WP4 Deriverable 4.2.1 Report on carbon stock in the IMIP modules

Quantification of the carbon sink and substitution effect

IMIP-SOE3/P3/E0963
Project funded by the Interreg Sudoe programme through the European Regional Development Funds (ERDF)

PROJECT CONTEXT

Project acronym	IMIP
Project title	Innovative Eco-Construction System Based on Interlocking Modular Insulation Wood & Cork-Based Panels
Project code	SOE3/P3/E0963
Coordinator	Universitat Politècnica de València (UPV), Instituto ITACA
Duration	1 May 2020 – 31 January 2023 (33 months)
Working Package (WP)	WP.4
Deliverable	TD 4.2.1
Summary	Report on carbon stock in the modules
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WP Leader	UPV
Activity coordinator	UPV
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Project funded by the Interreg Sudoe programme through the European Regional Development Funds (ERDF)

CONTENT

FOREWORD

Quantification of the carbon sink and substitution effect

The work is contemplated in the IMIP project of the INTERREG SUDOE Program, within Working Group 4: (GT4 Environmental assessment: ICT integration and climate change mitigation evaluation). The IMIP project focus on the development of modules and construction systems to be used in rehabilitation and new construction.

This report develops the delivery 4.2.1 that is the “Quantification of the carbon sink and substitution effect”.

The main objective of the deliverable is to understand the real state in this project related to the carbon dioxide (CO_2) emissions and carbon sink to show the triple balance / triple bottom line in the products systems of the developed IMIP wood-based construction systems, based from primary renewable materials such as wood and cork and their characteristics, in order to get the better quality materials in an sustainable development in the SUDOE area (Portugal, France, Spain).

Table 1: Programme and Project objectives and results.

Programme specific objective	To improve energy efficiency policies in public buildings and homes through the implementation of networks and joint experimentation.
Project main objective	To support the change towards a low carbon economy using bioproducts (wood and cork) for smart, sustainable, and inclusive growth with a special focus on the public construction sector.
Project specific objectives	To design, validate and implement a new ecological construction system to improve energy efficiency in public buildings. Related activities are: - To design an ecological construction system based on innovative wood and cork products supporting a low carbon economy, - To test prototypes, - To develop an Information and Communication Technology for design, modelling, and evaluation of potential construction solutions, - To compare the modular and interconnected insulating panels designed with currently used insulating panels, - To disseminate results and to train prescribers.
Programme result indicator	Percentage of actors in the energy efficiency sector participating in transnational cooperation projects.
Project results	An interconnected modular system of insulating panels made of wood and cork to improve energy efficiency of buildings, including their entire life cycle. A BIM plug-in to analyse the environmental benefits of bioproducts used in construction (carbon storage and substitute effect).

OBJETIVES

The specific objective of the deliverable D4.2.1 is to design, manufacture, install and maintain the IMIP construction products and systems with a minimum environmental impact, but with and a standard guarantee and quality, taking advantage of the high environmental quality of wood as a sustainable natural material, specifically taking into account its capacity to act as a carbon sink in sustainable construction.

Thus, the operative objective of this deliverable is to determinate the quantification of the carbon sink and substitution effect of the IMIP wood-based products and systems, applying the calculation of the biogenic carbon content of wood and the conversion to CO_2.

PARTNERS

ASSOCIATED PARTNERS

INTRODUCTION

CARBON STOCK

Carbon sinks refer to the increase in carbon stored in certain ecosystems, as a consequence of certain activities in the land use sector, land use change and forestry.

All removals or emissions derived from mandatory activities and those activities voluntarily chosen by the countries, will be subtracted (if they are sinks) or added (if they are sources) to the emissions of the rest of the sectors, and will contribute, as the variations of emissions of any other diffuse sector, to compliance or non-compliance with the objectives of reduction or limitation of emissions acquired in the scope of the Kyoto Protocol.

