Climate Policy Consequences of Value Judgements Inherent to Widely-Used Global Warming Potentials

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Abstract

For the implementation of the recently ratified Paris Agreement, international parties to the United Nations Framework Convention on Climate Change (UNFCCC) have requested guidance on the implementation of common metrics for the accounting of anthropogenic greenhouse gas emissions. Carbon dioxide (CO_2) is the most significant greenhouse gas for radiative forcing, followed by short-lived climate pollutants (SCLPs) methane (CH_4) and nitrous oxide (N_2O). To date, the applied methodologies described by the Intergovernmental Panel on Climate Change (IPCC) are based on the usage of Global Warming Potentials (GWPs) to account for the climate impact of non-CO_2 emissions under a single CO_2eq metric. The usage of GWPs has been the subject of much scrutiny due to their strong dependence on an arbitrary choice of time-horizon, however there exists no consensus on the implementation of any alternative metric. Despite this criticism, GWPs remain widely-used in national greenhouse gas inventories and in research regarding to the carbon intensity of energy, land-use, and transport sector policies. This paper presents a review of GWP implementation, usage and alternative metrics with an emphasis on clarifying the subjective value-judgements inherent to each choice. As case studies research is reproduced in each of energy, urban planning policies showing that seemingly objective conclusions can change substantially depending on the subjective choice of GWPs. We present a case for disaggregating CO_2eq metrics into individual gas emissions for policy synthesis.

1 Introduction

Greenhouse gases (GHGs) are molecules in the atmosphere that absorb and emit thermal infrared radiation due to their molecular vibrations. Solar energy absorbed by the planet is released into space as infrared radiation, thus the presence of molecules that absorb and re-emit the outgoing radiation traps energy within the planetary system (Wang, Yung, Lacis, Mo, & Hansen, 1976). The change in the energy balance of the planet due to these trace gases is described as radiative forcing, in units of Watts per m^2. Water is the primary GHG in the atmosphere, but is treated as a feedback agent (and not forcing agent) due to its regular condensation and precipitation out of the gas phase in the hydrological cycle. The well-mixed GHGs most significant as radiative forcers are carbon dioxide (CO_2) at 1.9 W/m^2, methane (CH_4) at 0.5 W/m^2 and nitrous oxide (N_2O) at 0.18 W/m^2 (Intergovernmental Panel on Climate Change, 2014). From these mechanisms, the accelerated accumulation of GHGs in the atmosphere due to anthropogenic activities since the industrial revolution is responsible for the increasing temperature of the planet. These processes have been well-known for at least a century. The role of the atmosphere in trapping heat has been discussed as early as the 1820's (Fourier, 1827), with the effect of carbon on warming the planet quantified as early as the 1890's (Arrhenius & Holden, 1897). Describing this phenomenon as the 'greenhouse effect' was first in 1901 (Ekholm, 1901) and popularized by Alexander Graham Bell, who warned of the climate changing consequences of unchecked burning of fossil fuels in 1917 (Grosvenor & Wesson, 1997).

Despite a long history of extensive scientific research, international cooperation and policies addressing the adverse effects of fossil fuel combustion and GHG emissions have continued to lag behind the knowledge. There now exists an additional novel problem whereby elected officials and significant fractions of the general public disregard scientific knowledge and continue to meet attempts at GHG mitigation policy with strong resistance (Dunlap, McCright, & Yarosh, 2016). To some degree, both of these phenomena can be understood in the context of the convenience of fossil fuels as an energy source and systemic economic dependence on their consumption. The communication of climate change science and the economic benefits of climate change policy (for current and future generations) thus become imperative to mobilizing an accelerated international response to an accelerating geophysical challenge. For this reason, discussions of geophysical processes may undergo simplifications in the process of

communicating science to policymakers and mobilizing international cooperation. These simplifications may be a cause of long-term systemic misunderstanding of fundamental processes, which can persist through efforts in the international policymaking framework

In this light, currently-applied metrics to account for GHG emissions have received significant scrutiny because of their inherent over-simplifications (Allen et al., 2016; Farquharson et al., 2016; Harmsen et al., 2016; O'Neill, 2003; Shine, Fuglestvedt, Hailemariam, & Stuber, 2005). As such, International parties to the United Nations Framework Convention on Climate Change (UNFCCC) have requested guidance on improving the implementation of common metrics for the accounting of anthropogenic greenhouse gas emissions (UNFCCC, 2015). In order to simplify the quantification of GHG mitigation policies, emissions of GHGs into the atmosphere are often grouped together under a single simplified CO_2 equivalent metric (CO_2eq). Masses of GHGs released are converted to a CO_2eq value using global warming potentials (GWPs) outlined by the IPCC (Intergovernmental Panel on Climate Change, 2014). Because CO_2 is the most significant GHG for climate change it is used as the reference point (1 gram CO_2 = 1 CO_2eq) with masses released of gases (CH_4, N_2O etc.) converted to a CO_2eq value using a single integer conversion factor. GHGs are each unique molecules with different lifetimes, different physical and chemical cycles (sources and sinks) and thus different degrees of influence over the climate. CH_4 for example has a significantly shorter lifetime than CO_2 (~10 years CH_4 vs ~200 years CO_2) but is significantly more efficient at trapping heat during its existence (Intergovernmental Panel on Climate Change, 2014). This creates a phenomenon not explicitly captured in aggregated metrics whereby CH_4 emissions have a high impact in the short-term with less-impact in the long term (Shine, Berntsen, Fuglestvedt, Skeie, & Stuber, 2007). Therefore, there is no single metric that would convert the comprehensive impact and full life cycle of one GHG to another. Aggregated metrics for reduction targets then by nature include entangled subjective value judgements about geophysical and social priorities (Fuglestvedt et al., 2003; Houghton, Jenkins, & Ephraums, 1990). This is analogous to comparing apples to oranges and bananas in order to come up with a total recommended dietary fruit intake. While the single metric is a useful simplified measure, it makes unclear inherent judgements about specific nutritional needs (i.e. the need for bananas to be weighed heavier for those with hypokalemia, and avoided for hyperkalemia is unaddressed). Despite these complexities, the use of GWPs to generate CO_2eq's is the single most commonly applied metric in nearly all GHG accounting and climate policy.

