Implications of Using Different GWP Time Horizons

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Introduction

Global warming potential (GWP) is a climate metric that is currently being extensively discussed by many CMR stakeholders, including policymakers, regulators, consumers, researchers, and industry representatives. Some are pushing for the use of a 20-year GWP time horizons as opposed to the currently accepted 100-year time horizons. For methane, this change inflates the reported impact that each pound of methane released to the atmosphere has on climate by a factor of 3 (86 vs. 28) compared to a pound of carbon dioxide. The switch to a 20-year time horizon by policymakers can have some important negative consequences for the natural gas industry, and for climate change itself. These include an accelerated push toward electrification of the residential sector and use of non-methane-based renewables (i.e., not renewable natural gas) for energy production, two initiatives that specifically target natural gas utilities.

The purpose of this white paper is to provide background information on what goes into the GWP calculations (and uncertainties), discuss one alternative climate metric (global temperature potential), and to show some potential negative impacts of using a 20-year GWP time horizon for setting policies and standards.

Climate Metrics

Climate metrics are used to put the presence of atmospheric greenhouse gases (gases that absorb radiation energy from the sun), such as methane, into perspective with another greenhouse gas such as carbon dioxide. These metrics are a simplification of many complex parameters with the goal of presenting various greenhouse gases on the same "playing field" and to simplify the representation of how climate may be influenced by emissions of different gases.

Metric calculations involve several complex modeled parameters and assumptions with inherent uncertainty associated with each parameter. The important thing to note is that metrics such as GWP were initially developed to simplify communication of a complex problem and illustrate the difficultly of that problem [1, 2]. They were not originally developed by scientists to be used to set policy, regulations, or standards, however as shown below these metrics were quickly adopted for doing just that. Current versions of the IPCC report now specifically state that the GWP time horizon used should be based on policy goals.

Global Warming Potential

GWP is defined "as the time-integrated radiative forcing due to a pulse emission of a given component relative to a pulse emission of an equal mass of CO_2." Since the calculation is time integrated, the GWP of short-lived atmospheric species such as methane will decrease relative to long-lived species like CO_2 as the time integration, called the time horizon, increases from 20 to 100 years. GWP is calculated from radiative forcing so the complexities and uncertainties involved in calculating radiative forcing are included, and it is not directly tied to a known temperature change that would occur from having one species in the atmosphere vs. another. GWP was presented in the IPCC First Assessment Report[3], with the caveat that there was no "universally accepted methodology" for representing all the relevant factors within a single GWP number.

GWP is a simplified representation of the impact on radiative forcing, which in turn influences temperature, but it is not a direct interpretation of temperature change. The IPCC fifth assessment (AR5) authors indicate that the name 'Global Warming Potential' may be somewhat misleading, and 'relative cumulative forcing index' would be more appropriate[4].

As an example, a GWP of 28 (i.e. the 100-year number for methane) for any species or time frame means that the impact to overall radiative forcing for every 1 pound of methane in the atmosphere is equivalent to 28 pounds of CO_2. GWP is used widely to normalize all greenhouse gases, such as methane to CO_2 referred to as CO_2e (CO_2 equivalent) by multiplying the mass of methane by the GWP for methane. The use as a multiplier is what makes GWP so important in regulatory discussions.

Methane is a potent greenhouse gas in the short term compared to CO_2. With a lifetime of approximately 12 years, nearly all of the absolute global warming potential (AGWP) for methane, which is the global warming potential of methane alone before it is compared to or divided by the AGWP of CO_2, occurs during the first few decades after it is emitted to the atmosphere, as shown in **Figure 1**. The AGWP for CH_4 (yellow curve) reaches a constant level after about five decades. In contrast, the AGWP for a long-lived species such as CO_2 continues to increase for centuries. Thus, the ratio of AGWP for CH_4 and AGWP for CO_2, which defines the GWP for CH_4 (black curve), falls quickly with the increasing time horizon of interest.

