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Life Cycle Assessment of Wood as a Sustainable Material: Greenhouse Gas Emissions and Life Cycle Costs

Mingjia Liu*

China Northwest Architectural Design And Research Institute Co., Ltd., Xi'an 710000, Shaanxi, China

**Author to whom correspondence should be addressed.*

Abstract: With the increasingly serious environmental problems, the use of sustainable materials is particularly important. This study focuses on the greenhouse gas emissions and economic costs of wood over its life cycle as a sustainable resource. We use a systematic life cycle assessment (LCA) approach to assess the entire process from raw material collection, processing, use to disposal. The study found that using wood can significantly reduce greenhouse gas emissions compared to traditional building materials such as steel and concrete. In addition, although the initial procurement costs of wood may be higher, its maintenance costs are lower in the long run, making the life cycle costs generally more economical. The results of this study highlight the environmental and economic advantages of wood in the selection of sustainable building materials, and provide a scientific basis for promoting the use of wood.

Keywords: Wood; Sustainable materials; Life cycle assessment; Greenhouse gas emissions; Life cycle cost

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1. Introduction

With the prominence of global environmental problems, human beings pay increasing attention to ecological protection and climate change. Therefore, the development and use of sustainable materials, especially in the construction industry, has become urgent. The subject of this study is wood, a renewable resource, to explore its environmental and economic performance as a building material. Compared with traditional non-renewable resources such as steel and concrete, wood has environmental advantages such as efficient absorption of carbon dioxide and trace greenhouse gases released during the life cycle. However, in terms of economic costs, the use of wood is not universally accepted, often due to its high initial procurement costs. Therefore, this study adopts a systematic life cycle assessment method to comprehensively analyze the whole process of wood collection, processing, use to waste, in order to measure its actual effect as a sustainable material and reveal its potential economic value. This will not only promote and enhance the use of wood in the field of construction, but also provide scientific theoretical basis and practical guidance for achieving double benefits of environmental protection and economy.

2. Sustainable development and sustainable materials

2.1. Importance of sustainable development

Sustainable development has gradually become the core issue of global social concern, and its importance is reflected in the comprehensive needs of environmental protection, economic development and social progress [1]. With the intensification of resource consumption and environmental pollution, mankind is faced with major challenges such as resource depletion and climate change. Sustainable development aims at meeting the needs of the present and preserving adequate resources and environmental conditions for future generations. This concept emphasizes that economic growth must go hand in hand with environmental protection to ensure the long-term health of ecosystems and sustainable human development.

Environmentally, sustainable development requires reducing dependence on fossil fuels and reducing greenhouse gas emissions in order to slow the rate of climate warming. Economically, shifting to renewable resources and sustainable solutions not only creates new jobs, but also drives technological innovation and makes resource use more efficient. On the social side, it is committed to achieving broader social equity and improving the quality of human life. In summary, the importance of sustainable development is not only related to the carrying capacity of the earth, but also to the future prosperity of human civilization [1–3]. The choice of sustainable materials, such as wood, is important to achieve this goal.

2.2. Definition and classification of sustainable materials

Sustainable materials are those that have the least impact on the environment during the production, use and waste stages and are economical. These materials focus on reducing resource consumption and pollution emissions throughout their life cycle to achieve long-term ecological balance. According to their source and characteristics, sustainable materials can be divided into natural renewable materials, recycled materials and low-energy materials. Natural renewable materials such as wood, bamboo, etc. are renewable and biodegradable. Recycled materials include materials processed from waste recycling, such as recycled paper and recycled plastics. Low-energy materials are materials that consume less energy during manufacturing and use, such as high-efficiency insulation. Through proper selection and use, sustainable materials can help mitigate environmental degradation and resource scarcity.

2.3. Advantages of wood as a sustainable material

Wood has multiple advantages as a sustainable material. Its biodegradability allows it to break down naturally at the end of its life cycle, reducing environmental pollution. Wood absorbs a large amount of carbon dioxide through photosynthesis during the growth process, thus exhibiting carbon-negative emission characteristics during the use stage. Compared with traditional materials, the processing of wood consumes less energy and the production process is more environmentally friendly. The good insulation properties of wood can also improve the energy efficiency of buildings and reduce energy consumption. These properties make wood an ideal material choice for sustainable construction.

3. Greenhouse gas emissions and life cycle assessment

3.1. Relationship between greenhouse gas emissions and environmental problems

Greenhouse gas emissions are one of the main drivers of global climate change, with significant negative impacts on the environment. These gases are mainly produced by human activities, including fossil fuel use, industrial processes, and land use changes. Carbon dioxide, methane, and nitrous oxide are the main greenhouse gases, and their long-term existence in the atmosphere causes the Earth's surface temperature to rise, which in turn causes

a series of environmental problems, such as frequent extreme weather events, sea level rise, and ecosystem imbalance [4–6]. As one of the world's important economic sectors, the construction industry is one of the main sources of greenhouse gas emissions. Careful evaluation of the selection and use of building materials, especially the assessment of greenhouse gas emissions, has become particularly important. Life Cycle Assessment (LCA) is a systematic approach that can be used to quantify the environmental impact of building materials over their entire life cycle. LCA enables the identification and quantification of greenhouse gas emissions from raw material extraction to final disposal, thereby providing a basis for the selection of low-emission materials and helping to drive the construction industry towards a lower environmental impact.