National inventories often group GHG emissions and future reduction targets according to a CO_2eq value. UNFCCC cooperative efforts have historically required parties to ratify reductions according to their carbon intensity in CO_2eq units. The recent Paris Agreements has included a primary goal for the "*…stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system*", and has made explicit mandates to control warming below 2°C (UNFCCC, 2015). Reduction targets however still primarily follow suit according to CO_2eq units.

In this paper, the consequences of widely-used GWP and CO_2eq values are investigated. The physical basis of GWPs and proposed alternative metrics are first described in detail. As a case study policy-relevant research evaluating the carbon intensity of energy sources is reproduced using alternative GWPs, showing that seemingly objective conclusions can change substantially depending on the subjective choice of metric. To conclude this work presents a case for disaggregating GHG emissions and describing policy by gas as a paradoxically simpler approach to climate policy.

2 Scientific Basis of Global Warming Potentials (GWPs)

GWPs are a comparison of the integrated (cumulative) radiative forcing of a pulse emission of a unit mass of a given pollutant to a unit mass of CO_2 (Intergovernmental Panel on Climate Change, 2014):

$$GWP(x) = \frac{\int_0^{TH} a_x \cdot [x(t)]dt}{\int_0^{TH} a_{CO2} \cdot [CO_2(t)]dt} \quad \text{(eq.1)}$$

Where GWP(x) is the global warming potential for a given pollutant x, TH is the time horizon over which cumulative radiative forcing is calculated, and a_x is the radiative efficiencies due to a unit increase in the atmospheric mixing ratio of a given pollutant and [x(t]] is the time-decaying abundance of the pollutant. Non-linearity in the absorptive efficiencies are calculated by estimating scenarios of future mixing ratios. Because the lifetimes and radiative efficiencies of GHG's vary significantly from gas-to-gas, the choice time horizon TH has a significant impact on the resulting GWP. For this reason, the IPCC reports GWP's according to 20, 100 and 500-year time horizons (Table 1).

Table 1: IPCC Fifth Assessment Report Global Warming Potentials (GWPs) (Intergovernmental Panel on Climate Change, 2014)

	20-year GWP	100-year GWP	500-year GWP	Lifetime (years)
Carbon Dioxide (CO_2)	1	1	1	-[a]
Methane (CH_4)	84	28	7.6	12.4
Nitrous Oxide (N_2O)	264	265	153	121.0
CFC-11	6,900	4,660	1,620	45.0
CFC-12	10,800	10,200	5,200	100.0

[a]Previous IPCC Assessment Reports (AR1-AR3) have listed the CO_2 lifetime at 50-200 (1990) and 5-200 (1995 and 2001), but since the Fourth Assessment Report (AR4 2007) the IPCC does not report a single lifetime for CO_2 and instead a non-linear response function.

Table 1 shows the GWP_{20}, GWP_{100} and GWP_{500} values for the top five well-mixed greenhouse gases from the IPCC 5th assessment report (FAR). These are the reference values used in inventory reports for submission to the UNFCCC and are commonly employed in climate science and policy research papers, with the GWP_{100} value being the default metric in most cases. Interestingly during the initial proposal of using GWP metrics in the 1990's, the 20, 100 and 500-year time horizons were never meant to be authoritative in this way. In the first IPCC assessment report, Houghten described the three time horizons as "*Candidates for discussion [that] should not be considered having any special significance"* (Houghton et al., 1990). From this one can infer the global reference Table 1 has not necessarily been designed intentionally. Furthermore in the FAR, the IPCC states *"There is no scientific argument for selecting 100 years compared with other choices…the choice of time horizon is a value judgement because it depends on the relative weight assigned to the effects at different times"* (Intergovernmental Panel on Climate Change, 2014). So while this inherent subjectivity and the need for conscious value judgements is communicated explicitly, in practical use this does not happen. Because sheer systemic inertia has made the GWP_{100} the defining metric of GHG emissions, value judgements – whether correct or misguided – are made unintentionally. One resulting questionable outcome is the comparison of radiative forcing for CH_4 over 100 years by using a

GWP_{100} conversion, despite the lifetime of the molecule in the atmosphere being 12.4 years. This means the radiative forcing of CH_4 is being calculated 87.6 years after the molecule has ceased to exist in the atmosphere. Figure 1 shows the nature of these calculations by comparing the absolute global warming potentials (AGWPs), which is the total radiative forcing contributed by a pulse emission up to a particular year, of CH_4 and CO_2 while showing the calculation of the GWP over 0 to 500 years.

