Criterion 5

Maintenance of forest contribution to global carbon cycles



Criterion 5 Maintenance of forest contribution to global carbon cycles

This criterion, which comprises only one indicator, Indicator 5.1a, reports on the amount of carbon stored in Australia's forests, and the effects of natural disturbance, forest management and forest land-use change on forest carbon dynamics. The indicator also reports the amount of carbon stored in wood products. Taken together, these parameters comprise the role of Australia's forests in the carbon cycle.

Internationally, concern about the effects of increased atmospheric concentrations of greenhouse gases, most importantly carbon dioxide (CO_2) , on the climate has focused attention on the carbon cycle and human-induced changes to it. Forests are a major component of the global carbon cycle because of the large amounts of carbon stored in forests, the sequestration of carbon by growing forests, the storage of carbon in wood and wood products in service and (at the end of service life) in landfill, and the potential reduction in emissions when wood is used instead of fossil fuels as an energy source or to replace more energy-intensive structural materials.

The role of forests and forest management in the carbon cycle is determined by their net effect across the landscape and the economy over long time periods, rather than by short-term, local changes at individual forest sites. National forest carbon dynamics thus need to be considered over long time frames (more than a decade) to properly assess the contribution of Australia's forests and forest management to the global carbon cycle, and sustainable management of forest carbon stocks.

The indicator presents data from the carbon stock account for Australia's forests for the period 2001 to 2016. These data are derived from the land use, land-use change and forestry component of Australia's National Greenhouse Gas Inventory, and cover native forests not used for wood production, native forests used for wood production, commercial plantations, trees planted for environmental purposes, and carbon stored in timber and wood-based products. The data also cover the range of activities and events, including wildfire, regrowth, and the harvest and growth of plantations, that cause changes in carbon stocks over time.

This icon indicates data, maps or graphics from Australia's State of the Forests Report 2018 that are available for electronic download. Data used in figures and tables in this criterion, together with higher resolution versions of maps, are available via www.doi.org/10.25814/5bda94dad76d8 and www.doi.org/10.25814/5be3bc4321162.



Tuan State Forest, Queensland.

Indicator 5.1a

Contribution of forest ecosystems and forest industries to the global greenhouse gas balance

Rationale

This indicator assesses the contribution of Australian forests to the global carbon cycle. Forest management can have a significant positive or negative impact on the global carbon cycle.

Key points

- A total stock of 21,949 million tonnes of carbon (Mt C) was stored in Australia's forests at the end of June 2016.
 - Of this, 85% was stored in non-production native forests, 14% in production native forests and 1.2% in plantations.
 - An additional 94 Mt C was present in wood and wood products in use, and 50 Mt C in wood and wood products in landfill.
 - In total, 22,093 Mt C was held in Australia's forests plus harvested wood products at the end of June 2016.
- Over the period 2011–16, forest carbon stocks increased by 129 Mt C.
 - This increase in carbon stocks was due to a combination of recovery from past clearing, additional growth of plantations, reduced clearing of native forest, expansion of the area of native forests, and recovery from bushfire and drought.
 - Over the period 2001–16, carbon stocks in forests have varied by no more than 0.7% of the total stock.
- Of the 21,949 Mt C stored in forests in 2016, 7,838 Mt C (36%) was in above-ground biomass and 14,110 Mt C (64%) was in below-ground biomass.
 - Above-ground forest biomass comprises living organisms, deadwood and litter, while below-ground forest biomass comprises living roots and soil.

- In the period 2001–16, transfers of carbon from Australian forests to harvested wood products were approximately 104 Mt C.
 - After including changes due to imports and exports, disposal and decay, carbon stocks in the pool of wood and wood products in use in Australia showed a net increase of 17 Mt C in the period 2001–16, while carbon stocks in the pool of wood and wood products in landfill in Australia showed a net increase of 9 Mt C.
 - The 25 Mt increase in carbon stocks in wood products over the period 2001–16 was greater than the 12 Mt decrease in carbon stocks in forests over this period.
- Overall, during the period 2011–16 Australia's land sector contributed net sequestration of an amount that offset 3.5% of total human-induced greenhouse gas emissions for this period from all sectors. This was primarily due to the gains through forest growth and forest management practices exceeding the losses from activities such as land clearing.
- Carbon stocks and stock changes presented in this indicator were calculated from Australia's National Greenhouse Accounts as reported in Australia's *National Inventory Report 2016*. They relate to the 139 million hectares of forest used for Australia's greenhouse gas accounting.
 - The forest carbon stock reported for various time-periods in SOFR 2018 is substantially higher than the forest carbon stock reported for these time-periods in SOFR 2013. This results from a reassessment of the forest area used for Australia's National Greenhouse Accounts, an increase in the model parameter for maximum biomass per hectare, and an increase in modelled carbon stocks in non-production forests.

International concern about the effects on climate of increased atmospheric concentrations of greenhouse gases such as carbon dioxide ($\rm CO_2$) has focused attention on the global carbon cycle²³⁵. Forests are an important component of the global carbon cycle, and maintenance of forest carbon stocks is a key indicator of sustainable forest management. This indicator quantifies and reports on the carbon balance of Australia's forests, and how this is affected by their stewardship, management and use. The indicator also considers how the forestry sector contributes to the global carbon cycle through storage of carbon in wood and wood products in use and, at the end of useful service life, in landfill²³⁶.

Forests absorb CO₂ from the atmosphere during photosynthesis and store carbon in biomass, which following tree death and decay is converted into deadwood, litter and soil organic matter. In turn, CO2 is released from forests by respiration, and by the decay and combustion of forest material. The rate at which carbon is sequestered into woody tissue is highest in the early-age to mid-age growth phases of trees (regenerating and regrowth forests). In mature and older forests, net exchange of CO₂ with the atmosphere is usually low, as slower growth is balanced by death and decay. Bushfires²³⁷, like any natural event, will generally have a transient impact on forest ecosystems as standing trees and forest debris are burned and subsequently recover, with recovery periods varying from a few years to many decades depending on the forest type and fire intensity. The non- CO_2 gases released in these events are out of the scope of this indicator.

The amount of carbon stored on Australia's forested lands can change over time because of:

- the natural developmental or successional dynamics of forests
- · bushfire, drought, dieback and regrowth
- human activities such as wood harvesting
- increases in forest area due to forest expansion, reforestation²³⁸, or establishment of commercial plantations and environmental plantings
- decreases in forest area due to clearing for agriculture, urban expansion or other land uses
- variation in climatic factors such as temperature and rainfall.

The role of forests in the carbon cycle is best interpreted at a macro-scale. This is because the atmosphere is influenced by the net effect of forest biology and forest management across landscapes, the nation and the economy, rather than local changes at individual forest sites.

Once wood has left the forest, its role in the carbon cycle is determined by factors such as:

- energy used and emissions produced during wood processing and transport
- change in the stocks of wood and wood products in use and in landfill
- reductions in net greenhouse gas emissions due to the use of wood for local energy generation displacing the use of fossil fuels, and due to the use of wood for structural purposes in place of more energy-intensive structural materials.

Forest carbon accounting

Australia's National Greenhouse Accounts during the SOFR 2018 reporting period have been maintained by the Department of the Environment and Energy²³⁹ (DoEE) and are available online²⁴⁰; they are published annually in Australia's *National Inventory Reports*²⁴¹. National inventory reports are annual reports of anthropogenic emissions by sources, and removals by sinks, of greenhouse gases not otherwise managed through the Montreal Protocol²⁴². These accounts constitute Australia's National Greenhouse Gas Inventory, and are prepared according to the rules specified under the United Nations Framework Convention on Climate Change and the Kyoto Protocol.