WOOD AS A CARBON STORE

Wood is a renewable raw material derived from sustainable forest management. It grows with increasing abundance in Europe, especially in the SUDOE area, where the forest area is increasing since decades and a large amount of forests have a sustainable forest management plan.

The wood sector in the SUDOE area is improving its activity in terms of sustainability, especially in the better integration of the forestry-wood chain and the circular bioeconomy by optimizing all resources including waste recovering and recycling, acting as an example of cascade use of the resources.

Additionally, architects, designers and final consumers in construction very well accept wood because it is beautiful, light and strong for construction, warm and cozy for everyday use.

Finally, wood-based construction offers a simple way to reduce carbon dioxide (CO_2) emissions, which are the main cause of Climate Change, through:

- the carbon sink effect of forests;
- the carbon storage effect of wood products;
- their replacement by carbon-intensive materials (steel, concrete, aluminum and plastics), which consume significant amounts of carbon in their production (see Fig.1).

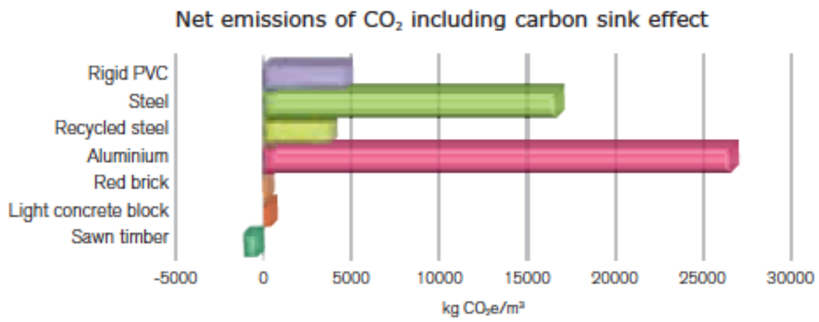

Fig. 1. A comparison of the CO_2 production of different materials (net CO_2 emissions including carbon sink effect) (RTS 2002)

Forests, wood and climate

Sustainably managed forests in the SUDOE area offer a very interesting source of raw material with huge opportunities. Growing trees store CO_2 from the air, and this remains in wood products throughout their life span. One cubic metre of wood absorbs about one tonne of CO_2. The use of wood precipitates forest renewal. Growing forests bind more carbon than old-grown forests. Sustainable forest management act as a tool to regenerate old forests in order to enable the persistence of the future ecosystem generations. Additionally, sustainable forest management in the SUDOE area has a key importance to prevent against wildfire risk, the most importance environmental disturbance in our region. The wood sector is a key industrial sector in Europe to tackle climate change, following the challenges of the EU Green Deal and all derived mitigation and adaptation policies at European, national and regional level. So, wood processing also provides opportunities to mitigate GHG emissions. The consumption of energy and natural resources and CO_2 emissions caused by the manufacture of wood products are significantly lower than in manufacturing and using other materials. In fact, in the production of sawn and planed products for construction, more energy is created (storage effect) than consumed (energy consumption in manufacturing and logistic processes). Wood is a carbon store as it sequesters CO_2 from the air as it grows. Wood can be used to replace materials whose manufacture is harmful to the environment. At the end of their life cycle, wood products can be used to produce renewable energy and so replace fossil fuels. The amount of CO_2 released when burning wood is equal to the amount that it has sequestered during its growth. Neither wood nor the products produced from its elements generate problems with waste, due to the well established recovering and recycling processes in the SUDOE region. Wood is a renewable material.

Managed forests

Left entirely to nature, forests will achieve a climax stage, where the site is supporting the maximum amount of biomass that the soil fertility, rainfall and temperature conditions will allow. At this point the forest only grows as trees fall from age, wind, landslip, disease or fire.

Although natural regeneration will occur, the dead and dying trees will decay or burn, emitting CO_2 from the stored carbon. Growth is matched by decay and, with no forest management; there is no net increase in carbon storage. Harvesting trees as they mature allows much of their carbon to be stored throughout the life of the resulting wood products, while at the same time giving the industry an incentive to plant new trees in their place.

