

# CIRCULAR ECONOMY PRACTICES FOR TIMBER WASTE MANAGEMENT ON CONSTRUCTION SITE AND IMPACT OF ENVIRONMENT, ECONOMIC AND SOCIAL: A REVIEW

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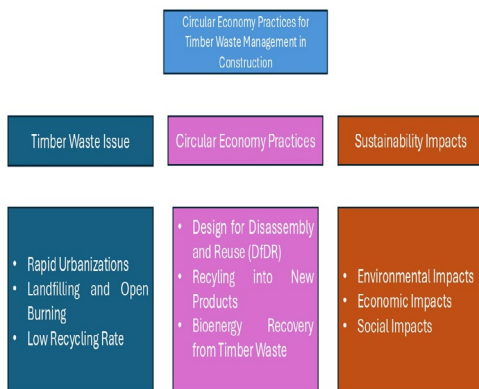
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## Graphical abstract



## Abstract

The construction industry significantly contributes to timber waste, posing various challenges. However, implementing effective waste management practices is complicated by the fast pace of construction and economic pressures that often prioritize cost and time over sustainability. The circular economy, by contrast, maintains the value of materials and products for extended periods, thereby minimizing raw material consumption, energy use and environmental consequences of resource extraction, emissions, and waste generation. This study reviews the implementation of circular economy principles for timber waste management in construction sites. This study conducted a systematic literature review using the Scopus database (2019–2024), analyzing research on circular economy, waste management, timber, wood, sustainable development, construction, and construction demolition waste. Further, a bibliometric analysis was conducted with VOSviewer software to identify key trends, followed by an in-depth analysis of the impacts of implementing circular economy principles in timber waste management to the environment, economic and social. The findings emphasize the potential of circular economy (CE) strategies, such as design for disassembly, recycling, and bio-energy recovery, to reduce timber waste and promote sustainability. Environmentally, these strategies lead to decreased greenhouse gas emissions and better resource conservation. Economically, they can result in cost savings, job creation, and innovation in sustainable construction practices. Socially, the circular economy fosters community engagement, improves public health, and encourages social inclusion. This review provides key insights for policymakers, researcher, and industry professional seeking to integrate circular economy (CE) strategies into timber waste management for more sustainable construction practices.

**Keywords:** Circular Economy, Timber Waste Management, Construction, Impact, Sustainability

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## 1.0 INTRODUCTION

The rapid developments in developing countries have dramatically escalated construction waste generation [1,2,3]. According to Ismael and Kassim [4], construction waste extends beyond brick, concrete, rubble, gypsum, and asphalt to encompass organic materials like timber and biosolids, metals

such as steel and aluminium, as well as glass and plastics. The construction industry consumes approximately 40% of all materials used annually [5], leading to significant concerns over the rising volume of waste, which heavily burdens landfills [6]. Effective waste management through reuse or recycling could reduce this negative impact and promote sustainability [7]. However, the fast-paced nature of construction projects and

financial constraints often prioritise cost and timelines over sustainable practices, hindering proper waste management. Notably, recycling timber waste offers significant environmental benefits and cost savings. [8]. In Europe, for example, 37% of wood waste is either landfilled or incinerated, 33% is recovered as material, and 30% is recovered for energy [8]. In contrast, regions like Malaysia recycle only a small fraction of construction waste, with estimates suggesting that as little as 5% of waste is effectively managed [9].

The construction industry increasingly turns to timber as a sustainable building material due to its lower carbon footprint than traditional materials [10]. This shift addresses waste production and aligns with broader sustainability goals by promoting renewable resources and minimizing environmental impact [11]. Conventional disposal methods, such as landfilling and open burning, contribute to land degradation and methane emissions, making them environmentally unsustainable [12,13]. An emerging trend in timber waste management focuses on reusing and recycling waste into value-added products. For example, a timber beam can be repurposed into a floorboard and later into a window frame [12]. Further, nowadays developed countries are repurposing wood waste in concrete to minimize environmental harm [13]. Then, in Malaysia, efforts are underway to convert timber waste into energy and diversify waste management strategies [14]. Despite these initiatives, systematic literature reviews on timber waste management practices at construction sites remain lacking.

The circular economy has emerged as a prominent sustainability framework, promoting a transition from a linear to a circular economy system to decouple economic development from reliance on non-renewable resources and environmental harm [15]. In recent years, the circular economy has attained substantial traction in policy and industry spheres, particularly in the construction sector, where they are increasingly recognized as instrumental in advancing sustainability objectives [16]. Adopting circular economy principles presents a viable solution for overcoming environmental challenges in the construction industry [17,18,19]. Academic interest in CE applications for construction has surged since 2017, as evidenced by a marked increase in scholarly publications [18]; however, the few practical applications of CE in construction remain limited [15]. Although research on timber waste management and circular economy principles has expanded, a comprehensive understanding of the current knowledge landscape, key contributors, and research gaps is still lacking. Hence, bibliometric analysis offers a systematic approach to addressing this gap by quantitatively assessing the research landscape, identifying trends, and uncovering areas requiring further investigation.