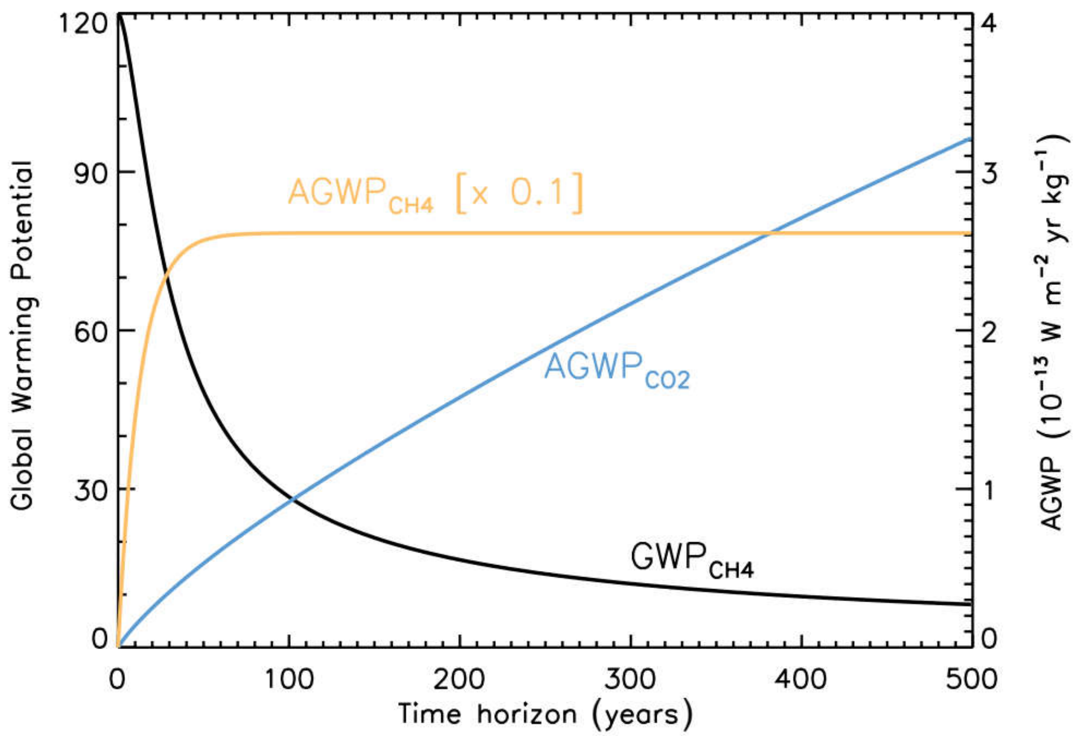

Figure 1: Time Horizon Impact on Methane AGWP and GWP (Figure 8.29 in Myhre et al. 2013[4]).

Global Temperature Potential (GTP)

Another climate metric, Global temperature potential (GTP), introduced in 2005, is the change in global mean surface temperature at a particular point in time in response to an emission pulse relative to that of CO_2 [4]. Unlike GWP, GTP is focused on the integrated radiative impact for a single year, therefore since methane is a short-lived atmospheric species, GTP for methane increases each year for the first 12 years (the atmospheric lifetime of methane) then decreases each year after that. The GTP at 20 years (GTP_{20}) is therefore the exact potential for a temperature change driven by a ton of methane that was emitted 20 years ago, compared to a ton of CO_2 that was emitted 20 years ago.

Some believe that GTP more accurately represents the impact of short-lived species on longer climate time scales (100+ years) since the impact is greater for shorter time frames and lesser for longer time frames, as the calculation is not integrated over longer time frames (or horizons) such as with GWP. Recognizing the issues with GWP, IPCC AR5 provides values for both GWP and GTP (**Figure 2**) should others wish to use that metric rather than GWP.

Table 8.7: GWP and GTP with and without inclusion of climate-carbon feedbacks (cc fb) in response to emissions of the indicated non-CO_2 gases (climate-carbon feedbacks in response to the reference gas CO_2 are always included).

