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Achieving zero carbon emissions in the construction sector:

The role of timber in decarbonising building structures

Abstract

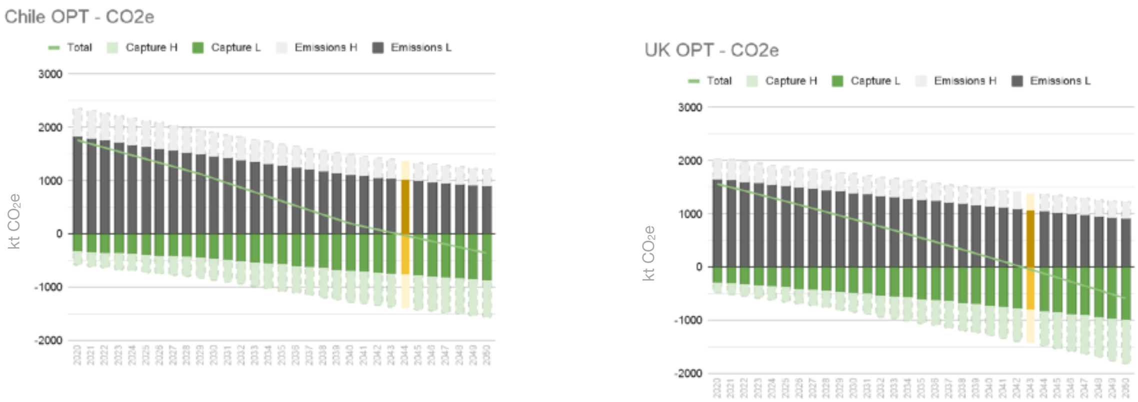
In the context of environmental concern and increasing demand for new housing units, the construction sector faces the challenge to deliver solutions and address climate change. The construction sector is responsible for over a third of global carbon emissions--a sector dominated by construction materials such as concrete and steel. Large amounts of carbon are emitted during the extraction and manufacturing of these products--numerous sources estimate these values in around 6% (concrete) and 7% (steel) of the global carbon emissions. In contrast, the use of timber has arisen in the last decades as a sustainable alternative to develop structures of various shapes and sizes--structures up to 24 stories have been completed, and proposals for taller buildings are under development. Trees absorb carbon as they grow, sequestering large amounts of carbon in wood products as long as they are used in buildings.

This research aims to evaluate a realistic timber adoption scenario as a way of reducing carbon emissions of construction in Chile and the UK for the period 2020-2050. First, a Building as Usual (BAU) scenario was evaluated, in which the market share of construction materials remains constant. Two intermediate scenarios were used to evaluate the impact of emission reductions (ER) and timber adoption (TA) separately. Finally the fourth Optimistic (OPT) scenario assumes that both ER and TA are present and evaluate their combined effect.

The results show that in the OPT scenario, the emissions in 2050 in Chile and the UK would decrease by 56,7% (from 2049 kt CO_2e to 1043 kt CO_2e) and 53,8% (from 2308 to 1066 kt CO_2e), respectively, while carbon storage would increase by 240% (from -506 to -1213 kt CO_2e) and 292,8% (from -479 to -1403 kt CO_2e). Moreover, the findings show that in the BAU scenario the annual carbon emission by 2050 would be 2,3 times higher than yearly carbon storage. However, in the OPT scenario, carbon emissions and storage would achieve equivalence (i.e. zero carbon) in 2043 (the UK, 1390,1 + (-1434,3) kt) and 2044 (Chile, 1365,5 + (-1393,1) kt).

The study finds that a gradual increase of timber construction could complement the emission reduction targets set by traditional materials, providing the needed carbon storage. This analysis shows the urgency to define the criteria that will allow to account for carbon storage in timber construction as a natural contribution to the Paris agreement. Finally, it is worth highlighting that the construction sector also faces several economical and social problems that need to be addressed urgently. Modern methods fo timber construction reduce emissions and at the same time improve health, security, gender gap, precision, speed and working conditions in construction.

Figure 01: Projection of carbon emissions and storage in an optimistic scenario of increasing adoption of timber in construction.



Projections assume a reduction of carbon emission of the concrete and steel industries according to their respective targets. Total carbon emissions and storage would be equivalent in 2044 in Chile and 2043 in the UK. Capture and emissions are measured in ranges (High and Low values provided)

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1. BACKGROUND

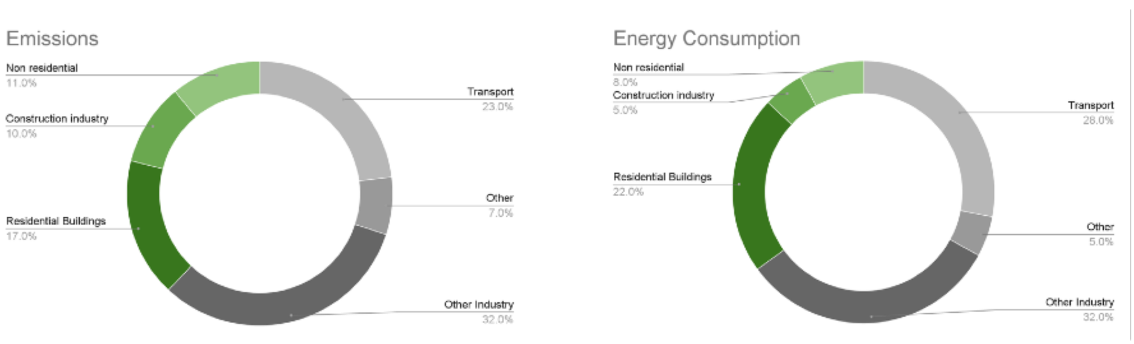
1.1. Housing demand in Chile and the UK.

There are currently 27.2 million households in the UK, and the UK government is committed to building around 1.5 million new homes by 2022[1]. A recent estimate by the UK Parliament has shown that the number of new homes needed in the UK is around 345,000 per year[2]. As per UK's Committee on Climate Change (CCC), in 2017, heating and hot water for UK homes made up 25% of total energy usage and 15% of total GHG emissions[1,3,4]. Direct emissions from homes were 64 million tonnes (Mt) CO_2 in 2017, which was 9% below 1990 levels, and declared on track to a 24% reduction by 2030[1].

In 2017, the Chilean housing stock comprised 6.5 million residential units, where 79.5% are houses and 17% are apartments[5]. In Chile, the residential sector accounts for 30% of the primary energy consumption, with most energy used for space heating[6]. Buildings-related GHG emissions in Chile was 5.9 $MtCO_2$ in 20167. The construction sector accounted for 30% of total GHG emissions in Chile in 2019[8]. A report by the Chilean Ministry of Housing and Planning estimated a housing deficit of 543,000 units in 2000 and suggested that 96,000 new housing units per year were needed just to accommodate new family demands[9]. Seventeen years later, in 2017, a World Bank report estimated that Chile had a qualitative deficit (renovation needs) of about 1.3 million housing units, and an absolute housing deficit of 397,613 units[8]. This report also emphasised that Chile has new capabilities of high-tech industrialised timber companies that can significantly reduce construction emissions from the 2017 levels.

1.2. Construction sustainability.

The Global construction market is set to grow by 85% in the next 15 years, amounting to $15.5 trillion worldwide by 2030[10]. The United Nations Environmental Programme estimated that in 2015 the construction sector accounted for 11-15% of global gross domestic product (GDP) and today involved far-reaching value chains of small and large businesses. It is a substantial provider of local jobs: around 220 million or 7% of total global jobs depend on it[11,12]. This sector is especially critical for bringing in local value chains and has significant macroeconomic impacts for any country[13]. Despite the economic and social potential, construction is among the least digitised sectors in the world, according to the MGI digitisation index[14].



