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Replacement scenarios for construction materials based on economy-wide hybrid LCA

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Abstract

As part of the Integrated Carbon Metrics project, which comprehensively quantifies embodied GHG emissions related to the built environment in Australia, this contribution evaluates construction material replacement scenarios at the economy-wide scale. We investigate the potential use of Engineered Wood Products (EWPs) in new building stock to assess the carbon outcomes of a potentially significant shift in the use of construction materials. This becomes increasingly relevant as Australia moves forward with augmenting the National Construction Code to allow the construction of mid-rise buildings utilizing timber. The selection of low-carbon and sustainable building materials is crucial in reducing the built environment's carbon footprint. The main objective of the replacement scenario analysis is to assess the potential reduction in future GHG emissions by replacing the use of reinforced concrete with EWPs. The scenarios include the comparison of mid-rise buildings (10-story) with standard reference buildings (using reinforced concrete) at the national scale. The analysis considers the full cradle-to-gate carbon footprint of construction materials embedded in buildings. Since the scenarios are implemented in an input-output model of the Australian economy, changes in the use of construction materials can also be evaluated with respect to indirect effects on industries involved in the production chain of these materials as well as their respective GHG emissions.

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Keywords: construction materials; construction industry; engineered wood products; input-output modelling; residential and non-residential buildings

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1. Introduction

Whilst the construction industry in Australia directly accounts for only about 2% of total national greenhouse gas emissions, the carbon footprint of construction products such as buildings and infrastructure contributes 18% to the total national carbon footprint [1]. This is because the production of construction materials is an energy- and carbon-intensive process particularly for bulk materials such as concrete and steel. The carbon footprint of construction takes into account the life-cycle emissions of all these materials and of all other goods and services used in the supply chain of buildings and other construction products [2, 3]. In 2013, the Australian carbon footprint was 23.8 Mt CO_2e for residential building construction, 16.8 Mt CO_2e for non-residential building construction, and 57.1 Mt CO_2e for non-building construction (which includes road and bridge construction with

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9.8 Mt CO_2e) [1]. Within the building sector, construction materials are widely known to be a key contributor of embodied emissions with concrete, cement, plasterboard, limestone, brick and other ceramics accounting for the highest amount of embodied emissions (39.2%), whilst other large contributors include other minerals (24.2%), iron and steel (9.8%), timber (9.3%) and other metals (9.2%) [1]. The results of Yu et al. [1] corroborate those of other studies which show that concrete and steel account for the most embodied emissions in the building sector, including a study by Giesekam et al. [4] who found that 44% of industrial emissions were derived from cement and steel, whilst a study by Yan et al. [5] found that concrete or reinforced steel contributed to 94-95% of embodied material emissions. For domestic houses in Sydney, Ximenes et al. [6] calculated that a house design with the maximum use of timber could result in almost half the greenhouse gas emissions (GHGE) – around 30t CO2e – compared to a reference house by swapping the floor components including the sub-floor and floor cover from concrete to wood.

The concept of mass timber construction (MTC) refers to a construction process which utilizes wood-based materials as the main product in its structural design and development. It is primarily applied in replacing more common building materials, including reinforced concrete and steel frames. As a substitute product, MTC is suitable for low- to mid-rise buildings, and has been used worldwide in public sector projects (e.g. libraries, community hubs) as well as standalone and multi-dwelling residential units [7]. Cross-laminated timber (CLT), known as one type of Engineered Wood Product (EWP), is a prime example of an MTC product, which is manufactured by using industrial adhesives to glue together the surfaces of timber boards laid length-wise and perpendicular to each other [8, 9].

As a sustainable alternative for traditional concrete and steel construction materials, the application of MTC has significant implications for the building industry. Compared to the manufacture of concrete and steel, the MTC process consumes less embodied energy [10]. Shifts and changes in policies towards taxing and pricing carbon mean that there is economic value in carbon sequestration through the use of timber products. A study by Buchanan et al. [11] postulates that increasing the use of timber in New Zealand's building sector by 17% would result in a 20% reduction in fossil fuel energy consumption and a corresponding 20% reduction in GHGE by the manufacturing industry. In a broader context, this represents a 1.5% reduction in New Zealand's national GHGE.

