Summary of Global Surface Temperature Change Values Associated With Global CH_4, CO_2, and $N_2$0 Emissions As Well As Global Livestock-Related GHG Emissions. By Todd Shuman, Senior Analyst, WUMU-WURU, 02/14/17.

Introduction

How much of the 2016 global surface temperature value can be attributed to the positive radiative forcing associated with anthropogenic CH_4, CO_2, and N_2O emissions during the 1950-2016 period? How much of the 2016 global surface temperature value can be attributed to the positive radiative forcing associated with anthropogenic CH_4, CO_2, and N_2O emissions *that have been discharged by global livestock supply chains (LSSC)* during the 1950-2016 period?

Possible answers for the latter question can be inferred from Gerber et al. (2013) and Goodland and Anhang (2009). The former analysis suggests a 14.5% value, while the latter analysis suggests a 51% value. Both analyses use a Global Warming Potential (GWP) metric to assess the contributory atmospheric heat-trapping effects of livestock-related carbon dioxide, methane, and nitrous oxide emissions. The former analysis uses a 100-year time interval for methane emission (GWP 25, p. 106) while the latter uses a 20-year time interval for methane emission (GWP 72, p. 13). These possible answers constitute two poles in the range of estimated livestock-supply-chain shares of total global human-induced Green House Gas (GHG) emissions. Both are based, in part, upon conversion of all global GHG emissions into carbon dioxide equivalencies for comparison and accounting purposes.

With respect to associated global surface temperature change, these analyses are limited in their utility, due to their reliance upon (and application of) the GWP metric, which provides information concerning gross estimates of radiative forcing caused by GHG emissions. The GWP metric does not provide substantial information concerning "downstream" global surface temperature values.

Recent critique concerning overuse, misuse, and inappropriate application of the GWP metric (Pierrehumbert [2014], Allen et al. [2016]) suggests that these questions might be more accurately answered through analysis that applies a different GHG atmospheric heat-trapping proxy metric.

In the analysis provided below, I attempt to answer *both questions posed above* by drawing upon the recent work of Allen et al. (2016) -- specifically Figure 2d. Figure 2d of Allen et al. (2016), presents graphed GHG/surface temperature change curves that are largely derived through the application of the Global Temperature Potential (GTP) metric. These graphed curves provide directly-correlated GHG emission/surface temperature change values projected 100 years into the future following year 2011 total global anthropogenic CH_4, CO_2, and N_2O emissions.

Allen et al. (2016) use the values presented in Figure 2d to project future global surface temperature change impacts associated with sustained GHG emissions into the distant future. In Figure 2e, Allen et al. (2016) present the global surface temperature change impact of GHG emissions sustained indefinitely at constant 2011 emission rates and projected 100 years into the future (starting from year 2011).

In the analysis provided below, I work backward in time, as opposed to working forward in time, as Allen et al. (2016) did with Figure 2e. I use a variety of source materials to conservatively reconstruct annual global $CH_4/CO_2/N_2O$ emission estimates for the 1950-2016 period. I then apply estimated mathematical factors to derive global temperature change values that can be reasonably associated with estimated annual $CH_4/CO_2/N_2O$ emissions for different periods within the overall 67 year timeframe.* The annual values are then aggregated over time to provide cumulative annual surface temperature change values associated with cumulative global $CH_4/CO_2/N_2O$ emissions over the 1950-2016 period, as well as projected future surface temperature change values related to prior GHG emissions.**

* The mathematical factors used in this study are both unity and fractional values, and application of them generates temperature change values that vary over time, relative to those values represented in three graphed curves presented in Figure 2d of Allen et al. (2016).