In Australia, the National Greenhouse Gas Inventory (DoEE 2018a) has been developed to provide emissions estimates covering the entire nation, including Australia's extensive land sector. The land use, land-use change and forestry (LULUCF) component of Australia's National Greenhouse Gas Inventory includes 139 million hectares of forests, as assessed by DoEE as at the end of June 2016²⁴³ (see Figure 5.1). During the period 2011–16, this forest area contributed to the net sequestration by the land sector of an amount that offsets 3.5% of total human-induced greenhouse gas emissions for this period from all sectors (DoEE 2018a,b), primarily due to the gains from regrowth and forest management practices exceeding the losses from activities such as land clearing.

DoEE has monitored forest cover using national coverages of Landsat satellite data over 25 time periods from 1972 to (most recently) 2016, including annually from 2004, for the National Greenhouse Gas Inventory. The Landsat data include the Landsat MSS, ETM+ and OLI data products²⁴⁴. The imagery is assembled as maps, and used to detect finescale changes in forest cover at a resolution of 25 metres by 25 metres. The changes are analysed to identify whether they

- ²³⁶ The National Greenhouse Gas Inventory, published by the Department of the Environment and Energy, became consistent with this scope in 2016.
- ²³⁷ Bushfire, wildfire and unplanned fire are used interchangeably in this report: see Indicator 3.1b.
- ²³⁸ Reforestation is re-establishment of native forest through human intervention on non-forest land that previously carried forest, whereas forest expansion is establishment or re-establishment of native forest on non-forest land without human intervention.
- ²³⁹ Until July 2016, the Department of the Environment.
- 240 See ageis.climatechange.gov.au/
- 241 www.environment.gov.au/climate-change/climate-science-data/ greenhouse-gas-measurement/publications#national
- ²⁴² The Montreal Protocol on Substances that Deplete the Ozone Layer (a protocol to the Vienna Convention for the Protection of the Ozone Layer) is an international treaty designed to protect the ozone layer by phasing out the production of numerous substances believed to be responsible for ozone depletion.
- ²⁴³ For methodological and measurement reasons, this forest area used for Australia's national inventory system for greenhouse gas accounting differs from the forest area (134 million hectares) presented in Indicator 1.1a and used elsewhere in this report (see Indicator 1.1a).
- ²⁴⁴ landsat.gsfc.nasa.gov/

²³⁵ While greenhouse gases other than CO₂ are included in national greenhouse accounts, the interest for this indicator is the changing stores of carbon in forests and forest products, the gains and losses of which result in sequestration and emission of CO₂.



Harvested plantation pine logs.

are due to human activity (e.g. wood harvesting, forest clearing, plantation establishment) or natural events (e.g. periods of dieback, drought or bushfire and subsequent regrowth, and expansion of forests onto previously non-forest land). Since 2013, only permanent changes in land use are incorporated in these forest area figures, with transient changes in canopy cover due to natural events being excluded. This resultant forest area coverage underpins the carbon accounts for Australia's National Greenhouse Gas Inventory system.

Changes in the carbon stock in Australia's forest area are then estimated using the Full Carbon Accounting Model (FullCAM), a modelling methodology consistent with international requirements²⁴⁵, with spatial simulations where relevant. FullCAM is an ecosystem model that uses a massbalance approach to carbon cycling for each of the following carbon pools:

- living biomass
 - above-ground biomass (stem or bole, branches, bark, leaves)
 - below-ground biomass (roots)
- dead organic matter
 - dead wood
 - litter
- soil organic matter.

Emissions of CO_2 related to harvested wood products (HWPs) are also reported in the LULUCF component of Australia's National Greenhouse Gas Inventory. Emissions over time depend on the useful life of wood-based products, the method of their disposal, and their eventual storage and decay in landfill.

The carbon stocks in forests and wood products reported in this indicator are thus derived from the same carbon stock data as are used to calculate emissions from the LULUCF sector for Australia's National Greenhouse Gas Inventory. Emissions values are determined according to the accounting rules specified under the United Nations Framework Convention on Climate Change or the Kyoto Protocol, and do not simply represent differences in carbon stocks over time.

Revisions since Australia's State of the Forests Report 2013

Carbon stock figures for this indicator are taken from the National Greenhouse Gas Inventory systems maintained by the Department of the Environment and Energy. Under methodological rules established under guidance from the Intergovernmental Panel on Climate Change, historical estimates of emissions are revised when improvements to data sources and compilation methods are made.

Since SOFR 2013, significant improvements to satellite observation technology have allowed a re-assessment of the forest areas used for carbon stock calculations. These changes led to increased detection of forest across the continent, primarily in drier regions. In addition, land simulation applications have been further developed to include native forest that is expanding into previous non-forest areas. The forest area figure for June 2016 used for this indicator (139 million hectares; DoEE 2018a) is similar to the forest area figure derived in Indicator 1.1a (134 million hectares) and used for all other indicators in SOFR 2018.

Improvements have also been made to the understanding of carbon dynamics, model parameters, source information for and modelling of soil carbon levels, and the maximum carbon content of different types of forest (Paul et al. 2017; Roxburgh et al. 2017).

The carbon data are now presented by financial year rather than calendar year, with reporting now occurring across 5-year periods ending on 30 June 2006, 2011 and 2016, consistent with other indicators.

Together, these changes led to revisions of figures presented in SOFR 2013, with total carbon stocks reported in SOFR 2018 being approximately 8,900 Mt C larger than those reported in SOFR 2013 across all time periods.

²⁴⁵ The UNFCCC subjects its Annex 1 parties (including Australia) to annual reviews of their methodology by panels of expert reviewers made up of other compilers and experts in the international community, so as to assure ongoing compliance with guidelines issued by the Intergovernmental Panel on Climate Change (IPCC).

Carbon stock account for Australia's forests, 2001–16

In 2016, the stock of carbon in Australia's forests was 21,949 million tonnes of carbon (Mt C) (Table 5.1). The stock of carbon in forests decreased by 13 Mt C (0.1%) between 2001 and 2016. This occurred through a reduction of 148 Mt in carbon stocks in 2001–06, followed by a small gain of 7 Mt C in 2006–11, and a more substantial gain of 129 Mt C in 2011–16 (Table 5.1). Over the period 2001–16, carbon stocks in forests have varied by no more than 0.7% of the total stock.

The decline of carbon stocks in Australia's forests over the period 2001–06 was driven by clearing and conversion of forest land to other land uses, mainly agriculture, but was also influenced by temporary losses of forest carbon to bushfire (especially in 2003) and drought. However, the extent of the decline from 2001 to 2006 was only 0.67% of the total forest carbon stock at 2001. The recovery of carbon stocks over the periods 2006 to 2011 then 2011 to 2016 was due to a combination of recovery from past clearing, additional growth of plantations, reduced clearing of native forest, expansion of the area of native forests, and recovery from bushfire and drought.

In 2016, the majority of the carbon in forests (18,668 Mt C, 85%) was held in the category 'Non-production native forests', which includes all areas of native forest not available for wood harvesting (Table 5.1). Most of the balance (3,009 Mt C, 14%) was held in 'production native forests'. A relatively small amount of carbon (258 Mt C, 1.2%) was held in plantations, and an even smaller amount (15 Mt C, 0.1%) was held in environmental plantings.

The distribution of carbon in Australia's forests is shown in Figure 5.1. Forests with higher biomass densities are found in the wetter areas of the south-west, south-east and east of Australia; the northern and inland forests have lower biomass densities.

