Market Access

Estimating the benefits of an emissions reduction fund method for the use of timber products in buildings

Project number: PRA541-2021

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Forest & Wood Products Australia

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Prepared for

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EXECUTIVE SUMMARY

Forest and Wood Products Australia contracted Natural Capital Economics to assess the potential benefits of an Emissions Reduction Fund (ERF) method for the use of sustainable structural timber products in buildings. The introduction of such a method has the potential to directly assist Australia in reducing its greenhouse gas emissions by incentivising greater use of sustainable timber in the structural components of residential and non-residential buildings in place of more emissions intensive building materials, like steel and concrete.

The introduction of the proposed ERF method may also lead to an increase in Australia's carbon sequestration potential through an increase in the domestic supply of softwood sawlogs. An increase in supply is predicated on increased sawlog demand placing upward pressure on sawlog prices and incentivising investment in domestic sawlog supply.

Key findings from the study include:

- A 1% upward shift in the market share of structural timber in place of steel and concrete, in class 1, class 2 (below 9 storey) and non-residential buildings over the period of 2021 to 2050 would reduce emissions by 1.3 Mt CO_2-e in total and 1.0 Mt CO_2-e domestically.

- The domestic emissions reduction from a 1% upward shift is equivalent to 0.03 Mt CO_2-e annually over the assessment period. A 10% and 20% increase in market share over this timeframe is estimated to have a ten and twentyfold effect on the level of emissions reductions.

- A 1% upward shift in the market share of structural timber will require a 5.3 million m^3 increase in above ground tree biomass between present day and 2050. This biomass has the potential to sequester 4.7 Mt CO_2-e, which equates to 0.15 Mt CO_2-e of reduced emissions annually.

Annual emissions reductions from a 1% increase in the market share of timber combined with potential additional annual carbon sequestration is equivalent to 2.2% of the abatement purchased by the Clean Energy Regulator in 2020. When these emissions reductions are combined (direct and indirect emissions reductions), the emissions reductions from carbon sequestration account for about 80% of the total estimated emissions reductions from the proposed ERF method. However, there is less certainty associated with emissions reductions from carbon sequestration than with the emissions reductions from greater use of sustainable timber. This is because an increase in sawlog supply is dependent on softwood sawlog prices increasing sufficiently to stimulate additional domestic plantation investment.

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1 BACKGROUND AND APPROACH

1.1 Background

Forest and Wood Products Australia (FWPA) contracted Natural Capital Economics (NCE) to assess the potential benefits of an emissions reduction fund (ERF) method for the use of sustainable structural timber products in buildings. The benefits of such a method would be in the form of greenhouse gas (GHG) emissions reductions being mainstreamed within national carbon accounting.

The introduction of this type of method has the potential to incentivise greater use of structural timber in residential and non-residential building construction and reduce the use of more emissions intensive building materials by allowing ERF participants to claim Australian carbon credit units (ACCU) for associated emissions reductions. The ability to claim ACCUs is expected to create a relative reduction in the price of structural timber compared to competing materials and is expected to increase demand for structural timber products. Increases in demand may also incentivise greater investment in the supply of sustainable domestic plantation timber, which would in turn increase Australia's carbon sequestration potential.

1.2 Scope and approach

To evaluate the benefits of the proposed ERF method, this study has investigated the reductions in carbon emissions that can be achieved through an increase in the use of structural timber in class 1[1], class 2[2] (below 9 storeys) and non-residential buildings (i.e. the estimated direct emissions reductions). This study has also considered how an increase in structural timber demand and wood use could help to increase carbon sequestration in Australian forests and plantations (i.e. the estimated indirect emissions reductions).

This study has involved high-level desktop analysis, drawing on publicly available data, with limited data validation. Two linked economic models were developed to calculate the direct and indirect emissions reductions that could potentially be achieved between present day and 2050. In the models, a range of values are used for most inputs which provides a range of results. This approach is used to address uncertainty around the exact value of each input.

Direct emissions model

The direct emissions model calculates the estimated reductions in emissions that would occur from an upward shift in the market share of structural timber in building construction over the period between present day and 2050. This reflects a substitution of timber for steel or concrete building inputs.

The direct emissions model considers three scenarios, a 1% (scenario 1), 10% (scenario 2) and 20% (scenario 3) uplift in market share for timber. These scenarios reflect a low, mid, and high outcome. For class 1 buildings, market share is assumed to be taken exclusively from steel due to the limited market share of concrete in these buildings. For class 2 and non-residential buildings, increased market share of timber is assumed to be taken from both steel and concrete.

The direct emissions model does not consider the emissions reductions available from replacing concrete or steel with timber in high rise (9 storey and above) residential buildings or for alterations and additions works on existing buildings. It also only considers the emissions reductions achieved by using timber instead of steel or concrete and not other structural building materials, like brick. Except

[1] Domestic or residential buildings – single, standalone single houses and horizontally attached houses, such as terrace houses, row houses or townhouses.

[2] Domestic apartment buildings.

for brick in class 1 buildings, other structural building materials have relatively low levels of market share.

Direct emissions reductions are estimated in terms of volume (Mt CO_2-e) and present value. Furthermore, they are reported as total emissions reductions (i.e. ignoring national borders) and as domestic emissions reductions. This is an important distinction as it is only emissions reductions that occur in Australia which are eligible for ACCUs, but total emissions reductions are more reflective of the transnational nature of climate change.

The direct emissions model framework is shown in Figure 1. Key inputs categories into the direct emissions model include:

- **Estimated market share of structural building materials.** For class 1 and class 2 (up to 3 storeys) buildings, present day market share is based on estimates reported in Australian Construction Insights (2018). In the absence of national data, market share for class 2 buildings (above 3 storeys) and non-residential buildings is based on market share in Victoria. This was determined through analysis of the Victorian Building Authority's (2018; 2019; 2020) permit data, which includes information on frame material. Market share in Victoria is expected to be similar to market share elsewhere in Australia. However, in Western Australia there is expected to be greater use of double brick as a building material than in Victoria.
- **Volume of residential and non-residential building construction between present day and 2050**. Present day residential construction volumes are based on the number of building approvals and dwelling size data from the Australian Bureau of Statistics (ABS 2021-a; 2018). For non-residential construction, ABS (2021-b) data on the national value of building approvals by sector were divided by Rawlinsons (2020) estimates of the cost of constructing different types of non-residential buildings to estimate the present day construction volume. The estimated growth in construction volumes to 2050 is primarily based on a construction forecast to 2035 by BIS Oxford (n.d.).
- **Estimated quantities of structural building materials used in building construction**. Building material estimates are based on building material quantities reported in published lifecycle assessments (see reference list) as well as FWPA estimates based on the quantity of material used by the building construction industry and volumes of construction.
- **Emissions factors relating to the production of building materials.** These emissions factors are based on data in published literature (see reference list).
- **Emissions factors relating to the transportation of building materials.** These emissions factors are based on data in published literature. The transportation distance between the production of the building material and the location of the building construction site was assumed to be between 10 and 50 km.
- **Estimates of the quantity of building materials being produced overseas**. These estimates are based on ABS data from input-output tables as well as other industry and government sources on the quantity of domestic production and imported products (see reference list).