** These annual and aggregated temperature change values for each estimated yearly global GHG emission are presented in full in the associated spreadsheet set. (See also Figure 2d with grid superimposed.) Extensive documentation concerning the scientific studies and sources that constitute the rationale for the values selected is presented in Sheet 2. For this text document, I note that all demarcated, typically-decadal period emission values for CH_4 (see Sheet 1) are less than the minimum EDGAR v4.2 CH_4 emission values for each associated typically-decadal GHG emission period (see Sheet 2). All period emission values for CO_2 (see Sheet 3) are drawn from the following sources: Table 6.1 [p 486], Page 489, Part 1, Chapter 6, IPCC AR5 (2013); and Peters, G.P. et al. (Dec, 2012) for the 1980-2011 period; Boden et al. (2016) and Figure 6.8 in part 1, Chapter 6, IPCC AR5 (2013) for the 1950-1980 period. All period emission values for N_2O (see Sheet 4), values are based upon material provided in Table 6.9 of Chapter 6, IPCC AR5 (2013) and the EDGAR v4.2 database. For a more complete disclosure of methodology and additional information, see Appendix 1.

Executive Summary

This analysis indicates that total cumulative anthropogenic CH_4, CO_2, and N_2O emissions from 1950-2016 appear to have increased gross annual global surface temperatures approximately 1.5 degrees C (in 2015 and 2016, and likely for 2017 and 2018 as well) above and beyond what such surface temperatures would otherwise have been without such anthropogenic CH_4/CO_2/N_2O emissions over the1950-2016 period. (See Lines 31/67 in Tables A and B below, for year 2016.)

This analysis also indicates that global livestock supply chain-associated GHG emissions (CH_4, CO_2, and N_2O only) are likely responsible for roughly one-fifth (20.5%) of the gross cumulative global surface temperature change over this period. (See Line 40, Table A below, for year 2016.) This value excludes foregone carbon sequestration due to the conversion of forests into pastures and livestock feed row crop production. If foregone carbon sequestration is included into the "equation", the livestock supply chain share of total increases to roughly a quarter (25.5%) of the global surface temperature rise that has occurred since 1950. (See Line 76, Table B below, for year 2016.)[1]

(Note: Excluded from the following analysis are the effects of negative atmospheric climate forcers [or atmospheric cooling agents, such as SO_2]. Also excluded from the following analysis are the effects of other positive climate forcers such as black carbon (BC) and fluorinated gases. Exclusion of LSSC-related black carbon/fluorinated gas emission shares from this analysis likely imparts a further conservative bias to this study. Diesel fuel-associated black carbon emissions and refrigeration-associated fluorinated gas emissions undoubtedly constitute GHG/BC emission effects of global LSSCs that should be incorporated into future analyses.)

1: Goodland, in 2013, argued: "The FAO's analysis [i.e. Gerber, et al. (2013)] also omits counting carbon dioxide from livestock respiration. Yet reality no longer reflects the old model of the carbon cycle, in which photosynthesis (carbon intake) balanced respiration (carbon emission). That model was valid as long as there were roughly constant levels of respiration and photosynthesis on Earth. But in recent decades, respiration has increased exponentially as livestock production has intensified (now totaling more than 60 billion animals raised on land every year). This has been accompanied by large-scale deforestation and forest-burning, in large part to graze livestock and grow crops for them, leading to huge increases in carbon emissions and a dramatic decline in Earth's photosynthetic capacity, and therefore in its capacity to sequester greenhouse gas. As a result, either carbon dioxide released via livestock respiration – or carbon absorption forgone on land set aside for livestock and feed production – should be counted as emissions." (http://www.earthisland.org/journal/index.php/elist/eListRead/fao_underplays_impact_of_livestock_industry_emissions/.) While I remain agnostic (and perhaps even skeptical) concerning Goodland's cattle respiration claim, I concur with Goodland that foregone CO_2 sequestration due to forest conversion into pasture and livestock feed crop production should be included in an overall accounting of livestock GHG emissions and emission-related surface temperature change impacts.

