CANADA'S APPROACH TO FOREST CARBON QUANTIFICATION AND ACCOUNTING: Key Concerns

Matthew J. Bramley, Special Advisor, Nature Canada
October 21, 2021

A background technical report for ***Missing the Forest:*** *How carbon loopholes for logging hinder Canada's climate leadership*

A background technical report for Missing the Forest: How carbon loopholes for logging hinder Canada's climate leadership.

Matthew J. Bramley, Special Advisor, Nature Canada
October 21, 2021

Table of Contents

1. INTRODUCTION

1.1 Choices with major implications for Canada's climate efforts and its forests

Forests store vast amounts of carbon, and they can emit or remove[*] large amounts of carbon to or from the atmosphere. The Government of Canada estimates that the country's forest land area removed 134 megatonnes (Mt) of carbon dioxide (CO_2) from the atmosphere in 2019,[1] but that wood harvested from this area emitted 139 Mt CO_2 to the atmosphere in the same year.[2,3] This paper will question the correctness of those numbers, but it is clear that forest carbon flows are considerable relative to Canada's total annual greenhouse gas (GHG) emissions from human activities, currently around 700 Mt CO_2 equivalent (CO_2e). This means that choices about exploiting or protecting Canada's forests have the potential to make a major negative or positive contribution to the country's efforts to combat climate change.

Making good choices requires good measurements, so policymakers need to be able to have confidence in the official numbers for forest carbon emissions/removals, such as the 134 and 139 Mt figures just cited. The calculation of these numbers, however, is far from straightforward, and their reliability should not be taken for granted. As this paper will elaborate, the scientific task of estimating forest carbon flows is complex and subject to large uncertainties; and deciding which flows to include or exclude depending on whether they are attributed to human activities, and how forest carbon emissions/removals should be counted towards national GHG emissions targets (or corporate emissions totals), are matters of considerable debate.

In other words, it is not just that different choices about how to manage Canada's forests can make a major difference in how effectively the country tackles climate change, but also that different choices about how to quantify and account for carbon flows in those forests can lead to different conclusions about how forest management needs to change as part of our climate change efforts. If we make the wrong quantification and accounting choices, producing the wrong numbers, then that is likely to lead to the wrong management choices – resulting not only in less effective climate efforts but also the risk of broader negative consequences for our forests.

1.2 Scientific quantification and subjective accounting

Canada's National Inventory Report for GHG emissions/removals, submitted annually to the UN climate secretariat, is the key reference for assessing the country's impact on the climate, and contains the Government of Canada's estimates for forest carbon emissions/removals. Canada's progress towards meeting its GHG targets is then assessed by combining figures from the national inventory with methods outlined in separate submissions to the UN, notably in Canada's "Nationally Determined Contribution" under the Paris Agreement (we will discuss an example of such methods in Section 4.2 below).

Traditionally, compilation of national GHG inventories has been regarded as a matter of purely scientific estimation and referred to as GHG quantification, while assessing progress towards

[*] In this paper, the words "remove", "removals" etc. are used exclusively to refer to removal of carbon from the atmosphere by growing trees, i.e., negative emissions (except in quoted text).

national GHG targets has involved more subjective, debatable choices and been referred to as GHG accounting. In particular, international climate negotiations have in the past involved contentious debate about whether and how to treat forest carbon flows differently from other sectors' GHG emissions when assessing countries' progress towards their national targets.

UN climate agreements require Canada to follow guidelines developed by the Intergovernmental Panel on Climate Change (IPCC) when compiling its GHG inventory, but IPCC guidelines for the forest portion of the inventory give countries wide discretion to adopt their own methods.[4] In addition, Canada has chosen to depart from key elements of those guidelines (as explained in Section 4.1 below). As a result, we consider that Canada is making subjective choices in its inventory that go well beyond scientific estimation. In light of this, we opt in this paper to use the terms quantification and accounting differently than in the traditional usage. We reserve "quantification" for "scientific estimation of included quantities" but broaden "accounting" to mean "deciding which quantities to include and how to include them". We therefore use "accounting" to cover not only Canada's approach to assessing progress towards its national GHG targets, but also subjective choices in the forest portion of the national GHG inventory as well as the treatment of forest carbon emissions/removals at the corporate level. The subjectivity common to all these accounting issues means that they all ultimately involve policy or political judgement.

We believe strongly that forest carbon quantification and accounting should provide as accurate a picture as possible of human influence on the climate. As organizations seeking to advance nature conservation – in particular the protection of forests – as well as efforts to curb climate change, we are committed to the scientific integrity of GHG calculations without regard to our nature conservation goals. We believe that choices about conservation should then take into account the full range of ecological and cultural values of forests, not just their ability to keep carbon out of the atmosphere. In this paper, however, we focus solely on carbon.

2. GENERAL CONCERNS

2.1 Conflicting mandates at NRCan and the need for greater scrutiny

The Government of Canada has, over many years, developed a sophisticated approach to forest carbon quantification and accounting. While Environment and Climate Change Canada (ECCC) is responsible for preparing and submitting the national GHG inventory, a team at Natural Resources Canada (NRCan) produces the inventory's forest carbon figures for ECCC under a memorandum of understanding (MoU) between the two departments.[5] The NRCan team does this using its National Forest Carbon Monitoring, Accounting and Reporting System (NFCMARS).[6] A key part of the NFCMARS is a highly detailed model known as CBM-CFS3 that is used to estimate changes in carbon stocks on forest land. Beyond the GHG inventory, NRCan has also taken the lead in shaping Canada's approach to accounting for forest carbon for the purpose of assessing progress towards its national GHG targets.

As the latest national inventory report states, "forest management practices (including harvesting, silvicultural treatments and regeneration) are the primary direct human influences on emissions and removals in forests".[7] NRCan's contribution to the inventory therefore consists, to a large degree, of determining the climate impact of the forest industry. At the same time, NRCan has long acted as an advocate for and defender of Canada's forest industry. The department's minister was tasked in his most recent mandate letter with "supporting and promoting the competitiveness of our Canadian companies" and with working "to strengthen the competitiveness and overall health of Canada's forest sector".[8]

The dual mandates given to NRCan both to support and promote the forest industry but also to determine its environmental impact are in direct conflict with one another. In this there is no suggestion of failings of integrity on the part of individual department scientists. But the structural conflict between mandates inevitably reduces confidence in the department's forest carbon quantification and accounting work, relative to an agency with greater independence from industry. This creates a strong case for greater transparency and scrutiny of Canada's official forest carbon numbers than of the GHG emissions figures for other sectors, and the concerns raised below, especially in Section 4, reinforce this case. (In contrast, ECCC has no mandate to support industry and so there is no structural conflict of interest when it calculates the GHG emissions of, for example, the oil and gas or electricity generation sectors.)

The unusual complexity of forest carbon calculations is, unfortunately, an obstacle to transparency and scrutiny. While NRCan has published detailed descriptions of its CBM-CFS3 model and the model's outputs in peer-reviewed journals, the calculations undertaken for the national inventory use millions of input numbers which are not publicly available.[9] Each year a team of international experts under UN auspices reviews the compliance of Canada's national GHG inventory with IPCC guidelines, but the experts are not expected to conduct a full audit and do not have the capacity to do so. And beyond the inventory, NRCan has not published full details of its "reference level" projection of forest emissions/removals that Canada is currently proposing to use to assess progress towards its 2030 GHG target (see Section 4.2). We are therefore left with a situation where NRCan is largely "marking its own homework" when it comes to forest carbon calculations.