Currently, Europe comprises the most developed markets in terms of MTC adoption, with countries such as Austria, Germany, Switzerland, Sweden and Norway leading the way for the rest of the world [7]. In comparison, the application of MTC in Australia is still in its infancy stages, having seen less than five total projects completed to date [7]. However, as of May 2016, amendments to the National Construction Code (NCC) and the Building Code of Australia (BCA) have allowed for the construction of residential and non-residential buildings up to 25 meters in height (or approximately 8 stories tall) in accordance with Deemed-to-Satisfy (DTS) provisions, which include the use of both EWPs like CLT and traditional lightweight timber framing [12-14]. This change in policy is anticipated to create greater opportunity and incentive for a more extensive use of timber in the development of Australia's city and urban landscapes. It is also a step forward in addressing the issue of direct GHGE from the construction industry, which is experiencing tremendous growth driven by a population that is expected to increase to 32 million people by 2036 and require an incremental 4.2 to 4.3 million new houses to be built [15]. To help drive construction of mid-rise timber buildings in Queensland, The University of Queensland has established a new research center, The Center for Future Timber Structures, to innovate new timber building products, assess the barriers to timber use and increase timber use in the built environment [16].

The aim of this paper is to investigate the consequences for total carbon footprint and direct industry GHGE when building designs shift towards using low-carbon construction materials. Scenario analysis based on hybrid life-cycle assessment (LCA) was conducted to evaluate the carbon footprint of timber building stocks and potential carbon savings through its use in the construction industry compared to more common building materials such as concrete. The results were also compared to an alternative scenario whereby low-carbon (geopolymer) concrete is used instead of timber. Geopolymer concrete does not contain any Portland cement, which is energy and emission intensive to produce, but is formed by blending industrial by-products such as fly ash and ground granulated blast furnace slag (GGBFS) with alkali activators [17-19]. For this paper, geopolymer concrete was used as a benchmark comparison to the timber replacement scenario.

Although for now DTS provisions only allow timber buildings of up to a maximum of 8-stories, the scenario analysis references the 10-story apartment Forte [20] as a model building because it is a real-life example of an existing building in Melbourne, Australia and multi-dwelling residential timber buildings of 4 to 20 stories have been constructed abroad [10, 21]. Outcomes of this study will help further understand the implications of substituting alternative building materials that are more sustainable and which can be utilized as main structural products in the construction industry in Australia.

2. Methods and Data

2.1. IO-based hybrid LCA method and data

An input-output (IO) based hybrid LCA methodology was used in this work to quantify the total carbon footprint of new residential and non-residential building construction in Australia. The IO-based hybrid method amalgamates the advantages of LCA to conduct precise assessments of specific products with the completeness of Input-Output Analysis (IOA) by applying an economy-wide system boundary and thereby eliminating the system boundary cut-off issue. IO-based hybrid LCA has been used successfully in previous work to calculate life-cycle-based, economy-wide, environmental implications of wind power generation [22], biofuels production [23, 24] and warm mix asphalt mixtures [25]. It has also been used to specify different electricity generation technologies for renewable electricity scenarios in Australia [26]. The scenario approach of that paper has been adopted in the present work (see section 2.3).

The issue of aggregation in IOA is overcome in the IO-based hybrid method by disaggregating the relevant industry sectors in the IO table and subsequently inserting specific process data of the selected product into the column of inputs to replace less specific IO data. In previous work, the authors hybridized IO sectors to more specific construction materials:

- Cement: The ‘cement’ sector was replaced with process data for Ordinary Portland Cement (OPC) [27].
- Concrete: The ‘Ready-mixed concrete and mortar’ sector was disaggregated into six types of concrete with varying degrees of OPC, fly ash and GGBFS as well as two types of geopolymer concrete [27].
- Timber: The ‘Glued Laminated Lumber’ sector was disaggregated into two types of EWPs: Glued Laminated Timber (GLT) manufacturing and Laminated Timber Element (LTE) manufacturing [28].
- Steel: ‘Other steel and iron manufacturing’ sector was disaggregated into two types of steel production: Basic Oxygen Furnace (BOF) steel manufacturing and Electric Arc Furnace (EAF) steel manufacturing. [29]

