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Measuring and reporting bushfire emissions

A discussion paper prepared by the Tasmanian Policy Exchange at the University of Tasmania

February 2024

ACKNOWLEDGEMENT OF COUNTRY

The University of Tasmania pays its respects to elders past and present, and to the Tasmanian Aboriginal community that continues to care for Country. We acknowledge the profound effect of colonial settlement on this Country and seek to work alongside Tasmanian Aboriginal communities, respecting their deep wisdom and knowledge as we do so.

The palawa/pakana belong to one of the world's oldest living cultures, continually resident on this Country for 42,000 years.[1] We acknowledge this history with deep respect, along with the associated wisdom, traditions, and complex cultural and political activities and practices that continue to the present.

The University of Tasmania also recognises a history of truth that acknowledges the impacts of invasion and colonisation upon Aboriginal people and their lands, resulting in forcible removal, and profound consequences for the livelihoods of generations since.

The University of Tasmania stands for a future that profoundly respects and acknowledges Aboriginal perspectives, culture, language and history, and continued efforts to realise Aboriginal justice and rights, paving the way for a strong future.

[1] Members of the Tasmanian Aboriginal community identify with a range of terms, including palawa, pakana, Pallawah, Aboriginal, Aborigine, Indigenous, Traditional Owners, First Nations, and First Peoples. In this submission, we use the term Tasmanian Aboriginal people and communities, while recognising that there are several other ways Tasmanian Aboriginal people may choose to refer to themselves.

ABOUT THE TASMANIAN POLICY EXCHANGE

The Tasmanian Policy Exchange (TPE) was established in 2020 to enhance the University's capacity to work with government and community partners to make timely and informed contributions to policy issues and debates which will shape Tasmania's future.

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CONTRIBUTORS

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ACRONYMS

ACRONYM	DEFINITION
BBM	Biomass Burning Model
CAMS	Copernicus Atmosphere Monitoring Service
CO_{2-e}	Carbon-dioxide-equivalent
DCCEEW	Department of Climate Change, Energy, the Environment and Water
FullCAM	Full Carbon Accounting Model
GHG	Greenhouse gas
GOSAT	Greenhouse Gases Observing Satellite
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Uses
LULUCF	Land-Use, Land-Use Change and Forestry
NGGI	National Greenhouse Gas Inventories
OCO-2	Orbiting Carbon Observatory-2
STGGI	State and Territory Greenhouse Gas Inventories
TPE	Tasmanian Policy Exchange
UNFCCC	United Nations Framework Convention on Climate Change

EXECUTIVE SUMMARY

Following the globe's hottest year on record, we are beginning to confront the reality of a world in which bushfires are more frequent, more intense, and more destructive. It is predicted that by the end of this century, the global number of extreme fire events will increase by up to 50% annually as a direct result of anthropogenic climate change; devastating, 'once in a generation' fire seasons will become the norm. In the aftermath of the traumatic 2019-20 'Black Summer' bushfires, Australian communities and governments have become more focused on the best ways to prepare for, fight, and recover from major fire events.

However, some of the less tangible impacts of largescale bushfires have attracted little public attention. The emissions impact of major fires, and how that impact is measured and reported, are two such issues. This is partly due to the complex nature of estimating GHG emissions from bushfires, a complicated and technical field that is nevertheless vital to our understanding of Australia's carbon footprint.

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This discussion paper aims to promote public awareness and inform policy debate by providing a clear explanation of how bushfire emissions are measured and reported, how this process has evolved, and how it could be improved. It builds on a workshop convened by the Tasmanian Policy Exchange in partnership with the Fire Centre at the University of Tasmania in August 2023, which brought together scientists and policymakers from across the country to discuss how the

Photo: Forest Products Commission, Western Australia process for measuring and reporting GHG emissions from bushfires in Australia could be improved. Drawing on the workshop findings and existing policy and scientific literature, the report examines four crucial topics.

1. The international framework for estimating and reporting emissions

The Australian Government publishes detailed annual data on Australia's GHG emissions, in line with its obligations as a party to the Paris Agreement and according to rules developed by the Conference of Parties of the United Nations Framework Convention on Climate Change (UNFCCC). Bushfires are a major source of GHG emissions within the Land Use, Land-use Change and Forestry (LULUCF) sector. UNFCCC reporting guidelines require countries to use a biomass burning model (BBM) to estimate their annual GHG emissions resulting from fires in different types of landscape. BBMs estimate emissions using data on burned area, biomass fuel load, and emission factors, and are classified in three tiers according to their level of sophistication.

2. How Australia models bushfire emissions

Australia uses the Full Carbon Accounting Model (FullCAM) – an advanced Tier 3 carbon (balance) model which contains a BBM module – for estimating and reporting bushfire emissions to the UNFCCC. Aligned with the Intergovernmental Panel on Climate Change (IPCC) guidelines, Australia differentiates between 'anthropogenic' fires (including controlled hazard/fuel-reduction burning and regeneration burning following forest harvesting) and 'natural' fires, which are those deemed to be beyond human control. This is intended to ensure that countries are not held accountable for emissions that result from natural phenomena, but the method for delineating between the two is somewhat controversial.

FullCAM has increased in complexity since it was developed in the early 2000s and is among the most sophisticated in the world. Notable improvements have included accounting for spatial-temporal variation of biomass across fire zones, the alignment of the model with data from other national reporting, and the standardisation of fire-related definitions across jurisdictions. Although there is little comparative analysis that tests Australia's approach against alternatives – such as top-down models that use satellite data to estimate emissions – the available evidence suggests that our BBM produces estimates aligned with other methods.

3. Improving Australia's approach to measuring and reporting fire emissions

We have identified two conceptual and technical areas in which Australia's approach to modelling and reporting bushfire emissions could be improved.

- The first conceptual challenge concerns emissions reporting. Emissions from large natural fires are reported at a national level (see Figure 3), but do not count towards Australia's net emissions calculations. However, research shows that bushfires are getting bigger, more intense, and more frequent due to human-induced climate change. The impact of anthropogenic climate change on fire severity, frequency, and impact has led some experts to argue that bushfires should be treated like any other source of anthropogenic emissions. Moreover, some argue that excluding bushfire emissions results in significant underestimation of Australia's contribution to the global carbon balance and associated climate emergency. However, we believe that instead of adding emissions from natural fires to Australia's net emissions, which would put us out of step with IPCC guidelines, the Commonwealth Government should provide clearer and more detailed data to ensure that the public can understand the impact and magnitude of bushfire emissions at the state or event level without compromising the consistency of our national-level accounts.

- The second conceptual challenge is the relationship between updates to Australia's emissions modelling and its emissions reduction targets. Regular revision of the model enhances its accuracy, but it means that the emissions values for all previous years are updated. Broadly, this is desirable and necessary. However, LULUCF emissions – and specifically those from bushfires – are more significantly altered by recalculations than those from other sectors. This makes it difficult to predict the extent to which reductions in this sector will contribute to Australia's targets, and is a compelling argument for more ambitious emissions reduction in sectors where estimates are more accurate. Recalculations can also create communication issues, with adjustments to emissions estimates providing ammunition to climate change sceptics. The response to this must be greater transparency regarding the methods used to generate emissions estimates and a concerted effort to increase public understanding of these methods.