For 2016, carbon stock figures for forests by state and territory are shown in Table 5.2. New South Wales has the largest forest carbon stocks (6,682 Mt, 30% of Australia's total), followed by Queensland (5,766 Mt, 26% of Australia's total). This principally reflects the larger areas of forest in these two states. The Australian Capital Territory has the least forest carbon (83 Mt, 0.4%), consistent with the small area of forest in the territory, followed by South Australia (614 Mt, 2.8%), a reflection of the comparatively drier landscape in that state.

Table 5.1: Carbon stored in forests and harvested wood products, 2001 to 2016

	2001	2006	2011	2016	2016
Forest category		Proportion of total forest carbon			
Non-production native forests ^a	18,813	18,627	18,586	18,668	85.1%
Production native forests ^b	2,951	2,956	2,971	3,009	13.7%
Total native forests	21,765	21,583	21,557	21,676	98.8%
Post-1990 environmental plantings ^c	6	8	11	15	0.1%
Total other forests	6	8	11	15	0.1%
Softwood plantations	148	152	151	147	0.7%
Hardwood plantations	42	70	101	110	0.5%
Total plantations	190	222	252	258	1.2%
Forests total	21,961	21,813	21,820	21,949	100.0%
Wood products in use	77	83	89	94	
Wood products in landfill	42	46	49	50	
Harvested wood products total	119	129	138	144	
Total forests and harvested wood products	22,080	21,943	21,958	22,093	

Mt C, million tonnes of carbon.

All years are financial years.

^a 'Non-production forests' are native forests not available for or subject to forestry industry activity. They are generally assumed to be in a state of equilibrium with the atmosphere unless exposed to disturbances, naturally dying, or regrowing from seed. They include forests of all species, including mangroves.

^b Under the National Greenhouse Accounts definition of *forest management lands*, 'Production native forests' are both multiple-use public native forests and private native forests managed for wood production.

^c Environmental plantings are forest that has been planted with native species, and without the intent of being eventually harvested for wood. They are part of the 'Other forests' category described in Indicator 1.1a.

Source: Department of the Environment and Energy.

🔊 This table, together with other data for Indicator 5.1a, is available in Microsoft Excel via <u>www.doi.org/10.25814/5bda94dad76d8</u>

Figure 5.1: Carbon density of Australia's forests, 2016



Note: Forest extent (139 million hectares) as determined for Australia's National Greenhouse Gas Inventory as at June 2016. This spatial coverage differs from that used in other SOFR 2018 indicators because of methodological and measurement reasons: see Indicator 1.1a.

A higher resolution version of this map is available via <u>www.doi.org/10.25814/5be3bc4321162</u>

Table 5.2: Carbon stored in forests and wood products by state and territory, 2016 (Mt C)

Forest category	ACT	NSW	NT	Qld	SA	Tas.	Vic.	WA	Australia
Non-production native forests	81	5,301	877	5,440	573	1,582	1,661	3,151	18,668
Production native forests ^a	0	1,335	0	306	0	808	279	281	3,009
Total native forests	81	6,636	877	5,746	573	2,390	1,940	3,433	21,676
Post-1990 environmental plantings	0	4	0.3	2	1	3	2	2	15
Total other forests	0	4	0.3	2	1	3	2	2	15
Softwood plantations	1	31	0	17	32	19	33	14	147
Hardwood plantations	0	11	1	1	8	12	33	45	110
Total plantations	1	42	1	18	40	31	66	59	258
Forests total	83	6,682	878	5,766	614	2,424	2,008	3,494	21,949
Wood products in use	0.4	29	0.1	13	8	12	23	9	94
Wood products in landfill	0.8	21	0.2	7	4	1	11	6	50
Harvested wood products total	1.2	50	0.3	20	11	13	34	15	144
Total forests and harvested wood products	84	6,731	878	5,787	626	2,437	2,042	3,508	22,093

Mt C, million tonnes of carbon.

Note: See footnotes to Table 5.1. NSW figures include figures for the Commonwealth territory of Jervis Bay.

^a The category 'production native forests' includes both multiple-use public forests and private native forests managed for wood production.

Totals may not tally due to rounding.

Source: Department of the Environment and Energy

🔊 This table, together with other data for Indicator 5.1a, is available in Microsoft Excel via www.doi.org/10.25814/5bda94dad76d8

Changes in carbon stocks over time

The carbon accounts for Australia's forests over three periods from 2001 to 2016 are presented in Table 5.3.

Major events causing reductions in forest carbon stocks include forest clearing for agriculture, urban or industrial development. Transient reductions in carbon stocks are caused by wood harvesting from production forests, prescribed burning, and natural events such as bushfire, drought, wind and outbreaks of pests or diseases.

Major increases in carbon stocks occur in forests following planting events, afforestation and reforestation; and during regeneration and regrowth from past events such as fires and wood harvesting. Regrowth may take 100 years for new trees to approach maturity (see Indicator 1.1b).

The national assessment of carbon stocks excludes transient changes in canopy cover arising from natural climatic cycles or events such as droughts and floods. The analysis takes a long-term view of carbon cycles, in the interests of accurately representing the long-range impacts of events on carbon stocks.

While bushfire does cause measurable changes in carbon stocks, as for the significant bushfire events of 2003 (Figure 5.4), these events have a lesser impact on the longterm trend in carbon stocks (Figure 5.2), because in the longterm carbon losses due to bushfires are typically recovered as the forests regrow. The turnaround in carbon stocks since 2007 is more broadly attributable to changes in land management and management practices, and expansion of native forest onto non-forest land.

Reclassifications to/from forest

Forest clearing is associated with the conversion of forested land to agricultural, urban or other land uses. When forest land is cleared it is reclassified as non-forest land, and all carbon stocks on that land immediately before the clearing event are reclassified to other land types. Similarly, when a grassland becomes a forest through plantation establishment, regrowth of native forest on previously cleared land, or natural regeneration or expansion of native forest²⁴⁶, the carbon stocks on that land before the planting or regeneration event are reclassified as forest carbon stocks. Table 5.3 shows the net amount of carbon subtracted from or added to the forest carbon accounts due to reclassification of forest land of various categories to or from non-forest land.

In the period 2001–06, there was a net loss of 194 Mt C from the forest carbon accounts due to reclassification to/from non-production native forests, mostly due to land clearing (Table 5.3). However, in 2011–16 the area of clearing was less than the area of regeneration and regrowth of non-production forests on previously non-forest land, leading to a net gain from land reclassification to/from non-production native forests of 53 Mt C in the forest carbon accounts (Table 5.3).

There has been a shift over time in the categories of forest being cleared. Over the period 2011–16, there has been a



Figure 5.2: Carbon stocks in Australian forests, 2001–2016

Mt C, million tonnes of carbon.

Note: The carbon stock in 'Other forests' is very small and would not be visible if shown separately on this histogram. Source: Department of the Environment and Energy.

The data used to create this figure, together with other data for Indicator 5.1a, are available in Microsoft Excel www.doi.org/10.25814/5bda94dad76d8

²⁴⁶ For the purposes of Australia's national carbon accounts, conversion from non-forest to forest occurs when the woody vegetation reaches over 2 metres in height and attains a canopy cover of at least 20%.