With the Kyoto Protocol in 2005 and following COP negotiations, the forest sector is receiving credit for managing this specific environmental quality of the forest, while the development and trade of carbon emission credits enhances the significance of the forest sector within the global economy.

Reforestation

The European forest-based industry recognizes that its future inextricably linked to the protection and expansion of its forests. This, coupled with strong and effectively enforced laws, ensures more trees are planted or natural regenerated than are harvested.

All European countries have policies and practices requiring reforestation. Spain, Portugal and France are good examples for this. Although the number of trees planted or natural regenerated per hectare will vary depending upon the species, site and management system, it will always be more than the number cut, in order to allow for natural losses and for the forest to be well stocked. Therefore the need be no confusion between deforestation in tropical regions - e.g. due to poverty or forest conversion for agricultural purposes - and sustainable forest management practices in the SUDOE area, strong controlled by national and regional legislation.

In average, nowadays only 64% of the annual increment of European forests is harvested. This harvesting rate is even lower in the SUDOE area, especially in the Mediterranean part, where it decreases to less than 20%. So, there is a potential maneuver to mobilise more wood in our forests, maintaining the sustainability principle in forest management and orienting the sylvicultural treatments and derived harvesting to actively prevent against wild fires but also to guarantee the natural regeneration of large unmanaged areas to enhance the natural regeneration of the future ecosystems.

WOOD PRODUCT PRODUCTION PRODUCES MORE ENERGY THAN IT CONSUMES

CARBON IS BOUND IN WOOD

In buildings with wooden elements, the carbon stored in the wood is stored as long-term carbon stores. In average, a single-family wooden house sequesters into its wooden structures about 30 tons of CO_2 (Frühwald et al. 2003). This is equivalent to the CO_2 emitted by the driving of an average car over a ten-year period. Carbon can remain bound in such structures for hundreds of years.

The manufacture of wooden products generates comparatively few CO_2 emissions, due to the efficient manufacturing and logistic processes, in comparison to other building materials like steel, aluminum, concrete or plastics. The amount of CO_2 stored in wood is much more than the emissions caused by the manufacture and logistics of wood products. When, at the end of their life (including recovering and recycling loops), wood products are converted to energy, they do not release into the atmosphere more CO_2 than they stored while the wood they are made of was growing.

The use of wood also reduces CO_2 emissions, as wood products replace products whose manufacture causes CO_2 emissions. When replacing other products (steel, concrete, bricks, aluminum, plastics) with wood, the effect of reducing CO_2 emissions is often greater than the mere carbon-storing effect of the wood. This is because of the wood's lightness (excellent relationship between weight and mechanical performance) and the fact that it often replaces materials that are considerably heavier than it and cause more emissions, e.g. in the logistic processes (including prefabrication) (see Fig. 2). Prefabrication of wood-based building components in factories means that construction sites can be made more efficient and produce less waste, as the components only need to be assembled on site. This leads to a reduction in energy consumption for transport and in the amount of waste generated (Koppelhuber and Bock 2019).

When a wall covering 1 m^2 is built of wood, a CO_2 store of about 52 kg is created. If a wooden wall replaces a similar concrete wall, CO_2 emissions of about 100 kg caused by the manufacture of the concrete wall are also avoided.