We have also identified a range of technical challenges that need to be considered. These include developing a better understanding of:

- Soil carbon emissions due to fire (and subsequent sequestration) which are not included in the current approach.

- How changes in forest type because of fire affect removals and sequestration.

- How emissions subject to the 'natural disturbance provision' (see p.18) are treated in Australia's national inventories.

4. Policy suggestions and priorities for further research

Based on our analysis, we propose the following three policy suggestions and two priorities for future research.

POLICY SUGGESTIONS

1. **Public reporting of fire-related emissions at the state and/or event level** – This would make it easier for researchers and the public to understand the impact and severity of individual fire events.

2. **Regular, long-term reporting of the carbon balance for areas affected by natural fires at state and/or event level.** This would provide a greater level of transparency regarding the complex area of landscape change and carbon sequestration during post-fire recovery.

3. **Increased public engagement on Australia's modelling of fire emissions.** There is an opportunity for the Department of Climate Change, Energy, the Environment and Water (DCCEEW) to increase its focus on providing accessible information relating to Australia's modelling of bushfire emissions. This could improve public 'climate literacy' and understanding of the emissions from significant bushfire events and subsequent recovery.

RESEARCH PRIORITIES

1. **Understanding changes in soil carbon due to bushfires.** Soil carbon emissions from fire are not currently estimated. This is a significant gap because soil carbon emissions from fire have been shown to be substantial in organic soils such as peatlands. Additionally, it is possible that the assumed transience of fire emissions may not apply to soil carbon in the same ways as above-ground biomass. From both emissions and sequestration perspectives, a greater understanding of soil carbon dynamics and the ability to accurately model them in FullCAM should be a priority.

2. **The treatment of landscapes that undergo a change in forest, species, or soil properties because of fire.** The way that emissions from fire are treated under the current natural disturbance provision approach struggles in cases where a fire causes a change in forest structure or composition and associated productivity and is unlikely to fully recover within a 15-year timeframe. While changes in forest state are the most dramatic example, it will also be important to account for the risk that forests may increasingly be unable to recover lost biomass within 15 years for non-conversion reasons, including reduced productivity associated with elevated mortality and lower rates of regeneration. As the intensity and frequency of fires increases, they will become more likely to significantly change the landscape and its carbon profile. Therefore, it will be important to develop alternative methods for reporting emissions that do not rely on forests recovering biomass in the same timeframe. As measurement techniques improve, moving towards reporting an annual carbon balance for areas affected by major bushfires could be one way to provide greater transparency and real-time recovery data.

Beyond these specific ideas, we argue that there is a need for more collaboration between the officials and scientists who compile inventory reports and the academic community more broadly.

Australia has a credible and sophisticated approach to estimating bushfire emissions, but it must constantly be refined as relevant technology and scientific knowledge improve. Moreover, it is essential to promote greater public awareness and understanding of bushfire emissions to ensure that Australian governments at all levels act appropriately. To this end, it is also vital that state, territory, and federal governments do their best to ensure that reporting on bushfire emissions is transparent, accurate, and accessible.

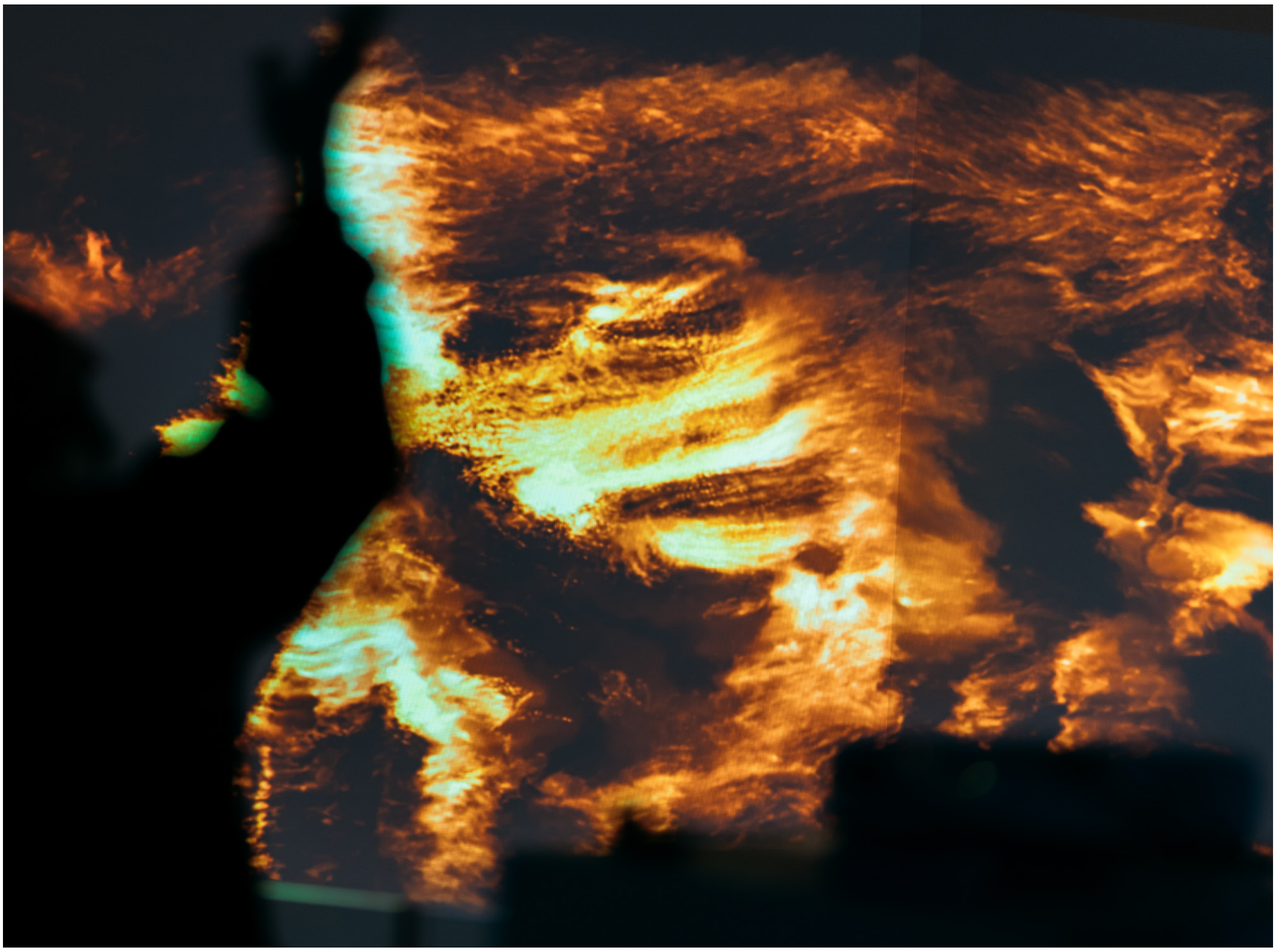


Photo: University of Tasmania

INTRODUCTION

This discussion paper provides an accessible, independent overview of the process for estimating greenhouse gas (GHG) emissions from bushfires. Although this complex area of carbon accounting is very important given the increasing frequency and intensity of bushfire events, it is poorly understood outside of the scientific community. We aim to make it easier for policymakers and the public to engage with this highly technical field, in the hope that this prompts further research and contributes to the development of a more transparent and accessible approach to measuring and reporting Australia's bushfire emissions.

