The International Journal of Life Cycle Assessment (2025) 30:2569–2572
https://doi.org/10.1007/s11367-025-02547-3

EDITORIAL NOTE

Biogenic carbon accounting in LCA (response to Silva et al. 2024)

Thomas Nemecek[1] · **Daniel Bretscher**[2] · **Francesco Cirone**[3]

Received: 26 August 2025 / Accepted: 17 September 2025 / Published online: 13 October 2025
© The Author(s) 2025

Keywords Carbon · Carbon balance · Greenhouse gases · Photosynthesis · Vegetation

The article of Silva et al. (2024) on the carbon (C) footprint of milk production in the São Paulo state in Brazil has raised our attention. The authors included the C uptake during photosynthesis, without taking into account the subsequent C release during livestock production and during the consumption of the food products. We thank the authors for putting forward this highly relevant topic. However, we consider this approach as incomplete, leading to a biased assessment and finally to misleading conclusions. As this is a commonly debated issue, we use the example of the dairy systems analysed by Silva et al. (2024) to illustrate the problematic of ignoring the temporary characteristic of the C storage during photosynthesis.

1 Biased C accounting

In their assessment, Silva et al. (2024) included the C uptake of the vegetation during photosynthesis: "The carbon captured during the growing process of agricultural products was accounted for in the approach that includes carbon captured during photosynthesis." However, the authors did not take into account that most if not all of this C is released within a short time again in the atmosphere. Figure 1 illustrates the main C flows within a typical dairy farming system.

C uptake by the vegetation occurs during photosynthesis. Part of this C is directly released again through plant respiration; crops are in fact C sinks during the day and C sources during the night (Machakaire et al. 2023). The net balance results in C uptake, which corresponds to the C content of the whole plant when harvested (Fig. 1). A part of this C enters the soil compartment in the form of crop residues. The harvested share of the plant is fed to livestock and is considered by Silva et al. (2024) in their C balance accounting. However, during livestock production, there are three main pathways of C output: (1) emissions to the air mostly as CO_2, a small share as methane; (2) excretion of C in manure; and (3) output of C in animal products (milk and the animal bodies of the dairy cow and her calves). Of these emission pathways, in Silva et al. (2024), only biogenic methane emissions have been taken into account.

To illustrate the magnitude of the C flows, we refer to the study of Felber et al. (2016) who measured the C flows of a pasture-based dairy herd. Only ~4% of the C intake of a dairy cow was released as methane; the major part was emitted as CO_2 from animal respiration (58%), followed by manure and milk. However, the characterization factor for biogenic methane emissions from IPCC (2021) already takes into account the fact that this C stems from a photosynthetic process, i.e., it considers only the additional global warming potential (GWP) of methane as compared to the CO_2 removed from the atmosphere by plants during their growth and emitted again. In summary, this means that Silva et al. (2024) accounted for 100% of the CO_2 uptake but none of the CO_2 emissions.

Livestock products (dairy and meat) for human nutrition are highly perishable and therefore stored for a few months at maximum. Therefore, most of this C will be released within less than a year again to the atmosphere.

C accounting by the IPCC for biogenic C flows relies on the principle of accounting for net and persistent changes of the CO_2 concentration in the atmosphere (IPCC 2019).

Communicated by Matthias Finkbeiner.