Input-output and GHGE data for 2008-2009 were extracted from the Australian Virtual Industrial Ecology Laboratory (IELab, https://ielab.info), which provides the most detailed enviro-economic accounts for Australia with a resolution of up to 1284 sectors and up to 2214 regions [30]. A national Supply and Use Table (SUT) was constructed in the IELab with a bespoke sector resolution deemed most appropriate to the analysis of built environment carbon footprints. Following the hybridization of concrete, timber and steel sectors described above, the final SUT consisted of 341 industry sectors, 345 product sectors, 5 value added rows and 6 final demand columns. This was further augmented with 26 sectors of imports from and exports to the rest of the world (RoW) as well as a domestic RoW transaction matrix sourced from Eora [31, 32] (see [33], Suppl. Information, page 4). Environmental extensions include direct industry emissions of methane (CH_4), carbon dioxide (CO_2), nitrous oxide (N_2O) and carbon dioxide equivalent (CO_2e).

2.2. Construction material data

The primary type of residential dwelling in Australia in the past has been detached housing. However, medium to high-density multi-unit dwellings have been growing rapidly and accounted for 25% of the total residential dwellings in 2014 [34]. The forecasted growth in high-density residential and commercial buildings underscores a significant shift in the Australian city lifestyle and working habits. Two types of ten-story buildings predominantly made of i) reinforced concrete (refer to Table 1) and ii) cross laminated timber (CLT) (refer to Table 1) as the main structural material were applied in this case study for the residential and non-residential sectors [20]. For the CLT building, concrete is used for the foundations while CLT is used beyond the first floor including the floor slabs, load bearing walls, stairwells and elevator cores. Process data were prepared by multiplying the quantity of supplied building products that is consumed in the development of a building block with the total number of building units in the given year and converted to monetary units. Although data for residential buildings in Australia are readily available via ABS in physical units, data for commercial buildings are scarce and are typically presented in monetary values. There is not available any published report which would state the national physical stock of commercial buildings in Australia [35, 36].

Therefore, the commercial building stock was estimated by dividing the surveyed average net floor area of an office (3612m^2) [37] by the total floor area of an average stand-alone office stock in Australia, which is available from Department of Climate Change and Energy Efficiency (DCCEE) [35]. The historical data (2009-2016) of the number of residential and non-residential buildings were derived from Australian Bureau of Statistics (ABS) [38] and DCCEE [35], whilst the number of building stock from 2016 to 2050 were projected from historical data [35, 38] assuming linear growth of 1.4% per year. Basic prices used in this study are the average national prices of the construction material components in 2009, exclusive of taxes and margins such as transport, retail or wholesale costs [27].

Table 1: Material requirements for a reinforced concrete building and a CLT building [20]

Material Requirements for Reinforced Concrete Building			**Material Requirements for a CLT Building**		
Materials	**Quantity**	**Unit**	**Materials**	**Quantity**	**Unit**
200mm hollow block wall	273	m^2	**10mm thick Uniroll**	1503	m^2
64 mm stud wall	361	m^2	**200mm hollow block wall**	273	m^2
Bar reinforcement	201	tonne	**64mm stud wall**	361	m^2
Concrete, 15MPa	163	m^3	**Alubond**	1478	m^2
Concrete, 32MPa	119	m^3	**Bar reinforcement**	83.24	tonne
Concrete, 40MPa	1441	m^3	**CLT, 090 mm thickness, 3 layer**	47	m^2
Concrete, 50MPa	24	m^3	**CLT, 094 mm thickness, 3 layer**	48	m^2
Cork tiles, 10mm thick	2282	m^2	**CLT, 095 mm thickness, 3 layer**	343	m^2
Uniroll	850	kg	**CLT, 125 mm thickness, 3 layer**	379	m^2
Internal insulation, rock wool	150	m^3	**CLT, 128 mm thickness, 3 layer**	3175	m^2
Glazin, double	687	m^2	**CLT, 140 mm thickness, 3 layer**	597	m^2
Glulam	1.68	m^3	**CLT, 145 mm thickness, 3 layer**	2575	m^2
Gravel	191.8	tonne	**CLT, 158 mm thickness, 3 layer**	90	m^2
Hebel panels	252	m^2	**Concrete, 15MPa, including in 70mm screed and flooring**	109	m^3
LLDPE	394.7	kg	**Concrete, 40MPa**	552.4	m^3
Plasterboard	13969	m^2	**Concrete, 50MPa**	24	m^3
Sand, at mine	36.08	tonne	**Glazing, double**	687	m^2
Structural steel beams	5.02	tonne	**Glulam**	1.68	m^3
Steel sheet 3mm thick, density of 7800 kg/m3	331	m^2	**Gravel**	192	tonne
Window frame, aluminium	120.6	m^2	**Hebel autoclaved concrete panels**	252	m^2
			LDPE film	395	kg
			Glass wool insulation	150	m^3
			Plasterboard 13mm	9380	m^2
			Plasterboard 16mm	3910	m^2
			Sand, at Mine	36.08	tonne
			Structural Steel	5.02	tonne
			Window frame, aluminium	120.6	m^2