Context

Debate is raging over the best and fastest ways to reduce GHG emissions as communities around the world begin to grapple in earnest with the magnitude of the climate emergency. Some 150 countries now have net-zero targets, dozens have committed to not building new coal-fired power stations and phasing out existing ones, and more than 98% of the world's population lives in a country that has ratified the Paris Agreement. However, the slow pace of past action and the inadequate ambition of current commitments mean that GHG emissions are yet to start falling. As a result, the world is almost certain to overshoot 1.5 degrees Celsius of global warming in the near future.

Carbon accounting and the accurate and timely reporting of emissions is a crucial element of the global response to climate change. Although we now have rigorous, sophisticated methods for measuring GHG emissions from sectors like energy or industrial processes, there are other areas in which methods for estimating emissions are relatively new and rapidly evolving. The 'Land-Use, Land-Use Change and Forestry' (LULUCF) sector is an excellent example of this: it remains immensely challenging to generate accurate emissions estimates in this field due to the dynamic and complex interactions between processes of vegetation growth, decomposition, human intervention, and events like fire, drought, or flood.

Terminology

In this report, we use the term 'bushfire' due to our focus on the Australian context. In international guidelines and literature from other countries, terms such as 'landscape fire' and 'wildfire' are also used.

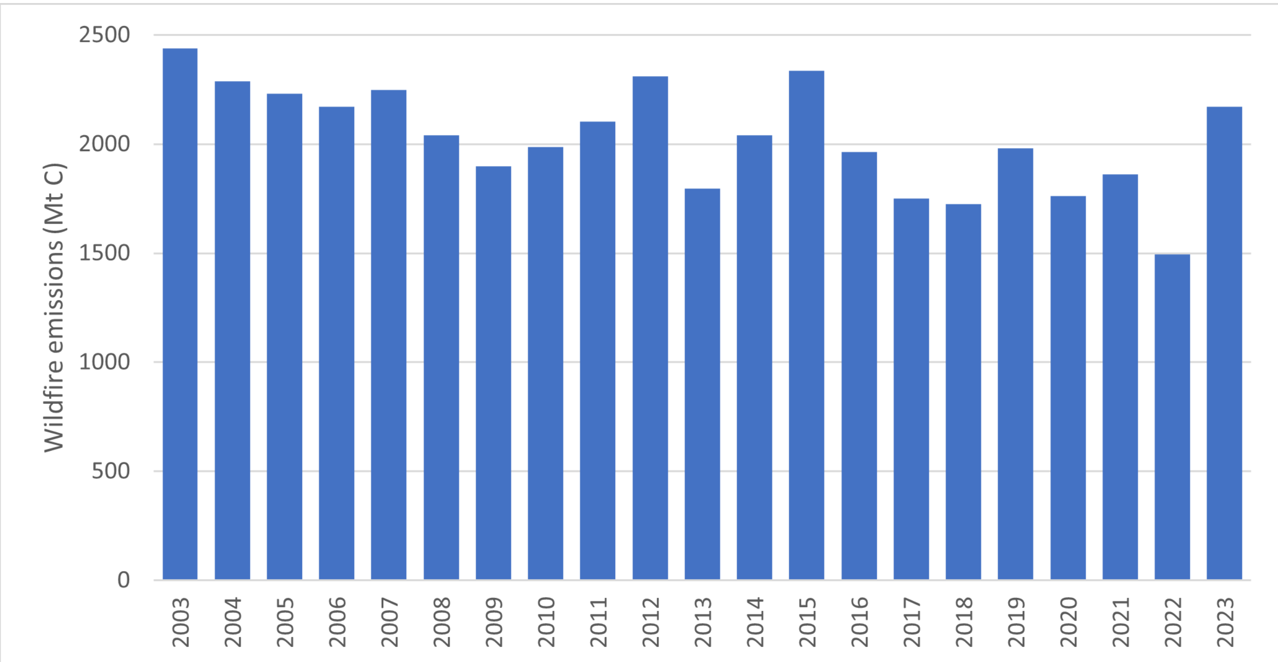
In particular, GHG emissions from bushfires (see box above) are difficult to estimate accurately. This uncertainty is cause for concern due to the enormous volume of emissions from bushfires. The Copernicus Atmosphere Monitoring Service (CAMS) estimates that bushfires across the globe produced 1.76 billion tonnes of CO2 in 2021 (see Figure 1) – approximately 5.1% of total emissions, and more than any single country in the world except for China, the US, India, and Russia. Importantly, the emissions impact of fire has historically been short-lived due to the increased sequestration productivity of regrowing burned areas. As a result, under

> bushfires contributed approximately 5.1% of total global emissions in 2021

normal conditions, it has been assumed that the long-run emissions from fire are likely to be zero or close to zero as long as no land-use change occurs. As climate change increases fire risk and disrupts natural recovery processes, however, the carbon-neutrality or 'transience' of fire emissions could begin to change. New research suggests that more frequent and intense fires could contribute to a dangerous 'feedback loop' in which rapidly increasing fire emissions drive faster climate change and thereby further increase the frequency and intensity of fires. It is predicted that by the end of this century, the global number of extreme fire events will increase by up to 50% annually as a direct result of anthropogenic climate change. Improving the accuracy of estimation in this area is therefore vital to better understand the extent of LULUCF emissions and removals and their impacts on climate change.

As a result of both the technical challenges and policies which underpin carbon accounting practices in the land-use sector, Australia's methods and obligations under the United Nations Framework Convention on Climate Change (UNFCCC) are not always well understood, including among some scientific experts in the field. Connecting the expertise of researchers with the goals and requirements of reporting frameworks is therefore of vital importance both to the quality and credibility of Australia emissions reporting.

***Figure 1**: CAMS estimate of total global bushfire carbon emissions, 2003-2023*



Structure

This discussion paper has four sections:

- **Section 1** describes the key rules and procedures developed by the UNFCCC for measuring LULUCF emissions, including from bushfires.
- **Section 2** explains how the UNFCCC methodology is applied in Australia using the Commonwealth Government's 'Full Carbon Accounting Model' (FullCAM) and assesses the logic of Australia's differentiation between 'natural' and anthropogenic fire events.
- **Section 3** examines how Australia's treatment of bushfires in the National Greenhouse Gas Inventories (NGGI) affects climate politics and policy, and the potential implications of any changes in this area.
- **Section 4** outlines priorities for future research and policy reform which we believe will: improve understanding and collaboration between academics, industry practitioners, and policy professionals; reinforce the credibility and authority of carbon accounting approaches; and support greater alignment across disciplines.

Photo: Brand Tasmania, Dunalley

1. THE INTERNATIONAL FRAMEWORK FOR ESTIMATING AND REPORTING EMISSIONS

Each year, the Australian Government publishes detailed data on Australia's GHG emissions, in line with its responsibilities as a party to the Paris Agreement and in accordance with the UNFCCC rules. These guidelines require countries to prepare an inventory of emissions and removals of all carbon-dioxide-equivalent[2] ($CO_{2\text{-}e}$) GHGs using a common reporting format across five sectors:

- Energy
- Industrial processes and product uses (IPPU)
- Agriculture
- Waste
- LULUCF

For most of these sectors, emissions estimates use the (comparatively) simple process of multiplying a quantity of consumed material by an emissions factor.[3] However, in the LULUCF sector the combination of anthropogenic and natural emissions and removals and the scale over which they occur makes the process much more complex.