This research reviews the implementation of circular economy principles for timber waste management on the construction site. It evaluates the impact of implementation on the environment, economy, and society. Through bibliometric analysis, it explores research trends, highlights key contributors, and identifies emerging themes and challenges. The findings of this study aim to contribute to the growing body of knowledge on sustainable construction practices and offer valuable insights for policymakers, researchers, and industry stakeholders on integrating circular economy principles into timber waste management and the impact on construction sites.

## 2.0 METHODOLOGY

The strategy employed in this study consisted of three main stages, as illustrated in Figure 1. A systematic literature review was conducted in the first stage to identify and synthesize existing research evidence, creating a comprehensive and reliable information source. This approach ensured the inclusion of all relevant, research-based evidence to support the study's objectives.

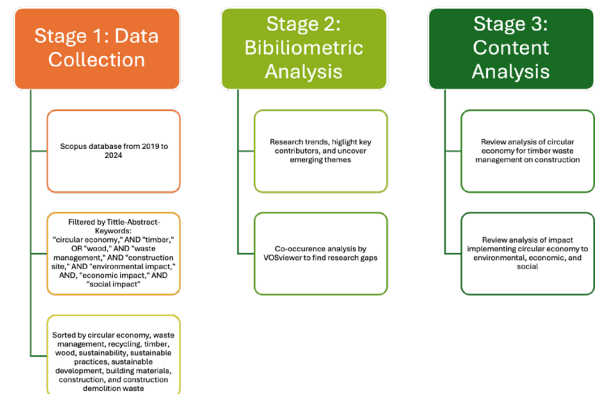


Figure 1 Research Strategy and Process

The Scopus database was used as the primary data for retrieving pertinent literature. To maintain relevance and comprehensiveness, a combination of specific keywords was applied, including "circular economy," "timber," "wood," "waste management," "construction site," "environmental impact," "economic impact," and "social impact." Boolean operators (AND and OR) were used separately and in combination to retrieve pertinent publications. Examples of search queries included: "circular economy" AND "timber" OR "wood," AND "waste management" AND "construction site," AND "environmental impact," AND "economic impact," AND "social impact." The search period was limited to 2019–2024, ensuring the inclusion of recent, relevant studies and the retrieval of novel insights and emerging research concepts. Most included publications were from the last five years, emphasizing the study's focus on current development. Compared to the previously published papers, the primary advantage of this review is that it discusses the current research in this area from a new perspective, taking into account the importance of environmental, economic, and social impacts of implementing a circular economy for timber waste management in construction sites. The initial database search identified 45 documents, including journal articles, peer-reviewed conference proceedings, and other academic sources. To ensure quality and relevance, we filtered the dataset to 19 full-length, peer-reviewed journal articles. Articles were included if they met these criteria: (1) published between 2019 and 2024, (2) written in English, (3) focused on circular economy practices related to timber waste in construction, and (4) available as full-text journal articles. Conference papers, editorials, and non-relevant articles were excluded. The screening process, shown in the PRISMA flow diagram Figure 2, improves transparency and reproducibility.

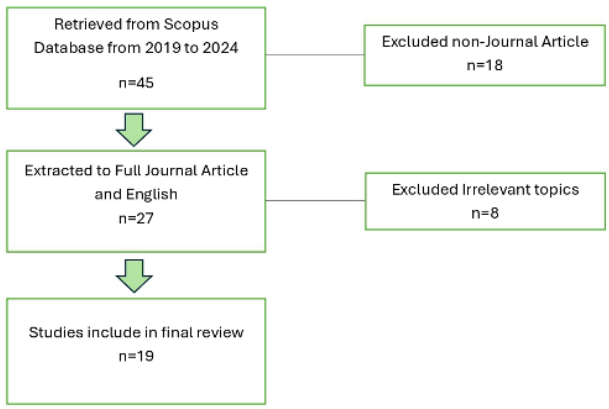


Figure 2 PRISMA diagram of the study

In the second stage, a bibliometric analysis was conducted to identify research trends, highlight key contributors, and uncover emerging themes within the field. This was followed by a co-occurrence analysis using VOSviewer tools to identify research gaps. The network visualization of trend keywords, presented in Figure 3, identifies Circular Economy and Waste Management as central themes, represented by large nodes and numerous connections. The analysis reveals two dominant clusters in which the Red Cluster focuses on broader topics such as sustainability and environmental impact. At the same time, the Green Cluster emphasizes practical strategies like recycling and reuse in construction. The relationships between concepts are illustrated by connecting lines, where thicker lines indicate stronger associations. This visualisation demonstrates that research on sustainable development is concentrated on specific industries or materials, particularly in construction, thereby supporting broader sustainability goals.