Table A: Summary of Global Surface Temperature Change Values Associated with Global CH_4, CO_2, and N_20, Emissions and Global Livestock-Related GHG Emissions [based solely on LSSC GHG proportions presented in Gerber et al. (2013)]. CO_2 Sequestration Foregone Due To Forest Conversion to Pasture and LFC Production **is excluded**. (Summary Table below copied from Sheet 1 in associated spreadsheet set titled "Anthropogenic GHG Emissions and Global Surface Temperature Change Values, 1950-2016". Line# from Sheet 1.)

Line# Note	2015	2016	2017	2018	2019	2020	2021
16	0.518967	0.523877	0.528611	0.531666	0.531087	0.525344	0.51492
17	0.44	0.44	0.44	0.44	0.44	0.44	0.44
18	0.228346	0.230506	0.232589	0.233933	0.233678	0.231152	0.226565
20	0.892189	0.915205	0.9384	0.960356	0.978961	0.992684	1.001991
21	0.05	0.05	0.05	0.05	0.05	0.05	0.05
22	0.044609	0.04576	0.04692	0.048018	0.048948	0.049634	0.0501
24	0.054023	0.055118	0.056211	0.057208	0.058107	0.058805	0.059243
25	0.53	0.53	0.53	0.53	0.53	0.53	0.53
26	0.028632	0.029212	0.029792	0.03032	0.030797	0.031166	0.031399
28	0.518967	0.523877	0.528611	0.531666	0.531087	0.525344	0.51492
29	0.892189	0.915205	0.9384	0.960356	0.978961	0.992684	1.001991
30	0.054023	0.055118	0.056211	0.057208	0.058107	0.058805	0.059243
31	1.465179	1.4942	1.523222	1.54923	1.568154	1.576833	1.576155
33	0.228346	0.230506	0.232589	0.233933	0.233678	0.231152	0.226565
34	0.044609	0.04576	0.04692	0.048018	0.048948	0.049634	0.0501
35	0.028632	0.029212	0.029792	0.03032	0.030797	0.031166	0.031399
36	0.301588	0.305479	0.309301	0.312271	0.313423	0.311952	0.308064
38	0.301588	0.305479	0.309301	0.312271	0.313423	0.311952	0.308064
39	1.465179	1.4942	1.523222	1.54923	1.568154	1.576833	1.576155
40	20.58%	20.44%	20.31%	20.16%	19.99%	19.78%	19.55%

Table B: Summary For Global Surface Temperature Change Values Associated With Livestock-Related GHG Emissions - CH_4, CO_2, and N_20. CO_2 Sequestration Foregone Due To Forest Conversion to Pasture and LFC Production **is included**. (Summary Table below copied from Sheet 1 in associated spreadsheet set titled "Anthropogenic GHG Emissions and Global Surface Temperature Change Values, 1950-2016". Line# from Sheet 1.)

Line# Note	2015	2016	2017	2018	2019	2020	2021
52	0.518967	0.523877	0.528611	0.531666	0.531087	0.525344	0.51492
53	0.44	0.44	0.44	0.44	0.44	0.44	0.44
54	0.228346	0.230506	0.232589	0.233933	0.233678	0.231152	0.226565
56	0.892189	0.915205	0.9384	0.960356	0.978961	0.992684	1.001991
57	0.132	0.132	0.132	0.132	0.132	0.132	0.132
58	0.117769	0.120807	0.123869	0.126767	0.129223	0.131034	0.132263
60	0.054023	0.055118	0.056211	0.057208	0.058107	0.058805	0.059243
61	0.53	0.53	0.53	0.53	0.53	0.53	0.53
62	0.028632	0.029212	0.029792	0.03032	0.030797	0.031166	0.031399
64	0.518967	0.523877	0.528611	0.531666	0.531087	0.525344	0.51492
65	0.892189	0.915205	0.9384	0.960356	0.978961	0.992684	1.001991
66	0.054023	0.055118	0.056211	0.057208	0.058107	0.058805	0.059243
67	1.465179	1.4942	1.523222	1.54923	1.568154	1.576833	1.576155
69	0.228346	0.230506	0.232589	0.233933	0.233678	0.231152	0.226565
70	0.117769	0.120807	0.123869	0.126767	0.129223	0.131034	0.132263
71	0.028632	0.029212	0.029792	0.03032	0.030797	0.031166	0.031399
72	0.374747	0.380526	0.386249	0.391021	0.393698	0.393352	0.390227
74	0.374747	0.380526	0.386249	0.391021	0.393698	0.393352	0.390227
75	1.465179	1.4942	1.523222	1.54923	1.568154	1.576833	1.576155
76	25.58%	25.47%	25.36%	25.24%	25.10%	24.95%	24.76%