Broadly, the LULUCF sector includes emissions and removals from land management practices that affect carbon storage in vegetation and soils.[4] Since 1990, Australia's LULUCF emissions have fallen by 179%, and the sector became a net 'emissions sink' in 2015 (see Figure 2). Much of this decline is due to reduced rates of land clearing and reforestation of previously cleared land. As of 2021, the most recent year for which inventory data are available, the LULUCF sector overall is sequestering approximately 63,000kt CO2-e more per year than it emits, reducing Australia's overall emissions by around 12%.

The LULUCF sector reports carbon stock change according to whether land use has remained the same as the previous inventory year or has varied (e.g., due to land clearing or afforestation). There are six categories of managed land:[5]

1. **Forest land,** which covers harvested native forest, other native forest, plantations, and areas used for fuelwood collection. The minimum size for an area to be classed as forest land is 0.2ha, and the vegetation in the area must meet tree height and canopy cover requirements.
2. **Cropland,** which includes land used continuously for cropping purposes and land that is periodically rotated between cropping and grazing/pastoral uses (if cropland is converted permanently to grazing land, it is reassigned to the grassland category).

[2] Carbon dioxide equivalence describes the global warming potential of different greenhouse gases in by comparison to carbon dioxide (i.e., 1 tonne of methane has the same global warming potential as 28 tonnes of carbon dioxide, and can therefore be expressed as 28 t-$CO_{2\text{-}e}$). The greenhouse gases reportable in national inventories are carbon dioxide (CO_2), methane (CH_4), nitrous oxide ($N2_O$), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF_6), and nitrogen trifluoride (NF_3).
[3] To calculate the $CO_{2\text{-}e}$ emissions that would result from incinerating municipal solid waste, for example, the weight of incinerated material in tonnes is simply multiplied by the relevant emissions factor (5.36).
[4] As the focus on land management practices suggests, LULUCF applies only to managed land, defined by the Intergovernmental Panel on Climate Change (IPCC) as: "land where human interventions and practices have been applied to perform production, ecological or social functions". In Australia, all lands are considered managed lands.
[5] More information on allocation and definition of these categories can be found on the State and Territory Greenhouse Gas Inventories (STGGI) data and methodology website and in the national inventory report.

3. **Grassland,** which may be used for grazing but also includes natural savannah and land with woody vegetation that is not dense enough to classify as a forest.
4. **Wetland,** which comprises all wetlands classified as such in the Commonwealth [Directory of Important Wetlands dataset] plus any other lakes, swamps, reservoirs, and other major water courses.
5. **Settlements,** which captures all land used for residential or industrial activities plus civic and transport infrastructure, communications infrastructure, and other features of the developed/built environment.
6. **Other land** is all land that does not fall into one of the above categories, including deserts, rock, bare soil, and so on.

The LULUCF sector also includes carbon stored in harvested wood products. When managed native or plantation forests are harvested, all carbon removed from the forest and processed is reassigned to the 'harvested wood products' sub-sector.[6] This process ensures that all movement of land or carbon between different uses and pools is tracked at a fine spatial resolution, and accounts for as many sources of GHG emissions as possible.

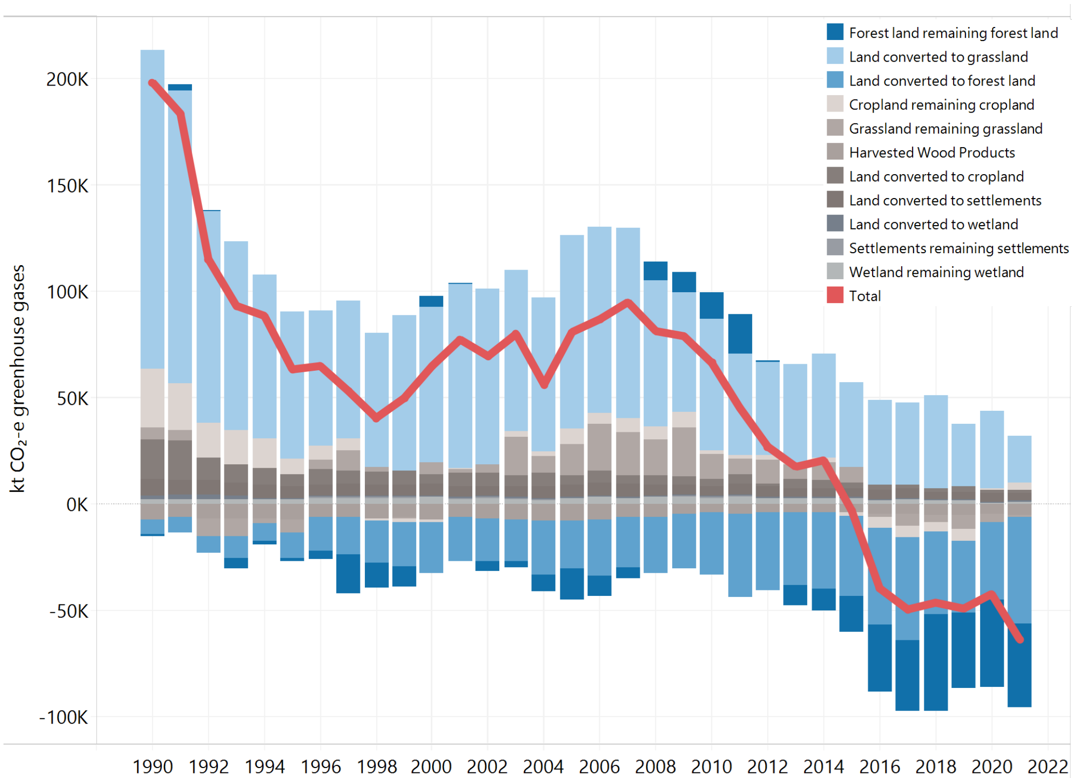


Figure 2: *Australia's LULUCF emissions, 1990-2021*

[6] Emissions produced during the harvesting process – primarily from regeneration/slash burning and hazard reduction burning – are recorded in 'forest land remaining forest land'.

1.1 Reporting emissions from bushfires

Bushfires are a major source of emissions – including CO2, other GHGs such as nitrous oxide and methane (IPCC 2019, 2.48), and harmful particulates – within the LULUCF sector. Therefore, Intergovernmental Panel on Climate Change (IPCC) reporting guidelines require countries to estimate GHG annual emissions resulting from fires in Forest Land, Cropland, and Grassland. It recommends a generic approach for estimating emissions using a biomass burning model (BBM).

Estimating fire emissions

There are two methods for estimating emissions from bushfires: bottom-up approaches and top-down approaches. Bottom-up approaches use "direct measures of the heat given off by a fire or estimates of the pre- and post-fire fuel load in a forest to determine fire emissions" (Viglione 2023). Countries that report fire-related emissions to the IPCC typically do so using a specific type of bottom-up approach called a biomass burning model (BBM). This method was first proposed in Seiler and Crutzen (1980) but has subsequently been adapted to suit different conditions.