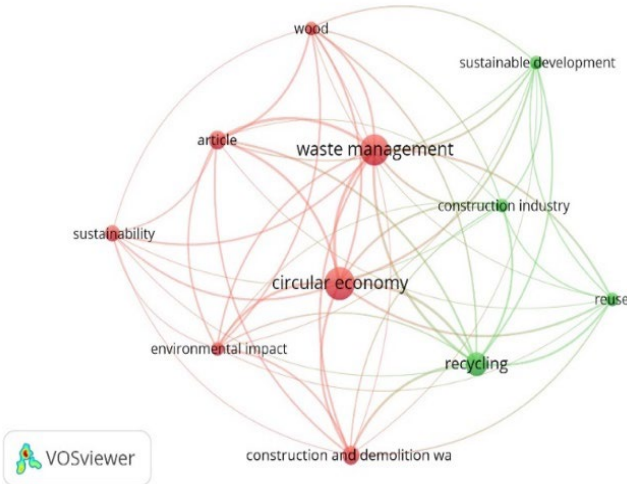


Figure 3 Co-occurrence analysis of keywords by VOSviewer

The annual publication count demonstrated an upward trend, with a notable surge in 2024 with 13 articles, indicating increasing academic interest in circular economy practices related to timber waste construction. The most active journal was Sustainability (Switzerland) with 7 articles. Resources, Conservation and Recycling published 3 articles, while Science of the Total Environment, Journal of Cleaner Production, and

Energies, each had 2 articles. Figure 4 is showing the network visualization of most active journal by Vosviewer. Co-authorship analysis of authors shown in Figure 5. Notable authors include Caro, Foster, and Flachenecker, each with two contributions, while other authors like Tonini, Lodato, Cristobal, and Damgaard contributed one. Figure 6 presents a Bibliographic analysis of countries, with Italy leading with five publications, followed by the US, the UK, and Poland each with three. Other contributing countries include Sweden, Belgium, Spain, Latvia, Germany, and Brazil.

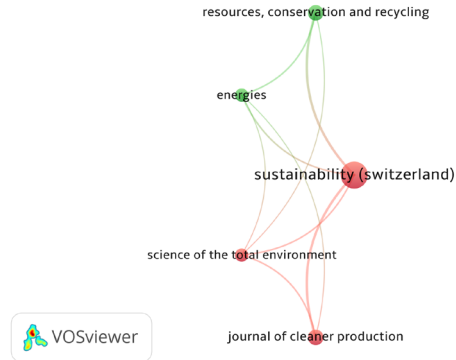


Figure 4 The most active journals analysis by Vosviewer

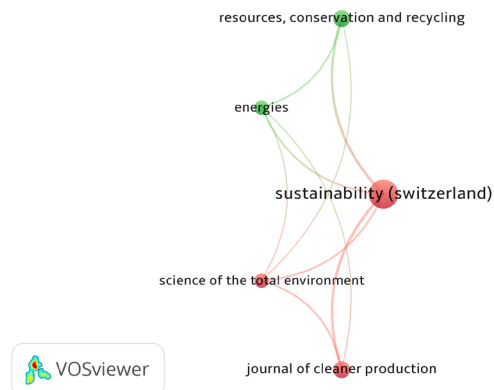


Figure 5 Co-authorship analysis of authors by VOSviewer

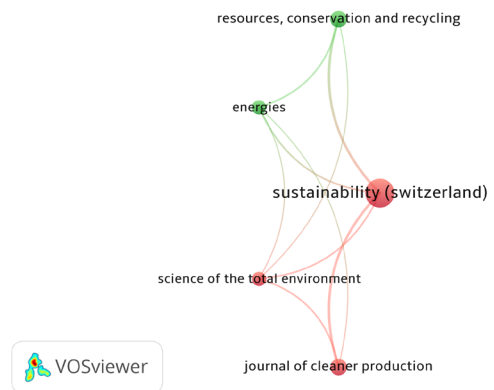


Figure 6 Bibliographic analysis of countries by VOSviewer

Building upon the bibliometric findings, the third stage involves analysing the existing literature on the circular economy in timber waste management within the construction sector. This stage aims to synthesize relevant studies, identify

key trends, and highlight gaps in the current research. The first part of the analysis examines the role of the circular economy in managing timber waste in the construction sector. This involves exploring various strategies to minimise waste and promote sustainability, such as recycling and reusing timber materials. This review identifies best practices and research gaps, providing valuable insights into practices of timber waste management on construction sites. The second part of the analysis evaluates the broader impacts of implementing a circular economy in terms of environmental, economic, and social factors. Environmentally, adopting circular practices can significantly reduce carbon emissions, decrease landfill waste, and make more sustainable use of natural resources. Economically, circular approaches may create cost-saving opportunities for construction companies, contribute to job creation in the recycling and repurposing sectors, and enhance the financial viability of sustainable building practices. Socially, the circular economy can drive policy changes, raise public awareness, and contribute to healthier living environments. By examining these factors, the review aims to assess the overall benefits and challenges of transitioning to circular construction practices.

### 3.0 RESULTS AND DISCUSSION

#### 3.1 Timber Waste in Construction

Timber waste in construction is commonly defined as any wood material discarded, unused, or deemed unsuitable for its intended purpose during construction [20]. One of the primary sources of timber waste in construction projects is formwork, which is used as temporary moulds for shaping concrete structures and often has limited potential for reuse, leading to considerable waste generation Wu et al. [21], Expanding on the complexities of timber waste, Thompson et al. [22] classified it based on condition, emphasising that "contaminated timber," such as chemically treated railway sleepers, poses significant recycling challenges due to its hazardous components. This type of waste contributes significantly to non-inert waste, complicating efforts toward sustainable waste management. According to Pandey [23], the scope of timber waste extends beyond construction activities; it includes discarded wood from wood packaging, demolition, wood processing industries, and even private households. This highlights the diverse origins of timber waste and underscores the broader challenge of managing it effectively.