	2001–06	2006–11	2011–16	2001–16
Opening stock	21,961	21,813	21,820	21,961
Reclassifications to/from ^a				
Non-production native forests	-194.5	-56.7	53.0	-198.2
Production native forests	0.0	0.0	0.0	0.0
Post-1990 environmental plantings	1.2	2.0	2.1	5.3
Softwood plantations	2.5	1.9	-1.3	3.0
Hardwood plantations	12.8	5.8	-18.2	0.3
Total reclassification	-177.9	-47.1	35.5	-189.5
Net growth/loss in ^b				
Non-production native forests	21.9	18.3	25.5	65.8
Production native forests	21.1	27.7	44.5	93.4
Post-1990 environmental plantings	0.8	1.0	1.3	3.2
Softwood plantations	17.0	14.1	13.7	44.8
Hardwood plantations	18.9	32.3	39.4	90.6
Total net growth	79.8	93.5	124.5	297.7
Fire and regrowth from fire ^c				
Non-production native forests	-13.6	-3.0	3.4	-13.2
Production native forests	-1.2	-1.1	-0.5	-2.8
Post-1990 environmental plantings	0.0	-0.2	-0.2	-0.4
Softwood plantations	0.0	0.0	0.0	-0.1
Hardwood plantations	-0.1	-0.2	-0.4	-0.6
Total fire and regrowth from fire	-14.9	-4.4	2.4	-17.0
Transfers to wood products ^d				
Native forests	-15.2	-11.9	-6.2	-33.3
Softwood plantations	-16.0	-16.4	-16.5	-48.9
Hardwood plantations	-3.5	-7.1	-11.1	-21.7
Total transfers to wood products	-34.7	-35.4	-33.8	-103.9
Closing stock	21,813	21,820	21,949	21,949

Mt C, million tonnes of carbon.

^a Reclassifications means the net conversions of land to or from a forest type. This includes the first-time clearing of forest, the re-clearing of regrowth forest, the establishment and removal of plantations, and the growth of native forest from seed on non-forest land.

^b Net growth/loss accounts for the carbon stock changes within a forest category over time. This includes the growth of trees (but not in non-production native forests that have been continuously forest since 1972, where growth is presumed to be balanced with decay), and losses of woody material left on site during harvesting events.

^c Net impacts of fire include the immediate losses of carbon in deadwood and litter due to a fire event, and the subsequent recoveries within the forest. Contributions of recovery are counted in the year where the regrowth occurs rather than in the year where the fire occurred.

^d Transfers to wood products (Table 5.5) and domestic accumulation of wood products in use (Tables 5.1 and 5.5) are not equal and opposite. Transfers to wood products is equated to logs removed from a harvesting site. Domestic accumulation of wood products in use includes imported material, excludes exported material, excludes waste lost during manufacturing, and includes losses due to the disposal of wood products in the waste system.

Source: Department of the Environment and Energy

🔊 This table, together with other data for Indicator 5.1a, is available in Microsoft Excel via www.doi.org/10.25814/5bda94dad76d8

continued reduction of the proportion of forest clearing that is first-time clearing of that land. Most forest clearing is now the re-clearing of regrowth on previously cleared land (Figure 5.3). In addition, the annual area of forest regrowing on cleared land has increased progressively over the last 15 years.

Over the period 2011–16, the NGGI data show first-time clearing was recorded for 0.29 million hectares of forest, 2.69 million hectares of forest regrew on land that had been cleared after 1972, and reclearing of 1.86 million hectares of regrowth forest was recorded (Figure 5.3). The total area of forest cleared over this period was 2.16 million hectares, and the net increase of forest area as a result of clearing, regrowth and reclearing was 0.53 million hectares.

In the year 2015–16, the NGGI data show first-time clearing was recorded for 60 thousand hectares of forest, 564 thousand hectares of forest regrew on land that had been cleared after 1972, and reclearing of 395 thousand hectares of regrowth forest was recorded (Figure 5.3). The total area of forest cleared in this year was 455 thousand hectares, and the net increase of forest area as a result of clearing, regrowth and reclearing was 108 thousand hectares.

Both regulatory constraints and farmers' terms of trade can be useful predictors of land clearing. Historically, economic considerations have been an important driver of land clearing for farmers and other land managers. When the prices of agricultural products have been high (reflected in farmers'

Figure 5.3: Annual areas of forest cleared, regrown, and recleared



Source: Department of the Environment and Energy. Clearing and reclearing data are annual area data from Figure 6.5a of *National Inventory Report 2016 Volume 2* (DoEE 2018a). Regrowth data are gross annual area of regrowth on land cleared since 1972 (Figure 6.5b of National Inventory Report 2016 Volume 2 shows the cumulative regrowth area after accounting for reclearing, and those area data are therefore different to the gross regrowth areas presented here). The year '2016' refers to the financial year.

The data used to create this figure, together with other data for Indicator 5.1a, are available in Microsoft Excel www.doi.org/10.25814/5bda94dad76d8

terms of trade²⁴⁷), landowners have had a stronger incentive to clear land and expand production. Typically, an increase in farmers' terms of trade has been followed by an increase in forest clearing about one year later, while a decrease in farmers' terms of trade has been followed by a decrease in forest clearing about one year later (DCCEE 2012).

In recent decades, state governments have passed legislation to restrict land clearing. The Queensland Government substantially restricted clearing from 2007 onwards and reinforced the restrictions in 2009. This policy change is reflected in the sharp drop in national land clearing figures since 2007 (Figure 5.3). Other recent reductions in rates of land clearing, deriving from legislation rather than economic conditions, were not accompanied by significant changes in farmers' terms of trade.

The reclassification of non-forest land to commercial plantations and environmental plantings was associated with additional forest carbon stocks in 2001–06 and 2006–11. However, in 2011–16, there was a small loss of 1.3 Mt in carbon stocks from plantings and removals of softwood plantations, while 18 Mt carbon was removed from the forest accounts due to the net reclassification of hardwood plantations to non-forest lands (Table 5.3). Additional carbon stocks resulted from a small amount of reclassification of land to environmental plantings in all time periods.

Net growth/loss

Figures for net growth/loss are dominated by natural growth of replanted or regenerating forest, or regrowth following wood harvest. Over the period 2001–16, this added 298 Mt C to the forest carbon accounts (Table 5.3), with growth of production native forests and plantations together accounting for 76% of this figure.

Net growth in production native forests increased their carbon stock by 28 Mt C in 2006–11 and 45 Mt C in 2011–16 (Table 5.3), with this forest category reaching a stock of 3,009 Mt C in 2016 (Table 5.1). The carbon stock in hardwood plantations reached 110 Mt C in 2016 (Table 5.1). By contrast, the increase in carbon stocks of the softwood estate through growth (44.8 Mt C over the period 2001–16) was exceeded by the amount of carbon transferred to wood products or emitted as CO_2 through the oxidation of harvesting debris and changes to soils (48.9 Mt C over this period) (Table 5.3).

Fire and regrowth from fire

Bushfires occur every year in Australia's forests (see Indicator 3.1b). The fire regime in forests varies with climatic zone, soil type and vegetation type. In particular, climatic variability contributes large year-to-year variations in the extent of fires. In general, forests in northern Australia burn more frequently but at lower severity than do forests in southern Australia.

Bushfires generally have transient impacts on Australia's forests, but the loss of carbon stocks from forest lands can be very high in years in which substantial bushfires occur in temperate forests (Figure 5.4). In the period 2001–16, bushfires across

²⁴⁷ 'Farmers' terms of trade' is the ratio of an index of prices received by farmers to an index of prices paid by farmers.



Figure 5.4: Carbon stock changes due to fire and regrowth from fire, by region, 2001–16

Note: Years represent fire seasons ending in June for temperate regions, and July for tropical and rangeland regions (for which the fire season runs from the beginning of the late dry season in August to the end of the subsequent early dry season in July).

Source: Department of the Environment and Energy. Carbon losses in fire are from litter and debris pools only.

The data used to create this figure, together with other data for Indicator 5.1a, are available in Microsoft Excel www.doi.org/10.25814/5bda94dad76d8

Australia burned 82 million hectares of forest, and resulted in net losses of 17 Mt C over this period. Of this, bushfires in temperate regions burnt a total of approximately 12 million hectares of forest, and resulted in losses of 132 Mt C from forest deadwood and litter stocks; this loss will be mostly mitigated through continuing recovery in future years.

