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To cite this article: Brendan Mackey *et al* 2022 *Environ. Res. Lett.* **17** 054028

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RECEIVED
6 February 2022

REVISED
6 April 2022

ACCEPTED FOR PUBLICATION
11 April 2022

PUBLISHED
28 April 2022

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LETTER

Net carbon accounting and reporting are a barrier to understanding the mitigation value of forest protection in developed countries

Brendan Mackey[1,*], **William Moomaw**[2], **David Lindenmayer**[3] **and Heather Keith**[1]

[1] Climate Action Beacon, Griffith University, Southport, Queensland, Australia
[2] Global Development and Environment Institute, Tufts University, Somerville, MA, United States of America
[3] Fenner School of Environment and Society, The Australian National University, Canberra, Australia
[*] Author to whom any correspondence should be addressed.

E-mail: b.mackey@griffith.edu.au

Keywords: mitigation, net accounting, forests, removals, negative emissions, GHG reporting

Abstract

Meeting the Paris Agreement global warming target requires deep and rapid cuts in CO_2 emissions as well as removals from the atmosphere into land sinks, especially forests. While international climate policy in the land sector does now recognize forest protection as a mitigation strategy, it is not receiving sufficient attention in developed countries even though they experience emissions from deforestation as well as from logging of managed forests. Current national greenhouse gas inventories obscure the mitigation potential of forest protection through net carbon accounting between the fossil fuel and the land sectors as well as within the different categories of the land. This prevents decision-makers in national governments, the private sector and civil society having access to all the science-based evidence needed to evaluate the merits of all mitigation strategies. The consequences of net carbon accounting for global policy were investigated by examining annual inventory reports of four high forest cover developed countries (Australia, Canada, USA, and Russia). Net accounting between sectors makes a major contribution to meeting nationally determined contributions with removals in Forest Land offsetting between 14% and 38% of the fossil fuel emissions for these countries. Analysis of reports for Australia at a sub-national level revealed that the State of Tasmania delivered negative emissions due to a change in forest management—a large and rapid drop in native forest logging—resulting in a mitigation benefit of ~22 Mt CO_2-e yr^{-1} over the reported period 2011/12–2018/19. This is the kind of outcome required globally to meet the Paris Agreement temperature goal. All CO_2 emissions from, and atmospheric removals into, forest ecosystem carbon stocks now matter and should be counted and credited to achieve the deep and rapid cuts in emissions needed over the coming decades. Accounting and reporting systems therefore need to show gains and losses of carbon stocks in each reservoir. Changing forest management in naturally regenerating forests to avoid emissions from harvesting and enabling forest regrowth is an effective mitigation strategy that can rapidly reduce anthropogenic emissions from the forest sector and simultaneously increase removals of CO_2 from the atmosphere.

1. Introduction

For the first time in 30 years of international climate negotiations, the Glasgow Climate Pact recognised the mitigation value of forest protection and biodiversity. Specifically, Article 38 emphasizes the importance of protecting, conserving, and restoring nature and ecosystems to achieve the Paris Agreement temperature goal, including through forests and other terrestrial and marine ecosystems acting as sinks and reservoirs of greenhouse gases (GHGs) and by protecting biodiversity (UNFCCC 2021). This decision

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represents the latest progression in how the UN Framework Convention on Climate Change (U.N. 1992) has recognized the role of forests in mitigation. In the Kyoto Protocol, it was simply promotion of sustainable forest management practices, afforestation and reforestation (U.N. 1998). The Paris Agreement on climate change extended the scope to activities related to reducing emissions from deforestation and forest degradation, and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries (UNFCCC 2015). While protection and conservation in The Paris Agreement could be interpreted as synonyms, in practice they are not as the latter refers to a range of interventions including promoting the sustainable use of natural resources, social and economic solutions, *ex situ* conservation and habitat restoration (Godet and Devictor 2018). Conversely, protection, means protecting forest from land use activities and other human-caused threatening processes and allowing natural processes, including evolution, to occur unimpeded (Dudley 2008).

While deforestation and degradation are widely understood to be a problem for developing countries, anthropogenic forest emissions are also significant for developed countries with Australia, Canada, USA and Russia in the set of ten countries with the most forest cover, and between them have 40% of the world's forest (FAO 2020a). It follows that policy makers would benefit from information on the mitigation value of forest protection. Given these developed countries employ sophisticated forest carbon modelling and accounting methods that underpin their national GHG inventories and reports (Prisley and Mortimer 2004, Waterworth and Richards 2008, Kurz *et al* 2009, Domke *et al* 2012), the required data should be available.

Here we focus on what we propose is a major barrier in developed countries to understanding the use of forest protection as a mitigation strategy. That barrier is, net accounting and reporting of carbon between and within sectors in reporting national GHG inventories. Net accounting (Krug 2018) enables GHG emissions to the atmosphere from one source at a given place to be offset by removals from the atmosphere by a sink at a different place and time. Two kinds of net accounting and offsetting are commonly employed and reported. First, fossil fuel emissions are netted out by removals into sinks in the land sector, predominantly forest ecosystems that accumulate carbon by sequestering and storing it in their living and dead biomass and soil. The second involves offsetting within the land sector where emissions at one location and ecosystem type are netted in the accounts by removals at a different location (and often different ecosystem type).

GHG accounting is intended to support agreed international climate policy by tracking progress toward net zero emissions along the timeline needed to limit global warming to well below 2 °C above pre-industrial levels and pursue efforts for limiting temperature rises to 1.5 °C (UNFCCC 2021). This requires reducing the rate of total anthropogenic GHG emissions to match the rate at which sinks (oceans and terrestrial ecosystems) remove them from the atmosphere. The timing of emissions reductions is critical as there is a near-linear relationship between the cumulative stock of atmospheric CO_2-e and average global temperature increase (Zhongming *et al* 2021). This means there is a limited quantity of cumulative permissible emissions of CO_2-e to the atmosphere for a given level of warming.

