Toward Climate Positive Beef: An Analysis of Proposed Actions — J.E. Sawyer, PhD, East Foundation and King Ranch® Institute for Ranch Management

Synopsis

Climate positive beef systems are feasible. Current systems may currently be climate neutral to positive in aggregate, depending on system boundaries and emissions metrics utilized. The use of more current metrics of warming equivalence for methane (GWP*) reduces estimated emissions intensity of beef (per unit of carcass weight) by approximately 50% from prior estimates. Accomplishment of small methane emissions reductions, through direct mitigation or improved methods of estimating current emissions, in combination with modest increases in land-based C uptake, can result in a beef warming footprint that it climate positive before 2040. Inclusion of current estimated net carbon uptake by grazing lands inside the system boundary results in a positive climate footprint beginning the 1980s.

Introduction

Utilization of forages and feedstuffs of no or low value for direct human consumption to produce high-nutrition value protein and numerous co-products is an important function of beef production systems in the US. This feature allows utilization of marginal lands and those unsuited for cultivation as a significant component of US beef production systems, and the management of lands associated with beef production generates significant additional ecosystems services. A consequence of the conversion of low-value (for humans) feedstuffs through ruminal fermentation is the generation of methane as a byproduct. These, and other emissions from production, are often cited as negative to the climate.

Background

Climate neutral production systems are those which do not increase global temperature change, and may serve to offset such effects from other systems (becoming 'climate-positive'). Currently, key drivers of global temperature change are believed to be greenhouse gases and other anthropogenic forcing agents; therefore, climate positive systems are those which internally mitigate such emissions to result in a neutral or negative (cooling) effect. The concentration of these agents in the atmosphere, and their resultant effects on radiative transmission, are considered effectors of global temperature change (Myrhe et al., 2013).

Different GHG exhibit different atmospheric behaviors, both in atmospheric lifetime and in the unit magnitude of radiative forcing effects which drive temperature effects. For very long-lived forcing agents (i.e., those which persist in the atmosphere for long periods of time, centuries to millenia), emissions may be a reasonable indicator of change in atmospheric burden when removal rates are relatively constant. However, for short-lived climate forcing agents (SLCF), the agent degrades in the atmosphere over relatively short time horizons (less than 100 yr). Emission rates are therefore not reliable indicators of atmospheric accumulation; at constant emissions, atmospheric concentration establishes an equilibrium rather than a continuous accumulation. Methane is a key example of a SLCF, and metrics that account for the relative change in emissions (such as GWP*; Allen et al., 2018; Cain et al., 2019; Collins et al., 2019) more effectively describe its effects on temperature (compared to GWP100, e.g.). The distinction in behavior of forcing agents is important, as it creates a point of departure between the terms 'climate-neutral (positive)' and 'carbon-neutral (positive)'. For a SLCF, it is not necessary for emissions to be zero in order to achieve atmospheric and temperature neutrality (Allen et al., 2018; Pierrehumbert, 2014); therefore, there may be 'carbon emissions' while 'climate neutrality' is achieved. Therefore, the terms 'carbon-neutral' and 'climate' neutral' are not synonymous. For this reason that the term 'CO2 warming equivalent' has been suggested to replace direct emissions-based radiative forcing equivalence metrics for SLCF.

Emissions of GHG result from many activities necessary to sustain beef production, and use of resources that result in emissions often serve to increase the overall output (feeding more people) and reduce the intensity (fewer resources per unit of product) of emissions. In beef production systems (to the farm gate) over 50% of the CO2-equivalent emissions result from methane generated through enteric fermentation and manure management, with the balance primarily representing direct and indirect CO2 emissions from energy use in generation of inputs and production activities (53%; Asem-Hiablie et al., 2019). This represents both an outcome of conversion of human-inedible feedstuffs into high-quality protein (Baber et al, 2019) and an energetic loss to feeding systems. Therefore, reducing methane emissions may be a high-leverage objective that improves production efficiency, reduces emissions intensity and (more importantly) warming contributions, and moves beef systems toward climate positivity.

