Detailed Project Description

Precast wood and straw walls

MANUFACTURE BOIS-PAILLE

Project developer contact :

- Name : Roger GARRIVIER / Eric RIGAUDIE
- Email: roger.garrivier@manufactureboispaille.fr / erick.rigaudie@activ-home.com

Riverse contact :

- Name : Clément GEORGET
- Email : clement.georget@riverse.io
- Tél : 06 82 05 40 91

Auditor contact :

- Name : Fanny Marcon
- Email : fanny@collectif-transition.fr

Date : 28/03/2023

List of source documents

Link to source document folder

Link to certification document folder

Criteria	Document Type	Sources
C1 - Measurability	• LCA Impact Assessment • FDES examples from base Inies	Manufacture BoisPaille - LCA LCI - Karibati
C2 - Real	• List of constructions site, with: m2 of living space, location, year of construction • Bill of Materials • List of origins for biobased elements (Wood : within 150 km from Lyon (except for 5%) , Straw: locally source)	6690 m2 of wall constructed in 2022 (3253m2 by MBP, 3437m2 by Activ'Home) Financial statement LCI - Karibati "A2-Transport des MP" sheet
C3 - Additionality	• Regulatory additionality proof • Annual financial accounts • between concrete building and Manufacture Bois Paille.	French Environmental Law French Energy transition Law REACH regulation French Bioeconomy strategy
C4 - Permanence	• External LCI (Inputs of materials) • Comparative LCA impact assessment	LCI - Karibati - "A1-Matières premières" sheet Manufacture BoisPaille - LCA "Final results" sheet
C5 - Unicity	Riverse and Manufacture Bois Paille Contract	Riverse Manufacture Bois Paille Contract signed
C6 - Co-benefits	LCA Impact Assessment on the following KPIs: • SDG8: Volume of construction panels (m2 or m3) manufactured and sold per year • Quantity of straw utilized (tons) / m2 built • SDG 15: List of providers of biobased materials with PEFC/other certification ratios of sustainable forestry used per materials	m2 livable space constructed until 2023

	• SDG 9: Abiotic Resource Depletion Potential of fossil fuels; ADPfossil fuels (MJ/ m2).	
C7 - Substitution	• Agence Qualité Construction (AQC) standards commitment - In compliance with the professional rules for straw construction and DTU 31.2	Insurance policy
C8 - Do no harm	• Certification document from PEFC • Agence Qualité Construction (AQC) standards	Insurance policy List of biobased material providers
C9 - Leakage	PEFC certification for structural walls	
C10 - Rebound effects	• Technical specifications of CLT panels (or competitors). • Cost analysis for both type of projects (CLT and timber frame)	
C11 - TRL	• Financial statements, indicating revenue and demonstrating commercial viability • Manufacture Bois Paille webpage	Financial statement https://www.manufactureboispaille.fr/
C12 - Targets Align.	Avoided emission percentage> 45%	Manufacture BoisPaille - LCA – "Final results" sheet
C13 - Min. Impact	The production forecast over the crediting period is at least of 60 000m2, as the yearly production capacity of the plants is 30 000m2 each: • MBP: 30000m2 • Activ-Home: 30000m2	
Focus LCA	Manufacture Bois Paille - LCA Impact Assessment	Manufacture BoisPaille - LCA – "Final results" sheet

Project presentation

Better construction and better use of buildings in the European Union (EU) would reduce by 42% our final energy consumption, by 35% our greenhouse gas emissions (GHG), and more than 50% of all extracted materials. Notably, in 2019, the construction and operation of buildings were responsible for 38 % of global energy-related CO2 emissions. However, due to the pandemic and global efforts to decarbonize the sector, emissions experienced a 10% decrease.[1] The adoption of biobased materials in construction presents a compelling solution to diminish the carbon footprint of the building sector. These materials not only involve fewer pollutant components but also require significantly lower energy inputs during the manufacturing process compared to materials such as concrete, gypsum, or steel. Furthermore, their implementation facilitates the long-term storage of atmospheric CO2[2].

Straw, as a bio-sourced material, holds great potential as a locally abundant resource, boasting exceptional thermal and environmental qualities. By combining wood with straw, it becomes possible to construct buildings that are both sustainable and conducive to well-being, offering optimal insulation and comfort.

In particular, the application of straw-insulated wood-frame panels, utilizing the innovative technology developed and patented by our partner, Activ Home®, enables swift and environmentally-friendly construction practices on-site. These panels not only comply with the demands of new energy regulations but also remain competitive when compared to conventional materials that contribute to pollution.

Overall, the utilization of straw and the development of prefabricated wood-frame panels provide a compelling solution for creating healthy, sustainable buildings that meet modern energy requirements while ensuring a cleaner and more efficient construction process.