Environmental sustainability

Figure 02: Environmental impact of construction: Global share of buildings and construction final energy and emissions in 2019 (Source: United Nations Environmental Programme, 202012)

Globally, building construction and operations accounted for the largest share of total final energy consumption (35%) and energy-related CO_2 emissions (38%) in 2019 (see Figure 2)[12.]. A regional breakdown shows that buildings accounted for 57% of total final energy consumption in Africa and

32% of total process-related CO_2 emissions[12]. In ASEAN, China and India, energy consumption in buildings accounted for 26% of total final energy consumption and 24% total process and energy-related emissions[12]. Buildings accounted for 24% of total final energy consumption in Central and South America and 21% of total process-related CO_2 emissions in 2019[3].

Emissions from building materials production and construction are primarily driven by cement and steel manufacturing at the global level (see Table 1). It remained a significant driver of building-related embodied carbon emissions. This sector contributed to 38% of total energy-related emissions in 2019, i.e., 9% direct emissions from buildings use phase, 19% indirect emissions from electricity and heat, 10% indirect buildings and construction value chain emissions, as shown in Table 1.

The CCC recommended reducing the whole-life carbon impact of new homes[1]. They acknowledge the need for new policies to support using wood in construction to displace high-carbon materials such as cement and steel. Increasing the number of new homes built in the UK each year using timber frame construction systems from around 27,000-50,000 in recent years to 270,000 annually could triple the amount of carbon stored in UK homes to 3Mt every year[1,2].

	2019 (Mt CO_2)	Share
Building use phase	9953	9% direct emissions
Coal	496	
Oil	939	
Natural gas	1663	
Electricity and heat	6855	
Building construction	130	19% indirect emissions
Construction energy use	130	10% indirect buildings and construction value chain emissions
Material manufacturing	3430	
Cement-and-steel-manufacturing for construction	2038	
Other	1391	
Buildings and construction value chain	13512	38% of total energy-related emissions

Table 01. Global buildings operation and construction emissions estimates for 2019 (Source: IEA, 202013)

Construction consumes 40% of the world's raw materials outperforming all other sectors combined[15]. It also produces around 35.9% of Europe's waste (Eurostat 2018). In the US, 69.7% of the debris is concrete, mainly from demolition[16].

Economic sustainability

The productivity of the construction industry is almost stagnant: globally, it has not increased more than 1% in the last 20 years[17]. The Clapes UC report on labor productivity in construction indicates that average productivity in Chile was USD 37,000 per worker in 2016, with zero growth in the last 20 years. This figure contrasts with the productivity of the rest of the sectors of the country's economy, which reached a value of USD 50,100 per worker, with an average annual growth of 1.7%. It is estimated that the lower productivity of construction in Chile, compared to the rest of the country's economy, generated annual losses of the order of 1.5% of GDP between 1996 and 2016.

The construction sector reports one of the lowest profit margins, ranking 15th among 17 classified sectors with 4.4% of profits[17]. In Germany, the construction sector has the lowest capital stock indicator, which reveals an industry with high impact, but with low investment[18]. According to the same study, the capital intensity, which indicates the amount of investment in infrastructure for each worker, also places construction in the lowest place. This gives an idea of the level of industrialisation of the sector, and the level of technology available to each worker to carry out their task[17].

In Germany, construction defects represent approximately 3% of investment volume and they are estimated to cost around € 2.8 billion[19]. DEKRA also notes that between 2002 and 2008 the number of defects per year has doubled in traditional construction.

Another trend observed globally is the rise in house prices at a rate greater than the increase in income. This means that, in most countries, buying a home today is proportionally more expensive than it was 10 years ago[20].

Social sustainability

The construction industry is one of the riskiest for worker's health. In absolute terms, it represents the sector with the most deaths in the United States, and in relative terms it ranks fourth[21]. These accidents cost the United States an estimated annual cost of about $ 10 billion[22]. In Germany, 1 in 6 workers suffers an accident per year, and 1 in 7000 dies[23]. In Chile, according to Bachelet V.C (2018)[24], there are 176,000 occupational accidents and 400 deaths in the construction sector annually.

Female employment in the construction industry is only 10% internationally, with a wage gap of 48% compared to the same job for a man, as per the World Economic Forum[25].

In addition, internationally, the construction industry has lost its appeal to new generations, due to its low levels of sophistication and harsh working conditions. In the United Kingdom, for example, jobs without adequate supply have doubled in 7 years[26].

1.3. New construction technologies based on engineered wood products as viable alternatives to steel and concrete.

The increasing demand for urban multi-storey housing units across regions intersects with the urgent need to address the impact of the construction sector. Steel and concrete consolidated as predominant materials during the 20th century[27]. Since the late 19th century, regulations have limited the use of timber in construction, prescribing solutions for multi-storey structures based on steel or concrete. For construction purposes, wood was widely restricted or relegated to single-family housing[28]. Yet, in the 1990s, the increasing adoption of performance-based codes opened the market for alternative materials if code compliance was demonstrated[28]. The development of solutions based on engineered wood products emerged for numerous other applications such as multi-storey buildings and large structures. These products are manufactured by gluing together small pieces to produce larger building elements. The latter allowed the industry to manufacture products with improved uniformity, greater efficiency, and dimensional stability[29]. Since the construction of the first 8-storey wood buildings in the late 2000s, the building industry has completed around 50 projects over six storeys globally, leaping from 8 to 24 stories in 12 years (Figure

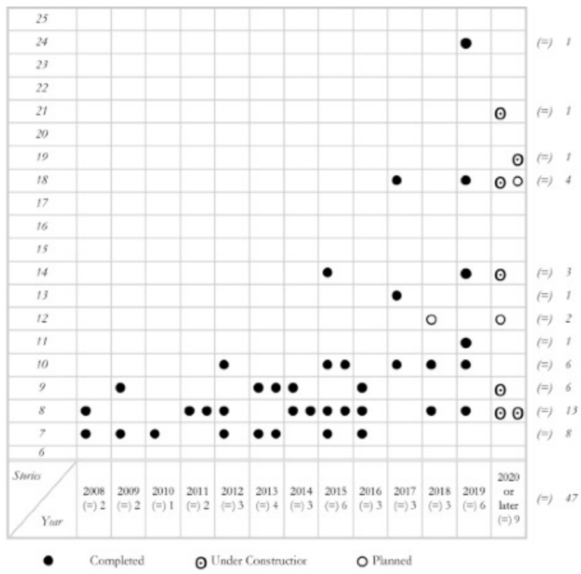


Figure 03: Multistorey buildings over six storeys completed since 2008 (Wiegand & Ramage, 2021).

3)[30].

1.4. Benefits of timber construction

Environmental benefits.

Several studies argue that the carbon footprint of timber-based building solutions is significantly lower than common solutions based on steel and concrete[31,32]. Through photosynthesis, forests absorb large amounts of carbon dioxide (CO_2) as they release oxygen (O2), capturing carbon (C) in the wood of the trees. The carbon remains sequestered in timber products as long as they are in use[33]. Moreover, wood is renewable; therefore, if well managed is an infinite resource[34]. Additionally, wood can be reused and recycled in several products for over 500 years before being safely degraded or used as biomass when needed[34]. At that moment, the carbon sequestered is released into the atmosphere, resulting in a potential neutral carbon cycle[34]. Because of this, the amount of construction waste landfilled can be reduced substantially[35].

Another important environmental benefit associated to the use of timber is related to the end of life (EoL) of the building. The biogenic carbon locked within timber elements is considered to be embedded within the material and transferred to the subsequent project when the timber is reclaimed and reused, the sequestered carbon is retained and carried forward within the timber elements being recovered and used[36]. A recent study indicates that the demand for reclaimed wood products in the building sector will rise since the preferred option has to be the reuse and the recycling of reclaimed wood. The thermal use of wood is the last option in the cascade of use[37]. Another study comparing total costs to the company's revenue for different materials reused, indicates how timber achieves positive profit margins[38].

Economic benefits.

The intensive use of wood results in new opportunities for local companies located in forest areas, as they have comparative advantages to adding value to forest resources[39]. As a result, several studies have demonstrated that the overall costs of timber projects can be reduced significantly[35,40]. Moreover, the prefabricated nature of timber components facilitates the buildings to be refurbished without affecting their structure—reducing the costs associated with maintenance[41]. Furthermore, the demolition process results in commodities that can be traded in marketplaces—to be reused or recycled—instead of waste to be landfilled[41].