Achieving The Paris Agreement temperature goal of 'holding the increase in the global average temperature to well below 2 °C and pursuing efforts to limit it to 1.5 °C' requires deep cuts in anthropogenic emissions from all sources. This includes land use change, and where possible to increase sinks and their carbon retention capacity, within a decadal time frame (Fankhauser *et al* 2021). However, some sectors (e.g. aviation) will have greater difficulty in reducing emissions rapidly than others. In which case, other sectors would need to produce net removals of GHGs (i.e. remove more GHG than they emit) for net zero emissions to be achieved globally. Additionally, the predicted Shared Socio-economic Pathways (Zhongming *et al* 2021) show that net removals will be required to stabilise the global temperature at 1.5 °C or 2 °C above pre-industrial levels because of the overshoot beyond 2050. This means we should be planning for the maximum amount of net removals in mitigation strategies, not merely achieving net zero within sectors.

The IPCC (Zhongming *et al* 2021) reported that 'Global warming of 1.5 °C and 2 °C will be exceeded during the 21st century unless deep reductions in CO_2 and other GHG emissions occur in the coming decades' (discussed hereafter as CO_2-e). Current emission reduction policies stated in nationally determined contributions are far from adequate to meet these goals as they are projected to deliver end-of-century warming of around 2.7 °C (CAT 2021, UNEP 2021). It follows that to achieve the agreed global warming limits, mitigation strategies must be enhanced such that the rate of reduction in fossil fuel emissions be accelerated over all sectors.

In parallel to mitigation strategies that reduce emissions, strategies are needed that increase removals. Both mitigation strategies need to be enacted immediately, and in this decade, to ensure we do not exceed the cumulative atmospheric CO_2 emissions that will limit global warming to 1.5 °C–2 °C. The mitigation potential of forests and forest management strategies is a key sector in which to achieve net removals. Reducing emissions and increasing removals by forests is a mitigation strategy that can be readily implemented and can take effect rapidly. It is well established that conventional forestry

management and harvest of naturally regenerating forests for commodity production (i.e. logging trees for timber, pulp and energy) (Matricardi *et al* 2020) causes significant CO_2 emissions (Puettmann *et al* 2015, Harris *et al* 2016, Mildrexler *et al* 2020) and that about 70% of the world's forests are managed in this way (FAO 2020b). Logging therefore results in CO_2 emissions and the depletion of forest ecosystem carbon stocks. If these forests are allowed to regrow they will remove carbon dioxide from the atmosphere and over time their ecosystem carbon stocks can be replenished, a mitigation strategy called 'proforestation' (Moomaw *et al* 2019). It is this natural regrowth following logging that provides a significant sink potential. Forest in its natural condition (i.e. primary forest *sensu* (FAO 2020b)) also provides sink capacity as old growth forests continue to sequester and store carbon as they age (Luyssaert *et al* 2008).

However, net accounting and reporting present a major barrier to policy makers understanding the potential of forests and forest management to contribute to GHG removals. This can occur when the losses and gains from different forest management practices and other land uses are not reported in national inventories and instead net accounting is used which obscures the effectiveness of mitigation strategies. Decision makers can be better informed if both emissions and removals from activities are reported separately and transparently rather than netted out.

2. Methodology

To provide empirical evidence in support of the proposition that net accounting and reporting are a barrier to understanding the mitigation value of forest protection, we completed two complementary case studies. We first analysed national GHG inventory reports from the four high forest cover developed countries—Australia, Canada, U.S.A. and Russia—to illustrate the problem arising from net accounting between sectors and within land use, land use change and forestry (LULUCF). The second case study examined net accounting within the LULUCF sector. We drew upon GHG inventory data from the Commonwealth of Australia and a sub-national jurisdiction of the Australian State of Tasmania that has high forest cover. This second case study examined the mitigation potential within the forest sector when forests are managed for protection and restoration, and how these gains are masked within reports of net accounting. We conclude with recommendations for how this barrier to maximising the mitigation potential of forests can be addressed through adoption of a more comprehensive carbon accounting approach (U.N. 2021).

We first examined the national inventory reports for Australia, Canada and the U.S.A. to identify: (a) the level of detail in the sector data reported (an English language version of the Russian inventory was not available) and (b) which tier of the Intergovernmental Panel on Climate Change (IPCC recommended methodologies was used. We also reviewed these countries' definition of forest and the tools used for modelling forest carbon stocks and stock changes.

For the first case study analysis, we selected Australia, Canada, USA and Russia as these are the four developed countries in the set of ten countries with the most forest cover, and between them support 40% of the world's forest (FAO 2020a). Their GHG inventory reports were accessed from the online database of annual GHG inventory reports submitted by nations under the UN Framework Convention on Climate Change. These reports are comparable as submissions are made in accordance with Articles 4 and 12 of the Climate Change Convention and the relevant decisions of the Conference of the Parties and therefore use, among other things, the same categories (U.N. 2022). For each country, we compared the emissions from 2018 with a baseline year of 2010 for: (a) CO_2 emissions from all sources other than the category LULUCF, (b) CO_2 net emissions/removals by LULUCF, (c) removals by the LUUCF sub-category 'Forest Land', and (d) CO_2 net emissions/removals with LULUCF. We then calculated the aggregate values for all four countries. Note that non-LULUCF emissions are mainly from fossil fuel use and cement production. Also, following what is now standard nomenclature, 'emissions' are to the atmosphere from a source and 'removals' are from the atmosphere to a sink.