Losses of carbon caused by fire are determined by the size of the areas burnt and the amount of biomass burnt per unit area. The rates of recovery of forest carbon stocks after fire vary with climate, ecosystem type, previous fire history and site conditions. Many Australian tree species are fire-tolerant; fire of moderate intensity often primarily burns fine debris and leaves and stimulates growth, without killing trees. Because of this ecology, the carbon accounts assume that most forest impacted by bushfire will reach effectively full recovery within a period of 11 years, with recovery times depending on the location of the fire, unless the area in question is impacted by another fire event.

Figure 5.4 shows the impact of fire on year-to-year carbon stock changes. In 2001–06 there was a net loss from fire of 15 Mt of carbon across all forest categories (Table 5.3). This includes 28 Mt of net carbon loss from forests during the significant temperate-region bushfires in 2003. The majority of the recovery in carbon stocks following these fires was modelled to also occur within the 2001–06 period (Figure 5.4). Similarly, the temperate-region forest fires of 2007 caused a net loss of 10 Mt of carbon, with recovery being reflected in the net carbon gains over the period 2011–16 (Figure 5.4, Table 5.3).

Recovery of carbon stocks from forest fires in tropical and rangeland regions is modelled to occur over a shorter timeperiod, which, when combined with the more frequent occurrence of fires in these regions, leads to tropical and rangeland fires having a much smaller net effect on carbon stocks within any one year. For example, in 2003, the large areas of forest fire in tropical and rangeland regions emitted 2.4 Mt C in that year, but these forests also sequestered 2.3 Mt C in recovery from previous fires.

Transfers to wood products

The amount of carbon removed from forests in the form of sawlogs, pulplogs and other log types (that is, transferred to wood products) was similar across all three time periods (2001–06, 2006–11 and 2011–16; Table 5.3), and totalled 104 Mt for the combined period 2001–2016. However, there was a progressive change in the sources of harvested wood, leading to changes over time in the pattern of carbon stock change. The amount of carbon in wood transferred from native forests to wood products declined over this period, while the amount of carbon in wood transferred from hardwood plantations to wood products increased. These figures reflect changing harvest volumes in different forest categories reported in other SOFR indicators. The amount of carbon in wood transferred from softwood plantations to wood product remained relatively constant over this period.

Mt C, million tonnes of carbon.

Distribution of carbon across pools

Table 5.4 shows the breakdown of carbon in Australia's forests between above-ground living biomass, deadwood, litter, below-ground living biomass and soil. Soil carbon is the largest pool of carbon in forests, and accounts for 52% of carbon stored on forest lands. Living biomass is the other significant pool, comprising tree stems, branches, bark and foliage as above-ground components, and roots as below-ground components. Living biomass accounts for 38% of carbon stored on forest lands, with the larger proportion of living biomass being above-ground. The remaining carbon is found in litter and deadwood above-ground; these two debris pools, especially litter, serve as the main fuel in bushfires (Sullivan et al. 2012) and are thus the main source of bushfire CO₂ emissions.

Above-ground living biomass will, upon death, become deadwood, either on the ground or first standing then on the ground, and litter. As these debris pools decay, a proportion will become soil carbon while the remainder will enter the atmosphere as CO_2 . Below-ground living biomass, upon death, will decay directly to soil carbon. Soil carbon will also gradually oxidise to CO_2 and enter the atmosphere if disturbed, such as by the loss of stabilising forest cover.

In 2011–16, forest carbon stocks increased in all pools except deadwood, with the largest increases being in soil (82 Mt C) and above-ground living biomass (33 Mt C). Similarly, in 2001–06 when forest carbon stocks were decreasing, the largest losses of carbon were in soil (66 Mt C) and above-ground living biomass (43 Mt C). The differences between carbon pools in the amounts of carbon gained and lost

reflect the sizes of the different carbon pools. In addition, more gradual gains of carbon in growing forests balance the modelled instantaneous losses of all carbon pools from the forest carbon accounts when land is reclassified to non-forest after, for example, land clearing.

Both the rate of input to the soil carbon pool and the rate of output from the soil carbon pool are affected by management activities, particularly forest clearing, soil cultivation or wood harvesting, as well as by bushfire (Page et al. 2011). Changes in total soil carbon stocks in response to management activities depend on initial soil carbon levels and past management practices. For example, soil carbon stocks generally decline under pine plantations established on land that had previously carried pastures, associated with a large loss of nitrogen from the soil and soil acidification, but do not decline on land that was formerly under native forest (Paul et al. 2002).

In most Australian native forests, the above-ground carbon pools (living trees, deadwood and litter) are most vulnerable to rapid loss through management events or bushfires. The temporal pattern of change in soil carbon stocks is slower than rates of change in above-ground carbon pools (Page et al. 2011), and the mass ratio of above-ground to below-ground carbon can vary markedly across the landscape.

The quality of soil carbon data is likely to improve over time, especially in native forests. The high spatial and temporal variability of soil carbon stocks and fluxes means that intensive sampling and measurement of soil carbon stocks and their change is required over large land areas, which is difficult to undertake. While advances have been made in the understanding of agricultural soils (and by extension the soils of lands newly converted to forest), overall understanding of the dynamics of soil carbon in Australian forests remains low, especially in native forests.

	2001	2006	2011	2016	2016
Pool	Mt C	Mt C	Mt C	Mt C	Proportion of total
Living biomass	5,639	5,596	5,594	5,627	26%
Deadwood	1,629	1,620	1,618	1,618	7.4%
Litter	596	590	590	593	2.7%
Above-ground total	7,864	7,806	7,802	7,838	36%
Living biomass	2,682	2,658	2,654	2,665	12%
Soila	11,416	11,349	11,363	11,445	52%
Below-ground total	14,097	14,007	14,018	14,110	64%
Total forest	21,961	21,813	21,820	21,949	100%

Table 5.4: Carbon pools in forests

Mt C, million tonnes of carbon.

^a Soil carbon is reported to a depth of 1 m for mangrove forests, but to 30 cm for all other forests.

🔊 This table, together with other data for Indicator 5.1a, is available in Microsoft Excel via www.doi.org/10.25814/5bda94dad76d8

Box 5.1: The Emissions Reduction Fund

The Emissions Reduction Fund (ERF) is a voluntary offsets scheme that allows farmers and land managers to create carbon credits either by reducing greenhouse gas emissions or by storing carbon in vegetation or soils.

The ERF commenced in 2014. It builds on the preceding Carbon Farming Initiative (CFI), expanding coverage to encourage emissions reductions across the economy. Existing CFI projects were automatically transitioned to the ERF.

ERF methodologies set out the rules and instructions for undertaking projects, estimating abatement, and reporting to the Clean Energy Regulator. Each ERF project must use an approved ERF methodology to ensure that abatement is measurable and verifiable.

Sequestration projects remove CO_2 from the atmosphere by sequestering carbon in plants as they grow and as they increase soil organic matter. Examples are revegetation, establishing commercial plantations, and increasing soil carbon. Projects that avoid losses of vegetation, such as protecting native vegetation at imminent risk of clearing for agricultural purposes, are also treated as sequestration projects.

ERF participants can bid in an auction for a contract to sell carbon credits generated by their projects to the Clean Energy Regulator. Participants can also choose to sell credits from their projects to businesses to offset emissions from those businesses, as well as other ERF projects looking to fulfil their contracts with the Australian Government. In 2017, projects protecting or establishing native vegetation on agricultural land represented more than half the total contracted abatement under the ERF.

