Methane Emissions and Greenhouse Gas Accounting: A Case Study of a New Approach Pioneered by the State of New York

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Abstract:

Greenhouse gas (GHG) inventories are a critical tool for understanding how to reduce emissions and meet climate targets, but most inventories understate the importance of methane as an agent of global warming on the time scale of the next few decades. In 2019, New York State passed legislation that mandates a novel approach for considering methane, requiring inclusion of emissions from outside of the boundaries of the State if they are associated with energy use in the State, and requiring comparison of methane with carbon dioxide over a 20-year time frame. The new legislation also mandates a 40% reduction in GHG emissions by 2030 and an 85% reduction by 2050, relative to 1990 emissions. This paper compares estimates for emissions calculated using this new approach with those previously reported for New York State. The previously reported estimates indicated a decrease in emissions since 1990, but this is not true when methane is included using the new protocol: decreases in carbon dioxide since 1990 have been matched by increases in methane from greater use of natural gas. The residential and commercial sectors are major sources of GHGs, largely driven by natural gas for heating. Emissions from consumption of petroleum products in the transportation sector are also important, followed by emissions from the use of natural gas to produce electricity. To meet the 40% reduction by 2030, a large-scale effort toward electrification of heating and transportation and a greatly expanded use of renewable energy for electricity production will be required.

Keywords:

Greenhouse gas emissions; greenhouse gas inventory; CLCPA; methane emissions; climate and energy policy

Carbon dioxide is widely recognized as the most important driver of climate change, certainly over long time scales. Less commonly acknowledged, methane too is a major greenhouse gas (GHG) with a radiative forcing of approximately 1 W m^{-2} when indirect effects are included, 60% of the radiative forcing of 1.66 W m^{-2} for carbon dioxide (IPCC 2013). Radiative forcing by all other GHGs is less.

Methane and carbon dioxide affect the climate on fundamentally different time scales. The climate system responds far more quickly to changes in methane (Shindell et al. 2012), and reducing methane emissions provides a possible path to reaching the United Nations COP21 target of keeping the Earth well below a 2^o C increase in global temperature, as compared to the pre-industrial baseline (Collins et al. 2018). Reducing carbon dioxide emissions is critical, since carbon dioxide emitted today will continue to influence the climate for centuries to come. However, lowering carbon dioxide emissions alone is not sufficient to reach the COP21 target because of lags in the response of the climate system to those reductions. Methane has a half-life in the atmosphere of only 12 years or so (IPCC 2013), and so methane emissions are far less important to the far-distant climate, unless warming over the coming few decades leads to tipping points and fundamental changes in the climate system. An important aspect to consider: the consequences of climate disruption over the next few decades could potentially cause massive social disruption, caused by food and water shortages and more frequent extreme weather events, among other factors.

Greenhouse gas inventories provide information to policy makers that is essential for making decisions for pathways to reduce GHG emissions, but currently inventories tend to under-state the importance of methane over the coming several decades. Almost all governments in the world rely on the inventory framework outlined originally in the Kyoto Protocol in 1997, with only modest adjustments over the years since. This accounting approach compares the heat-trapping effect of methane with carbon dioxide using the Global Warming Potential (GWP) considered over a 100-year time frame. This greatly under-represents the importance of methane as a GHG over shorter time periods (Howarth 2014), which is a critical flaw since with current emissions the Earth is on target to reach the COP21 target within the next 20 to 30 years (Shindell et al. 2012). The 100-year time frame established by the Kyoto Protocol is arbitrary, and the IPCC (2013) has recommended choosing a time frame commensurate to the concern. I have suggested that GHG inventories separately report carbon dioxide and methane emissions, using a 20-year GWP time frame, so that policy makers and the public can fully evaluate the importance of both gases when considering fossil fuel reduction strategies (Howarth 2014).