Social benefits.

Timber is a particularly structurally efficient material due to its high strength to weight ratio[34]. Therefore, it is an excellent material to be used in prefabricated construction components. The negative externalities that usually affect communities close to construction sites are significantly reduced due to off-site manufacturing and fast assembly processes. As a result, works on-site involve mostly dry activities, reducing vehicular congestion, noise, and pollution[42]. The users are benefited from better quality buildings as the construction processes are improved due to quality control in construction lines in factories[35]. Moreover, the prefabricated nature of timber construction makes components easy to repair or replace according to the users' needs[41]. Furthermore, timber buildings are more flexible to be refurbished and adapted to the changing needs of the users in time, increasing their service life and reducing the number of buildings being demolished[41].

Engineered timber also offers an opportunity to address the issue of female employment in construction, which currently accounts for a 10% participation with a 48% gender wage gap[25]. The factory-based construction provides a fixed work location and less physically demanding jobs, both for lifting and climate exposure, improving access to a broader demographic, including women[43].

The use of exposed timber in structures is likely to have physiological and mental health benefits for building occupants. Spaces with exposed timber elements are found to increase the number of social interactions between individuals and improve the emotional state of users[44,45]. In educational settings in particular, the classroom design can have a high impact on the learning process of students[46]. Classrooms with exposed timber have been shown to result in reduced heart rate and perceived levels of stress in students compared to classrooms where other materials are used[47].

1.5. Social, environmental and economic challenges

Chile extracts about 45MM m3 of industrial round timber per year, of which 58% is exported[48]. 82% of the exported products are from a primary transformation with low added value, mainly pulp (47%). This focus on a few products based on the same species, treated as commodities, needs a standardised production that translates into a monoculture of 2.3MM hectares of radiata pine (55%) and eucalyptus (37%)[48]. These are exotic plantations mostly owned by big companies and that concentration also affects the exports in which 1% of the exporting companies generate 76% of the revenues. This highly concentrated sector fails to provide a tangible development resource to the general population and faces harsh social criticism, uprisings and violence. The focus on secondary transformation products, such as construction and furniture could increase employment by 113% and business transactions by 456%, according to what is seen in Germany and France[49–53]. Additionally, the lack of a strategic focus on high added value products has reduced the demand for native species, reducing their value to the point in which they are illegally logged for burning and to create agricultural land. Increasing demand isn't the solution by itself, but coupled with a solid monitoring and traceability system, it could provide a scenario in which an economic development is compatible with social and environmental requirements.

In Chile the monoculture plantations have mainly replaced agricultural and barren land, but they have also replaced native forests, reducing biodiversity and in some cases the water availability. Over the last 25 years, plantations have grown 650.000 hectares, replacing 86.278 hectares of native forests[48,54]. Traditional radiata pine plantations still might have a potential for growth on barren land where that species is proven to be able to grow and provide a competitive economic return of investment. These eroded patches of land currently add up to 400.000 hectares,[55] providing a viable scenario for native forest restoration and an eventual growth of demand of up to 500.000 m3 of structural timber. In 2020, Chile produced 8.03 Mm^3 of sawn wood,[15] of which 0.49 Mm^3 (6.1%) were structural timber for construction.

In February 2021 the Chilean Senate's Commission for Future Challenges created a workgroup called "Future forestry for a sustainable Chile". Since then, over 170 national and international participants have been discussing an integrated view of sustainable development based on forestry. Its social, economic and environmental repercussions and possibilities. The consensus is that monoculture plantations will need to be mixed with patches of restored native forests. The production of timber will need to be balanced with other ecosystem services in collaboration with local communities. Restoration, reforestation and biodiversity will need to be monitored and valued to compensate for alternative economic activities such as wood production, energy, or agricultural use of the land.

1.6. Timber supply: Total forest area and availability of timber resources across regions.

The FAO in its 2018 report on the "State of the World's Forests" argues that a key step to achieving one of its sustainable development goals by using resources efficiently is 'developing policies that encourage the use of wood products for construction'. This is in light of the fact that half of global (and a fifth of European) wood removals are for wood fuel[4,5], whereas construction wood is a higher-value, longer-term use of trees, and therefore store of carbon.

Forests cover a third of the world's land area (Chile 27%, UK 13%), less than 10% of which are plantations (FAO, 2020). While deforestation due to agriculture-related land-use change and illegal logging is a continuing challenge, as is climate-change-related forest loss due to pests, diseases and fire, Europe's forest cover has increased by 20 Mha since the 1990s[4] (roughly the area of Portugal). Notably, we only harvest around two-thirds of annual forest growth in Europe. Moreover, the total volume of sustainably-sourced FSC or PEFC certified wood is increasing; in 2016, 689 Mm^3 of roundwood – corresponding to 38% of global industrial roundwood production – was from 429 Mha of certified forest (of which 40% is in Europe).

Norway spruce (Picea abies) and European beech (Fagus sylvatica), the two main species used by European CLT, glulam and laminated-veneer lumber (LVL) producers, dominate Europe's forests, occupying ~10% of its area (14 Mha). The mean annual stand volume growth is around 20 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ for Norway spruce, and 11 $m^3 \cdot ha^{-1} \cdot yr^{-1}$ for beech, giving a total yield of ~1500 $m^3 \cdot ha^{-1}$ for Norway spruce and ~1000 $m^3 \cdot ha^{-1}$ for beech.[7] Based on the annual growth of these two wood species alone, at least 140 Mm^3 of construction-grade timber is available. For comparison, the annual production of pulpwood for paper in Europe is over 200 Mm^3. Various estimates, suggest that a multi-storey residential CLT building uses about 0.3 m^3 of timber for every m^2 of floor area, or roughly 20-30 m^3 of timber for a three-bedroom apartment. Each of these apartments can be "grown" in 7 seconds or made from 3 ha growth in one year. The utilisation of the entire 140 Mm^3 of annual growth in Norway spruce and European beech in Europe alone is sufficient to build 4.6 million apartments each year – or 230,000 buildings for 14 million people. 4 million homes is the current backlog of homes needed in England, as published in a recent report by the National Housing Federation. Following a 'sustainable-yield logging' model in which the minimum design lifespan of a CLT-based apartment matches the forest rotation period of 50 years, an area of forest the size of a tennis court (~ 2.5 times the size of the apartment) is required to sustain that accommodation indefinitely.