For the second case study analysis, we used GHG inventory data from the Commonwealth of Australia and for the State of Tasmania. These data are recorded at a fine level of detail in terms of the subcategories that relate to different classes of forest cover and land use within the LULUCF sector, including naturally regenerating forests which are managed for commodity production and the focus of this study. We use data published by the relevant forest management agency on changes over time in harvested area and in pulpwood production to help interpret the change in emissions and removals for Tasmania over the time period 1990–2018.

3. Results

3.1. Forest definitions and forest carbon accounting approaches

The four countries use different definitions of forest but all are within the UNFCCC guidelines for area, cover and tree height. However, this means the areas of forest reported are not completely comparable between countries. The methods of calculation of carbon stocks and carbon stock changes also differ for each country. The IPCC guidelines (IPCC 2006, 2019) are followed but using different tiers of methodologies, which include level of detail, spatial and

temporal resolution. The Russian Federation applies a Tier 2 methodology which uses emission and stock change factors that are country-specific, and disaggregated activity data to correspond with country-defined coefficients for specific regions and specialised land use. Australia applies a combination of Tier 2 and 3 methodologies that uses country-specific land use activity data and carbon dynamics modelling but is not fully spatially explicit (Australian Government 2020a). Canada and the USA apply Tier 3 methodologies using models and inventory measurement systems, repeated over time, and driven by high resolution activity data and disaggregated at sub-national level (ECCC 2021, US EPA 2022). In terms of their UNFCCC reporting, all four countries provide statistics on: (a) gains and losses and net change in living biomass and (b) net carbon stock change for mineral and organic soil, dead wood, litter.

3.2. Case study of four developed countries national GHG accounting reports

Reducing emissions from deforestation and degradation is generally understood to be a mitigation challenge for developing tropical countries with high forest cover such as Brazil, Democratic Republic of the Congo and Indonesia as recognized by the United Nations REDD+ programme (UN-REDD programme 2020). The world's forest resources, however, are distributed across developed as well as developing countries. Of the world's 4.1×10^9 ha^{-1} of forest land, the top 20 forested countries (termed 'forest majors') support 73% of the world's forests and four of these—Russia, Canada, USA and Australia—support 40% of the world's forests (FAO 2020b). These four countries are classified as 'Annex 1' countries under the U.N. Framework Convention on Climate Change (UNFCCC), are major fossil fuel emitters, and are not included in the REDD+ programme as it is designed for developing countries (U.N. 1992).

Using the accounting rule book and reporting format for national GHG inventories negotiated under the UNFCCC (IPCC 2006, 2019), we examined the significance of net carbon accounting between the fossil fuel sector and what is defined as the LULUCF sector, and within it the 'Forest Land' category, using the data reported by the four selected high forest Annex 1 countries (Australia, Canada, Russia and USA). National GHG inventory summaries are submitted annually to the UNFCCC which report on: (a) CO_2 emissions from fossil fuel use (and other GHGs), (b) net LULUCF emissions, and (c) net CO_2 emissions (i.e. CO_2 emissions minus net LULUCF fluxes. Net LULUCF emissions are the difference between emissions from LULUCF and removals from the atmosphere of CO_2 into LULUCF sinks. The main LULUCF sink is the category called 'Forest Land'. The LULUCF-Forest Land account includes: (a) emissions from conversion of forest to a non-forest land use (i.e. deforestation), (b) emissions from logging (i.e. forest degradation) and (c) removals of CO_2 from the atmosphere by new forest growth. Summaries of the reported data for the four focal countries are provided in tables 1 and 2.

For the four Annex 1 high forest cover developed countries, net accounting between sectors makes a major contribution to meeting nationally determined mitigation commitments under the Paris Agreement with removals in Forest Land offsetting between 14% and 38% of their fossil fuel emissions (table 1). The global significance of net accounting between sectors is apparent when the aggregate CO_2 accounts are examined for these countries. With a total forest area of 1.61×10^9 ha, around 1.49×10^9 t CO_2-e was removed by Forest Land in 2018 which was nearly the same as net emissions and removals in the LULUCF sector and equivalent to 18% of CO_2-e emissions without LULUCF. These removals were from the natural growth occurring that year in the sub-category of 'managed forests', i.e. the component of the total forest area which is managed for commodity production that was unlogged that year (table 2).

3.3. Case study of net accounting and reporting within the LULUCF sector for Australia and Tasmania

Within the LULUCF sector, offsetting occurs between and within categories with the noticeable consequence of masking the emissions from logging and therefore the mitigation benefits from forest protection. However, to properly interpret national inventory reports, it is first necessary to understand how native forests are classified and their emissions/removals accounted within the LULUCF Forest category:

- All forested land is included in the category 'Forest Land' which is equivalent to 'Forest Land Remaining Forest Land' plus 'Land Converted to Forest Land';
- The category 'Forest Land Remaining Forest Land' encompasses 'Harvested Native Forests' + 'Other Native Forests' + 'Pre-1990 plantations';
- 'Harvested Native Forests' are those forests comprised of endemic species arising from natural regrowth;
- 'Other Native Forest' includes those forests that are comprised of endemic species, which are not harvested native forests or plantations. This subdivision includes protected areas (such as wilderness areas and National Parks) not previously subject to harvesting or harvested a long time ago.

We examined the national GHG inventory for Australia for each of these categories within 'Forest Land Remaining Forest Land' to show the change in net emissions over the time series from 1990 to 2018 (figure 1). It is apparent that a significant decrease in net emissions occurred in Harvested

Table 1. CO_2 emissions with and without LULUCF, and the contribution to these emissions from Forest Land for the four high forest cover Annex 1 countries (Russian Federation, Canada, United States of America and Australia). Data sourced from (UNFCC 2018) (emissions are positive, removals are negative).