2.2 High levels of uncertainty

Forest carbon numbers in Canada's national GHG inventory are subject to very high uncertainty. The latest edition estimates that net CO_2 removals from forest land in 2019, reported as 134 Mt (see Section 1.1), could actually range from 112 to 185 Mt (95% probability range), and that "not all sources of uncertainty have been captured"; the report also mentions that "a 50% uncertainty about biomass increment [the rate of tree growth] is assumed".[10] The inventory's estimated uncertainty in emissions from harvested wood is variously stated as ±10%[11] and ±24%[12].

More physical measurement and improved scientific understanding (see Section 2.3) could help make forest carbon flows less uncertain, but a large degree of uncertainty is unavoidable, especially for large land areas, because of the complexity of the biological and chemical processes involved. Debatable accounting choices then add considerable extra uncertainty to the numbers. For example, countries have wide discretion regarding the size of the "managed forest" – land on which *all* emissions and removals are to be included in their national inventory, according to IPCC guidelines (see Section 4.1 for further discussion of this).

The high uncertainty arising from both quantification and accounting means that Canada's forest carbon statistics should always be presented with appropriate caveats, and policy decisions based on them should, in our view, apply a precautionary approach in which climate impacts are assumed to be higher than the central estimate. For example, Canada's GHG inventory currently portrays the country's forest land area as a net annual carbon source of just 5 Mt CO_2 (134 Mt of removals minus 139 Mt of emissions – see Section 1.1). But if uncertainty means that the 5 Mt is actually, say, 5 ± 50 Mt (the ± 50 is just an illustration[13]), then policymakers should arguably adopt policies on the precautionary basis that current management of forest land may be resulting in a 55 Mt annual source.

2.3 Heavy reliance on modelling; too little actual measurement

As noted earlier, the forest carbon figures in Canada's national GHG inventory rely heavily on NRCan's CBM-CFS3 model, which is used to estimate changes in carbon stocks on forest land. Although the model, developed over many years, is highly detailed, the NRCan modelling team acknowledges that due to problems of insufficient scientific understanding, a lack of data or of spatial representation, the model omits a number of processes that could significantly affect carbon flows.[14] The team has stated that "large uncertainties and knowledge gaps remain regarding the quantification of fluxes and the factors controlling site-specific and interannual responses to changing environments"; and that there are also omissions related to the treatment of permafrost, mosses, lichens and earthworms, and the effect of wood harvesting on soil carbon.[15] In addition, some forest lands are peatlands and the CBM-CFS3 does not account for peatlands (NRCan has begun work to remedy this).[16] Peatland soils have an extraordinarily high carbon density, and despite occupying less than a quarter of Canada's boreal zone, contain the majority of its soil carbon stocks.[17]

More on-site physical measurements of Canada's forest carbon flows are needed both to secure the better scientific understanding and data needed to produce more accurate models, as well as to provide independent checks on NRCan's current modelling. Unfortunately, such on-site measurements have been few and far between. For example, Canada's National Forest Inventory (NFI, not to be confused with the national GHG inventory) includes physical measurements of carbon at hundreds of forest sites, but for now each round of measurement takes a decade.[18] To date, carbon stock changes from two successive instances of the NFI have not been compared with those calculated with the CBM-CFS3.[19] The NRCan modelling team wrote in 2013: "In recent years, the numbers of climate-monitoring stations, permanent sample plots, and flux towers in Canada's boreal forest have all decreased while the need for monitoring data has increased".[20]

The accuracy of the calculations performed with the CBM-CFS3 depends not only on the details of the model itself but also, crucially, the input numbers fed into it. These include measurements of human activity, notably wood harvest levels supplied[21] by provincial and territorial governments. A recent investigation by Radio-Canada based on testimony from whistle-blowers concluded that wood harvest levels reported by the Québec government are being systematically under-measured.[22] This raises the possibility of similar problems in other provinces, and of significant underestimation of emissions due to logging.

A further omission from both the CBM-CFS3 and most physical measurements of the effect of Canada's forests on the climate is full consideration of GHGs other than CO_2, notably methane. Global warming due to methane emissions from human activities since the 19th century is estimated to be more than half as much again of the warming due to CO_2 emissions from human activities in the same timeframe.[23] IPCC guidelines for the forest portion of national GHG inventories do not consider methane except for the very small amounts emitted by fires.[24] However, recent measurements in Ontario have shown that the climate forcing effect of methane fluxes in managed forests can be greater than that of CO_2.[25] We will not consider this emerging issue further in this paper but suggest that it could take on considerable importance in the future.

3. SPECIFIC QUANTIFICATION CONCERNS

3.1 Underestimation of deforestation/degradation

Forest carbon flows are affected by many industrial activities besides large-scale logging. These include the clearing of forests for agriculture, oil and gas production, mines and settlements, as well as for the creation of logging roads, seismic lines for oil and gas exploration, and electricity transmission corridors. The associated carbon emissions are captured in Canada's GHG inventory if the loss of trees falls under NRCan's definition of deforestation (also called "forest conversion"), which is "permanent forest removal[*] wider than 20 m from tree base to tree base and at least 1 ha in area".[26] But many instances of long-term forest cover loss are narrower and/or smaller than this, so are not classified as deforestation.[27] In these cases the associated carbon emissions are not captured in the national inventory.[28]

Logging roads provide a clear example: industrial forestry creates a vast network of such roads as well as roadside surfaces that remain barren while the logged forest regrows ("logging scars"). Canada's latest GHG inventory quantifies only about 2000 ha per year of new forest roads[29] – about 0.3% of the annual wood harvest area.[30] Yet a recent examination by Wildlands League of numerous clear-cut areas in north-western Ontario found that an average of 14% of these areas had been converted to roads and other essentially barren roadside surfaces,[31] the vast majority of which is evidently not being captured in the GHG inventory. Seismic lines for oil and gas exploration are another example: they occupy as much as 1% of forest area in parts of western Canada[32] but are too narrow to be considered deforestation.

If the definition of deforestation excludes such narrow and/or small areas of forest cover loss, then they are instead examples of forest *degradation,*[33] despite possibly long-term loss of cover. But more important than the label applied is the fact that NRCan's deforestation definition is resulting in these areas not being measured, and their carbon emissions being ignored. This may have been reasonable given the monitoring technology available when the definition was adopted some 15 years ago,[34] but today's technology is undoubtedly more capable.

What is the likely scale of emissions being omitted from Canada's GHG inventory due to the neglect of narrow and/or small areas of forest cover loss? One way to obtain a rough, conservative estimate is to consider a scenario where 7% of the national wood harvest area becomes barren logging scars (i.e., half of the proportion found in Ontario by Wildlands League), and to make the approximation that emissions per unit area of scar are equal to an estimate derived from the inventory for mean emissions per unit area due to forest conversion

[*] To avoid any confusion with carbon removals, we refer to this subsequently as "forest cover loss".

to settlements (the inventory classifies those forestry roads that it does capture, as well as other transportation infrastructure, as settlements). Using these assumptions, creation of logging scars Canada-wide would result in annual emissions of 13 Mt CO_2.[35] This excludes emissions from the wood harvested from the areas that become scars (those emissions are already captured in the GHG inventory).