Line# Notes from Sheet 1 associated with Table A and Table B above:

16/52: Select Global Surface Temperature Change Values Associated With Cumulative Anthropogenic Methane Emissions (1950-2016); Degrees C

17/53: Livestock-Related (Enteric, Manure, and Other) Share [4/9 approx] Of Total Methane Emission Pulse: Based on Gerber et al. (2013), Page 15. [Gerber et al. include "upstream" and "downstream" CH_4 emission sources in the livestock supply chain. (Enteric and manure sources are considered neither "upstream" nor "downstream" -- they are classified within the "animal production unit" category - see page 7.]

18/54: Global Surface Temperature Change Values Associated With Cumulative Anthropogenic Livestock-Related CH_4 Emissions (1950-2016), in Degrees C. Livestock Supply Chains are associated with 44% of Total Anthropogenic CH_4 Emissions in year 2005 -- Source: Gerber, et al. (2013), page 15 and Sheet 1

20/56: Select Global Surface Temperature Change Values Associated With Cumulative Anthropogenic Carbon Dioxide Emissions (1950-2016); Degrees C

21: Livestock-Related Share [1/20 approx] Of Total Carbon Dioxide Emission Pulse -- Source: Gerber et al. (2013), page 15.

22: Global Surface Temperature Change Values Associated With Cumulative Anthropogenic Livestock-Related CO_2 Emissions (1950-2016), in Degrees C. Livestock Supply Chains are associated with 5% of Total Anthropogenic CO_2 Emissions in year 2005 -- Source: Gerber, et al. (2013), page 15 and Sheet 3

24/60: Select Global Surface Temperature Change Values Associated With Cumulative Anthropogenic Nitrous Oxide Emissions (1950-2016); Degrees C

25/61: Livestock-Related Share [53/100 approx] Of Total Nitrous Oxide Emission Pulse – Source: Gerber et al. (2013), page 15.

26/62: Global Surface Temperature Change Values Associated With Cumulative Anthropogenic Livestock-Related N_2O Emissions (1950-2016), in Degrees C. Livestock Supply Chains are associated with 53% of Total Anthropogenic N_2O Emissions in year 2005 -- Source: Gerber, et al. (2013), page 15 and Sheet 4

28/64: Global Surface Temperature Change Values Associated With Cumulative Anthropogenic CH_4 Emissions (1950-2016), in Degrees C.

29/65: Global Surface Temperature Change Values Associated With Cumulative Anthropogenic CO_2 Emissions (1950-2016), in Degrees C.

30/66: Global Surface Temperature Change Values Associated With Cumulative Anthropogenic N_20 Emissions (1950-2016), in Degrees C.