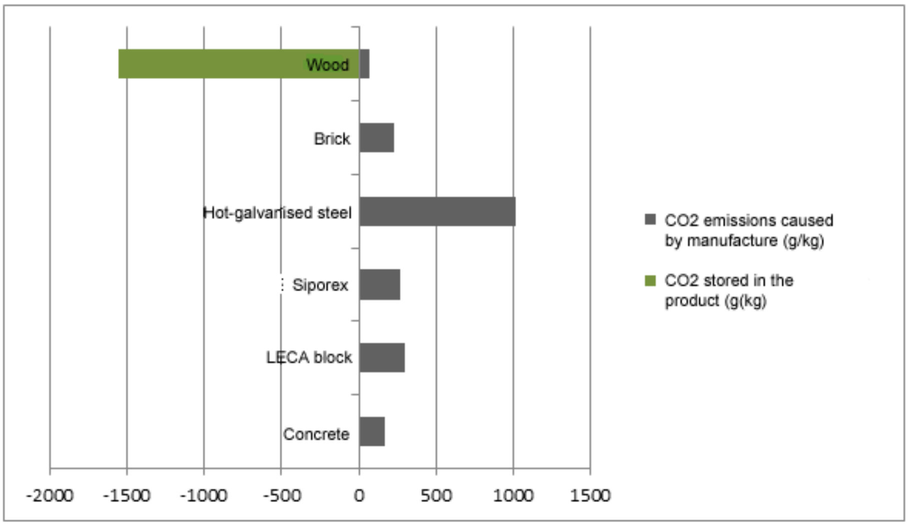

Fig. 2. CO2 emissions caused by the manufacture of different building materials (Source: Building Information Group RT environmental reports).

The recycling economy depends on renewable materials: wood is the better example for a circular bioeconomy

A change is taking place in industry towards utilizing renewable natural resources and renewable energy. This is being expedited by the decline in oil resources and other non-renewable natural resources as well as by climate change. It is not possible to satisfy mankind's growing need for energy and materials with non-renewable raw materials. We are heading for an unavoidable crisis in energy and resources.

The increase in the use of renewable building materials in modern zero-energy construction is a major challenge in slowing down climate change. In a comparison of the results of 19 international studies, it can be seen that the carbon footprint of a wood-framed building will always be smaller than the carbon footprint of a concrete or steel-framed building, however the emissions are calculated. The carbon footprint produced by the manufacture of a wooden building frame was, on average, 55% of that of the control frame. Many studies also show the major impact of foundations and ground-works. A low-carbon building is easier to construct as a timber-framed building and located preferably on a site where piling or stabilization is not required. Constructing low-carbon buildings in the future will be goal-oriented teamwork with a dream-team consisting of planner, client, designer, building inspector and building contractor.

If the EU is involved there are going to be standards

Guidelines for calculating the environmental impacts of European buildings can be found in several EN Standards. These set out mutually agreed rules on e.g. calculating carbon footprint and other environmental impacts in an impartial, comparable, scientifically based manner. These standards also describe a way of drawing up environmental declarations for building products. Environmental declarations are the most reliable way for architects, designers, clients and consumers to compare the ecological aspects of alternative products.

Wood building has been at the forefront while the standards were being set. The first product group environmental declarations to be drawn up (EN 16485) were for wood-based building products. The guidelines make it easier for companies to draw up environmental declarations and aim to clarify different interpretations of the Standards.

