The Use of GWP* in
Corporate Greenhouse Gas Accounting

Companion White Paper to **Bridging the Climate-Corporate Gap: Utilizing GWP* with GWP100 for Livestock Companies' Greenhouse Gas Inventories, published in**

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Key Takeaways

- Methane (CH_4) is a short-lived greenhouse gas (GHG) compared to nitrous oxide and carbon dioxide that are long lived gases. Unlike the standard GWP100 metric that evaluates a pulse emission of GHG on warming over a 100-year period, the GWP* metric evaluates CH_4 changing emission rate over 20 years. Therefore, GWP* can better capture CH_4's shorter-lived impacts on warming compared to GWP100.

- For the first time a methodology has been developed to incorporate GWP* into corporate greenhouse gas inventories. The methodology advocates for a split gas dual reporting approach using both GWP* and GWP100. Corporate GHG emissions can be reported on both an absolute and intensity basis.

- Utilizing both GWP* and GWP100 can enable companies to inclusively evaluate long-term and short-term impacts of their respective GHG emission profiles and provides companies with livestock emissions with a means to report in a manner that aligns more closely with their stated climate goals.

- By building a shadow company, organizations will be able to utilize GWP* in corporate GHG accounting. Utilizing multiple GHGs can provide clearer guidance on how corporations can dispense financial resources to accomplish their climate goals.

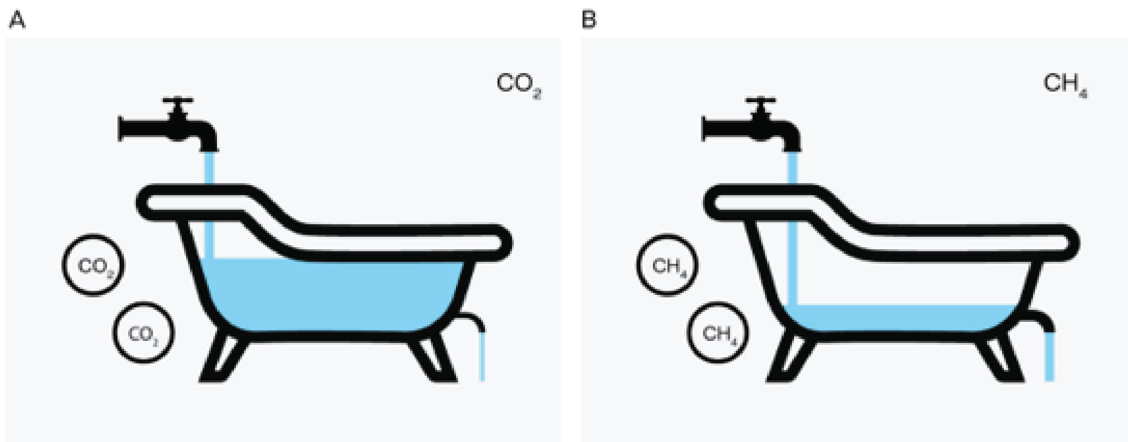
Introduction

According to CDP (previously known as the Carbon Disclosure Project), in 2024, 9 out of 10 food and beverage reporting companies disclosed their Scope 3 (upstream and downstream) greenhouse gas (GHG) emissions (CarbonCloud, 2024). This represents a 38% increase in Scope 3 reporting from 2021 and a 90% increase from 2020. Not only are food companies volunteering to disclose their Scope 3 emissions, but with increasing compliance regulations, such as the European Union Corporate Sustainability Reporting Directive and SB 253 in California, many food companies will soon be required to report their Scope 3 emissions. With increased scrutiny of corporate GHG inventories, companies will need to continue to evolve GHG accounting and incorporate the best available science into their inventories. This is particularly true for food companies where over 90% of their emissions are Scope 3 (CarbonCloud, 2014; Thompson et al., 2025). Only with improvements in corporate reporting and accurate depictions of GHG impact on warming will companies be able to holistically understand their supply chains' impact on climate, enabling them to effectively distribute climate change mitigation resources.