In July of 2019, the State of New York enacted the Climate Leadership and Community Protection Act (CLCPA 2019). This broad-ranging law sets ambitious goals for statewide GHG emission reductions of 40% by 2030 and 85% by 2050 compared to 1990 emissions. It also mandates a new approach for GHG accounting, one that allows policy makers to better evaluate the importance of both carbon dioxide and methane emissions. Emissions for all major GHGs are to be reported individually, in the common unit of carbon-dioxide equivalents (CO_2-eq); methane emissions are to be evaluated over a 20-year integrated time horizon, rather than the 100-year approach; and emission estimates are to include those that occur outside of the boundaries of New York State if they are associated with the use of energy within the State (CLCPA 2019). This last provision allows residents and policy makers to fully evaluate the consequences on climate of energy use within the State of New York. These provisions were included in GHG analyses adopted recently by Cornell University (2016) and Tompkins County (2016) in central New York State. The CLCPA recognizes the importance of emissions from agriculture, but specifically excludes these sources from GHG accounting and targeted reductions, choosing to focus on fossil fuel use, industrial product emissions, and waste-stream emissions. The CLCPA includes nitrous oxide and fluorocarbons in addition to carbon dioxide and methane, but does not include emissions of sulfur or black carbon.

In this paper, I estimate GHG emissions for the State of New York in 1990 and in 2015 using the new CLCPA guidelines, and compare these with emission estimates as previously reported. I focus on energy systems and on emissions of carbon dioxide and methane, since these dominate overall GHG emissions in New York State. My approach uses data on statewide annual energy consumption by type of fuel (EIA 2016) and emissions per energy use by fuel type. Fuel types considered are coal, natural gas, and the sum of petroleum products, which includes gasoline, diesel, jet fuel, and heating oil. Emission factors are based on a full lifecycle analysis regardless of where the emissions occur, as mandated by the CLCPA (2019); see Table 1 and Appendix for information on the emission factors used. Methane emissions for all fossil fuels are expressed as CO_2-equivalents using a 20-year GWP of 86, which includes indirect climate feedbacks (IPCC 2013).

Emissions from coal, petroleum products, and natural gas for 1990 and 2015 estimated using the CLCPA approach are presented in Table 2. Carbon dioxide emissions for imported electricity are as reported by New York State (NYSERDA 2018); methane emissions from imported electricity are estimated from the carbon-dioxide emissions and assuming that coal was the fossil fuel used to produce it in 1990 and natural gas in 2015 (as was the case for electricity produced within the State at those two times). Also shown are emissions for waste streams, including waste incineration, landfills, and municipal wastewater treatment plants; for carbon dioxide, these are as reported by the State (NYSERDA 2018); methane emissions are also from the State (NYSERDA 2018) but are corrected using the 20-year GWP value of 86 rather than the 100-year value of 25 used by the State. Even for the 100 year horizon, the value of 25 is low relative to 34 presented in the most recent IPCC (2013) synthesis report.

Total GHG emissions from energy use are little changed in 2015 as compared to 1990, 309 Tg CO_2-eq yr^{-1} versus 315 Tg CO_2-eq yr^{-1}, respectively (Table 2). However, direct carbon dioxide emissions in 2015 are 14% less than in 1990 while methane emissions are 29% greater (Table 2). Reduced use of both coal and petroleum products contributed to the decreased carbon dioxide emissions, while the increase in methane emissions is driven by a large increase in consumption of natural gas.

Total emissions from waste streams saw relatively little change between 1990 and 2015 (Table 2); these emissions are dominated by methane from landfills and wastewater treatment plants, with carbon dioxide emissions from incineration of trash being a relatively minor source (NYSERDA 2018). The State has estimated emissions of carbon dioxide from industrial manufacturing processes (such as limestone use and production of cement) as well as emissions of nitrous oxide and various fluorocarbons from multiple sources in this sector as totaling approximately 8 Tg CO_2-eq yr^{-1} in 1990 and 14 Tg CO_2-eq yr^{-1} in 2015. Combining these values with those from fossil fuels and waste streams (Table 2), GHG emissions for New York State equaled 373 Tg CO_2-eq yr^{-1} in 1990 and 369 Tg CO_2-eq yr^{-1} in 2015. A robust conclusion is that total emissions have changed little over the past 25 years.