Even as emissions are mitigated, opportunities to remove GHG from the atmosphere within the production system may also exist; when such removals are part of a process within the production system, they serve to move the product toward climate positivity (i.e., reduce its 'climate footprint'; ISO 14067:2018). When such removals occur outside the boundaries of a production system, they are considered as offsets or 'negative emissions' that do not directly reduce the climate impact (footprint) of a discrete product, but may be deployed to counteract those impacts. In US beef production systems, grazing by cattle is a significant land use; grazing or land management practices that are a component of beef production systems can serve as a sink for atmospheric GHG, creating a second leverage point to move toward climate positive beef production.

Objective

The primary objective of this analysis is to evaluate the potential of achieving stated goals to result in climate neutrality or positivity, based on achieving 'net-zero' or better warming potential equivalent emissions. Secondary objectives include: 1) estimation of the historical contribution of US and global beef cattle population expansion to atmospheric methane burden, as an indicator of warming contribution; and 2) estimation of the 'warming intensity' of beef (carcass weight basis) resulting from achievement of stated goals.

Approach

Beef Cattle Inventory

Beef cattle inventory values were taken from annual January 1 inventory estimates reported by the National Agricultural Statistics Service (USDA-NASS). This data series extends from 1867-2020 for all cattle and the subclass of dairy cows. A shorter reference data set (~40 years) was used to estimate the annual inventory of dairy replacement heifers. Dairy cows and dairy replacement heifer inventories were subtracted from the total cattle inventory to estimate the total number of cattle used for beef production. Beef cattle inventory was further refined by class (cows, weaned calves/stockers, feedlot, replacement heifers, bulls) and methane emissions were estimated in alignment with US-EPA greenhouse gas inventory reporting methods defined by the Intergovernmental Panel on Climate Change (IPCC). This value formed the basis of emissions projections in the range of years 1920 through 2020. Future inventory levels were projected to remain, on average, near current levels, with cyclic variation patterned on observed cyclicity over the last 45 years. This allows the direct assessment of the effects of achieving stated goals on target outcomes, without confounding effects of inventory dynamics.

Emissions Estimation

Emissions and warming potential were estimated based on methane (as the object of the mitigation goal) and non-methane C02 equivalents. Methane emissions were estimated on an inventory basis, using a Tier 2 approach (IPCC, 2006). Currently the US EPA GHG inventory report uses this Tier 2 method to account for differences among subclasses and provide (in principle) a more granular view of sector level emissions within the livestock population.

Non-methane emissions were predicted from results of Asem-Hiablie et al. (2019), which provided an LCA-based total GHG emissions value for US beef on a carcass weight basis. Their results were disaggregated to estimate methane- and non-methane contributions to the total emissions footprint, and the proportion derived from non-methane emissions were estimated. In their study, emissions are reported as GWP100 based CO_2 equivalents, using a GWP100 value of 25 (IPCC, 2006) to weight methane emissions. An adjustment for this factor was made, such that non-CH_4 GHG emissions (inclusive) could be estimated as a direct function of total inventory.

Greenhouse Gas Equivalence

Non-GHG emissions were expressed as kg of C02 equivalence during estimation and were not adjusted further.

Methane emissions (kg) were adjusted to CO_2 equivalents using 2 methods. First, to maintain correspondence with IPCC reports and other reports using IPCC equivalence calculations, a value of 28 units CO_2 equivalence per unit of methane was utilized to express methane emissions as GWP100 CO_2 equivalents (Myrhe et al., 2013). It is notable that current US EPA reports utilize a GWP100 value of 25 (IPCC, 2006; Forster et al., 2007). Differences in the selected equivalence factor can be a source of discrepancy among reports and LCA analyses; these should be evaluated whenever emissions estimates are compared. In this report, emissions on this basis will be designated as GWP100 and reported as kg of CO_2 equivalents.

