SYNERGIES & TRADE-OFFS OF WAGENINGEN CLIMATE SOLUTIONS IN PRIMARY PRODUCTION SYSTEMS

URBAN CASE STUDY

BIOBASED CONSTRUCTION MATERIALS: CONTRIBUTING TO A SUSTAINABLE HOUSING SYSTEM IN EUROPE AND ENHANCING CLIMATE NEUTRAL AND RESILIENT CITIES

WAGENINGEN UNIVERSITY & RESEARCH

KB 34 Circular and climate neutral society

CASE STUDY ASSESSMENT REPORT
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Introduction

The transition from a fossil-based economy to a biobased economy and to climate positive production chains requires the establishment of a systematic approach to understand the use of different biomass feedstocks to produce biobased products. The transition towards a biobased economy and sustainable development in the housing system offers greater perspectives for biomass utilization in the building sector as a renewable material. A biobased economy will help to reduce Europe's dependency on oil, coal and gas and help to meet its ambitious environmental, societal, industrial and climate policy targets for 2050 (European Commission, 2021a).

There are several strategies for climate change mitigation. One option is through the reduction of greenhouse gas (GHG) emissions from fossil sources by substituting fossil based raw materials for renewable ones (e.g., retrofitting buildings to make them more energy efficient, development of highly energy efficient processes, use of renewable energy). Another option is through GHG removal such as increasing the carbon sinks (e.g., sustainable agricultural production and practices, reducing land use change, increasing afforestation). A third possibility is a combination of both options, substituting fossil-based products with those made from biomass in various ecosystems which we aim to address in this case study (Wang et al., 2021). There are scientific studies available that comment on the substitution of materials, chemicals and energy sources with biobased alternatives. However, there is still a lack of integrated insights about the potential reduction of GHG emissions and the potential scale of applications with long-term carbon storage for the building and housing sectors. Also, little is known about the environmental, social and economic effects of biobased materials in the building sector (Ottelin et al., 2021).

The high demand for housing could be embraced as an opportunity to contribute to sustainable urbanization and climate neutral cities in Europe, using biobased construction materials to partially substitute fossil-based industries and mineral-based products in the European building sector. The European Climate Pact aims to create awareness about the energy consumption in the building sector in Europe as 40% of total EU energy consumption is used by the building sector and 36% of total GHG emissions come from buildings (European Union, n.d.). A rising demand of biobased construction materials could provide incentives to increase innovation in the building sector to provide higher quality of buildings and living environments. Biobased materials (derived from plants, trees or animal products) for housing construction are gaining traction as sustainable alternatives to traditional materials such as wood and Cross Laminated Timber (CLT), Glulam straw bale construction, hempcrete, mycelium-based materials, miscanthus, flax, coconut filberts, leather and wool to mention a few (European Commission, 2021a; Schulte et al., 2021; Wang et al. 2014).

This research aims to understand how long-term storage of carbon in biobased construction materials can contribute to a more sustainable housing construction in Europe and enhance climate neutral and resilient cities. Additionally, this case study aims to understand the relevance of biobased construction materials and their contribution to the Sustainable Development Goals (SDGs) understanding their synergies and trade-offs. In general terms we studied how biobased construction materials can be used as a solution to contribute to the 17 different SDGs. The analysis provided an overview of what are the enablers and barriers for biobased construction materials production, processing and implementation. It also identifies possible stakeholders involved and/ or affected by such solutions. Furthermore, research questions were formulated to address knowledge gaps on this topic and a description of terms and concepts to contribute to the Wageningen climate dictionary.

The methodology used in this case study included a general description based on literature review complemented with expert knowledge. Moreover, two workshops were organized with a multidisciplinary group of Wageningen Research experts as primary data collection for this study. Approximately 12 to 15 selected participants attended both workshops. The workshops addressed the importance of biobased construction materials as tools to reduce and sequestrate GHG emissions, as well as the identification of barriers, enablers, synergies and trade-offs using the SDGs as a framework.

Climate mitigation solution

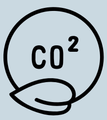
The anticipated growth of European population and urbanization over the next several decades will create a vast demand for the construction of new housing, commercial buildings and accompanying infrastructure. In Europe alone, about 190 million square meters of housing space are built each year, mainly in cities, and the amount is growing quickly at the rate of nearly 1% a year (Aalto University, 2020; Churkina et al., 2020). The production of cement, steel and other building materials are already a major source of GHG emissions and might continue in the future unless other ways to decarbonize the building sector become known (Churkina, et al., 2020). It is estimated that 20-25% of the life cycle emissions of the current EU building stock are embedded in building materials (EEA, 2022).

Concrete and steel productions in particular are responsible for a large share of global emissions. The IPCC's Sixth Assessment Report states that global GHG emissions from buildings were in 2019 at 12 GtCO$_2$-eq, equivalent to 21% of global GHG emissions that year, out of which 57% were indirect emissions from offsite generation of electricity and heat, 24% direct emissions produced onsite and 18% were embodied emissions from the use of cement and steel (high evidence, high agreement). However, it is possible to transform this source of emissions into a tool to mitigate climate change. By recognizing the climate mitigation potential of embedded GHG emissions in buildings, the European Union (EU) is already planning a whole life cycle performance roadmap towards an economy with net-zero GHG emissions from buildings by 2050 through the European Green Deal (Amiri et al., 2020; Cabeza et al. 2022; EEA, 2022). The European Commission, aligned with the European Green Deal, has proposed to boost renovation and decarbonization of buildings such as homes, schools, hospitals, offices and other buildings across Europe. It aims that all new public and private buildings must be zero-emission already as of 2030 (European Commission, 2021b).