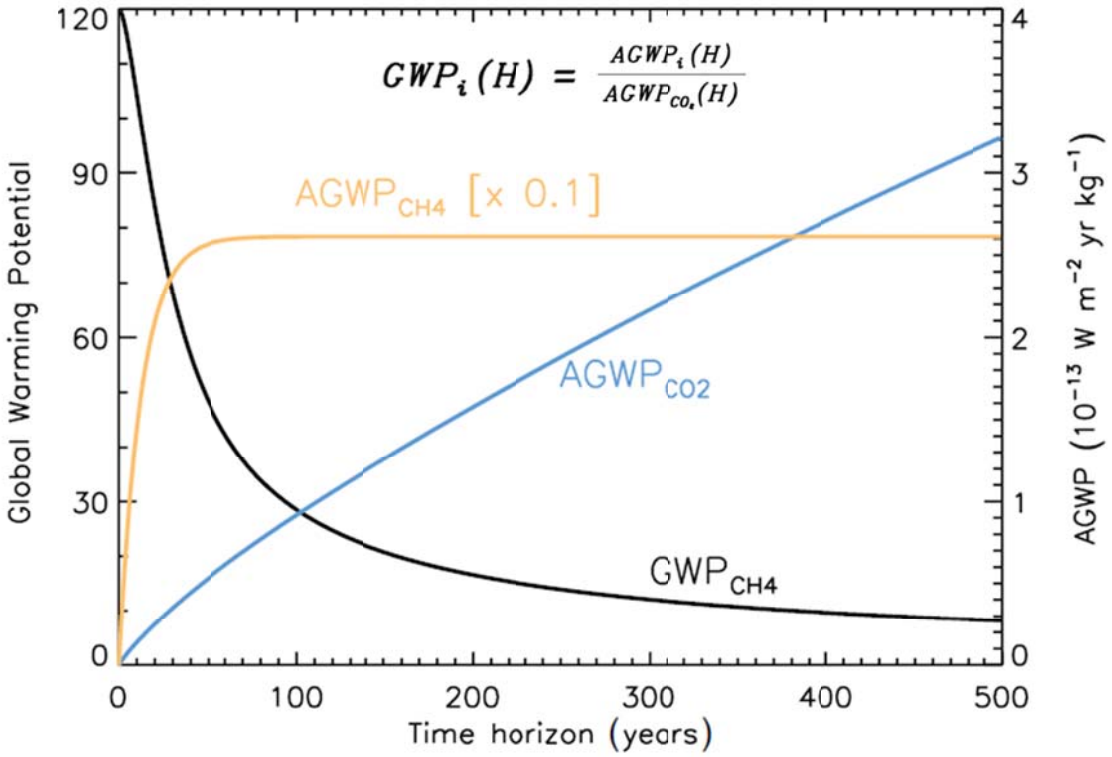

Figure 1: Comparison of the Absolute Global Warming Potentials (AGWP) of CH_4 (yellow line) and CO_2 (blue) showing the resulting GWP (black) from the IPCC FAR (Intergovernmental Panel on Climate Change, 2014).

The CH_4 AGWP curve (yellow) in Figure 1 ceases to be a factor in radiative forcing at ~45 years. This is still longer than the CH_4 lifetime because of thermal inertia retaining some of the energy trapped by CH_4 during its cycle in the atmosphere (Shine et al., 2007). The CO_2 AGWP curve (blue) increases about linearly as it continues to trap heat consistently over 500 years. The

GWP of CH_4 (black) then, depends on the high relative forcing of CH_4/CO_2 before ~45 years, and depends only on the radiative forcing of CO_2 afterwards. As such, the GWP of CH_4 becomes less meaningful for time horizons after 45 years, because the molecule and its effects would simply cease to exist. Despite this however, the GWP_{100} for CH_4 is the most widely-used metric to describe the most important non-CO_2 greenhouse gas. In almost all cases, the justification in national inventories for using the GWP_{100} metric is through a simple reference to the IPCC tables (Table 1), without addressing the value judgements the IPCC says GWP_{100} usage necessitates. The implications for this are far reaching in the perception of relative contributions to climate changing effects. Figure 2 shows comparisons of sector contributions to total GHG emissions according to different GWP time horizons.

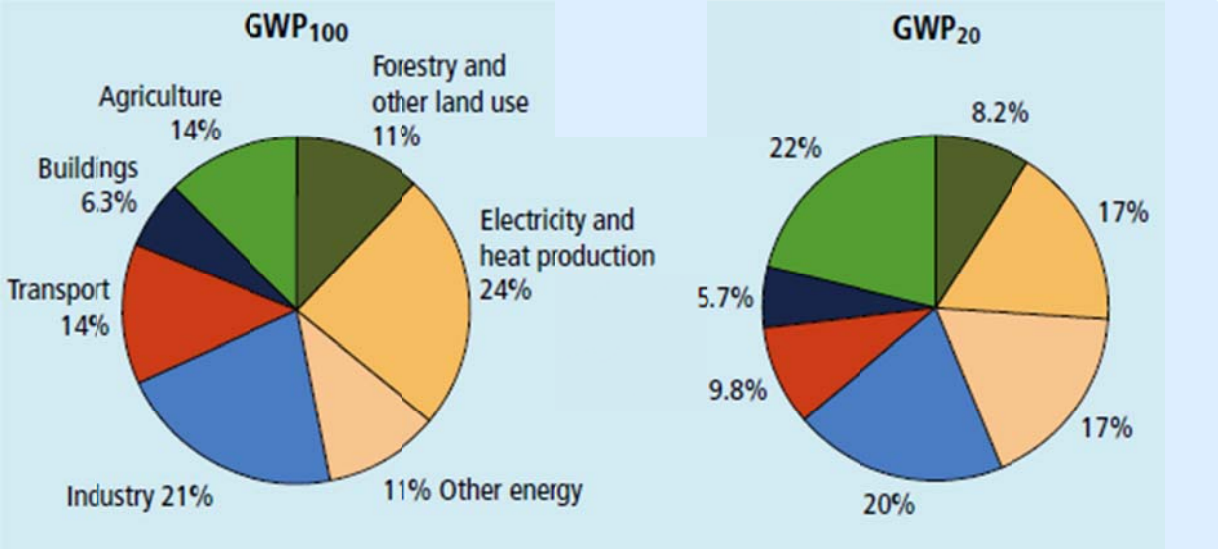

Figure 2: Comparison of relative sector contributions to total global GHG emissions according to GWP_{100} (left) and GWP_{20} (right) metrics for the year 2010 (Intergovernmental Panel on Climate Change, 2014).