Type : Removals

Location: Villefranche-sur-Saône, France

Credit issuance period: January 2022 - December 2026

Duration: 5 years

[1] UN Environment Programme. (2022). *CO2 emissions from buildings and construction hit new high, leaving sector off track to decarbonize by 2050: UN*. Retrieved March 15, 2023, from https://www.unep.org/news-and-stories/press-release/co2-emissions-buildings-and-construction-hit-new-high-leaving-sector

[2] Bowers, J. (2022, November 30). *Bio-based materials improve the comfort and carbon footprint of buildings*. Polytechnique Insights. Retrieved January 23, 2023, from https://www.polytechnique-insights.com/en/columns/planet/bio-based-materials-improve-the-comfort-and-carbon-footprint-of-buildings/

General Criteria

C1 - Measurability

The emissions avoided and removed by Manufacture Bois Paille (MBP) structural wall with straw insulation panels are calculated from a comparative cradle-to-grave Life Cycle Assessment (LCA) using the climate change impact category, and evaluating the impact of different materials used through PED/FDES from INIES database. This comparative LCA determined the greenhouse gas emissions of the materials used by MBP compared to the emissions of a prefabricated concrete wall under 2 scenarios. The climate change impact was calculated from the construction phase to the end of its life.

C2 - Real

All currently available carbon credits are ex-post, meaning that the carbon reductions have already been verified and are therefore real.

The verification of carbon credits will be done by auditing the evidence associated with the following key impact indicators (KIIs):

1. Volume of construction panels (m2) manufactured and installed per year
2. List of providers of biobased materials with PEFC/other certification ratios of sustainable forestry used per materials
3. Payment bills of straw

The project Monitoring Plan is detailed at the end of this DPD.

C3 - Additionality

a. Regulatory additionality

The construction of buildings with improved energy and resource efficiency are expected to be implemented as an outcome of the RE2020. This regulation mandates a new calculation framework for assessing energy and material consumption performance, to improve environmental performance and comfort. Indirectly, this new regulation promotes the construction of new buildings with biobased materials since their environmental impacts are lower. However, **the regulation does not specifically mandate the use of bio-based materials** but rather, stimulates its use to reduce resource consumption as well as improve the energy efficiency of existing and new buildings[3].

[3] Cardellini, G., & Mijnendonckx, J. (2022). *Synergies , energy efficiency and circularity in the renovation wave*. Bio-based products for the renovation wave. European Environment Agency.

One of France's objectives is to reduce the carbon footprint of buildings which is constantly being adapted to current environmental issues, as well as new regulations on energy consumption. This should make it possible to move even further towards the widespread use of positive energy and low-carbon buildings noted that the Climate Plan sets carbon neutrality by 2050. All building sectors are concerned (single-family homes, apartment buildings, service sector buildings), whether in new or old buildings, for construction, renovation, or operation.

Mandatory regulations are involved for the construction of buildings financed by the French government[4]. For instance, the French Environmental Law passed in 2019, requires that all public buildings have **a minimum of 50% of their wood-based materials come from sustainable sources**. Other regulations involved in biobased materials are The French Energy Transition Law which sets a target to reduce energy consumption by 50% by 2050, and proposes that one way to do this is the use of biobased materials in construction. Another regulation is the REACH regulation which is more focused on the restriction of chemicals and encouragement to use more safer and environmentally friendly materials like bio-based; this is also the aim of the French Bioeconomy strategy enacted in 2017. **However, this does not imply a mandatory implementation for the private sector.** Therefore, there is no specific rule regarding the bio-based share within a product.

b. Financial additionality

Even with the good performance of biobased materials in terms of successful environmental and physical performance levels, there is a **challenge for the expansion of projects in France**. The price of prefabricated concrete walls (+ polystyrene insulation) remains much lower than that of wood-frame walls, by about 50 to 80€/m2. The carbon credits allow a subsidy of the activity up to 3 to 4€/m2, which allows for a reduction of the price difference.

c. Prevalence additionality

Currently, around 230, 000 tons of biomass produced in France are valorized in the building sector. The integration of biobased materials for insulating and finishing materials in construction **reached 10 %[5] in 2020, which is far less than concrete use**. Therefore, the

[4] Dalheim, R. (2020, February 13). *France to require all public buildings be built with 50 percent wood*. Woodworking Network. Retrieved March 15, 2023, from https://www.woodworkingnetwork.com/news/woodworking-industry-news/france-require-all-public-buildings-be-built-50-percent-wood

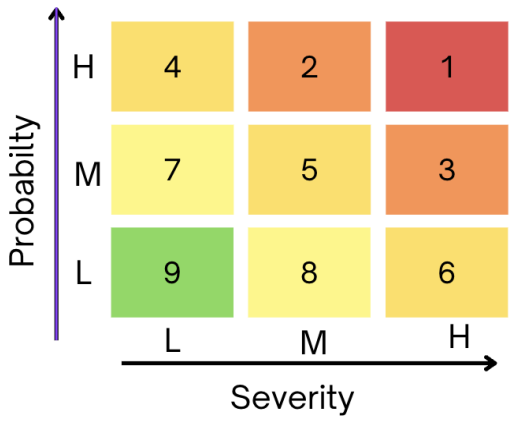
[5] *Sustainability of biomass-based insulation materials in buildings: Current status in France, end-of-life projections and energy recovery potentials*. Available from: https://www.researchgate.net/publication/356835626_Sustainability_of_biomass-based_insulation_materials

implementation of these materials by Manufacture Bois Paille with financing through carbon credits can help to increase the market share by reducing the costs.