Indirect emissions model

The indirect emissions model estimates the potential increase in carbon sequestration in Australian forests and plantations as a result of a 1% (scenario 1), 10% (scenario 2) and 20% (scenario 3) uplift in market share for timber. The model uses estimates of the change in timber use from the direct emission model and converts these to sawlog and above-ground tree biomass equivalent volumes before determining the potential amount of embedded carbon. Indirect emissions reductions are estimated in terms of volume (Mt CO_2-e) and present value.

The indirect emissions model framework is outlined in

Figure 2. Key input categories into the indirect emissions model include:

- **Estimates of wood use** from the direct emissions model.
- **Wood recovery rates** as presented in Downham, Gavran & Frakes (2019), Ximenes, Gardner & Kathuria (2008), and Ximenes & Grant (2012).
- **Estimates of embedded carbon in wood** from ABARES (2013)

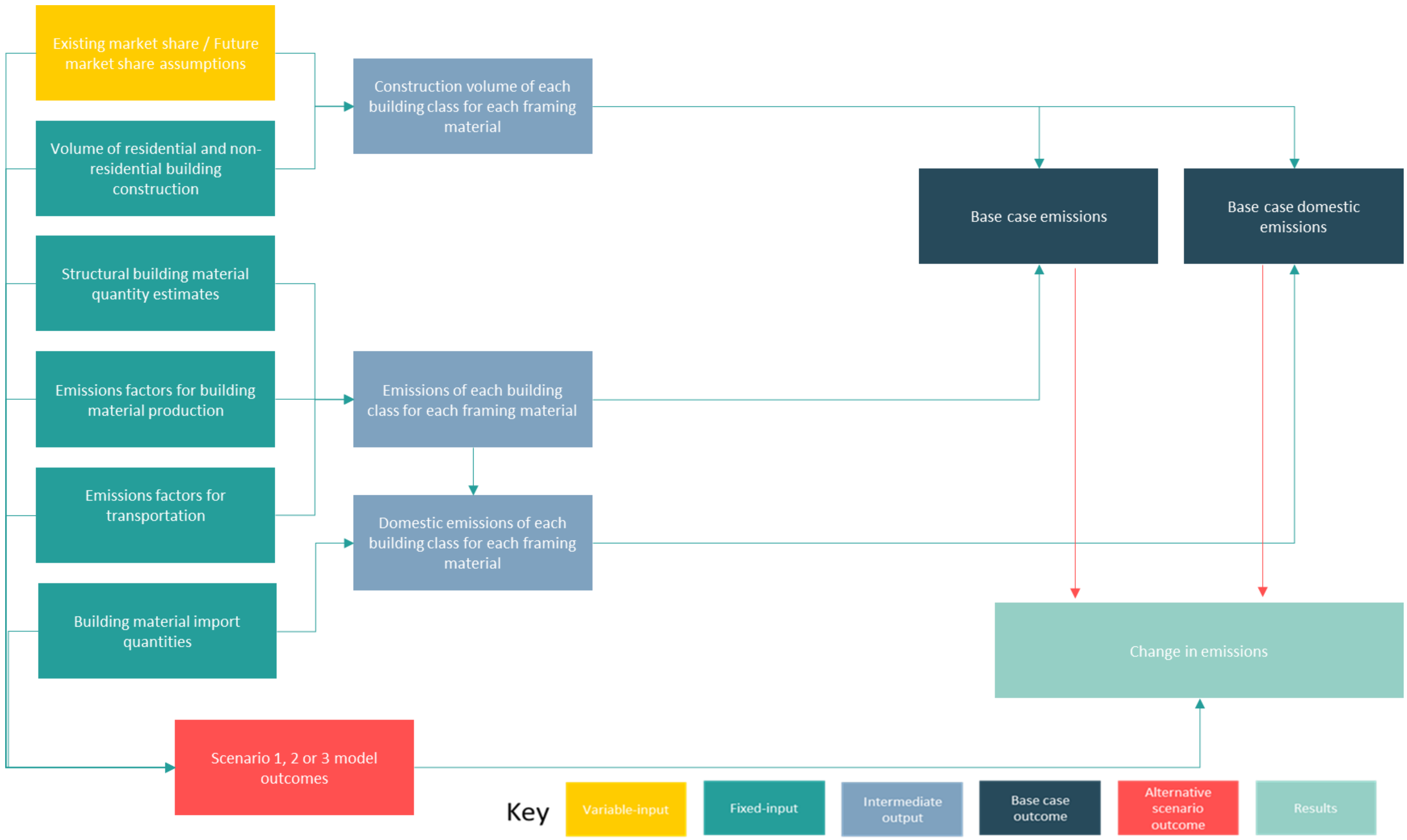

Figure 1. Direct emissions model framework

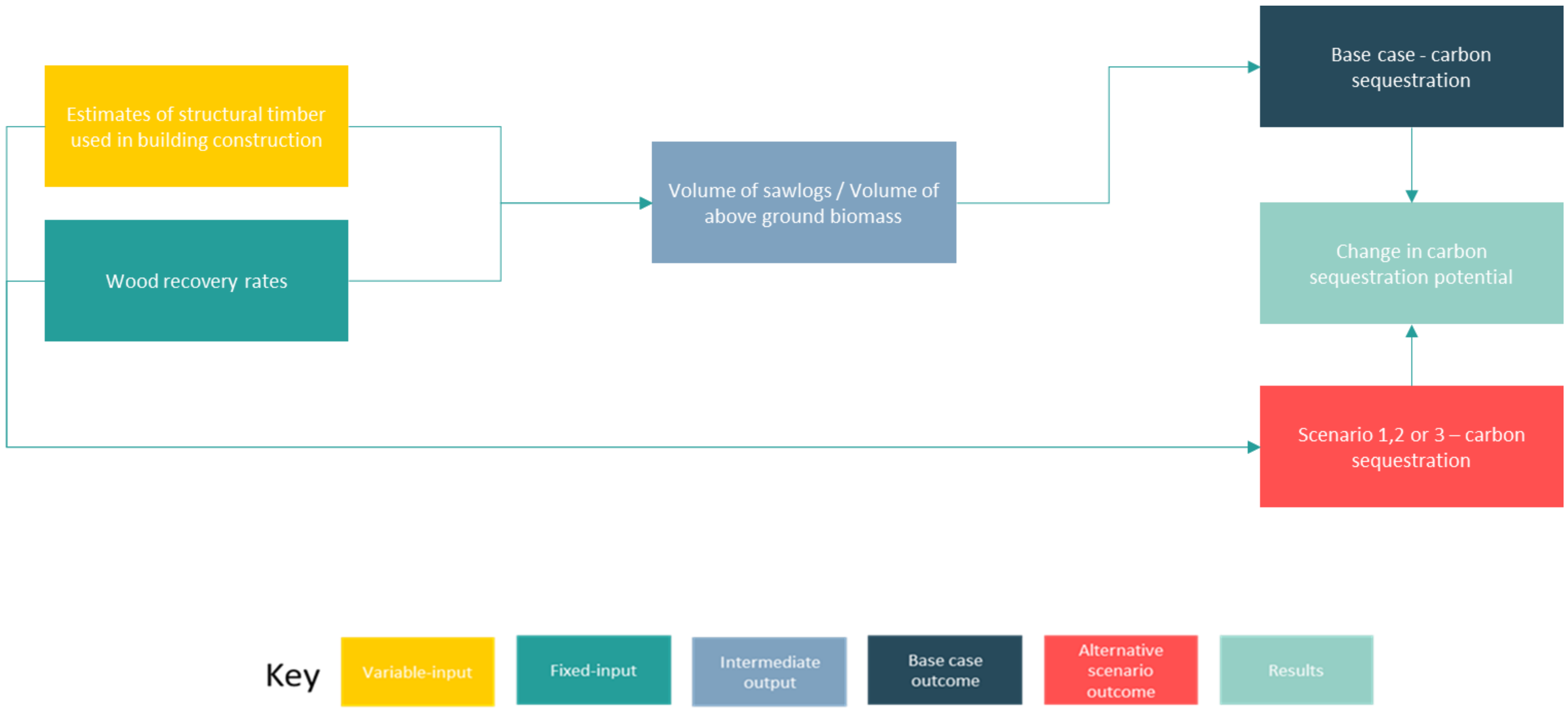

Figure 2. Indirect emissions framework

2 RESULTS

2.1 Direct emissions reductions from increased use of structural timber

The results of the direct emissions analysis for total emissions reductions are shown Table 1. It indicates that a 1% increase in structural timber market share in class 1, class 2 and non-residential buildings is estimated to reduce total emissions by between 0.8 and 2.6 Mt CO_2-e (megatonnes of carbon dioxide equivalent) between present day and 2050. The present value of these emissions is estimated to be between AUD9.5 and AUD37.2 million with the low estimate based on the current ACCU price and the high estimate based on achieving an ACCU price of $100/tonne CO_2-e by 2050. A 10% (scenario 2) and 20% (scenario 3) increase in market share over this timeframe is estimated to have a ten and twentyfold effect on the level of emissions reductions and the present value of emissions.

Table 1. Estimated total emissions reductions results (direct emissions)

Increase in market share of timber to 2050	Estimated emissions reductions (Mt CO_2-e)			Estimated present value ($ million)		