2.3. Methodology for IO-based scenario analysis

Leontief [39] developed a computational method which allows the assigning of environmental impacts to the final demand for goods and services by using a series of input-output equations [40, 41]. The Leontief inverse matrix (L) expresses direct and indirect relationships between economic sectors, and allows for an evaluation of the total environmental impact across different levels of production. L is calculated as $(I-A)^{-1}$, where I is the identity matrix and A is a technology coefficients matrix, which in turn consists of the proportions of inputs from each sector *i* to the total input of sector *j* in the transaction matrix (x_{ij}). The direct GHGE intensity e_j of industry j is calculated by dividing direct industry emissions from the satellite block (E_j) by the total output of industry j (X_j). From this, the matrix vector of GHGE intensities (e_j) is multiplied by the L matrix and subsequently by the final demand vector (y) to derive the total carbon footprint (CF) measured in Mt CO_2e. The sector breakdown is preserved if final demand is placed on the diagonal of a symmetric matrix; this allows for the identification of selected products, e.g. residential buildings construction. This CF incorporates both direct and indirect emissions from cradle to gate, encompassing total emissions across the entire supply chain from raw material production to the manufacture of the final product.

When changes to the residential building sector's annual input data is introduced, there will be a mismatch in total inputs and total outputs in the table. The "analytical approach" developed by Malik et al. [42, page 86] and further applied in Wolfram et al. [26] rebalances the table through internal scaling of all other economic sectors. Basically, a new total output vector (X) and a new SUT are calculated following changes in industry inputs and intermediate and final demand for products for each year of the scenario time series.

In this study the inputs of construction materials to the building sectors were changed by gradually replacing concrete and steel with timber over time at the rate of 2.4% a year until the material is 100% replaced with the alternative building material in 2050 (refer to 2.4). The underlying assumption in this model was that only the coefficients in the residential and non-residential product rows of the technology coefficients matrix A change, whilst the input percentages of all other economic sectors remained consistent. Thus, the modification was made to the total inputs as a result of adjustments in total outputs.

The carbon footprint of all sectors as well as the new direct GHGE of all industries were calculated across all industries under a scenario, with the implicit assumption that the intensity of GHGE and hence the carbon efficiency of these industries (other than that of the residential and non-residential building sector) remain unchanged over time. In reality, other industries are likely to achieve some GHGE reductions as well; however, the simplifying assumption was made in line with the focus of this study on the residential and non-residential building sector. It allowed for both a more manageable data sourcing and modelling process, as well as an isolated view and impact assessment of the building sector.

2.4. Assumptions for material replacement scenarios

The four scenarios considered in this study for the residential building and non-residential building sector in Australia are as follows:

- Business-as-usual (BAU) scenario: uses reinforced concrete design (refer to Table 1) from 2009 to 2050, with electricity generated from fossil fuels.
- Business-as-usual with Renewable Energy (BAU-RE) scenario: uses reinforced concrete design (refer to Table 1) from 2009 to 2050 and assumes 96% renewable energy supply combined with an increase in electricity demand of 143% by 2050 based on a scenario from ClimateWorks [43].
- Timber scenario: Reinforced concrete design (refer to Table 1) decreases at the rate of 2.4% from 100% in year 2009 to 0% in year 2050, whilst CLT design increases from 0% in 2009 to 100% in 2050 at the same rate. Growing renewable electricity supply and demand as per the BAU-RE scenario. Two variations of this timber scenario were explored – with and without sequestration. Sequestration was estimated at 787 kg CO_2e per m^3 of softwood product [44].
- Concrete scenario: Reinforced concrete design (refer to Table 1) decreases at the rate of 2.4% from 100% in 2009 to 0% in 2050, whilst low-carbon concrete building using blended concrete increases from 0% in 2009 to 100% in 2030 and gradually decreases back to 0% in 2050. Over the same period, geopolymer concrete use increases from 0% to 100% from 2030 to 2050. Growing renewable electricity supply and demand as per the BAU-RE scenario.