C4 - Permanence

The carbon credits in this case would be issued based on the type of emissions avoidance and short-term carbon removal, taking into account the 100-year lifespan of the wood frames. To determine the impacts, we utilize Life Cycle Assessment (LCA) and consider the respective lifetimes of the products. This approach allows us to calculate climate impacts, considering the timing of greenhouse gas (GHG) emissions or sequestration in relation to a specific time horizon[6]. The carbon credits issued for this project are **removals, with a long-term storage duration**. The lifetime of the materials (Pre-cast wood & straw walls) is at least 100 years and contains biobased materials with a lifetime duration of 100 years as well. The biogenic content is therefore guaranteed to be sequestered for a minimum of 100 years.To verify that the removal occurs as expected over the 5-year crediting period, verification will be done as production proceeds. The effectiveness and permanence of avoidance or removal will be ensured every 6 months by Riverse through the KIIs. Table 1 below presents an overview of potential risks associated with the project's various categories. It includes information on the risk level, and the corresponding risk management methodologies. Risks are assessed on a scale of 1 to 9, with 9 indicating a low level of risk and 1 denoting the highest.

Figure 1 Determination of risk level



_iln_buildings_Current_status_in_France_end-of-life_projections_and_energy_recovery_potentials [accessed Mar 15 2023].

[6] Peñaloza, D. (2017). *The role of biobased building materials in the climate impacts of construction* [KTH Royal Institute of Technology]. https://kth.diva-portal.org/smash/get/diva2:1096048/FULLTEXT01.pdf

Table 1 Matrix of Risk Analysis

Category	Risk	Impact	Probability	Severity	Level of risk	Manage of risk
Social	Local farmers decide not to work with MBP anymore as conflicts arise due to secondary reasons	Higher costs for MBP Lower producti on	Low	Medium	8	MBP should review and revise their contracts with local farmers to ensure fairness, clarity, and transparency.
Economic	Price of straw and associated costs gets higher due to inflation	Lower capacity production	Low	Medium	8	Project developer maintains good relations with farmers and keep providers close to production site (as local as possible).
Environmental	Extreme weather and fires make the amount of feedstock not to be delivered, and the amount of cc can be reversed.	Reduced revenue from decreased production capacity	Medium	High	3	Wood certification - Sustainable forest management.
Technical	Leakage process-competition with other sectors for the use of wood	Carbon shifting	Medium	High	3	Wood certification.
Administrative	Not applicable					

*Colors in the level of risk column correspond to the interactions between probability and severity as described in figure 1.

C5 - Unicity

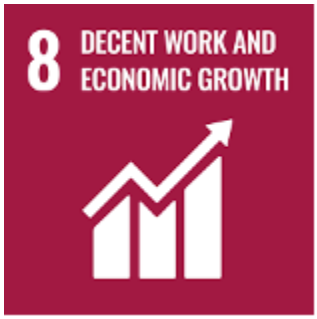
In order to ensure transparency, all pre-credits and credits are visible on the Riverse registry, which is accessible online along with all other project information. Therefore, carbon credits will be counted once as the recommendations by Bilan Carbone, GHG Protocol, or Net Zero Initiative.

Furthermore, Manufacture Bois Paille has committed not to issue or sell carbon credits through any other standard or registry during the contract validity period.

C6 - Co-benefits

The project is consistent with the following UN Sustainable Development Goals (SDGs):

Goal 8: "Decent Work and Economic Growth"



In particular, sub-goal 8.4 "**Improve global resource efficiency in consumption and production**". By choosing biobased materials for construction, this project embodies a circular economy and demonstrates efficient resource use by utilizing straw locally available. Furthermore, the end-of-life of the building can be either incinerated or recycled, creating energy through co-generation, or giving a second life to another use such as wood pellets. According to the association "Règles Professionnelles de la construction en Paille Remplissage isolant et support d'enduit (RFCP)", the straws from cereals are produced in all the regions in France and its supply will most likely not exceed 150 km. Therefore, straw can be found in short distances. There are approximately 20 million tons of wheat straw processed in France today, which can be used to construct around 5000 straw bale buildings. Therefore, the amount of straw needed is not a lot to reach high production. It would take only 10% of wheat straw produced annually to insulate all the new homes built in France every year[7].

The key impact factor for this goal would be to monitor the **quantity of straw utilized (tons) per m2 and multiplied it by the amount of wall installed per year (m2 /year)** throughout the certification period. The amount of straw utilized is **0,480 ton/m2** .

[7]DREAL. (2019). Les matériaux de construction BIOSOURCÉS & GÉOSOURCÉS. Extracted from https://www.hauts-de-france.developpement-durable.gouv.fr/IMG/pdf/2019_plaquette_nationale_materiaux_biosources_geosources_a5_8p.pdf

Calculations for these values can be seen in Manufacture BoisPaille - LCA - SDGs sheet.

Goal 9: "Industry, innovation, and infrastructure"[8]

Implementing Manufacture Bois Paille for buildings can help to achieve the specific subgoal 9.4: "**by 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action following their respective capabilities**". This happens because less material would be used to build new walls, which reduces the use of natural resources. Therefore, this is a greater adoption of clean and environmentally better technology compared to concrete walls. Straw has a low environmental impact and it is a byproduct of agricultural activity quite developed in the world[9].