Country	Variable	Emissions, in kt CO_2 equivalent		Total forest area (1 000 ha)	Fraction of CO_2 emissions without LULUCF equivalent to Forest Land removals (%)
		Base year (1990)	Last inventory year (2018)		
Australia	CO_2 emissions without LULUCF	278 424.7	415 953.9	134 005	
	CO_2 net emissions/removals by LULUCF	169 893.1	−39 818.9		
	Removals by Forest Land	−6 600.3	−57 210.6		
	CO_2 net emissions/removals with LULUCF	448 317.8	376 135.0		14
Russian Federation	CO_2 emissions without LULUCF	2 525 293.8	1 691 360.4	815 312	
	CO_2 net emissions/removals by LULUCF	−109 767.8	−640 699.7		
	Removals by Forest Land	−226 107.2	−635 361.9		
	CO_2 net emissions/removals with LULUCF	2 415 526.0	1 050 660.7		38
Canada	CO_2 emissions without LULUCF	462 117.4	586 504.6	346 928	
	CO_2 net emissions/removals by LULUCF	−60 922.1	−13 766.1		
	Removals by Forest Land	−202 922.5	−139 729.7		
	CO_2 net emissions/removals with LULUCF	401 195.2	572 738.5		24
United States of America	CO_2 emissions without LULUCF	5 128 300.6	5 424 881.5	309 795	
	CO_2 net emissions/removals by LULUCF	−860 746.8	−799 621.5		
	Removals by Forest Land	−777 923.3	−655 816.7		
	CO_2 net emissions/removals with LULUCF	4 267 553.8	4 625 260.0		14

Table 2. Aggregate CO_2 emissions with and without LULUCF, and the contribution of removals by Forest Land for the four high forest cover Annex 1 countries (UNFCCC 2018). See table 1.

Greenhouse gas inventory variable	Reporting year 2018 (kt CO_2-e)
CO_2 emissions without LULUCF	8 118 700
CO_2 net emissions/removals with LULUCF	6 624 794
CO_2 net emissions/removals by LULUCF	−1 493 906
Removals by Forest Land	−1 488 119
Fraction of CO_2 emissions without LULUCF equivalent to Forest Land removals (%)	18

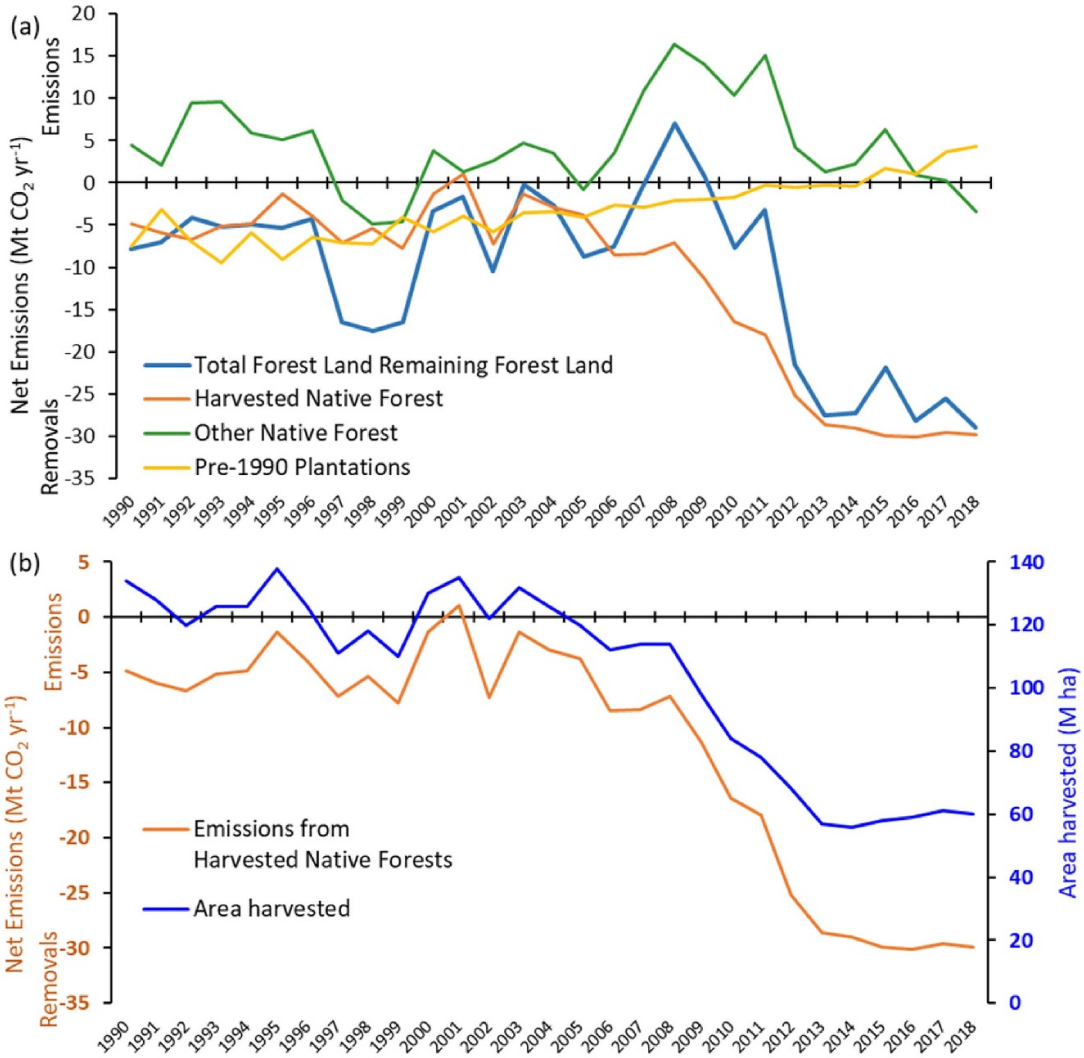

Figure 1. (a) Net emissions from Forest Land Remaining Forest Land and sub-categories of Harvested Native Forests, Other Native Forests and Pre-1990 Plantations used in the national greenhouse gas inventory for Australia from 1990–2018, (b) Sub-category Harvested Native Forests comparing the time series of net emissions and area harvested. Source: (Australian Government 2020a, 2020b).