	Low	Mid	High	Low	Mid	High
1% (Scenario 1)	0.8	1.3	2.6	9.5	14.4	37.2
10% (Scenario 2)	8.5	13.4	26.3	95.2	144.3	371.6
20% (Scenario 3)	16.9	26.2	50.9	187.9	281.4	715.8

When only domestic emissions are considered the benefit of the proposed ERF method decreases. This is because, under this model, the emissions associated with producing building materials are excluded for imported products[3]. This makes the emissions of building materials appear lower than they actually are. The assumptions associated with the percentage of each building material imported are presented in Table 2.

Table 2. Building material imports as a percentage of the total building material used in building construction.

Building material	Residential building construction			Non-residential building construction		
	Low	Mid	High	Low	Mid	High
Cement (for concrete)[4]	3.0%	3.8%	9.2%	1.8%	2.3%	9.2%
Steel	20.0%	25.0%	30.0%	30.2%	37.7%	45.3%
Timber	9.3%	11.7%	28.0%	9.3%	11.7%	50.0%

The results of the direct emissions analysis for domestic emissions reductions are shown in Table 3. They estimate that a 1% increase in structural timbers market share may reduce domestic emissions by between 0.7 and 2.1 Mt CO_2-e between present day and 2050. The present value of these emissions is estimated to be between AUD7.8 and AUD29.4 million.

[3] Only emissions reductions that occur in Australia are eligible for ACCUs

[4] Cement is imported to create concrete. Cement manufacturing is estimated to account for 85% of the embodied energy of concrete (Marceau, Nisbet & VanGeem, 2007)

Table 3. Estimated domestic emissions reductions results (direct emissions)

Increase in market share of timber to 2050	Estimated emissions reductions (Mt CO_2-e)			Estimated present value ($ million)		
	Low	Mid	High	Low	Mid	High
1% (Scenario 1)	0.7	1.0	2.1	7.8	11.3	29.4
10% (Scenario 2)	6.9	10.4	20.8	77.6	112.7	294.5
20% (Scenario 3)	13.9	20.5	40.3	153.8	220.0	568.4

A comparison of total and domestic emissions reductions across time is shown in Figure 3. Importantly, the results shown represents the midpoint of the estimates. Annual domestic emissions reductions may be higher if a lower level of building materials are imported.