3.2 Risk of underestimating the climate benefit of protecting primary forests

There is a growing scientific consensus on the importance of expanding the area of "intact and effectively protected land", which includes primary forests (those that have never been industrially logged), both to advance nature conservation as well as to combat climate change.[36] It is therefore important to be able to quantify the environmental benefits of proposed new protected areas of primary forest, including the effects on carbon flows. The climate benefit of protecting a forest can be calculated as the difference between (i) estimated carbon emissions/removals if that forest is protected, and (ii) estimated carbon emissions/removals if the forest is not protected.[37] Part (i) of this calculation depends on the carbon estimated to be removed from the atmosphere by a protected primary forest. Although older stands, of which there will be more in primary than in secondary forests, typically remove carbon more slowly per unit area than younger ones, a global review of hundreds of plot studies in boreal and temperate regions found that old-growth forests are usually carbon sinks (i.e., with net removals) up to 800 years old, and that "the probability of finding an ensemble of ten old-growth forests that [is] carbon neutral is negligible".[38,39] Consistent with this, direct physical measurements of net carbon removals from multiple sites in Canada's boreal forest showed that all remained sinks at stand ages from 80 to 160 years.[40]

NRCan's forest carbon model (CBM-CFS3) will likely be the tool of choice in the near term to evaluate climate benefits from proposed new protected forest areas in Canada. Whether CBM-CFS3 appropriately captures carbon removals by primary forests will depend especially on the volume-age curves that must be inputted by the user and that specify wood volume as a function of stand age for each species or forest type.[41] Several boreal studies as well as the Ontario government have assumed – in contradiction to the reviews cited in the previous paragraph – that stand volumes fall significantly at higher ages,[42] which implies carbon stocks also fall,[43] and removals (carbon sink) switch to emissions (carbon source). NRCan's modelling team has also highlighted "debate about the role of old-growth forests as continuing C [carbon] sinks".[44] If evaluations of the climate benefits of protecting primary forests assume that old forests become carbon sources, then those benefits are likely to be underestimated. There is therefore a need to examine more closely which volume-age curves should be used with NRCan's model, across the full range of ecozones as well as climate and soil conditions.

3.3 Uncertainty of the climate benefit of long-lived wood products

As noted in Section 1.1, Canada's national GHG inventory estimates that wood harvested from the country's forest land emitted 139 Mt CO_2 to the atmosphere in 2019 – 19% of Canada's total reported GHG emissions.[45] Long-lived solid wood products like lumber can withhold their carbon from the atmosphere for decades, and so Canada's inventory defers emissions from these products to future years, on the reasonable basis that the figures should reflect "what the atmosphere sees". In recent years, the inventory has deferred around 25 Mt of CO_2 emissions each year. More specifically, the inventory estimates that in 2019 the equivalent of 162 Mt CO_2 were taken out of the country's forest land area in the form of wood; while wood harvested and burned that year, as well as wood products produced in earlier years and now disposed of, released a total of 139 Mt CO_2 to the atmosphere.[46] The c. 25 Mt per year of deferred emissions is therefore a net figure involving wood harvested, used and disposed of over many years. It represents a significant climate benefit.

There are many sources of uncertainty (see Section 2.2) in the inventory's calculation of this benefit, and some of them are large. They include uncertainties in the volume of wood harvested, the proportion of wood that ends up in long-lived uses like construction materials rather than short-lived uses like paper or fuel, the rate at which long-lived solid wood becomes waste, and the rate at which the carbon in waste wood is released to the atmosphere as a result of landfilling or combustion in Canada or the U.S. (where much of Canada's wood is exported). As an illustration of uncertainty, the Ontario government has estimated that 35% of the wood harvested in the province was converted into solid wood products from 1999 to 2010,[47] which the national GHG inventory assumes to have half-lives of 25 to 40 years.[48] This contrasts with a recent finding by Wildlands League that typically under 20% of wood harvested in a conventional Ontario context ends up in long-lived products.[49]

The true amount of emissions from wood products that are deferred to future years could be significantly lower or significantly higher than the amount that NRCan estimates for the national inventory. For example, if the proportion of long-lived products is being overstated, then the estimated amount of deferred emissions could be too high. But if long-lived products are lasting longer in buildings and/or landfills than currently assumed, the estimated amount of deferred emissions could be too low. There is a need for greater transparency and scrutiny of the harvested wood product calculations, of which relatively few details are given in the GHG inventory report. In the absence of that, we believe that a precautionary approach should be taken (see Section 2.2) in which policies are adopted on the basis that the amount of deferred emissions is lower than the inventory's central estimate.

4. SPECIFIC ACCOUNTING CONCERNS

4.1 Overestimation of carbon removals by approximately 80 Mt/year CO_2

Industrial logging at a level close to today's only began in Canada in the 1960s, and before the 1930s the level was very low in relative terms. (Only in the 1960s did the decadal rate of industrial wood production first exceed 50% of today's, and production during 1921–30 is estimated to have been less than one-tenth of the level during 2001–10.[50]) Since a typical rotation period – the time until forest can be logged for a second time – is 80 years, Canada is therefore still largely in the process of converting primary forests into industrially logged forests. During this process the forest land area is adjusting to a significant overall increase in the rate of tree loss, as large-scale logging has been added to the continuing occurrence of wildfires.[51] The increased rate of tree loss will cause a significant reduction in mean stand age, and this must result in a large transfer of carbon to the atmosphere since the now younger forest will contain less carbon than when it was older[52] (and any deferral of emissions through long-lived wood products – see Section 3.3 – will only be temporary). This reduction in carbon stock during the logging of primary forests implies many decades of net emissions; the stock reduction, equal to the accumulation (sum) of those emissions, can be viewed as a "carbon debt".[53]

This understanding of the impact of logging on carbon stock appears to contradict NRCan's calculations for the national GHG inventory, which portray Canada's entire forest land area as a net annual carbon source of just 5 Mt CO_2 in 2019 (134 Mt of removals minus 139 Mt of emissions – see Section 1.1). The fact that the 5 Mt incorporates the deferral of c. 25 Mt of annual CO_2 emissions due to long-lived wood products (see Section 3.3) is only a relatively small consideration. It turns out that there are two much bigger factors explaining the contradiction: NRCan's interpretation of the concept of the "managed forest", and its procedure for removing wildfire emissions from the inventory.

Interpretation of "managed forest"

National GHG inventories are meant to include only *anthropogenic* emissions and removals of carbon, i.e., those due to human activities, in order to be a guide to human action to protect the climate. Current IPCC guidelines (2006) for national inventories require countries to include forest carbon sources and sinks using the "managed land proxy", whereby a country defines land it considers to be "managed" and then includes in its inventory *all* emissions and removals from that land. Although some of these will be natural, not anthropogenic, there is no scientific consensus on how to separate the two, and so countries agreed to adopt this simplified approach on the basis that (i) the majority of anthropogenic carbon flows occur on managed land, and (ii) the natural emissions/removals that also occur there will sum to zero over time.[54] However, the IPCC guidelines' definition of "managed land" is quite vague: "land where human interventions and practices have been applied to perform production, ecological or social functions".[55] This leaves countries free to interpret the definition in a wide range of ways.[56] NRCan has chosen a very large "managed forest" that includes a considerable proportion[57] of primary forest areas that are not likely "managed" according to the normal meaning of the word. Although multiple considerations enter into which areas are included in the managed forest,[58] it appears that its furthest boundaries are mainly determined by provinces' plans for future logging. We explain the effect of NRCan's expansive interpretation of "managed forest" below after considering the second key factor in the national inventory's surprisingly small number for net emissions from forest land.

