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FOREST PRODUCT DEMAND AND SUPPLY IN A BIOECONOMY TRANSITION: THE POSSIBLE ROLE OF TIMBER FOR CLIMATE CHANGE MITIGATION

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ABSTRACT: Policy- and decision-making in the bioeconomy transition at local and global levels are currently limited by a lack of information about the likely supply and demand scenarios for forest products in a functioning and growing forest-based bioeconomy. This paper seeks to provide insights by offering an up to date and overall understanding of the impact of global mega-trends, particularly those related to the drive to decarbonize industrial supply chains, on the likely supply and demand for forest products. The focus is on forest products used in the building and construction sector, such as engineered wood, given the sector's significant contribution to global greenhouse gas emissions. This paper begins with a review of existing literature before presenting global scenario-based forecasting results impacting forest product supply and demand dynamics in the built environment through 2070. The modelling analysis incorporates population growth, urbanization, adoption rates of engineered wood products, floor area per capita, wood use intensity, and climate change dynamics. Additionally, this outlook study provides a preliminary analysis of the building and construction sector's potential to reduce carbon emissions through greater adoption of forest products.

KEYWORDS: Forest products, bioeconomy, supply and demand, decarbonization, built environment

1 – INTRODUCTION

As the world confronts climate change and resource depletion, bioeconomy has emerged as a strategy to transition away from fossil-based materials. Bioeconomy encompasses the production, use, conservation, and regeneration of biological resources, with the aim of providing sustainable solutions across all economic

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sectors, as well as enabling a transformation to a sustainable economy [1].

Forests play a key role in the bioeconomy transition. Among other services, forests provide renewable products that contribute to sustainability and carbon reduction efforts. However, global trends—such as digitalization, urbanization, and a movement towards sustainability and net zero emissions—are reshaping the demand and supply trajectories of forest products. As a result, the use of forest products is evolving across multiple sectors of the bioeconomy [1].

Increased use of sustainably sourced forest products represents a potential opportunity to help decarbonize the building and construction sector, which was responsible for 37% of global energy and process-related carbon dioxide (CO_2) emissions in 2022 [2]. Innovation in products such as engineered wood products (EWPs) is expanding the possibilities of wood to replace carbon-intensive construction materials such as concrete and steel, thus offering substantial new capacity to store carbon in the built environment [3, 4].

Forest products, including wood products used in residential construction, can contribute to climate mitigation in two ways: carbon storage in products, and material substitution effect [5]. Carbon storage refers to the quantity of carbon stored in products, which can be deduced using life cycle assessment (LCA) approaches and carbon conversion factors [3, 6]. Substitution effects are defined as the amount of emissions avoided when using wood-based products as opposed to other products with the same functional end-use. For the construction sector, estimates suggest that for every additional kg C of wood product used for structural construction, an additional 1.3 kg C of emissions could be saved [7].

To maximize these opportunities, policymakers and practitioners in the bioeconomy and built environment would need to understand and anticipate how global trends, especially the push for decarbonization, may impact long-term forest product supply and demand. This paper analyzes key drivers of forest product use and explores how these drivers may shape the future supply of and demand for forest products in the building and construction sector. To do so, this paper summarizes the current understanding of forest product supply and demand based on a literature review. This review informs the modelling framework used in the ongoing scenario-based analysis, with preliminary results presented here, including the climate mitigation potential of forest product adoption in the built environment (the final study results will be published later this year). From this analysis, the paper seeks to highlight the importance of sustainable practices in ensuring that increased forest product use contributes effectively to the bioeconomy and climate goals.

2 – BACKGROUND

2.1 MEGA-TRENDS IN FOREST PRODUCT USE

The forest industry is evolving, driven by several mega-trends in forest product use related to technological advancements, sustainability initiatives, and innovations in the sector. Digitalization, or the growing adoption of digital technology, is projected to continue the decline in paper demand by 2030 under various internet adoption scenarios [8], with recent data indicating a 4% decline in global production of paper and paperboard between 2021 and 2023 [9]. Moreover, digitalization is spurring innovation in industries through improvements in energy efficiency, process optimization, advanced digital infrastructure, and big data analytics, which in some cases reduces carbon emission from manufacturing [10, 11].