Because GWP100 and other forcing-equivalent based conversion factors do not effectively reflect the effects of SLCF (various reports), methane emission equivalence was also estimated using GWP* methods according to Cain et al. (2019) and Lynch et al. (2020). The GWP* metric uses a GWP100 factor in its calculation to maintain correspondence with (and allow conversion of) missions estimated as GWP100; the GWP100 value of 28 was maintained in the GWP* calculation for this report. GWP* was calculated as:

$$GWP* = \left(r \times \frac{\Delta E_{slcf}}{\Delta t} \times H + s \times E_{slcf}\right) \times GWP_H$$

The time series of population and resultant annual estimates of CH_4 emissions were used to estimate GWP*, fully accounting for inventory (and therefore emissions rate) dynamics. In this report, GWP* values will be reported as kg of GWP* warming equivalents or w.e., to maintain distinction from the GWP100 values.

Land-based Carbon Sequestration

The objective of this analysis was to determine if mitigation pathways based on land-based carbon accumulation were feasible, and their contribution toward climate positive beef. Explicit land-based removals were included beginning in year 2021; uptake of C was converted to CO_2 equivalence by molar mass and treated as a direct removal of CO_2-equivalent emissions, internal to the production system, within each year. This evaluation indicates the efficacy of goal achievement toward the larger objective of climate neutrality(positivity). Carbon mass goals were expressed in terms of C or CO_2 storage per unit of land area, and compared to reported values to provide a feasibility assessment (i.e., is the goal attainable).

This first stage analysis implies only 'additionality' of C sequestration, without consideration of current internal removals. A subsequent analysis was performed (as a pro forma) to estimate current internal removals; these are treated as constant throughout time, based on current estimates of US grazingland area and observed carbon flux from rangeland in the western half of the US (Svejcar et al., 2008). This approach is likely a conservative estimate of historical values, due to decreases in grassland area over time and the relatively lower C uptake of arid and semi-arid rangelands which dominate the flux estimates in the referenced study. Alternate outcomes, considering these current internal removals as direct reductions in net emissions, were estimated as above.

Results

'Bottom-up' GHG inventory methods are all dependent, ultimately, on the number of emitting units. Therefore, the dynamics of the US cattle population are an important component of any evaluation of goals associated with GHG emissions. Figure 1 includes the reported total beef cattle inventory from 1920 through 2020. Following peak cattle inventory in 1975, US beef cattle inventory declined cyclically. Over the last 15 years, population has stabilized although cyclical oscillations in population continue and are likely to do so, while the trend in population is relatively flat over that period.

Figure 1. US population, beef cattle inventory, and beef production.

Methane, on a unit basis, generates more radiative forcing that carbon dioxide. Therefore, reductions in methane emissions are viewed as 'more effective' at mitigating temperature effects than similar mass reductions in CO2. In an effort to create comparisons among greenhouse gas emissions effects in common units, emissions values are transformed. The most common transformation is the global warming potential at 100 years (GWP100), which is a direct multiple of emissions and therefore does not account for atmospheric removal of methane, resulting in overstatements of the temperature effects of cumulative methane emissions over time (Allen et al., 2018). An alternate transformation, GWP*, is based on the change in emissions over time rather than direct emissions, and more accurately reflects the behavior of methane in the atmosphere (Cain et al., 2019). Both metrics are expressed as CO2 equivalents, and both were estimated for this analysis, but GWP* is used for goal assessment (Fig. 2).