As shown in Figure 2, the differences in sector contributions are 8% (Agriculture), -2.8% (Forestry and other Land Use), -7% (Electricity and Heat Production), -1% (Industry), -4.2% (Transport), -0.6% (Buildings) and 6% (Other Energy). Agriculture is most significantly impacted, and can be more than 1.5x the contributing factor depending on choice of metric. Considering the total GHG emissions for the year 2010 were 45,863 megatonnes of CO_2eq, a

difference of 8% corresponds to ~3700 Mt, which is many factors higher than the total GHG emissions of most countries (Canada's GHG emissions in 2010 were 706 Mt CO_2eq), and ~63% of the net emissions from the United States. The data output from GWP_{100} applications are of critical importance for policy development, UNFCCC parties weigh successes based on decreases in the GWP_{100}-derived CO_2eq totals listed. Furthermore, the sector contributions in Figure 2 are used for policy-design and further value judgements on where the most strategic mitigation policies can be best implemented. With more heavily-weighted CH_4 emissions through the use of a lower time horizon metric, agricultural emissions of CH_4 (primarily through the enteric fermentation of cattle/livestock) would be a more significant choice for technological development. Thus the root value judgement of which metric to use – and why – cannot be overlooked.

2.1 Alternative Metrics: Global Temperature Potentials (GTPs)

An available alternative to using GWPs is the design of Global Temperature Potentials (GTPs) (Shine et al., 2005). The GTP is a measure of the change in average global temperature due to a pulse emission of a gas at a particular point in time. Therefore, unlike GWPs, the timescale indicated does not have a 'memory effect' of carrying radiative forcing (or lacktherof) from previous years. The time dimension is to directly anticipate results at a specific instant. Figure 3 shows the measure of GTPs for notable GHGs from the original work (Shine et al., 2005).

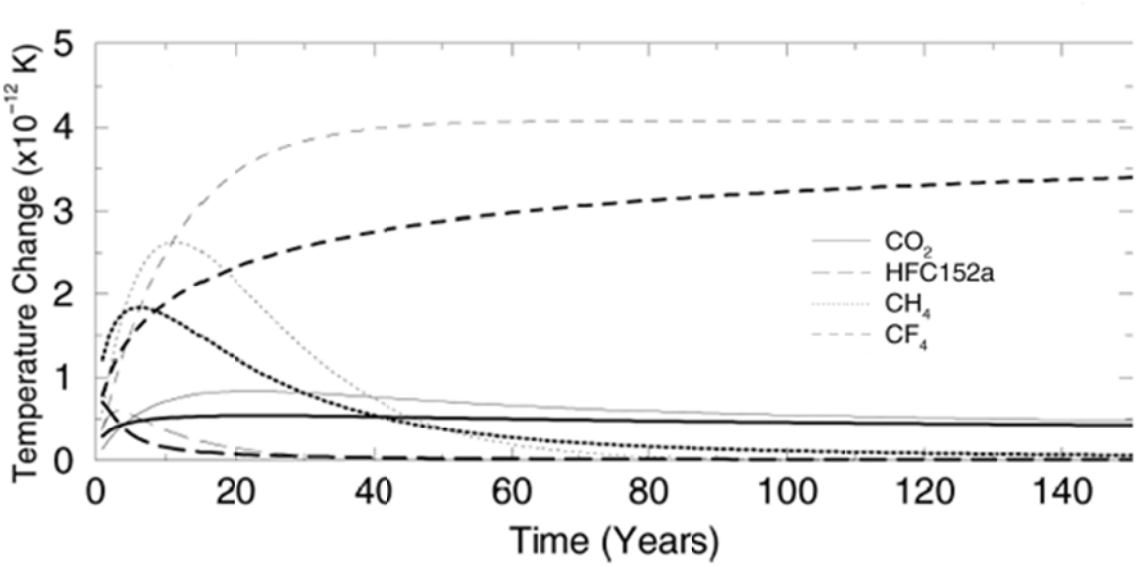

Figure 3: Global Temperature Change Potentials for a 1 kg pulse emission of CO_2 (solid line), CH_4 (dotted line), CF_4 (broken line) and HFC152a (dashed line) as shown in (Shine et al., 2005).

Consistent with GWP's, the primary determining factor for the impact of a GHG is a) its lifetime and b) its radiative efficiency. For that reason, while the GTP provides a slightly different approach to the time horizon problem, it maintains the same challenge of grouping chemically different molecules into the same basket. Figure 4 shows a recent comparison in Allen et al., 2016 of the GWP_{100} and GTP metrics.