Wildfire exclusion procedure

Additionally, NRCan departs from the managed land proxy by excluding from reported emissions/removals all areas of the managed forest significantly affected by "natural disturbances". In 2019, almost one-quarter of the managed forest area was excluded on this basis.[59] The excluded areas that are most significant in terms of emissions are those affected by stand-replacing wildfires. Such areas are, however, re-inserted into reported emissions/removals once the trees have regrown to "commercial maturity" (after 76 years on average)[60] (see Figure 1(a)). NRCan explains this exclusion and re-insertion of lands by deeming emissions from major wildfires and removals from post-fire regrowth up to commercial maturity not to be anthropogenic, but removals by commercially mature post-fire trees to be anthropogenic, *even though no human activity is involved in the regrowth of these trees either before or after they reach commercial maturity.*

That this wildfire exclusion procedure is problematic is clearest when we consider how it applies to primary forest. In the primary portion of Canada's very large managed forest, NRCan is omitting all the carbon emissions from major wildfires, but retaining all the removals from the growth of older trees. As a result, the primary forest area of the managed forest will always be calculated to be a large carbon sink. But this does not reflect reality: in an idealized primary forest where the fire rate is stable over time (and emissions from disturbances other than fire are not significant), a steady state is reached where emissions from fires are equal and opposite to removals from growing trees:[61] the total carbon stock becomes constant and the forest is neither source not sink. Yet NRCan's methodology would, again, find such a forest to be a large sink (Figure 1(b)). The mismatch between a zero real sink but a large calculated sink reveals a major bias in the methodology.

NRCan's wildfire exclusion procedure has been motivated by large year-to-year fluctuations in emissions from wildfires (and insect outbreaks) that mask the underlying trend in emissions/removals due to human activities.[62] Annual wildfire emissions have exceeded 200 Mt CO_2 in some recent years but been less than 100 Mt CO_2 in others.[63] But excluding *all* major wildfires from Canada's GHG inventory is clearly a major over-compensation for this problem.[64] The size of the resulting bias is then amplified by the size of the managed forest, because the larger the managed forest, the larger the removals by commercially mature post-fire trees that are deemed to be anthropogenic and included in reported emissions/removals. Most of these removals will be occurring in the primary forest portion of the managed forest, close to its furthest boundaries. This is where NRCan's expansive interpretation of "managed forest" becomes a key factor in the national inventory's surprisingly small number for net emissions from forest land.[65]

The extent of the bias

Using the example above of how NRCan's methodology applies to an idealized primary forest, if emissions from wildfires are excluded from reported emissions/removals, then *all* removals from post-fire regrowth on the same areas of land must also be excluded in order to eliminate the bias from the methodology. Only then would the forest be realistically portrayed as neither source nor sink. The size of the bias is therefore given by the size of removals by commercially mature post-fire trees that NRCan includes in reported emissions/removals. NRCan has stated that these removals were a 102 Mt CO_2e sink in Canada's GHG inventory for 2016.[66] The most recent national inventory report does not give an update to this number but includes a graphic showing that its mean value during 2005–19 was around 95 Mt CO_2 (see Figure 1(a)), that it is falling gradually, and that its value in 2019 was a little over 80 Mt.[67] This means that the inventory's 134 Mt CO_2 of annual carbon removals from Canada's forest land in 2019 is overestimated by around 80 Mt. Accordingly, rather than being a net annual carbon source of just 5 Mt CO_2 in 2019, as the inventory claims, Canada's forest land area in that year should instead be considered to be a net annual source of around 85 Mt CO_2.

While estimation of the net carbon flow associated with Canada's forest land is a scientific task, we view NRCan's two key choices that lead to the c. 80 Mt/year overestimation of removals in the national GHG inventory as subjective ones that go well beyond scientific estimation. Accordingly we consider them to be accounting choices that ultimately involve policy or political judgement. The choice of a very large managed forest is a subjective interpretation of a vague definition. This interpretation in turn amplifies a bias that results from a further subjective choice to deem removals by post-fire trees starting at a specific age (76 years on average) based on an economic criterion (commercial maturity) to be anthropogenic. Although NRCan describes these choices in a scientific context, they are not simply scientific choices.

It should also be noted that while the GHG inventory report does additionally present total net emissions from the managed forest that include those from all wildfires as well as all post-wildfire removals, the figures that Canada reports to the UN as well as the "headline" numbers in the report – those included in total national emissions, in summary tables and the associated descriptive text – all incorporate the c. 80 Mt/year overestimation of removals. The figures for total net emissions from the managed forest do not make their first appearance until page 149.

Additional considerations

New IPCC guidelines (2019) for national GHG inventories (officially, the "2019 Refinement to the 2006 IPCC Guidelines") continue to require countries to use the managed land proxy, which Canada is not doing as it excludes selected areas of the managed forest from reported emissions/removals. However, the guidelines do now provide for how inventories can disaggregate emissions/removals attributed to natural disturbances.[68] The 2019 guidelines are not yet formally in force, but they are expected to be adopted by international climate negotiators for purposes of assessing countries' progress towards their Paris Agreement GHG targets for 2030. The new guidelines state that "when emissions from natural disturbances are disaggregated, it is good practice that subsequent removals are also disaggregated until the balance [between emissions and removals] has been reached". In other words, if lands with wildfire emissions are excluded from the inventory's calculation of anthropogenic emissions/removals, those lands should only be re-inserted into the calculation when the wildfire emissions have been fully balanced by removals from subsequent tree regrowth.

Three lines of reasoning indicate, however, that NRCan's wildfire exclusion procedure, as implemented in Canada's GHG inventory, will result in removals from post-fire regrowth up to commercial maturity – excluded from the inventory – falling short of balancing the emissions from fires that are excluded from the inventory. We conclude that the procedure therefore fails to comply with good practice for disaggregation of natural disturbances as set out in the 2019 IPCC guidelines:

- As explained above, in an idealized primary forest with a stable long-term fire rate (and where emissions from disturbances other than fire are not significant), emissions from fires are equal and opposite to removals from growing trees. Therefore, if emissions from wildfires are excluded, then to achieve balance between excluded emissions and excluded subsequent removals, *all* removals from post-fire regrowth must be excluded as well. There is no age threshold, such as the average of 76 years used for Canada's inventory, at which removals from post-fire regrowth can be re-inserted. Although this is a limiting case, there will be no abrupt mathematical discontinuity between the limiting case and cases that include increasing amounts of logging.
- Canada's latest inventory report indicates that during 2005–19, mean annual emissions from major wildfires (excluded from the inventory) were around 130 Mt CO_2, but mean annual removals from post-fire regrowth up to commercial maturity (also excluded) were only around 40 Mt CO_2 (see Figure 1(a)). The discrepancy is presumably exacerbated by today's fire rate being higher than the mean rate over the past several decades: smaller areas burned in the past, so today's removals from regrowth on those areas up to commercial maturity fall even further short of the emissions from fires on larger areas today, relative to a scenario in which the fire rate had remained more constant.

- NRCan defends its procedure by noting that areas that burned and were excluded from the inventory during 1990–2016 had an average age that was five years less than the average age at which they are due to be re-inserted into the inventory in several decades' time.[69] It states that this "gives a degree of assurance that, on average, most stands will be reasonably close to the predisturbance condition when they meet the age thresholds for [re-insertion into the inventory]."[70] However, this is far from ensuring balance between excluded emissions and excluded subsequent removals. First, many stands that burn with a mean age of, say, 75 years will burn again before they reach the age threshold (say, 80 years) to be re-inserted into the inventory. The stands that burn for a second time will not have grown for long enough to balance the emissions that occurred when they first burned. Second, when considering the appropriateness of re-inserting 80-year-old stands during 1990–2016, it is not the average fire age from 1990–2016 that matters but rather the average fire age 80 years earlier. NRCan states that fire ages from decades ago are not known,[71] but they could be estimated by modelling the past age distribution of the forest.

A final consideration regarding emissions from wildfires is that today's rising trend in the fire rate is widely understood to be a consequence of human-caused climate change. This means that some fraction of wildfire emissions are "indirect" anthropogenic emissions. National GHG inventories are inconsistent in the extent to which they include indirect anthropogenic emissions/removals in the forest sector.[72] A desire to exclude indirect emissions/removals could motivate excluding a portion of wildfire emissions, but it would be necessary at the same time to ensure all other significant indirect forest emissions/removals were excluded.