In addition to boosting farmers' and landholders' incomes through the sale of carbon credits, the ERF provides other benefits. For example, the environmental plantings methodology could be used by landholders who want to establish plantings to provide shelter for stock, minimise erosion, reduce salinity, improve water quality or provide habitat for wildlife.

Carbon stored in vegetation and soils can be released to the atmosphere, reversing the environmental benefit of the sequestration project. For this reason, all sequestration projects are subject to permanence obligations. The ERF permanence rules recognise the realities of Australia's natural environment and climatic conditions. Owners of environmental planting projects will not be penalised for the project areas losing carbon because of bushfire, drought, pests or disease. In most cases, vegetation and other carbon stores will recover naturally after these events; if not, landowners must take reasonable action to re-establish carbon stores.

Participants can use the Australian Government's publicly available FullCAM modelling software to calculate carbon stocks. Additional information about the ERF and the supporting tools is available at <u>environment.gov.au/</u> <u>climate-change</u>.

Carbon stored in wood products in use and in landfill

Harvesting of forests for wood products results in the loss of carbon to the atmosphere during and after the harvesting event, sequestration of carbon from the atmosphere during subsequent regeneration and regrowth, and a transfer of carbon to the wood products pool. The lifecycle of wood products in use is modelled to vary from short-term (e.g. paper products) to long-term (e.g. structural timber). Wood products that are not recycled are disposed to landfill, where a proportion of their carbon will gradually decay into carbon dioxide or methane, while the remainder (including carbon from some paper products) remains stable in the landfill.

Changes in the carbon stock of harvested wood products are quantified using a model-based method, which employs decay rates for each wood product category (DoEE 2018a). A national database of domestic wood production, including import and export, has been maintained in Australia since the 1930s (most recently reported in ABARES 2017b). This consistent and detailed collection of time-series data was an input to development of a national wood products model. The model links intake of raw materials, through various processing options, to outputs of products and by-products, including to export, recycling, entry to and decomposition in landfill, use for bioenergy, and loss to atmosphere. A detailed description of the harvest wood products model is given in Section 6.15 of the *National Inventory Report 2016, Volume 2* (DoEE 2018a).

A total of 22,093 Mt C was present in Australia's forests and harvested wood products at the end of 2016 (Table 5.1), of which 144 Mt C (0.7%) is in harvested wood products in use and in landfill. After including changes due to imports and exports, disposal and decay, carbon stocks in the pool of wood and wood products in use in Australia showed a net increase of 17 Mt C in the period 2001–16, and carbon stocks in the pool of wood and wood products 5.1 and 5.5). The increase in carbon stocks of harvested wood and wood products in use and in landfill over this period was larger than the decrease in forest carbon stocks over this period, leading to a net gain of 13 Mt C in forest plus wood and wood products over this period (from 22,080 Mt C to 22,093 Mt C) (Table 5.1).



Handling bulk waste at a paper recycling plant.

Trends in wood products in use, for disposal and in landfill

On average, carbon accumulated in harvested wood products in use by 1.5% per year over the period from 2001 to 2016. The bulk of this was stored in relatively long-lived products such as timber used for construction. In 2016, 94 Mt C was stored in wood products in use (Table 5.5).

The amount of waste generated in the disposal of wood products to landfill depends on how much material at the end of its useful life is diverted to other disposal paths or uses, including combustion for energy, recycling, or disposal to aerobic treatment processes.

In the period 2001–16, 13.6 Mt C in wood and paper products was transferred to landfill (Table 5.5). The total mass of carbon in wood products stored in landfill in 2016 was 51 Mt C (Table 5.1).

Both paper and wood in landfill decay relatively slowly, although at different rates. In one reported study, 10% of the carbon in wood transferred to a well-managed landfill decayed over a span of some decades, with the remainder being present for longer periods (Wang et al. 2011). Consequently, with the current quantities of wood being disposed of to landfill, the total stock of carbon stored in landfills will continue to increase.

Trends in waste paper generation and disposal

The amount of carbon in annual paper usage (consumption, calculated as production plus imports minus exports) rose from 147 thousand tonnes in 1945 to 1,845 thousand tonnes in 2016 (Figure 5.5), reflecting both an increasing population, and that the per capita consumption of paper increased almost four-fold between 1945 and 2016 (from an estimated annual 20 kg C per person in 1945, to an annual 76 kg C per person in 2016).

The amount of carbon in waste paper transferred annually to landfill increased from 188 thousand tonnes C in 1945 to a maximum of 927 thousand tonnes in 1995, then declined to 210 thousand tonnes C by 2016 as a result of a shift from disposal in landfill to recycling since the late 1980s (Figure 5.5). The proportion of waste paper recycled increased from 28% in 1990 to 85% in 2016, while the proportion of paper disposed in landfill has declined since the mid-2000s (Figure 5.5). The increase in the proportion of product recycled partly reflects the effectiveness of a number of state government waste management initiatives.

Energy from woody biomass

In 2015–16, the burning of wood and wood waste combusted 2,500 tonnes of carbon, with a gross calorific value²⁴⁸ of 95.6 petajoules (PJ²⁴⁹) of energy. The majority of this wood was consumed in the residential sector (1,300 tonnes carbon, with a gross calorific value of 49.2 PJ); the manufacturing sectors (700 tonnes carbon, with a gross calorific value of 29.2 PJ) are also significant consumers. The electricity generation sector is a relatively small user of wood and wood waste to produce energy, combusting only 400 tonnes of wood and wood waste in 2015–16 with a gross calorific value of 16.9 PJ (DoEE 2017b).

²⁴⁸ The gross calorific value of a fuel is the amount of heat released during its combustion under standard conditions

²⁴⁹ 1 petajoule = 10^{15} joules

Table 5.5: Carbon input to	, and output from, t	he harvested wood	d products pool in	Australia (Mt C)
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	2001–06	2006–11	2011–16	2001–16
Wood products in use – opening stock	76.7	83.2	88.8	76.7
Domestic production	24.1	24.2	23.5	71.8
Imports	5.4	5.9	6.0	17.4
Exports	-10.8	-11.4	-12.5	-34.8
Disposal to landfill	-6.1	-4.5	-3.0	-13.6
Other losses from use	-6.1	-8.5	-8.8	-23.4
Wood products in use – closing stock ^a	83.2	88.8	94.1	94.1
Wood products in landfill – opening stock	41.9	46.2	49.0	41.9
Disposal into landfill	6.1	4.5	3.0	13.6
Decay in landfill	-1.8	-1.7	-1.5	-5.1
Wood products in landfill – closing stock ^b	46.2	49.0	50.4	50.4

Mt C, million tonnes of carbon.

^a 'Wood products in use – closing stock' is calculated as 'Wood products in use – opening stock', plus 'Domestic production', plus 'Imports', less 'Exports', less 'Disposal to landfill', less 'Other losses from use'.

^b 'Wood products in landfill – closing stock' is calculated as 'Wood products in landfill – opening stock', plus 'Disposal into landfill', less 'Decay in landfill'. Source: Department of the Environment and Energy

🔊 This table, together with other data for Indicator 5.1a, is available in Microsoft Excel via www.doi.org/10.25814/5bda94dad76d8



Figure 5.5: Carbon in paper consumed, recycled and disposed to landfill annually, 1945–2016

Note: Consumption is calculated as production plus imports minus exports.

Source: DoEE (2018a), based on ABARES (2017b), Wilson (1969), and Australian Paper Industry Council (APIC) statistics (unpublished).