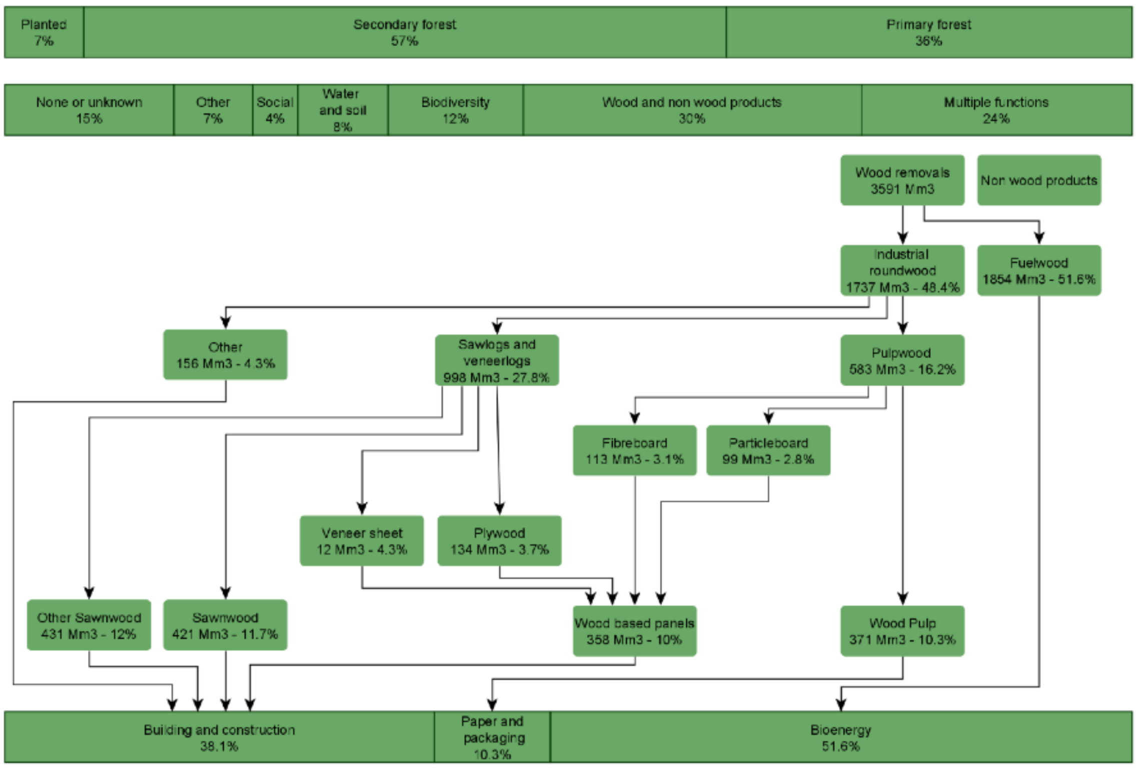


Figure 4. Produced by the authors. Based on (Ramage et al., 201734)

2. CARBON IN THE BUILDING SECTOR

2.1. Climate Commitments

The UK and Chile, like all the Parties subscribed to the Paris Agreement, must implement the necessary actions to fulfil the commitments agreed in its Nationally Determined Contribution (NDC). Both countries have laid out specific actions to prevent the increase in global average temperature, raise global resilience, and mobilise public and private investments on a decarbonisation path. The UK Clean Growth Strategy describes the UK Government's current policies and measures to decarbonise all sectors of the UK economy through the 2020s and beyond. The Chilean Senate has approved the Bill for the Framework Law on Climate Change. The purpose of the Bill is to achieve carbon neutrality by 2050, increase resilience against the effects of climate change; and comply with international commitments.

2.2. Concepts definition

The building sector is responsible for the largest single energy use worldwide and is the largest global consumer of materials[56]. In 2019, the building sector was responsible for 35% of global energy consumption and 38% of total global energy-related carbon emissions[12]. From these emissions, 28% come from operating buildings, while 10% of the carbon emissions come from the manufacturing of three building construction materials (i.e. concrete, steel and aluminium)[13].

Upfront emissions are caused during the materials production and construction phases of the lifecycle before the building or infrastructure begins to be used[57]. This upfront carbon usually comprises the majority of a material's embodied carbon impact, and is considered especially important due to the importance of reducing carbon emissions as quickly as possible[58]. A recent study that analysed the GHG emissions at the time of occurrence showed that the upfront 'carbon spike' from building production, highlighting the need to address and reduce the GHG 'investment' for new buildings[59].

However, whole life carbon (WLC) in buildings involves much more than just operational and upfront carbon emissions. Embodied carbon arises from producing, procuring, installing the materials and components that make up a structure. These also include the lifetime emissions from maintenance, repair, replacement and ultimately demolition and disposal[36].

Figure 05: Project lifecycle showing both the scope and need for whole life consideration (WorldGBC, 201957)

As new floor space doubles by 2050 in developing countries[12], and buildings become more efficient during their operation due to increasing energy efficiency policies, the share of embodied carbon is expected to increase[60]. While embodied currently accounts for only 10% of emissions globally, it is estimated that more than half of total carbon emissions from all new construction between 2020 and 2050 will be due to upfront carbon emissions[57]. Building the necessary new urban infrastructure with current average technologies will consume one-quarter to one-half of the remaining carbon budget to 1.5°C[61]. A recent study presents life cycle assessments (LCAs) of 60 building cases built from 2013 to 2021 demonstrating that embodied carbon is 2-4 times greater than operational carbon, for a 50-year as well as an 80-year reference study period[62]. Hence, there is an urgent need for the building sector to focus on reducing embodied emissions in new buildings.

As the building sector begins to understand the role of embodied carbon in decarbonisation efforts, there is also a significant interest in exploring the potential of building materials to be used as carbon storage or carbon sinks[63]. Carbon storing can be achieved by natural or artificial means. Kuittinen et al. describe three types of carbon storage in the built environment: Carbon captured off and stored on the site (i.e. Bio-based and CO_2-based building materials: Wood, bamboo, CO_2-cured concrete), carbon captured and stored on the site, and carbon captured on and stored off the site[64]. Carbon Sequestration is the process by which carbon dioxide is removed from the atmosphere and incorporated as biogenic carbon in biomass. Biogenic Carbon is the carbon removal associated with carbon sequestration into biomass as well as any emissions associated with this sequestered carbon[65].

2.3. How to calculate the carbon footprint of materials

Currently, Life-cycle Assessment (LCA) is widely recognised as the most robust method for analysing a product or service's environmental impacts. During all the life cycle stages, from the extraction of raw materials to the end of life[66]. Since its inception, LCA has been applied to create decision support tools across different industries. The ISO 14040 series of standards, based on ISO 14040 and ISO 14044 establish the predetermined parameters to develop an LCA. In recent years, the building industry has adopted LCA as the globally accepted method for evaluating and communicating environmental impacts, and applied these methods to the study of materials, products, and assemblies[67].

Environmental labels and declarations are necessary market tools created to distinguish environmentally preferable products. The International Standards Organisation (ISO) classifies environmental labels into three typologies: types I, II, and III, described in standards ISO 14021, ISO 14024, and ISO 14025, respectively (ISO 2001, 140). Environmental Product Declaration (EPD), also known as a type III label, is a standardised, third-party verified LCA-based label that provides "quantified environmental data using predetermined parameters and, where relevant, additional environmental information"[68]. EPDs are a growing source of environmental data in the building products market, and are increasingly being used for (1) environmental performance assessment of buildings and (2) product comparison for procurement decisions during the later stages of building design[58]. Several studies show that EPDs represent an advantage when used as LCA data source compared to generic data[69].

- ISO 14025 establishes the principles and specifies the procedures for developing Type III environmental declaration programmes and Type III environmental declarations. However, both by ISO and the European Committee for standardisation (CEN) developed specific standards for building product to better specify the requirements of EPDs for construction products:
- ISO 21930:2017 - Sustainability in building construction - Core rules for environmental declarations of construction products and services and:
- EN 15804:2012+A1:2013 +A2:2019- Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products.

At present there is broad industry consensus around assessment methodologies for calculating the life-cycle impact of building materials, based on the ISO 21930 and EN 15804 standards.

2.4. How to calculate the carbon footprint of buildings.

There is also industry consensus around whole life cycle assessment methodologies for buildings, based on the EN 15978 standard. Several professional bodies have also published guidance for whole life cycle assessment of buildings, including the Royal Institute of Chartered Surveyors (RICS), the Institution for Structural Engineers (IStructE), and the Carbon Leadership Forum (CLF).

At present, there is not yet industry consensus concerning accounting methods for the life cycle impacts of biogenic carbon (atmospheric carbon physically sequestered in plant-based building materials) in construction. Hoxha et al (2020)[70] identify four commonly used calculation methodologies for the life-cycle impacts associated with biogenic carbon:

- 0/0 or "Carbon Neutral" Approach: CO_2 released at a building product's end of life is assumed to be balanced by sequestration during biomass growth, meaning that no net CO_2 emissions or removals are ascribed to the biogenic carbon in the building product.
- +1/-1 Approach: All biogenic carbon flows are tracked as they enter the product system from the forest and leave the product system at the end of life of the product. This also results in whole-life net-zero CO_2 emissions associated with the biogenic carbon in the building product. However, unlike the 0/0 approach, carbon flows are described explicitly.
- Dynamic: Impulse functions describing the climate effects of greenhouse gases in the atmosphere over time are used to calculate the impacts of net carbon emissions or removals over the product lifetime and the time taken to grow (or re-grow) the plants used in the building product.
- Sequestration before harvest: Carbon removals associated with photosynthesis in plants are assumed to occur before harvest of plants used in the bio-based product.
- Sequestration after harvest: Carbon removals associated with photosynthesis in plants are assumed to occur after harvest of plants used in the bio-based product.