It was assumed that all calculations for the 2009 to 2050 building stock have been conducted using the model 10-story building [20] for both the residential and commercial building sectors. The building stock quantity estimates for the residential sector are only inclusive of apartment residential buildings, and for the non-residential sector, only inclusive of office buildings. Historical residential and non-residential building stock were applied from year 2009 to the current year (2016), whilst building stock from 2016 onwards to 2050 were projected at a linear growth rate of 1.4% per year. The IO model assumed constant prices, i.e. the relationship between total physical quantity of materials and their total value in the IO table is constant.

All emissions intensities of all sectors remain constant in BAU, so that changes in construction materials could be studied in isolation and not affected by changes in other sectors. One exception to this principle was made for electricity in BAU-RE for which we adopted a renewable electricity scenario S2 from [26]. The reason being that electricity is a very important sector, both in terms of total GHGE (largest emitter in Australia) as well as the potential for decarbonization through rapidly changing markets for renewable electricity generation.

The decreasing GHGE intensity of electricity in BAU-RE has implications on all other sectors, and these changes were reflected in all the scenarios except for BAU. In detail, BAU-RE, Timber and Concrete scenarios assume 96% renewable energy supply combined with an increase in electricity demand of 143% by 2050 based on a scenario from ClimateWorks [43]. Economic growth of 150% by 2050 as assumed in [43] was applied in this scenario analysis.

3. Results and Discussion

The potential emissions savings were estimated with a number of replacement scenarios for both the residential and non-residential building stock for the time period of 2009 to 2050 (refer to 2.4). The carbon footprints of the four scenarios of the residential building sector are presented in Fig. 1~~Figure 1~~, excluding and including sequestration respectively. Reductions of CFs are achieved in all of the scenarios compared to BAU, with the timber scenario representing the best-case scenario across both figures. Under the BAU scenario, the CF of residential buildings is modelled to increase by 66% (26 Mt CO_2e) between 2009 and 2050. In comparison, under the timber scenario, the CF of residential buildings stays almost the same (excluding sequestration) but reducing by 236% (93 Mt CO_2e) when sequestration is considered. In this study, the carbon sequestration scenario assumes carbon is stored in the timber building materials indefinitely. If all the residential building stocks were constructed from CLT instead of reinforced concrete, emission reduction of 39% (26 Mt CO_2e) could be achieved in 2050 without sequestration compared to the BAU scenario. This saving would be even greater if sequestration was considered, with a potential to reduce emissions by 182% (119 Mt CO_2e) over the same period. The concrete scenario replaces reinforced concrete with geopolymer concrete in the residential building stock by 2050, representing a potential to reduce emissions by 38% (25 Mt CO_2e) compared to the BAU scenario.

