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Letter to Editor of Nature Communication (https://www.nature.com/ncomms/)

Criticisms of the paper: "Risk to rely on soil carbon sequestration to offset global ruminant emissions" Wang et al., 2023 (https://doi.org/10.1038/s41467-023-43452-3).

Dear Editor,

we read the original article entitled "Risk to rely on soil carbon sequestration to offset global ruminant emissions" by Wang et al., published in November 2023 in your Journal. We are writing to bring to your attention some criticisms on this paper that can lead to possible misinformation about the important discussed issue, and that can have significant consequences on the livestock sector, considering the very high reputation of the Journal and of the authors of the work. This letter is aimed to highlight the concerns with the paper, for which we would like to receive an answer, without claiming to be in the right.

Briefly we found 4 important points that should be better clarified: 1) the appropriateness of the used climate model; 2) the choice of the scenario used for the calculation; 3) the calculation of the amount of C needed to offset a continuous emission of GHG based on the proposed model; 4) the amount of global C sequestration needed to offset the global emissions of the ruminant sector, and the gap with the available carbon sequestration potential operated by the global superficies of grazed grassland.

The first point is related to the model used. The authors stated that with the aim "to improve the quantification of the GHG mitigation effect of soil C-sequestration in grasslands in ruminant systems" they use an alternative approach allowing to "overcoming the shortcomings of GWPs or GWP*". The model was that proposed by Persson and Johansson (2022), which "assess the (cumulative) climate impacts of GHGs fluxes over time, allowing the climatic differences between short-lived GHG emissions and (theoretically) long-lived but finite soil C-sequestration to be accounted for". In our opinion, and according to the same authors of the model, to describe and study emission scenarios at regional or global level, we need "a model that includes the non-linear responses of the climate system (e.g., on greenhouse gas lifetimes and radiative forcings), such as the FAIR model (Smith et al. 2018)"; we add, and believe, that when we refer to emission scenario of short-lived GHG the use of GWP* should not be avoided. This metric, although as reported by the authors

has been criticized, is one the most appropriate tool to account for the differences in the lifetime between short and long lived GHG (IPCC 2021) and, in particular, to assess the warming effect of a given GHG in historical or future emissions scenarios, when a time-series of emissions is being evaluated (FAO 2022). Accordingly, scientists are beginning to consider and use these new metrics for estimates of GHG emissions from methane, as documented by recent papers (Del Prado et al., 2021; Place and Mitloehner, 2021; Liu et al., 2021; Correddu et al., 2023). These observations agree with the comments of the Reviewer 1. The Reviewer also used a very easy approach to understand the magnitude of CO_2 needed to offset the continuous emission of CH_4 (1t/y); that approach is the same we used when we first read the paper and it is based on the use of GWP_{100} for CH_4, that provides a result very close to that obtained by the authors with a more complicated model. Briefly, considering the GWP_{100} of CH_4 = 27.2 CO_2e (as pointed also by the authors), it means that sequestering 2,720 tons of CO_2e (3,500-3,700 tons in the study) would offset annual emissions of 1 ton of CH_4 over 100 years. The answer of the authors to this comment is not convincing, as well as those provided for the other reviewer's comments. We agree with the authors that "GWP fails to reveal the stabilization of the climate effect of the continuous CH_4 emissions", but, accordingly, the use of GWP* could be more appropriate.

The second point regards the choice of the emissions scenario. In particular, the paper aims to find the most realistic amount of C sequestration, hectares of grassland, that can offset the emission of GHG of ruminant sector. However, the authors fail because they base all their calculations and considerations on a non-realistic emission scenario. The emission scenario is not realistic because we are in a situation of almost constant emission of CH_4. In the last 80 years, on average, the global CH_4 emissions from livestock has increased annually of the 0.7% (FAOSTAT, 2023). Consequently, the amount of C that is needed to offset these emissions should be calculated considering that the scenario cannot start form a point (year) zero. In this contest the rate of emissions is crucial and the GWP* represents, for the moment, the most appropriate metric.