	Lifetime (year)		GWP_{20}	GWP_{100}	GTP_{20}	GTP_{100}
CH_4	12.4[a]	No cc fb	84	28	67	4.3
		With cc fb	86	34	70	11
HFC-134a	13.4	No cc fb	3710	1300	3050	201
		With cc fb	3790	1550	3170	530
CFC-11	45.0	No cc fb	6900	4660	6890	2340
		With cc fb	7020	5350	7080	3490
N_2O	121.0[a]	No cc fb	264	265	277	234
		With cc fb	268	298	284	297
CF_4	50000.0	No cc fb	4880	6630	5270	8040
		With cc fb	4950	7350	5400	9570

Note:
Uncertainties related to the climate-carbon feedback are large, comparable in magnitude to the strength of the feedback for a single gas.
(a) Perturbation lifetime is used in calculation of metrics.

Figure 2: GWP and GTP Values in the IPCC AR5 Report

Compared to the GWP, GTP, goes one step further down the cause–effect chain by accounting for the climate sensitivity and the exchange of heat between the atmosphere and the ocean. The GTP includes physical processes that the GWP does not, however, there are also issues with GTP for policy applications. The calculation of GTP is more complicated than that for GWP, as it requires modeling how much the climate system responds to increased concentrations of GHGs (the climate sensitivity) and how quickly the system responds (based in part on how the ocean absorbs heat). These processes, in particular, are poorly understood in their direct impact on climate. Thus, the relative uncertainty ranges are wider for GTP compared to GWP, hindering the wide-spread use of GTP.

CO_2e Emission Calculations

Choice of Metric and Time Horizon

After GWP was introduced in the first Intergovernmental Panel on Climate Change (IPCC) report in 1990, an IPCC report released in 1995 detailed when the 20-year and 100-year time horizons should be used (in Section 5.3.2 of "Climate Change 1994").[5] In particular, the 20-year time horizon should be used when the emphasis of the policy is limiting short-term non-linear climate responses, and the 100 or 500-year time horizon should be used when a policy is trying to reduce long-term seemingly irreversible climate-related changes. One example used by IPCCs authors to illustrate the long-term changes is the slow build-up of and recovery of sea-level changes that are governed by relatively slow processes that may influence the overall warming of the oceans. When deciding which horizon to use, the potential exists to focus on short-term changes at the expense of long-term climate specific benefits.

Since the IPCC was most interested in minimizing the magnitude of long-term impacts, they adopted the 100-year integration period (GWP_{100}) as the time horizon to implement the multi-gas approach in the 1997 Kyoto Protocol and subsequent agreements. Further in the IPCC fifth assessment (AR5, Section 8.7 Climate Change 2013 The Physical Science Basis), the authors further emphasize that time-frames are policy-driven and that scientific studies must ultimately back up the different approaches and policy choices.

Because the climate forcing effect of CO_2 emissions is used as a baseline regardless of the time horizon chosen (CO_2 always has a GWP or GTP of 1), the impact of time horizon choices may appear to affect calculations of CO_2e only by adjusting the contributions of short-lived gases. However, this is the case only if reductions to those short-lived gas emissions occur independently of CO_2 emissions. If, however, technology choices or fuel substitutions that reduce short-lived gas emissions simultaneously cause CO_2 emissions to increase, the choice of a short time horizon to reduce emissions of gases such as methane may cause the unintended consequence of increasing the long-term magnitude of climate change due to higher levels of long-lived gases, especially CO_2.

Figure 3 shows the GWP and GTP of methane vs. the time horizon chosen on a semi-log scale. GWP estimates the total amount of energy per unit area that would have been lost to space if the greenhouse gas was not present relative to what the same quantity of CO_2 would have done from time zero up to the chosen time horizon. As mentioned earlier, it does not estimate the global temperature change caused by the greenhouse gas compared to what would have been caused by the same amount of CO_2, that is the left to the GTP metric. The combination of infrared absorption and short lifetime for methane, the potential to cause climate change, decreases quite sharply between 20 and ~50 years. With these aspects in mind, lower overall methane emissions are always better, but with respect to building standards reducing methane emissions is generally not possible without causing changes to emissions of other greenhouse gases, most importantly CO_2.