The estimates presented in this paper, calculated using the criteria mandated by the CLCPA (2019), are dramatically different than those currently reported by the State of New York (NYSERDA 2018). For carbon dioxide emissions from fossil fuels, the State reports emissions that are lower than those presented in Table 2, that is 202 Tg CO_2 yr^{-1} in 1990 and 177 Tg CO_2 yr^{-1} in 2015 (NYSERDA 2018), compared to my estimates of 226 and 194 Tg CO_2 yr^{-1} respectively (Table 2). I believe my estimates more accurately reflect statewide GHG emissions since they are based directly on fossil fuel consumption data, as opposed to the algorithms used by the State, which estimate emissions based on indirect data such as number of vehicle miles driven and number of households using different types of heating. This approach seems to underestimate energy consumption in the State by approximately10%.

Of greater significance, the estimates for methane emissions from fossil fuels based on the CLCPA (2019) approach presented here are more than 40-times higher than the values reported by New York State. For 2015 using the CLCPA approach, carbon dioxide makes up 63% of total emissions from fossil fuels, and methane 37% (Table 2), while in the estimates reported by the State, carbon dioxide was 98.5% of emissions and methane just 1.5% (NYSERDA 2018). The difference is due to three factors: 1) the higher 20-year GWP mandated by the CLCPA; 2) a full accounting for lifecycle methane emissions associated with fuel use even if a portion of the emissions occur outside of the State; and 3) a higher methane emission factor based on the best and most recent literature; the traditional approach used by the State relied on outdated and low estimates for methane emission, using values from a non-peer-reviewed, joint EPA-industry study in the 1990s (Howarth 2014).

The CLCPA (2019) mandates that total GHG emissions in New York State should be reduced by at least 40% by 2030 relative to emissions in 1990 and by at least 85% by 2050, excluding agricultural emissions. That is, relative to the estimated total GHG emissions of 373 Tg CO_2-eq yr^{-1} in 1990, emissions should be 224 Tg CO_2-eq yr^{-1} or less in 2030, a reduction of at least 149 Tg CO_2-eq yr^{-1}. By 2050, emissions should be reduced by 317 Tg CO_2-eq yr^{-1} or more, to no more than 56 Tg CO_2-eq yr^{-1}.

Figure 1 shows total GHG emissions for fossil-fuel energy statewide by sector and by type of fuel in 2015, both as reported by New York State (NYSERDA 2018) and as estimated using the CLCPA (2019) guidance, showing both carbon dioxide and methane emissions. The estimates from the CLCPA guidance are based on Table 2; values are apportioned to sectors using the portions for each fuel contributing to carbon dioxide emissions from Table S-4 in NYSERDA (2018).

Viewed through the lens of the traditional GHG accounting (NYSERDA 2018), emissions from using petroleum products (gasoline, diesel, jet fuel) for transportation dominate (Figure 1). Emissions from natural gas in the residential and commercial sector and to generate electricity are important, but substantially less so. This traditional reporting is completely dominated by carbon dioxide emissions.

The take-home message from the CLCPA-based accounting is quite different: emissions from natural gas dominate, particularly in the residential and commercial sectors, with methane contributing somewhat more than carbon dioxide to these emissions (Figure 1). Most of the energy use in residences in New York State is for space heating and domestic hot water, and natural gas is the primary fuel used for this (EIA 2009). Petroleum use for transportation is the next largest source of emissions, followed by electricity production, which as with the residential and commercial sector, is dominated by natural gas. To meet the CLCPA 2030 target of a 40% emissions decrease will require a focus on greatly reducing the use of natural gas in the residential and commercial sector and petroleum products in transportation. To date, the State has focused little attention on GHG emissions from these sectors, and has instead prioritized reducing the use of fossil fuels to produce electricity.