31/67: Global Surface Temperature Change Values Associated With Cumulative Anthropogenic Emissions (1950-2016), in Degrees C [CH_4+CO_2+N_2O]

33/69: Global Surface Temperature Change Values Associated With Cumulative Anthropogenic Livestock-Related CH_4 Emissions (1950-2016), in Degrees C. Livestock Supply Chains are associated with 44% of Total Anthropogenic CH_4 Emissions in year 2005 -- Source: Gerber, et al. (2013), page 15 and Sheet 1

34: Global Surface Temperature Change Values Associated With Cumulative Anthropogenic Livestock-Related CO_2 Emissions (1950-2016), in Degrees C. Livestock Supply Chains are associated with 5% of Total Anthropogenic CO_2 Emissions in year 2005 -- Source: Gerber, et al. (2013), page 15 and Sheet 3

35/71: Global Surface Temperature Change Values Associated With Cumulative Anthropogenic Livestock-Related N_20 Emissions (1950-2016), in Degrees C. Livestock Supply Chains are correlated with 53% of Total Anthropogenic N_20 Emissions in year 2005 -- Source: Gerber, et al. (2013), page 15 and Sheet 4

36/72: Global Surface Temperature Change Values Associated With Cumulative Anthropogenic Livestock-Related Emissions (1950-2016), in Degrees C [CH_4+CO_2+N_2O]

38/74: Global Surface Temperature Change Values Associated With Cumulative Anthropogenic Livestock-Related Emissions (1950-2016), in Degrees C [CH_4+CO_2+N_2O]

39/75: Global Surface Temperature Change Values Associated With Cumulative Anthropogenic Emissions (1950-2016), in Degrees C [CH_4+CO_2+N_2O]

40/76: Livestock Supply Chain Emission-Related Temperature Change Values[CH_4+CO_2+N_2O] As A Proportion [%] of Total Cumulative Anthropogenic CH_4+CO_2+N_2O Emission-Related Temperature Change Values (1950-2016 period)

57: Livestock-Related Share [132/1000 approx] Of Total Carbon Dioxide Emission Pulse. This value is based on Gerber et al. (2013), page 15 and Goodland and Anhang, (2009, pages 11 and 15). (The Gerber value of 5% is added to estimated foregone CO_2 sequestration value of 8.2%. The 8.2% value is derived from the estimated foregone CO_2 sequestration value presented in Goodland and Anhang [2009], divided by the global annual mean CO_2 emission value for 2000-

2010, derived from Table 6.1[page 486], Chapter 6, Part 1, IPCC, 2013. [2.672 Gt/32.6 Gt=8.2%. 32.6 Gt is 8.9 GtC multiplied by 3.667, which yields 32.6 GtCO_2.]

58: Global Surface Temperature Change Values Associated With Cumulative Anthropogenic Livestock-Related CO_2 Emissions (1950-2016), in Degrees C. Livestock Supply Chains are associated with 13.2% of Total Anthropogenic CO_2 Emissions. This value is based on Gerber et al. (2013) [page 15] and Goodland and Anhang (2009, pages 11, 15). (The Gerber value of 5% is added to estimated foregone CO_2 sequestration value of 8.2%. The 8.2% value is derived from the estimated foregone CO_2 sequestration value presented in Goodland and Anhang [2009], divided by the global annual mean CO_2 emission value for 2000-2010, derived from Table 6.1[page 486], Chapter 6, Part 1, IPCC, 2013. [2.672 Gt CO_2e/32.6 GtCO_2=8.2%. 32.6 GtCO_2 is 8.9 GtC multiplied by 3.667.]

70: Global Surface Temperature Change Values Associated With Cumulative Anthropogenic Livestock-Related CO_2 Emissions (1950-2016), in Degrees C. Livestock Supply Chains are associated with 13.2% of Total Anthropogenic CO_2 Emissions. This value is based on Gerber et al. (2013) [page 15] and Goodland and Anhang (2009, pages 11, 15). (The Gerber value of 5% is added to estimated foregone CO_2 sequestration value of 8.2%. The 8.2% value is derived from the estimated foregone CO_2 sequestration value presented in Goodland and Anhang [2009], divided by the global annual mean CO_2 emission value for 2000-2010, derived from Table 6.1[page 486], Chapter 6, Part 1, IPCC, 2013. [2.672 Gt CO_2e/32.6 GtCO_2=8.2%. 32.6 GtCO_2 is 8.9 GtC multiplied by 3.667.]