The third point regards the calculations. Using the climate model indicated by the authors (Persson and Johansson, 2022) for the quantification of climate impact of the GHG fluxes over time, we obtain slightly different results. This is because, the values of RF and AGTP of the three GHG used in the paper and reported in supplementary materials (sheet name: Fig.1) are different from those reported in the model (https://zenodo.org/records/5957222). In particular "Given a 100-year timeframe, the amount of CO_2 that needs to be stored to compensate the climate impact of a continuous flow of CH_4 (one t per year) equals about 3.51 kt for RF and 3.49 kt for global surface temperature change (3.7 and 3.5 for Wang et al., 2023), and the amount of CO_2 needed to compensate the climate impact of a continuous flow of N_2O (one t per year) equals 33.5 kt for RF and 31.1 for

temperature change (35.4 and 31.0 for Wang et al., 2023). Actually, these differences are of little importance, but need a clarification. On the other hand, the crucial point is represented by the method of calculation: to obtain the conversion ratio at each year, the authors calculate the ratio between RF of CH_4 at each year and the corresponding value for the CO_2. It may be correct if we consider a pulse emission of both CO_2 and CH_4; however, in the figure 2 the values are calculated for a continuous emission (1t/y) of CH_4 or N_2O compared to a pulse emission of one t of CO_2. This pose an important problem: the authors consider and use for the calculation a RF that accumulates (CH_4, because the emissions are 1t/y) and a RF that decreases over time (because CO_2 is a pulse emission of 1t CO_2) as reported in the figure 1a (calculated by the authors of this letter using the available model, https://zenodo.org/records/5957222). It means that, in the first years, when the RF of CO_2 is high, that of CH_4 is low; when the RF of CH_4 increases (because it accumulates) the RF of CO_2 is decreased. If we spread in 500y the same amount of CO_2 RF needed to offset 1t/y of CH_4 for 500y (5.1 kt in 500 years = 10.28 t/y of CO_2), we obtain a different pattern (figure 1b).

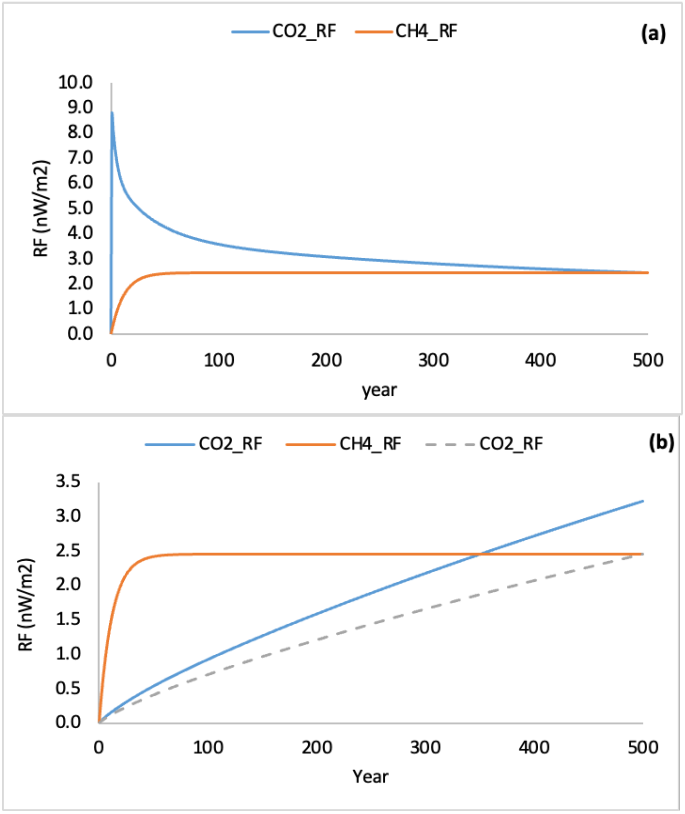


Figure 1. ***a*** *Cumulative radiative forcing of a continuous yearly emission of one t of CH_4 for 500 years (orange line) and radiative forcing of one pulse emission of 5.1kt of CO_2 for 500 years (blue line).* ***b*** *Cumulative radiative forcing of a continuous yearly emission of one t of CH_4 during 500 years and two scenarios of continuous yearly emission of CO_2: i) (blue line) corresponding to the calculated amount of CO_2 needed to offset the CH_4 emission (5.1 kt) spread over 500 years (obtained with the pulse CO_2 hypothesis), and ii) (orange line) corresponding to the amount of CO_2 needed to offset the CH_4 emission (5.1 kt) spread over 500 years (calculated with the continuous CO_2 emission hypothesis).*

This was expected, but the important thing is that the correspondence between the RF at the end point (500y) of the two gases is different: indeed, when a continuous emission of CO_2 is considered, less amount of CO_2 is needed to offset the same amount of CH_4 at 500 years: 5.1kt of CO_2 (figure 1a) and 3.9 kt of CO_2 (figure 1b) for a pulsed emission and a continuous emission (7.83 t/y), respectively, a not negligible difference of 25%. For this reason, the choice of a pulse emission of CO_2 to offset continuous emission of CH_4 is, at least, disputable.