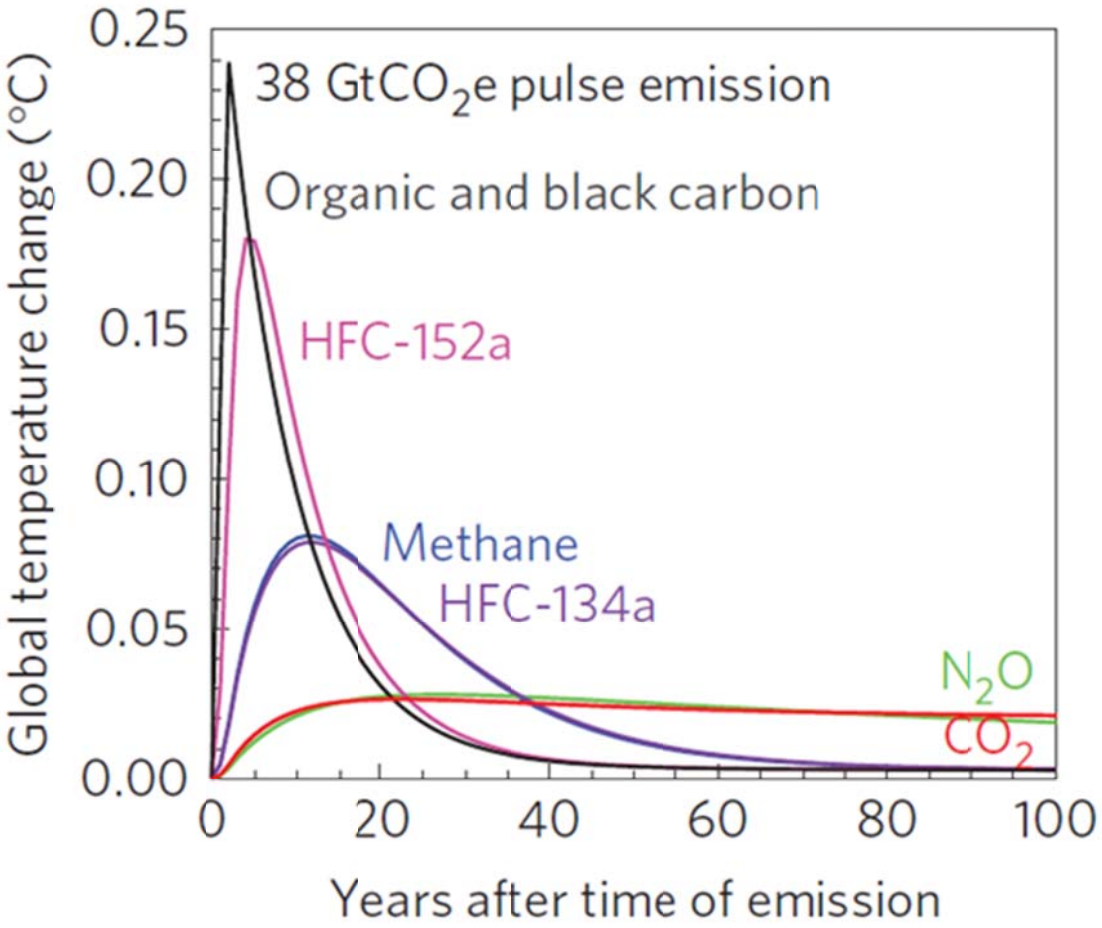

Figure 4: Comparison of the mean global temperature change according to GWP_{100}-derived CO_2eq pulse emission of given GHGs. Note this is not equivalent to pulse emissions of equal mass.

As seen in Figure 4, equal CO_2eq masses are not causing the same changes to the global climate. If the GWP_{100} was a reliable metric for aggregating the warming effect of GHGs, the curves would be overlapping. Thus Figure 4 is showing deviations from the CO_2-eq behavior. For a 100-year time horizon, N_2O overlaps closely with CO_2 due to the longer 121-year lifetime of N_2O (thus it would not be chemically removed from the atmosphere for the timeframe of Figure

4). All other molecules show strong deviation from CO_2 up-to ~20 years, with CH_4 showing deviation up-to and after ~38 years. This demonstrates the GWP_{100} metric is reliable for predicting the temperature-changing consequences of CH_4 at ~38 years. This shows underestimation of the temperature-impact of short-lived climate pollutants (SCLPs) like CH_4, organic and black carbon, and HFCs in the near-term (0-40 years), and overestimation of their importance after (40-100 years). This is especially relevant considering the effects of climate change the Paris Agreements expect to control (peak warming below 2°C) are projected to occur within the next 40 years (Rogelj et al., 2014) (Figure 5).