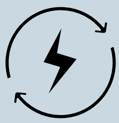
The use of biobased construction materials could have a positive effect on the increase of green buildings in European cities by reducing environmental impact, improving indoor air quality, promoting energy efficiency, supporting local economies, and fostering sustainable waste management practices. Likewise, using biobased construction materials such as wood and other organic materials can solve many of the problems which the building industry is facing today due to the material's ability to sequester carbon in its growth phase. Designing structural timber elements from certified managed forests is a way to align our projects with the recommendations of the IPCC scientists (European Climate, 2022). A dramatic reduction of carbon emitted in the construction phase can be created while provide a constructed "carbon storage." Also, to help achieve climate neutrality and enhance climate resilience in urban areas (Jones and Brischke, 2017).

The integration of biobased materials into urban planning and construction practices can lead to the development of green buildings, climate-neutral cities, and enhanced urban climate resilience. By embracing these sustainable materials and practices, we can transform the building sector into a powerful tool for mitigating climate change and promoting a sustainable future (see Figure 1).

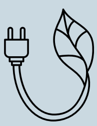
Figure 1. Climate mitigation solutions of biobased construction materials



Carbon sequestration
Biobased materials such as wood, bamboo, straw bale and miscanthus have the ability to sequester carbon during their growth phase. As plants grow, they absorb carbon dioxide from the atmosphere and store it in their biomass. When used as construction materials, these biobased materials effectively store carbon for the lifetime of the building, reducing overall GHG emissions (Jones and Brischke, 2017; Schulte et al., 2021). For instance, carbon sequestered for Glulam ranged between 938-1,038 kg of CO_2/m^3 in a study developed by Bowers et al. (2017).



Lower embodied energy
The production of biobased materials generally requires less energy than conventional construction materials, such as concrete and steel. This reduced energy consumption results in lower GHG emissions throughout the life cycle of these materials. Additionally, many biobased materials can be sourced locally, which minimizes the transportation-related emissions associated with material transport (Suttie et al., 2017; Amziane and Sonebi, 2016).



Thermal insulation and energy efficiency
Biobased insulation materials, such as hempcrete, cellulose (like miscanthus), and flax, provide excellent thermal insulation, reducing the energy required for heating and cooling buildings. Improved energy efficiency in buildings contributes to a reduction in GHG and enhances urban climate resilience (e.g., mitigating impacts of heatwaves and extreme cold events). Likewise, biobased insulation materials have the potential to address the energy crisis by improving energy efficiency in buildings and reducing reliance on non-renewable resources (Schulte et al., 2021).

End-of-life disposal and recycling (Circular economy)
Biobased construction materials promote a circular economy by offering renewable, low-impact alternatives to traditional building materials, and by facilitating the efficient use, reuse, and recycling of resources. Biobased materials are often biodegradable or recyclable, reducing the environmental impacts associated with waste disposal and promoting a circular economy. Moreover, biobased materials can be reused or repurposed at the end of their life cycle, further reducing their environmental footprint (Zaborowska and Bernat, 2023; Jones and Brischke, 2017).

Sustainable construction and green buildings
Green buildings are designed and constructed with a focus on reducing their environmental impact and promoting resource efficiency throughout their lifecycle. These buildings aim to minimize environmental impacts and enhance occupant well-being through sustainable design, construction, and operation practices. The use of biobased materials can contribute to the development of green buildings, as they offer renewable, low-impact alternatives to traditional construction materials, improve energy efficiency, and support a circular economy (Jones and Brischke, 2017; Pacheco-Torgal et al., 2020; Wang, et al. 2014).

Climate neutral and climate resilient cities
Biobased materials play a crucial role in the development of climate neutral and climate resilient cities by offering environmentally friendly alternatives to traditional construction materials, sequestering carbon, improving energy efficiency, and promoting a circular economy. Integrating biobased materials into urban planning and construction practices can contribute significantly to mitigating the environmental impacts of cities and enhancing their resilience to climate change (Amiri et al., 2020; Churkina et al., 2020; Pacheco-Torgal et al., 2020; Wang, et al. 2014).

Enablers and barriers

Housing is currently an urgent topic on the agenda of European policy makers, mainly due to high pressure to supply housing after the high demand since the financial crisis of 2008 and the COVID-19 pandemic faced during the last years. In the recent years, there has been an erratic and rapid increase in the housing market demand and on the prices of construction materials due to inflation between 2020 and 2023. As well, there has been a higher demand of (blue-) green urban areas, and more sustainable housing for different layers of society. Next to this, the housing renovation wave strategy from the European Commission aims to improve the resource- and energy-efficiency of construction materials. It tries to enhance sustainability and circular economy within the building sector to help deliver the European Green Deal and achieve climate change mitigation and adaptation targets by 2050. The 2021-2023 energy crisis felt primarily in Europe with immediate impact worldwide, has aroused the need to adopt energy savings in the housing sector (e.g., through insulation materials) and the use of renewable energy as energy efficiency measures (Battistini et al. 2021; Belaïd et al., 2023; European Commission, 2021; Snell and Pleace, 2022).