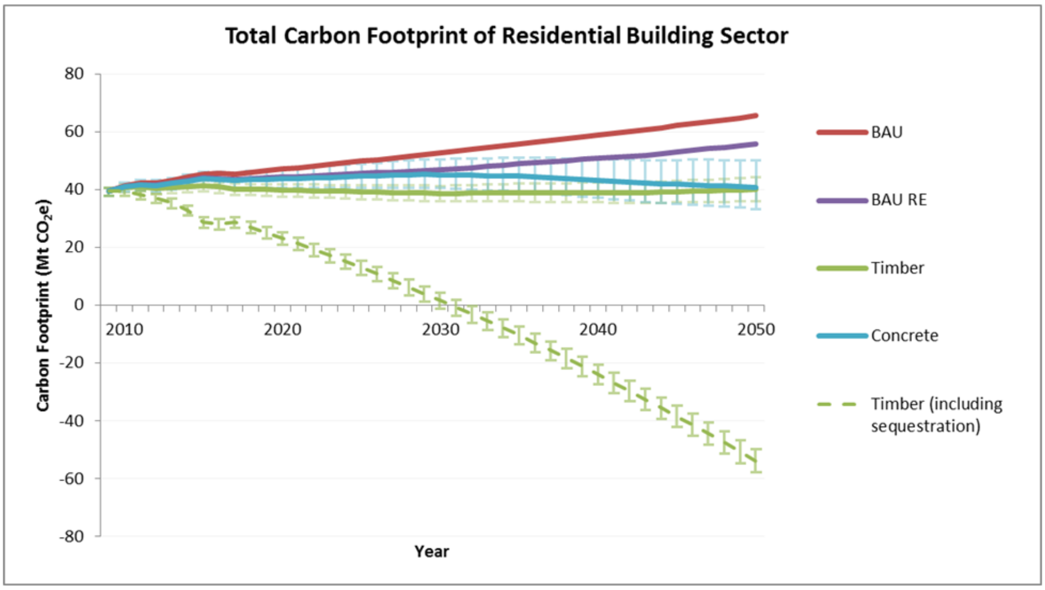

Fig. 1. Carbon Footprint of Residential Building Sector (excluding and including sequestration). See main text for an explanation of the uncertainty ranges.

Fig. 2~~Figure 2~~ shows the carbon footprint of commercial building stock emissions from 2009 to 2050, excluding and including sequestration respectively. The overall outcomes are in line with that of the residential building sector. Compared to the BAU scenario, all the other scenarios accomplished a reduction in CF with the timber and concrete scenario producing similar outcomes for commercial buildings when sequestration is not accounted for. The CF increased by 63% (17 Mt CO_2e) from 2009 to 2050 under the BAU scenario, whereas under the timber and concrete scenario it increased by a mere 15% (4 Mt CO_2e). By 2050, the timber scenario achieved an emission saving of 29% (13 Mt CO_2e) without sequestration, and 62% (28 Mt CO_2e) with sequestration, making it the best-case scenario.

The direct GHG emissions of the residential and commercial building sector had little or no change (0% to 1%) from 2009 to 2050. This is because the direct emissions of these industries mainly consist of operating construction equipment, such as trucks, caterpillars, pumps, hoists, cranes, etc. for which no emission changes were modelled (except electricity in BAU-RE). However, other sectors that are part of the intricate web of supply chains involving various construction-related and manufacturing industries in the economy show significant changes. For example, in the timber scenario, direct GHGE of timber-related supply chains such as the softwood industry increased by 179% (148 kt CO_2e), whilst concrete-related supply chains such as the cement industry decreased by 55% (12Mt CO_2e) from 2009 to 2050. Due to economy-wide system boundary in the IO-based hybrid method, the change of emissions in every sector resulting from the interdependencies of the supply chains in the economy can be modeled.

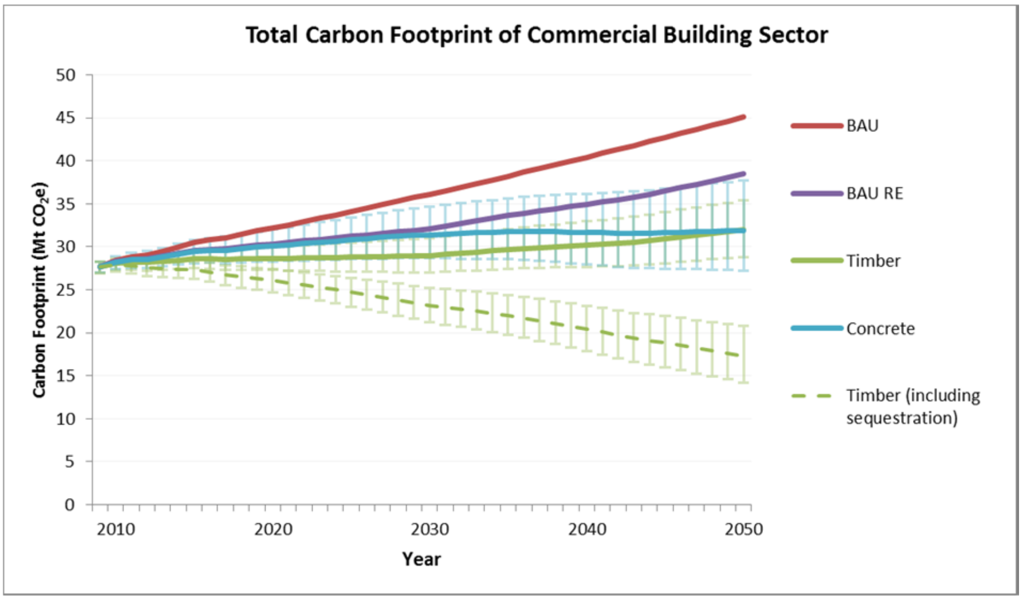

Fig. 2. Carbon Footprint of Commercial Building Sector (excluding and including sequestration). See main text for an explanation of the uncertainty range".