The key performance indicator for this goal would be obtained by comparing the impact of the use of non-renewable resources associated with the production and consumption of fossil fuels, including coal, oil, and natural gas between the project and baseline scenario. For this, we would use the indicator impact of Abiotic Resource Depletion Potential of fossil fuels; ADPfossil fuels (MJ/ m2), which can also be expressed in terms of Energy Content of Fossil Fuel (MJ). This indicator evaluates the potential depletion of abiotic resources caused by the extraction and use of fossil fuels, expressed in megajoules (MJ). The ADPfossil fuels value provides an estimate of the potential depletion of abiotic resources caused by the extraction and utilization of these fossil fuel sources. A higher ADP fossil fuels value indicates a greater potential impact on abiotic resource depletion. **The reduction of the impact of fossil fuels on the utilization of non-living resources, measured in terms of energy units (megajoules - MJ), is 103 % compared to the baseline scenario.**

Calculations for these values can be seen in Manufacture BoisPaille - LCA - SDGs sheet.

[8] https://sdgs.un.org/goals/goal9

[9] Díaz Fuentes, C. X., Pérez Rojas, M. C., & Mancilla, J. J. (2020). Physical-thermal straw properties advantages in the design of a sustainable panel-type construction system to be used as an architectural dividing element. *Journal of Physics: Conference Series*, *1587*(1), 012032. https://doi.org/10.1088/1742-6596/1587/1/012032

Goal 2: Zero hunger[10]

Manufacture Bois Paille production is aligned with the subgoal 2.3: **Double the productivity and incomes of small-scale food producers.** This refers to double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, **family farmers**, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, **financial services, markets and opportunities for value addition and non-farm employment.**

Manufacture Bois Paille allows the production, processing, and distribution of local products. Therefore, obtaining biogenic sources like straw from local agriculture represents an additional source of income. For this, the KPI would be monitored by considering the price of straw per m2 (euros/m2). The estimated income is **6,6 euros/m2** in one year. Calculations can be seen in Manufacture Bois Paille - LCA - SDGs sheet.

C7 - Substitution

Manufacturing process developed and patented by Activ'Home allows producing a real replacement for concrete for any type of building. Manufacture Bois Paille's managers are trained in the professional rules of wood-straw construction validated by the 2P (Règles Professionnelles de la construction en Paille Remplissage isolant et support d'enduit") or, in English, ***"Professional Rules for Straw Construction, Insulating Filling, and Plaster Support"***; and the AQC. The compliance to these regulations attests to the technical qualities of materials (reaction to fire, durability, mechanical resistance, etc.) and guarantees the insurability of the buildings in which they are used.

Bio-sourced materials mixtures have **exceptional thermal properties**. In Table 2[11], we can see the density and conductivity of different materials used in construction. The low conductivity of straw represents good thermal insulation or a high heat insulating capacity, and it is better than traditional materials. Additionally, the thermal conductivity of a straw bale is lower than that of concrete (0.3-1.8 W/m.K), bricks (0.3-1.1 W/m.K), and wood

[10] https://www.un.org/sustainabledevelopment/hunger/

[11] Díaz Fuentes, C. X., Pérez Rojas, M. C., & Mancilla, J. J. (2020). Physical-thermal straw properties advantages in the design of a sustainable panel-type construction system to be used as an architectural dividing element. *Journal of Physics: Conference Series*, *1587*(1), 012032. https://doi.org/10.1088/1742-6596/1587/1/012032

(0.14-0.22 W/m.K)[12]. These characteristics allow us to determine **a better performance compared to common building materials**, since straw materials can control temperature and relative humidity variation to improve indoor comfort while emitting little embodied energy and CO_2[13].

Table 2. Physical-thermal properties of materials.

Material	Density (Kg/m^3)	Thermal Conductivity λ (W/mK)
Compressed soil wall	1.4	0.6
Compressed soil block	1.7	0.81
Adobe	1.2	0.46
Straw bales	60	0.067
Mass concrete with aggregates	2.4	1.63
Solid brick wall	1.8	0.87

Additionally, biobased construction materials play a crucial role in enhancing indoor air quality (IAQ) by contributing to healthier and cleaner air. These materials emit significantly lower levels of volatile organic compounds (VOCs), which are known to have adverse effects on air quality.

C8 - Environmental & social do no harm

The development and implementation of bio-based materials have certain ecological implications that should be taken into account. For example, ecosystem services provided by forests can be threatened. This means that ecosystem services such as reduction of erosion, water filtration, controlling floods, sustaining biodiversity and genetic resources, can be reduced when the provision of wood takes place[14].

[12] Tlaiji, G., Biwole, P., Ouldboukhitine, S., & Pennec, F. (2022). A Mini-Review on Straw Bale Construction. *Energies*, *15*(21), 7859. https://doi.org/10.3390/en15217859

[13] Tlaiji, G., Ouldboukhitine, S., Pennec, F., & Biwole, P. (2022). Thermal and mechanical behavior of straw-based construction: A review. *Construction and Building Materials*, *316*, 125915. https://doi.org/10.1016/j.conbuildmat.2021.125915

[14] USDA Forest Service. (2022). *Ecosystem Services | Climate Change Resource Center*. Retrieved March 16, 2023, from https://www.fs.usda.gov/ccrc/topics/ecosystem-services

To meet this criterion, Manufacture Bois Paille **ensures that 100 % of the wood used for the structure wood for the buildings is PEFC labeled.** The use of this certification ensures that the use of forests and forest land happens at a rate and in a way that preserves their biodiversity, productivity, capacity for regeneration, vitality, and potential to fulfill relevant ecological, economic, and social functions at local, national, and international scales while avoiding harm to other ecosystems.