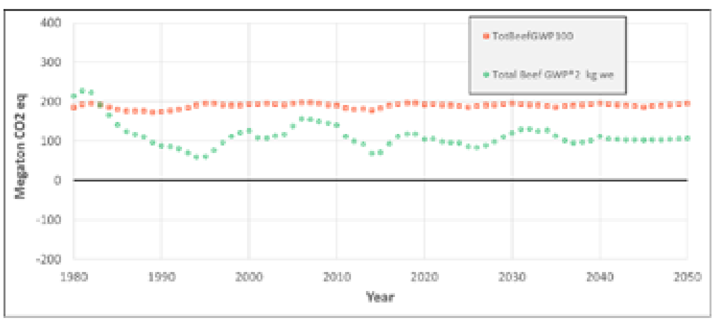

Figure 2. Methane emissions from US beef cattle, 1980-2050 (projected), expressed as GWP100 or GWP* equivalents.

Mitigation strategies that result in annual reductions of methane emissions by 0.4% or 1.5% per year were evaluated (Fig. 3). While a reduction of 0.4% annually is sufficient to result in neutrality of methane emissions alone, this offset is not sufficient to obviate the entirety of non-methane emissions in the production system, most of which are generated in the production of inputs, not directly by beef producers (and as a result are not affected by the beef sector goals in this analysis). Mitigation strategies that combine to achieve 1.5% annual reductions, because GWP* can take on negative values, are sufficient to fully offset the non-methane element, and could achieve warming neutrality by the mid 2030's.

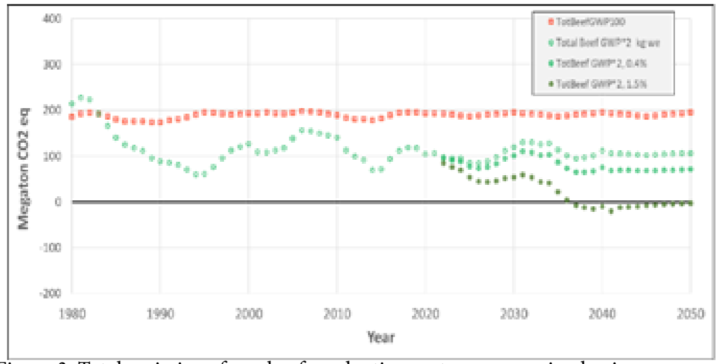

Figure 3. Total emissions from beef production systems, assuming business as usual, a 0.4% or a 1.5% annual reduction in methane emissions, and expressed as GWP* warming equivalents. Unmitigated emissions expressed as GWP100 equivalents are displayed for reference.

Other removals are available in the system. Mitigation resulting from increase carbon uptake in grazinglands used for beef production by 25 kg C/acre or 45 kg C/acre annually result in substantial generation of additional insets (Fig. 4). As observed with methane, the more modest increase in land-based C assimilation is not alone sufficient to result in climate neutrality, but the more ambitious assimilation target offsets all other warming equivalent emissions from beef production and achieves neutrality soon after implementation. These target values are applied across all US grazinglands; while it is unlikely that such uniform change is possible, the amounts are modest enough that they are likely t o be achievable. For example, if 75 kg of additional C were assimilated on 1/3 of grazing lands, then the modest goal could be achieved. This is approximately equal to the 0.2 tonnes of CO2 equivalent uptake suggest by USDA in the COMET planner tool that results from managed grazing, even without consideration of other available practices.

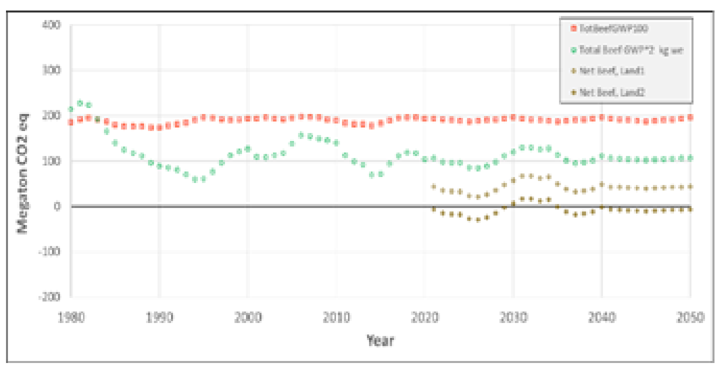

Figure 4. Total emissions from beef production systems, assuming business as usual, a 25 kg C/acre or a 45 kg C/acre annual increase in land-based carbon assimilation, when methane emissions are expressed as GWP* warming equivalents. Unmitigated emissions expressed as GWP100 equivalents are displayed for reference.