For several years, ISO 21930 offered one of the most accepted guidance to account and report biogenic carbon over the life cycle of timber construction products. This standard promotes that sequestered carbon should only be considered a benefit when the timber is sustainably sourced. This should be confirmed according to a FSC certification or equivalent, or that the country from where the timber comes from, has stable net carbon stocks or increasing. Most EPD follow the standard 21930.

For biogenic carbon accounting, the ISO21930 standard follows the +1/-1 Approach. The biogenic carbon removals and emissions throughout the product system shall be reported as a flow of biogenic carbon expressed in CO_2 in the LCI. When entering the product system, the biogenic carbon flow shall be characterised in the LCIA with −1 kg CO_2e/kg CO_2 of biogenic carbon in the calculation of the GWP, since it represents a removal. When the bio-based material, is converted to emissions, biogenic CO_2 shall be characterised with +1 kg CO_2e/kg CO_2 of biogenic carbon in the calculation of the GWP (ISO, n.d.).

Once carbon sequestration has been calculated using one of the methods presented above, the reporting of carbon sequestration should follow existing guidelines. Several documents have been produced to provide alignment in biogenic carbon measurement and comparisons. The LETI Embodied Carbon Alignment, for instance, indicates that there are two scopes that projects should be reported against: Upfront Carbon modules A1-A5 excluding sequestration, and Total Embodied Carbon (A1-5, B1, C1-4, including sequestration) (LETI, 2021). This means that if a building is reporting or benchmarking only upfront carbon, then sequestered carbon should not be included.

The RICS Guidelines establish specific guidance for biogenic carbon reporting. First, it establishes that Carbon sequestration results should be reported separately. Secondly, when analysing Total Embodied Carbon, the sequestration in module A should be balanced by emissions or transfer of biogenic carbon in Module C, also known as end-of-life stage (EoL). Different scenarios at the EoL lead to different impacts of timber into account in the calculations. For instance, if the timber product is incinerated or taken to landfill and left to decompose, CO_2 as well as CH4 (methane) are released to the atmosphere. When the timber product is reclaimed and reused at the EoL, it is assumed that the sequestered carbon is kept in the timber element and carried forward within the timber product used in a subsequent project[36]. The sequestered carbon should be accounted for in module [D] as a potential future benefit locked within products deriving from recovered timber, as described in the European Standard EN 16485:2014.

2.5. Our position:

For this study the embodied carbon of the different structural systems has been calculated using existing embodied carbon coefficients (ECCs) for each one of the building materials. All the components of the superstructure have been identified, quantified independently and multiplied by ECCs to obtain the total carbon of the structure. The existing data includes GHG emissions for life cycle data scope for stage A, manufacturing phase, only. Carbon sequestration factors for each type of timber product are used as carbon storage values from the ICE v3.0 database, aligned with how most EPDs have reported carbon footprint of timber.

3. DATA AND METHODS

This study evaluates the impact of timber construction on the carbon emissions and storage of the housing by 2050 (cradle to gate) in Chile and the UK. As a base line, a "Building as Usual" (BAU) scenario assumes that the market share of timber construction remains constant, as it is today, across buildings of different heights. This BAU scenario also assumes that all materials continue to emit carbon dioxide or store it with the same coefficients as 2020. Two additional scenarios were projected to assess the individual contribution of an increased Timber Adoption (TA) and an Emission Reduction (ER). TA assumes an increasing adoption of timber as a structural material, at an achievable but challenging rate. It projects different rates of adoption based on building height and considers two intervals (2021-2030 and 2030-2050). TA starts with a slow rate of adoption, considering research, knowledge transfer and regulation changes, and increases the rate in the second interval. ER considers a steady reduction of emissions in steel and concrete since those sectors have a clear and declared roadmap. Timber on the other hand doesn't have a declared reduction plan so it is maintained at 2020 values. A fourth scenario, optimistic scenario (OPT), was modelled using TA + ER to evaluate the combined effect of what could be achieved by 2050. The OPT that considers a realistic uptake of timber technologies based on the current infrastructure, regulatory and cultural limitations.

3.1. Data sources

Material Quantities

For calculating the carbon emissions, it is required to estimate the amount of materials used across the various construction typologies. Table 03 shows the sources of representative buildings studied. These were classified by height (Category) and building system (Construction typologies). It is worth highlighting that only structural elements were included as it was assumed that non-structural elements could be potentially the same across construction typologies. Several sources of data were considered for different typologies to make them representative. Variations across cases resulted in low and high quantities; therefore, the resulting calculations are presented as ranges.

Table 03. Sources of material quantities across construction typologies and categories.

Category		Sources
	Construction Typologies	Government data, literature, expert knowledge, and in-progress research.
1-2 storeys	Light Frame	Estimations calculated by the authors based on: (1) data provided by researchers and experts; (2) data published by Chilean Ministry of housing (MINVU), (3) and other sources (E.g. Pajchrowski et al, 2014).
	Reinforced Concrete	Estimations calculated by the authors based on: (1) data provided by researchers and experts; (2) data published by Chilean Ministry of housing (MINVU).
	Steel	Estimations calculated by the authors based on: (1) data provided by researchers and experts; (2) data published by Chilean Ministry of housing (MINVU), (3) and other sources (E.g. Kaziolas et al, 2017).
	Masonry	Estimations calculated by the authors based on: (1) data provided by researchers and experts; (2) data published by Chilean Ministry of housing (MINVU), (3) and other sources (E.g. Pajchrowski et al, 2014).
3-6 storeys	Light Frame	Estimations calculated by the authors based on: (1) data provided by researchers and experts; (2) data published by Chilean Ministry of housing (MINVU), (3) and other sources (E.g. Peñaloza et al, 2013; Allan & Phillips, 2021).

	Reinforced Concrete	Estimations calculated by the authors based on: (1) data provided by researchers and experts; (2) data published by Chilean Ministry of housing (MINVU), (3) and other sources (E.g. Peñaloza et al, 2013).
	Steel	Estimations calculated by the authors based on: (1) data provided by researchers and experts; (2) data published by Chilean Ministry of housing (MINVU); (3) websites (E.g. www.steelstructures.info); (4) and other sources (Allan & Phillips, 2021).
	Masonry	Estimations calculated by the authors based on: (1) data provided by researchers and experts; (2) data published by Chilean Ministry of housing (MINVU), (3) and other sources (E.g. Puskás & Moga, 2016).
7-12 storeys	Engineered Wood	Estimations calculated by the authors based on: (1) data provided by researchers and experts; (2) data published by Chilean Ministry of housing (MINVU), (3) and other sources (E.g. Sandanayake et al, 2018; Allan & Phillips, 2021; Skullestad et al, 2016).
	Reinforced Concrete	Estimations calculated by the authors based on: (1) data provided by researchers and experts; (2) data published by Chilean Ministry of housing (MINVU), (3) and other sources (E.g. Skullestad et al, 2016).
	Steel	Estimations calculated by the authors based on: (1) data provided by researchers and experts; (2) data published by Chilean Ministry of housing (MINVU); (3) websites (www.steelstructures.info); (4) and other sources (E.g. Allan & Phillips, 2021).
	Masonry	Estimations calculated by the authors based on: (1) data provided by researchers and experts; (2) data published by Chilean Ministry of housing (MINVU), (3) and other sources (E.g. Puskás & Moga, 2016).
13-18 storeys	Engineered Wood	Estimations calculated by the authors based on: (1) data provided by researchers and experts; (2) data published by Chilean Ministry of housing (MINVU), (3) and other sources (E.g. Skullestad et al, 2016) .
	Reinforced Concrete	Estimations calculated by the authors based on: (1) data provided by researchers and experts; (2) data published by Chilean Ministry of housing (MINVU), (3) and other sources (E.g. Sandanayake et al, 2018).
	Steel Structure	Estimations calculated by the authors based on: (1) data provided by researchers and experts; (2) data published by Chilean Ministry of housing (MINVU); (3) websites (www.steelstructures.info); (4) and other sources (E.g. Allan & Phillips, 2021).
	Masonry	No cases
19+ storeys	Engineered Wood	Estimations calculated by the authors based on: (1) data provided by researchers and experts; (2) data published by Chilean Ministry of housing (MINVU), (3) and other sources (E.g. Skullestad et al, 2016).
	Reinforced Concrete	Estimations calculated by the authors based on: (1) data provided by researchers and experts; (2) data published by Chilean Ministry of housing (MINVU), (3) and other sources (E.g. Skullestad et al, 2016).
	Steel	Estimations calculated by the authors based on: (1) data provided by researchers and experts; (2) data published by Chilean Ministry of housing (MINVU); (3) websites (E.g. www.steelstructures.info); (4) and other sources (E.g. Allan & Phillips, 2021).
	Masonry	No cases

Housing Stock

Data about the housing stock (number of dwellings completed, area per unit, height, and predominant structural material) was found in the literature or government databases.