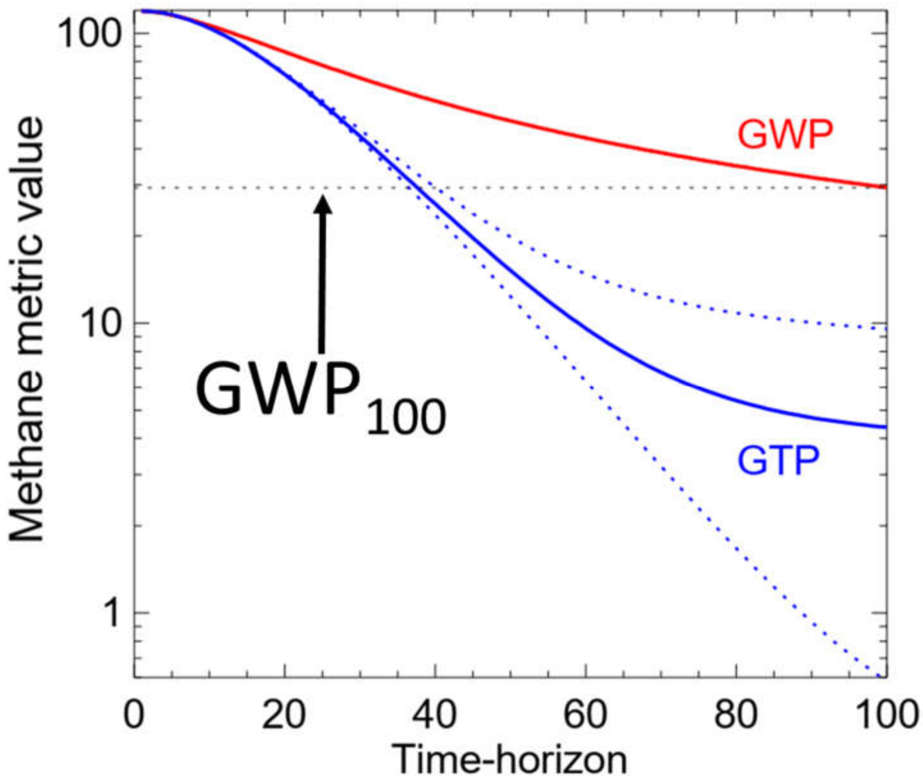

Figure 3: GWP and GTP of Methane (adapted from Allen et al. 2016[6]).

Unintended Consequences of Short Time Horizon Metrics

The choice of a particular time horizon has a strong effect on GWP values and thus on the calculated contributions of CO_2e emissions by component, sector, or nation. As has been discussed, a shorter (e.g., 20 year) time horizon may be useful if the speed of potential climate change is of greater interest than the eventual magnitude of the change. The IPCC adopted the 100-year integration period (GWP_{100}), but other agencies, such as the California Air Resources Board, have begun considering shorter term impacts for atmospheric species such as methane, and have provided comparisons based on the 20-year integration period (GWP_{20}).

When developing policies focused on the short-term impacts of greenhouse gases, it may be possible to have long term impacts. For instance, if a technology that emits a smaller amount of methane at the expense of emitting a higher amount of CO_2 is used over one that does the opposite, there may be advantages in the near-term but disadvantages in the long-term. To study instances where this could occur, a more in-depth analysis is required than simply looking at GWPs. One area where just such a scenario can arise is in the residential building sector.

In some cases, making changes to buildings in an effort to reduce CO_2e based on the GWP_{20} metric will result in increases in CO_2e calculated using a GWP_{100} metric. This occurs, for instance, when electric equipment ultimately fueled by natural gas or coal power generation replaces direct use natural gas equipment, thereby reducing full-fuel-cycle methane emissions while increasing CO_2 emissions from fossil fuel combustion associated with the electric alternative to natural gas direct use in the building.