As cities and populations grow, the demand for materials for housing and infrastructure also increases. If the market share of timber-based buildings increases in the future, urbanization could intensify demand for forest products [12, 13]. Infrastructural development such as the expansion of transportation systems could lead to the permanent loss of nearby natural forests, particularly in tropical regions [14].

Innovation in the forest sector, particularly in products and processes, is increasing the value from forest-based supply chains [15]. Technological advancements in EWPs, notably cross-laminated timber (CLT) and glued laminated timber (glulam), have expanded the possibilities of wood-based construction. Their structural properties make them viable substitutes for concrete and steel in urban mid-rise buildings [3].

Increased production of EWPs could also increase sawmilling by-products such as wood chips, sawdust, and other residues, providing potential feedstock for the wood pulp industry. At the same time, the diversion of chemical and mechanical wood pulp from newsprint and graphic paper production is prompting a reorientation of feedstocks towards biorefineries that can produce innovative products such as wood fiber-based textiles, bio-chemicals, and biofuels [1, 15].

2.2 SUSTAINABLE SUPPLY OF FOREST PRODUCTS

Naturally regenerated forests[1] account for the majority of the world's forest area, covering 92% in 2023 [9]. These types of forests also supply more than half of the world's industrial roundwood, and while the area of naturally regenerating forests have declined in some regions, notably in the tropics and subtropics, overall production volumes are expected to remain stable [16].

Meanwhile, planted forests[2] account for just 8% of global forest area but contribute almost half of the world's industrial roundwood supply [9, 17]. While the expansion of planted forests and productivity improvements in production areas already under management can help meet

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the demand of increasing wood supply without overexploiting natural forest areas [16], forests in general face challenges in terms of competing land uses. Agricultural and urban land expansion, rising land values, difficulties in predicting future markets, as well as climate-related forest disturbances are some factors that could limit the sustainable supply of forest products [18].

Balancing global forest product supply and demand is thus essential for sustainability, with research pointing to a range of possible future supply-demand balances of forest products. Focusing on construction timber demand, Churkina et al. [3] suggest that forests can meet the global demand for timber in a future where up to 50% of new mid-rise buildings are built with timber as the primary structural material. However, Pomponi et al. [19] conclude that global timber supply would only cover around 36% of the total demand required to construct new buildings out of timber in the period of 2020-2050.

Other studies that have modelled future global timber demand have given estimates ranging from 3.6 to 11.2 billion cubic meters of roundwood demand by 2060, with the upper range representing a near three-fold increase in demand from 2015 values (Fig. 1). In terms of the extent of forest area that is required to meet future demand, some models estimate that plantations,[3] which are projected to contribute to an increasing share of global roundwood production, could expand by almost 177% by 2100 [20]. The variation in projections is due to the methodological frameworks and scenario assumptions used in separate studies, reflecting the complexity of modelling long-term forest sector developments [21-23]. Nevertheless, modelling future forest product supply and demand remains an important task to highlight sustainability challenges that may arise in the transition to a forest-based bioeconomy.