Despite its construction to waste, timber as a sustainable building material is gaining interest in construction [24]. Countries worldwide are adopting policies to promote timber usage due to its lower carbon footprint than conventional materials. For instance, in France, regulations introduced in 2022 require that at least 50% of materials used in new public buildings be timber or other natural materials [25]. The 2021 International Building Code (IBC) revisions in the United States marked a significant regulatory milestone by incorporating dedicated provisions for timber construction for the first time [26]. Concurrently, Germany's latest coalition agreement has formally established a national timber construction strategy, reflecting a broader policy transition toward sustainable building materials across both nations [24].

Unfortunately, the generation of timber waste arises from construction activities, having a negative impact on the environment. For example, a considerable amount of wood is often left over as off-cuts during the cutting and shaping of timber for structural elements. These off-cuts are typically discarded, leading to significant waste [27]. Additional sources of waste include timber damaged during transportation or handling of materials that fail to meet the quality standards, which are often disposed of rather than repurposed [14]. Traditional waste management practices, often involving landfilling, remain prevalent in the construction sector. While convenient, landfilling timber waste contributes to resource depletion, greenhouse gas emissions and environmental degradation [14,28,29]. In Malaysia, more than half of construction contractors choose not to manage timber using the 3Rs: reduce, recycle, and reuse when managing timber waste [14]. This is further compounded by contractors' limited awareness and insufficient government support for timber waste recycling [14], the absence of a credit system for timber resources, along with a weak market for used timber, further hinders sustainable waste practices [30]. As a result, a significant proportion of timber waste continues to end up in landfills or is incinerated. A study conducted in Finland found that only approximately 4% of timber from construction and demolition waste is recovered in material form, while the majority is incinerated for energy production [31]. Although energy recovery provides certain environmental benefits, it does not maximize timber's potential as a reusable resource.

Addressing these issues requires a shift in focus toward sustainable waste management practices, particularly the adoption of circular economy (CE) principles. The circular economy promotes the extension of material lifecycles, emphasizing strategies such as recycling, reuse, and resource recovery. Applying these principles to timber waste management can significantly reduce landfill dependency, minimize environmental impacts, and contribute to the construction sector's broad sustainability goals.

#### 3.2 Circular Economy and Application in Construction Sites

The Circular Economy (CE) is an economic model that aims to minimize resource input, waste, emissions, and energy leakage by slowing, narrowing material and energy loops, and using closed loops of products and materials as part of environmental protection and socio-economic benefits [20,32]. Then, according to Kromoser et al. [33], the circular economy represents an economic model inspired by natural cyclical processes, emphasizing optimal resource utilization while maintaining materials in continuous circulation loops. The primary goal of CE is to preserve the value of products, materials, and resources in the economy for as long as possible through strategies such as reuse, repair, remanufacturing, and recycling [34]. As a relatively recent concept in sustainability, CE aligns with the three fundamental pillars of sustainability, which are environmental, economic and social [35], which are also key areas influenced by CE practices [36]. The growing urgency to adopt CE principles stems from the need to counteract the negative impacts of the traditional linear economic model, which is marked by excessive resource consumption and high waste generation, leading to significant threats to ecological integrity and human well-being [37]. This paper defines the circular economy in timber waste

management as a strategic approach that involves designing for reuse, recycling, and bioenergy recovery. These practices aim to preserve the value of timber materials throughout the construction lifecycle, thereby minimizing environmental impacts and promoting sustainability.

### 3.2.1 Circular Economy in the Construction Sector

The construction sector is one of the most resource-intensive and has a high potential for CE implementation, mainly through eco-friendly materials, waste reduction strategies, and innovative technologies [38, 39]. The implementation of the CE principle in the construction promotes three key sustainable outcomes; increased utilization of renewable materials, optimized material recovery processes, and significant reduction in both waste production and landfill dependence [40,41,42]. Due to the rising demand for construction materials, material shortages, and growing environmental concerns, resource-efficient construction has received global attention at different levels, including government policies, industry initiatives, and academic research [18,43]. Hence, the circular economy focuses on reducing and recycling C&D waste and exploring new design approaches, such as designing for deconstruction and increasing materials efficiency [44,45].

The circular economy promotes a regenerative system in which goods are designed to last, be repaired, and be recyclable. This approach reduces waste and extends product life cycles [46,47]. This approach decreases dependence on limited resources while creating new business opportunities, enhancing economic resilience, and promoting environmental sustainability [48,49]. In the construction industry, (CE) has emerged as a modern and practical strategy to achieve sustainability goals, particularly in waste management and resource conservation [50]. By fostering a circular system, the CE aims to decouple economic growth from resource consumption, thereby contributing to a more sustainable future [34]. This concept is closely aligned with the sustainable development goals (SDGs), notably Target 12.5, which emphasizes the reduction of waste generation through prevention, reduction, recycling, and reuse [51].