✉ Thomas Nemecek
Thomas.nemecek@agroscope.admin.ch

[1] Life Cycle Assessment Research Group, Zurich, Agroscope, Switzerland

[2] Climate and Agriculture Research Group, Zurich, Agroscope, Switzerland

[3] ecoinvent, Zurich, Switzerland

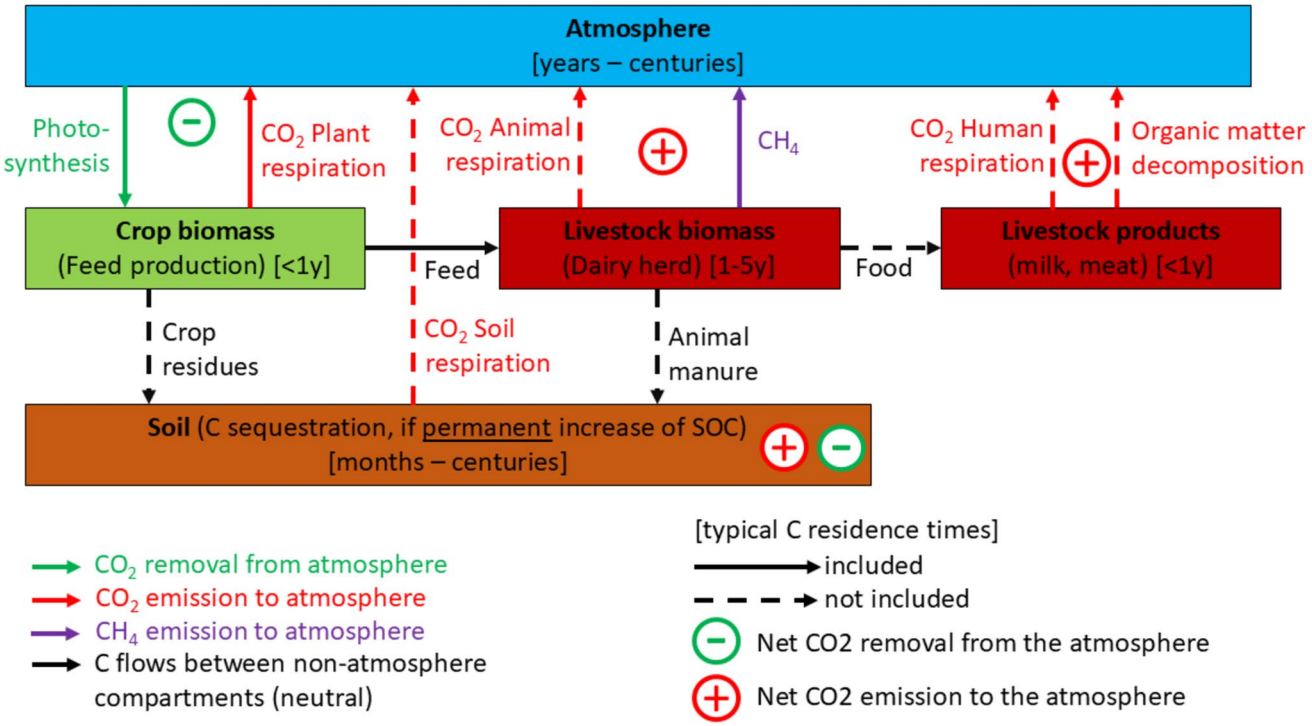

Fig. 1 Carbon flows in a typical dairy production system. Values in brackets indicate typical carbon residence times in the compartment. Solid arrows represent flows included in the article Silva et al. (2024); dashed lines represent ignored flows

A temporary storage of C in biomass for days, months, or a few years does not lead to a relevant change in atmospheric CO_2 concentrations. Figure 1 shows that most of the C pools have short residence times. Most of the crop biomass is decomposed within 1 year. Dairy cows typically do not live longer than 5 years on average, and food products are consumed within less than a year. Leather and horn products could store carbon over decades, but their relevance can be considered negligible. The only compartments with residence times of over 100 years are the atmosphere and the soil. Crop residues and animal manure could lead to a permanent increase of soil organic C (SOC) and therefore to C sequestration in the soil. If clear evidence can be provided for such an effect (e.g., by repeated measurements of SOC), this should be included in the C balance. Likewise, any decreases in the SOC should also be considered. Grassland soils can be C sinks or sources, depending on their history and numerous soil, climate, and management factors (McSherry & Ritchie 2013).

The authors highlight the difficulty of a complete C accounting, and we fully agree with this statement. However, if biogenic flows are taken into account, the balance must be complete at least at the level of inventories between reference products and by-products, and only net changes in atmospheric CO_2 should be considered. This principle was not respected in the article of Silva et al. (2024). The authors conclude that "Five of the evaluated farms had higher captures than emissions and have the potential to be considered carbon stores." We are convinced that this conclusion is a consequence of an incomplete C balance, and this result would not persist if the C balance was complete and conducted in accordance with common methodological standards.

2 Principles of biogenic C accounting

We take the opportunity to recall some of the principles of biogenic C accounting, since there is a high potential that such biased results are misused by stakeholders to support their agenda. The complexity of the topic often leads to confusion and misunderstandings.

- Only *net* and *persistent* changes of CO_2 concentrations in the atmosphere should be taken into account.
- For temporary storage of C, we recommend considering only storage for a minimum of 10 years (ISO 2018). For most of the agricultural systems, this applies only to long-term carbon storage in the soil and wood of trees or shrubs.
- In case the temporary storage period is less than 100 years (in case of GWP100, or less than the time horizon considered by the impacts assessment method), the impact on climate change should be taken into account

by considering the duration of the storage (see e.g. Brandão et al. 2013; BSI, 2011; Leifeld & Keel 2022; Leifeld 2023).