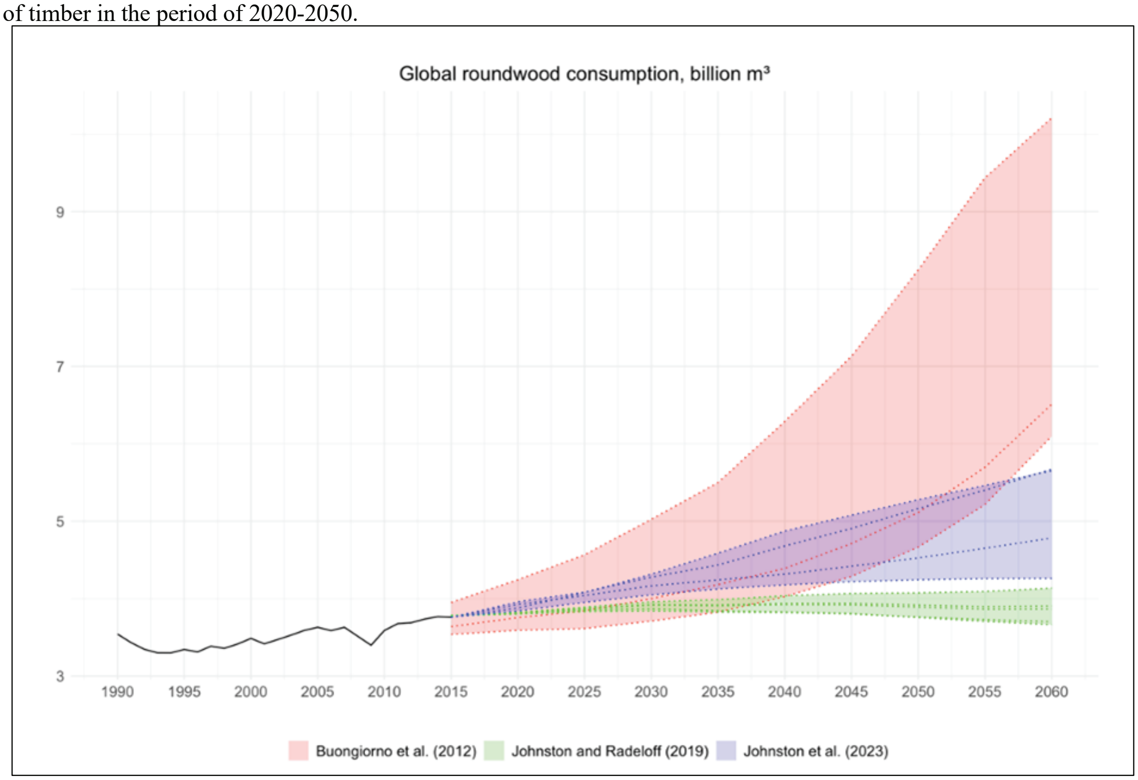

Figure 1. Global total roundwood demand (billion cubic meters) from 1990 to 2060, based on own compilation of projection results from various sources [21-23].

3 – METHODS

3.1 FUTURE FOREST PRODUCT SUPPLY AND DEMAND

This paper provides preliminary forecasting analysis based on the use of the Forest Resource Outlook Model (FOROM), a recursive dynamic partial equilibrium model of the global forest sector that includes forest resources, timber supply, demand for intermediate and final products, and international trade. The model's main objective is to evaluate how production, consumption, trade, and pricing of raw materials, intermediates, and final goods, as well as forest land area and standing stock, may respond to external factors such as economic growth, climate change, trade policy shifts, or forest management practice [24].

FOROM represents the global wood product market through 20 interconnected product groups and covers 55

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countries and regions. The model incorporates several assumptions to forecast future trends: (1) demand is driven by economic and population growth; (2) changes in gross domestic product (GDP) per capita influence both market dynamics and marginal costs of production through adjustments in forest area and standing inventory; (3) technological advancements are factored in to account for improvements in the efficiency of converting raw materials into finished products across sectors; and (4) trade openness is reflected in the model by the friction associated with the movement of goods between regions, and is estimated by adjusting the transportation costs between regions.

To account for the impact of climate change on forest productivity, FOROM adjusts supply costs by integrating projected changes in net primary productivity (NPP). Projections on NPP are obtained from the MC2 dynamic global vegetation model based on climate inputs including precipitation, temperature, vapor pressure, and atmospheric CO_2 concentrations, and are simulated to 2070 at a 0.5-degree resolution [25].

To explore how the demand for forest products in residential construction may increase materially above what historical patterns and future income levels may suggest, an additional demand shift for sawnwood of species type *k* (i.e. coniferous, non-coniferous) was constructed. This additional demand shift represents increased demand for EWPs in residential construction, and is driven by several factors (1):

$$additional\ demand_{i,t}^{k} = \Delta pop_{i,t} * urban\ rate_{i,t} * adopt_{i,t} * floor\ area_{i,t} * wood\ use\ intensity_{i,t} * share_{i,t}^{k} \quad (1)$$

where:

