performance can improve investment decisions and encourage the development of financially sustainable recycling infrastructure.

6.5 Academic Implications

This paper contributes to the literature by integrating Life Cycle Assessment, Life Cycle Costing, and circular economy principles within a single conceptual framework. The framework extends previous studies that examined environmental and economic performance separately and provides a theoretical foundation for future empirical research. It can be used to develop quantitative models, comparative case studies, and decision-support tools for sustainable construction waste management.

7. Future Research Directions

Construction and demolition (C&D) waste recycling has gained considerable attention because of its potential to improve resource efficiency, reduce environmental impacts, and support circular economy objectives. Despite significant progress, several research opportunities remain that can further strengthen the sustainability of recycling systems.

Future studies should focus on validating the proposed conceptual framework through empirical investigations using operational data from construction and demolition waste recycling plants. Integrating Life Cycle Assessment (LCA) with Life Cycle Costing (LCC) using real-world data will improve understanding of the relationship between environmental performance and economic viability under different geographical and operational conditions.

Comparative studies between stationary and mobile recycling plants should also be expanded. Such research can evaluate differences in energy consumption, greenhouse gas emissions, transportation requirements, and operating costs to determine the most sustainable recycling strategy for different project types and locations.

Another important research direction is the integration of renewable energy technologies within recycling facilities. Future studies should assess the environmental and economic impacts of using solar, wind, or other renewable energy sources to power crushing, screening, and material handling equipment. This would provide valuable insights into reducing the carbon footprint of recycling operations.

Emerging digital technologies such as Building Information Modelling (BIM), Geographic Information Systems (GIS), Artificial Intelligence (AI), Internet of Things (IoT), and digital twins offer significant opportunities for improving waste forecasting, material tracking, process optimization, and recycling efficiency. Future research should investigate how these technologies can be integrated into construction waste management systems to support intelligent and automated recycling operations.

Future investigations should also incorporate Social Life Cycle Assessment (S-LCA) alongside environmental and economic assessments. Including social indicators such as employment generation, occupational health and safety, stakeholder acceptance, and community well-being would provide a more comprehensive sustainability evaluation of recycling plants.

Further research is needed to examine the influence of government policies, environmental regulations, financial incentives, landfill taxes, and carbon pricing mechanisms on the adoption of recycling technologies. Comparative policy analyses across different countries can identify best practices that encourage investment in sustainable construction waste management.

Finally, future studies should develop integrated decision-support models that combine environmental, economic, technical, and social dimensions using multi-criteria decision-making techniques. Such models can assist policymakers, construction companies, and investors in selecting optimal waste management strategies while promoting circular economy principles and sustainable infrastructure development.

8. Conclusion

Construction and demolition (C&D) waste has emerged as one of the largest and fastest-growing waste streams worldwide, creating significant environmental, economic, and resource management challenges. Conventional landfill disposal is no longer a sustainable solution because it accelerates the depletion of natural resources, increases greenhouse gas emissions, and occupies valuable land. Consequently, recycling C&D waste has become an important strategy for improving resource efficiency and supporting the transition towards a circular economy.

This conceptual paper reviewed the existing literature on construction and demolition waste management, circular economy, Life Cycle Assessment (LCA), Life Cycle Costing (LCC), energy consumption, greenhouse gas emissions, and the economic viability of recycling plants. The review indicates that although recycling operations consume electricity and diesel fuel, they generally offer lower environmental impacts than landfill disposal through reduced extraction of virgin materials, lower greenhouse gas emissions, and improved material recovery. Similarly, previous studies suggest that economically viable recycling plants can generate long-term financial benefits through recycled aggregate production, recovered metals, reduced landfill costs, and improved resource utilization.

A major contribution of this paper is the development of an integrated conceptual framework that combines Life Cycle Assessment and Life Cycle Costing for evaluating the sustainability of construction and demolition waste recycling plants. The framework illustrates the relationships among recycling operations, energy consumption, environmental impacts, operational costs, and sustainability outcomes. It also emphasizes the importance of circular economy principles in promoting material recovery, reducing waste generation, and conserving natural resources.

The proposed framework has important implications for policymakers, researchers, construction companies, and recycling plant operators. It provides a structured approach for evaluating recycling systems from both environmental and economic perspectives and can support evidence-based decision-making in sustainable construction waste management. Furthermore, the framework may assist governments in designing policies that encourage higher recycling rates, greater use of recycled construction materials, and investment in advanced recycling technologies.

Despite these contributions, this study is conceptual in nature and does not include empirical validation using operational data from recycling plants. Future research should apply the proposed framework using Life Cycle Assessment software and Life Cycle Costing models to evaluate recycling facilities under different geographical, technological, and policy conditions. Incorporating renewable energy systems, digital technologies, and social sustainability indicators would further strengthen future assessments.

In conclusion, integrating environmental and economic assessment methods provides a comprehensive understanding of the sustainability of construction and demolition waste recycling plants. The proposed framework offers a valuable foundation for future empirical research and supports the development of resource-efficient, low-carbon, and economically sustainable construction waste management systems that contribute to achieving circular economy and sustainable development goals.

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