However, the implementation of circular economy principles faces several challenges. Various barriers hinder the transition from a linear to a circular model, including insufficient consumer awareness, a lack of supportive policies, and financial constraints [36]. For instance, in sectors like construction, the adoption of circular practices is often slow due to regulatory hurdles and the entrenched nature of traditional practices [52,53]. Moreover, small and medium-sized enterprises (SMEs) frequently encounter more significant obstacles in adopting circular economy strategies due to limited resources and capabilities compared to larger corporations [37,54]. Addressing these barriers requires a concerted effort from policymakers, businesses, and consumers to create an enabling environment that fosters innovation and collaboration [55]. Technology plays a crucial role in advancing CE practices, with innovations such as digital twins, artificial intelligence (AI), and blockchain enhancing resource management and optimizing supply chains [56,57]. For example, digital twin technology is utilised in the construction industry to monitor and manage resources more effectively, reducing waste and improving efficiency [52]. Additionally, Industry 4.0 technologies enable businesses to track product

life cycles and implement circular practices more seamlessly, addressing some of the traditional challenges associated with resource recovery and recycling [46,56].

According to Yu et al. [17] and Khiyana et al. [58], applying Circular Economy (CE) concepts could be a potential solution to the environmental challenges faced by the construction sector. For a CE strategy to be successfully implemented, collaboration among various economic and social stakeholders is essential to achieve a circular flow of materials and the associated efficiency gains [59]. The CE model aims to establish a sustainable economic system by reducing waste, minimizing energy losses, and lowering resource consumption through strategies that limit, postpone, and ultimately end the resource cycle [50]. This strategy addresses environmental issues and enhances economic resilience by reducing dependence on limited resources and creating new business opportunities [60]. Moreover, CE practices can lead to a more equitable distribution of resources while generating jobs and fostering economic growth [61,62]. A comprehensive approach is necessary to effectively develop and implement circular strategies tailored to specific contexts and socially inclusive. This approach requires the involvement of various stakeholders, including businesses, policymakers, and communities [63,64].

### 3.2.2 Practices of Circular Economy for Timber Waste

The potential for recycling and reusing timber waste is substantial, as it can lead to the creation of new products and materials, thereby reducing the need for virgin resources and minimizing environmental impact [65,66]. For instance, sawdust and wood scraps can be repurposed into engineered wood products or used as raw materials for new construction applications [67]. Additionally, using recycled wood-based materials, including used pallets and construction waste linked together with cementitious material, offers a variety of applications in building construction and is viable solutions for the construction sector [68]. By focusing on design for disassembly and reuse, recycling into new products, and improved processing techniques, the construction site can significantly minimize waste and contribute to sustainability.

#### 3.2.2.1 Design for Disassembly and Reuse (DfDR)

Design for Disassembly and Reuse (DfDR) is a critical principle in the circular economy (CE) approaches to construction, emphasizing the design of buildings and products to allow for easy disassembly, component recovery, and material reuse [69]. This approach aligns with the principles of a circular economy, focusing on resource efficiency and waste minimization [11,20]. Modular timber construction is one of the practices of DfDR that emphasizes prefabrication and modularity [70]. In this approach, buildings are constructed using pre-manufactured timber modules that can be easily assembled and disassembled on-site [71]. This method reduces construction waste by minimizing on-site cutting and waste generation [72]. Additionally, modular components can be designed for multiple uses, allowing them to be repurposed in different configurations or projects over time [73]. The flexibility of modular construction supports the principles of DfDR by enabling the reuse of materials and components,

thereby reducing the demand for new resources and contributing to sustainability goals [74].

Moreover, the integration of advanced technologies, such as Building Information Modelling (BIM), can facilitate the planning and execution of DfDR practices. BIM allows for the simulation of construction processes, enabling stakeholders to identify opportunities for material recovery and reuse at the design stage [75]. BIM can enhance decision-making regarding material selection and lifecycle management by digitally representing physical and functional characteristics, ultimately supporting circular economy objectives [76].

By incorporating DfDR principles into the design phase, architects and builders can facilitate the efficient reuse of timber, conserving resources and minimising waste generation [77]. Chiletto et al. [11] highlight that adopting such design principles in timber construction can significantly reduce waste and enhance the potential for material recovery. Applying DfDR waste management will improve the local and national economy by introducing new jobs [20]. Structures incorporating timber and designed according to DfDR principles demonstrate substantially lower greenhouse gas emissions compared to conventional demolition or recycling oriented construction methods, while offering additional environmental benefits [78].

### 3.2.2.2 Recycling into New Products

Recycling timber into new products is a critical component of sustainable development, particularly in the circular economy context. It is easy to sort and does not require complex processing [79,80,81]. The significant advantages of recycling timber waste are the potential to create engineered wood products. Engineered wood products offer design flexibility. The ability to create customized dimensions and configurations allows architects and engineers to explore innovative designs that were previously challenging with traditional materials [82,83]. For example, timber-concrete composite systems leverage the strengths of both materials, enhancing performance in terms of stiffness and vibration control [82,84]. Projects like InFutUReWood and RECOVERS focus on reusing and recycling recovered timber to produce structural materials, which not only minimizes waste but also contributes to a circular economy in the construction sector [85]. This approach aligns with the findings of Lin et al. [14], who emphasize the need for improved recycling methods for timber waste, particularly to mitigate the environmental burdens associated with landfill disposal.