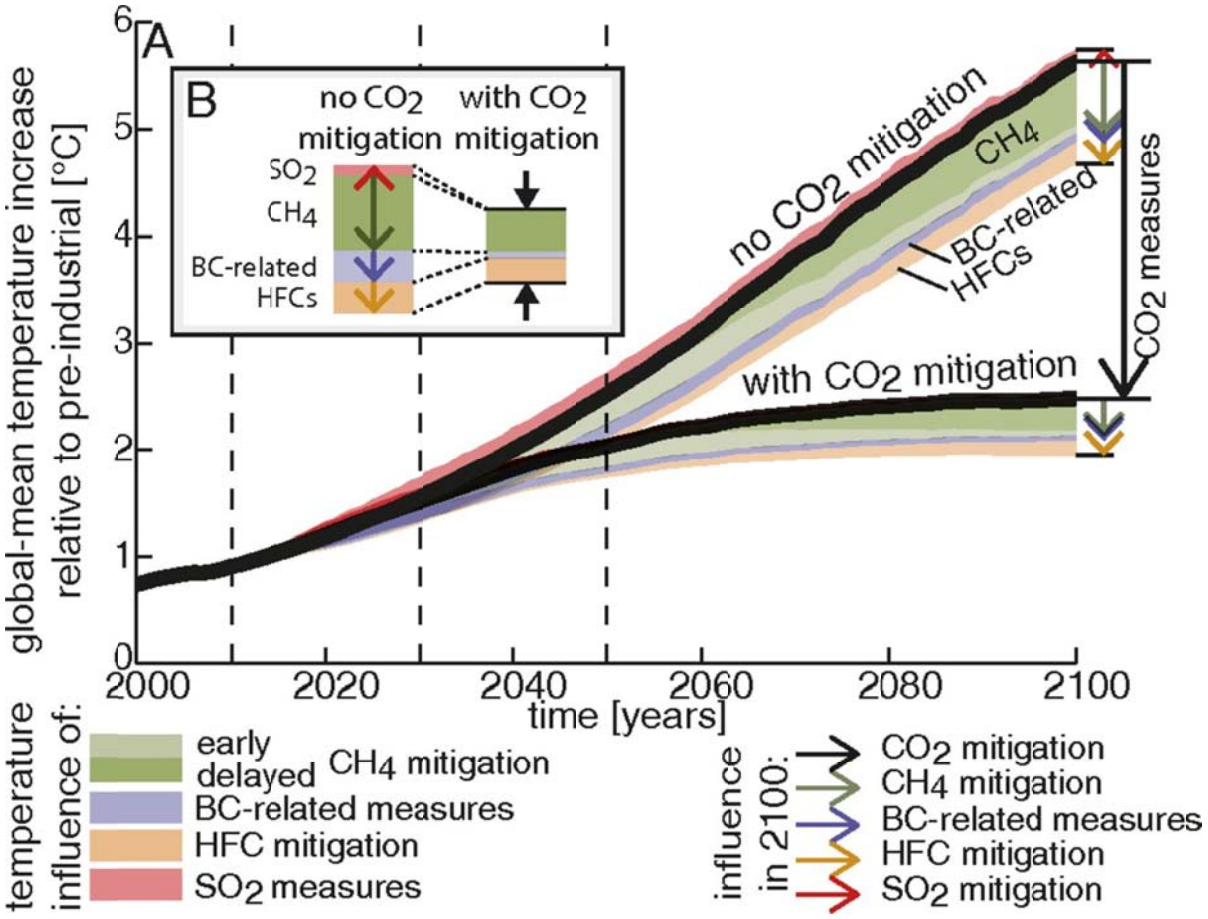

Figure 5: Projected global mean temperature changes depending on various mitigation factors from (Rogelj et al., 2014).

3 Impact of GWP Metrics in Urban Planning and Energy Policy

In this section the direct consequences of widespread GWP_{100} use are investigated for research directly relevant to policy development. Two case studies are used as examples, **3.1** discusses the assessments of energy-source carbon intensities (using the GWP_{100} metric), in the context of the Alberta Oil Sands and **3.2** discusses policy development for landfill emissions quantification and capture in the province of Ontario.

3.1 Subjective Assessments of GHG Intensity in Oil and Gas Production

The carbon intensity of fossil fuel sources is commonly discussed in one of two ways: 1) Total GHG emissions from a particular facility (Environment Canada, 2015) or 2) Full-lifecycle assessments of GHG intensity (Brandt, 2012; Burnham et al., 2011; Lattanzio, 2015). The former is a measure of the GHG emissions released into the atmosphere at an exact site over a given period of time. The latter is a comprehensive assessment of a) GHG emissions from a site, b) energy consumption and land-use for production, and often c) GHG emissions associated with transport and eventual combustion at the endpoint, i.e. 'wells-to-wheels'. In either case, government oversight and policy is heavily dependent on the results of this work. And yet, in order to aggregate total GHG emissions into a binned value, these studies often subtly depended on the choice of metric in calculations, which is more often than not the default 100-year GWP. Figure 6a shows GHG emissions from select highest emitters in the Canadian GHG reporting program according to the currently used GWP_{100} metric, and Figure 6b shows the result from applying a GWP_{20} metric.

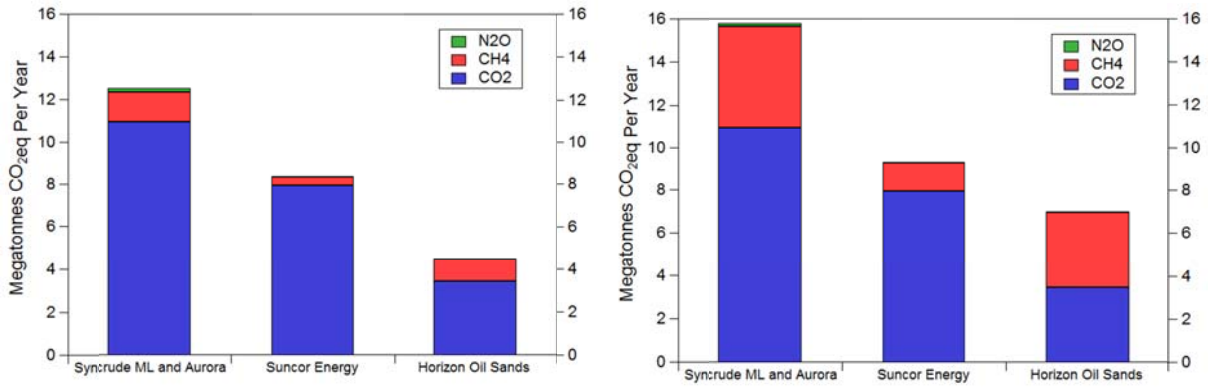

Figure 6: GHG Emissions from select highest emitters (top 5) to the Canadian GHGRP reprogram. Total emissions (CO_2eq) are calculated using the GWP_{100} default metric (left) and GWP_{20} metric (right).