The carbon footprint of block of flat during the life-cycle

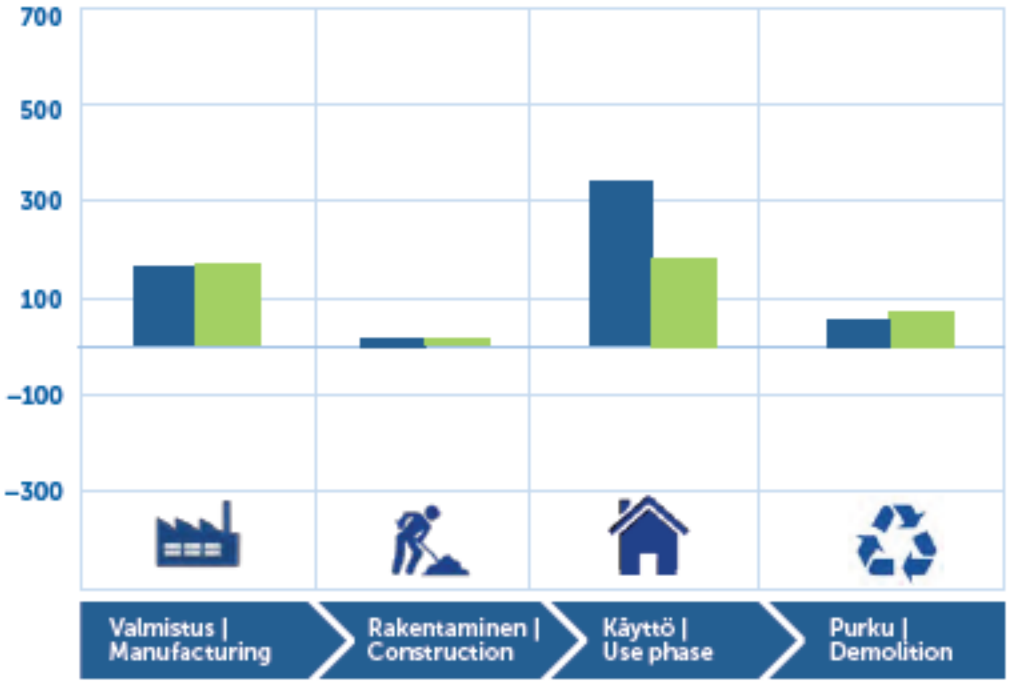

Fig. 3. Carbon footprint in the building phases. Source: Dodoo et. al. (2013).

As can be seen ion Fig. 3, the carbon footprint of a building is made up largely of energy consumption during use (blue column). When we switch to the use of passive buildings, the carbon footprint is reduced and the proportion of emissions at the manufacturing stage increases (green column). Taking into account the relationship between carbon footprint and building costs for wall construction, the carbon footprint is generated by adding together the emissions produced during the manufacture of the material. The costs consist of those for materials and those for work. The U-values of the constructions being compared are the same.

EU vision for the future: wooden construction for CO_2 reduction in the building sector

The construction sector is a major contributor to greenhouse gas emissions in the SUDOE area of Europe, and thus an important factor in terms of damage to the climate. The emissions come mainly from the use of fossil fuels for the production of heat and electricity in buildings, and from the production of building materials. There is a real need for measures to reduce greenhouse gas emissions in the construction sector, e.g. by using renewable energies, improving the energy performance of buildings, and using sustainable building materials (Lotz et al. 2023).

The European Union stresses that the use of wood as a building material presents a great opportunity, as it is a sustainable and cost-effective alternative and complement to traditional building materials such as concrete and steel (ESSC 2023). Another advantage is the high labour productivity of timber construction, which allows for faster and more efficient construction of buildings. The possibility of prefabricating components in factories also reduces costs and increases safety during construction.

In the SUDOE area, in order to increase the importance of sustainably produced wood as a building material in the construction industry, the need for sustainable forest management for the production of wood as a raw material should be emphasised. Sustainable forest management involves managing and using forests in such a way that they are not only environmentally, but also economically and socially, sustainable. This means that forests are preserved for both current and future generations, and that natural resources are used responsibly. One important element of sustainable forest management is preserving forests' biodiversity and ecosystem services. It is also important to reduce forests' vulnerability to natural disruptions, such as forest fires.

Wood-based construction opens significant opportunities for SMEs, but also for architects, designers, engineers and workers, especially in rural areas, in the development of the timber construction sector. Good jobs in the wood industry and timber construction can help to improve the economic situation in rural areas where the wood industry plays an important role. Education, training and lifelong learning of the workforce in the field of timber construction is more important than ever. Education and training must be the result of social dialogue with the involvement of all social partners.

Timber construction can make an important contribution to developing a more circular economy and in particular to the objective of a more bio-based economy in the SUDOE area, as set out in the relevant EU policies. The applications and material properties of wood and wood-based products need to be further developed in this regard. In particular, the recyclability of wood products plays an essential role in this connection, but combinations of wood with other materials will also become increasingly important. Action, coordinated and supported at SUDOE level, to promote research cooperation in the fields of material properties and composite materials can play an important role here and stimulate innovation, as has beed done in the frame of the IMIP project.