- *Δpop* is the change in population in region *i* at time *t*, which influences the demand for housing and construction materials.
- *urban rate* is the percentage of the population living in urban areas, where residential construction is more intensive and reliant on wood products.
- *adopt* is the rate of adoption of EWPs in residential construction methods in urban development, which is especially important as the adoption of EWP technologies like glulam and CLT increase.
- *floor area* is the per capita change in floor area, which directly affects the material demand per individual.
- *wood use intensity* is the amount of wood required per square meter of construction, reflecting changes in building practices and material efficiency.
- *share* is the share of total domestic sawnwood production in region *i* sourced from coniferous or non-coniferous materials. This parameter assumes that the increased demand for EWPs is supplied using species types consistent with domestic sawnwood production to capture regional differences in forest cover and production capabilities.

Table 1 presents a scenario matrix that outlines various assumptions related to urban adoption rates, floor area per capita, wood use intensity, and climate scenarios to assess future demand for EWPs in residential construction. In this paper, urban adoption rates are based on regional projections of urban population changes according to the Shared Socioeconomic Pathway (SSP) scenario of moderate development and urbanization trends, i.e. SSP2 [26]. Floor area rates are based on three socioeconomic pathways of floor area development as reported in Fishman et al. [27]. Wood use intensity is represented by three levels of the amount of wood usage per unit of floor space (e.g. cubic meters per square meter) in timber constructions, based on several sources [28-31].

The climate scenarios are based on the Representative Concentration Pathways (RCPs). RCP4.5 denotes an intermediate warming scenario in which mitigation efforts stabilize greenhouse gas (GHG) concentration by mid-century. RCP8.5 is a high warming scenario without effective global GHG mitigation. Both climate scenarios are based on SSP2 and are layered onto the "medium EWP demand" scenario (Table 1).

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Table 1: Scenario matrix used in this paper. EWP: engineered wood products.

Scenario	Urban adoption rate (capita)	Floor area (m^2/capita)	Wood use intensity (m^3/m^2)	Climate (RCP)
Business-as-usual	None (0%)	---	---	Reference
Medium EWP demand	Medium (20%)	Medium	Medium (0.4)	Reference
Low adoption	Low (10%)	Medium	Medium (0.4)	Reference
High adoption	High (30%)	Medium	Medium (0.4)	Reference
Low floor area	Medium (20%)	Low	Medium (0.4)	Reference
High floor area	Medium (20%)	High	Medium (0.4)	Reference
Low wood intensity	Medium (20%)	Medium	Low (0.4 - 0.6%/y)	Reference
High wood intensity	Medium (20%)	Medium	High (0.4 + 0.6%/y)	Reference
RCP4.5	Medium (20%)	Medium	Medium (0.4)	RCP 4.5
RCP8.5	Medium (20%)	Medium	Medium (0.4)	RCP 8.5

3.2 CLIMATE MITIGATION POTENTIAL OF FOREST PRODUCTS IN THE BUILDING AND CONSTRUCTION SECTOR

The climate mitigation potential analysis of this paper focuses on the projected demand for EWP from Section 3.1. The analysis follows a simplified approach that quantifies emissions savings based on the sum of the carbon storage and substitution effects of EWP demand [32-34].

Carbon storage is quantified by multiplying EWP demand with default carbon conversion factors for coniferous and non-coniferous sawnwood [35]. Substitution effects are calculated using substitution factors for sawnwood that are intended for the construction of both generic and residential buildings as well as for specific construction-related end-uses such as floorings, claddings, and window frames. These substitution factors were derived from multiple sources [36-40]. The analysis does not include carbon dynamics from forest growth and forest harvests, given that these are not considered in the modelling framework in Section 3.1.

4 – RESULTS

Under a business-as-usual scenario that does not consider additional shifts in EWP demand, the demand for sawnwood and industrial roundwood largely follows historical patterns, with a steady increase primarily driven by growth in economic activity and population.

Fig. 2 illustrates how shifts in urban adoption rates, floor area rates, and wood use intensity can drive additional demand for EWPs beyond what is projected in the business-as-usual scenario. In scenarios with higher urban adoption rates, the demand for EWPs increases correspondingly, reflecting a potential trend in the building and construction sector toward more sustainable building materials such as wood. Moreover, the wood use intensity scenarios indicate that shifts toward more wood-intensive construction practices could lead to substantially higher demand for forest products, potentially straining supply chains and requiring careful management of forest resources to balance growing demand with sustainability goals.