Figure 2. Enablers of biobased construction materials.

Policy and regulatory support
Government policies and regulations promoting the use of biobased materials in construction are vital enablers. Financial incentives, such as tax breaks, subsidies, and green building certifications, can encourage developers to adopt biobased materials in their projects. The European Union's strategies for a circular economy and the bioeconomy also support the integration of bio-based materials in the building sector. European Union policies, such as the Circular Economy Action Plan and the European Green Deal, promote the use of sustainable, renewable, and low-carbon materials in construction (European Commission, 2020).

Research and innovation
Investments in research and development can drive innovation in biobased construction materials, leading to improved performance, cost-effectiveness, and broader applicability. Collaborative efforts between academia, industry, and governments can facilitate the development and dissemination of new knowledge, technologies, and best practices. European research programs, such as Horizon Europe, support the development of sustainable technologies and materials (European Commission, 2020; Pacheco-Torgal et al., 2020).

Local availability of biobased resources
The availability or creation of locally sourced biobased materials, such as wood, straw, bamboo, miscanthus, etc. can be a strong trigger for their use in construction. Utilizing locally available resources can reduce transportation costs, carbon emissions, and support the local economy (Jones and Brischke, 2017; Kibert, 2016).

Industry collaboration
Partnerships between biobased material producers, construction companies, and other stakeholders can foster the development and adoption of sustainable construction materials. Industry associations and networks, such as the European Bio-based Industries Consortium (BIC), can help create synergies and share expertise, facilitating the market penetration of biobased materials. Collaboration between various stakeholders, such as material suppliers, architects, engineers, and construction companies, can drive the adoption of biobased materials in construction projects. Sharing knowledge, experience, and best practices can help overcome barriers and accelerate the transition to more sustainable construction and green buildings (European Bio-based Industries Consortium, n.d.; Jones and Brischke, 2017; Pacheco-Torgal et al., 2020).

Environmental awareness and consumer demand
Increasing awareness of climate change and environmental issues has led to a growing demand for sustainable and eco-friendly construction. Consumers are seeking energy-efficient, low-impact housing options that utilize biobased materials (Kibert, 2016).

Certification schemes and standards
Green building certification schemes, such as BREEAM (Building Research Establishment Environmental Assessment Method) and DGNB (German Sustainable Building Council), promote the use of sustainable and biobased materials in construction projects. Implementing standards for the performance and quality of biobased materials can also support their widespread adoption (European Commission, n.d; Jones and Brischke, 2017).

Education and training
Educating architects, engineers, builders, and other construction professionals about the benefits and proper application of biobased materials can help foster their adoption. Offering training programs and workshops can further encourage the use of these materials in construction projects (Jones and Brischke, 2017; Pacheco-Torgal et al., 2020).

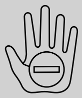
The adoption of biobased construction materials in the European building sector and housing system can contribute to sustainable development, climate mitigation and adaptation. Several enablers (see Figure 2) facilitate the use of these materials, including policy and regulatory support, research and innovation, industry collaboration, environmental awareness and consumer demand, certification schemes and standards, local availability of bio-based resources, education and training (Jones and Brischke, 2017; Pacheco-Torgal et al., 2020).

The adoption of biobased construction materials in the building sector and housing system in Europe faces several barriers (see Figure 3), which can hinder their widespread use. Some of the key challenges include:

Figure 3. Barriers of biobased construction materials.

Limited awareness and knowledge
Many construction professionals, such as architects, engineers, and builders, may not be fully aware of the benefits and potential applications of biobased materials. This limited knowledge can impede their adoption in construction projects (Jones and Brischke, 2017; Pacheco-Torgal et al., 2020).

Performance concerns
Biobased materials can sometimes face skepticism regarding their performance, durability, and suitability for various construction applications. This can result in a preference for more conventional, well-established materials like concrete and steel (Amziane and Sonebi, 2016; Carcassi et al., 2019).



Regulation and standardization
The lack of clear regulations and standards for biobased materials can create uncertainty and hesitation among construction professionals when considering these materials for their projects. This can limit their adoption and slow down the development of more sustainable construction practices (Jones and Brischke, 2017; Pacheco-Torgal et al., 2020).

Supply chain challenges
The limited availability and inconsistent quality of biobased materials can also pose challenges for their widespread adoption. In addition, the supply chain for these materials may not be as well-developed as that of conventional materials, creating logistical challenges for procurement and transportation (Jones and Brischke, 2017; Amziane and Sonebi, 2016).

Higher initial costs
Biobased materials can sometimes have higher initial costs compared to conventional materials, which can be a deterrent for their use in construction projects. However, it is essential to consider the long-term benefits and potential cost savings through energy efficiency and reduced maintenance (Jones and Brischke, 2017; Schulte et al., 2021).

Farmlands and land use change
There is a need to consider direct and indirect land use change in life cycle assessments (LCA) and potential conflicts between using farmlands for biobased material production and food production, biodiversity conservation and deforestation. Sustainable land use planning and the adoption of responsible land management practices are important to overcome some of the barriers for primary production of biobased construction materials (OECD, 2022).