Several EU policies (EU Green Deal, Bioeconomy Directive, EU Forest Strategy 2030) underline the many environmental benefits of timber construction, also to be applied not only in central and Northern Europe, but also in the SUDOE region. One of the biggest advantages is that wood is a renewable raw material that produces lower carbon emissions than other building materials in the production of components and buildings, and over their life cycle. Furthermore, the use of wood in the construction sector promotes the conservation and maintenance of forests, by providing incentives for sustainable forest management. Wood absorbs and stores CO_2 from the atmosphere as it grows. Thus, when it is used for building, it becomes a green building material and contributes to the overall reduction in greenhouse gases.

Principles and methodology

Principles: Life Cycle Analysis and Carbon Footprint Analysis

Climate destabilization due to human activity has been identified as one of the greatest challenges facing our society, with major implications for social, biological, and technological systems (IPCC 2007).

I response, diverse initiatives are being developed and implemented at the local, national, and international levels to limit the amount of greenhouse gases (GHG) in the Earth's atmosphere. These initiatives rely on the assessment, monitoring, reporting and verification of GHG emissions and removals. To ensure that actions are effective at mitigating climate change, the accounting of GHG flows associated with products and materials should be done in a life cycle perspective. In other words, the analysis should consider all inputs (e.g. energy, materials) and outputs (e.g. emissions, waste, co-products) for each stage of processing, from extraction or regeneration through ultimate use, maintenance and disposal.

There are several distinct temporal stages in the life cycle of a building. These include the extraction of raw materials; the processing of raw materials into prepared building materials; the assembly of diverse materials into a ready building; the occupation or use of the building; maintenance of the building; and the demolition of the building and the disposal or re-use of the demolition material. Transport of materials may be involved in all stages.

Life Cycle Assessment (LCA) is an analytical framework for determining the environmental impacts resulting from processes, services and products and may be used to analyse climate impact of buildings. All life cycle stages (see Fig. 4) need to be included in a full LCA.

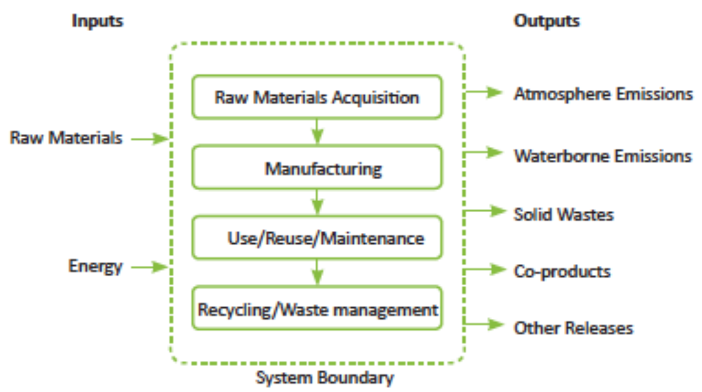

Fig. 4. Schematic diagram of life cycle stages, inputs and outputs Source: Dodoo et. al. (2013).

A formal LCA analysis includes four phases (ISO 2006). Goal and scope definition describes the purpose of the study, the system boundaries of the analysis, and the functional unit used for assessment and comparison. Inventory assessment quantifies the inputs and outputs of mass and energy attributable to processes occurring within the system boundaries. Impact assessment characterizes the effects of these inputs and outputs considering resource depletion, human health, ecosystem quality, and climate change. Interpretation of the inventory and impact assessment results seeks to identify significant conclusions, recommendations and implications for decision-making. Carbon footprint analysis is a related discipline focused exclusively on Global Warming Potential (GWP), an LCA impact category measured by the climate change potential of GHG emissions in units of CO2 equivalent.