Overall, the total Australian carbon footprint of all the scenarios as compared to the BAU scenario showed significant reductions, with the timber and concrete scenario achieving 26% (213 Mt CO_2e) reduction, followed closely by the BAU-RE scenario with 23% (187 Mt CO_2e) reduction by 2050 (shown in ~~Figure 3~~). Assuming there are no other emission changes in the Australian economy, this means that construction material replacements, together with renewable electricity, have the potential to prevent a rise in GHGE due to economic growth. Sensitivity analysis was further conducted to analyze the uncertainty of CF results under the timber scenarios (excluding and including sequestration) and the concrete scenario, and is illustrated as error bars in Fig. 1~~Figure 1~~ and Fig. 2~~Figure 2~~. These were calculated by changing two variables, namely the retail market prices of materials and the number of projected buildings according to the high and low growth population projection data [45]. The uncertainty for the timber scenarios (excluding and including sequestration) and the concrete scenario were found to be in the range of 15-16% and 22-35% respectively. These values represent the maximum possible range of CF results of timber and concrete scenarios with respect to changes in the two independent variables.

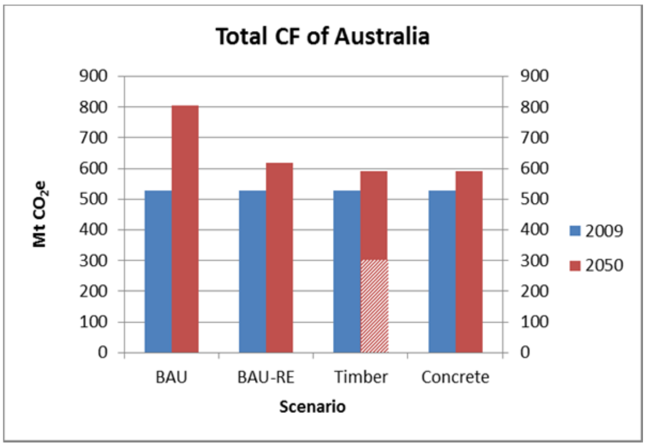

Fig. 3. Total Carbon Footprint of Australia (the dashed frame represents CF including sequestration)

Buchanan et al. [11] showed that a 17% shift in the use of timber building products in various types of buildings of New Zealand resulted in a 20% GHGE reduction (including sequestration) in the building supply chain. This study similarly modelled an increase in use of timber building products in Australia, which resulted in a 39% reduction in GHGE excluding sequestration, whilst a reduction of 182% can be reached when sequestration is considered under a scenario whereby there is 100% use of timber building products in 2050. In a national context, Buchanan et al. [11] concluded that it would result in a 1.5% reduction in New Zealand's national GHGE, whilst this study suggests that 62% of national reduction in CF can be achieved when carbon storage is considered. Another study by Braun et al. [46] modelled the substitution of traditional building products with timber products in Austria and established that emission savings of 1.5 million kt CO_2e (equivalent to around 20 years' worth of annual emissions) can be reached in a span of 90 years when taking into account carbon stock. This confirms that when sequestration is taken into account, much larger emission savings are achieved.

A study conducted by [2, 6] compared the CF of a concrete and wooden building in Sweden and Australia using the LCA method using a few different software (GaBi, SimaPro and Environmental Load Profile (ELP)). In both studies, the wooden building achieved a much lower CF ranging from 200 to 380 tons of CO_2e compared to the concrete building. The difference in CF results between the different software stemmed from country specific data i.e. SimaPro and GaBi holds European data while ELP holds data from Sweden. Sinha et al.'s study [2] stresses the importance of using country specific data to produce more accurate results. The bottom-up approach is useful when assessing environmental impacts of a single building whilst the hybrid approach enables a nation-wide assessment of buildings. However, the CF of a single building can also be computed by dividing the total CF by the number of buildings, especially in this case study because a singular model building was assumed. The CF of the model building Forte using the hybrid approach, which covers emissions from cradle to gate, resulted in 324 tons of CO_2e. The global warming potential of the Forte building quantified with the LCA approach, considering only the material and construction phase of the life cycle, resulted in 795 tons of CO_2e [20]. The higher result from LCA is due to the assumptions underlying the CLT, whereby CLT is produced and shipped from Austria, whereas in the hybrid approach CLT is assumed to be made and produced in Australia, with renewable energy in the electricity mix in 2050.