Stakeholders

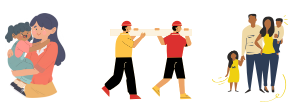
The stakeholders in the value chain of biobased construction materials in the building sector and the housing system in Europe (see Figure 4) include suppliers of raw materials, manufacturers, distributors, builders, architects, engineers, regulators, and end-users. These actors play critical roles in the production, marketing, distribution, and adoption of biobased materials in the construction industry. Jones and Brischke (2017) and Pacheco-Torgal et al. (2020) discuss the different actors and their roles in the value chain of biobased construction materials in the building sector. They highlight the importance of collaboration and coordination among stakeholders to overcome the barriers to adoption and promote the wider use of these sustainable materials in the construction industry:

Figure 4: Identified stakeholders

The suppliers of raw materials such as plant fibers, bioplastics, and natural resins are essential actors in the value chain, as they provide the primary inputs for biobased construction materials. Similarly, manufacturers that transform these raw materials into usable products and distributors that transport and market them are also critical actors.

Builders, architects, and engineers are also important stakeholders in the value chain, as they play a central role in selecting and specifying materials for construction projects. These professionals' decisions can influence the adoption of biobased materials in the building sector and the housing system.

Regulators and policymakers also play an essential role in the value chain, as they can create an enabling environment for the adoption of biobased materials through the development of standards and regulations that support their use



End-users, such as homeowners and building occupants, also have a role to play in driving demand for biobased materials through their preferences and purchasing decisions.

Sustainable Development Goals as a framework

The seventeen Sustainable Development Goals (SDGs) came into force on the 1 January 2016 and have been adopted by world leaders to fulfil the 2030 Agenda for Sustainable Development (see Figure 5).

The SDGs offer a well-known framework for dialogue an international level and a good channel towards circular economy. These goals recognise that ending poverty, inequality, and tackle climate change, must go hand in hand with strategies which build economic growth while addressing social needs, education, health, social protection and job opportunities and environmental protection (van Eijk and van Kruchten, 2020).

The effective incorporation of sustainability is complex and requires all stakeholders in the value chain to be involved, therefore using common frameworks that drives understanding and effectiveness is important. The SDG framework is a shared plan for promoting sustainable economic growth, advancing social inclusion, and safeguarding the natural environment. This framework provides the basis for initiating and developing a common ground and facilitate international, national, or regional dialogues (van Eijk and van Kruchten, 2020, Sustainable Development Goals, n.d.).

Figure 5: Sustainable Development Goals (Source: UN SDG's)

The goals universally apply to all and although they are not legally binding, governments are expected to take ownership and establish national frameworks for the achievement of the 17 Goals. Countries have the primary responsibility for follow-up and review of the progress made in implementing the Goals, which will require quality, accessible and timely data collection. Countries and businesses should mobilize their efforts to end all forms of poverty, fight inequality and tackle climate change, while ensuring that no one is left behind (van Eijk and van Kruchten, 2020, Sustainable Development Goals, n.d.).

Identification of synergies and trade-offs

Identifying synergies and trade-offs of biobased construction materials with the SDGs (see Figure 6 and Figure 7) is crucial for informed decision-making. Recognizing synergies enables us to harness the potential of biobased materials to address multiple SDGs simultaneously, optimizing resource use and promoting sustainable development. By understanding the trade-offs, will help to identify potential conflicts and unintended consequences. Therefore, biobased construction practices can be aligned better with overarching SDGs, foster inclusive development, and mitigate any negative impacts. This assessment could guide policymakers, stakeholders, and communities in making choices that balance economic, environmental, and social objectives for a more sustainable production, processing and implementation of biobased construction materials in the housing system.

Figure 6: Identified synergies of biobased construction materials relevant to the SDGs (Selected). SDG 1 to 7

NO POVERTY

Urban and Rural Opportunities and Income diversification (rural producers):
Biobased production can create employment opportunities and income diversification for local urban and rural communities, especially in developing regions, reducing unemployment and poverty rates.

QUALITY EDUCATION

Promote Education on Sustainability and Biobased Products:
Biobased products can serve as an educational opportunity to learn about sustainability, renewable resources, and eco-friendly building practices.

CLEAN WATER AND SANITATION

Reduced Water Pollution:
Biobased construction materials often have lower environmental impacts during production and use, reducing the release of pollutants into water.

ZERO HUNGER

Empowerment of Farmers:
The cultivation of biobased materials can empower farmers by providing them with additional income sources. This empowerment enables them to invest in their farms, purchase better seeds and tools, and increase their overall food production.

GOOD HEALTH AND WELL-BEING

Improved Soil/Air Quality:
Contribution to prevent soil and air pollution during the biomass production period. Air quality can also improve in the interior environment of buildings.

Mental Health and Well-being:
Buildings made with biobased materials can be designed to encourage mental and physical activity through the inclusion of green spaces and sustainable materials. More natural environments can help to reduce stress and increase thermal comfort.

AFFORDABLE AND CLEAN ENERGY

Renewable Energy Production:
Biobased materials, such as wood and bamboo, can be used in the construction of renewable energy infrastructure, including biomass power plants and wind turbine towers. These materials are sustainable and support clean energy generation.

Energy-Efficient Buildings:
Biobased construction materials often have excellent insulation properties, helping to create energy-efficient buildings. Reduced energy consumption for heating and cooling contributes to clean energy goals (net-zero) by lowering the demand for fossil fuels.

