Accounting for all territorial emissions and sinks is important for development of climate mitigation policies

Anders Lindroth1* and Lars Tranvik2

Abstract
The Paris agreement identifies the importance of the conservation, or better, increase of the land carbon sink. In this respect, the mitigation policies of many forest rich countries rely heavily on products from forests as well as on the land sink. Here we demonstrate that Sweden’s land sink, which is critical in order to achieve zero net emissions by 2045 and negative emissions thereafter, is reduced to less than half when accounting for emissions from wetlands, lakes and running waters. This should have implications for the development of Sweden’s mitigation policy. National as well as the emerging global inventory of sources and sinks need to consider the entire territory to allow accurate guidance of future mitigation of climate change.

Keywords: Territorial carbon balance, Emissions from inland waters, Sweden’s mitigation policy

Background
The Paris agreement on climate change [1] has led to sharpening of emission reduction targets in many countries. The emission pathways leading to a global warming not higher than 1.5 °C in 2100 are based on the state of the global carbon budget, climate sensitivity, lag times and different emission scenarios [2]. In order to reach the 1.5 degree target the atmospheric CO2 concentration in 2100 must remain below the 2016 level [2] which at that time was approximately 400 ppm [3]. The calculation of the pathways is based on the net emissions into the atmosphere. Hence, all emissions and sinks, both anthropogenic and natural, count. Still, the integrated overall net emissions are seldom discussed in the context of emission targets. Most focus so far has been on reduction of fossil fuel emissions and partly also on reduction of emissions from deforestation.

The global carbon budget is a closed system and since we know the state of the atmosphere quite precisely, we can calculate how the mean concentration of CO2 equivalents (CO2eq) in the atmosphere changes depending on how much CO2 and other greenhouse gases are injected or removed in/out of the atmosphere, and thus, based on the climate’s sensitivity to CO2, CH4 and other gases also the impact on the temperature of the atmosphere. But the situation is different at the national level. National carbon budgets are not closed systems. All fluxes, lateral and vertical, crossing a nation’s borders must be known in order to estimate the impact on the atmospheric CO2eq concentration by a particular nation.

Main text
So, how is this important for the climate mitigation work? We will illustrate this with the case of Sweden. Sweden has adopted very ambitious emission reduction goals [4]: “by 2045, Sweden will have net zero emissions of greenhouse gases into the atmosphere and should thereafter achieve negative emissions”. It is also stated that the “net zero emissions” should be achieved with only limited...
accounting of the Land Use, Land-Use Change, and Forestry (LULUCF) sector but also that this sector can be used for obtaining the negative emissions. Taking this literally, it implies that Sweden has the goal of actually starting to reduce the CO₂ concentration in the atmosphere by 2045. In the latest national emission report to the UNFCC by Sweden for year 2018 [5], the emissions amounted to 51.8 M ton of CO₂-equivalents (CO₂eq) and the sink in the LULUCF sector was 42.0 M ton of CO₂eq. The reduction in emissions relative to 1990 was 27% which means about 1% per year. In order to achieve net zero emissions by 2045 the decrease in the rate of emissions must therefore be much higher.

The emission reductions have to a large extent been obtained in the energy sector by utilizing more products from forests to replace fossil fuels. This has so far been possible without reduction of the sink in the LULUCF sector. However, the demand for bioenergy is now heavily increasing, and practically all initiatives are pointing at the forest as the main resource. The average harvest level including other losses has been about 80% of the annual growth in production forests [6] during the last decades, and only a minor fraction, ca. 20% of the harvest is transformed into long-term carbon storage. An increasing demand will most likely increase the harvested fraction of the annual growth and thus also reduce the forest carbon sink [7]. Most of today’s forest sink is in the living biomass with only a smaller fraction, ca 25% going into the soil pool. Considering the time-lag from harvest to re-establishment of a forest carbon sink, increased use of forest products is contrary to the ambition of achieving negative emissions after 2045.