Additional Notes:

Gerber, P.J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A. & Tempio, G. 2013. Tackling climate change through livestock – A global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations (FAO), Rome. [Page 15]

Goodland and Anhang, 2009, World Watch, Nov/Dec, 2009, page 11 and 13, "Livestock and Climate Change", World Watch Magazine, November/December, Volume 22, No. 6

“Short-Lived Climate Pollution”, R.T. Pierrehumbert, Annu. Rev. Earth Planet. Sci. 2014. 42:341–79, page 374-375

“New use of global warming potentials to compare cumulative and short-lived climate pollutants,” Myles R. Allen, Jan S. Fuglestvedt, Keith P. Shine, Andy Reisinger, Raymond T. Pierrehumbert and Piers M. Forster, Nature Climate Change, PUBLISHED ONLINE: 2 MAY 2016 | DOI: 10.1038 /NCLIMATE 2998, Figure 2d

Peters, G. P., et al., 2013: The challenge to keep global warming below 2°C. Nature Clim. Change, 3, 4–6.

Boden et al. 2016; Global CO2 Emissions from Fossil-Fuel Burning, Cement Manufacture, and Gas Flaring: 1751-2013 April 19, 2016 Source: Tom Boden , Bob Andres Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory and Gregg Marland, Research Institute for Environment, Energy Economics, Appalachian State

Appendix A: Study Methodology

The method used to derive numerical values for the lines (16/52, 20/56, and 24/60) on both Table A and Table B (pdf text document) and the spreadsheet set tables near the top of Sheet 1 is presented below.

Values on Lines 81-85 (Sheet 1), Lines 1-4 (Sheet 3), and Lines 1-4 (Sheet 4) are estimated future annual global surface temperature change (EFAGSTC) values associated with year 2011 global GHG pulse emissions for CH_4, CO_2, and N_2O. These numerical values are estimated through superimposition of a grid on Figure 2d. (See Figure 2d with grid superimposed.) The graphs in figure 2d are derived largely through use of the GTP metric. (See Allen et al. [2016].)

The year 2011 EFAGSTC values for CH_4 are applied for the years 2006-2016. The year 2011 EFAGSTC values for CO_2 and N_2O are applied for the years 2011-2016.

For earlier typically-decadal periods (going back to 1950), EFAGSTC values for CH_4, CO_2, and N_2O are reduced relative to year 2011 EFAGSTC-associated values by multiplying the 2011 EFAGSTC-associated values by a factor that corresponds to the fraction of that decade's GHG emission (in terms of mass) *relative to the year 2011 GHG emission* (in terms of mass, as specified by Allen et al. [2016]). These factors are based upon information from a number of different authoritative sources that provide estimated mean anthropogenic GHG emission values (in terms of mass) for the pre-2011 decadal periods. (See notes in Sheet 2 of spreadsheet set.) The factors (which are correlated with estimated emission values for a particular typically decadal period) are smallest in 1950 and the increase over the 1950-2016 period is modeled in quantum fashion until achieving unity during the 2006-2016 period for CH_4 and 2011-2016 period for CO_2 and N_2O. This reduction is calculated and represented in lines 87-119 (Sheet 1), 6-44 (Sheet 3), and 6-44 (Sheet 4).

All the EFAGSTC values for associated estimated annual CH_4, CO_2, and N_2O emissions during the 1950-2016 are presented on lines 125-193 (Sheet 1), 52-118 (Sheet 3), and 52-118 (Sheet 4). All of these annual EFAGSTC values are added together using the automatic spreadsheet sum function on line 195 (Sheet 1), line 120 (Sheet 3), and line 120 (Sheet 4). The summed 2016 value for CH_4 over the complete 1950-2016 period is located in cell BP 195 of Sheet 1. The summed 2016 values for CO_2 and N_2O are located in cells BP 120 of Sheets 3 and 4.