Figure 6: Identified synergies of biobased construction materials relevant to the SDGs (Selected). SDG 8 to 17

DECENT WORK AND ECONOMIC GROWTH

Job Creation:
The production, processing, and installation of biobased construction materials create employment opportunities in various sectors, including agriculture, forestry, manufacturing, and construction. This job creation supports economic growth and provides decent work for individuals in both rural and urban areas.
Entrepreneurship Opportunities:
Biobased construction materials and production can empower entrepreneurs, including women and small-scale businesses, by creating opportunities for startups and small enterprises. This fosters economic diversity and resilience.

REDUCED INEQUALITIES

Value Chain Development:
Developing local or regional biobased value chains can ensure that more economic value stays within communities. This prevents wealth concentration and promotes local economic development, reducing economic inequalities.
International Trade:
Developing a biobased construction industry can lead to international trade opportunities, potentially benefiting regions that were previously excluded from global markets and reducing global economic inequalities.

RESPONSIBLE CONSUMPTION AND PRODUCTION

Resource Efficiency:
Promotion of responsible consumption and production by utilizing renewable resources efficiently and minimizing waste during the manufacturing process.
Reduced Waste:
The use of biobased construction materials results in less construction-related waste, aligning with responsible consumption and production goals.

LIFE BELOW WATER

Reduced Pollution:
Biobased materials often have lower environmental impacts during production and use compared to conventional construction materials. Using these materials can reduce the pollution of water bodies and oceans from manufacturing and construction activities.

INDUSTRY, INNOVATION AND INFRASTRUCTURE

Innovation and Infrastructure:
Drive innovation in construction techniques and materials, fostering sustainable infrastructure development.

SUSTAINABLE CITIES AND COMMUNITIES

Improved Indoor Air Quality:
Enhance indoor air quality in buildings, contributing to healthier urban environments and more sustainable communities.
Green Cities/Net-Zero Cities and Green Housing:
Biobased materials can help contributing to the development of sustainable housing, cities and communities with less CO2 emissions.

CLIMATE ACTION

Reduced Carbon Footprint:
Lower embodied carbon footprint compared to traditional materials like concrete and steel, helping to mitigate climate change.

LIFE ON LAND

Sustainable Land Management:
The cultivation and harvesting of biobased materials often follow sustainable land management practices. These practices help prevent deforestation, soil erosion, and land degradation, contributing to the conservation of terrestrial ecosystems.
Habitat/Biodiversity Protection:
Responsible forestry practices for sourcing biobased materials can protect natural habitats and biodiversity on land. Preserving forests and other ecosystems supports the survival of various species and maintains ecological balance.

PEACE, JUSTICE AND STRONG INSTITUTIONS

Transparency and Accountability:
Sustainable practices in biobased construction promote transparency and accountability in resource management and construction processes, reducing the potential for corruption and fostering trust in institutions.
Community Engagement:
Involving local communities in bio-based construction projects ensures their participation in decision-making, promoting social cohesion and peaceful cooperation among diverse stakeholders.
Legal Frameworks:
Developing and enforcing legal frameworks for sustainable construction practices using biobased materials strengthens institutions by ensuring compliance with environmental and ethical standards, fostering a culture of responsible construction and resource management.

Figure 7: Identified trade-offs of biobased construction materials relevant to the SDGs (Selected). SDG 1 to 5

NO POVERTY

Initial Cost vs. Long-term Savings:
While some biobased materials may have a lower upfront cost, their adoption may require investments in technology, training, and infrastructure. These initial expenses could be a barrier for impoverished communities, even though the long-term cost savings and economic benefits may be substantial.

QUALITY EDUCATION

Resource Allocation:
Prioritizing sustainability and construction materials might necessitate a reevaluation of resource allocation within educational budgets, potentially impacting funding available for educational programs, staffing, and infrastructure development.
Cultural Appropriation Concerns:
The adoption of indigenous biobased materials and building techniques without proper respect for indigenous knowledge and consent can raise concerns of cultural appropriation and exploitation, potentially eroding the cultural heritage and identity of indigenous communities.

ZERO HUNGER

Competition for Agricultural Land:
The use of biobased materials may compete with food production for agricultural land and resources, potentially impacting food security goals.

GOOD HEALTH AND WELL-BEING

Allergen Sensitivities:
Some biobased materials, such as natural fibers, can trigger allergies in sensitive individuals. Proper sealing and treatment may be required to minimize allergen exposure, potentially affecting indoor air quality and occupant well-being.
Maintenance Requirements:
Biobased materials may have different maintenance needs compared to traditional materials. Failure to address these requirements could lead to degradation and potential health hazards if not properly managed, impacting occupant well-being.

Figure 7: Identified trade-offs of biobased construction materials relevant to the SDGs (Selected). SDG 6 to 17

CLEAN WATER AND SANITATION

Water Use in Agriculture:
The cultivation of biobased materials can require significant water resources, potentially leading to competition for water between agriculture and other essential uses, including drinking water and sanitation. Sustainable/Integrated water management practices are necessary to mitigate this trade-off.
Wastewater Impacts:
The use of biobased materials may introduce organic matter into wastewater systems, affecting treatment processes and potentially requiring additional treatment measures. Balancing the benefits of biobased materials with wastewater considerations is essential to maintain clean water and sanitation standards.