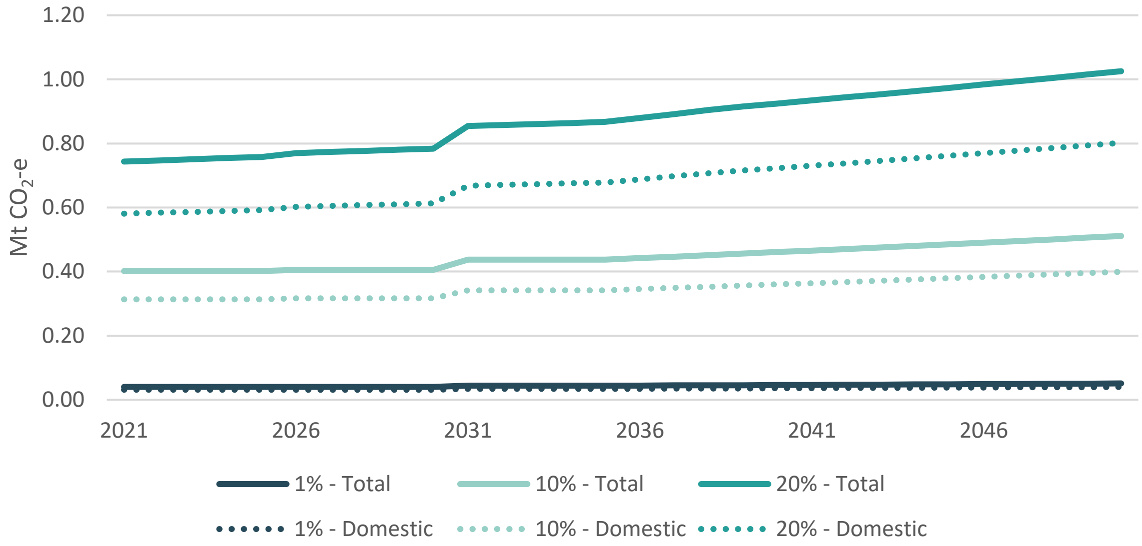

Figure 3. Estimated total and domestic emissions reductions with increased market share of structural timber

Across building classes, the biggest reduction in emissions for a 1% increase in market share is attributed to non-residential buildings. This comes despite the volume of non-residential building construction being about half that of class 1 building construction (on a square meter basis). The increased use of structural timber in non-residential buildings is estimated to account for 66% of the domestic emissions reductions, while class 1 buildings and class 2 buildings are estimated to account for 25% and 9% respectively. Estimated emissions reduction by building class are present in Appendix A.

There are multiple reasons why an increase in market share of timber in non-residential buildings is expected to result in the biggest impact. In non-residential construction (as opposed to class 1), timber buildings result in greater carbon emissions reductions per square meter, relative to steel buildings. This is due to a greater differential in the volume of materials being used, which is partly attributed to changes in design associated with higher storey buildings. Additionally, in non-residential construction, timber is assumed to take market share from concrete, which is the most carbon intensive of the three structural building material investigated.

2.2 Indirect emissions reductions from increased supply of sawlogs

ABARES estimated plantation and native forest sawlog availability and sawlog demand in Australia to 2050. Based on this data and the level of sawlog exports in 2019-20 (4.4 million m^3), the average annual supply shortfall of softwood sawlogs is calculated to be between 3.4 and 6.3 million m^3. For hardwood sawlogs, supply outweighs demand by an average of 0.8 million m^3. Based on this data, additional carbon sequestration in Australia could be achieved by increasing the supply of softwood sawlogs to meet demand. Sustainable structural timber products for use in buildings are mostly derived from softwood sawlogs (ABARES, 2016; 2019; 2020; Burns et al, 2015; Whittle, Lock & Hug, 2019).

The results of the indirect emissions reductions analysis are presented in Table 4 and Figure 4. They indicate that a 1% increase in structural timber's market share in class 1, class 2 and non-residential buildings has the potential to increase carbon sequestration by between 3.9 and 8.9 Mt CO_2-e between present day and 2050. The present value of the CO2-e abatement is estimated to be between AUD42.4 and AUD129.6 million. Associated increases in above-ground tree biomass for each scenario are presented in Table 5.

Table 4. Estimated indirect emissions reductions results

Increase in market share of timber to 2050	Estimated emissions reductions (Mt CO_2-e)			Estimated present value ($ million)		
	Low	Mid	High	Low	Mid	High
1% (Scenario 1)	3.9	4.7	8.9	42.4	51.3	129.6
10% (Scenario 2)	38.6	47.3	89.2	424.2	513.2	1295.8
20% (Scenario 3)	73.7	90.8	170.5	797.2	972.9	2462.7

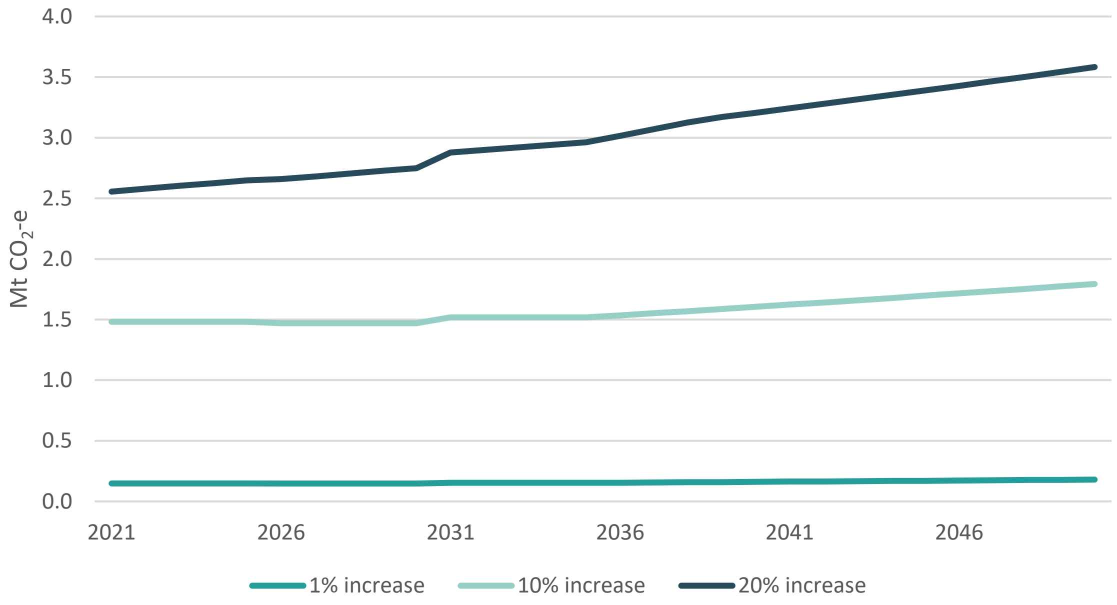

Figure 4. Estimated indirect emissions reductions through time

Table 5. Estimated increases in above ground timber biomass

Increase in market share of timber to 2050	Estimated increase in above ground timber biomass (million m^3)		
	Low	Mid	High
1% (Scenario 1)	4.4	5.3	10.0
10% (Scenario 2)	43.8	53.4	100.5
20% (Scenario 3)	83.9	102.7	192.2

2.3 Australian context

To put these emissions reductions in context, the range of emissions reductions targets that Australia (at a national and state level) is (or was) committed to achieving has been considered.