Electrification of heating (ground- and air-sourced heat pumps) and transportation (electric vehicles) provides a pathway to meeting the GHG-reduction mandates of the CLCPA (Jacobson et al. 2013). Heat pumps extract energy from the environment, allowing the delivery of far more heat energy than the electrical energy used to power the pumps. As a result, converting from the use of natural gas to a modern heat pump will reduce GHG emissions even if the heat pump is powered by electricity generated from fossil fuels (Hong and Howarth 2016). Similarly, electric vehicles reduce overall emissions compared to gasoline and diesel powered vehicles, even if fossil fuels are used to produce the electricity, because of the greater efficiency of the electric vehicles (Jacobson et al. 2013). Consequently, to reduce overall GHG emissions for New York State, electrification of heating and transportation systems must proceed as quickly as possible, even if this precedes reduction of fossil fuels to produce electricity.

The guidelines for GHG accounting enacted in the CLCPA (2019) do not necessarily require policy makers to treat carbon dioxide and methane as equally important. Rather, the guidelines specify that estimates for both gases be presented clearly, with the methane emissions compared to carbon dioxide over a 20-year time frame. It is then up to decision makers to weigh the shorter-term and long-term consequences of the two gases in developing policies to achieve the stated climate protection goals. For New York State, our political leaders chose to weigh methane emissions over the 20-year time period as quite important, given the COP21 targets and the current rate of global warming. This is a substantial step forward from the GHG accounting mechanisms originally set up under the Kyoto protocol of 1997. Our understanding of the importance of methane as a contributor to global warming has grown tremendously since then (Shindell et al. 2012; IPCC 2013). I am pleased to see the State of New York chart a new way forward for GHG accounting.

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Appendix: Supporting information on emission factors presented in Table 1.

Carbon dioxide: Emission factors for carbon dioxide from all fossil fuels are based on high-heating values, are from Hayhoe et al. (2002), and were used in Howarth et al. (2011).

Methane from coal and petroleum products: For methane emissions for coal, I use a factor of 0.185 g CH_4 MJ^{-1} based on data for average methane emissions from the coal industry and total coal production in the United States in 1990 (Table 2 of IPCC 1996), assuming an energy content of 27 MJ kg^{-1} for coal (Howarth et al. 2011). This estimate is robust for 1990. It may not well represent methane emissions from coal in 2015, but by 2015, the use of coal in New York State was minimal (Table 2; Figure 1). For methane emissions from petroleum products, I use an emission factor of 0.093 g CH_4 MJ^{-1} (NETL 2008; Howarth et al. 2011). This value is fine for 1990 but may underestimate emissions in 2015 due to increased petroleum production from shale oil (Howarth 2019).