Table 04. Sources of housing stocks. Quantities, distribution and market share per material.

Data	Sources	
	Chile	United Kingdom
Participation of each category in the market in 2019. (dwellings 1-2: 3-6: 7-12: 13-18: 19+)	National Institute of Statistics, 2019 (INE, Instituto Nacional de Estadisticas)	Multiple sources (E.g. English housing Survey 2017-18, 2019; Structural Timber Association, 2017; Piddington et al, 2017; Office for national Statistics, 2019).
Market share of construction typologies 2019 (timber, reinforced concrete, steel, masonry, others).	World Bank: , 2020 The Construction of Timber Houses in Chile	Multiple sources (E.g. English housing Survey 2017-18, 2019; Structural Timber Association, 2017; Piddington et al, 2017; Office for national Statistics, 2019).
Number of dwellings completed in 2019.	Chilean chamber of Construction (CChC) Information Center - Statistics	(UK Housing Statistics, 2021).
Average area per dwelling in 2019.	Ministry of Housing and Urbanism	Average area extracted from multiple sources (E.g. English housing Survey 2017-18, 2019; Piddington et al, 2017; Office for national Statistics, 2019; UK Housing Statistics, 2021).

Carbon coefficients

Whole life carbon calculations in buildings vary significantly depending on the embodied carbon coefficients (ECC) chosen for the study [71,72]. Neither the UK nor Chile have established an official database to carry out whole life carbon assessments for the construction sector, which causes significant variance in the results depending on the data chosen for the study. Typically, the chosen data include industry proprietary data, Environmental Product Declarations (EPD), publicly available government data or some combination of the above.

Nevertheless, several efforts have been carried out in the past to aggregate and harmonise existing carbon data sources. One of this efforts is the Inventory of Carbon and Energy (ICE) developed from a large literature review done by researchers from the University of Bath[73]. Since its inception the database is updated periodically. Now in its third version ICE v3.0 contains data for over 200 materials, broken down into over 30 main material categories [74]. The ICE database is currently accepted as the most consistent database for carbon factors in the UK [75].

In Chile, several isolated efforts have been made in the past to make ECC available for the industry. The ECOBASE inventory developed in 2015 provided ECC for five product categories. Product-specific Environmental Product Declarations have been published by two EPD programs for some products such as concrete, steel and cardboard plaster. No EPDs have been published by timber product companies in Chile. In recent years, the specialised ÁBACO-Chile platform has been developed to provide a comprehensive cost and embodied carbon assessment for public procured projects [76].

Since this study aims to assess a realistic timber adoption scenario in order to reduce carbon emissions in Chile and the UK from a comparative perspective, this study considered the carbon coefficients from the existing ICE v3 database. This methodological decision was based considering the importance of using updated and consistent ECC values for both countries.

Table 05. Sources of carbon coefficients

Data	Sources	
	Chile	United Kingdom
Carbon Coefficients	Inventory of Carbon and Energy 2019 (ICE, 2019); and Environmental Product Declarations (EPD) provided by private companies when available.	Inventory of Carbon and Energy 2019 (ICE, 2019)
Carbon Coefficients (Storage)	Inventory of Carbon and Energy 2019 (ICE, 2019)	Inventory of Carbon and Energy 2019 (ICE, 2019)

Projections

Three sets of projections were needed in order to create the four scenarios. The BAU scenario used the current values of material market share and height distribution. Housing increment is based on the population growth provided by official sources. The TA scenario uses different rates of timber adoption per category (based on height). This is based on estimated achievable rates in function of current know-how, regulations and cultural practices. The ER scenario applied reduction targets declared by each industry, however it does not consider reduction from Carbon Capture Utilisation and Storage (CCUS). This is due to the current stage of the technology, which requires large investment in infrastructure, from private and public sources, and policy changes to enable its development and scaling in time, which in the case of concrete requires to be developed and deployed by 2030. (GCCA. Concrete future roadmap 2021)

Table 06. 2020-2050 BAU, TA and ER assumptions.

Scenario	Data	Chile	United Kingdom
Building as usual (BAU)	Participation of each category in the market between 2020 and 2050. (dwellings 1-2: 3-6: 7-12: 13-18: 19+)	The participation of each category is maintained stable based on 2021	The participation of each category is maintained stable. Multiple sources (E.g. English housing Survey 2017-18, 2019; Structural Timber Association, 2017; Piddington et al, 2017; Office for national Statistics, 2019).
	Market share of constriction typologies 2020-2050 (timber, reinforced concrete, steel, masonry, others).	The market share of each construction typology across categories is maintained stable. Based on values from "World Bank: , 2020 The Construction of Timber Houses in Chile".	The market share of each construction typology across categories is maintained stable. Multiple sources (E.g. English housing Survey 2017-18, 2019; Structural Timber Association, 2017; Piddington et al, 2017; Office for national Statistics, 2019).

	Number of dwellings between 2020 and 2050.	Projection of an annual increment based on the projected population growth (INE 2018 Estimaciones y proyecciones de la población de Chile 1992-2050) on top of an increment of 10% over the average construction (CChC - Information Center - Statistics) to be able to reduce the current deficit in 15 years.	Projection (0.98%) based on the period 2000 to 2019 (UK Housing Statistics, 2021).
	Average area per dwelling between 2020 and 2050.	50 m2 maintained stable, based on the current value.	Average area extracted from multiple sources (E.g. English housing Survey 2017-18, 2019; Piddington et al, 2017; Office for national Statistics, 2019).
Timber adoption (TA)	Participation of each category in the market between 2020 and 2050. (dwellings 1-2: 3-6: 7-12: 13-18: 19+)	The participation of each category is maintained stable based on 2021.	The participation of each category is maintained stable. Sources (E.g. English housing Survey 2017-18, 2019; Structural Timber Association, 2017; Piddington et al, 2017; Office for national Statistics, 2019).
	Market share of constriction typologies 2020-2050 (timber, reinforced concrete, steel, masonry, others).	Market share of each construction typology was projected starting from the 2019 baseline and increased as follow: +2% per year for 1-2 storeys. * +2% per year for 3-6 storeys. * +1% per year for 7-12 storeys. *+0.5% per year for 13-18 storeys. *+0.25% per year for 19+ storeys. From 7 stories up it is assumed that a R+D phase is still necessary so the increased market share was projected from 2030.	Market share of each construction typology was projected starting from the 2019 baseline and increases as follow: +2% per year for 1-2 storeys category. * +1.5% per year for 3-6 storeys category. * +1% per year for 7-12 storeys category. * +0.5% per year for 13-18 storeys category. * +0.25% per year for 19+ storeys category.
	Number of dwellings between 2020 and 2050.	Projection of an annual increment based on the projected population growth (INE 2018 Estimaciones y proyecciones de la población de Chile 1992-2050) on top of an incremet of 10% over the average construction (CChC - Information Center - Statistics) to be able to reduce the current deficit in 15 years.	Projection (0.98%) based on the period 2000 to 2019 (UK Housing Statistics, 2021).
	Average area between 2020 and 2050.	50 m2 maintained stable, based on the current value.	Average area extracted from multiple sources (E.g. English housing Survey 2017-18, 2019; Piddington et al, 2017; Office for national Statistics, 2019).