DECENT WORK AND ECONOMIC GROWTH

Skills and Training Needs:
Transitioning to biobased construction may require additional training and skills development for the workforce, which can temporarily disrupt job stability and economic growth until the workforce is upskilled.
Market Competition:
The biobased construction industry may face competition with traditional construction sectors, potentially impacting existing jobs and economic structures in regions heavily reliant on conventional construction materials and practices. Balancing this competition while promoting sustainable growth is a challenge.

REDUCED INEQUALITIES

Resource Allocation Disparities:
Prioritizing sustainability and biobased materials might necessitate reevaluating resource allocation within communities or regions, which can impact vulnerable populations and lead to disparities in resource distribution if not carefully managed.

RESPONSIBLE CONSUMPTION AND PRODUCTION

Limited Availability of Products:
Some biobased materials have limited availability, which can hinder responsible consumption and production efforts.
Resource Intensive Production:
The production processes for certain biobased materials can be resource-intensive, potentially conflicting with responsible resource consumption goals.

LIFE BELOW WATER

Water Resource Allocation:
The cultivation of biobased materials may require significant water resources, potentially leading to competition for water between agriculture and maintaining healthy aquatic ecosystems. Sustainable water management practices are crucial to mitigate potential conflicts.

PEACE, JUSTICE AND STRONG INSTITUTIONS

Resource Conflicts:
The demand for biobased materials can sometimes lead to disputes over land and resources, potentially causing conflicts that challenge peace and require legal institutions to resolve.
Regulatory and Enforcement Challenges:
Ensuring sustainable and ethical practices in the biobased construction industry may require strengthened regulatory and enforcement mechanisms to prevent illegal logging, land grabbing, or exploitation of indigenous knowledge, contributing to the need for stronger institutions.

AFFORDABLE AND CLEAN ENERGY

Energy-Intensive Processing:
Some biobased materials may require energy-intensive processing methods, such as drying or treatment, which could increase the energy footprint of their production. Balancing the environmental benefits of biobased materials with their energy requirements is essential.
Biomass Resource Competition:
The use of biobased materials in construction can compete with biomass resources used for clean energy production, such as biofuels or biomass power generation. Managing the allocation of biomass resources is crucial to ensure a sustainable balance between construction and energy needs.

INDUSTRY, INNOVATION AND INFRASTRUCTURE

Durability and Maintenance:
Some biobased materials may require more frequent maintenance or have shorter lifespans, affecting the sustainability of infrastructure.

SUSTAINABLE CITIES AND COMMUNITIES

Higher Initial Costs:
They can have higher initial costs, potentially challenging efforts to provide affordable housing and infrastructure in cities.

CLIMATE ACTION

Production, Processing and Transportation Emissions:
Some biobased materials may require energy-intensive production and processing methods, which could result in greenhouse gas emissions. The transportation of biobased materials over long distances may result in increased emissions, counteracting climate action efforts.

LIFE ON LAND

Land Use Conflict:
The cultivation of biobased materials may lead to conflicts with land use for agriculture or natural ecosystems, potentially affecting land preservation goals.
Certification Challenges:
Ensuring the sustainability and legality of biobased materials can be challenging, potentially undermining efforts to protect terrestrial ecosystems.

PARTNERSHIPS FOR THE GOALS

Intersectoral Cooperation:
Achieving partnerships across various sectors involved in biobased construction may require overcoming differences in goals and objectives, potentially requiring additional time and effort for effective collaboration.

Research questions for other domain experts

- How can biobased construction materials be effectively integrated into building design, construction and maintenance practices, while enhancing their climate neutrality and resilience?
- How can biobased construction materials be sustainably sourced, produced and processed at scale, while maintaining high levels of environmental and social sustainability?
- What are the environmental, economic and social benefits of using biobased construction materials in the construction of sustainable housing systems?
- How can interdisciplinary collaboration between academia, industry, government and communities be effectively leveraged to advance the development and deployment of biobased construction materials?
- To what extent can biobased construction materials contribute to reduce GHG emissions and sequestrate CO2 in comparison to conventional construction materials?

Research gaps from the case study in relation to the SDGs

- How can the widespread adoption of biobased construction materials be optimized to maximize their positive impact on achieving specific SDGs?
- To what extent can the promotion of biobased construction materials and practices help bridge the gap between rural and urban development and contribute to the SDGs?
- What policies and regulatory frameworks can be implemented at the national and international levels to incentivize the use of biobased construction materials and production processes in a way that aligns with various SDGs?
- How can the integration of indigenous and traditional knowledge into the development and use of biobased construction materials enhance their contribution to achieving SDGs, particularly those related to biodiversity conservation and cultural preservation?
- What innovative financing models and investment strategies can be developed to support the adoption of biobased construction materials and sustainable building practices, facilitating progress toward the SDGs related to economic growth, industry innovation, and climate resilience?
- How can sustainable land and water management practices be integrated into the entire life cycle of biobased construction materials to enhance their contribution to achieving SDGs related to urban, rural and landscape contexts?

Terminology for Wageningen climate dictionary

This case study contributes to essential terminology and practical concepts for the Wageningen climate dictionary, enriching the discourse on climate mitigation and adaptation. The terms and definitions can be found in Annex 1.

Conclusions

The adoption of biobased construction materials offer significant potential for long-term carbon storage in sustainable housing construction. Biobased materials are a critical component of the global carbon cycle, and provide a unique opportunity to mitigate climate change while advancing across multiple Sustainable Development Goals (SDGs), as shown in figure 8.