An important question in this context is how well the National Inventory Reports (NIR) to the United Nations Framework Convention on Climate Change [1] represent the emissions and sinks of the territory of Sweden. As stated above, this is crucial when to judge the total climate impact of a country. We don’t discuss the emission inventories from industry, transport, livestock enteric fermentation, etc. or the lateral import/export of carbon but will focus on the LULUCF sector, as it is defined in the National Inventory Report. The methods used to calculate emissions and removals are in accordance with the IPCC 2006 Guidelines for National Greenhouse Gas Inventories, IPCC supplementary guidelines for Kyoto Protocol LULUCF, and the 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. The inventory seems to be quite complete since [5] “All land areas are inventoried in the field except high mountains, military impediments and urban land. We believe that their relative importance for the Swedish GHG inventory is small. The inventory of the LULUCF-sect or is complete in the sense that all carbon pools and other sources, where methods are provided in the 2006 GL, are reported for land use categories that are considered managed.” A key word here is “managed”. According to the guidelines the inventory should only consider managed land but according to those responsible for producing the report, all productive forests including set aside forests are included. Thus, all forest land that has any significant impact on the sink should be included.

So, what is missing? Within the territory of Sweden we also have mires, lakes and rivers that have processes involving exchanges of greenhouse gases. None of these categories are included in the Swedish NIR reporting. Mires are typically sinks of carbon dioxide and sources of methane and both the uptake of CO₂ and the emission of CH₄ depend strongly on vegetation type [8] and it is therefore not so easy to estimate the net emission expressed as CO₂eq for the whole mire area of Sweden. Moreover, their greenhouse gas balance is sensitive to drainage and rewetting. However, one such attempt was made [9] and the conclusion was that mires (including bogs, fens, and marshes) in Sweden are emitting ca. 2.5 M ton CO₂eq annually. Lakes, streams and rivers emit substantial amounts of carbon originating from the terrestrial environment. Based on data from [10] we estimate emission of CO₂ from lakes in Sweden to 8.25 M ton CO₂ and [11] estimated the corresponding value for rivers and streams to 9.9 M ton CO₂. In addition, lakes [12] and streams [11] emit methane, additionally corresponding to 2.2 and 0.5 M ton CO₂eq respectively. This makes a total net emission of 23.4 M ton CO₂eq for lakes and inland waters. Adding this to the reported LULUCF sink, we estimate the territorial land area sink in Sweden to ca 18.6 M ton CO₂eq. Hence, when considering mires, lakes and running waters, the national sink is reduced to less than half of that reported in the NIR. In 2019, the IPCC has published a refinement to the Guidelines for National Greenhouse Gas Inventories [13] which includes areas that are flooded due to human activities. This is likely to result in only marginal improvement of future National Inventory Reports, since most wetlands and inland waters are still excluded.

Conclusions
Territorial emissions of atmospheric CO₂eq are the result of numerous sources and sinks. A full account of those is crucial to guide mitigation of climate change. Here, we show that in the case of Sweden, a complete inventory reveals a weaker territorial C sink than what is currently considered, i.e. the complete land sink balances less of the national emissions than is offset by the reported LULUCF sink. Although there is considerable uncertainty in these numbers as well as potentially unaccounted sources and sinks, they demonstrate that care should be taken to
preserve the forest carbon sink, rather than intensifying harvesting of forest biomass. Without high ambitions in maintaining carbon sinks, the Swedish goal of obtaining negative emissions after 2045 cannot be retained. We recommend that guidelines and methods for estimation of total territorial greenhouse gas balances should be developed to make such estimations possible in all countries. Moreover, complete territorial inventories and their certainty are seriously hampered by lack of fundamental data. Improved data collection and complete territorial inventories are important for policy development of climate mitigation strategies.

Acknowledgements
The Department of Physical Geography and Ecosystem Science, Lund University, Lund, Sweden and the Department of Ecology and Genetics, Uppsala University, Uppsala, Sweden are acknowledged for salary and other support to the authors.