Australia's current emissions target for 2030 is set at 26 to 28% below 2005 levels. In 2005, Australia's GHG emissions were estimated to be 615.5 Mt CO_2-e, which set the target level to 443.1 Mt CO_2-e (28%). To meet this target, Australia will be required to achieve abatement of between 56 and 123 Mt CO_2-e between 2021 and 2030 (DISER, 2020; 2020-a).

Before it was repealed, the Clean Energy Act 2011 set out an objective for Australia to reduce its GHG emissions by 80% from 2000 levels by 2050 (Climate Change Authority, n.d.). In 2000, Australia's GHG emissions were estimated to be 544 Mt CO_2-e, which set the target level to about 110 Mt CO_2-e. This is a reduction in emissions of about 400 Mt CO_2-e on 2020 emissions levels (DISER, 2020-a).

In Australia, all states and territories are aiming to achieve net-zero emissions by 2050. This means that by 2050, any emissions will need to be offset by carbon storage. This aim is in alignment with the Paris Agreement (Climate Council, 2020).

In September 2020, the Clean Energy Regulator (CER) purchased 8.7 Mt CO_2-e abatement via the 10th and 11th ERF auctions. This brings the total abatement purchased by the CER since 2015 to 200 Mt CO_2-e. Of this purchased abatement, 29.5% has been delivered to date (CER, 2020).

Table 6 presents the emissions reductions results of this study relative to the activity of the CER. When both direct (domestic) and indirect emissions reductions are considered, the proposed ERF method has the potential to reduce emissions at an annual rate equivalent to between 2.2 and 41.7% of the total abatement purchased in 2020. If timber achieves a higher market share than 20%, this rate will increase.

Based on the three scenarios presented, between present day and 2050, the proposed ERF method could potentially reduce emissions in Australia by an amount equivalent to between 2.9 and 55.7% of the total abatement purchased to date by the CER. This data suggests that an ERF method for the use of sustainable structural timber products in buildings could make a considerable contribution to Australia achieving its GHG emissions reductions targets.

Table 6. Emissions reductions in relation to activity of the Clean Energy Regulator

	Increase in market share of timber to 2050					
	Estimated average annual emissions reductions (Mt CO_2-e)			Estimated emissions reductions to 2050 (Mt CO_2-e)		
Emissions model	**1%**	**10%**	**20%**	**1%**	**10%**	**20%**
Direct emissions (domestic)	0.03	0.35	0.68	1.04	10.44	20.52
Indirect emissions	0.16	1.58	3.03	4.73	47.26	90.82
Total emissions reductions	0.19	1.92	3.71	5.77	57.69	111.34
Total emissions reductions as a % of abatement purchased in 2020	2.2%	21.6%	41.7%		n/a	
Total emissions reductions as a % of abatement purchased to date		n/a		2.9%	28.8%	55.7%

2.4 Limitations

The models developed for this study include a number of assumptions and have relied on imperfect data.

Key limitations of this study include:

- **Estimated building materials** contained in timber, concrete and steel buildings are a key driver of the results of this study. However, they are based on a limited number of studies. To strengthen the model and its outcomes, a larger sample size of building material estimates for each class of building and for each framing type is required.

- **Imported materials** is a critical variable to the direct emissions model. It influences the proportion of the total emissions reductions eligible to earn ACCUs. All else equal, the higher the level of building material imports, the less influence the proposed ERF method will have in reducing Australia's GHG emissions under existing accounting standards. To improve the robustness of results, a more detailed analysis of the origin of building materials is required.

- **Sawlog supply and carbon sequestration -** This study has not considered the likelihood of an increase in the domestic supply of softwood sawlogs driven by an increase in demand and price of structural timber or factored in the time required for Australia to increase domestic supply. An increase in the domestic supply of sustainable timber products is required for the proposed method to be able to deliver an indirect emissions reduction benefit in the form of increased carbon sequestration.

  An increase in demand for sawlogs may not increase the price of sawlogs or domestic sawlog supply. Firstly, a price increase may not be high enough to stimulate additional plantation investment. Secondly, an increase in demand may be met by an increase in imports, or with sawlogs previously earmarked for export. These alternative scenarios have the potential to limit the indirect emissions reductions benefit associated with the proposed ERF method.

  The proposed ERF method still has the potential to provide an indirect emissions reductions benefit if Australia's domestic supply of sawlogs remains constant. This would occur if its introduction increased the global supply of sustainably sourced[5] sawlogs which would in turn increase global carbon sequestration capacity. However, under current carbon accounting standards, this benefit would not assist Australia in meeting its emissions targets.

- **Change in market share -** The introduction of the proposed ERF method is expected to cause an upward shift in market share for the use of structural timber. However, there may also be a gradual increase in market share through time that occurs as builders' transition from using other materials to timber. The models developed for this study only accounts for a one-off upward shift. The faster market share increases, the more emissions reductions which will be achieved by 2050, and vice versa.

- **Plantation forestry ERF method -** The plantation forestry ERF method outlines how ACCUs can be claimed for stored carbon in plantation forests. As part of calculating eligible carbon abatement, carbon emissions from management activities like harvesting must be considered (ERF, 2021). According to Tucket et al (2009), the production of an average softwood log creates 26 kg CO_2-e per m^3. This carbon accounting approach means that for some wood products (those coming from plantation forests and using the plantation forestry method) part of their emissions are offset against sequestered carbon. This makes the net emissions of these products lower and suggests that the results of this study may underestimate the direct emissions reductions associated with using timber in buildings. The degree to which emissions reduction are underestimated will depend on the volume of timber products coming from plantation forests using the plantation forestry method to claim carbon credits as well as the quantity of emissions associated with management activities.

To account for uncertainty, results have been presented as a range rather than discrete estimates with the low and high estimates set at 10% and 90% confidence intervals, respectively. These ranges have been determined from sensitivity analysis using a Monte Carlo simulation with 50,000 iterations.

[5] Sustainable timber refers to timber that has been harvested responsibly from well managed forests that are continuously replenished (Accoya, n.d.)

3 CONCLUSION

The introduction of the proposed ERF method has the potential to assist Australia to reduce its GHG emissions and meet its emissions target in 2030. This would occur by incentivising greater use of structural timber and potentially from increasing the supply of domestic softwood sawlogs and carbon sequestration potential from Australia's forestry estate.