Calculation methodology

Taking into account the methodology exposed, this deliverable summarizes the results of the calculation of the biogenic carbon content of wood and conversion to CO2 for each panel type and for each pilot action developed in the SUDOE IMIP project. The calculation methodology is based on the formula of the standard NBN EN 16449 (2014). This methodology allows calculating how much kgCO2 is stored in the wood of the products (panels and buildings). We can show that IMIP wood-based building materials have a very positive carbon footprint.

To reach the final result, the formula from the NBN EN 16449 has been applied divided in two main parts:

1. IMIP panels
2. IMIP pilot projects

So, the formula has been implemented in each part separately.

Formula

$$P_{co2} = \frac{44}{12}\ x\ cf\ x\ \frac{P\omega\ x\ V\omega}{1+\frac{\omega}{100}}$$

- P_{co2} is the biogenic carbon oxidized as CO_2 emission from the product system into the atmosphere (e.g. energy use at the end-of-life) (kg).
- 44/12 is the ratio between the molecular mass of CO_2 and C molecules.
- Cf is the carbon fraction of woody biomass (oven dry mass) 0.5 as the default value.
- ω is the moisture content of the product (e.g. 12%).
- $P\omega$ is the density of woody biomass of the product at that moisture content(kg/m^3).
- $V\omega$ is the volume of the solid wood product at that moisture content(m^3).

For wood-based products, wood volume content $V\omega$ = VP * percentage of wood
VP is the gross volume of the wood-based product.

Calculations and results

Following tables show the main results obtained for the panels and for the pilot action of IMIP.

IMIP Panels Types

PANEL A

Layer	Dimensions*			total m³	Density value kg/m³	Moisture	Layers	Pco2 (kg CO2)
	length	width	thickness					
Ribs	6000	200	60	0,072	500	12	4	22.392,86
Cork	6000	1200	200	1,44	500	12	1	111.964,29
CLT	6000	1200	60	0,432	500	12	1	33.589,29
Totaal				**1,944**				**167.946,43**

PANEL B

Layer	Dimensions*			total m³	Density value kg/m³	Moisture	Layers	Pco2 (kg CO2)
	length	width	thickness					
Top CLT	1000	2000	45	0,09	500	12	1	6.997,77
Cork	1000	2000	100	0,2	500	12	1	15.550,60
Bottom CLT	1000	2000	45	0,09	500	12	1	6.997,77
Totaal				**0,38**				**29.546,13**

PANEL C

Layer	mensions*			total m³	Density value kg/m³	Moisture	Layers	Pco2 (kg CO2)
	length	width	thickness					
Top CLT	6000	1200	60	0,432	500	12	1	33.589,29
Cork	6000	1200	200	1,44	500	12	1	111.964,29
Ribs	6000	200	60	0,072	500	12	4	22.392,86
Bottom CLT	6000	1200	60	0,432	500	12	1	33.589,29
Totaal				**2,376**				**201.535,71**

PANEL D

Layer	mensions*			total m³	Density value kg/m³	Moisture	Layers	Pco2 (kg CO2)
	length	width	thickness					
CLT	1000	1000	1000	1	500	12	1	77.752,98
Cork	1000	1000	1000	1	500	12	1	77.752,98
Totaal				**2**				**155.506**

*units are given in mm.

1 Portugal Pilot Action; Total Construction Area: 8,75 m2

PORTUGAL PILOTN ACTION

PANEL C

Layer	mensions*			total m³	Density value kg/m³	Moisture '	Layers	Pco2 (kg CO2)
	length	width	thickness					
Top CLT	6000	1200	60	0,432	500	12	1	**33.589,29**
Cork	6000	1200	200	1,44	500	12	1	**111.964,29**
Ribs	6000	200	60	0,072	500	12	4	**22.392,86**
Bottom CLT	6000	1200	60	0,432	500	12	1	**33.589,29**
Totaal				**2,376**				**201.535,71**