Native Forests from about 2008 (figure 1(a)). This appears to be related to a decrease in the area of native forests harvested (Australian Government 2019). A reduction in the amount of logging resulted in: (a) reduced emissions from logging (as immediate fluxes and longer-term rates from decomposition) and (b) greater removals of CO_2 from the larger area of forest that is continuing to regrow. Although the different categories of Forest Land are subdivided, reporting is for the net flux of emissions and removals within each of these categories.

Note that the net emissions in the 'Harvested Native Forest' and 'Pre-1990 Plantations' categories include both the emissions due to logging in the relatively small areas that are logged each year and removals due to growth in the whole region designated as being available for harvest (whether or not it is or has been harvested). Emissions and removals due to fires are also included in the net emissions. In contrast, net emissions for the 'Other Native Forest' category included only emissions and removals due to fires (wildfires and prescribed fires) as the carbon stocks in their biomass and soil pools are considered to be at 'equilibrium'. This means that the CO_2 removals due to natural forest growth in those forests are not counted in the 'Other Native Forests' category, but the same carbon flow is included in the 'Harvested Native Forest' and 'Pre-1990 plantation' categories.

We further examined the Australian national GHG inventory to identify the source of the reductions in net emissions from Harvested Native Forests. The national inventory is compiled from the annual reports submitted to the Australian Government from each of the nation's six state and two territory governments. It was reported for the State of Tasmania that during 2018, total emissions from all sectors was −2.2 Mt CO_2-e and had declined by 111.2% from a level of 20 Mt CO_2-e in 2005 (figure 2). The decrease in emissions occurred abruptly between 2011 and 2012 (Australian Government 2020b).

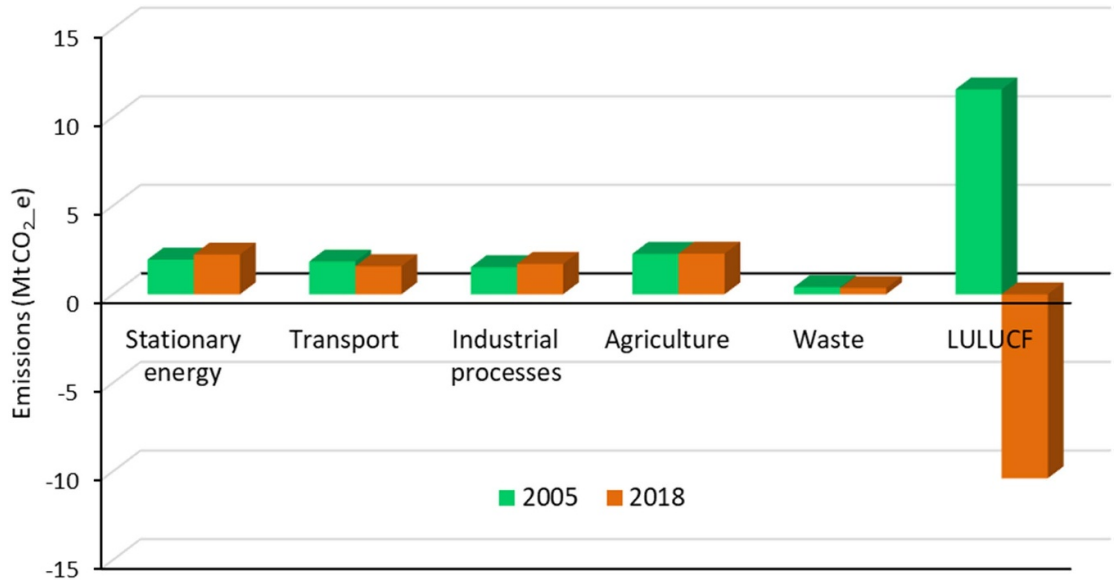

Figure 2. Change in CO_2-e emissions (into the atmosphere) and removals (from the atmosphere) by sector between 2005 and 2018 in Tasmania (Source: figure 14 in (Australian Government 2020b)).

The dominant change which led to the very large reduction in emissions was in the LULUCF sector. In 2005, the base year for change measurement specified by IPCC (2018), net emissions from LULUCF were 12 Mt CO_2-e, or 60% of total emissions. By 2018, they had decreased to −10 Mt CO_2-e (figure 2). This reduction in net emissions was due to a decrease in gross emissions from native forest harvesting for commodity production, plus removals by forest growth were maintained. As around 84% of Tasmania's electricity demand is met through hydroelectricity and 10% from wind power, the state's fossil fuel CO_2 emissions are relatively low, coming primarily from the remaining electricity production and transport, along with other GHGs from agriculture and land fill waste (Tasmania Government 2017, Office of the Tasmanian Economic Regulator 2018).