3.2. Concepts and methods of life cycle assessment

Life Cycle Assessment (LCA) is a systematic method for assessing the environmental impact of a product throughout its life cycle. Its main steps include definition of objectives and scope, inventory analysis, impact assessment and interpretation of results. This approach provides a comprehensive understanding of a product's environmental footprint by analyzing the stages from raw material acquisition to production, use and final disposal. In the field of environmental science, LCA is widely used to quantify greenhouse gas emissions and other environmental impacts. It helps decision makers identify the most environmentally responsible parts of the product life cycle and provides scientific support for sustainable production and consumption. LCA assessments of sustainable materials, particularly wood, reveal their potential to reduce carbon emissions and resource consumption.

3.3. Assessment of greenhouse gas emissions from wood

Greenhouse gas emissions from wood as a building material are assessed using a life cycle assessment approach. The assessment covers all stages from raw material collection, processing, and manufacturing to use and disposal. Wood sequesters carbon through photosynthesis as it grows, reducing overall greenhouse gas emissions. The relatively low energy consumption and emissions at the processing stage further enhance its environmental advantages. Compared to traditional building materials, the use of wood significantly reduces carbon dioxide emissions, which is attributed to wood's natural carbon sequestration capacity and lower manufacturing energy consumption, providing a strong environmental case for its use as a sustainable building material.

4. The life cycle cost of wood

4.1. Cost of wood collection and processing

The cost of collecting and processing wood plays an important role in its life cycle cost. During the collection process, the main costs come from forest management, harvesting operations, and raw material transportation [7]. Efficient forest management helps to reduce the cost of harvesting and ensure the sustainability of resources. In logging operations, the use of machinery, fuel consumption, and labor costs are the main components of the cost. During the transportation phase, the logistics costs of transporting wood from the harvesting site to the processing plant significantly affect the overall cost, with distance and traffic conditions being key factors.

The processing cost mainly involves two stages of wood primary processing and deep processing. In the initial processing stage, common processes such as sawing and drying require a lot of energy, and equipment depreciation and labor costs constitute the main expenses at this stage. The deep processing stage involves fine processing and finished product production, which also requires high-tech equipment and skilled labor, resulting in higher costs. Thanks to technological advances and scale effects, processing efficiency has been improved, and unit costs have been reduced. Costs in these processes can also be affected by regional energy prices and labor

market fluctuations.

4.2. The cost of using wood

The cost of using wood plays an important role in the life cycle of a building, including maintenance, repair, and maintenance. Compared to other building materials, wood has good durability and natural thermal insulation, reducing the need for additional energy and thus reducing long-term operating costs [8]. The lightweight nature of this material not only simplifies structural design but also reduces equipment and labor costs during construction. In daily maintenance, wood needs to be regularly treated against insects and moisture, but these costs are relatively low due to the repairability and ease of processing of the material itself. The natural aging process of wood gives the building a unique aesthetic value, increasing the attractiveness of long-term investments and market competitiveness. These factors make wood significantly cost-effective at the use stage.

4.3. Waste disposal cost of wood

The cost of wood disposal plays an important role in life cycle cost assessment. The abandonment stage includes demolition, transportation, and final disposal, and the main factors affecting the cost of disposal are local waste management policies and infrastructure. Compared with other materials, due to the renewable and biodegradable properties of wood, the processing cost can be reduced through recycling and biological treatment. The recycling of waste wood not only reduces its treatment costs but also provides raw material support for subsequent industries. The cost of wood disposal is economically advantageous and meets the requirements of sustainable development, which helps to reduce the environmental burden [9].

5. Comparison of wood and other building materials

5.1. Comparison of wood and steel

When comparing the performance of wood versus steel as a building material, the focus is on greenhouse gas emissions and life-cycle costs. The production process of steel involves high temperature heating and REDOX reactions, resulting in significant carbon dioxide emissions, and is one of the major sources of greenhouse gas emissions. In contrast, wood absorbs carbon dioxide through photosynthesis during its natural growth and is sequestered during its use stage, which results in lower net emissions over its life cycle. Maintenance and corrosion protection of steel often require additional energy inputs and chemical treatment, increasing the environmental load during its use phase. In terms of economic costs, although the initial purchase of wood may be costly, the low maintenance and processing costs show long-term economic advantages over its life cycle. The superior performance of wood in environmental benefits and economy provides an effective material choice for the transformation of the construction industry to the direction of low-carbon and sustainable development [10, 11].