Authors’ contributions
The authors contributed equally to the design of the study and to the writing of the text. All authors read and approved the final manuscript.

Funding
The primary funding comes from the authors institutions.

Availability of data and materials
All data comes from published sources.

Declarations
Competing interests
The authors declare that they have no competing interests.

Author details
1 Department of Physical Geography and Ecosystem Science, Lund University, Lund, Sweden. 2 Department of Ecology and Genetics, Uppsala University, Uppsala, Sweden.

Received: 20 January 2021   Accepted: 2 April 2021
Published online: 10 April 2021

References
1. UNFCC. The Paris Agreement. 2015. https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement. Accessed 15 Oct 2020.
2. Rogelj J, Shindell D, Jiang K, Fifita S, Forster P, Grinburg V, Handa C, Kheshgi H, Kobayashi S, Krieger E, Mundaca L, Sérétian R, Vilarino MV. Mitigation Pathways Compatible with 1.5 °C in the Context of Sustainable Development. In: Masson-Delmotte V, Zhai P, Pörtner H-O, Roberts D, Shukla PR, Pirani A, Moufounma-Oka W, Péan C, Pidcock R, Connors S, Matthews JBR, Chen Y, Zhou X, Gomis MI, Lonnoy E, Maycock T, Tignor M, Waterfield T, editors. Global Warming of 1.5 °C. An IPCC Special Report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. World Meteorological Organization, Geneva, Switzerland, 2018. p. 93–174.
3. NOAA. Climate Change. Atmospheric carbon dioxide. 2020, https://wwwclimate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide. Accessed 17 Oct 2020.
4. The Government of Sweden. The climate policy framework. 2017. https://www.government.se/articles/2017/06/the-climate-policy-framework/. Accessed 15 Oct 2020.
5. Agency SEP. National Inventory Report Sweden 2020. Stockholm: Swedish Environmental Protection Agency; 2019.
6. Swedish University of Agricultural Sciences. Forest statistics. Official statistics of Sweden 2020. Umeå: Swedish University of Agricultural Sciences; 2020. p. 2020.
7. Lundmark T. Skogen räcker inte – hur ska vi prioritera? Future Forests Rapportserie 2020:4. Umeå: Sveriges lantbruksuniversitet; 2020.
8. Nilsson M, Mikkelø C, Sundh I, Granberg G, Svensson BH, Ranneby B. Methane emission from Swedish mires: national and regional budgets and dependence on mire vegetation. J Geophys Res. 2001;106:20847–60.
9. Kasimir-Klemedtsson Å, Nilsson M, Sundh I, Svensson B. Våxthusgasflöden från myrar och organogena jordar. Rapport 5132. Stockholm: Naturvårdsverkets Forlag; 2000.
10. Raymond PA, Hartmann J, Lauerwald R, Sobek RS, McDonald C, Hoover M, Butman D, Stigiel R, Mayorga E, Humborg C, Kortelainen P, Durr H, Meybeck M, Ciais P, Guth P. Global carbon dioxide emissions from inland waters. Nature. 2013;503:353–9.
11. Wallin M, Campeau A, Audet J, Bastviken D, Bishop K, Kolus J, Laudon H, Lundin E, Laflamme L, Natchimuthu S, Sobek S, Teutschbein C, Weyhenmeyer GA, Grabs T. Carbon dioxide and methane emissions of Swedish low-order streams—a national estimate and lessons learnt from more than a decade of observations. Limnol Oceanogr Lett. 2018;3:156–67.
12. Bastviken D, Pace M, Cole J, Tranvik L. Methane emissions from lakes: Dependence of lake characteristics, two regional assessments, and a global estimate. Global Biogeochem Cycles. 2004. https://doi.org/10.1029/2004GB002338.
13. IPCC. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html. Accessed 23 Mar 2021.

Publisher’s Note
Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.