The evaluated mitigation pathways are not exclusive; strategies that could achieve the modest target reductions in methane emissions can be deployed simultaneously with those intended to increase land-based carbon assimilation (Fig. 5).

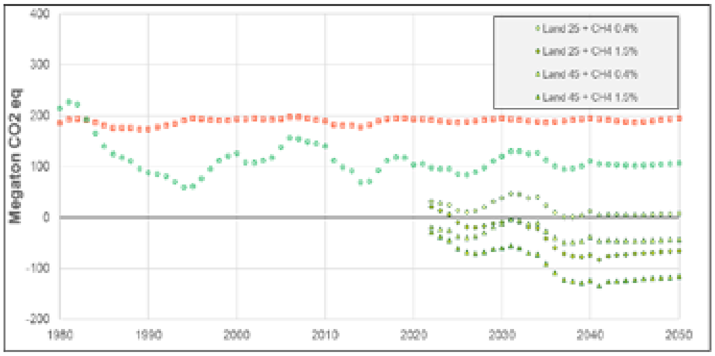

Figure 5. Total emissions from beef production systems, combining methane mitigation and land-based carbon assimilation strategies when methane emissions are expressed as GWP* warming equivalents. Unmitigated emissions expressed as GWP100 equivalents are displayed for reference.

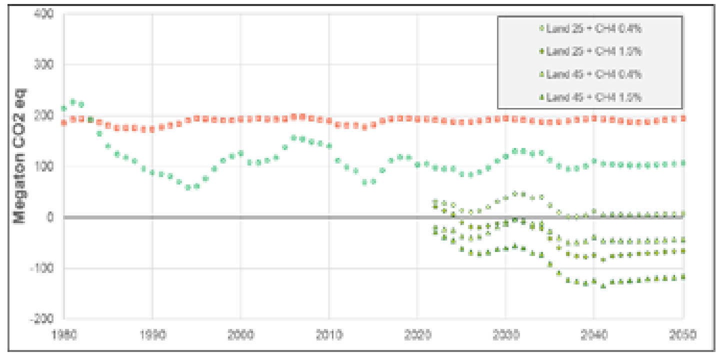

Figure 6. Total emissions from beef production systems, including an estimate of current land-based carbon assimilation (75 kg C/ac; Svejcar et al., 2008) when methane emissions are expressed as GWP* warming equivalents. Unmitigated emissions expressed as GWP100 equivalents are displayed for reference.

Combining the two most modest strategies (0.4% annual reduction in methane and 25 kg C/acre land-based assimilation) approach neutrality in the near term, and achieve it by 2040. Combinations which include at least one (or both) of the more ambitious strategies result in climate positive beef production over the same time frame. These targets are well within estimates of feasible mitigation using current approaches. For example, commonly applied feed amendments or diet management tools can reduce methane 5 to 30%; genetic selection for methane emissions has been estimated to result in a population level improvement of 0.4% per year; effective range management practices have been demonstrated that can increase soil assimilation 30 to 300 kg/ac per year.

As presented above, the land-based carbon removal goals are treated as pure 'additionality'. Additionality is a challenging quantitative concept suggesting that only outcomes above 'what would have happened anyway' be considered as offsets or removals (external or internal) to systems of production. However, in land-based systems such as beef production, the management of grazing lands is inherent to the system, and uptake of carbon by these lands may be substantial based on the area allocated to this production. Average C flux on western US rangeland sites was estimated at 76 kg C, or 281 kg CO2, per acre (Svejcar et al., 2008). Note that this accumulation rate is a mean estimated primarily from sites in the western half of the continental US on rangelands, and incorporates significant annual and regional variability. While further refinement of this value is needed, this value is defensible in aggregate, and illustrative. Importantly, when average land-based removal is considered in the beef system, net emissions of GHG from beef has been 'climate positive' since 1986 (Fig. 6).