Currently, GWP100 is the most ubiquitous accounting metric used to determine the effect of GHG emissions on climate warming. This metric is based on a 100-year timeframe and expresses all GHG on a carbon dioxide (CO_2) equivalent basis (CO_2-e; IPCC, 2023). In this metric CO_2 has a warming potential of 1 and biogenic methane (CH_4) has a warming potential of 28 (based on the IPCC AR5 report). As it stands, GWP100 is the only metric allowed by the corporate GHG reporting standard body, Greenhouse Gas Protocol (GHGP). Although GHGP dictates GWP100 use, the metric presents limitations and has received criticism, particularly when assessing warming impacts of some GHG species (O'Niel, 2000; Shine, 2009). The GWP100 metric relates pulse (one off) emissions of various GHG emissions to a CO2-e, which is adequate for long-lived climate pollutants (LLCP), such as nitrous oxide and CO2. However, GWP100 falls short when evaluating the warming impacts of short-lived climate pollutants (SLCP), such as CH4 under continuous emission scenarios. Fractions of LLCP will persist in the atmosphere for centuries and continue to increase their "stock" (atmospheric concentrations) without long-term sustained interventions that drawdown that atmospheric pool (Lynch et al. 2020, Eby et al., 2009). This increase in stock GHGs leads to a compounding increase on temperature (Lynch et al., 2020). In essence, emissions of past decades will continue to add warming in coming decades. In contrast, CH_4 with a lifespan of 12 years operates as a "flow" gas. When the rate of CH_4 disappearance, due to atmospheric oxidation is equal to the rate of CH_4 emission to the atmosphere, there will be no increase in atmospheric CH_4 concentrations (Cain et al., 2019). Accordingly, changes in emission rates over time are an important consideration when assessing the warming impact of SLCP.

A simplistic analogy for comparing stock and flow GHG emissions is the bathtub model (Figure 1). In this example, the accumulation of GHGs are equated to the accumulation of water in a bathtub. The level of water in the bathtub is determined by the rate of water flowing out of the tap and the rate of water exiting the drain. The wider the drain, the faster water can exit the bathtub; the smaller the drain the slower water exits the bathtub. For LLCP, like CO_2, the bathtub has a small drain and the rate of water entering the tub is faster than the rate of water exiting, resulting in water accumulating in the bathtub. However, for the SLCP like CH_4, a wide drain opening allows for rapid removal of water from the bathtub and the water does not accumulate in the bathtub at the same rate as the LLCP. The shorter the atmospheric lifespan the larger the "drain opening" and the faster the GHG will be removed from the atmosphere. In relationship to atmospheric gases, CH_4 will leave the bathtub at a faster rate than CO_2 when emission rate is below oxidation rate.

Figure 1: Metaphorically Comparing Stock and Glow Greenhouse Gases to Faucets and Drains in Bathtubs.



GWP*

SLCP emissions that would be equivalent to the cumulative warming impact of a pulse of CO_2 (Smith et al., 2021). In other words, incorporating the short-lived lifespan of CH_4 (i.e., the large drain in the bathtub example), into its warming equivalence. The latest version of the GWP* metric for CH_4 is as follows:

$$CO_2 - we = 128 \times E_{CH_{4(t)}} - 120 \times E_{CH_{4(t-20)}}$$

Where CO_2-we emissions of CH_4 at year t (GWP* value), and ECH_4 is the CH_4 emissions in tons of CO^2-e (using AR5 GWP100 values) at years t or t minus 20 (t–20). Because the equation is based on a weighted difference in the rate of emissions at two different times, it essentially equates the rate of change in emissions of a short lived GHG to a single pulse release of a long lived GHG. The differences between the GWP100 and the GWP* metric are described in Table 1.

Table 1: Differences between the GWP* and GWP100 metric.

GWP100	GWP*
Global warming potential based on 1 time point (pulse emission)	Global warming potential based on year -20 and year -1
Global warming potential factor is constant	Global warming potential varies based on changes in emission rates
Formula: 28 x kg of annual CH_4, based on IPCC AR5	Formula: GWP*= (128 * Year 1 kg of CH_4)-(120* Year -20 kg of CH_4)
Does not delineate between stock and flow gases.	Short lifespan of CH_4 is embedded in formula.
Easy for businesses to use, required by Greenhouse Gas Protocol	Businesses have been limited in their ability to use the metric due to formula obstacle.

Although there is societal debate surrounding the use of GWP* (Meinshausen and Nicholls, 2022), when the cumulative effects of warming over time GWP* was found to approximate the additional warming effect on climate from a time series of SLCP more closely than other metrics like GWP100 (Collins et al., 2020). In addition, in an IPCC Expert Review, commenters stated that "GWP* may better represent the actual warming caused by CH_4 emissions", and "GWP* provides a useful additional perspective about the effect of cumulative CH_4 emissions" (IPCC, 2022). Overall, the cumulative effect of CH_4 on warming overtime is substantially different when using GWP* verses GWP100, as seen in Figure 2. In Figure 2, the green shading represents the difference in the suggested contribution to warming from continuous CH_4 emissions between GWP100 and GWP* metrics, demonstrating that GWP100 can overestimate CH4's contribution to warming. However, if CH_4 continues to increase overtime, GWP100 can also underestimate CH_4's contribution to warming.