Of Tasmania's 3.35×10^6 ha of forest, 91% is native forest and the remainder is hardwood plantations and exotic plantations. The permanent timber production zone comprises 812 000 ha of which 46% is native forests available for logging (Sustainable Timber Tasmania 2019). Between 2004-5 and 2018-9, the area of native forest logged in Tasmania declined by around 50% (figure 3(a)). The key decrease in wood products was a sudden drop in native forest pulpwood production which contracted by 86% in 2011/2012 compared to 2005, and remained 63% lower in 2018/2019 than in 2005 (figure 3(a)). This resulted in a sudden and sustained drop in emissions from Total Forest Land Remaining Forest Land in Tasmania and this was the main sector contributing to the trend in LULUCF (figure 3(b)). The fall in logged area and in pulpwood production thereby avoided significant CO_2 gross emissions in Forest Land Remaining Forest Land that would otherwise have occurred if harvesting had continued at pre-2011/2012 levels in these carbon-dense natural forests (Dean *et al* 2012b, Keith *et al* 2015). Cessation of logging therefore resulted in immediate, large-scale avoided anthropogenic emissions. Furthermore, excluding future logging allowed ongoing growth and accumulation of forest carbon following their previously planned harvest date, resulting in substantial additional removals from the atmosphere. The decrease in native forest harvesting has occurred in all jurisdictions in Australia to some extent, but most dramatically in Tasmania. Tasmania contributed 44% of the negative net emissions (i.e. removals) reported for Forest Land Remaining Forest Land in Australia.

4. Discussion

Although forest definitions and methods for calculating forest carbon stocks and changes reported by each country are not completely comparable, our objectives did not require direct comparisons between countries. Rather, the focus of our study was the accounting within, and reporting by, each country, in terms of the stocks and gross flows from declared forests areas. From the descriptions of the data and modelling applied in the four developed countries, it could be assumed that gross emissions and removals are calculated. However, this proved not to be the case as these data are not publicly available in inventory reports. The only source of gross flux data available is in the tables submitted to the UNFCCC where living biomass gains and losses are reported, but only net stock change is reported for all other carbon stock components. Therefore, the mitigation value of forest protection would not be readily apparent from

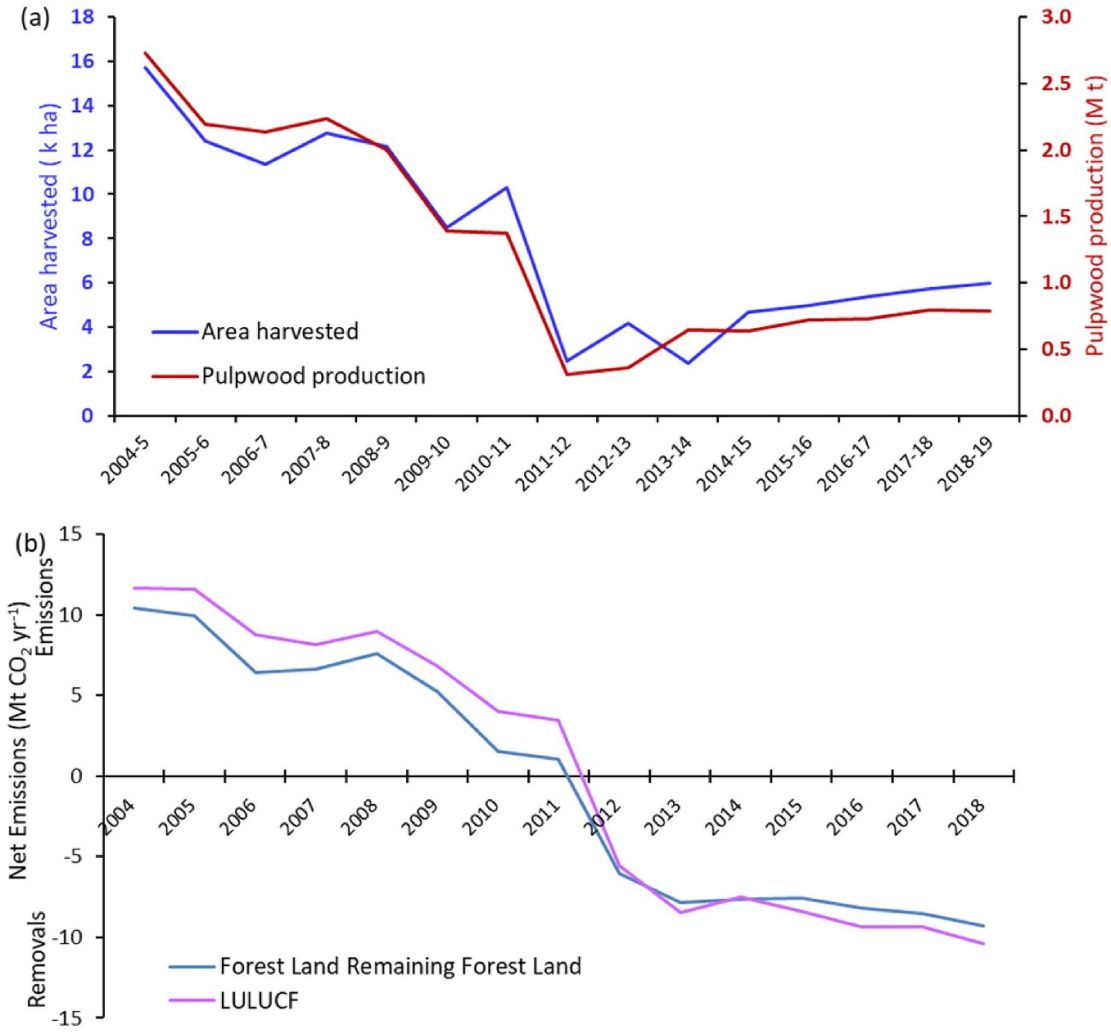

Figure 3. (a) Area (1000s ha) of native forest in Tasmania harvested annually (blue) and pulpwood production (M tonnes) (red) (for the Australian financial year which is July to June in successive calendar years) Source: (Sustainable Timber Tasmania 2019). (b) Net emissions (Mt CO_2-e yr^{-1}) for LULUCF (magenta) and the sub-category of Forest Land Remaining Forest Land (blue) in Tasmania. [Source: (Australian Government 2020b)].