Generating accurate emissions estimates using BBMs can be challenging because they require high-quality data on burned and unburned areas, fire severity, the different types of vegetation present, the estimated mass of different fuels and their emission factors, and the soil carbon content (Bowman et al 2020, 348-49). Fortunately, the quality and availability of these data have improved significantly over the past few decades, as technological advances in remote sensing have allowed for modelling the presence of fuel components (such as tree branches, live and dead leaves, coarse and fine roots) and consumption rates (French at al 2011, 3).

More recently, researchers have begun to employ top-down approaches that use "satellite measurements and atmospheric transport models to estimate the amount of CO_2 associated with a particular burn" (Viglione 2023). Data from satellites such as the Greenhouse Gases Observing Satellite (GOSAT) and the Orbiting Carbon Observatory-2 (OCO-2) facilitate the direct measurement of CO_2 concentration in the atmosphere because of fire events. However, these approaches are still being refined and are not widely used for international reporting at this stage.

The IPCC categorises BBM models into three tiers, with Tier 1 being the most basic and Tier 3 the most sophisticated. The Tier 1 approach involves inputting default values into an equation (see Figure 3). Tier 2 approaches require using "more refined country-derived emission factors and/or more refined estimates of fuel densities and combustion factors" than the default values (IPCC 2019, 2.49). Tier 3 approaches, such as that used in Australia, are more comprehensive again, and "include considerations of the dynamics of fuels (biomass and dead organic matter)" (IPCC 2019, 2.50).

***Figure 3:**: IPCC equation for estimating emissions from fires*

Equation 27

Estimation of greenhouse gas emissions from fire

$$L_{fire}=A*M_b*C_f*G_{ef}*10^{-3}$$

Where:

L_{fire} = amount of greenhouse gas emissions from fire, tonnes of each GHG (e.g., CH_4, N_2O, etc)

A = area burnt, ha

M_b = mass of fuel available for combustion, tonnes ha^{-1}. This includes biomass, ground litter, and dead wood. When Tier 1 methods are used then litter and dead wood pools are assumed zero, except where there is a land-use change.

C_f = combustion factor, dimensionless

G_{ef} = emissions factor, g kg^{-1} dry matter burnt

2. HOW AUSTRALIA MODELS BUSHFIRES

Australia's GHG emissions from bushfires are sometimes so large that they eclipse those from all other sources. For example, according to some estimates, the devastating 2019-20 Australian 'Black Summer' bushfire season emitted some 715 million tonnes of carbon dioxide – more than 1.5 times greater than the total reported emissions for all other sectors combined that year. This means that generating accurate estimates of Australia's fire-related emissions is vital to understanding our overall carbon footprint.

> the 2019-20 Australian 'Black Summer' bushfire season emitted over 1.5 times more than all other sectors combined

To this end, Australia uses an advanced Tier 3 BBM for estimating and reporting our fire-related emissions to the UNFCCC (discussed in Section 2.3). However, before discussing Australia's model it is important to understand which types of bushfires are included in Australia's main inventory, the National Greenhouse Gas Inventory (NGGI). Existing concentrations of wood supply resources, processing and/or manufacturing operations, domestic and/or international transport links, and strong potential for growth.

2.1 Natural versus anthropogenic fires and the natural disturbance provision

Australia's emissions reporting differentiates between 'anthropogenic' fires (resulting from human activity) and 'natural' fires. Anthropogenic fires include all prescribed burning (for example, controlled hazard/fuel reduction burning) and other deliberate and managed uses of fire (such as regeneration/slash burning following forest harvesting) on non-settlement land-use types (i.e., not including urban house fires). Any fire on land converted to forest land (plantations on previously cleared land, for example) is also considered anthropogenic.

Very large fires that are deemed to be beyond human control are dealt with according to IPCC guidance on 'natural disturbances' (see box on following page). This is intended to ensure that countries are not held accountable for emissions that result from natural phenomena. Natural disturbances are differentiated from anthropogenic fires by calculating a background level of fire-related emissions and an associated margin of error using the IPCC method (see IPCC 2019, 2.48–2.50). For Australia, the background level is the mean of a 30-year time series (the 'calibration period') of annual fire-related emissions, and the margin is two standard deviations beyond the mean. At the national level, any fire season in which emissions exceed the margin is classified as anomalous. For an anomalous season, if the area burned in a state and territory (excluding anthropogenic fires) exceeds the mean area burned area for the calibration period by one standard deviation, then all emissions from non-prescribed fires in that state or territory are reported separately, or disaggregated, in Australia's reporting (Bowman et al 2023, 4).

Initially, the model assumes that areas burned by natural fires will recover and that therefore, emissions will be cancelled out by carbon sequestration in recovering forests. The burned areas are then monitored for 15 years to assess whether this regrowth and carbon recapture is occurring. If it does not, the resulting emissions are reported "in the appropriate land conversion category" and debited from the year of the event (DCCEEW 2021, 299). Figure 3 shows the national and subnational thresholds for the natural disturbance test, and the number of 'natural disturbance years' between 1989-90 and 2020-21 (DCCEEW 2021, 299).

Australia's reporting to the UNFCCC includes emissions and reduction totals both with and without the natural disturbances provision applied. The former "allows a clear presentation of the national emissions trend" which might otherwise be obscured by natural disturbance variability; and the latter provides a holistic picture of overall emissions and reductions (DCCEEW 2020, p. 15).

Despite being embedded in the IPCC guidance, the distinction between anthropogenic and natural fires is becoming increasingly contested as the frequency and intensity of all fires increases due to human-induced climate change (Bowman et al 2023, 6-7). This issue is further discussed in Section 3.2.

The 'natural disturbance' provision

The IPCC guidelines define natural disturbances as "non-anthropogenic events or non-anthropogenic circumstances that cause significant emissions and are beyond the control of, and not materially influenced by a country" (IPCC 2019, 2.71). This includes fires that are not the result of human activity. The IPCC recommends that emissions from natural disturbances are reported separately from human-induced emissions.

Australia reports areas affected by natural disturbances separately in the NGGI until:

> pre-disturbance levels are reached to ensure completeness and balance in reporting. A modelling approach is then applied to ensure that emissions and subsequent removals from non-anthropogenic natural disturbances average out over time, leaving greenhouse gas emissions and removals of anthropogenic fires as the dominant result in the national inventory (DCCEEW 2021, 298).

FullCAM also monitors natural disturbance areas for "permanent changes in land use, in which case emissions are reported in the appropriate land conversion category, and salvage logging emissions are reported" (DCCEEW 2021, 277).

It is assumed that in Australia, emissions from natural fires are 'transient' because they will be offset by rapid forest regrowth.