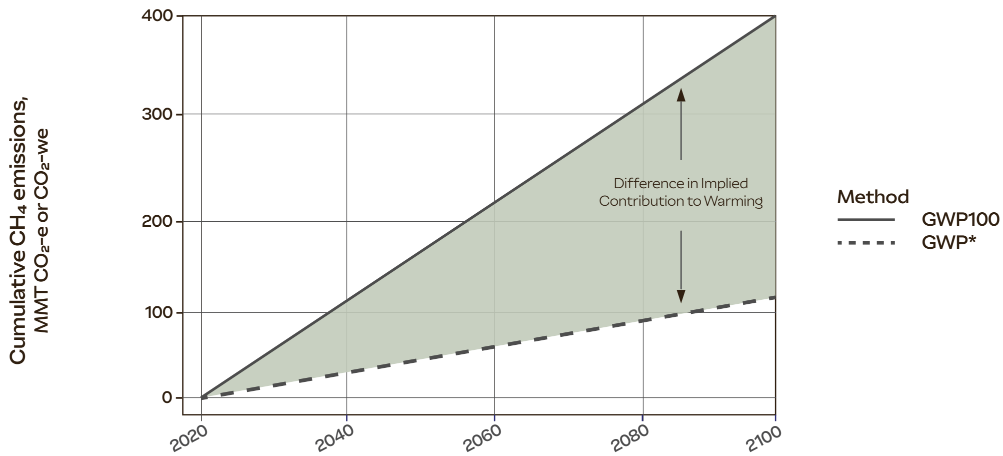


Figure 2: Using GWP100 and GWP* to determine CH_4's cumulative warming impact on climate over time.

Using GWP* in Corporate Accounting

The most recent IPCC report refrains from recommending one metric because the appropriateness of metric choice depends on the purpose for which gases are being compared (IPCC, 2021). The same reasoning can be extrapolated to corporations and why utilizing multiple metrics can aid organizations in having a more complete understanding of their warming contributions. Furthermore, multi-metric reporting may allow readers of the GHG disclosure reports to make a more accurate assessment of a company's contribution to climate warming and provide some companies with a means to report, evaluate, and mitigate GHG in a more meaningful way. Thereby, using GWP* with GWP100 may be more appropriate for assessing corporations' climate commitments than GWP100 alone. Although other GHG metrics have also incorporated the short-lived aspect of CH_4 into their warming equivalent (such as Cumulative Global Temperature Change), GWP* has received more attention, in recent years than other metrics and has been used and/or advocated by multiple public and private establishments (Fonterra, 2022; Mazzetto et al., 2022; Deakin, 2024). The adoption of the GWP* metric into private companies and increasing focus from livestock and meat organizations has instigated the need to design a consistent methodology for corporations who desire to dual report their emissions with GWP*. This methodology in turn can provide scientific and application guardrails.

The How-to Guide

The GWP* calculation requires 20-years of emission data. Although this temporal component of GWP* has enabled the metric to better assess CH_4's impact on warming, it subsequently has limited companies' ability to adopt the metric. As many food companies have only calculated their emissions within the last decade and do not have 20 years' worth of corporate data, the GWP* metric has been unusable for corporate emissions reporting.

The most recent IPCC report refrains from recommending one metric because the appropriateness of metric choice depends on the purpose for which gases are being compared (IPCC, 2021). The same reasoning can be extrapolated to corporations and why utilizing multiple metrics can aid organizations in having a more complete understanding of their warming contributions. Furthermore, multi-metric reporting may allow readers of the GHG disclosure reports to make a more accurate assessment of a company's contribution to climate warming and provide some companies with a means to report, evaluate, and mitigate GHG in a more meaningful way. Thereby, using GWP* with GWP100 may be more appropriate for assessing corporations' climate commitments than GWP100 alone. Although other GHG metrics have also incorporated the short-lived aspect of CH_4 into their warming equivalent (such as Cumulative Global Temperature Change), GWP* has received more attention, in recent years than other metrics and has been used and/or advocated by multiple public and private establishments (Fonterra, 2022; Mazzetto et al., 2022; Deakin, 2024). The adoption of the GWP* metric into private companies and increasing focus from livestock and meat organizations has instigated the need to design a consistent methodology for corporations who desire to dual report their emissions with GWP*. This methodology in turn can provide scientific and application guardrails.