The data used to create this figure, together with other data for Indicator 5.1a, are available in Microsoft Excel www.doi.org/10.25814/5bda94dad76d8

Case study 5.1: Carbon stocks in the Great Barrier Reef catchment zone

The capability to produce carbon stock accounts for any ecosystem in Australia is under development by the Department of the Environment and Energy. The Great Barrier Reef (GBR) catchment zone is of particular interest as an ecosystem due to its relationship with the Great Barrier Reef. The health or management of a set of catchments will be directly related to the health of a coastal reef through changes to runoff and coastal stability. The GBR catchment area is one of a range of ecosystems of interest to parties participating in pilot projects to develop accounts under the new System of Environmental-Economic Accounting.

A total of 4,018 Mt C was present in the land in the GBR catchments in 2016 (Table 5.6). Of this, 79% was present on forest land, including 3.7% on land carrying mangroves. Figure 5.6 shows the spatial distribution of those carbon stocks. The highest carbon densities are in areas of coastal and montane rainforest and in mangrove forests, while the lowest carbon densities are in grassland and agricultural land.

Over the period from 2001 to 2016, the total carbon stocks of the GBR catchments declined progressively from 4,078 Mt C to 4,018 Mt C (a 1.5% decline). However, the carbon stocks in forests declined initially, but have increased slowly since 2009. Forest carbon stocks changed in line with changes in the area of forest in the GBR catchments, with the initial decline being due to clearing, followed by a rise due to reforestation as well as subsequent regrowth of forests. Carbon in non-forest land initially increased due to addition to the accounts of stocks of below-ground carbon on land that had been cleared and reclassified from forest land, then decreased through loss of this carbon by oxidation over the subsequent decade. It is projected that, if forest recovery continues, the total carbon stocks in the GBR catchments will begin to rise.

Of particular interest to the GBR catchment region are the coastal mangrove forest communities. Mangroves comprise only 0.9% by area of the forest in this region, but contain 4.7% of the total forest carbon (Table 5.6), as the carbon density (mass per unit area) of carbon in mangroves is high (Table 5.7). A large proportion of the carbon in mangrove forests (83%) is below-ground, which reflects the large amounts of carbon stored in mud in tidal ecosystems. Accordingly, excavation activities in mangroves can be a more significant source of carbon emissions than the clearing of other types of forest.

catchments, 2016 Great Barrier Reef catchment zone Carbon density (tonnes per hectare) 40 to <80 120 to <200

Figure 5.6: Carbon density of land in the Great Barrier Reef



Note: Map includes carbon stored on non-forest land.

A higher resolution version of this map, together with other data and maps for Indicator 5.1a, is available via <u>www.doi</u>. org/10.25814/5be3bc4321162



Oliver Creek, Daintree forest, Queensland

Continues

Table 5.6: Carbon stocks of the Great Barrier Reef catchments, 2001-16

	2001	2006	2011	2016	2016
Vegetation type		Mt	t C		Proportion of total carbon stock
Mangrove forest	149	149	149	149	3.7%
Non-mangrove forest	3,070	3,013	3,007	3,017	75%
Total forest	3,219	3,162	3,156	3,165	79%
Non-forest	855	881	867	848	21%
Total GBR catchments	4,074	4,043	4,023	4,013	100%

Mt C, million tonnes of carbon.

Total may not tally due to rounding.

🔊 This table, together with other data for Indicator 5.1a, is available in Microsoft Excel via www.doi.org/10.25814/5bda94dad76d8

Table 5.7: Carbon stocks of the Great Barrier Reef catchments, by carbon pool, 2016

Vegetation type	Area ('000 ha)	Above-ground carbon (Mt C)	Below-ground carbon (Mt C)	Total carbon (Mt C)	Carbon density (t C/ha)	Proportion of total carbon that is below- ground
Mangrove forest	217	26	123	149	686	83%
Non-mangrove forest	23,252	1,082	1,935	3,017	130	64%
Total forest	23,469	1,108	2,058	3,165	135	65%
Non-forest	19,554	21	827	848	43	98%
Total GBR catchment	43,024	1,128	2,885	4,013	93	72%

Mt C, million tonnes of carbon.

🔊 This table, together with other data for Indicator 5.1a, is available in Microsoft Excel via www.doi.org/10.25814/5bda94dad76d8

Case study 5.2: Carbon dynamics of managed native forests in Australia

Forestry and forest management can play many roles in mitigating climate change. These roles include maintaining or increasing existing carbon stores in forest biomass, in soil and in harvested wood products, both in plantations and native forests, and assisting in reducing greenhouse gas emissions through use of wood instead of other, more energy-intensive products.

A collaborative project between the NSW Department of Primary Industries, CSIRO and state forest agencies in New South Wales and Victoria measured or modelled all key carbon stocks in, and flows from, three forest types and regions, including into harvested wood products. The project took a life cycle assessment (LCA) approach, which incorporates all relevant emissions to the atmosphere and removals from the atmosphere, as needed to determine the climate impacts of an industry sector. Over 500 mature native forests trees were weighed (Figure 5.7), and the impact of disturbances (harvest and fire) on carbon pools were considered along with the dynamics of carbon in harvested wood products in use and in landfill. The study also considered the fossil fuel displacement benefits arising from using biomass for bioenergy, the impacts of product substitution, and the socioeconomic implications of native forest management for the case-study regions.

Study sites were paired within three species/region combinations (each site containing either forest managed for production or forest managed for conservation), and had a known history of disturbances (harvest, thinning and bushfire events). Forest management and forest product scenarios were modelled using the software tool "ForestHWP" (Figure 5.8), including baseline options (business as usual, BAU) for production or conservation, scenarios with increased incidence of fire, alternative management options for biomass (e.g. increasing bioenergy production), and end-of-life use options for forest products.

The greenhouse gas impact of different forest management and forest product scenarios (long-term carbon storage and reduced emissions) was expressed in similar terms. For the conservation scenario, this is the long-term forest carbon store (tonnes carbon per hectare, tC/ha). For the production scenario, this is

the long-term forest carbon store in 1 hectare of forest *plus* the store of carbon in harvested wood products from 1 hectare of forest, in use and in landfill, *plus* the reduced carbon emissions associated with use of harvested wood products from 1 hectare of forest instead of other products. The emission footprint of the harvested wood products was also expressed as tonnes carbon emitted per tonnes carbon in harvested wood products, which allowed comparison with the emissions associated with production of alternative materials.

Key findings of the study include:

- Total above-ground carbon was high, but not as high as previously reported for some forests in Australia.
 - Studies of mature forest stands that do not weigh biomass directly can significantly overestimate biomass values, and caution is required when interpreting their results in terms of optimum forest management regimes or the contribution of mature forest stands to the global carbon balance.
- The long-term average greenhouse gas benefits (reduction of net greenhouse-gas emissions) of the production and conservation scenarios (excluding belowground carbon dynamics) were determined for the study sites (Figure 5.9).
 - For the mountain ash (*Eucalyptus regnans*) forest in the Central Highlands, Vic., production scenarios resulted in greater greenhouse gas benefits compared to conservation scenarios (60% greater for the BAU production scenario, increasing to 67% greater in other production scenarios).
 - For the silvertop ash (*E. sieberi*) forest on the south coast of NSW, the BAU production scenario had slightly (4.3%) greater greenhouse gas benefits than the conservation scenario, increasing to 15% greater in other production scenarios.
 - For the blackbutt (*E. pilularis*) forest in northern coastal NSW, the conservation scenario gave 12% greater greenhouse gas benefit than the BAU production scenario. However, production scenarios where a fraction of the harvest residue biomass was used for bioenergy or pulp production gave greenhouse gas benefits up to 30% greater than under the conservation scenario.
- Figure 5.7: A mountain ash (*Eucalyptus regnans*) log from a production site being weighed
- Enternet
 Enternet

- Large volumes of harvest residues and mill residues are currently under-utilised, and could be utilised for applications such as bioenergy generation, with beneficial impacts on net emissions.
- Using harvested wood products as substitutes for other materials mitigates greenhouse gas emissions, in the same way as does the use of sustainably sourced (renewable) forest biomass for bioenergy generation instead of fossil fuels.
 - Expressed on the basis of their life-cycle impact on emissions, domestic native harvested wood products have an emission footprint of approximately 0.2 tonne carbon per tonne of carbon in the product, which is 20-fold less than the emissions footprint of imported hardwood for decking and flooring or fibre-cement cladding, and 10-fold less that the emissions footprint of concrete slabs and steel or concrete transmission poles.
- Use of Australian native forest pulpwood for paper production also reduces greenhouse gas emissions compared to use of pulpwood from native forests in SE Asia.
 - This is due to the large emissions caused by forest harvesting in SE Asia and associated forest degradation and loss, especially on peatlands.
- The overall greenhouse gas benefits of wood use are maintained regardless of the fate of wood at the disposal stage, that is, whether it is recycled, used for energy production, or disposed in landfill.