Additionally, the production of particleboards from construction and demolition (C&D) wood waste has been explored, where wood residues are processed into particles and combined with adhesives to create composite materials suitable for various applications [86]. Producing particleboards from recycled wood waste not only diverts materials from landfills but also maximizes resource efficiency in the wood industry [87,88]. Recent advancements in adhesive technology, including eco-friendly binders, have improved the performance and sustainability of particleboards, making them a viable option for environmentally conscious consumers [89,90]. This method demonstrates the feasibility of utilizing timber waste effectively while also addressing the demand for sustainable building materials.

### 3.2.2.3 Bioenergy Recovery from Timber Waste

Bioenergy is energy generated by converting biomass such as plant or organic waste into heat, electricity, or other power sources [91]. Bioenergy recovery from timber waste represents a significant sustainable energy production and waste management opportunity. Between 2009 and 2020, timber research commenced with waste-to-energy conversion through biofuel and bioenergy generation [92]. By converting timber waste into energy, the volume of waste is significantly decreased, alleviating pressure on waste management systems and reducing landfill costs [14].

A practice of bioenergy recovery is the use of sawdust as a biomass feedstock for power generation. Sawdust, a byproduct of timber processing, can be combusted directly in biomass power plants or converted into briquettes for more efficient burning [93]. Research indicates that sawdust has a high energy density, making it a suitable candidate for energy recovery [94]. The combustion of sawdust provides a renewable energy source and mitigates the environmental impact associated with its disposal, such as open burning or landfill accumulation [92]. Moreover, integrating sawdust into existing energy systems can enhance energy efficiency and reduce reliance on fossil fuels [95].

In Malaysia, a significant initiative has been undertaken to recycle construction timber waste into energy. A case study conducted by Lin et al. [14], highlights the potential of converting timber waste into energy through various methods, including incineration and gasification. This study emphasizes that timber waste constitutes a substantial portion of construction waste, and its energy conversion can significantly alleviate the burden on waste management systems while providing a renewable energy source [14]. The Solid Waste and Public Cleansing Corporation (SWCorp) in Malaysia has actively promoted such initiatives, showcasing the feasibility of large-scale bio-energy recovery from timber waste [14].

Furthermore, developing innovative technologies for managing biofuel production from timber waste is crucial for maximizing energy efficiency. Recent advancements focus on creating economic and mathematical models that optimize the logistics of biofuel production, considering factors such as feedstock availability, moisture content, and transportation distances [96]. These models are essential for enhancing the viability of bio-energy projects, particularly in regions where timber waste is abundant but underutilized.

## 3.3 Environmental, Economic, and Social Impact of Circular Economy for Timber Waste

### 3.3.1 Environmental Impact

Integrating CE strategies in timber construction can significantly reduce greenhouse gas emissions, contributing directly to broader climate change mitigation goals [80,92]. The construction sector contributes substantially to environmental degradation due to its reliance on concrete and steel, which are resource-intensive and have a larger carbon footprint than timber [97]. Since timber is a renewable resource that sequesters carbon during its growth phase, reusing timber elements and adopting practices like "Design for Deconstruction" reduces carbon emissions and decreases resource depletion, minimizes construction waste, and lowers

energy consumption in material processing [98]. These practices contribute to reduced landfill waste and decreased environmental pollution, leading to a more sustainable built environment.

Extending the lifespan of timber materials through innovative approaches like upcycling further reduces demand for virgin raw materials [98], helping to conserve forests and biodiversity [14]. Research shows that ambitious circular economy scenarios in timber construction could substantially decrease CO<sub>2</sub> emissions, with potential reductions ranging from 34.0% to 8.2% by 2030 [99,100].

Moreover, circular economy frameworks encourage collaborative waste management strategies, benefiting the environment and society [101,102]. Policies promoting sustainable timber waste management ensure compliance with recycling initiatives while reducing environmental burdens such as deforestation [103] and excessive landfill accumulation [104]. These policies drive innovation in construction practices and enhance the industry's ability to implement waste minimization and resource efficiency measures, directly contributing to reducing environmental impact [103]. Additionally, circular practices generate economic benefits through lower waste disposal costs and the development of recycling-based industries [14]. The environmental impacts of a circular economy for timber waste are visually summarized in Figure 6.