The sourcing of materials is done as much as possible with local partners, especially for straw and wood. The process is purely mechanical and electrical, and therefore, produces very little waste and pollution. Furthermore, There is **no waste produced that needs special treatment**. Therefore, there is no risk for dangerous waste to be harmful to human health or the environment.

The REACH Regulation of the European Union[15] limits the amount of formaldehyde that can be released into the air by composite wood products sold in the EU, and it mandates that producers register their products and disclose details about their chemical make-up and any potential hazards to human health and the environment.

France has also set its own national laws. The French Decree n° 2011-321, for instance, establishes guidelines for the labeling and testing of composite wood products, including those that contain phenol-formaldehyde resin. According to the decree, producers must regularly test their goods to make sure they adhere to formaldehyde emission limitations and label them with a statement showing compliance. Manufacture Bois Paille **complies with these regulations and has minimized the risk of toxic chemicals to human health**.

C9 - Leakage

There is competition with other sectors for the use of wood for timber e.g. paper, packaging, and bio-energy production. This resource competition can lead to the expansion of land for wood production at the expense of native species, primary forestry, and other untouched places[16]. To mitigate this risk, ensure that the extraction of the raw materials used for the construction of the panels does not represent any competition with other sectors. This can be ensured since straw is a byproduct of agriculture harvesting[17]. Nowadays, 40 % of the

[15] *EU REACH*. (2023). International Trade Administration. Retrieved March 16, 2023, from https://www.trade.gov/eu-reach

[16] Ramage, M. H., Burridge, H., Busse-Wicher, M., Fereday, G., Reynolds, T., Shah, D. U., ... & Scherman, O. (2017). The wood from the trees: The use of timber in construction. *Renewable and Sustainable Energy Reviews*, *68*, 333-359.

[17] Vegetal(e). (2022). TOUTE LA CONSTRUCTION BIOSOURCEE. Le portail de la construction biosourcee. Extracted from http://www.vegetal-e.com/

straw available in France is not used; therefore, it can be inferred that there will be no competition for the use of straw, at least in the short and medium term. Considering that other types of straw can also be used if all the walls of new buildings built every year in France were insulated with straw, there would be a need to use less than 2 million tons, i.e. 10% of the production of wheat straw alone.

To mitigate this risk, **forest conservation is important**[18]. Therefore, **PEFC/FSC/other certification** plays a key role by ensuring that forest management activities maintain, conserve, and enhance biodiversity[19].

C10 - Rebound effects

Increased consumption

Identified risks:

- One possible outcome can be to increase the intensity of cultivation of certain species needed for wood or increase the land expansion for harvest. Therefore, part of the reduction in demand for concrete will be offset by higher demand for wood.
- Another outcome is under the same supposition. If the demand for wood increases, the intensity of cultivation can increase in areas further than the current areas where wood is supplied. Therefore, GHGs emissions from transportation may increase.

Approach:

- MBP approach to controlling the initial outcome centers around a careful consideration of the wood utilized for the project. The use of timber frame walls and floor panels used by Manufacture Bois Paille is **less material-intensive**. This happens because the insulation material comes from local sources compared to a wood panel that contains 100 % of wood.
- One approach is to monitor the distances between the supply of the wood and the manufacturing site, which is in the LCI provided by MBP. Additionally, in case the distance covered by the transportation of wood becomes significant, MBP considers acquiring or setting up new production facilities at a location as close as possible to customers is necessary. It is in fact already

[18] Verena Göswein;Jana Reichmann;Guillaume Habert;Francesco Pittau; (2021). *Land availability in Europe for a radical shift toward bio-based construction . Sustainable Cities and Society, (), –.* doi:10.1016/j.scs.2021.102929

[19] PEFC international (2022). *Our approach - PEFC - Programme for the Endorsement of Forest Certification.* (n.d.). Retrieved March 16, 2023, from https://pefc.org/what-we-do/our-approach

the approach used by Activ'Home partnering with MBP to address needs in Auvergne Rhone Alpes in France.

C11 - TRL

Manufacture Bois Paille building construction is at **TRL9** (Technology Readiness Level 9) meaning it has been used in commercial, operational, real-world applications. TRL9-level technologies are considered widely used and reliable. Last year, MBP had a production capacity of 6690 m2. However, the company has made significant progress, and its current maximum production capacity (at full) is set to 30 000 m2 per year. This growth highlights the company's commitment to expanding its operations.

C12 - Targets Alignment

The comparative analysis shows a CO2 saving of 56% for type A structural wall, which is the most commonly produced by MBP. This is higher than the 45% required by the Riverse Standard Rules for the construction and housing sector.

C13 - Minimum impact

According to the LCA results, Manufacture Bois Paille has a net removal capacity of 93,16kgCO2eq/m2 **of type A panels** built and **64.76 kgCO2eq/m2 of type B panels.** Therefore, Manufacture Bois Paille would have to construct approximately 11000 m2 of space/building over the 5 year crediting period to reach Riverse Standard's requirement of 1000 TCO2eq. In 2022 Manufacture Bois Paille production was 6690 m2, and the production is planned to ramp up over the coming years, therefore the minimum requirement is assured.