Key synergies are found in SDG 13 (Climate Action), where these materials sequester carbon and contribute to climate mitigation. For SDG 15 (Life on Land), sustainable forest management contributes to biodiversity and ecosystem protection. For SDG 12 (Responsible Consumption and Production), the deployment of biobased materials is an very good initiative to reduce greenhouse gas emissions and to stablish the circular economy concept. For SDG 1 (No Poverty) and SDG 8 (Decent Work and Economic Growth) also benefit from biobased materials by creating job opportunities and fostering economic growth, particularly in rural areas. Additionally, SDG 9 (Industry, Innovation, and Infrastructure) sees synergies through innovations in sustainable biobased materials for urbanization. SDG 3 (Good Health and Well-being), where biobased materials such as wood improve indoor air quality and mental health.

However, several trade-offs need to be carefully managed. SDG 2 (Zero Hunger) faces a trade-off between land use for food production versus biobased material production, while SDG 6 (Clean Water and Sanitation) highlights potential competition for water resources. SDG 7 (Affordable and Clean Energy) encounters a trade-off between energy and material production, and SDG 10 (Reduced Inequalities) risks creating global disparities between richer and poorer regions. SDG 15 (Life on Land) and SDG 11 (Sustainable Cities and Communities) must balance biobased material production with the preservation of biodiversity and sustainable land use and sustainable production practices are critical to avoid over-exploitation and ensure the materials contribute to long-term sustainability.

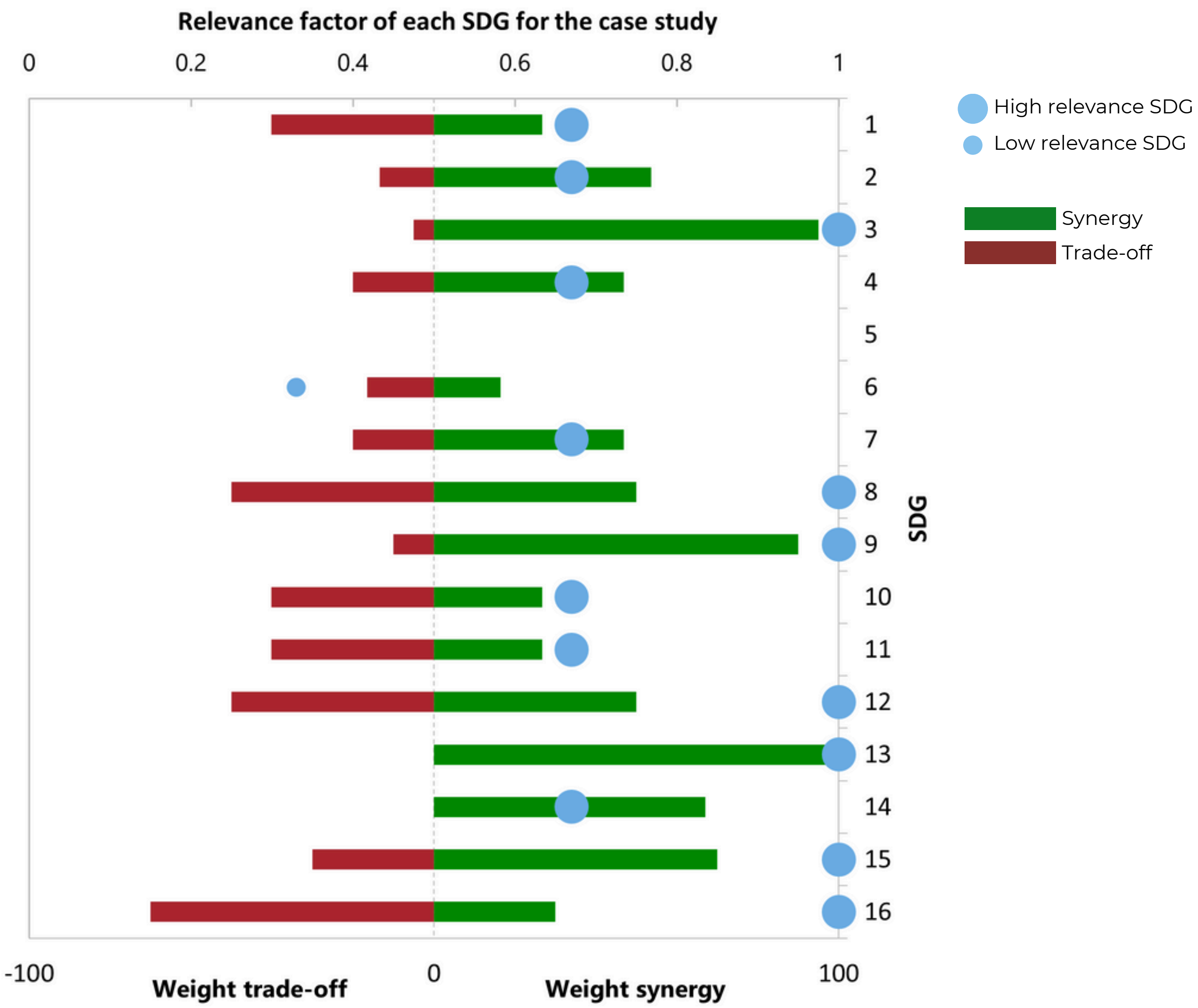


Figure 8. Overview with weight of importance of the synergies and trade-offs, and relevance of each SDG to the case study of biobased construction materials. The weight of each synergy and trade-off is a combination of the relevance of the SDG for the case study (blue dots; upper axis) and an expert judgement based weighing between trade-offs and synergies (green and red bars; lower axis).