Methane emissions from natural gas: In this paper, I use an emission of 3.6% of the methane in natural gas that is consumed, based on full lifecycle analysis from production through delivery to final consumer. As noted in the main text, the CLCPA (2019) mandates such a full lifecycle approach, including emissions outside of New York State that are associated with use of natural gas within the State. To derive the 3.6% emission factor, I sum an estimate of 14.1 Tg CH_4 yr^{-1} emissions from production, gathering, processing, transmission, and storage of natural gas (top-down estimate from Alvarez et al. 2018) and an estimate of 4.4 Tg CH_4 yr^{-1} for downstream distribution emissions from the recent analysis of Plant et al. (2019). The Alvarez et al. (2018) estimate is for 2015 and is based on a compilation of many recent studies in several gas-producing regions in the United States; note that their top-down estimate used here is 11% greater than their bottom-up estimate. I use the top-down estimate since several studies have suggested bottom-up estimates underestimate total emissions (Miller et al. 2013; Howarth 2014; Vaugn et al. 2018). This may still be conservative, as Alvarez et al. (2018) excluded from their top-down analysis several studies that showed very high fugitive emissions (ie, Caulton et al. 2014; Schneising et al. 2014). Plant et al. (2019) analyzed downstream, distribution emissions from natural gas systems across the major metropolitan area of the northeastern United States, stretching from Boston to Washington, DC, concluding that emissions are 9.5 times greater than the gridded estimates from the US Environmental Protection Agency. Scaled to the entire United States, this yields an estimate for distribution emissions of 4.4 Tg per year. This estimate may or may not apply to the entire United States, but it well applies to New York State. I therefore conservatively estimate total, full-lifecycle methane emissions from natural gas in the United State to be 18.5 Tg per year in 2015, summing the upstream and midstream emissions derived from Alvarez et al. (2018) with the downstream emission estimate derived from Plant et al. (2019). Based on consumption of natural gas in the United States in 2015 (550 Tg CH_4 yr^{-1}, reported as 27.2 trillion cubic feet; EIA 2019), and assuming 93% of natural gas is methane (Schneising et al. 2014), 3.6% of natural gas consumption is emitted to the atmosphere. In a recent reanalysis of global trends in methane emissions based on changes in the ^{13}C content of methane in the atmosphere over time, I concluded that it is likely that at least 3.5% of new methane emissions from natural gas production over the past decade was emitted to the atmosphere (Howarth 2019). That estimate is equivalent to approximately 4% of emissions when scaled to consumption, but has a large degree of uncertainty. Nonetheless, the 3.6% emission factor relative to consumption used in this paper is highly conservative.

Table 1. Emission factors for carbon dioxide and methane.

Fossil fuel type and greenhouse gas	Emission factor	References and notes
Coal		
Carbon dioxide	92 g CO_2 MJ^{-1}	High-heating value; Hayhoe et al. (2002); Howarth et al. (2011)
Methane	0.185 g CH_4 MJ^{-1}	Calculated from average methane emissions from coal production and total coal production in the U.S. in 1990; Table 2 of IPCC (1996)
Petroleum products		
Carbon dioxide	73 g CO_2 MJ^{-1}	High-heating value; Hayhoe et al. (2002); Howarth et al. (2011)
Methane	0.093 g CH_4 MJ^{-1}	NETL (2008); Howarth et al. (2011)
Natural gas		
Carbon dioxide	55 g CO_2 MJ^{-1}	High-heating value; Hayhoe et al. (2002); Howarth et al. (2011)
Methane	3.6%	Calculated as percentage total consumption, using full lifecycle; upstream and midstream emissions based on top-down estimates of Alvarez et al. (2018); downstream distribution estimates based on Plant et al. 2019); natural gas consumption for 2015 from EIA (2019).

See Appendix for further discussion and supporting details.

Table 2. Greenhouse gas emissions for the State of New York from energy consumption and waste streams (Tg CO_2-eq per year)

		Carbon Dioxide	Methane*	Total
1990				
	Coal	34	5.9	40
	Petroleum	138	15	153
	Natural gas	52	68	120
	Imported electricity	1.6	0.3	1.9
	Total for energy	226	89	315
	Wastes	1.2	49	50
	TOTAL	227	138	365
2015				
	Coal	4.0	0.7	4.7
	Petroleum	101	11	112
	Natural gas	81	95	176
	Imported electricity	8.0	8.6	17
	Total for energy	194	115	309
	Wastes	3.4	43	46
	TOTAL	197	158	355

*Methane emissions calculated using a 20-year GWP of 86 (IPCC 2013).