The proposed ERF method is expected to increase demand for structural timber. It is also expected to create a significant emissions reductions benefit. The magnitude of this benefit will depend on how quickly and to what degree timber can take market share from other structural building materials and which building materials lose market share. This high-level analysis has attempted to present realistic scenarios relating to changes in market share, however, more detailed investigation and analysis would improve the accuracy of the assumptions.

Of the two benefits assessed (direct and indirect emissions reductions), the indirect emissions reductions associated with an increase in sawlog supply and carbon sequestration has potential to be the most beneficial from an emissions reductions perspective. However, further investigation is required to understand what size increase in domestic timber supply is achievable. The likelihood of the proposed ERF method resulting in an increase in supply will depend on the magnitude of any change in demand and price, as well as the economics of plantation timber which must consider land values, the price of carbon and international competitiveness.

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APPENDIX A - EMISSIONS REDUCTION RESULTS BY BUILDING CLASS

Appendix A present the result of this study by building class.

Table 7. Midpoint direct emissions reduction results by building class (Mt CO2-e)

	Total emissions reductions (midpoint estimates)			Domestic emissions reductions (midpoint estimates)		
	Increase in market share of timber to 2050					
Building Class	**1%**	**10%**	**20%**	**1%**	**10%**	**20%**
Class 1	0.3	3.3	6.1	0.3	2.6	4.7
Class 2 (1-3 storeys)	0.0	0.2	0.6	0.0	0.2	0.5
Class 2 (4-8 storeys)	0.1	0.9	1.8	0.1	0.8	1.6
Non-residential	0.9	8.9	17.8	0.7	6.9	13.7
Total	1.3	13.4	26.2	1.0	10.4	20.5

Table 8. Midpoint indirect emissions reduction results by building class (Mt CO2-e)

	Increase in market share of timber to 2050		
Building class	**1%**	**10%**	**20%**
Class 1	0.3	3.3	6.1
Class 2 (1-3 storeys)	0.0	0.2	0.6
Class 2 (4-8 storeys)	0.1	0.9	1.8
Non-residential	0.9	8.9	17.8
Total	1.3	13.4	26.2

APPENDIX B – MODEL INPUTS

Appendix B present the inputs for the direct and indirect emissions models.

Direct emissions reductions model inputs

Table 9. Volume of building materials inputs

Description	Building Class	Framing Material	Material	Low	Mid	High	Input	Units	Source	Assumptions
Estimates of the volume of building materials by framing material	Class 1	Concrete	Concrete	1.194	1.342	1.489	1.342	t/m²	John et al. (2008); Carre & Crossin (2015); Carre (2011); Dodoo (2019)	The low and high input values are based on building material quantities from published lifecycle assessments. For Class 1, steel-steel and wood-wood, the mid input is based on FWPA estimates of materials used in residential construction based on an understanding of market share and quantity of materials used. The remaining mid input values reflect the average of the low and high input values
	Class 1	Concrete	Steel	0.022	0.044	0.066	0.044	t/m²		
	Class 1	Concrete	Wood	0.000	0.063	0.127	0.063	m³/m²		
	Class 1	Steel	Concrete	0.149	0.349	0.549	0.349	t/m²	John et al. (2008); Carre (2011); Dodoo (2019); FWPA estimates	
	Class 1	Steel	Steel	0.020	0.027	0.090	0.027	t/m²		
	Class 1	Steel	Wood	0.003	0.013	0.023	0.013	m³/m²		
	Class 1	Wood	Concrete	0.101	0.248	0.396	0.248	t/m²		
	Class 1	Wood	Steel	0.002	0.008	0.014	0.008	t/m²		
	Class 1	Wood	Wood	0.044	0.082	0.242	0.082	m³/m²		
	Class 2 - Low	Concrete	Concrete	1.194	1.342	1.489	1.342	t/m²	John et al. (2008); Carre & Crossin (2015); Carre (2011); Dodoo (2019)	
	Class 2 - Low	Concrete	Steel	0.022	0.044	0.066	0.044	t/m²		

Description	Building Class	Framing Material	Material	Low	Mid	High	Input	Units	Source	Assumptions
	Class 2 - Low	Concrete	Wood	0.000	0.063	0.127	0.063	m^3/m^2		
	Class 2 - Low	Steel	Concrete	0.149	0.349	0.549	0.349	t/m^2		
	Class 2 - Low	Steel	Steel	0.020	0.055	0.090	0.055	t/m^2		
	Class 2 - Low	Steel	Wood	0.003	0.013	0.023	0.013	m^3/m^2		
	Class 2 - Low	Wood	Concrete	0.101	0.248	0.396	0.248	t/m^2		
	Class 2 - Low	Wood	Steel	0.002	0.008	0.014	0.008	t/m^2		
	Class 2 - Low	Wood	Wood	0.044	0.143	0.242	0.143	m^3/m^2		
	Class 2 - Mid	Concrete	Concrete	1.194	1.342	1.489	1.342	t/m^2		
	Class 2 - Mid	Concrete	Steel	0.022	0.044	0.066	0.044	t/m^2		
	Class 2 - Mid	Concrete	Wood	0.000	0.063	0.127	0.063	m^3/m^2		
	Class 2 - Mid	Steel	Concrete	0.149	0.349	0.549	0.349	t/m^2		
	Class 2 - Mid	Steel	Steel	0.020	0.055	0.090	0.055	t/m^2		

Description	Building Class	Framing Material	Material	Low	Mid	High	Input	Units	Source	Assumptions
	Class 2 - Mid	Steel	Wood	0.003	0.013	0.023	0.013	m^3/m^2		
	Class 2 - Mid	Wood	Concrete	0.101	0.248	0.396	0.248	t/m^2		
	Class 2 - Mid	Wood	Steel	0.002	0.008	0.014	0.008	t/m^2		
	Class 2 - Mid	Wood	Wood	0.044	0.143	0.242	0.143	m^3/m^2		
	Non-residential	Concrete	Concrete	1.194	1.342	1.489	1.342	t/m^2		
	Non-residential	Concrete	Steel	0.022	0.044	0.066	0.044	t/m^2		
	Non-residential	Concrete	Wood	0.000	0.063	0.127	0.063	m^3/m^2		
	Non-residential	Steel	Concrete	0.149	0.349	0.549	0.349	t/m^2		
	Non-residential	Steel	Steel	0.020	0.055	0.090	0.055	t/m^2		
	Non-residential	Steel	Wood	0.003	0.013	0.023	0.013	m^3/m^2		