Regarding SDG 16 (Peace, Justice, and Strong Institutions) emphasizes the importance of strong governance and legal frameworks to ensure fair trade and prevent conflicts over land rights. Unregulated production of biobased materials could lead to land disputes, necessitating effective policy enforcement.

Overall, while biobased materials offer significant contributions to climate action, economic growth, and health, however their adoption must be managed with strong regulatory frameworks to avoid negative socio-environmental impacts and ensure global equity.

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Annex 1

Terminology for Wageningen Climate Dictionary

Table 1. Terminologies for biobased construction materials research.

Terminology*	Description	Source
Biobased construction materials		
Biobased/ Bio-based materials:	Are wholly or partly derived from materials of biological origin, excluding materials embedded in geological formations and/or fossilized.	(European Commission, n.d.(a))
Natural materials:	Materials that are sourced from natural resources, such as wood, cork, straw, and clay, are minimally processed.	(Ashby and Johnson, 2013)
Renewable materials:	Resources that have a natural rate of availability and yield a continual flow of services which may be consumed in any time period without endangering future consumption possibilities if current use does not exceed net renewal during the period under consideration.	(European Environment Agency, n.d.)
Sustainable materials:	Materials that have minimal environmental impact, are non-toxic, and can be recycled or biodegraded at the end of their life cycle.	(Ding, 2014)
Green materials:	Materials that are environmentally friendly and have low embodied energy, meaning that they require minimal energy to produce.	(Turan and Findik, 2015)
Eco-friendly materials:	Materials that are produced with minimal environmental impact can be recycled or biodegraded at the end of their life cycle.	(European Consumer Centre France, 2022)
Sustainable construction		
Sustainable construction:	Refers to the practice of designing and constructing buildings in an environmentally friendly, socially responsible, and economically viable manner.	(British Assessment Bureau, 2021)
Green building:	It is the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life cycle from sitting to design, construction, operation, maintenance, renovation and deconstruction. This practice expands and complements the classical building design concerns of economy, utility, durability, and comfort.	(U.S. Green Building Council, 2022)
Low-carbon building:	A building that is designed to minimize greenhouse gas emissions and reduce its carbon footprint.	(Climate CoLab, 2016)
Net-zero energy building:	A building that produces as much energy as it consumes, typically through the use of renewable energy sources such as solar or wind power.	(U.S. Department of Energy, 2022)
Passive house:	A building standard that emphasizes energy efficiency through a combination of insulation, airtightness, and heat recovery ventilation.	(Passive House Institute, 2022)
Circular building:	A building that is designed to minimize waste and maximize the reuse of materials through strategies such as modular construction and material recovery at the end of the building's life cycle.	(Ellen MacArthur Foundation, 2019)

Terminology*	Description	Source
Climate neutral cities		
Climate-neutral cities:	It is one that reduces the majority of carbon emissions and offsets residual emissions, to the point that its operations do not result in a net increase in emissions.	(The United Nations Framework Convention on Climate Change, 2021)
Carbon-neutral city:	A city that achieves net-zero carbon emissions, typically through a combination of energy efficiency measures, renewable energy sources, and carbon offsets.	(ICLEI, 2022)
Zero-emissions city:	A city that eliminates all greenhouse gas emissions, including carbon dioxide, methane, and nitrous oxide, through a combination of energy efficiency, renewable energy, and low-carbon transportation.	(NETZEROCITIES, n.d.)
Climate-positive city:	A city that goes beyond zero-emissions and actively removes carbon from the atmosphere through measures such as carbon sequestration and regenerative agriculture.	(Institute for Global Environmental Strategies, 2019)
Eco-city:	A city that prioritizes sustainability and livability through measures such as green infrastructure, sustainable transportation, and renewable energy sources.	(Bibri, 2020)
Smart city:	It is a place where traditional networks and services are made more efficient with the use of digital solutions for the benefit of its inhabitants and business. A smart city goes beyond the use of digital technologies for better resource use and less emissions. It means smarter urban transport networks, upgraded water supply and waste disposal facilities and more efficient ways to light and heat buildings. It also means a more interactive and responsive city administration, safer public spaces and meeting the needs of an ageing population.	(European Commission, n.d.(b))
Resilient city:	Resilient cities are cities that can absorb, recover and prepare for future shocks (economic, environmental, social & institutional). Resilient cities promote sustainable development, well-being and inclusive growth.	(OECD, n.d.)
IPCC Terminology		
Harvested Wood Products (HWP) reservoir	Wood that is harvested from Forest Land, Cropland and other types of land use remains in products for differing lengths of time. HWP includes all wood material (including bark) that leaves harvest sites. Material left at harvest sites should be regarded as dead organic matter. HWP constitutes a carbon reservoir. The time carbon is held in products will vary depending on the product and its uses. E.g., fuelwood and mill residue may be burned in the year of harvest; many types of paper are likely to have a use life in uses less than 5 years which may include recycling of paper; and sawn wood or panels used in buildings may be held for decades to over 100 years.	(Calvo Buendia, 2019)

***These terminologies are often used interchangeably, and their use can depend on the context and specific characteristics.**