In fact, preliminary regional level results indicate that the supply of these products is projected to face constraints in certain regions due to the limits of forest growth and less efficient production systems, potentially leading to imbalances between demand and sustainable production capacity over time.

The analysis on climate-induced changes in forest productivity reveals, as expected, that the moderate climate change scenario (RCP 4.5) results in smaller productivity and harvest increases relative to the high warming scenario (RCP 8.5). Results highlight the stronger impact of more severe climate change on forest growth rates and harvest potential, with subsequent impacts on regional capacities to supply raw materials.

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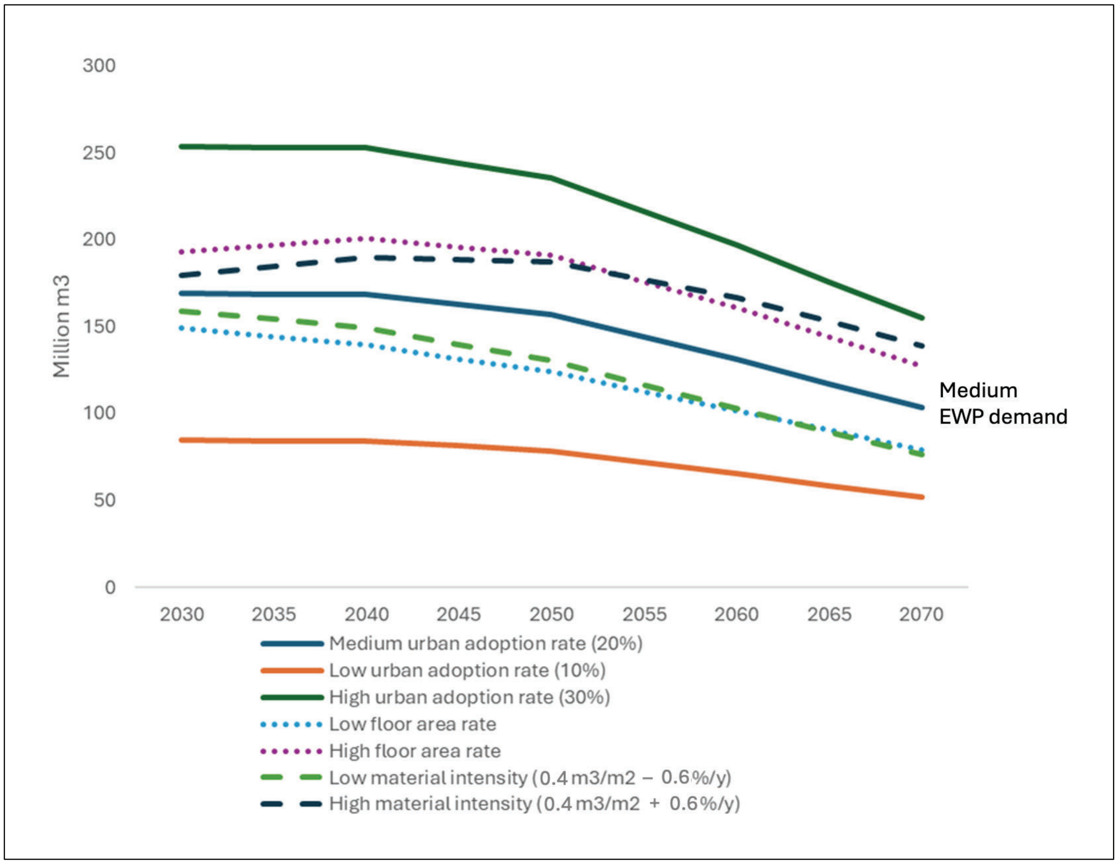

Figure 2. Additional forest product demand for residential construction across scenarios, 2030 to 2070 (million cubic meters). The 'medium EWP demand' scenario is not to be confused with the business-as-usual scenario, which assumes no substantial EWP demand by 2070 and is hence not shown here.