- If no net and persistent changes occur, the biogenic flows can be ignored to simplify the calculation. This has no effect on the impact assessment and is therefore consistent with the ISO 14040/14044 standards (ISO 2006a,b).
- If biogenic flows are taken into account, the balance must be complete (see Fig. 1 as an example). Only taking into account C uptake during photosynthesis, without considering subsequent CO_2 emissions from respiration, is not good practice.
- Biogenic C flows and their impacts on the climate should be represented separately, as recommended by ISO 14067 (ISO 2018).
- If biogenic C flows are calculated based on generic LCI databases or greenhouse gas accounting tools, the completeness and correctness of the calculations for the specific application case needs to be checked thoroughly and adapted to case-specific needs.

3 Challenge to represent biogenic C flows in generic LCI databases

In generic LCI databases, the processes of C uptake and C release are typically represented by different elementary exchanges, properties, unit processes, or datasets. Taking the example of dairy production, the feedstuff production would be represented by a series of dedicated datasets, the livestock production by one or several datasets, and the consequent food consumption—if included at all—would be included in other datasets. The challenge related to this fact is that the flows of C uptake and C release are comparatively large, highly uncertain, and modeled in different unit processes. This means that a small error can have a high impact on the difference. If biogenic CO_2 flows are taken into account from generic databases, the correctness and completeness of the C balance have to be thoroughly checked for the particular case of application, and if it cannot be ensured, we recommend excluding biogenic CO_2 flows. Furthermore, most databases do not represent the full life cycle from cradle to disposal of waste from human consumption. Thus, the risk of incomplete balances is high if biogenic CO_2 flows are included.

Acknowledgements The authors thank Maria Bystricky and Mélanie Douziech from Agroscope for their helpful comments.

Author contribution All authors contributed to the conceptualization and methodology. T. Nemecek prepared the original draft, and D. Bretscher and F. Cirone reviewed and edited the draft.

Funding Open access funding provided by Agroscope.

Declarations

Conflict of interest The authors declare no competing interests.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

References

Brandão M, Levasseur A, Kirschbaum MU, Weidema BP, Cowie AL, Jørgensen SV, Hauschild MZ, Pennington DW, Chomkhamsri K (2013) Key issues and options in accounting for carbon sequestration and temporary storage in life cycle assessment and carbon footprinting. Int J Life Cycle Assess 18(1):230–240

BSI (2011) PAS 2050:2011 - Specification for the assessment of the life cycle greenhouse gas emissions of goods and services. Bsi Br Stand. https://knowledge.bsigroup.com/. Accessed 28 July 2025

Felber R, Bretscher D, Münger A, Neftel A, Ammann C (2016) Determination of the carbon budget of a pasture: effect of system boundaries and flux uncertainties. Biogeosciences 13(10):2959–2969. https://doi.org/10.5194/bg-13-2959-2016

IPCC (2019) 2019 Refinement to the 2006 IPCC guidelines for national greenhouse gas inventories. http://www.ipcc.ch. Accessed 26 Nov 2019

IPCC (2021) Climate change 2021: the physical science basis. Contribution of working group I to the sixth assessment report of the intergovernmental panel on climate change 2(1):2391. http://www.ipcc.ch

ISO (2006a) ISO 14040:2006 - Environmental management - life cycle assessment - principles and framework. Int Organ Standardisation. https://www.iso.org/standard/37456.html. Accessed 12 Sept 2011

ISO (2006b) ISO 14044:2006 - Environmental management - life cycle assessment - requirements and guidelines. Int Organ Standardisation. https://www.iso.org/standard/38498.html. Accessed 12 Sept 2011

ISO (2018) ISO 14067:2018 - Greenhouse gases - carbon footprint of products - requirements and guidelines for quantification. Int Organ Standardisation. https://www.iso.org/standard/71206.html. Accessed 28 July 2025

Leifeld J, Keel SG (2022) Quantifying negative radiative forcing of non-permanent and permanent soil carbon sinks. Geoderma 423:115971. https://doi.org/10.1016/j.geoderma.2022.115971

Leifeld J (2023) Carbon farming: climate change mitigation via non-permanent carbon sinks. J Environ Manage 339:117893. https://doi.org/10.1016/j.jenvman.2023.117893

Machakaire ATB, Steyn JM, Franke AC (2023) Photosynthesis rate, radiation and water use efficiencies of irrigated potato in a semi-arid climate using eddy covariance techniques. J Agric Sci 161(2):217–229. https://doi.org/10.1017/S0021859623000175

McSherry ME, Ritchie ME (2013) Effects of grazing on grassland soil carbon: a global review. Glob Change Biol 19(5):1347–1357. https://doi.org/10.1111/gcb.12144

Silva MC, Mourad AL, Alves ATS (2024) Milk production from family agro-industries in São Paulo state: carbon balance accounting. Int J Life Cycle Assess 29(12):2213–2225. https://doi.org/10.1007/s11367-023-02157-x

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