these reports. The barrier we identified here related to both accounting and reporting issues. Ideally, the accounting rules for definitions, classifications and table structure would disaggregate forest areas that have been logged in the inventory year, areas that have been logged previously, areas available for logging, and areas not available for logging. Furthermore, reporting in the accounting tables would include row items for gross gains and losses of carbon stocks in each forest area category.

The data presented here from the two case study analyses help reveal how the mitigation potential of forests for helping to reduce atmospheric GHG concentrations is masked and neutralised by net accounting within national GHG inventory reports. Both the losses of carbon as gross emissions that are occurring due to logging and the potential for gains in carbon due regrowing, restoring and protecting forests that allows gross removals need to be identified so that mitigation activities can be evaluated.

Globally in 2018, the Forest Land sink removed around 1.49 billion tonnes CO_2-e from the atmosphere which was 18% of total fossil fuel (and other GHG) emissions (tables 1 and 2). For the four developed country forest majors, the Forest Land sink for 2018 was: Australia 57.211 million tonnes CO_2-e; Canada 139.730 million tonnes CO_2-e; Russia 635.362 million tonnes CO_2-e; USA 655.817 million tonnes CO_2-e. By using these removals as offsets through net accounting, their mitigation benefit was neutralised and the equivalent amount of fossil fuel CO_2-e was emitted to the atmosphere.

Within the LULUCF sector, there are several categories that encompass forests including: natural forests managed for commodity production, planted forests (plantations) also managed for commodity production, and natural forests that are exempt from extractive land uses and have important values such as for biodiversity conservation, water supply or cultural protection. The data for Australia and the State of Tasmania reveal the mitigation benefits of changing forest management from 'commodity production' to 'protection' and the sink capacity from previously-logged forests and natural regrowth and continued

growth. Reduction of logging in Tasmania provided a mitigation benefit of around 22 Mt CO_2-e yr^{-1}, consisting of avoided gross emissions plus ongoing removals through forest growth, between 2011/12 and 2018/19.

We were able to identify the mitigation consequences of changing forest management at the subnational level in the State of Tasmania because the data were available in a sufficiently disaggregated form by the Australian Government's national GHG inventory (Australian Government 2020b). However, the aggregate mitigation value of avoiding emissions and allowing natural regrowth is masked when carbon accounting allows offsets between and within sectors.

Under the current rules, countries are free to meet nationally determined mitigation commitments using net accounts that offset fossil fuel emissions with removals in LULUCF. It is also legitimate for countries to net out logging emissions through natural forest regrowth. The rules are also explicitly biased against recognising the mitigation benefits of forest protection, in particular including removals from natural growth in Harvested Forest but not in protected areas. However, as noted above, this is the critical decade for tackling climate change and limiting global warming to well below 2 °C. Given this, there is merit in governments considering all policy options including maximising the mitigation potential of protecting natural forests. The ability of a government to adopt this option will depend on its national circumstances, including the extent of its forest cover and the extent of its plantation estate and alternative sources of wood.

In theory it could be possible to re-negotiate the GHG inventory reporting rules and guidelines so that net accounting across and within sectors was prohibited and there were separate emission reduction targets for the fossil fuel (and other GHG) sector and the LULUCF sector. To improve the guidelines, a complementary approach to GHG accounting could be adopted that provided a stock and flow system for LULUCF accounts so that both gross emissions and removals are reported more transparently for sectors and categories. Net change in atmospheric carbon stock (and equivalents from GHGs) and the contributions from sectors and nations could then be calculated. However, international climate negotiations are fraught and slow as they require consensus among all parties and the current climate agenda is already full. Nonetheless, some level of international cooperation could provide incentive for high forest cover countries to take a more progressive stand on better informed carbon accounting.

The 'club approach' to climate negotiations (Carattini and Löschel 2021) is one way forward where a group of high forest cover countries collaborate to apply and demonstrate GHG inventory methods and reporting that clearly communicate the mitigation potential of forest protection in meeting their nationally determined mitigation contributions. The Australian national GHG inventory accounts do provide the relevant information but their UNFCCC reporting is limited by the netting of emissions and removals within the LULUCF sector. Reporting by a 'Forest Protection Club' to make more transparent information on the benefits of forest protection could be improved by using an approach such the U.N. System of Environmental Economic Accounting—Ecosystem Accounts (SEEA-EA) (U.N. 2021). With the SEEA-EA framework, all land areas and carbon reservoirs are included and classified according to the condition of the ecosystem in terms of their qualities of stability, longevity and resilience of the carbon stocks. This means that carbon stocks with different qualities cannot be equated through offsetting. The accounting is based on disaggregated stocks and gross stock changes or flows, rather than net accounting of annual flows. These comprehensive accounts can reveal the full mitigation benefits of both avoiding anthropogenic emissions from cessation of logging and increasing removals through forest growth (Keith *et al* 2021). Such accounts can support more transparent reporting to assist decision makers in developing mitigation policies and programs that incentivize governments to register the full suite of benefits from forests. Specifically, they can show how changing forest management from 'commodity production' to 'protection' has the twin mitigation benefits of avoiding logging emissions and maximising removals from forest regrowth.