4. Limitations

In reality, the amendments to the NCC and the BCA allow for the construction of residential and commercial buildings of approximately up to 8 stories (25 meters in height), but this scenario analysis strives to see what would happen if an existing 10-story Forte timber building model were applied in the shift to 100% timber building scenario in Australia. This study has also assumed a homogenous residential and non-residential building stock of a 10-story building. Australia's current and future building stock is more likely to have a heterogeneous assemblage, that is, different sized buildings with varying structural material quantities. In order to improve the accuracy of the results, it is recommended that further research be undertaken to identify a more representative building stock assemblage. The analysis taken in this study does not consider the service life of EWPs and geopolymer concrete because CF results reflect cradle-to-gate stages of new building stocks which is until the point of building completion. However, it is worth noting that CLT products are certified by the UK Building Research Establishment to have a lifespan of around 60 years [47], whilst geopolymer concrete is still an emerging product and hence its lifespan in real-world applications is not yet known [48]. Data for the national physical stock of commercial buildings were not available and were assumed in this study [35, 36]. Better results can also be achieved with better availability of building stock data. To date, CLT utilized in Australia is produced and shipped from Europe, but in the hybrid model, international container transport of CLT from Austria has not been taken into account.

5. Conclusions

By comparing residential and non-residential building stock scenarios using an IO-based hybrid LCA scenario method, this study was able to gain some insight into potential emissions reductions opportunities. The best-case emissions scenario would require all new building stock (both residential and non-residential) to be constructed from a timber structural design (timber scenario), with the worst-case emissions scenario being the one in which new building stock is constructed from conventional reinforced concrete design (BAU scenario). If 100% of new residential building structures were to be constructed from EWPs instead of 100% reinforced concrete, a saving of 26 Mt CO_2e can be achieved by 2050. This saving is even greater when sequestration is considered, with a potential to reduce emissions by 119 Mt CO_2e. Similarly, if 100% of new commercial building structures were to be constructed from EWPs instead of 100% reinforced concrete, a saving of 13 Mt CO_2e can be achieved by 2050 and when sequestration is considered, a higher emission saving of 28 Mt CO_2e can be achieved.

Past studies have shown that embodied emissions are contributing more to a buildings life-cycle emissions, with strategies focusing solely on improving operational emissions insufficient to meet sector emission reduction targets [49]. Despite this, existing policies in Australia are still primarily targeted at reducing operational emissions. It was suggested by the Australian Sustainable Built Environment Council (ASBEC) [50] that Australia should aim to achieve net zero operational emissions buildings by the year 2050 if it were to comply with the Paris Climate Change Agreement commitments. This study shows that this alone would not be sufficient as the building sector continues play a crucial role in carbon emissions through embodied emissions. Hence, the use of timber as a low embodied energy construction material is to be recommended in the construction of buildings, at least with respect to lowering GHG emissions. However, there are some barriers in preventing the uptake of CLT (as well as other novel alternatives) as a construction material, including conservative views by construction industry participants, lack of information about the benefits of CLT and cost concerns [51]. Fortunately, the recent amendments to the NCC and BCA in Australia have allowed for the construction of residential and non-residential buildings up to approximately 8 stories [5, 6], and this is a step forward for Australia in the utilization of timber in new building stocks. This change in policy is anticipated to create greater opportunity and incentive for a more extensive use of timber in the development of Australia’s city and urban landscapes.

The use of EWPs in construction seems to be on the rise globally, as evidenced by the 20-30% increase of CLT production per year in Central Europe since 2008 and the use of wood frame buildings in UK have increased from 8% to 25% in 10 years (1998-2008) [52]. However, it is also crucial to view material properties holistically and not focus solely on one environmental parameter such as embodied carbon emissions. There are other environmental impacts from increased wood production and it depends on the exact forestry practices to determine whether these impacts are detrimental or beneficial to the environment. Furthermore, due consideration needs to be given to the choice of materials as they influence functionality and operational efficiency of buildings. Extensive research into the performance of EWP buildings has highlighted that these buildings are similar or even better than equivalent steel and concrete buildings, not just in terms of embodied emissions, but also in aspects of constructability, fire resistance and thermal capacity [53].

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