***Figure 4:** Calculations for the natural disturbance test at national and state/territory levels, 1989–90 to 2020–21 (table reproduced from DCCEEW 2021, 299)*

Calibration Period	Calculation details	Threshold		No. of natural disturbances, 1989-90 to 2020-21
	Step 1: National Level Test			
1989-90 to 2019-20	Applied to: gross emissions (not including removals). Threshold calculation: mean plus two standard deviations of calibration period	65,689 kt $CO_{2\text{-}e}$		6
	Step 2: Regional Test			
1989-90 to 2019-20	Only applies in national outlier years (following Step 1 test). Applied to: annual area burned. Threshold calculation: mean area burned plus one standard deviation of calibration period.	ACT	0.02 kha	3
		NSW	223.19 kha	3
		QLD	167.50 kha	2
		SA	42.52 kha	3
		TAS	16.71 kha	4
		VIC	119.67 kha	5
		WA	336.36 kha	4

2.2 Fire emissions under FullCAM

As we have noted, Australia uses a Tier-3 BBM to estimate its annual bushfire emissions as an element of the broader FullCAM model used for estimating carbon stock change in other areas of the LULUCF sector. FullCAM is a software tool that estimates "fluxes of carbon into and out of all biomass, litter, debris and soil carbon pools in forest and agricultural systems" using several "sub-models that describe the processes of biomass growth and decay, litter decomposition, and soil carbon dynamics" (Surawski et al 2012, 6).

The BBM used in FullCAM has increased in sophistication since it was developed in the early 2000s, with notable improvements including: spatial-temporal variation of biomass across fire zones; the alignment of the model with data from other national reporting (for example on deforestation); standardisation of fire-related definitions across jurisdictions; the incorporation of 'standing dead' pools of carbon into the model; improved modelling of impacts on live biomass; and accounting for seasonality.[7] These improvements helped to shift FullCAM from a Tier 2 model to a Tier 3 model.

[7] For more information, see https://publications.csiro.au/rpr/download?pid=csiro:EP193940&dsid=DS6

Fires are included in FullCAM as 'events' and are categorised as one of six types:

1. Forest fire (used when it cannot be determined if type 5 or 6 is more appropriate)
2. Prescribed burning (describes anthropogenic fires where no trees are killed)
3. Site preparation – broadcast burn
4. Site preparation – windrow and burn
5. Wildfire – trees killed
6. Wildfire – trees not killed.

The effect of each fire event on emissions is determined by 36 parameters (see Table 1),[8] which combine to model three main carbon flux processes (Surawski et al 2012, 7):

1. Emissions to the atmosphere from burned tree and debris components
2. The transition of living tree components to debris, and debris components to the inert soil pool in response to fire
3. The effect of fire on vegetation regrowth.

Photo: NIFPI

[8] In practice the decomposable and resistant debris parameters must be assigned the same values (Surawski et al 2012, 8).

	Parameter	Description
General parameters	1. Affected portion	Percentage of forest affected by fire. Dependent on factors including weather conditions, vegetation type, and fire extent
	2. Leaf re-growth percentage	The percentage of leaves that automatically regrow after 1 year following fire event
Parameters related to affected portions – tree components	3. Stem – to atmosphere 4. Stem – to debris 5. Branches – to atmosphere 6. Branches – to debris 7. Bark – to atmosphere 8. Bark – to debris 9. Leaves – to atmosphere 10. Leaves – to debris 11. Coarse roots – to debris 12. Fine roots – to debris	These parameters specify the combustion ratio (expressed as a percentage of the pre-fire mass) of each tree component directly to the atmosphere and to the debris pool
Parameters related to affected portions -decomposable debris	13. Dead wood – to atmosphere 14. Dead wood – to inert soil 15. Chopped wood – to atmosphere 16. Chopped wood – to inert soil 17. Bark litter – to atmosphere 18. Bark litter – to inert soil 19. Leaf litter – to atmosphere 20. Leaf litter – to inert soil 21. Coarse dead roots – to atmosphere 22. Coarse dead roots – to inert soil 23. Fine dead roots – to atmosphere 24. Fine dead roots – to inert soil	These parameters specify the combustion ratio (expressed as a percentage of the pre-fire mass) of decomposable debris directly to the atmosphere and to the inert soil pool
Parameters related to affected portions – resistant debris	25. Dead wood – to atmosphere 26. Dead wood – to inert soil 27. Chopped wood – to atmosphere 28. Chopped wood – to inert soil 29. Bark litter – to atmosphere 30. Bark litter – to inert soil 31. Leaf litter – to atmosphere 32. Leaf litter – to inert soil 33. Coarse dead roots – to atmosphere 34. Coarse dead roots – to inert soil 35. Fine dead roots – to atmosphere 36. Fine dead roots – to inert soil	These parameters specify the combustion ratio (expressed as a percentage of the pre-fire mass) of resistant debris directly to the atmosphere and to the inert soil pool

***Table 1:** Fire parameters in FullCAM*

2.3 Comparison to other models

There is not a great deal of peer-reviewed research that compares the BBM used in FullCAM to other emissions estimation models. A study by Byrne et al (2021, 13) found that top-down and bottom-up estimates of the emissions from the Black Summer fires were generally consistent. Specifically, they show that the best estimate from FullCAM fell within the range of both their study and that by van der Velde et al (2021) (see Table 2), although the FullCAM best estimate was somewhat higher than the equivalent provided by the top-down studies. This indicates that although some FullCAM fire parameter default values have not in all cases been subject to extensive, independent verification (Surawski et al 2012, 18-19), the resulting estimates align reasonably well with other approaches. However, as noted in Section 3.1, there is clearly scope to further refine the BBM used in FullCAM, and the Commonwealth public servants responsible for parameterising FullCAM make such revisions and changes regularly.

Type	Study	Range (TgC)	Best (TgC)
Top-down	Byrne et al 2021	113-236	167
	van der Velde et al 2021	141-236	195
Bottom-up	Shiraishi & Hirata 2021	141-153	147
	Bowman et al 2020	85-282	184
	FullCAM 2020	-	232

Table 2: *Comparison of top-down and bottom-up estimates of emissions from the Black Summer fires by Byrne et al (2021)*

2.4 Summary

Australia uses a sophisticated, Tier 3 BBM to estimate its bushfire-related GHG emissions. Although there is little comparative analysis that tests Australia's approach against alternatives – such as top-down models – the available evidence suggests that our BBM produces estimates aligned with other methods. However, there may still be a need to revisit Australia's differentiation between natural and anthropogenic fires considering the way that human-induced climate change is increasing the frequency and intensity of fire events.

Photo: Brand Tasmania, Dunalley

3. IMPROVING AUSTRALIA'S APPROACH TO MEASURING AND REPORTING FIRE EMISSIONS

Australia's modelling and reporting of bushfire emissions is a world-leading approach to a complex set of thorny technical challenges. The Australian BBM is underpinned by the best available scientific evidence and aligned with rules and guidelines developed under the auspices of the UNFCCC. Moreover, it is being continuously improved as new research facilitates increasingly accurate assumptions regarding the parameters discussed above. Nevertheless, there are several areas in which Australia's approach could be further improved. Based on discussions with technical experts, we have identified two policy challenges that need to be addressed, as well as a handful of technical issues.

3.1 Policy challenges

3.1.1 Natural versus anthropogenic fires

The first challenge is how Australia differentiates between natural and anthropogenic fires.[9] As noted above, emissions from natural fires are reported but do not count towards Australia's net emissions calculations and are not included in state inventories, while the affected area is monitored during recovery to understand the extent to which new growth offsets fire emissions.