Emission reductions (ER)	Emission reductions for steel	Reduction of 80%. Linear projection between 2020 and 2050 based on Low carbon roadmap - Eurofer, 2019.	Reduction of 80%. Linear projection between 2020 and 2050 based on Low carbon roadmap - Eurofer, 2019.
	Emission reductions for concrete	Reduction of 39%. Linear projection between 2020 and 2050 based on UK Concrete and Cement Industry Roadmap to beyond Net Zero, MPA 2020.	Reduction of 39%. Linear projection between 2020 and 2050 based on UK Concrete and Cement Industry Roadmap to beyond Net Zero, MPA 2020.
	Emission reductions for Timber	No ambition was detected, no reduction was performed.	No ambition was detected, no reduction was performed.

Calculations

Material quantities per construction typology can vary depending on the particularities of different projects. Therefore, this research considered a range based on multiple cases that resulted in low and high values. Based on these values, it was possible to determine carbon emissions and storage of each construction typology per area ($kgCO_2e/m2$). The sum of the structural materials that conform each construction typology was calculated as follows:

*(volume/area) * (density of material) * (carbon coefficient) = (emissions/area)*

or

$$(m3/m2) * (kg/m3) * (kgCO_2e/kg) = (kgCO_2e/m2)$$

The carbon emission/storage ($kgCO_2e/m2$) was multiplied by the total area projected. This value was calculated in ranges for every year according to the projections. This process was conducted for both the UK and Chile cases, considering the two scenarios previously presented in this research.

(emissions/area) * (area) = (total emissions per year)

or

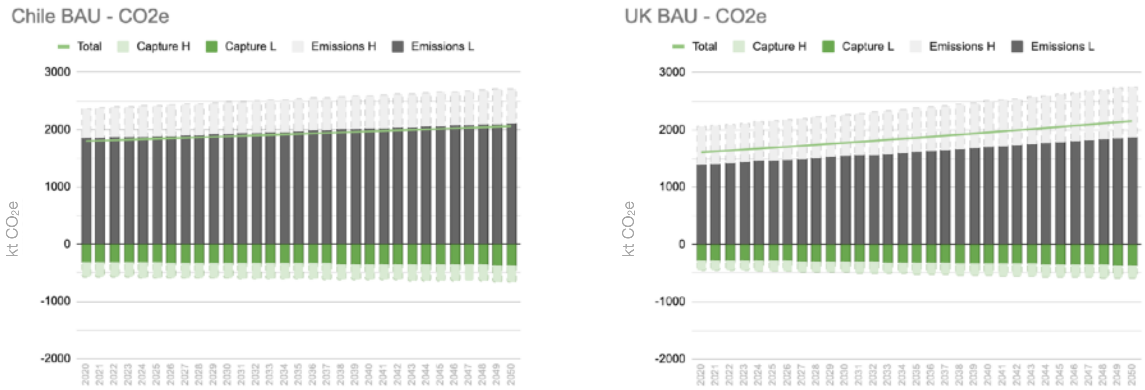
$$(kgCO_2e/m2) * (m2) = kgCO_2e$$

4. RESULTS

This study found that the calculations of total carbon emissions and storage for Building as Usual (BAU) and Optimistic (OPT) scenarios were significantly different. This section presents the main results.

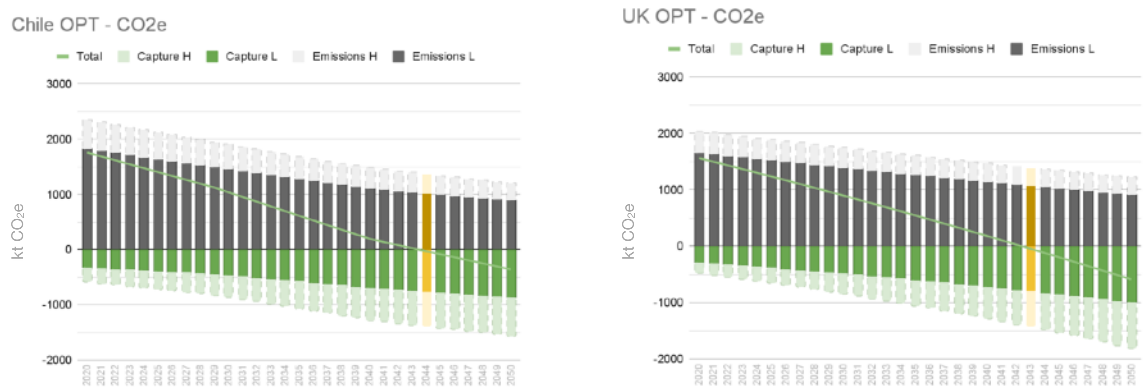
4.1. Boundary scenarios

If we project business as usual from 2020 to 2050 (Figures 05-06), the population growth and reconstruction will increase the demand for new dwellings, increasing CO_2e emissions between 14 and 34% (from 2369 to 2711 kt CO_2e for Chile and from 2052 to 2749 kt CO_2e for the UK), without increasing the relative possibilities of storage.



Figures 05-06. Projection of carbon emissions and storage in Chile and the UK for the 2020-2050 period (BAU Scenario).

Combining an increased timber market share with the reduction of the emissions from concrete and steel shows that Chile and the UK could achieve a construction that has a negative embodied carbon footprint by 2044-2043 (Figures 07-08). In this scenario the construction could have an emission/capture ratio between 0,68 and 0,72 by 2050 thus resulting in a carbon negative construction. Chile would transition from emissions of 2351 to 1201 kt CO_2e and a capture of 591 kt CO_2e in 2020 to 1159 kt in 2050. In the same period the UK would experience a reduction of emission going from 2035 kt to 1222 kt CO_2e while increasing the capture form 474 to 1809 kt CO_2e.

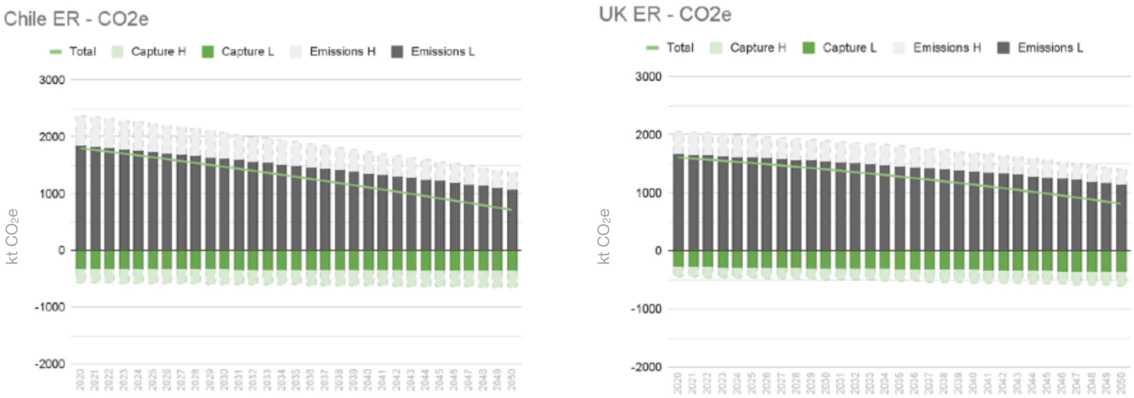


Figures 07-08. Projection of carbon emissions and storage in Chile and the UK for the 2020-2050 period (OPT Scenario).

4.2. Intermediate scenarios

Emission reductions.