Fig. 3 compares the potential emissions savings between the medium EWP demand scenario and all scenarios related to urban adoption rates, floor area rates, and wood use intensity. The 'high adoption', 'high wood use', and 'high floor area' scenarios all result in greater emissions savings compared to the medium EWP demand scenario. Globally, this could translate to as much as 358 megatonnes CO_2 equivalents in 2050 for the 'high adoption' scenario, which is about 50% more than the emissions savings from the medium EWP demand scenario.

5 – DISCUSSION

Global mega-trends in the forest sector are expected to reshape forest product markets. For the building and construction sector, EWP demand is estimated to play an important role. Increased urban adoption of EWPs in multi-story residential construction is likely to substantially elevate future demand for sawnwood and industrial roundwood, pushing demand well beyond business-as-usual projections.

Policymakers in the forest-based bioeconomy are encouraged to ensure a sustainable balance between forest product supply and demand, given the anticipated rising demand for EWPs, climate-induced changes in forest productivity, and other shifts in forest product markets globally. Sustainable forest management should remain the centre of policy frameworks for the bioeconomy. This would entail investing in strong governance frameworks to ensure sustainable harvest levels, improved silvicultural practices, and effective monitoring of environmental and socioeconomic impacts.

There is also a need to integrate forest management and wood utilization strategies into climate and bioeconomy policy frameworks, which could help maximize carbon sequestration while also support sustainable economic growth [12]. Integrating these practices would therefore help ensure that any effort to increase forest supply levels to meet demand remains within sustainability limits.