Description	Building Class	Framing Material	Material	Low	Mid	High	Input	Units	Source	Assumptions
	Non-residential	Wood	Concrete	0.101	0.248	0.396	0.248	t/m²		
	Non-residential	Wood	Steel	0.002	0.008	0.014	0.008	t/m²		
	Non-residential	Wood	Wood	0.044	0.143	0.242	0.143	m³/m²		

Table 10. Imported building material inputs

Description	Building Type	Materials	Low	Mid	High	Input	Units	Source	Assumptions
% of materials imported	Residential	Concrete (Cement)	3.0%	3.8%	9.2%	0.038	%	ABS (2020-a); Cement Industry Federation (2020)	Inputs based on estimates from input-output tables (reference year 2017-18) and statistics on material imports relative to domestic production.
	Residential	Steel	20.0%	25.0%	30.0%	0.250	%	ABS (2020-a);Anti Dumping Commission (2017)	
	Residential	Wood	9.3%	11.7%	28.0%	0.117	%	ABS (2020-a)	
	Non-residential	Concrete (Cement)	1.8%	2.3%	9.2%	0.023	%	ABS (2020-a)	
	Non-residential	Steel	30.2%	37.7%	45.3%	0.377	%	ABS (2020-a)	
	Non-residential	Wood	9.3%	11.7%	50.0%	0.117	%	ABS (2020-a); FWPA estimate	

Description	Building Type	Materials	Low	Mid	High	Input	Units	Source	Assumptions
% of emissions occurring overseas for imports	Residential	Concrete	68%	85%	100%	0.850	%	Marceau et al. (2007)	Cement accounts for approximately 85% of concrete emissions. As such, the domestic emissions of concrete are assumed to be reduced by 85% when cement is imported.
	Residential	Steel	80%	100%	100%	1.000	%	NCE assumption	
	Residential	Wood	80%	100%	100%	1.000	%	NCE assumption	
	Non-residential	Concrete	68%	85%	100%	0.850	%	Marceau et al. (2007)	
	Non-residential	Steel	80%	100%	100%	1.000	%	NCE assumption	
	Non-residential	Wood	80%	100%	100%	1.000	%	NCE assumption	

Table 11. Emissions inputs

Description	Material	Low	Mid	High	Input	Units	Source	Assumptions
Product emissions factors	Concrete (Standard, precast, blocks)	0.10	0.16	0.23	0.16	t CO2-e / t of material	Carre (2011); Carre & Crossin (2015)	GWP based on data in published LCAs.
	Steel (Structural, reinforcing, sheet)	0.45	2.02	3.60	2.02	t CO2-e / tonne of material	John et al. (2010); Carre (2011)	
	Wood (Softwood, Hardwood, CLT, LVL, glulam, plywood, particle board)	0.16	0.31	0.47	0.31	t CO2-e /m^3 of material	Carre & Crossin (2015)	

Description	Material	Low	Mid	High	Input	Units	Source	Assumptions
Transport emissions factor		0.0001	0.0004	0.0007	0.0004	t CO2 / t.km	Greenhouse gas protocol (2017)	
Transport distance		10.00	20.00	50.00	20.00	km	NCE estimate	
Density of wood products transported	Wood	0.50	0.55	0.85	0.55	tonnes / m^3	Carre & Crossin (2015); John et al. (2008); Chen et al. (2010)	
Carbon Price – present day			16.55		16.55	$ / t CO2e	CER (2020)	
Carbon Price - 2050		16.55	45.00	100.00	45.00	$ / t CO2e	Reputex Energy (2021); AFR (2021)	
Discount rate		0.03	0.07	0.10	0.07	%		
Transport emissions factor		0.0001	0.0004	0.0007	0.0004	t CO2 / t.km	Greenhouse gas protocol (2017)	
Transport distance		10.00	20.00	50.00	20.00	km	NCE estimate	
Density of wood products transported	Wood	0.50	0.55	0.85	0.55	tonnes / m^3	Carre & Crossin (2015); John et al. (2008); Chen et al. (2010)	
Carbon Price – present day			16.55		16.55	$ / t CO2e	CER (2020)	
Carbon Price - 2050		16.55	45.00	100.00	45.00	$ / t CO2e	Reputex Energy (2021); AFR (2021)	
Discount rate		0.03	0.07	0.10	0.07	%		

Table 12. Construction volume inputs

Description	Building Class	Building type	Low	Mid	High	Input	Units	Source	Assumptions
Construction volume in 2020	Class 1	Houses	91,555	114,444	137,333	114,444	no.	ABS (2020)	3 year average
	Class 1	Semi-detached, row or terrace houses, townhouses	23,602	29,503	35,404	29,503	no.		
	Class 2 - Low	Apartments - In a one or two storey block	974	1,217	1,461	1,217	no.		
	Class 2 - Low	Apartments - In a three storey block ;	2,023	2,528	3,034	2,528	no.		
	Class 2 - Mid	Apartments - In a four to eight storey block	14,396	17,995	21,594	17,995	no.		
Construction value in 2020	Non-residential	Retail and wholesale trade buildings	4,819,947	6,024,933	7,229,920	6,024,933	$ 000'		
	Non-residential	Transport buildings	1,246,152	1,557,690	1,869,228	1,557,690	$ 000'		
	Non-residential	Offices	6,698,708	8,373,385	10,048,062	8,373,385	$ 000'		
	Non-residential	Commercial buildings	626,299	782,874	939,448	782,874	$ 000'		
	Non-residential	Factories and other secondary production buildings	915,782	1,144,727	1,373,672	1,144,727	$ 000'		
	Non-residential	Warehouses	3,551,097	4,438,872	5,326,646	4,438,872	$ 000'		
	Non-residential	Agricultural and aquacultural buildings	330,257	412,821	495,385	412,821	$ 000'		
	Non-residential	Other industrial buildings	755,874	944,843	1,133,812	944,843	$ 000'		
	Non-residential	Educational buildings	6,102,548	7,628,185	9,153,822	7,628,185	$ 000'		
	Non-residential	Religious buildings	189,291	236,614	283,937	236,614	$ 000'		
	Non-residential	Aged care facilities	1,528,096	1,910,120	2,292,144	1,910,120	$ 000'		