To overcome this, Klopatek et al. (2026) developed an approach to construct previous emissions data which is grounded in national and supply chain scale emissions, where calculated historical emissions form a "shadow company". Through development and implementation of this shadow company, for the first time, food companies will now be able to use the GWP* metric starting from their baseline reporting year.

Calculating Baseline Year Emissions

To demonstrate how to apply the GWP* metric to a corporate inventory we generated a mock beef company, termed Global Beef Company. To initiate GHG reporting, the baseline year needs to be identified. This baseline year is critical for companies, for all future GHG inventories will be compared to this initial inventory. For Global Beef Company the baseline GHG reporting year was 2020. For simplicity, only Scope 3 cattle emissions were included in the Global Beef Company GHG inventory. Although the Global Beef Company was limited to cattle emissions, the GWP* metric can be applied to a variety of livestock SLCP emissions including but not limited to dairy, swine, and poultry (Beck et al., 2023). To determine baseline year emissions for Global Beef Company all emissions were first calculated at the country level of operation. Calculating GHG inventories at the country level will be critical for proper shadow company development. For the Global Beef Company, 2020 GHG inventories were calculated for Brazil, Australia, and the United States, with each operating country harvesting a million head of cattle a year, equating to 3 million head annually. Currently, many corporate GHG inventories are compiled on a CO_2-e basis. However, because GWP* only applies to SLCP like CH_4, GHG emission inventories will need to be decoupled by species (i.e., separate CH_4, CO_2 and N_2O). Decoupling GHG within corporate inventories will require more effort, however there are multiple benefits for this undertaking. Not only will corporations be able to utilize multi-metric reporting, they will also be able to set GHG reduction targets by species as suggested by the IPCC (IPCC, 2021). For Global Beef Company, all baseline emissions were calculated using the Global Livestock Environmental Assessment Model (using AR5 values; GLEAM) database, which is a United Nations Food and Agriculture carbon accounting tool (FAO GLEAM, 2023). In terms of livestock specific emissions, utilizing publicly available datasets who report GHG by species, such as the United Nations Food and Agriculture GLEAM tool may make the transition to a spilt gas reporting manageable. The current analysis was limited to biogenic CH_4 only. At this time, non-biogenic CH_4 should not be included in the shadow company or GWP* calculations. Following reporting guidelines (i.e. 14067 and others), we advise calculating non-biogenic CH4 using GWP100 and reporting non-biogenic CH_4 separately from biogenic CH_4. With the recent changes made in the GHGP land use standards, land use change was out of scope for the present analysis. For total emissions for Global Beef Company see Table 2. Emissions were expressed in million metric tons (MMT). If desired, Scope 1 and 2 CH_4 could be considered in practice if they are biogenic.

Table 2: Scope 3 Category 1a1 methane (CH_4), nitrous oxide (N_2O), carbon dioxide (CO_2) and total GHG emissions for Global Beef Company.

	GHG Emissions [2], MMT CO_2e			
Operating County	CH_4	N_2O	CO_2	Sum
Australia	0.21	0.04	1.09	1.31
Brazil	0.29	0.04	0.65	0.95
United States	0.17	0.05	1.21	1.38

[1]Category 1a, Purchased Goods and Services in corporate GHG category as defined in Greenhouse Gas Protocol (GHGP, 2025). This category includes all upstream (i.e., cradle-to-grave) emissions from the production of products purchased or acquired by the reporting company in the reporting year. For the current analysis, only purchased livestock were included in Category 1a. Land use change was excluded for this analysis.

[2]Emissions were based on GLEAM AR5 emission factors and expressed for total herd. Annually, 1,000,000 animals were harvested per country. Emissions expressed on mass and not CO_2 equivalence for model input. For additional material see supplemental material in Klopatek et al., 2026.

Building the Shadow Company

With many companies having acquisitions, divestments, and lack of historical data, basing shadow company emissions on historic company (pre-baseline year) emissions in most cases is not feasible. To avoid challenges of back computing company emissions or any pretense of greenwashing, the current methodology dictates the use of national GHG emissions databases, which all signatory countries of the UNFCCC must generate. The Environmental Protection Agency (EPA) generates this data for the U. S. and publishes it annually in its Inventory of U.S. Greenhouse Gas Emissions and Sinks report (apart from the most recent reporting year, 2025). What's unique about national inventory GHG data is the ability to reflect changes in livestock emissions over time at the country level. These changes in emissions can be related to improvements in efficiencies and changes in livestock populations. Representing these fluctuations in emissions in varying countries can create a fairness across all businesses around the globe. If a national inventory containing agricultural emissions is not available for a particular country, the default emissions database, such as the FAO dataset, could be utilized.