As shown in Figure 6, there is a significant change for an alternative metric for CH_4, and little to no change for N_2O (GWP_{20} and GWP_{100} for N_2O are approximately equal in Table 1). The change is according a factor of 3.36, as a result the impact of CH_4 emissions on total GHG intensity is more than tripled. For relative contributions, CH_4 emissions from Syncrude, Suncor and CNRL go from 11% (Syncrude), 5% (Suncor) and 23% (CNRL) to 30%, 14% and 51% of total emissions respectively. CH_4 emissions from these facilities are >95% fugitive emissions and not a necessary or intentional by-product of oil production (Gordon et al., 2015; Johnson et al., 2016; Siddique, Penner, Klassen, Nesbø, & Foght, 2012; Small, Cho, Hashisho, & Ulrich, 2015; Strausz & Alberta Energy Research Institute, 2003). This is an attractive opportunity for reduction in Oil Sands GHG intensity, which may be neglected to the subjective perception of CH_4 contributions to total emissions because of using the GWP_{100} metric.

3.2 Urban Policy for Landfill CH_4 Emissions

In the province of Ontario there is an active policy to reduce landfill emissions of CH_4 through Ontario Regulation 232/98 in the *Environmental Protection Act* ("Landfill gas capture : a guideline on the regulatory and approval requirements for landfill gas | Ontario.ca," n.d.). This requires landfills above a capacity of 1.5 million m^3 to install capture and generation stations.

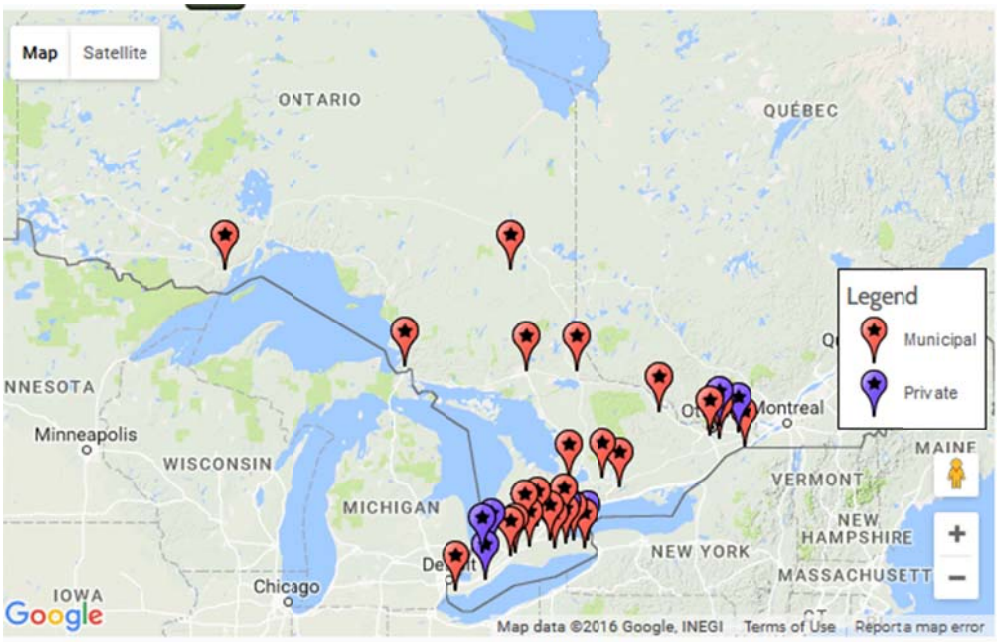

Figure 7: Map of 32 large landfill sites in Ontario (above a capacity of 1.5 million m^3) required to install CH_4 gas capture systems

Interestingly, not shown on the map in Figure 7 is the Keele Valley Landfill (KFL) which was the largest landfill in Canada (now out of use) but continues to capture CH_4 being actively released into the atmosphere similar to other sites. In 2012, the KFL released ~19,000 tonnes of CH_4 (Environment Canada, 2015), and collected a massive ~1,800,000 tonnes of CH_4 (City of Toronto, 2012). This indicates a capture efficiency of ~99%, although the City of Toronto reports an efficiency of 95%, which may be indicative of unaccounted for CH_4 emissions. In general landfill emissions are comparable in size to total CH_4 emissions from natural gas leakages in transmission and distribution (Table 2). In addition to improvements in natural gas infrastructure, landfill emissions are both major sources of CH_4 in provincial inventories and an attractive opportunity for CH_4 capture through more aggressive provincial policy.

Table 2: Top 18 Facilities Emitting CH_4 in Ontario (Environment Canada, 2015).

GHGRP ID	Reference Year	Facility Name	CH_4 (tonnes per year)	CH_4 (tonnes per hour)	Facility City/District/Municipality	Facility Province
G10565	2013	Natural Gas Transmission and Distribution	23,882.00	2.73	Chatham	Ontario
G10161	2013	Keele Valley Landfill	18,827.81	2.15	Maple	Ontario
G10343	2013	Ridge Landfill	15,990.00	1.83	Blenheim	Ontario
G10109	2013	Enbridge Gas Distribution Inc.	9,578.21	1.09	North York	Ontario
G10376	2013	Britannia Sanitary Landfill Site	7,840.00	0.89	Mississauga	Ontario
G10364	2013	Essex County Landfill No. 3	6,570.61	0.75	Lakeshore	Ontario
G10365	2013	Essex County Regional Landfill	6,019.28	0.69	Essex	Ontario
G10163	2013	TransCanada Pipeline, Ontario	5,515.61	0.63	Kenora	Ontario
G10348	2013	Trail Road Waste Facility	4,587.16	0.52	Ottawa	Ontario
G10337	2013	Walker Environmental Group Inc. Landfill Sites	4,574.16	0.52	Niagara Falls	Ontario
G10762	2013	Twin Creeks Landfill (formerly Warwick Landfill	4,437.00	0.51	Watford	Ontario
G10310	2013	W12A Landfill	4,220.04	0.48	London	Ontario
G10358	2013	Eastview Landfill	3,293.19	0.38	Guelph	Ontario
G10471	2013	Green Lane Landfill	3,099.84	0.35	St. Thomas	Ontario
G10632	2013	HUMBERSTONE LANDFILL	2,328.33	0.27	Welland	Ontario
G10193	2013	Mohawk Street Landfill	1,986.90	0.23	Brantford	Ontario
G10540	2013	Waterloo Landfill Site	1,961.76	0.22	Waterloo	Ontario
G10032	2013	Brock West Landfill	1,469.30	0.17	Pickering	Ontario