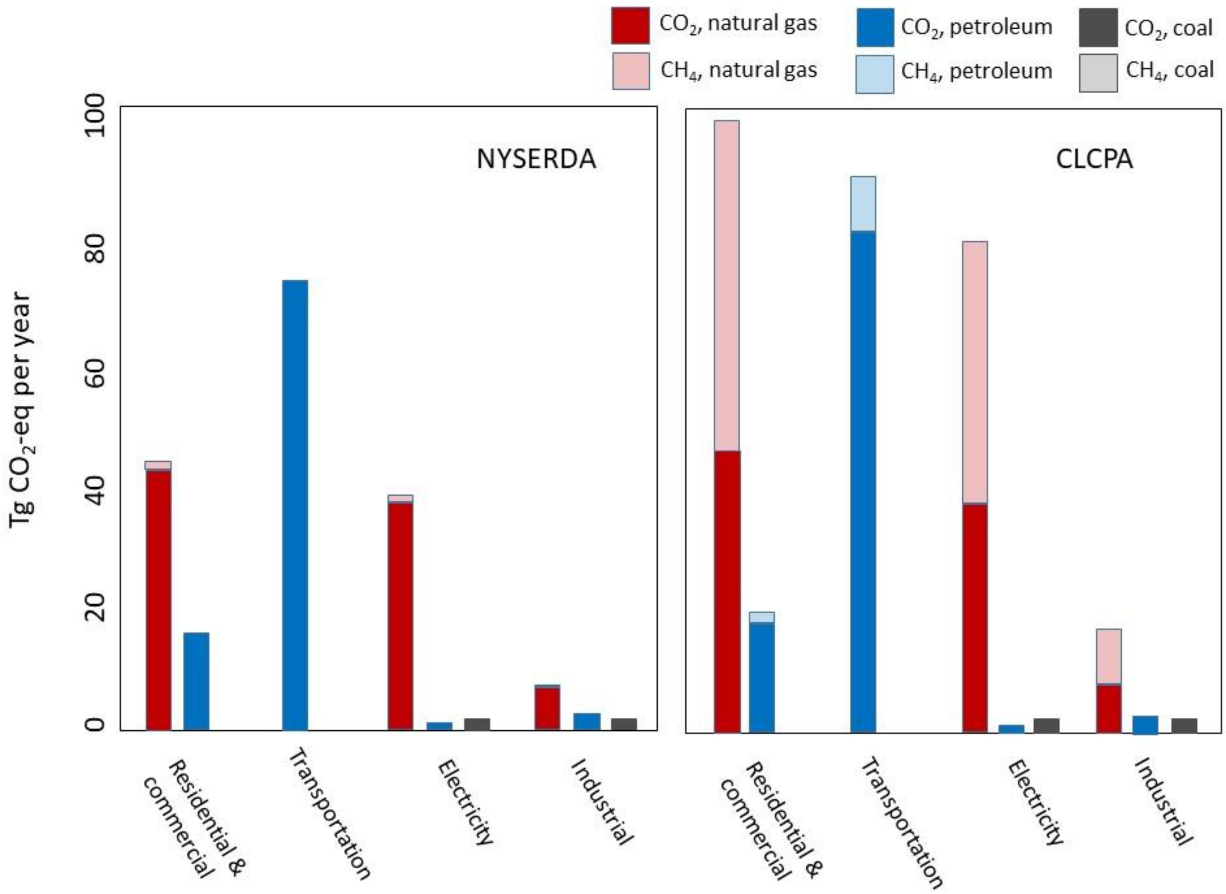

Figure 1. Greenhouse gas emissions by sector and fuel type for fossil fuel energy use in New York State for 2015. Estimates reported by the State are shown on the left ("NYSERDA"). Estimates calculated using the CLCPA guidelines and as developed in this paper are shown on the right ("CLCPA"). Direct emissions of carbon dioxide are illustrated in dark colors. Methane emissions reported as CO_2-equivalents are shown in lighter colors. The NYSERDA estimates use a GWP of 25 for methane. The CLCPA estimates are based on a GWP of 86 for methane. Imported electricity is included in the electricity sector.