The fourth point is related to the available amount of grassland and, consequently, to the possibility to offset radiative forcing of the CH_4 and N_2O emissions from ruminant system across the globe. According to the FAO data (FAOSTAT, 2023; latest data referring to 2021) the annual amount of CH_4 released by the ruminant sector (cattle, buffaloes, goats and sheep) accounts for about 100 Mt. According to the values and calculations proposed by the authors, to offset 110 Mt of CH_4 and 2.4 Mt of N_2O annually, we need 135Gt of C over 100 years. Using GWP_{100}, the value is 100Gt of C over 100 years.

Considering a C sequestration potential over 100 years of 50 t C/ha, the number of hectares needed to offset the total animal emissions released by the ruminant sector over 100 years is 2 billion ha (calculated considering the GWP_{100}) and 2.7 billion ha (calculated by the values provided by the authors). This amount of grassland is sufficient to balance the global emissions of the ruminant sector considering that: a) the global temporary and permanent pastures and meadows are estimates to account for 3.3 billion of hectares (FAOSTAT 2023).

Lastly, if we consider a prudential estimated C sequestration of 0.29 t/ha per year on average for all grazing land on the planet (Dondini et al., 2023), the calculations for the compensation of methane emissions from all livestock (and not only ruminants) on a FAOSTAT basis and with the standard IPCC metrics (GWP) and the new GWP* metric, at least for the next 20 years, are as follows:

C sequestration: 0.29 t C /ha/y (1.064 t CO_2e/ha/y) (Dondini et al., 2023);

Temporary and permanent pastures and meadows (FAOSTAT, 2023): ha 3.3 billion ha

Total CO_2 sequestration: 3.3 billion ha x 1.064 t CO2e/ha/y = 3.5 Gt CO_2e/y

Livestock CH_4 emissions (FAOSTAT 2023): 1991 = 89,167 kt; 2001 = 88,418 kt; 2021 = 102,257 kt.

GWP (2021): 102,275 kt x 27.2 kg CO_2e = 2.7 Gt CO_2e

GWP* (2001-2021) = 1.6 Gt/y CO_2ew (Cain et al., 2019)

GWP* (1991 – 2021) = 1.5 Gt/y CO_2ew (*idem*)

b) we are not taking into account the C sequestration potential of other agricultural land uses (e.g. permanent crops, temporary crops, fallow, temporary meadows and pastures, primary forest, other naturally regenerated forest, planted forest, etc.) such as Mediterranean agroforestry systems for which, we well know, have higher C sequestration potential than grasslands (e.g. for Dehesa, Reyes-

Palomo et al, 2022 found value of 3.3 t CO_2e $ha^{-1}y^{-1}$). Considering the agroforestry systems at global level, Kim et al. (2016), analyzing 109 earlier observations from 56 peer reviewed publications of net rates of change of biomass and/or soil carbon stocks in agroforestry systems, found C increments ranging from 0.3 to 7.7 t C ha^{-1} y^{-1} in biomass and 1.0 to 7.4 t C ha^{-1} y^{-1} in soils; on average agroforestry sequestered 3.8 ± 1.3 t C ha^{-1} y^{-1} in above ground biomass, with no evidence of changed rates for stands aged 5-25 years. In additions, all studies reported soil C sequestration rate of more than 8 t C ha^{-1} y^{-1} for the first year after agroforestry establishment. Overall, agroforestry stands of 14 years old sequestered 7.2 ± 2.8 t C ha^{-1} y^{-1}, with biomass and soil sequestration contributing about 70% and 30% of increment, respectively.

We agree with the authors on the high variability at regional level and that different factors (well reported in the work) contribute in some cases to give a very high gap between emissions and potential C sequestration. However, this is important from a political point of view, at regional and global level to discuss strategies for the reduction of the emissions, to improve the C sequestration and to promulge adequate normative. However, when we refer to the entire livestock sector, we think that the amount of C sequestration could be sufficient to offset the total direct emissions, also considering that the soil grazed by ruminant is represented not only by grassland, but also by other superficies that contribute to increase the amount of C sequestration as evidenced previously.

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