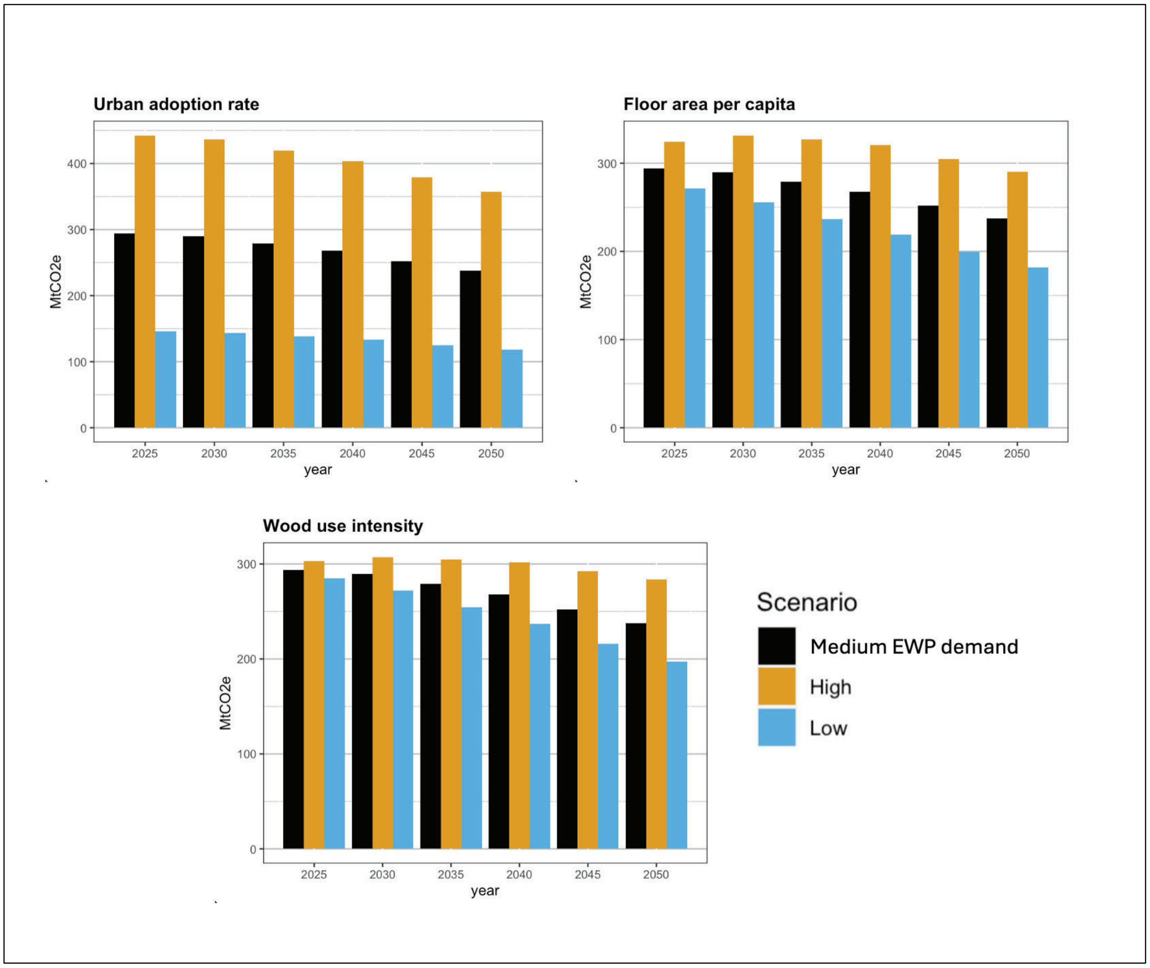

Figure 3: Potential emissions savings (megatonnes CO_2 equivalent) across scenarios, 2025-2050.

In the context of the building and construction sector, integrating the 11R framework could help decouple forest product demand from forest harvests, thus addressing the potential supply-demand imbalances that may arise [41].[4] According to the 11R framework, building codes and innovative designs that incorporate space use optimization along with engineered wood adoption could reduce the quantity of timber that is needed for the same area of floorspace. Efforts to reuse or remanufacture building components and materials could also contribute towards material use reduction, hence lowering the need for additional forest harvest to meet growing urbanization material demands [41].

Facilitating global trade of sustainable forest products could also help ensure that forest supply can sustainably cope with future demand in forest products. In particular, trade policies and international cooperation frameworks should enable efficient flows and supply chains of forest products while ensuring forest conservation and restoration. This could involve harmonizing sustainability standards, reducing trade barriers, and investing in infrastructure to improve logistics and connectivity within global supply chains.

In terms of climate change impacts, this paper has shown that global warming is likely to influence forest productivity and harvest levels. It should be noted that the analysis focuses on the effects of CO_2 concentrations and other climatic conditions on productivity, but does not capture the effects of interacting natural disturbances. Moreover, the model does not consider potential shifts in forest management strategies to adapt to climate change (e.g. changes in tree species and silvicultural practices), which may affect the availability of forest resources.

Furthermore, this paper has demonstrated the potential emissions savings that could arise with rising EWP demand. These emissions savings could support global efforts in meeting emission targets to limit global warming, provided that policies aiming to increase forest product use (e.g. forest area expansion, increasing market share of timber-based construction) are in line with sustainability standards. More research is also needed to fully quantify the global climate effects of a growing demand for forest products, taking into account the full spectrum of forest growth and product life cycle stages.

The forest-based bioeconomy presents an opportunity for sustainable growth, greater international cooperation,

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and climate mitigation. A greater emphasis on forest product use in the built environment could help reduce the sector's carbon footprint and contribute to global climate mitigation efforts. Policymakers and practitioners in the bioeconomy and built environment will need to address the anticipated changes in forest product markets to maximize the climate and environmental benefits of the forest-based bioeconomy transition. Through its preliminary analyses, this paper informs policy- and decision-making in these sectors by demonstrating how forest product supply and demand and the associated climate mitigation potential could change with regards to increasing wood use in the built environment.

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6 – NOTES

[1] *Naturally regenerating forests* are forests that consist mostly of trees established through natural regeneration [42].

[2] *Planted forests* are forests which are predominantly composed of trees established through planting or deliberate seeding [42].

[3] *Plantations* are planted forests that are intensively managed and meet the following criteria at planting and stand maturity: one or two species, even age class, and regular spacing [42].

[4] The 11R framework is a set of principles related to the circular economy, ranging from 'Refuse' (e.g. removing functions from building components that are redundant) to 'Recycle' (e.g. producing building materials from construction and demolition waste), with the last-resort option of 'Recover' (e.g. incinerating building materials for energy recovery) [41].

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