The overall conclusion of this study is that, across the three regions studied, halting native forest management for wood production would not reduce overall greenhouse gas emissions. In addition, there is considerable room for improvement in the greenhouse gas outcomes of production forestry for all the three case study regions included in this study. These improvements could be achieved primarily by a combination of reduced wastage, increased recovery, increased physical carbon storage in hardwood forest products, and increased use of wood biomass instead of fossil fuels to produce energy.

A full account of this study, together with the modelled economic impacts of different forest management scenarios, is available in Ximenes et al. (2016).



Image courtesy of Stephen Roxburgh, CSIRO



Figure 5.9: Long-term average results for mountain ash forest and forest products at the Victorian Central Highlands site, for each of the major carbon balance components, and alternative forest management and forest product scenarios

BAU, business as usual; EoL, end-of-life; HWP, harvested wood products. Notes:

Six carbon pools are reported across 15 forest management scenarios.

Carbon in biomass is expressed as tonnes C per hectare of forest. Carbon in wood products is expressed as tonnes C deriving from one hectare of forest. Carbon resulting from use of wood instead of other materials or sources is expressed as the reduction in tonnes C added to the atmosphere due to use of wood from one hectare of forest.

Details of scenarios are given in Table 6.2 of Ximenes et al. (2016).

Source: redrawn from Ximenes et al. (2016).

Case study 5.3: Western Arnhem Land Fire Abatement (WALFA) project

Australia's vast northern tropical savannas²⁵⁰ are extremely flammable. Fire has always been one of the most important tools utilised by Aboriginal people for managing their country. Following European settlement and the displacement of Aboriginal people from their clan estates, Aboriginal fire management began to break down across much of northern Australia. Fire regimes became dominated by bushfires in the late dry season. Large and environmentally destructive, these wildfires also contribute significantly to Australia's greenhouse gas emissions. In 2018, the National Inventory Report 2016 stated that these grassland and woodland fires accounted for 9.5 million tonnes of CO_2 e, and are the main source of emissions in Grazing Land Management²⁵¹ (Table 11.36 of DoEE 2018b; see also Maraseni et al. 2016). However, initiatives by Indigenous fire managers and partner agencies to reinstate traditional early-dry-season burning practices have demonstrated that a significant

reduction in carbon emissions is possible, along with highly valued social, cultural, environmental and economic benefits for Aboriginal landowners.

Western Arnhem Land in the Northern Territory of Australia is one such region which had a recent history of severe late-dry-season wildfires covering many thousands of square kilometres annually. In the late 1990s, Aboriginal landowners from Western and Central Arnhem Land and a small group of non-Aboriginal scientists began talking about fire in the landscape. Aboriginal elders – among the last to be born in the bush outside missions and settlements – spoke of "orphaned country", which had become unhealthy through being devoid of people undertaking customary fire management. These discussions led to the development of a vision of people living on healthy country, and ultimately to the program of fire management now known as the Western Arnhem Land Fire Abatement (WALFA) project (Russell-Smith et al. 2009).

Figure 5.10: Aboriginal rangers in Arnhem Land undertake ground burning in the early dry season



Continued

²⁵⁰ A savanna is a tropical or subtropical, woodland/grassland ecosystem with trees sufficiently widely spaced that the canopy does not close. Areas of savanna where the canopy cover reaches or exceeds 20% are classified as woodland forest. Rainfall is seasonal, and dry-season fires are frequent.

 $^{^{251}}$ CO₂-e is 'carbon dioxide equivalent': one tonne of CO₂-e is one tonne of CO₂ or an amount of another greenhouse gas that has the same greenhouse capacity as one tonne of CO₂.

In 2006, the WALFA project commenced formal operation, with the goal of reinstating Indigenous fire management over the remote Arnhem Plateau. WALFA is a partnership between the five Aboriginal ranger groups with responsibility for that part of Western Arnhem Land, the Northern Territory Government, the Northern Land Council, the Darwin Centre for Bushfires Research, and ConocoPhillips (a global oil and natural gas company). With the advent of the Commonwealth Government Carbon Farming Initiative (CFI) and subsequent Emissions Reduction Fund (ERF) legislation, the WALFA project became the landscape-scale model upon which the approved Savanna Burning Methodology²⁵² was based, enabling registered fire projects to earn Australian Carbon Credit Units (ACCUs²⁵³).

To support their engagement with the Emissions Reduction Fund, and their production of ACCUs, the Aboriginal ranger groups with responsibility for the WALFA project in Arnhem Land formed Arnhem Land Fire Abatement (NT) Limited (ALFA; formerly WALFA Ltd). ALFA is a not-for-profit company limited by guarantee and owned exclusively by Aboriginal people with custodial responsibility for those parts of Arnhem Land under active bushfire management. ALFA registered the WALFA project as an eligible offsets project in 2014. Since then, ALFA has expanded to register and support five fire projects in central, north-east and southeast Arnhem Land.

The Arnhem Land fire abatement projects use strategic fire management activities (including early-dry-season burning and late-dry-season firefighting) to reduce the extent and severity of destructive late-dry-season bushfires and in doing so reduce the fire-generated emissions of greenhouse gases. One main activity is for Aboriginal ranger groups within the project areas to undertake aerial and ground burning in the early dry season to reduce fuel loads, protect important environmental and cultural sites, and to establish a mosaic of low-intensity burns around and within the project area (Figure 5.10). This reduces the intrusion of fires from neighbouring lands and contains other fires within the project area, thus reducing the total area that is burnt each year and shifting the seasonality of burning from late dry season to early dry season. This in turn reduces emissions because the resultant fires are less intense and overall less country is burnt each year. The five fire projects are operated by nine Aboriginal ranger groups, consisting of traditional custodians and their families. These ranger groups manage and implement all of the fire project operations in Arnhem Land including fire planning, consultations, early-dry-season burning, late-dry-season firefighting, data recording and fire monitoring.

The five registered fire projects in Arnhem Land cover an area of almost 80,000 km², which is an area larger than the area of Tasmania. To date, the projects have been issued with 1.8 million ACCUs representing an abatement of 1.8 million tonnes of CO_2 -e. The fire projects in Arnhem Land account for 4 % of the 45.4 million ACCUs issued by the Clean Energy Regulator in Australia across all approved methodologies to date. The fire projects in Arnhem Land therefore make a very real contribution to reducing Australia's greenhouse gas emissions.

²⁵² Updated in April 2018: see www.environment.gov.au/climate-change/ government/emissions-reduction-fund/methods/savanna-firemanagement-2018-emissions-avoidance

 $^{^{253}}$ An ACCU represents one tonne CO2-e stored by a project or the emission of one tonne CO2-e which is avoided by a project.

Criterion 5 References

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