There are two main arguments against this approach. First, research from Australia and around the world clearly shows that bushfires are getting bigger, more intense, and more frequent as a result of human-induced climate change. From 2001-2019, the area burned globally by fires annually has almost doubled, and fires now burn some 3 million hectares (roughly the land area of Belgium) more on average per year than they did in 2001. This increase is at least partly due to global warming causing higher average temperatures, changing patterns of rainfall, and decreasing soil moisture. The argument is that if fire-related emissions are increasing because of human-induced climate change, then there is a case for treating bushfire like any other source of anthropogenic emissions. Moreover, even if the ignition of bushfire is natural the scope of the subsequent fire can be influenced by prior landscape management and firefighting response.

Second, some experts argue that excluding natural fire emissions for Australia's net emissions calculations results in significant underestimation of Australia's contribution to the climate emergency given the magnitude of emissions from large fire events such as the 2019-20 Black Summer fires and the 2013 Tasmanian Dunalley fires. This may undermine public understanding of, and confidence in, Australia's emissions estimates and climate policy.

Conversely, the intent of UNFCCC reporting is to hold countries accountable for emissions that occur within their territorial jurisdiction and that they can control. Although human-induced climate change exacerbates the incidence and severity of fires, the occurrence of fires in one country is not directly causally linked to that country's carbon footprint. Regardless of the success or failure of Australia's emissions reduction efforts, it will continue to experience more

[9] Other countries also struggle with this issue.

intense and devastating fires as the climate emergency progresses. Changing the rules to make Australia or other fire-prone countries 'responsible' for the resulting emissions could risk masking their progress (or lack thereof) in emissions reduction in other areas. Australians could even become complacent about cutting their own personal emissions if their efforts pale into insignificance every time there is a large fire.

However, including emissions from natural fires in Australia's net emissions would undermine the comparability of our emissions data with other countries. There are two reasons for this. First, most comparable countries do not report CO_{2-e} emissions from natural fires. Instead, these countries typically use a long-term (10+ years) average of emissions, with subsequent removals captured by long-term measurement of tree growth in forest lands. Second, by including natural fire emissions, Australia's targets would no longer reflect domestic mitigation efforts in a way that is consistent with the Paris Agreement. Given that comparability is one of the five principles that underpin the UNFCCC reporting process, changing Australia's approach in this way would undermine our adherence to international best practice

Overall, we believe that there is a clear case to more effectively communicate and disaggregate Australia's emissions from different types of fire in different places. More specifically, we support clearer and more accessible reporting of both anthropogenic and natural fire emissions at the state or even event level. This would help to bolster public understanding of and confidence in Australia's emissions estimates and provide researchers with valuable baseline data against which to test the robustness of our current method against others in common use among forest scientists.

Ignition

It might seem logical to designate a fire as natural or anthropogenic depending on whether it is started by humans (deliberately or accidentally) or by a natural event such as a lightning strike. However, this method of delineation becomes complicated where the relevant government has done all it reasonably can to prevent people starting fires, for example by criminalising arson and imposing fire bans at times of high fire danger. In these cases, can the country as a whole be held responsible? Moreover, the severity and intensity of a fire is largely determined by the climate and landscape conditions at the time of ignition, rather than whether the fire was started by humans or a natural event – and these conditions are increasingly being shaped by human behaviour.

3.1.2 Model updates and emissions reduction targets

The second challenge relates to how updates to Australia's emissions modelling affect its emissions reduction targets. In most cases,[10] emissions targets involve a commitment to reduce emissions by a specific percentage compared to a baseline year: Australia's national target is to reduce emissions to 43% below 2005 levels by 2030. Constantly updating the model is a requirement under the Paris Agreement, which obliges countries to incorporate new data and/or methodologies as they become available. This means that, when emissions models are updated in line with Paris Agreement requirements, these changes are applied retrospectively to Australia's National Inventory Reports in what is referred to as a 'recalculation'. With each new National Inventory Report, the emissions values for all previous years – including the baseline year – are updated.

The impact of modelling updates on emissions targets highlights the enormous complexity of this field. Recalculations reflect the process working well: as our knowledge of the processes underlying land-use emissions, fire, and sequestration improves, so too does our modelling. However, there are two issues worth noting.

First, LULUCF emissions – and specifically those from bushfires – are more significantly altered by recalculations than those from other sectors (see box on following page). This has important policy implications, because it makes it difficult to predict the extent to which reductions in this sector will contribute to Australia's overall emissions target. Therefore, it would be unwise for the Australian Government to focus its future emissions reduction plans too heavily on the LULUCF sector – particularly if this comes at the expense of developing comprehensive plans for decarbonisation in other sectors. Uncertainty regarding the extent of LULUCF emissions is a compelling argument for faster and more ambitious emissions reduction in other sectors – such as energy generation and industrial processes – where estimates are more accurate.

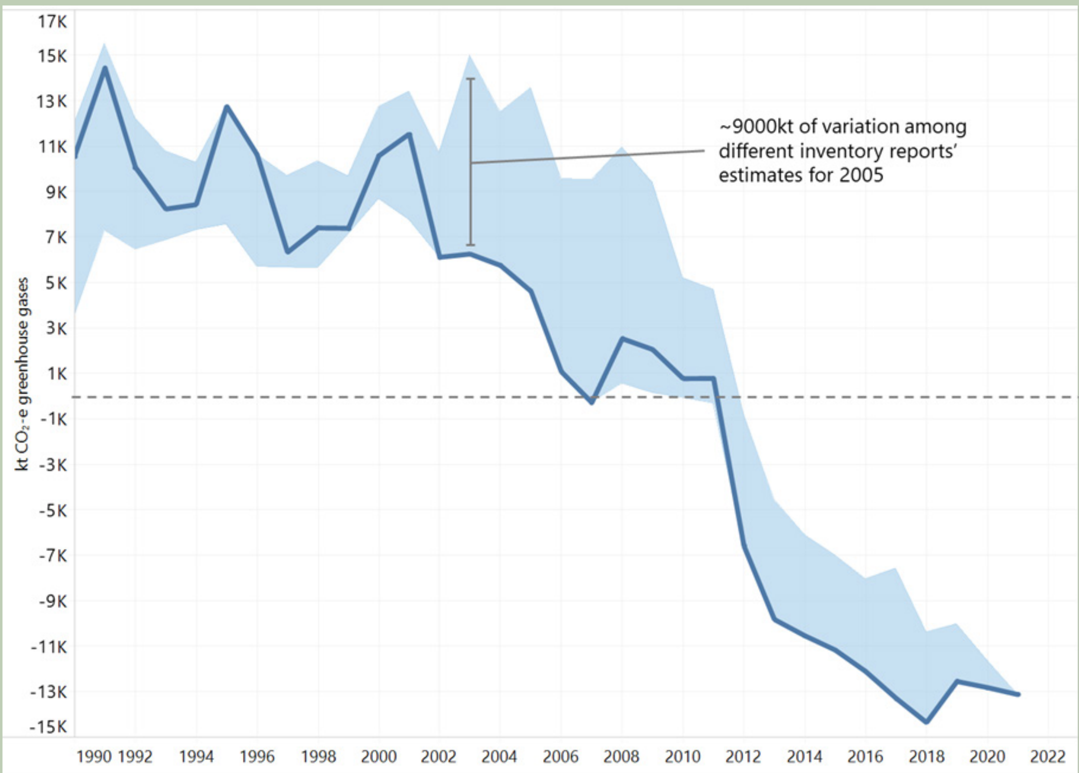
Second, recalculations can create communication challenges, with adjustments to emissions estimates providing ammunition to critics who seek to undermine public confidence in climate science. The response to this must be greater transparency regarding the methods used to generate emissions estimates and a concerted effort to increase public understanding of these methods.