5.2. Comparison between wood and concrete

There are significant differences between wood and concrete in terms of greenhouse gas emissions and life cycle costs. In the process of concrete production, due to the need for high-temperature calcination of limestone, it will release a lot of carbon dioxide, making its greenhouse gas emissions significantly higher than those of wood. Concrete production involves several resource-intensive steps, including mining, transportation, and processing, which have a much higher energy consumption and environmental impact than wood. Wood, as a natural material, its collection and processing process has a low impact on the environment, and it can also sequester carbon during the use stage, which helps to mitigate climate change. In terms of life cycle costs, although the initial procurement cost of wood may be higher than that of concrete, due to the lower maintenance and restoration costs of wood,

considering its full life cycle costs, wood is more economical. The above comparison shows that wood has advantages in terms of both environmental friendliness and economy, providing a sustainable alternative for the construction industry [12].

5.3. Demand and utilization of wood in the construction industry

The demand for and use of wood in the construction industry has shown a growing trend in recent years, mainly due to its widely recognized ecological advantages as a sustainable material. Compared to steel and concrete, wood attracts more construction companies because of its low carbon emissions and lower life cycle costs. In the promotion of green building and environmental protection regulations, wood is gradually used for structure, decoration, furniture, and other purposes. Its renewable and aesthetic characteristics have further increased the market demand, and an increasing number of construction projects have begun to prioritize wood, creating opportunities for innovation and transformation in the industry [13, 14].

6. Conclusion and future outlook

6.1. Environmental and economic significance of the results of this study

A detailed analysis of the life cycle of wood as a sustainable material reveals its environmental and economic significance. In terms of the environment, the use of wood can significantly reduce greenhouse gas emissions and has a positive effect on climate change mitigation compared to traditional building materials such as steel and concrete. This will not only help meet global greenhouse gas reduction targets, but also provide a green, low-carbon solution for the construction industry.

At the economic level, although wood may lead to higher inputs when initially purchased, low maintenance costs throughout its life cycle make the total cost more economical. This cost-effectiveness continues to stand out over the long term, providing sustainable economic support for construction projects. Especially in the context of sustainable development and green economic transformation, the economic competitiveness of wood has been further reflected [15].

This study not only validates the dual advantages of wood as a sustainable material, but also provides a scientific and forward-looking reference basis for policymakers and industry practitioners in the selection of materials, helping to promote the widespread use of sustainable materials in the construction industry.

6.2. The application prospect of wood as a sustainable material

Wood holds great promise as a sustainable material, and its use in the construction industry helps to reduce environmental impact and reduce long-term economic costs. Due to its low carbon footprint and renewable properties, wood will play an important role in the future of green buildings. Wood's unique structure and ability to regenerate make it an ideal alternative material, especially in the context of rapid urbanization. With the advancement of technology and the improvement of design standards, the durability and safety of wood are gradually enhanced, opening up more application possibilities. The increase in policy support and market demand will also drive the expansion of sustainable wood applications, contributing to the low-carbon transition in the construction industry.

6.3. Suggestions for future research directions

Future research should focus on the sustainability performance of wood in different geographical and climatic settings to more fully understand its potential benefits. In-depth analysis of wood's synergies with other emerging sustainable materials can reveal its potential for use in innovative architectural design. Research into technological

innovations in wood production and processing can help further reduce costs and environmental impact. Considering the changing policy and market trends, it is also important to study how to promote the use of wood by optimizing supply chain management and sustainable building policies. These directions will help promote the wider application and development of wood on a global scale.

7. Conclusion

Using life cycle assessment (LCA) methods, this study examines wood from raw material collection, processing, use to waste, and reveals the environmental and economic benefits of wood as a sustainable resource compared to traditional building materials such as steel and concrete. The results of the study show that although the initial procurement cost of wood may be higher, in the long term, its overall life cycle cost is economically beneficial due to its lower maintenance costs. At the same time, wood can effectively reduce greenhouse gas emissions, showing superior environmental performance. Therefore, the promotion and application of wood in the field of construction has great potential and significant environmental and economic benefits. However, this study only evaluated wood as a sustainable material from the perspectives of greenhouse gas emissions and life cycle costs, and it did not take into account other environmental factors such as forestry management and wood sources. Therefore, further evaluation and discussion are needed in future studies. Future studies will also need to consider the source of wood, such as whether it comes from sustainable forest management, and whether it has an impact on biodiversity. It is hoped that these studies will provide a more comprehensive and in-depth assessment to support decision makers in making informed choices by choosing sustainable building materials. This study provides a strong scientific basis for promoting the use of wood and provides a new research direction for future studies of wood as a sustainable material.

Disclosure statement

The author declares no conflict of interest.

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