To explore this idea, we used the Carbon Management Information Center's Source Energy and Emissions Analysis Tool (SEEAT). SEEAT calculates source energy consumption and selected air emissions including greenhouse gases associated with annual site energy consumption by purchased fuel type of baseline and alternative applications defined by user-selectable and default inputs. Default power plant efficiency, fuel mix, and emissions data contained in the current and previous eGRID databases allow the user to determine source energy consumption and GHG emissions (as well as SO_2, NOx, and Hg) associated with annual site electricity consumption at national, NERC region, eGRID sub-region, and state levels as well as for marginal generation mixes. Energy consumption and emissions associated with extraction, processing, transportation, and distribution are also determined for electricity and other energy forms based on government data sources.

Specifically, we looked at alternative gas and electric building heating and water heating options in cities across the United States. Systems and efficiency levels were selected to achieve comparable source energy use calculated with the US average 2017 electric grid mix. The three cases shown in **Table 1** are examples from the northern United States where a natural gas furnace and air conditioning was replaced by a high efficiency electric heat pump, and in some cases, an electric heat pump water heater. Taking Des Moines, IA as a specific example, the result of the changes was a decrease in CH_4 emissions of 25.7%, but the decrease caused a 5.5% increase in CO2 emissions. There was a similar pattern in Minneapolis, MN and Chicago, IL.

Table 1: CO_2, CH_4, and CO_2e emissions cases in the northern United States.

	Des Moines, IA			Minneapolis, MN			Chicago, IL		
	Gas Baseline	Alternative	% decrease	Gas Baseline	Alternative	% decrease	Gas Baseline	Alternative	% decrease
CO_2	20287	21411	-5.5%	22308	23510	-5.4%	20223	21944	-8.5%
SO_2	9.9	16.5	-67.2%	10.2	20.1	-98.1%	9.7	18.8	-92.8%
NOx	23.6	21.2	9.9%	26.3	22.1	16.1%	23.6	20.7	12.4%
CH_4	79.6	59.1	25.7%	90.3	56.8	37.1%	79.8	53.1	33.4%
N_2O	0.38	0.29	22.1%	0.43	0.29	32.5%	0.38	0.27	28.7%
	CO2e (1000 lb)			CO2e (1000 lb)			CO2e (1000 lb)		
GWP_{100}	22.6	23.1	-2.4%	24.9	25.2	-0.9%	22.6	23.5	-4.2%
GWP_{20}	27.1	26.5	2.3%	30.0	28.4	5.5%	27.0	26.5	2.0%
GTP_{100}	20.7	21.7	-4.9%	22.8	23.8	-4.5%	20.6	22.2	-7.7%
GTP_{50}	21.5	22.3	-3.8%	23.7	24.4	-2.9%	21.4	22.8	-6.1%
GTP_{20}	25.7	25.5	1.0%	28.5	27.4	3.8%	25.7	25.6	0.4%
Cost	$1,601	$2,146	-34.0%	$1,761	$2,657	-50.9%	$1,621	$2,451	-51.2%
Building kWh	10261	13245		7745	14185		7745	14185	
Building therms	222	0		536	66		536	66	

Equipment	Des Moines, IA Gas Baseline	Des Moines, IA Alternative	Minneapolis, MN Gas Baseline	Minneapolis, MN Alternative	Chicago, IL Gas Baseline	Chicago, IL Alternative
Heating	Natural Gas AFUE 96%	20.5 SEER/13 HSPF Heat Pump	Natural Gas, AFUE 96%	20.5 SEER/13 HSPF Heat Pump	Natural Gas, AFUE 96%	18 SEER/9.2 HSPF Heat Pump
Cooling	18 SEER (12.8 EER) A/C	20.5 SEER/13 HSPF Heat Pump	18 SEER (12.8 EER) A/C	20.5 SEER/13 HSPF Heat Pump	18 SEER (12.8 EER) A/C	18 SEER/9.2 HSPF Heat Pump
Domestic Hot Water	Natural Gas EF 0.62 storage	Natural Gas EF 0.62 storage	Natural Gas EF 0.62 storage	Electric EF 3.25	Natural Gas EF 0.62 storage	Electric EF 1.70
Range	Natural Gas	Natural Gas	Natural Gas	Natural Gas	Natural Gas	Natural Gas
Dryer	Natural Gas	Natural Gas	Natural Gas	Natural Gas	Natural Gas	Natural Gas