Life Cycle Assessment

The LCA presented considers a static LCA for the overall emissions. A static baseline emission rate is more appropriate for GHG projects that are substituting for existing plants or technologies, like the construction sector. Bio-based construction stores/removes carbon by capturing CO2 from the atmosphere during photosynthesis and retaining it within the bio-based material for a number of years[20]. Carbon storage benefits are

[20] Pawelzik, P.; Carus, M.; Hotchkiss, J.; Narayan, R.; Selke, S.; Wellisch, M.; Weiss, M.; Wicke, B.; Patel, M.K. (2013). *Critical aspects in the life cycle assessment (LCA) of bio-based materials – Reviewing methodologies and deriving recommendations. Resources, Conservation and Recycling, 73(), 211–228.* doi:10.1016/j.resconrec.2013.02.006

accounted for because it delays radiative forcing and can offset current anthropogenic carbon emissions[21]. In this study, biogenic carbon removals were considered when materials' lifespans were longer than 50 years.

For the assessment of the life cycle impact of biobased materials, we focus on a *cradle-to-grave* analysis[22]. The scope of the assessment focuses on the construction materials, as opposed to their integration into a building. Therefore, energy, construction, and water use during the use-stage of the building is not taken into account. However, the use stage of the material itself is considered, which includes processes such as repair and replacement.

The life cycle of materials produced by Manufacture Bois Paille in both scenarios is structured into four distinct phases. The first phase (A1-A5) encompasses the entire process from raw material acquisition to completed construction. The second phase involves the use of the materials, which can include repairment, refurbishment, and meeting electricity and heat needs during the service life (B1-B6). However, this LCA only focuses on the use aspects (B1). This selection is based on Riverse's methodology for biobased construction materials, which specifically addresses emissions related to material production and end-of-life, rather than indirect effects on building energy efficiency. The third phase relates to the demolition and waste treatment (C), excluding the impact of deconstruction sites, furniture, and electro-mechanical equipment. Finally, the fourth phase (D) considers the additional benefits beyond the direct life cycle, such as savings derived from waste treatment, like energy/heat from incineration or secondary products obtained through recycling (refer to Figure 1).

[21]GHGP. Product life accounting and reporting standard. GHGP – The Greenhouse Gas Protocol World Resources Institute & World Business Council for Sustainable Development. Extracted from: https://ghgprotocol.org/sites/default/files/standards/Product-Life-Cycle-Accounting-Reporting-Standard_041613.pdf

[22] Not exclusively. The project itself can change this scope.

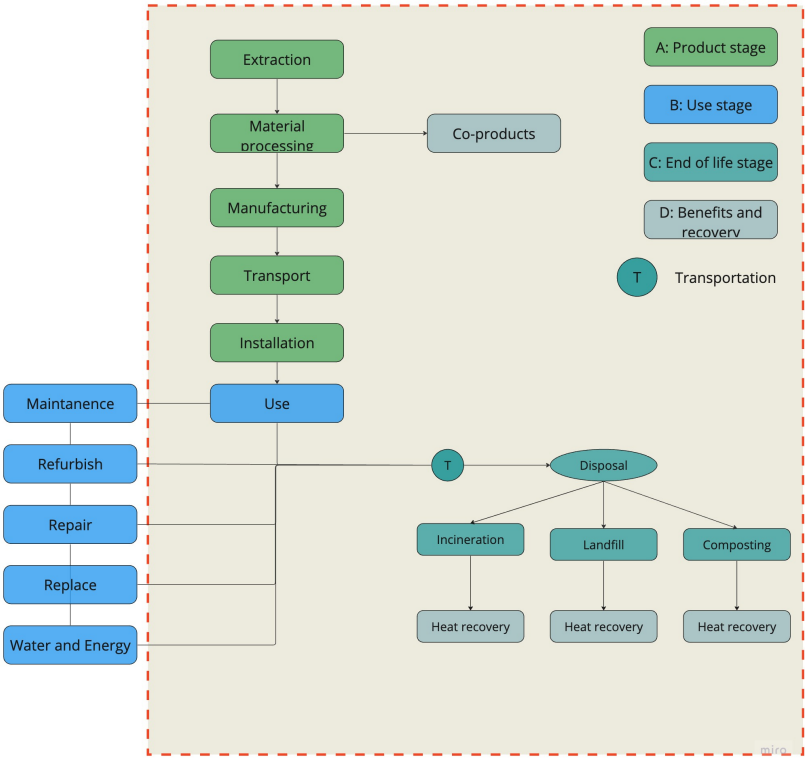


Figure 1. System boundaries for project and baseline scenario

Functional unit

The main function of this system is to provide a place for residents to live, described as a reference surface. Therefore, the functional unit is 1 m2 of load-bearing wall with an insulation thermal value of at least R=5 m^2.kW for a reference time of 100 years.

The insulation made out of straw has a dimension of 37 cm x 47 cm x L (Variable length between 80 and 120 cm).