These internal removals are not typically accounted for in LCA of beef systems (Asem-Hiablie, 2019), with a few exceptions (Beauchemin et al., 2010; Pelletier et al., 2010; Stanley et al. 2018). Recently, a global evaluation of grassland systems indicates that North American grasslands are a net carbon sink, even after accounting for livestock production and wild ungulate population changes (Chang et al., 2021). Assignment of GHG removals by processes internal to the production system is acceptable within an LCA for greenhouse gas footprinting (ISO, 2018) but may not then be counted as an offset to an emission external to the system (to avoid double counting). It might be a more effective strategy to consider the 'business as usual' removals from land management as internal to production, and to consider 'additionality' through achievement of land management goals separately, such that they might become assets in an offset marketplace. Accounting for the internal and external nature of removals is technically challenging, and further research and evaluation of this topic is an important component of the overall role of beef production systems and their management in climate mitigation policies.

Conclusions

The total magnitude of US beef system methane contribution to atmospheric methane accumulation (and thus warming) is very small, and statistically is likely insignificant. Efforts to further illustrate the relative impacts of ruminant methane on global climate should be illustrated; the false logic that 'methane is a greenhouse gas, cattle produce it, therefore cattle cause global warming' can be misleading and cause creation of policy that is misaligned from effective outcomes.

Expressing methane emissions in units more closely aligned with their impact on warming (GWP* rather than GWP100) results in reduced estimates of the GHG impact of beef production. Importantly, because GWP* is dependent on changes in emissions rates over time, a stable population with constant emissions will result in ongoing constant emissions that are 25% of GWP100 expressed emissions.

Modest reductions in methane emissions estimates, through management or improved measurement of current emissions levels, can result in climate neutrality. Combining these strategies with land management that results in very modest increases in carbon assimilation provide for several pathways that can achieve 'climate positive beef' in the US system within decadal time horizons.

Considering current land-based C uptake by grazinglands utilized in beef production at the national aggregate scale as an internal removal should be evaluated. Under preliminary analysis, including land uptake (not the 'additional' uptake implied by the land based assimilation strategies above) suggests that the US beef system has been climate positive since 1986, without other mitigation. Under that scenario, reductions in emissions and achievement of additional carbon sequestration in US grazinglands represent a substantial 'credit' to beef systems.

Climate positive beef systems are not infeasible, and current systems may already be climate neutral to positive in aggregate. Significant departures from previous analyses include the use of more current metrics of warming equivalence for short-lived climate forcing agents (especially methane), and inclusion of grazinglands and their carbon uptake inside the system boundary.

Literature Cited

Allen, Myles R., Keith P. Shine, Jan S. Fuglestvedt, Richard J. Millar, Michelle Cain, David J. Frame and Adrian H. Macey. 2018. A solution to the misrepresentations of CO2-equivalent emissions of short-lived climate pollutants under ambitious mitigation. npj Climate and Atmospheric Science (2018) 1:16. https://doi.org/10.1038/s41612-018-0026-8

Baber, J, JE Sawyer, and TA Wickersham. 2018. Estimation of human-edible protein conversion efficiency, net protein contribution, and enteric methane production from beef production in the United States. Translational Animal Science 2:439-450. https://doi.org/10.1093/tas/txy086

Cain, Michelle, John Lynch, Myles R. Allen, Jan S. Fuglestvedt, David J. Frame and Adrian H. Macey. 2019. Improved calculation of warming-equivalent emissions for short-lived climate pollutants. npj Climate and Atmospheric Science (2019) 2:29. https://doi.org/10.1038/s41612-019-0086-4