4.2 Altered accounting that produces 19 Mt of "free" reductions in annual emissions

Canada's current Paris Agreement target is to reduce its anthropogenic GHG emissions by 40–45% between 2005 and 2030. Excluding land-use, land-use change and forestry, emissions need to be reduced from 739 Mt CO_2e in 2005[73] to at most 443 Mt in 2030, a gap of 296 Mt.[74] This is the standard "net-net" approach to setting and meeting national GHG targets: the national inventory emissions level in the target year (2030) is compared to the inventory level in the base year (2005). Including forest land in Canada's target using net-net accounting would contribute to making the 296 Mt gap smaller by a projected 6 Mt, without implementing any new policies affecting forests. This is because, under NRCan's inventory methodology (see Section 4.1), the managed forest was a net 10 Mt CO_2e sink in 2005[75] but is projected, without new policies, to be a net 16 Mt CO_2e sink in 2030[76]. The Government of Canada has stated, however, that it does not intend to use the net-net approach for the managed forest. Instead, it intends to use "reference level" accounting that ignores the 2005 inventory level. The reference level is a counter-factual projection of what forest emissions would be in 2030 if logging continued until then at a historical rate (the mean for 1990 to 2016). The government then plans to take the difference between reference level emissions and actual (national inventory) emissions in 2030 as an "accounting contribution" towards closing the 296 Mt gap.[77] Given that the logging rate in 2030 is expected to be less than the historical rate, the government currently projects the actual managed forest emissions in 2030 of −16 Mt CO_2e (see above) to be 25 Mt below the reference level emissions of +9 Mt (again without any new policies), so that the reference level approach will generate an accounting contribution of 25 Mt[78] (see Figure 2).

This means that by choosing reference level accounting for forest carbon over net-net accounting, Canada is awarding itself a projected 19 Mt CO_2e benefit (25 Mt minus 6 Mt) towards meeting its 2030 GHG target – without any change in policies affecting forests.

The key argument for the reference level approach is that forest carbon emissions/removals associated with a given level of human activity today, notably logging, depend not just on that level but also on the levels of logging and natural disturbances in past decades.[79] This contrasts with, e.g., production of electricity from coal, where emissions today have a fixed relationship to the level of activity today. If a specific constant level of logging starts in a forest in, say, 1990 or in 2005 (the exact date does not matter), then if that results in a higher rate of tree loss than in previous decades ("case A"), there will be net emissions (declining over several decades) as the forest adjusts towards a new steady state through a reduction in the mean stand age, which means an ongoing transfer of carbon to the atmosphere. If instead the same constant level of logging starts in 1990 or 2005 in a forest where that results in a lower rate of tree loss than in previous decades, most likely because the forest was even more intensively logged in the past ("case B"), then there will be net removals (declining over decades) as the forest adjusts through an increase in the mean stand age and ongoing transfer of carbon from the atmosphere to the forest. In case A, emissions will fall during 2005–30 and the forest will contribute – even with a constant logging rate – towards the country's target to reduce emissions by some percentage over that period. In case B, with the same current level of logging as case A, removals will fall during 2005–30 and so the forest will increase the difficulty of meeting the country's target. The reference level approach can eliminate this distinction between cases A and B.[80]

There are, on the other hand, multiple arguments against reference level accounting and in favour of net-net accounting for forest carbon:

- Canada has a weak case for being concerned about being "penalized" by net-net accounting given that the latter is projected to result in the managed forest contributing towards meeting its Paris Agreement GHG target, even without new policies affecting forests (see above).
- Net-net accounting creates consistent incentives to reduce GHG sources and enhance GHG sinks, e.g., by reducing logging rates and protecting forests, just as reference level accounting does.[81]
- Net-net accounting reflects "what the atmosphere sees" while reference level accounting does not.
- Reference level accounting for forest carbon contradicts the stated aim of Canada's GHG target and creates an "honesty problem". If, for example, a minister declares that Canada's target is to reduce emissions by 40–45% during 2005–30, that is not actually true because forest emissions are being treated differently.
- It is reasonable for countries to be accountable for *all* their anthropogenic emissions/removals, even if they result in part from choices made in past decades. If a country has a declining net forest sink today because of exceptionally intensive logging in the past ("case B"), it should, arguably, be held to account for the consequences.
- Other sectors have large legacy effects from pre-2005 choices but this is not used as a reason to abandon net-net accounting using a 2005 base year. For example, Canada

increased power generation from zero-emitting sources by 58% between 1980 and 2005,[82] making emissions from that sector in 2005 significantly lower than if that increase had relied on fossil fuels, and reducing the scope for emission reductions during 2005–30.

- Under the Paris Agreement, concerns about legacy effects in net-net accounting are moot as countries are choosing their own GHG targets, and can set them at a level that takes account of such concerns. Reference level accounting is itself a legacy of international negotiations a decade ago on the second commitment period of the Kyoto Protocol. The Paris Agreement is a quite different context where countries are free to choose their own accounting approaches.[83]
- In its most recent biennial report to the UN climate secretariat (submitted shortly before the end of the Obama administration), the U.S., Canada's closest partner, stated its intention to use standard net-net accounting for forest carbon.[84]
- Reference level accounting introduces unnecessary complexity and reduces transparency. The reference level emissions/removal scenario is more difficult to understand and scrutinize than a simple base-year inventory figure, as it will typically be a projection obtained from a complex model incorporating multiple economic parameters. Countries using reference level accounting have a perverse incentive to inflate reference level emissions (e.g., through their choice of historical logging rates that enter into the scenario) as a way to artificially reduce the difficulty of meeting their targets.

Overall, the Government of Canada's current choice of reference level accounting gives the impression that it is picking and choosing accounting approaches for forest carbon depending on what gives the most favourable result. For its national GHG inventory, Canada chooses a very large managed forest and then excludes areas affected by major wildfires, which greatly exaggerates the forest's carbon removals (see Sec 4.1). But when using the 2005 inventory as the comparison point for meeting its GHG target would give only a modest benefit, Canada replaces the inventory by a different comparison point that gives a much bigger benefit. An observer could be forgiven for concluding that the government has adopted the reference level approach simply to gain 19 Mt of "free" reductions in annual emissions.

4.3 An inappropriate incentive for logging and wood-burning

Although, as discussed above, NRCan undertakes a highly complex quantification of the carbon emissions/removals associated with industrial forestry for Canada's national GHG inventory, those emissions/removals are currently exempted from Canada's carbon pricing laws. Pulp and paper facilities must pay a carbon price under the federal Output-Based Pricing System (OBPS) for their use of fossil fuels, but the current OBPS regulations deem emissions from burning wood and other biomass – common in forest industry facilities – to be zero.[85] The regulations likewise deem emissions from combustion of wood in other large industrial or electricity generation facilities to be zero, which means there is no carbon price to be paid. In addition, the current OBPS completely overlooks emissions/removals on forest land,[86] as well as emissions from paper and solid wood products when they are disposed of. The OBPS strongly influences provincial carbon pricing systems because the federal government requires that they be of comparable stringency.[87]

We view this as a carbon accounting issue, as it is a decision to exclude an entire category of anthropogenic emissions/removals from accountability, in this case in the domestic policy context. The decision is based on the notion that carbon emissions from biomass use, especially as fuel, are exactly balanced by carbon removals from biomass production (growing plants), and so both can be ignored. Accordingly, energy from wood is routinely described as "renewable" energy. But as we have seen earlier in this paper, emissions and removals do not balance in Canada's forestry sector: as laid out in Section 4.1, Canada's forest land area and the associated wood products should be considered to be a net source of many tens of Mt CO_2 per year. This means that there will be forestry companies that are routinely harvesting wood resulting in carbon emissions significantly outweighing the genuinely anthropogenic carbon removals by the forests that the companies manage.