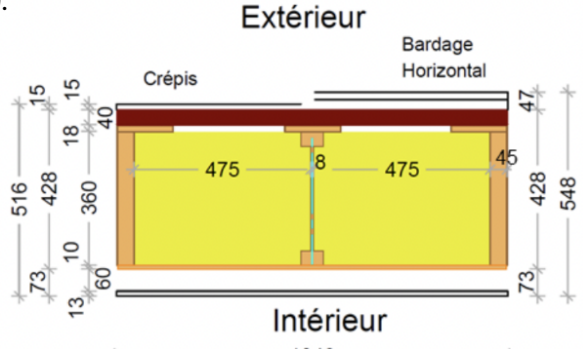


Figure 2. Dimensions of straw

System Boundary

The scope of the LCA is a *cradle-to-grave* assessment, and it takes into account all stages of the life cycle, from production, to use and waste treatment collection which includes demolition, and the phase of benefits beyond life cycle which involves heat recovery through incineration. More specifically, the manufacturing of building components, the construction site and removal of solids, the maintenance of the building, and the deconstruction or demolition of the building were included. The life cycle stages included and excluded from the LCA are detailed in Table 2.

Table 2. Description of the system boundary for both scenarios

Product stage - Phase 1			Comments
A1	Raw material supply	✓	Manufacture of building components
A2	Transportation	✓	
A3	Manufacture	✓	
Construction stage - Phase 2			
A4	Transport post-production	✓	
A5	Construction installation process	✓	
Use stage- Phase 3			
B1	Use	✓	Building use and maintenance
B2	Maintenance	✓	Building use and maintenance
B3	Repair	X	No information in database
B4	Replacement	✓	
B5	Refurbishment	X	No information in database
B6	Operational energy use	X	Not relevant
B7	Operational water use	X	Not relevant

End of life stage- Phase 4			
C1	De-construction / dissembling	✓	Deconstruction or demolition of the building
C2	Transport	✓	
C3	Waste processing	✓	
C4	Disposal	✓	
Benefits - Phase 5			Modular wood considered to be incinerated as well as some components for the baseline

Description: "X' = not considered in the study ✓ = considered in the study
A1-A5 happens within the first year, B extends for 50 years, and C & D only happen after 50 years.

Assumptions

The environmental data needed for the environmental assessment were collected in the INIES database and are freely available. This database presents the emissions coming from each material used for the construction of the wood frame wall prefabricated by Manufacture Bois Paille. INIES database helped us to obtain the emission factors, material biogenic carbon embedded (Kg C), and the lifetime of materials. To transform the kilograms of carbon stored to kilograms of CO2eq emissions, the carbon stored is multiplied by 3.67 (molecular mass of CO2 of 44.01 g/mol divided by mass of C of 12.011 g/mol).

The emissions are expressed in terms of kg CO2 eq/FU. Additionally, emissions were expressed for the lifetime of each material. Therefore, for calculating the total emissions, a normalization was done considering the 100 years over which the product would have been used. Final calculations were made using the following equation:

Baseline Scenario

Nowadays, wood construction accounts 11 % in European union[23], showing a positive trend for substituting conventional materials such as concrete and steel. In 2021, the building sector consumed 63% of cement in France[24]. Therefore, it can be concluded that concrete still represents a big market share for materials in construction.

The baseline scenario consists in the mixture between two different structures. Precast concrete[25] refers to concrete pieces produced in a controlled setting, such as a factory or specialized precast facility. Based on the project specifications, these pieces are cast into specified forms, sizes, and patterns. Walls, slabs, beams, columns, and other structural parts are examples of precast concrete components. They are normally made with molds or formwork and may be modified with different finishes, textures, and reinforcements. On the other hand, concrete blocks, also known as concrete masonry units (CMUs), are commonly used building blocks made of concrete. They are manufactured in large quantities in a factory or production facility and are available in standard sizes and shapes. Concrete blocks are primarily used for constructing walls, either load-bearing or non-load-bearing, in residential, commercial, and industrial buildings. Therefore, the baseline scenario corresponds to a mixture between:

- 50% “complex 1”: 20 cm precast concrete + extruded polystyrene insulation
- 50% “complex 2”: Concrete block + extruded polystyrene insulation

The assessment of the base scenario is based on the FDES available in the INIES database.

Project Scenario

A wood frame wall prefabricated by Manufacture Bois Paille has an area of 8.94 m2. To compare the impact to the basic scenario, the measurements have been reduced to m2.

[23] https://afry.com/en/insight/concrete-alternatives
[24]https://finance-climact.eu/wp-content/uploads/2021/06/synthesis-stp-cement-first-results-2021.pdf
[25] Hong, W.-K. (2020). Conventional precast assembly. In *Hybrid Composite Precast Systems* (pp. 1–14). Elsevier. https://doi.org/10.1016/B978-0-08-102721-9.00001-7

The project scenario involves the production of a wall (1 m2) with a wooden frame and straw insulation by Manufacture Bois Paille. This project encompasses two distinct structural wall types, namely type A and type B, which are both manufactured and sold by Manufacture Bois Paille. In 2022, only type A panels were built and considered in the net removal evaluation. The main difference between both types of structural walls is the type of wood incorporated. Type A includes Solid wood type, whereas type B utilizes Glue laminated wood type.

Results

The main modular wooden frame developed by Manufacture Bois Paille (type A) emits 153 kg of CO2 eq /m2 and stores 147kgCO2, impacting in a net removal capacity of 93,16kgCO2/m2 considering the baseline that emits 98kgCO2e/m2. This sequestration horizon of 100 years falls into Riverse's category of "long-term carbon removal".