Globally, approximately 1.15×10^9 ha of forest is managed primarily for the production of wood and non-wood forest products (FAO 2010). Given the large area of Forest Land which is available for harvesting, and the emissions that arise from logging and associated silvicultural practices (Macintosh 2011, Dean *et al* 2012b), it is interesting to note that Forest Land is a sink globally (table 1) despite the ongoing impacts of degradation in both developed and developing countries (Evans 2016, Curtis *et al* 2018). As our analysis has demonstrated one reason that these emissions are 'hidden' is the annualised net accounting approach whereby for each forest category, emissions from logging are summed with the removals by forest growth in each reporting year. In the four Annex 1 high forest cover countries examined here, the area harvested annually is small compared to the total area of managed land. In Australia, for example, the extent of native forest that is available for commercial wood production was 28.1 million ha in 2015–16; i.e. 'Harvested Native Forest' in the national GHG inventory. The net harvestable area available (and suitable) for commercial wood production in multiple-use public native forests when additional local restrictions (such as mesoscale harvesting exclusions) are taken into account is 5.0 million ha. The total area harvested within multiple-use public native

forests in 2015–16 was 73 000 ha, which is 1.5% of the net harvestable area of public native forest (ABARES 2018). Much more carbon therefore, is removed into 'Forest Land Remaining Forest Land' than is emitted from forest logging annually as the area of managed forest is much larger that the area of the forest that is being logged. The result is that the net accounting approach in effect, masks the substantial emissions generated by logging operations, and hence the potential for avoiding these emissions by changing forest management.

All CO_2 emissions from, and atmospheric removal into, a forest ecosystem carbon stocks now matters and should be counted and credited if we are to achieve the deep and rapid cuts needed in atmospheric GHG over the coming decades. Accounting and reporting systems need to be able to show gains and losses of carbon stocks in each reservoir. Changing forest management to avoid emissions from harvesting and enabling forest regrowth is, for those countries in a position to deploy it, an effective mitigation strategy that can rapidly reduce anthropogenic emissions from the land and forest sector and simultaneously increase removals of CO_2 from the atmosphere. This combination of change in practices results in a more rapid effect on atmospheric CO_2 than the much slower CO_2 removals through reforestation and afforestation that require land preparation, tree planting and growth of small trees (Körner 2017, Moomaw *et al* 2019, Mackey *et al* 2020). Technological CO_2 removal—such as biomass energy with carbon capture and storage, enhancing natural weathering by adding silicate minerals to soils, or conversion of nitrous oxide (N_2O) and methane (CH_4)—are in early stages of development, are expensive and will take many decades to be mobilized at scale (Fuss *et al* 2020). At best, these are long- term prospects, whereas cost-effective solutions are needed now and that can be implemented at scale.

Various forest management mitigation strategies based on modifying conventional management of forests for commodity production in ways that reduce logging emissions and take account of the carbon stored in wood products have been proposed as constituting the most effective mitigation (Fuss *et al* 2020, Verkerk *et al* 2020). However, other empirical case studies have challenged these proposals (Keith *et al* 2015) and shown that alternative forest management practices such as reduced impact logging do little to reduce atmospheric CO_2 compared to forest protection and regrowth (i.e. allowing growth to continue) whereas tree harvesting immediately releases large amounts of CO_2 (Law *et al* 2018).

Another important consideration is whether a reduction or cessation of logging following implementation of a forest protection and regrowth strategy would result in 'leakage' where a reduction in harvest volume in one area results in an equivalent increase in another (Kallio and Solberg 2018). One solution is the nesting of projects into larger programmes at a sub-national or national scale, allowing the integration of GHG accounting across different scales of implementation (Streck 2021). An alternative strategy is to source timber and fibre from industrial tree plantations on previously cleared land (FAO 2020a). This is an increasingly feasible strategy given that plantations are being established and expanded to satisfy increasing global demand for timber products (Mcewan *et al* 2020).

The assumption that 'Other Native Forests' are in a steady state resulting in the CO_2 removals due to natural forest growth not being counted can be challenged on scientific grounds. Primary forests, including old growth forests and wet temperate forests such as those found in Tasmania, have substantial carbon stocks (Dean *et al* 2012a). Even old growth forests can continue to function as carbon sinks in their biomass and soils for centuries (Luyssaert *et al* 2008, Zhou *et al* 2006) and changing current management practices in native forests from harvesting to proforestation would double the amount of carbon accumulated in global forest stocks (Erb *et al* 2018). The IPCC may have underestimated the potential for global natural forest regrowth by 32% (Cook-Patton *et al* 2020).

5. Conclusion

Meeting global warming targets will require enhanced mitigation actions above current commitments. Every effort should be made by countries to become net carbon negative as soon as possible. Changing forest management practices and having strategic forest climate reserves have significant mitigation benefits. A combined approach of high forest cover countries could lead the way in demonstrating the feasibility of this mitigation strategy. However, this would need to be supported by a more comprehensive stock and flow-based accounting system.

Data availability statement

The data that support the findings of this study are openly available at the following URL/DOI: www.industry.gov.au/data-and-publications/national-greenhouse-accounts-factors.

Acknowledgments

This work was supported in part by a grant from the Rockefeller Brothers Fund and from a charitable organisation which neither seeks nor permits publicity for its efforts. All authors declare that they do not have any conflict of interest.

ORCID iDs

Brendan Mackey https://orcid.org/0000-0003-1996-4064
William Moomaw https://orcid.org/0000-0003-2690-2339
David Lindenmayer https://orcid.org/0000-0002-4766-4088
Heather Keith https://orcid.org/0000-0001-5956-7261

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