[10] Given that Tasmania already has a net-negative carbon emissions profile, and has a target of simply remaining carbon-neutral or better, this is less of a problem here than it is in other states or at the national level.

LULUCF emissions in Tasmania

Tasmania's claim to be an 'emissions negative' jurisdiction is heavily reliant on the LULUCF sector acting as a carbon sink: in 2021, the sector was responsible for -13,120kt CO_{2-e}. However, Figure 4 shows how estimates of Tasmania's emissions from this sector have changed with each new edition of the State and Territory Greenhouse Gas Inventories (STGGI). Most alterations are minor on a year-to-year basis, but the cumulative impact over time has been substantial. The range of emissions estimates for Tasmania's LULUCF sector in 2005 varies by nearly 9,000kt CO_{2-e} – more than the whole state's absolute emissions in 2021 – across different editions of the STGGI.

Figure 5: *Comparing Tasmania's LULUCF Emissions as reported in STGGIs since 2008*



3.2 Technical and scientific refinement

Australian scientists are engaged in a continuous process of refining model assumptions and parameters to reflect advances in underlying physical science. To date, technical refinement has been effective in updating the model with regards to many of its crucial forest type and carbon density parameters, but there are still areas that need further research:

- **Understanding soil carbon changes due to fire** – One key issue is the impact of fire on soil carbon. As of 2021, the loss of soil carbon due to fire was not included in Australia's fire-related emissions modelling. The emerging evidence base[11] on the impact of fire on soil carbon is not yet comprehensive enough to be used for bushfire emissions modelling in FullCAM. Given the potentially substantial impact of soil carbon emissions in some bushfires, this should be an important focus for researchers and research funding.
- **Recovery and changes in forest type because of fire –** the assumption that emissions from natural fires are 'transient' (that they are reabsorbed within approximately 15 years by rapid forest regrowth) is a key pillar of Australian carbon accounting for land-use emissions. Areas that have been affected by fire are closely tracked to ensure that this is the case, but there are some circumstances in which revision of the processes currently used may be appropriate. As noted above, for natural fires both the initial emissions impact and subsequent removals in the affected area are disaggregated (assessed and reported separately) in Australia's accounts for a period of up to 15 years. If the area in question does not fully recover in that time, the difference between its current and former (pre-fire) carbon stock is debited from the year of the initial fire. In most cases, full recovery occurs within the assumed timeframe. However, as climate change makes fires more frequent and severe, it could become more common for recovery to fail in ways that pose challenges to the current method. Specifically, high severity 'stand-replacing' fires and fires that result in a change of forest type due to population collapse potentially require a different approach. Further refining Australia's approach in this area would bolster our existing reputation as a world leader in research on post-fire landscape recovery.

[11] See, for examples, Bennett et al (2020), Dooley et al (2023), and Carroll et al (2023).

4. POLICY SUGGESTIONS AND PRIORITIES FOR FURTHER RESEARCH EMISSIONS

In conclusion, we think that all bushfire-related emissions should be reported more prominently and transparently, although in the interests of consistency with international standards this should be separate from Australia's national or state and territory accounts. We also believe there are several ways in which the methods for modelling their impacts could be improved. Some of these improvements and changes can be implemented immediately but others will require further research.

> all bushfire related emissions should be reported more prominently and transparently - separate from Australia's national or state and territory accounts

Some policy changes we believe can and should be considered include:

1. **Public reporting of fire-related emissions at state and/or event level –** This would make it easier for researchers and the public to understand the impact and severity of individual fire events. Further to this, it could also help to improve Australia's BBM by making official FullCAM assessments easier to independently scrutinise and verify using other modelling methods.
2. **Regular, long-term reporting of the carbon balance for areas affected by natural fires at state and/or event level –** Supplementary to the first suggestion, this would provide a greater level of transparency regarding the complex area of landscape change and carbon sequestration during post-fire recovery. Anthropogenic climate change will increasingly affect the ability of landscapes to recover from burning as fires increase in frequency and severity. Making state/event level data and Australia's world-leading modelling of landscape recovery more accessible would provide more scope for researchers to provide constructive feedback and to learn from our approach. This increased transparency could also increase public confidence in Australia's long-term carbon stock modelling.
3. **Increased public engagement on Australia's modelling of fire emissions –** Currently, Australia's National Inventory Reports are extremely dense and technical. This is appropriate for the intended audience (UNFCCC auditors), but makes it difficult for the public to engage with this complex area. This may lead to the misinterpretation of and confidence in Australia's emissions reporting regime and progress towards reduction targets. Therefore, there is an opportunity for the Department of Climate Change, Energy, the Environment and Water (DCCEEW) to increase its focus on providing accessible information relating to Australia's modelling of bushfire emissions, with the goal of increasing public 'climate literacy'. This could take the form of short explainer documents that accompany each National Inventory Report, publishing articles through respected outlets such as The Conversation, and producing a series of one page summaries on key topics such as the link between recalculations and Australia's targets.

In addition to policy and reporting implications, there are a handful of areas in which Australia's approach would benefit from further research. While the list below provides several specific areas in which more evidence is needed, we also believe that there is a general need for more collaboration and understanding between the officials and scientists who compile inventory reports and the academic scientific community more broadly. These two groups do not always understand each other's methods and research needs as well as they might. More dialogue and collaboration would not only help to bridge divides and avoid misunderstandings, but would help to ensure that research is focussed on answering those questions most pertinent to improving Australia's models for estimating bushfire emissions.

1. **Understanding changes in soil carbon due to bushfires –** The most pressing area for further research concerns the emissions impact of fires on soil carbon. As noted above, soil carbon emissions from fire are not currently estimated due to high uncertainty and an insufficiently comprehensive evidence base. This is an important gap because soil carbon emissions from fire can be substantial. Additionally, it is possible that assumed transience of fire emissions may not apply to soil carbon in the same ways as above-ground biomass. For example, some research suggests that more frequent fires associated with climate change not only depletes soil carbon over the long term but also slows the recovery of forests as a result. On the other hand, some studies have reported the promising finding that less intense controlled fuel reduction burning can not only reduce the severity of bushfires but also stabilise or even increase storage of soil carbon. Overall, from both an emissions and sequestration perspective, a greater understanding of soil carbon dynamics and an ability to accurately model them in FullCAM should be a major priority in the coming years.
2. **The treatment of landscapes that undergo a change in forest, species, or soil properties because of fire –** The second area in which we believe more technical refinement is required concerns the treatment of landscapes that undergo a change in forest, species, or soil type as a direct result of one or several fire events. The way that emissions impacts from natural fires are treated under the current approach struggles in cases where a forest does not undergo a land-use change but is unlikely to return to its former state (at least not within a 15-year timeframe). As fires become more intense and frequent, and more likely either to be stand-replacing or to lead to population collapse, it will be important to develop alternative methods for reporting their emissions that don't rely on their regenerating in their previous form.

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