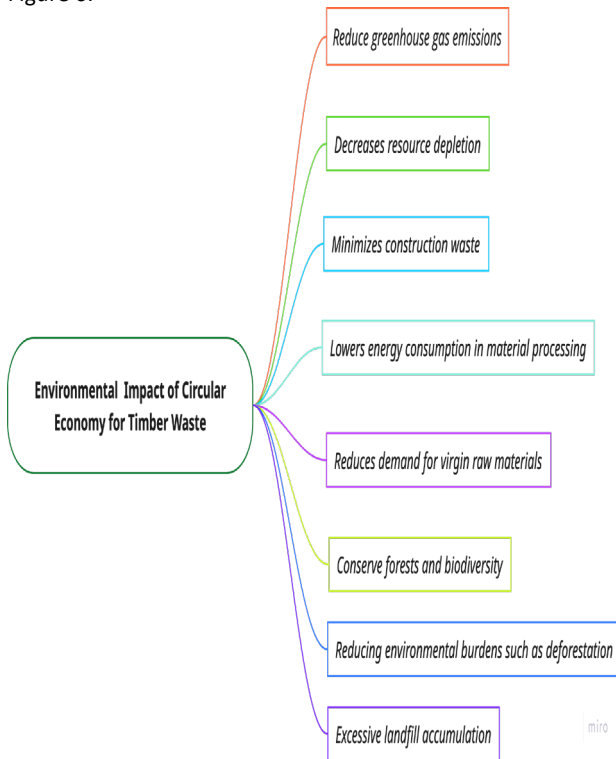


Figure 6 Environmental Impacts of Circular Economy for Timber Waste

### 3.3.2 Economic Impact

The economic impact of adopting a circular economy (CE) approach to timber waste is varied, encompassing cost reductions, innovation, job creation, and community involvement. Transitioning from a linear economy to a circular economy within the timber sector can substantially improve resource efficiency and encourage sustainable economic development [105]. One of the primary economic benefits of integrating CE principles in the timber industry is reduced waste disposal and resource acquisition costs. By reusing and recycling timber waste, companies can reduce expenses associated with landfill fees and sourcing raw materials [105]. Utilizing the 3R principle (reduce, reuse, recycle) can result in significant savings while increasing the economic value of waste materials [106]. This is particularly important in engineered wood products, where reclaimed timber can be converted into high-value materials, thus promoting economic growth [107].

Moreover, the circular economy promotes innovation within the timber industry by encouraging the development of new business models and practices. Research indicates that the implementation of circular economy models can lead to the emergence of innovative solutions that add value to production chains, benefiting both the economy and the environment [108]. For example, modular volumetric timber buildings have been identified as a promising avenue for reducing carbon emissions and enhancing resource efficiency, with potential cost reductions of up to 25% compared to traditional construction methods [100]. This shift supports economic growth while aligning with sustainability goals. The economic implications of circular economy practices extend beyond individual businesses to encompass broader societal benefits.

Transitioning to a circular economy can create job opportunities in recycling, waste management, and sustainable construction sectors. Studies have shown that resource productivity, recycling rates, and environmental innovation are positively correlated with GDP growth, particularly in the context of the European Union [108]. This suggests that embracing circular economy principles can stimulate economic development while addressing environmental challenges. Circular economy principles offer substantial economic advantages, such as cost savings from resource efficiency and the creation of new markets. By shifting from a traditional linear model to a circular one, companies save costs through material efficiency, reduced waste management expenses, and the extension of product lifecycles [109]. This also fosters economic resilience as businesses reduce dependence on raw materials, often facing price volatility [110]. Furthermore, CE encourages investment in eco-innovative technologies, enhancing competitiveness and market differentiation for companies embracing sustainable practices [111]. Figure 7 displays the economic impacts of the circular economy for timber waste that was created from the analysis of the examined articles.



Figure 7 Economic Impacts of Circular Economy for Timber Waste

3.3.3 Social Impact

From a social perspective, the circular economy promotes job creation and social inclusion by generating employment opportunities in recycling, remanufacturing, and green technology sectors [112, 113,114]. Research indicates that circular economy solutions can create numerous job opportunities, especially in waste management and recycling [115]. For instance, community-based waste management initiatives, such as waste banks, have empowered local populations by providing stable employment and fostering a sense of ownership over waste management processes [116]. These initiatives create jobs and enhance social cohesion by encouraging collaboration among community members. By creating new job opportunities and increasing community engagement in sustainability practices, CE helps improve overall social well-being [117,118].

Moreover, the circular economy promotes education and awareness regarding sustainable practices. Programs that educate citizens about waste sorting and recycling can significantly impact community behavior and attitudes towards waste management [108]. For example, initiatives that engage households in sorting and managing their waste can lead to a cultural shift towards valuing materials and reducing waste generation [119]. Such educational efforts are crucial for fostering a community-oriented approach to waste management, which is essential for successfully implementing circular economy practices.

The social impact of circular economy practices extends to improving public health and environmental quality. Proper management of timber waste can prevent hazardous materials from contaminating local ecosystems, thereby protecting community health and biodiversity [120]. Furthermore, the

circular economy encourages the use of sustainable materials, which can lead to healthier living environments and improved overall well-being. Additionally, the circular economy fosters social innovation by encouraging the development of new practices and technologies that address waste management challenges. Social innovation initiatives can engage consumers and communities in sustainable practices, creating networks that promote resource efficiency and reduce waste [121]. By leveraging local knowledge and resources, communities can develop innovative solutions that address waste issues and enhance social ties and community resilience.

By prioritizing the needs of these groups in circular economy strategies, policymakers can ensure that the benefits of sustainable practices are equitably distributed across society. CE also fosters a cultural shift toward sustainable consumption, encouraging communities and individuals to adopt environmentally responsible behaviours [122,123,124]. This shift is often driven by public awareness campaigns and education initiatives, which highlight the importance of reducing waste and conserving resources. When individuals become more aware of sustainable practices, it can lead to greater community involvement and responsibility towards environmental stewardship, reinforcing social bonds around shared values of sustainability [125,126]. Based on the analysis of the reviewed papers, Figure 8 presented a mind map depicting the social impacts of a circular economy for timber waste.