Exemption of such a large net emissions source is a major distortion to the emissions-reduction incentive created by the carbon price. It means that most of the climate harm associated with the forestry industry and its products is not being reflected in economic decisions. The sector is receiving an effective subsidy, equal to the carbon price payments from which it is exempted, that will act as an incentive for more logging and more wood-burning than would otherwise be the case. The exemption is, moreover, at odds with Environment and Climate Change Canada's stated "intent [that the OBPS] remain aligned with the treatment of biomass under Canada's National Greenhouse Gas Inventory"[88], because the inventory explicitly quantifies forest carbon emission/removals rather than assuming them to be zero. Companies could be required to undertake the same explicit quantification using methods already developed over many years at the national level.

The exemption of wood burning is of particular concern as it accounts for a considerable fraction of emissions from wood products (and, unlike with long-lived products, there is no deferral of the emissions to future years). Of the 143 Mt CO_2 that the national GHG inventory estimates were emitted in 2019 by wood harvested from the forest land area (including forest conversion),[89] more than 59 Mt were due to burning wood for energy[90] – more than the total Canadian emissions from burning coal (47 Mt).[91] Companies had to pay a carbon price for the emissions from coal, but not for their emissions from wood. This encourages the substitution of coal (and other fossil fuels) by wood, notably for electricity generation, despite the fact that such substitution can result in increased emissions for many decades.[92] In any case the incentives affecting such substitution will be distorted if the associated emissions and removals are not all properly quantified and subject to the same carbon price.

ACKNOWLEDGEMENTS

The author would like to thank all those who have given their time over the past months to discussing the topics covered by this paper and reviewing earlier drafts, especially Michael Polanyi and Graham Saul of Nature Canada, Jennifer Skene and Anthony Swift of NRDC, multiple colleagues from other environmental organizations, and officials of ECCC and NRCan. The author is particularly grateful to Professors Jay Malcolm and Sean Thomas of the University of Toronto who generously provided extensive comments on an earlier draft.

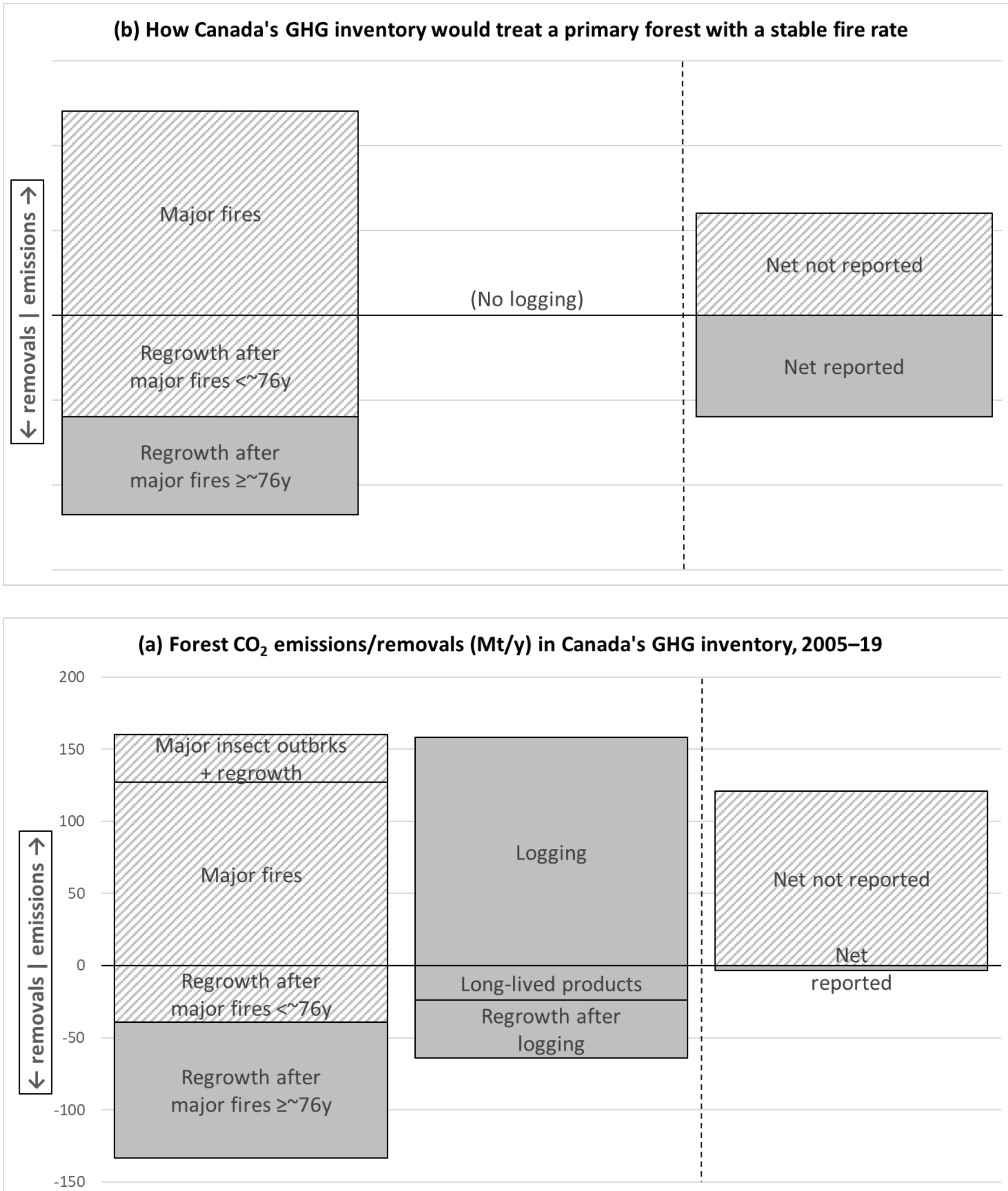

Figure 1. Panel (a) shows components of forest carbon flows in Canada's GHG inventory averaged over the last 15 years.[93] The left-hand column shows major wildfires, insect outbreaks and subsequent regrowth; the middle column shows logging – displayed as total carbon taken out of the forest, minus the net portion withheld from the atmosphere by long-lived products – and subsequent regrowth; the right-hand column shows the sum of the other two. Components that Canada reports to the UN and includes in the inventory's "headline" numbers have solid shading; components not reported have diagonal shading. Net reported emissions are very close to zero, portraying the managed forest as almost carbon neutral. Panel (b) shows how the same approach would treat an idealized primary forest (in which emissions from disturbances other than fire are not significant) that has reached a steady state. The forest is neither source not sink, but NRCan's methodology would portray it as a large sink.