Emissions of CH_4 from landfills have increased since 1990 from 236 kt per year to 300 kt per year. In the Ontario inventory report using a GWP_{100} metric, this accounts for 3-4% of total GHG emissions in Ontario. Alternatively using a GWP_{20} metric, this would increase contributions from CH_4 sources to total CO_2eq by a factor of ~3.4. Ontario is planning to implement a cap-and-trade scheme for all facilities above a threshold of 25,000 tonnes of CO_2eq per year (Ontario Ministry of the Environment, 2016). This is through the *Quantification, Reporting, and Verification of Greenhouse Gas Emissions Regulation* O. Reg. 143/16 made under the *Climate Change Mitigation and Low-carbon Economy Act* in May 2016. Because a CO_2eq factor is being used, this would systemically underrepresent CH_4 emissions from landfills that may not reach

that threshold (i.e. anything below ~1000 kt of CH_4). This includes more than half of the currently operating CH_4 emitting landfill sites. In addition, for the landfill sites above the threshold, reductions in CH_4 emissions (and thus total CO_2eq) are more economic by simply expanding infrastructure, demonstrating systemic inequality in the cap-and-trade scheme. This may incentivize more aggressive CH_4 capture systems in landfills in the future through market pressures. In any case, the use of a basket approach to aggregate GHG emissions to a CO_2eq confounds the challenge beyond a direct approach to CH_4 mitigation.

4 Conclusions and Recommendations

This paper was part of an effort to address the requests of international parties to the United Nations Framework Convention on Climate Change (UNFCCC) on the implementation of common metrics for the accounting of anthropogenic greenhouse gas emissions. Communications in the scientific community have questioned the ability for the Paris Agreement to be successful, given there appears to be a contradiction between the indicated GHG emissions reductions (if successful) and the targets to control peak warming by 2°C (Rogelj et al., 2009, 2016; Rogelj, McCollum, O'Neill, & Riahi, 2013; Schellnhuber, Rahmstorf, & Winkelmann, 2016; Victor & Kennel, 2014). Through investigating the scientific and international-policy basis for GHG emissions metric, it has been shown that the widely-used GWP_{100} contains several subjective value judgements. Because the application of GWP_{100} metrics have been widely accepted and applied without full explanation, these value judgements are being made unintentionally. An alternative metric, the GTP, was also evaluated. While the GTP provides a unique perspective on time-horizons through snapshot future changes in temperature, it retains the same problem of attempting to aggregate molecules with vastly different chemistry, cycles and lifetimes into a single basket. It has further been shown that these generalizations, while useful for providing binned targets for international emissions reduction policy, have the potential to suppress key areas of efficient climate change mitigation opportunities, particularly for SLCPs like CH_4. It has been shown in the energy sector that the carbon intensity of Canadian Oil Sands production increases by 26% when using a GWP_{20} metric due to higher-weighted fugitive CH_4 emissions. An investigation into these fugitive Oil Sands emissions also shows that there is the potential for reduction by 50%, which would also reduce the carbon intensity, an opportunity that has been perhaps overlooked due to the use of the GWP_{100} metric

underestimating the near-term impact of CH_4 emissions. In a similar fashion, it has been shown that landfill biogas (CH_4) capture technology and policy exists in Canada, however execution of this policy and the cap-and-trade policy to begin in 2017 is confounded by the aggregated metric. The use of the GWP_{20} metric once again increases these CH_4 emissions by a factor of 3.3.

The ultimate aim of the Paris Agreements and climate policy is to limit warming to below 2°C. Model projections have shown that this target will likely be surpassed within the next ~50 years. For this reason, parties to the UNFCCC should consider the implementation of shorter time-horizon GWP metrics in order to better highlight non-CO_2 emissions that can be opportunities for economically and environmentally attractive mitigation policies. Considering that in the last century of atmospheric policy there have been specific reductions for air-quality gases due to their specific chemical behavior, i.e. CFC's for stratospheric ozone depletion, SO_2 and NO_2 for acid rain and smog formation and particulate matter as a public health issue, it should not be difficult to develop policy specific for each GHG. Indeed, the United States and Canada have recently agreed on a *specific* reduction target for CH_4 of 45% from 2012-2025 (Prime Minister of Canada, 2016). The Prime Minister's statement contains explicit reasoning that CH_4 is of higher consequence for temperature changes in the near term and an attractive opportunity for economically feasible and aggressive reduction targets. These are clearly-made value judgements that are communicated to a) policymakers and decision-makers, b) international partners and c) the general public. While binning GHG's for general-basket policy has proven useful, this is an excellent example of the benefit of disaggregating GHG's. This case-by-case approach avoids the unclear value judgements made in metrics altogether for specific, strategic and effective policy.

Acknowledgements

This work was funded through the National Science and Engineering Research Council Collaborative Research and Training Experience (NSERC CREATE) program Integrating Atmospheric Chemistry and Physics from Earth to Space (IACPES). Thanks to Dr. Robert McLaren, Dr. Jochen Rudolph, and Carol Weldon for their organization of the NSERC CREATE IACPES program which provided valuable opportunities for mentorship and professional development.

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