Figure 8 Social Impacts of Circular Economy for Timber Waste

Table 1 below enhances clarity and organises the findings by summarising the three key impact areas of circular economy practices in timber waste management in construction: environmental, economic, and social. It also presents their sub-impacts and relevant literature references. This overview simplifies referencing and emphasizes the topic's multidisciplinary aspects.

**Table 1** Summary of Environmental, Economic, and Social Impacts from Literature

Impact Categories	Sub-impacts	Corresponding Authors			
Environmental	reduce greenhouse gas emissions	Ghobadi and Sepasgozar, 2023; Jahan et al., 2022		Encourages investment in eco-innovative technologies, enhancing competitiveness and market differentiation for companies embracing sustainable practices	Chioatto et al., 2024
	Decrease resource depletion	Tüpənaitė, L et al. 2023; Cognoli et al., 2024		Social inclusion by generating employment opportunities in recycling, remanufacturing, and green technology sectors	de Souza et al., 2023; Piao et al., 2023; Valencia et al., 2023
	Minimizes construction waste	Cognoli et al., 2024; Mihajlov et al., 2021; Grabowski, 2021		Promotes education and awareness regarding sustainable practices	Ghisellini and Ulgiati, 2020; Nikonorova et al., 2020;
	Lowers energy consumption in material processing and Reduces demand for virgin raw materials	Cognoli et al., 2024;		Impact on community behaviour and attitudes towards waste management	Hysa et al., 2020
	Conserve forests and biodiversity	Lin et al., 2021		Lead to a cultural shift towards valuing materials and reducing waste generation	Wikurendra et al., 2022
	Reducing environmental burdens such as deforestation	Aguilar-Hernandez et al., 2021; Hailemariam and Erdiaw-Kwasie, 2023; Kayenat, 2024		Prevent hazardous materials from contaminating local ecosystem, thereby protecting community health and biodiversity	Vargas-Sanchez, 2023
	Excessive landfill accumulation	Noor et al., 2023		Fosters social innovation by encouraging the development of new practices and technologies that address waste management challenges	Durand, 2020
	Decrease costs related to waste disposal and resource acquisition, companies can reduce expenses associated with landfill fees and sourcing raw materials	Seier, 2024		Encouraging communities and individuals to adopt environmentally responsible behaviours	Geissdoerfer et al., 2020; Rodríguez-Espíndola et al., 2022; Kiefer et al., 2024
	Utilizing the 3R principle can result in significant savings while increasing the economic value of waste materials	Siregar et al., 2023; Szichta et al., 2022			
	Development of new business models and practices	Szichta et al., 2022			
Economic	Lead to the emergence of innovative solution that add value to production chains	Hysa et al., 2020	Social		
	Create job opportunities in recycling	Seier, 2024			
	Stimulate economic development while addressing environmental challenges	Hysa et al., 2020;			
	Cost savings from resource efficiency and the creation of new markets	Bocken and Geradts., 2020;			
	Companies save cost through material efficiency, reduced waste management expenses, and the extension of product lifecycles	Bocken and Geradts., 2020;			
	Fasters economic resilience as business reduce dependence on raw materials, often facing price validity	Tvaronavičienė et al., 2024			

#### 4.0 CONCLUSION

Implementing circular economy principles in timber waste management provides a comprehensive approach to addressing the environmental, economic, and social impacts the construction sites face. The findings indicate that adopting circular economy (CE)-based waste management strategies, such as design for disassembly, recycling, and bio-energy recovery, can significantly further sustainability goals. The application of CE principles in timber waste management results in a significant reduction in greenhouse gas emissions, a decreased reliance on landfills, and improved conservation of natural resources. The construction industry's environmental footprint can be minimized by prioritizing reuse, recycling, and energy recovery. Additionally, adopting CE practices helps combat the negative consequences of traditional disposal methods, such as deforestation, land degradation, and pollution from open burning or incineration.

From an economic perspective, CE practices offer significant cost-saving opportunities for construction companies through resource efficiency and waste reduction. The reuse and recycling of timber materials can lower procurement costs, reduce disposal expenses, and promote the development of new markets for recycled wood-based products. Additionally, the expansion of CE-based industries

creates employment opportunities in waste management, material recovery, and sustainable construction sectors. Investment in CE initiatives can also drive innovation, particularly in sustainable building design, modular construction, and the development of eco-friendly materials.

In addition, adopting Circular Economy (CE) principles in timber waste management also significantly enhances social impact. Sustainable waste management practices improve public health by reducing air and land pollution commonly associated with traditional disposal methods. Furthermore, engaging communities in sustainable construction initiatives raises environmental awareness and promotes responsible waste disposal behaviour. Moreover, CE strategies foster inclusivity by encouraging collaboration among various stakeholders, including policymakers, businesses, researchers, and the public. Further research should focus on developing stronger policy frameworks that support these initiatives and leverage emerging technologies to enhance timber waste management. A systematic approach to implementing CE is crucial for achieving long-term sustainability in the construction industry, ultimately benefiting both the environment and society.

This review has limitations because it relies solely on sources indexed in the Scopus database. Therefore, some relevant information from other databases or grey literature may have been missed. Future research should include more databases, incorporate longitudinal case studies, and conduct quantitative assessments of circular economy practices in real timber construction projects. Furthermore, additional studies are necessary to develop policy frameworks and incentive mechanisms that promote CE adoption.

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### Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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