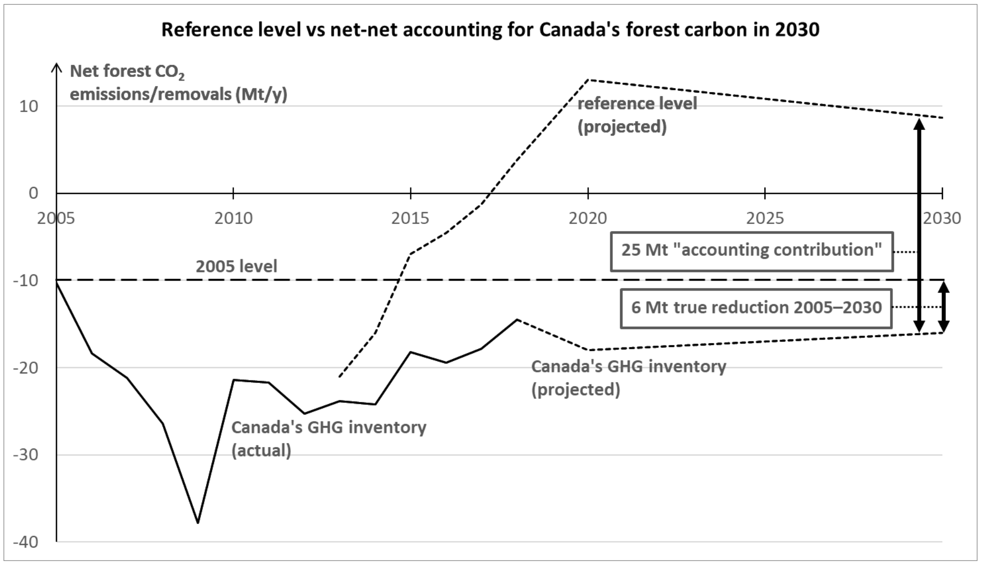

Figure 2. Projected reference level emissions are higher than the projected level of emissions in Canada's GHG inventory because the former are based on a higher, historical rate of logging. Accordingly, reference level accounting produces a 25 Mt contribution towards meeting Canada's 2030 GHG target, while net-net accounting would produce a 6 Mt contribution. Data sources are cited in the text above. (For consistency with the projected inventory values, actual inventory values are taken from the 2020 inventory report, not the 2021 report used elsewhere in this paper.)

---

[1] Environment and Climate Change Canada, *Common Reporting Format Tables* (2021a), Table 4.
[2] Environment and Climate Change Canada, *National Inventory Report 1990–2019: Greenhouse Gas Sources and Sinks in Canada* (2021b), Part 1 p.142. This figure is deduced from the "combined net flux from Forest Land and Harvested Wood Products... [which] amounted to net emissions of 4.6 Mt".
[3] Both figures cited are for "forest land remaining forest land" and the associated wood products. If forest conversion (deforestation) is included, the 134 and 139 Mt become 121 and 143 Mt respectively. The 121 Mt is deduced as 134 Mt of removals minus 13 Mt of forest conversion emissions (Environment and Climate Change Canada (2021b), Part 1 p.171); and the 143 Mt is from Environment and Climate Change Canada (2021a), Table 4.G.
[4] For forest carbon emissions/removals, Canada use "Tier 3" methods, which are those that allow countries the maximum freedom to choose their own approach. See Intergovernmental Panel on Climate Change (2006), *IPCC Guidelines for National Greenhouse Gas Inventories*, Vol. 4 Chapter 4.
[5] Environment and Climate Change Canada (2021b), Part 1 p.19.
[6] https://www.nrcan.gc.ca/climate-change/impacts-adaptations/climate-change-impacts-forests/carbon-accounting/13087, accessed July 19, 2021.
[7] Environment and Climate Change Canada (2021b), Part 1 p.148.
[8] https://pm.gc.ca/en/mandate-letters/2019/12/13/minister-natural-resources-mandate-letter, accessed April 4, 2021.
[9] Natural Resources Canada officials, personal communication, June 2021.
[10] Environment and Climate Change Canada (2021b), Part 1 p.152, Part 2 p.133.
[11] Ibid., Part 1 p.158.

[12] Ibid., Part 2 p.19. The two different figures are based on different statistical methods (Environment and Climate Change Canada officials, personal communication, June 2021).
[13] Further analysis would be needed to correctly combine the inventory's actual uncertainty estimates for removals from forest land and emissions from harvested wood.
[14] W.A. Kurz et al., "Carbon in Canada's boreal forest — A synthesis", *Environ. Rev.* 21: 260–292 (2013).
[15] Ibid.
[16] K.A. Bona et al., "The Canadian model for peatlands (CaMP): A peatland carbon model for national greenhouse gas reporting", *Ecological Modelling* 431: 109164 (2020).
[17] W.A. Kurz et al. (2013).
[18] https://nfi.nfis.org/en/history, accessed March 5, 2021.
[19] Natural Resources Canada officials, personal communication, February 2021.
[20] W.A. Kurz et al. (2013).
[21] Environment and Climate Change Canada (2021b), Part 2 p.125.
[22] Radio-Canada, "Le ministère des Forêts du Québec est-il à la solde de l'industrie?", March 4, 2021, https://ici.radio-canada.ca/nouvelle/1774723/foresterie-mesurage-terres-publiques-complaisance-gouvernement, accessed March 5, 2021.
[23] Intergovernmental Panel on Climate Change (2021), "Summary for Policymakers", in *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Figure SPM.2.
[24] Intergovernmental Panel on Climate Change (2019), *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Vol. 4 Chapter 4.
[25] S.C. Thomas et al., "Managed forests and methane: recent research and prospects for best management practices", in Y. Wang et al. (eds), "Forest management for climate change mitigation: recent innovations and research needs", *Handbook of Environmental Chemistry* vol. 698, Springer (2021, in review).
[26] Environment and Climate Change Canada (2021b), Part 1 p.173. This is consistent with the government's definition of forests as having a minimum area of one hectare and a minimum width of 20 m (see https://www.nrcan.gc.ca/climate-change/impacts-adaptations/climate-change-impacts-forests/carbon-accounting/inventory-and-land-use-change/13111, accessed April 6, 2021). IPCC guidelines allow countries to set their own definitions (see Intergovernmental Panel on Climate Change (2019), Vol. 4 p.3.9).
[27] See also Wildlands League, *Boreal Logging Scars* (2019), p.52–56.
[28] Natural Resources Canada officials, personal communication, May 2021.
[29] Environment and Climate Change Canada (2021b), Part 1 p.172.
[30] The reported forest harvest area in 2018 was 748 kha (https://cfs.nrcan.gc.ca/statsprofile/forest/CA, accessed July 20, 2021).
[31] Wildlands League, p.3.
[32] C.A. Pattison et al., "The Landscape Impact of Linear Seismic Clearings for Oil and Gas Development in Boreal Forest", *Northwest Science* 90(3): 340-354 (2016).
[33] There is no internationally agreed definition of forest degradation, but the UN Food and Agriculture Organization (FAO) describes it as "a reduction or loss of the biological or economic productivity and complexity of forest ecosystems". See FAO and UNEP (2020), *The State of the World's Forests 2020*, p.19.
[34] Environment and Climate Change Canada officials, personal communication, May 2021.
[35] The numbers used for this calculation are as follows: (i) in 2019, 27 kha of forest land was converted to settlements, and emissions from such conversion were 6.6 Mt CO_2 (Environment and Climate Change Canada (2021b), Part 1 p.170); (ii) the total harvest area in 2018 (the figure for 2019 is not yet available) was 748 kha (https://cfs.nrcan.gc.ca/statsprofile/forest/CA, accessed July 20, 2021).
[36] See, e.g., H.O. Pörtner et al., *Scientific outcome of the IPBES-IPCC co-sponsored workshop on biodiversity and climate change*, IPBES secretariat (2021), Synposis point 9.
[37] This is the standard way in which the benefits of proposed GHG reduction policies are evaluated: by comparing emissions in a "with policy" scenario to those in a "without policy" scenario.
[38] S. Luyssaert et al., "Old-growth forests as global carbon sinks", *Nature* 455: 213–215 (2008).