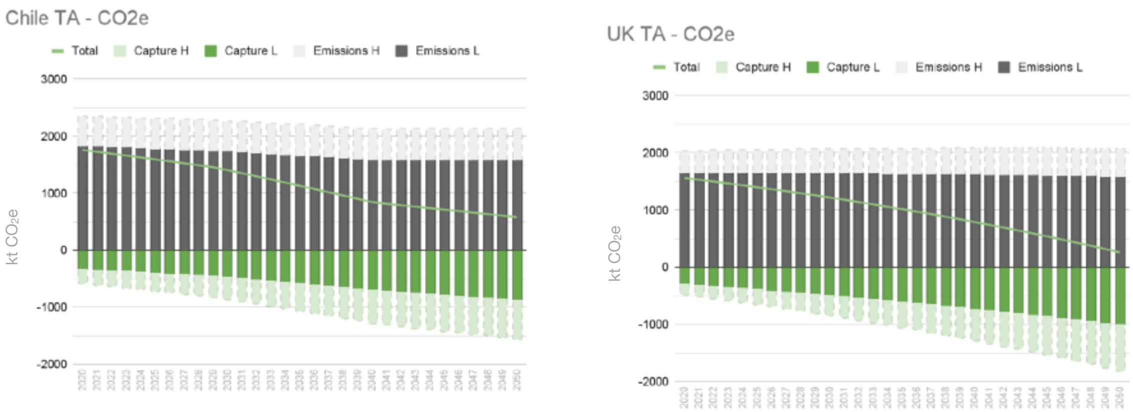
If we take into account the emissions reduction roadmaps from cement and steel industries, by 2050 we could achieve a reduction of emissions between 31 and 42%, without affecting the relative possibilities of CO_2e storage (Figures 09-10). We would still be emitting 2.1-2.4 times more than we are storing by 2050.



Figures 09-10. Projection of carbon emissions and storage in Chile and the UK for the 2020-2050 period (ER scenario)

Timber adoption.

Increasing market share of timber construction, especially in the segment between one and six stories, in itself is not enough to neutralise emissions, reducing them by 1 to 11%, but it provides a strong potential to store CO_2 inside the structure of the buildings (Figures 10-11). The balance is still not enough to create a CO_2 neutral construction but we could lower the emission to storage ratio value between 1.15 and 1.3.



Figures 10-11. Projection of carbon emissions and storage in Chile and the UK for the 2020-2050 period (TA Scenario).

4.3. Timber demand

The study found that in the case of Chile, using the TA or OPT scenarios, the demand could gradually increase to 1.3 Mm^3 /y of structural sawn timber and 0.63 Mm^3 /y of plywood and OSB, by 2050. In the case of the UK the demand could gradually increase to 1.14 Mm^3 /y of structural sawn timber and 0.62 Mm^3 /y of plywood and OSB.

5. LIMITATIONS

Sustainable Sourced Forestry: This study assumes that all timber products installed in the residential building are sourced from sustainable managed forests. According to ISO 21930 for timber products, biogenic carbon may be characterised with a –1 kg CO_2e/kg CO_2 carbon flow when entering the product system only when the wood originates from sustainably managed forests.

The sustainability requirements of various manufacturing sectors will lead to an increase in the demand for wood, but the supply presents its own challenges and sustainable sourcing cannot be taken for granted. Forestry is a highly diverse industry, strongly affected by local conditions. In some countries forestry is regarded as a sustainable activity and in other cases it is perceived as a source of social inequality and environmental destruction. Global forest and plantation growth will need to consider and protect other ecosystem services and local communities. Nature based solutions need to be closely monitored to ensure that carbon sequestration efforts are compatible with other drivers such as biodiversity, water supply and local economic development.

To face the challenges in construction described herein the demand for timber will increase. Chile produces 8 Mm^3 /y of sawn timber of which 0,49 Mm^3 /y are structural. A gap of 0,81 Mm^3 /y needs to be solved in 20 years. Different alternatives are available.

- Plantation management: Plantations can be managed to produce better quality roundwood logs, increasing the amount of structural timber that can be obtained.
- Plantation growth: In Chile, there are 400.000 hectares of eroded barren land with high forestry potential that could provide up to 0.5 Mm3 /y of structural timber among other products.
- Structural optimisation: The quantity of structural timber can be increased through processes to eliminate defects, such as finger joints or engineered wood.
- Product optimisation: A reduction of material intensity in construction can be achieved with flexible manufacturing systems, minimising material losses.

Material quantities: This study estimates the amount of materials used across different construction typologies using different existing sources of data. This leads to a wide range of variability across categories. Representative housing typologies were chosen from existing studies and material quantities were estimated using calculations for each construction typology in the different categories.

Embodied Carbon Coefficient (ECC): This study aims to assess a realistic timber adoption scenario in order to reduce carbon emissions in Chile and the UK from a comparative perspective, therefore this study considered only the carbon coefficients from the existing ICE v3 database. This was based on the importance of using updated and consistent ECC values for both countries, however the limitations of using ECCs from different geographical locations brings several implications that should be acknowledged.

Another important limitation of the study is that only initial embodied carbon of building products is considered and does not include maintenance, replacement, energy use, or end of life impacts. Different LCA data is built based on different assumptions regarding extraction, manufacturing methods and transportation.

End-of- life Scenarios: The results of this study are built on the underlying assumption that timber elements are reclaimed at the EoL and are not left to decompose in landfill or incinerated. According to the RICS guidelines[36], from a whole life carbon perspective, it is crucial to take the EoL impacts of timber into account in the calculations. In the construction sector, however, little is known about the different approaches at the EoL. In Chile, for instance, most residential buildings are demolished at the EoL with limited tracking of the destination of most building elements.

6. DISCUSSION AND CONCLUSIONS

Chile and the UK have both set challenging targets for construction. This study evaluates credible reduction scenarios that could be handled by private companies, and projected plausible timber adoption scenarios. The study shows that both measures need to be implemented at the same time to achieve the goals. If the focus is reducing embodied emissions only, there will not be enough storage to compensate them. Conversely, if only timber market share is increased, the emissions will still be greater than the capture by 2050. The combination of the two actions could allow the UK and Chile to achieve carbon neutrality in residential construction by 2043-2044.

In order to achieve the emission reduction targets in construction, three actions need to occur.

- The embodied emissions from all materials need to be reduced.
- Carbon storage embodied in construction materials needs to be measured and considered using standards to increase harmonisation and comparability.
- The use of timber in construction needs to be promoted and enabled.

The different scenarios described in this document show that steel and concrete will continue to dominate construction. This means that their emission reduction is critical, and it can be significantly reduced by adopting existing technologies. Additional measures such as Carbon Capture Usage and Storage require major public and private investment, to help concrete and steel companies in achieving their goals. An economically viable alternative is to use timber as a carbon storage solution.

Timber construction is also a viable solution for the sustainability of concrete and steel sectors. These sectors will still need to reduce their emissions but replacing part of the construction with timber could help to achieve the goals without major public and private spending. The structural elements for new constructions in Chile and the UK will occupy a volume of up to 150,000,000 m^3. This is a physical space in which carbon could be stored, and timber is the only structural material that can provide a dual function of carbon storage and structural element.

While growing, the tree breaks down CO_2, releasing the oxygen, capturing the carbon atom and storing it in the wood. Both ends of the life cycle, the capture conditions and the disposal, are being debated with strong arguments for and against the long-term storage capability of timber structures. Internationally we haven't yet reached a consensus and it is halting the progress towards the decarbonisation of construction. This report provides evidence that, if considered, carbon storage in timber construction could help achieve the targets for Chile and the UK by 2050. We urgently need to discuss and define the conditions that need to be met, in order to consider the carbon storage in timber structures. Increasing timber construction is a cultural shift that will require changes in regulations, education, promotion, technology and research and development, and we don't have much time.

The study also provides evidence of a sustainability crisis in the construction industry. Social, environmental and economic issues have crippled the productivity and appeal of one the most important human activities. Timber not only provides a carbon storage solution but also helps to improve gender gap, health, speed, safety and precision, representing a systemic solution to several pressing problems.

Global sustainability challenges, particularly measures to mitigate climate change, will require the world to move away from fossil fuels. This transition towards a bio-economy will generate growth opportunities for those countries capable of meeting international requirements, which are rapidly moving towards a greater integration of environmental and social variables. At the base of all this potential development, forestry can represent an opportunity to promote sustainable local development but only if it includes the consideration for other ecosystem services and local communities.

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