The life cycle of type B panels, emits 270kgCO2e/m2 and stores 236kgCO2/m2, impacting in a net removal capacity of 64,76kgCO2e/m2.

In the case of materials made out of concrete, the vast majority of the impact of the building materials' life cycle comes from cement production. Cement is produced by the combustion of large amounts of limestone (CaCO3) in cement manufacturing plants[26]. 90% of Greenhouse gas (GHG) emission is due to the extraction of raw materials for concrete preparation, cement production, mixing, placing, and transportation of concrete and its constituent materials.

According to the LCA results, the cradle-to-grave emissions from the project are slightly higher than the baseline, so no Avoidance Credits are issued (Table 3). However, the project has large carbon removals, which are subtracted from the total emissions, resulting in net reduced emissions for the project scenario.

[26] Jang, J.G.; Kim, G.M.; Kim, H.J.; Lee, H.K. (2016). *Review on recent advances in CO2 utilization and sequestration technologies in cement-based materials. Construction and Building Materials, 127(), 762–773.* doi:10.1016/j.conbuildmat.2016.10.017

Table 3. Comparison of emissions (Kg CO2 eq/m2) between project and baseline scenario

Phase	Project- type A	Project- type B	Baseline
A1-A3 with add. biogenic carbon >50y	24,4	57,4	83,7
A4-A5	10,1	15,4	17,8
B	0,0	0,0	-3,5
C	133,5	217,8	1,2
D	-15,4	-20,9	-1,2
Emissions (kg CO2 eq)	**152,6**	**269,7**	**98,1**
Biogenic carbon w/ lifetime <100y	-93,4	-185,3	0,0
Biogenic carbon w/ lifetime >=100y	-54,2	-51,0	0,0
Biogenic carbon counted as removals (kg CO2 eq)	**-147,6**	**-236,3**	**0,0**
Total emissions (Kg CO2 eq)	4,9	33,3	98,1
Total removal (Kg CO2 eq)	93,2	64,8	
% of reduction	93,1	64,1	-

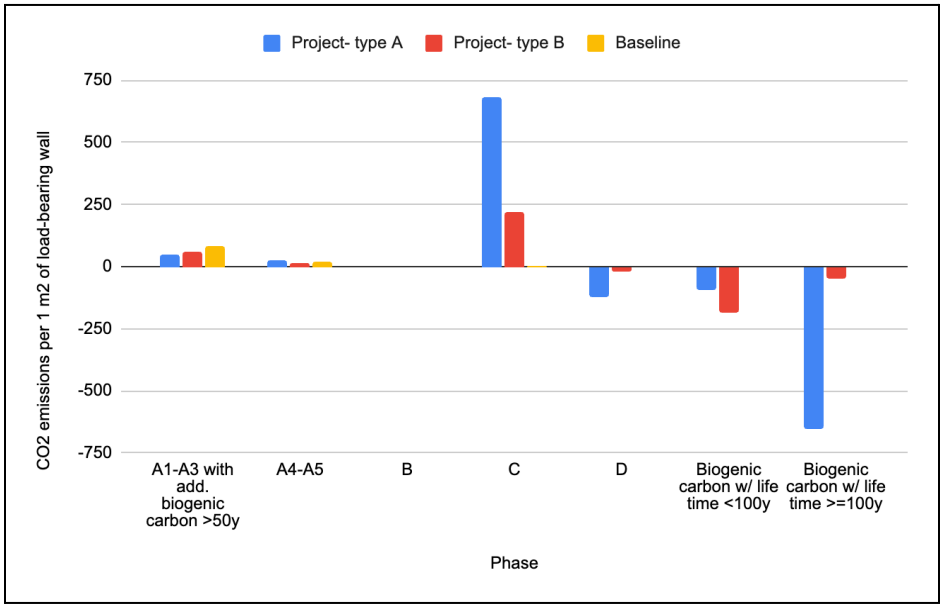


Figure 2. Comparison of emissions between Manufacture Bois Paille and Concrete loading wall (m2) per stage

Monitoring plan

This part describes the list of audited KPIs per criteria, and the according documents to justify this impact over time.

Every issuance of carbon credits needs to be justified by a verification report following this monitoring plan.

This monitoring plan is audited and validated by the 3rd-party auditor during the certification process.

Criteria	KPI	Sources
C2 - Real	Volume of construction panels delivered (in m2)	Building/Delivery certificates of each construction Consolidated list of constructions
C2 - Real	PEFC/other certification of sustainable forestry used per building	List of providers of wooden structure
C6 - Co-benefits	SDG8: Volume of straw valorized per year	Volume of construction panels delivered (in m2)
C6 - Co-benefits	SDG 2: Total income generated for farmer	Volume of production and price of straw
C6 - Co-benefits	SDG 9: Variation of abiotic Resource utilization potential of fossil fuels; ADPfossil fuels (MJ/ m2) between project and baseline scenario..	Consolidated list of constructions Certified Accounting documents

Documents list, definition, origin and update:

Document	Definition and content	Origine and update frequency
Consolidated production	Consolidated production of precast wall in (m2)	Annual, from project developer
Certified sustainable wood	List of providers of biobased materials with PEFC levels	Annual, from project developer
Certified Accounting documents	Certified accounting document enabling to cross-check production volume	Annual, from project developer