---

[39] The details of the analysis by Luyssaert et al. (2008) have recently been challenged, but without affecting the overall conclusion that forests continue to accumulate carbon into old age. See P. Gundersen et al., "Old-growth forest carbon sinks overestimated", *Nature* 591: E21–E23 (2021) and S. Luyssaert et al., "Reply to: Old-growth forest carbon sinks overestimated", *Nature* 591: E24–E25 (2021).
[40] C. Coursolle et al., "Influence of stand age on the magnitude and seasonality of carbon fluxes in Canadian forests", *Agricultural and Forest Meteorology* 165: 136–148 (2012).
[41] S.J. Kull et al., *Operational-scale Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3) version 1.2: user's guide*, Natural Resources Canada (2019), p.13.
[42] J. Malcolm et al., "Forest harvesting and the carbon debt in boreal east-central Canada", *Climatic Change* 161: 433–449 (2020).
[43] Total carbon stocks will fall if the reduction in biomass carbon outweighs any continued accumulation of carbon in dead wood, litter and soil organic matter.
[44] W.A. Kurz et al. (2013).
[45] Total reported emissions were 730 Mt CO_2e excluding or 740 Mt including land use, land-use change and forestry (Environment and Climate Change Canada (2021b), Part 1 p.8).
[46] Environment and Climate Change Canada (2021a), Table 4.G; Environment and Climate Change Canada (2021b), Part 1 p.156. The cited figures are for "forest land remaining forest land" and the associated wood products. If forest conversion (deforestation) is included, the 162 and 139 Mt become 167 and 143 Mt respectively.
[47] J. Chen et al., *Carbon Stocks and Flows from Harvest to Disposal in Harvested Wood Products from Ontario and Canada*, Ontario Ministry of Natural Resources (2013), p.i,18. The 35% is the proportion of harvested biomass carbon; one would expect the figure for the proportion of wood harvest volume to be very similar.
[48] Environment and Climate Change Canada (2021b), Part 2 p.137.
[49] Wildlands League, unpublished research. The 20% is the proportion of wood harvest volume.
[50] J. Chen et al., "Carbon Profile of the Managed Forest Sector in Canada in the 20th Century: Sink or Source?", *Environ. Sci. Technol.* 48: 9859−9866 (2014), Supplementary Information, Table S7. Harvest volumes for 2000−18 were obtained from https://cfs.nrcan.gc.ca/statsprofile/forest/CA, accessed January 28, 2021.
[51] Although industrial logging is accompanied by fire suppression activities, there continues to be a high rate of wildfires within the very large "managed forest" area over which NRCan calculates forest carbon flows – as discussed later in Section 4.1.
[52] That a forest of a specific type contains more carbon when older than when younger is a corollary of the finding (see Section 3.2) that forests remain carbon sinks up to advanced ages.
[53] J. Malcolm et al.
[54] G. Grassi et al., "Reconciling global-model estimates and country reporting of anthropogenic forest CO_2 sinks", *Nature Climate Change* 8: 914–920 (2018), Supplementary Information.
[55] Intergovernmental Panel on Climate Change (2006), Vol. 4 p.3.6.
[56] G. Grassi et al.
[57] Estimates of this proportion are discussed in L.A. Venier et al., "Effects of natural resource development on the terrestrial biodiversity of Canadian boreal forests", *Environ. Rev.* 22: 457–490 (2014).
[58] Environment and Climate Change Canada (2021b), Part 2 p.124.
[59] Ibid., Part 1 p.149.
[60] Ibid., Part 2 p.127–128.
[61] W.A. Kurz et al. (2013).
[62] Environment and Climate Change Canada (2021b), Part 2 p.127.
[63] Ibid., Part 1 p.149.
[64] We do not mean to imply that the solution is necessarily instead to exclude only some portion of major wildfires. One obvious alternative solution would be to continue excluding all major wildfires but also to exclude all removals from post-fire regrowth. See the following subsection "The extent of the bias".
[65] The large size of Canada's managed forest creates a more general problem in a context where the managed land proxy (MLP) is adhered to: it reduces the likelihood that natural emissions/removals that occur there will sum to zero over time, which is one of the bases of the MLP.

[66] W.A. Kurz et al., “Quantifying the impacts of human activities on reported greenhouse gas emissions and removals in Canada’s managed forest: conceptual framework and implementation”, *Can. J. For. Res.* 48: 1227–1240 (2018).
[67] Environment and Climate Change Canada (2021b), Part 1 p.151.
[68] Intergovernmental Panel on Climate Change (2019), Vol. 4 p.2.71–2.72.
[69] W.A. Kurz et al. (2018).
[70] Ibid.
[71] Ibid.
[72] G. Grassi et al.
[73] Environment and Climate Change Canada (2021b), Part 1 p.8.
[74] Government of Canada, *Canada’s 2021 Nationally Determined Contribution under the Paris Agreement* (2021), p.20.
[75] The figure cited is for “forest land remaining forest land” (FLFL) and the associated wood products. Removals from FLFL and total emissions from wood products are from Environment and Climate Change Canada, *Common Reporting Format Tables* (2020), Table 4. The latter are adjusted by subtracting wood product emissions from forest conversion, taken from Environment and Climate Change Canada, *Canada's Greenhouse Gas and Air Pollutant Emissions Projections 2020* (2021c), p.38. (For Figure 2, interpolated values are used for wood product emissions from forest conversion for 2006–12.)
[76] Environment and Climate Change Canada (2021c), p.39. The figure cited is for “forest land remaining forest land” and the associated wood products.
[77] Environment and Climate Change Canada, *Canada’s 4th Biennial Report to the United Nations Framework Convention on Climate Change* (2019), p.160–162.
[78] Environment and Climate Change Canada (2021c), p.10,39. Again, this is for “forest land remaining forest land” and the associated wood products.
[79] H. Böttcher et al., “Accounting of forest carbon sinks and sources under a future climate protocol – factoring out past disturbance and management effects on age–class structure”, *Environ. Sci. Policy* 11: 669–686 (2008).
[80] Ibid.
[81] Ibid., Table 5.
[82] U.S. Energy Information Administration, https://www.eia.gov/international/data/country/CAN/electricity/electricity-generation, accessed October 8, 2021.
[83] G. Grassi et al.
[84] U.S. Department of State, *Second Biennial Report of the United States of America under the United Nations Framework Convention on Climate Change* (2015), p.9.
[85] *Output-Based Pricing System Regulations*, subsection 22(1).
[86] We recognize that the federal government is proposing to issue offset credits for improved forest management (https://www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work/output-based-pricing-system/federal-greenhouse-gas-offset-system.html, accessed July 23, 2021), but participation would be voluntary, and the carbon price incentive would not cover more than a fraction of the activities that could be subject to mandatory carbon pricing under the OBPS regulations.
[87] *Greenhouse Gas Pollution Pricing Act*, subsection 166(3).
[88] https://www.canada.ca/en/services/environment/weather/climatechange/climate-action/pricing-carbon-pollution/output-based-pricing-system.html, accessed April 7, 2021.
[89] Environment and Climate Change Canada (2021a), Table 4.G.
[90] Environment and Climate Change Canada (2021b), Part 1 p.156. The 59 Mt figure is for “firewood”. The number should be somewhat higher because although Canada’s GHG inventory does include emissions from wood chips and pellets, burned for energy, it does not currently count them under “firewood” (see Part 2 p.136).
[91] Environment and Climate Change Canada (2021a), Table 1.A(a).
[92] J. Malcolm et al.
[93] The numbers depicted in the figure are for “forest land remaining forest land” and the associated wood products. They were calculated from Environment and Climate Change Canada (2021b), Part 1 p.149,151,156,171

and Environment and Climate Change Canada, *Common Reporting Format Tables* (2021a), Tables 4 and 4.G. The calculation excluded indirect CO_2 emissions; it used some interpolation for 2006–13, missing from Tables 6-5 and 6-7, and data read off Figure 6-3, for which the report does not provide numbers. Wood product emissions from forest conversion were assumed to be constant over the entire period.