1 U		TOTAL	201.535,71

PANEL B

Layer	Dimensions*			total m³	Density value kg/m³	Moisture '	Layers	Pco2 (kg CO2)
	length	width	thickness					
Top CLT	1000	2000	45	0,09	500	12	1	**6.997,77**
Cork	1000	2000	100	0,2	500	12	1	**15.550,60**
Bottom CLT	1000	2000	45	0,09	500	12	1	**6.997,77**
Totaal				**0,38**				**29.546,13**

3 U		TOTAL	88.638,39

PANEL D

Layer	mensions*			total m³	Density value kg/m³	Moisture '	Layers	Pco2 (kg CO2)
	length	width	thickness					
CLT	1000	1000	100	0,1	500	12	1	**7.775,30**
Cork	1000	1000	100	0,1	500	12	1	**7.775,30**
Totaal				**0,2**				**15.551**

AREA	28 M2	TOTAL	435.416,67

	Pco2 (kg CO2)
TOTA	**725.590,77**

2 Valencia Pilot Action; Total Construction Area: 36 m2

VALENCIA PILOTN ACTION

PANEL A

Layer	Dimensions*			total m³	Density value kg/m³	Moisture '	Layers	Pco2 (kg CO2)
	length	width	thickness					
Ribs	6000	200	60	0,072	500	12	4	**22.392,86**
Cork	6000	1200	200	1,44	500	12	1	**111.964,29**
CLT	6000	1200	60	0,432	500	12	1	**33.589,29**
Totaal				**1,944**				**167.946,43**

5	U	TOTAL	839.732,14

PANEL C

Layer	mensions*			total m³	Density value kg/m³	Moisture '	Layers	Pco2 (kg CO2)
	length	width	thickness					
Top CLT	6000	1200	60	0,432	500	12	1	**33.589,29**
Cork	6000	1200	200	1,44	500	12	1	**111.964,29**
Ribs	6000	200	60	0,072	500	12	4	**22.392,86**
Bottom CLT	6000	1200	60	0,432	500	12	1	**33.589,29**
Totaal				**2,376**				**201.535,71**

8	U	TOTAL	1.612.285,71

PANEL D

Layer	mensions*			total m³	Density value kg/m³	Moisture '	Layers	Pco2 (kg CO2)
	length	width	thickness					
CLT	1000	1000	100	0,1	500	12	1	**7.775,30**
Cork	1000	1000	100	0,1	500	12	1	**7.775,30**
Totaal				**0,2**				**15.551**

AREA	117,6	M2	TOTAL	1.828.750,00

	Pco2 (kg CO2)
TOTA	**4.280.767,86**

3 Espadilla Pilot Action; Total Construction Area of cover renovation: 102 m2

ESPADILLA PILOT ACTION

PANEL D

Layer	mensions*			total m³	Density value kg/m³	Moisture '	Layers	Pco2 (kg CO2)
	length	width	thickness					
CLT	1000	1000	140	0,14	500	12	1	**10.885,42**
Cork	1000	1000	120	0,12	500	12	1	**9.330,36**
Totaal				**0,26**				**20.216**
AREA	101,7 M2						TOTAL	2.056.146,35

	Pco2 (kg CO2)
TOTA	**2.071.696,95**

Project funded by the Interreg Sudoe programme through the European Regional Development Funds (ERDF)

CONCLUSIONS

After analyzing the results obtained for the carbon footprint of both IMIP panels and IMIP pilot actions, we can conclude that the IMIP construction systems based on the construction of maritime pine wood and natural cork are CO_2 sinks. That is to say, in the circle of life as well as in their cascading use, they act as a sink absorbing and accumulating atmospheric CO_2.

This capacity of the IMIP systems represents a clear advantage as opposed to substitute systems such as those based on reinforced concrete, structures or systems based on steel or those based on brick. These systems are a clear example of systems that require high-energy consumption and involve the generation of waste that emits an amount of CO_2 greater than approximately 4 times the absorption of IMIP systems.

Therefore, IMIP systems are a clear sustainable alternative to other construction systems in the industry with equal benefits.

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