Table 2 shows similar results for two cases in the southern United States. Most importantly, for all of the example cases in Table 1 and Table 2, the switch to high efficiency electric heat pumps resulted in decreased CO_2e emissions if the GWP_{20} or GTP_{20} was used for the calculation with the GWP20 showing the largest decrease in emissions of 2.3% for the Des Moines, IA example. On the other hand, there was an increase in the calculated CO_2e emissions if the GTP_{50}, GTP_{100}, or GWP_{100} was used with the largest increase coming from the GTP_{100} calculation.

The scenarios that generated increased CO_2e emissions when working on a 50 or 100-year basis therefore, may have a greater impact on long term climate. The results suggest that in certain regions of the U.S., regulations and standards using GWP_{20} that force a shift to all electric appliances in these northern U.S. cities can have negative climate consequences. For these cases, the argument that GWP_{20} should be used in place of GWP_{100} conflicts with climate change mitigation policy objectives.

Table 2: CO_2, CH_4, and CO_2e emissions cases in the southern United States.

	Phoenix, AZ			Atlanta, GA		
	Gas Baseline	Alternative	% decrease	Gas Baseline	Alternative	% decrease
CO_2	14193	14588	-2.8%	15511	16483	-6.3%
SO_2	10.6	12.8	-21.2%	9.1	14.0	-53.9%
NOx	14.3	13.5	5.4%	17.1	15.6	8.9%
CH_4	40.6	33.8	16.8%	54.7	40.5	25.9%
N_2O	0.20	0.17	13.9%	0.26	0.20	21.9%
	CO2e (1000 lb)			CO2e (1000 lb)		
GWP_{100}	15.4	15.6	-1.3%	17.1	17.7	-3.3%
GWP_{20}	17.7	17.5	1.1%	20.2	19.9	1.2%
GTP_{100}	14.4	14.8	-2.5%	15.8	16.7	-5.7%
GTP_{50}	14.8	15.1	-2.0%	16.4	17.1	-4.6%
GTP_{20}	17.0	16.9	0.4%	19.2	19.3	0.0%
Cost	$1,573	$1,609	-2.3%	$1,647	$1,724	-4.7%
Building kWh	10261	13245		7745	14185	
Building therms	222	0		536	66	

Equipment						
Heating	18 SEER/9.2 HSPF Heat Pump	18 SEER/9.2 HSPF Heat Pump		Natural Gas, AFUE 96%	18 SEER/9.2 HSPF Heat Pump	
Cooling				18 SEER (12.8 EER) A/C		
Domestic Hot Water	Natural Gas EF 0.62 storage	Electric EF 1.70		Natural Gas EF 0.62 storage	Electric EF 0.95	
Range	Natural Gas	Electric		Natural Gas	Electric	
Dryer	Natural Gas	Electric		Natural Gas	Electric	

Conclusions

The use of different time horizons for GWP to drive policies have specific goals and intentions. Users of the GWP information must understand that shorter time horizons focus on short term nonlinear climate impacts as opposed to longer term climate impacts. The goals of the two types of horizons are quite different. The use of one horizon over another must not be taken lightly, and all known scenarios must be explored before choosing one as there may be unintended consequences. For example, in some scenarios using GWP_{20} values to justify replacement of residential natural gas heating and cooling may have a greater impact on long term climate than using the longer-term GWP_{100} values and staying with natural gas appliances. Scenarios like this highlight the issues that may arise if a holistic approach is not taken when evaluating policies, standards, or regulations and the consequences that may arise from the different time horizon scenarios.

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