Chang, J., Ciais, P., Gasser, T. et al. 2021. Climate warming from managed grasslands cancels the cooling effect of carbon sinks in sparsely grazed and natural grasslands. Nature Communications 12:118. https://doi.org/10.1038/s41467-020-20406-7

Collins, William J., David J Frame, Jan S Fuglestvedt and Keith P Shine. 2020. Stable climate metrics for emissions of short and long-lived species—combining steps and pulses. Environ. Res. Lett. 15:024018. https://doi.org/10.1088/1748-9326/ab6039

FAO. 2018. Food and Agriculture Organization of the United Nations. FAOSTAT Database. Rome, Italy: FAO. Retrieved 20 Oct 2020 from http://faostat3.fao.org

Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz and R. Van Dorland, 2007. Changes in Atmospheric constituents and in Radiative Forcing. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

International Standards Organization. 2018. ISO 14067:2018 – Greenhouse gases – carbon footprint of products – Requirements and guidelines for quantification. Accessed 01/05/2021 https://www.iso.org/obp/ui/#iso:std:iso:14067:ed-1:v1:en

IPCC. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol. 4: Agriculture, Forestry, and Other Land Use. Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan.

K.A. Beauchemin, H. Henry Janzen, S.M. Little, T.A. McAllister, S.M. McGinn. 2010. Life cycle assessment of greenhouse gas emissions from beef production in western Canada: a case study. Agric Syst 103:371-379

Myhre, G., D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestvedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G. Stephens, T. Takemura and H. Zhang, 2013: Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Naik, V., A. Voulgarakis, A.M. Fiore, et al. 2013. Preindustrial to present-day changes in tropospheric hydroxyl radical and methane lifetime from the Atmospheric Chemistry and Climate Model Intercomparison Project (ACCMIP). Atmospheric Chemistry and Physics, 13(10) https://doi.org/10.5194/acp-13-5277-2013

Pelletier, Nathan, Rich Pirog, Rebecca Rasmussen. 2010. Comparative life cycle environmental impacts of three beef production strategies in the Upper Midwestern United States. Agricultural Systems 103:380-389. https://doi.org/10.1016/j.agsy.2010.03.009.

Pierrehumbert, R.T. Short-lived climate pollution. 2014. Annu. Rev. Earth Planet. Sci. 2014. 42:341–79. 10.1146/annurev-earth-060313-054843

Stanley, PL, JE Rowntree, DK Beede, MS DeLonge. 2018. Impacts of soil carbon sequestration on life cycle greenhouse gas emissions in Midwestern USA beef finishing systems. Agric Systems 162:249-258. https://doi.org/10.1016/j.agsy.2018.02.003

Stevenson, DS, A Zhao, V Naik, FM O'Connor, S. Tilmes, G Zeng, LT Murray, WJ Collins, PT Griffiths, S Shim, LW Horowitz, LT Sentman, and L Emmons. 2020. Trends in global tropospheric hydroxyl radical and methane lifetime since 1850 from AerChemMIP. Atmos. Chem. Phys., 20:12905–12920 https://doi.org/10.5194/acp-20-12905-2020

Svejcar, T, R. Angell, JA Bradford, W Dugas, et al. 2008. Carbon fluxes on North American Rangelands. Rangeland Ecol Manage 61:465-474. https://doi.org/10.2111/07-108.1

Zimmermann, P. H., Brenninkmeijer, C. A. M., Pozzer, A., Jöckel, P., Winterstein, F., Zahn, A., Houweling, S., and Lelieveld, J. 2020. Model simulations of atmospheric methane (1997–2016) and their evaluation using NOAA and AGAGE surface and IAGOS-CARIBIC aircraft observations, Atmos. Chem. Phys., 20, 5787–5809, https://doi.org/10.5194/acp-20-5787-2020