Description	Building Class	Building type	Low	Mid	High	Input	Units	Source	Assumptions
	Non-residential	Health buildings	2,829,172	3,536,465	4,243,758	3,536,465	$ 000'		
	Non-residential	Entertainment and recreation buildings	2,829,813	3,537,267	4,244,720	3,537,267	$ 000'		
	Non-residential	Short term accommodation buildings	2,891,167	3,613,959	4,336,751	3,613,959	$ 000'		
	Non-residential	Other non-residential	2,913,027	3,641,284	4,369,540	3,641,284	$ 000'		

Table 13. Market share inputs

Description	Building Class	Framing Material	Low	Mid	High	Input	Units	Source	Assumptions
Market share - 2017-18	Class 1 - Detached	Concrete	-	-	-	-	%	Australian Construction Insights (2018)	
	Class 1 - Detached	Steel	0.11	0.14	0.16	0.14	%		
	Class 1 - Detached	Wood	0.59	0.74	0.88	0.74	%		
	Class 2 - Low	Concrete	0.18	0.22	0.26	0.22	%		
	Class 2 - Low	Steel	0.06	0.07	0.08	0.07	%		
	Class 2 - Low	Wood	0.37	0.46	0.55	0.46	%		
	Class 2 - Mid	Concrete	0.23	0.28	0.34	0.28	%	Victorian Building Authority (2020)	Based on average market share between 2018-2020 in Victoria,

Description	Building Class	Framing Material	Low	Mid	High	Input	Units	Source	Assumptions
	Class 2 - Mid	Steel	0.32	0.41	0.49	0.41	%		according to building permit activity data
	Class 2 - Mid	Wood	0.07	0.08	0.10	0.08	%		
	Non-Residential	Concrete	0.09	0.12	0.14	0.12	%		
	Non-Residential	Steel	0.57	0.71	0.86	0.71	%		
	Non-Residential	Wood	0.03	0.04	0.04	0.04	%		
Lost market share to steel - 2050 (Base case)	Class 1	Wood	0.05	0.10	0.20	0.100	%	Growth in market share of steel based on data from the National Association of Steel Housing, HIA studies and the Victorian Building Authority as reported by Sinclair (2018)	Under the base case, the market share of framing materials remains constant except for steel and wood in class 1 buildings. Under the base case, steel continues to take market share from timber in Class 1 buildings based on current trends.
	Class 2 - Low	Wood		-		-	%		
	Class 2 - Mid	Wood		-		-	%		
	Non-Residential	Wood		-		-	%		
Gain in market share		Wood		0.0		0.010	%		Class 1 - Increase wood by 1%, decrease steel by 1%; Others -

Description	Building Class	Framing Material	Low	Mid	High	Input	Units	Source	Assumptions
- 2050 (Scenario 1, 2 & 3)									Increase wood by 1%, decrease steel and concrete .05%
		Wood		0.1		0.100	%		
		Wood		0.2		0.200	%		

Indirect emissions reductions model inputs

Table 14. Indirect emissions reductions model inputs

Description	Low	Mid	High	Input	Units	Source
Sawlog recovery rate	0.52	0.65	0.78	0.65	%	Downham, Gavran, Frakes (2019); Ximenes, Gardner & Kathuria (2008); Ximenes & Grant (2012)
Sawn timber recovery rate	0.37	0.43	0.50	0.43	%	
Carbon sequestered in wood	0.787	0.88	0.98	0.88	t CO2-e/m3	ABARES (2013)

APPENDIX C – CASE STUDIES

The consequences of timber losing market share in class 1 buildings.

Timber is the dominate framing material used in class 1 building construction. In 2017/18, timber's markets share was estimated to be 74%. Lightweight steel is the next most common framing material. In the same year, its market share was estimated to be 14% (Australian Construction Insights, 2018).

Historical data suggest that the market share of steel framing in residential construction is growing. With timber being the dominate framing material used in class 1 construction, this growth is expected to be largely at the expense of timber framing. On current trends, steels market share will be about 25% in 2050 (Sinclair, 2018)

A loss of market share for timber framing in class 1 buildings will have consequences for Australia's timber industry. It will also have consequences for Australia's level of greenhouse gas emissions as the construction of steel framed houses is estimated to produce more carbon emissions per square meter than timber framed houses.

Using the emissions models developed for this study, the increase in carbon emissions and forgone carbon sequestration associated with timber framing losing 10% market share to steel by 2050 has been estimated. These estimates are presented in Table 15 and assume a linear change in market share between 2021 and 2050.

Table 15. Increase carbon emissions associated with timber losing 10% market share to steel between 2021 and 2050 (Mt CO_2-e)

	Low	Mid	High
Net increase in emissions (total)	0.2	1.8	8.2
Net increase in emissions (domestic)	0.0	1.4	6.5
Foregone forest and plantation carbon sequestration	9.7	12.0	38.5

The potential of wood midrise buildings to reduce Australia's carbon emissions.

In the United States, wood is the dominant structural building material used in 5 to 6 storey residential buildings with about 60% of the market. In 7 to 8 storey residential buildings, wood's market share is about 30% but with an aspirational growth target of reaching more than 50% by 2035 (FP innovations & Ben Romanchych Consulting, 2020). For similar buildings in Australia, wood's market share is estimated to be about 8%, with steel holding an estimated 41% market share (Victorian Building Authority 2018; 2019; 2020). This data suggests there is an opportunity for greater use of wood to construct midrise buildings in Australia.

Based on estimates compiled in this study, the construction of a midrise wood building would produce only 60% of the carbon emissions associated with an equivalent steel building and about 30% of the emissions of an equivalent concrete building. Therefore, increasing the use of wood to construct midrise building has the potential to reduce carbon emissions.

Using the emissions models developed for this study, the carbon emissions reductions and potential carbon sequestration associated with wood achieving similar levels of market share for midrise (4-8) building in Australia as in the United States has been estimated. These estimates are presented in Table 16 and assume a direct upward shift of market share in 2021 until 2050. A 50% increase in market share is estimated to reduce Australia's emissions by 3.9 Mt CO_2-e between 2021 and 2050.

Table 16. Emissions reduction associated with an upward shift in the market share of structural timber in midrise buildings between 2021 and 2050 (Mt CO_2-e)

Increase in market share of timber to 2050 in midrise buildings (4-8 storey)	Total emissions reductions			Domestic emissions reductions			Potential increase in forest and plantation carbon sequestration		
	Low	Mid	High	Low	Mid	High	Low	Mid	High
50%	2.8	4.5	6.5	2.5	3.9	5.7	4.3	9.9	16.1
60%	3.1	5.2	7.7	2.8	4.5	6.6	5.3	12.0	19.4
70%	3.2	5.6	8.3	2.9	4.8	7.1	6.3	14.1	22.0