Most national GHG inventories segregate GHG emissions by source and species. The emissions to be evaluated by the shadow company should only include the emissions that are being evaluated within the corporate GHG inventory. For the Global Beef Company, GWP* was applied to cattle enteric and manure CH_4 emissions only, therefore the shadow company exclusively referenced cattle enteric and manure emissions. To ensure the proper use of the shadow company methodology, individual shadow companies were built for each country of operation. For the Global Beef Company historic cattle emissions (pre-baseline year) were computed for Brazil, Australia, and the U.S. from 2000 to 2020. The shadow companies' emissions from year -20 to -1 were calculated by multiplying the proportional change in national GHG emission inventories (e.g. EPA GHG inventory) by the Global Beef Companies relevant country level baseline year CH_4 inventory (i.e. enteric and CH_4 manure emissions). This means that the shadow companies' calculated emissions remain proportional to the national inventories and therefore reflect real changes that occur within the livestock industry. For example, if the country level historic cattle emissions were 20% lower in the year 2001 compared to 2020 then the shadow company's historic emissions would be 20% lower in 2001 compared to the corporate GHG inventory baseline year. After the shadow company(s) CH_4 inventories have been built the GWP* formula (CO_2-we =128 × Yrbaseline – 120 × Yr-20) can be applied country by country. Only after the individual shadow companies were calculated at the country level could the shadow companies be combined to create one global shadow company and one set of company methane emissions at the global level. For a summation of shadow company development see Table 3. For details on how GWP* impacts a company at the individual country of operation level and to utilize a shadow company template for one's own operations see Klopatek et al. (2026) and the accompanying supplemental material.

Re-baselining

Over time, companies may need to recalculate and re-establish GHG emissions for the base year to reflect "significant" changes in a company's structure or inventory, such as mergers, acquisitions, or divestitures. The present methodology for re-baselining follows the GHGP guidelines on re-baselining. For re-baselining scenarios and additional guidance see Klopatek et al. (2026).

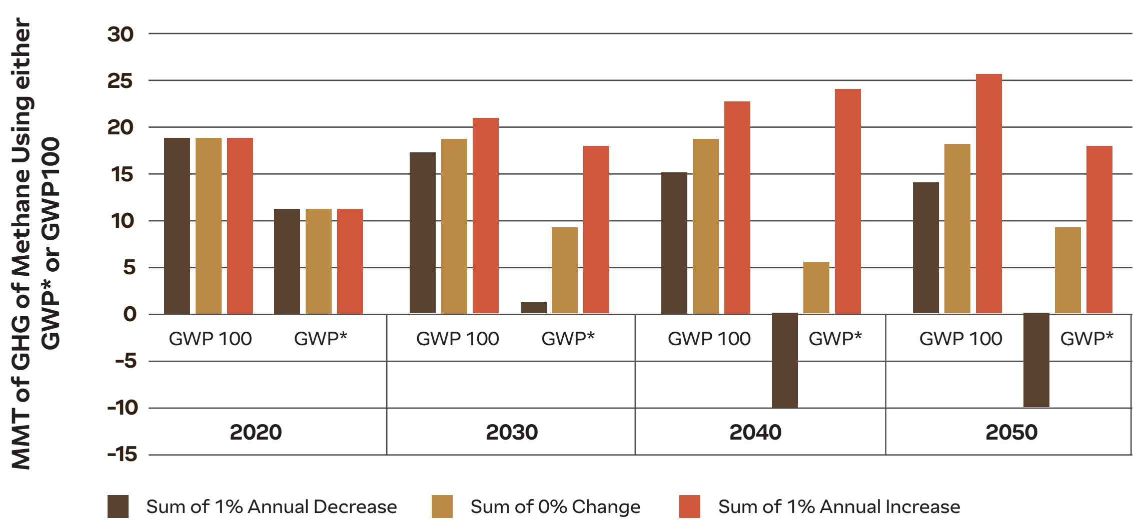
Table 3: Steps for Building a Shadow Company with Biogenic Methane (CH_4) Emissions in the Inventory

Steps	Steps for Building a Shadow Company with Biogenic Methane (CH_4)
Step 1	Separate biogenic CH_4 emissions by country level. Convert baseline year CH_4 from global warming potential into kg. For GWP100 reported in metric tons convert metric tons into kg, then divide by the GWP of 28 to get mass of the CH_4 in kg.
Step 2	Input baseline year's biogenic CH_4 for each country (kg of methane, non CO_2-e). Baseline emissions for livestock can be calculated using emission internal harvest inventory data and emission modeling tools like GLEAM. Include methane from only biogenic sources (i.e., enteric and manure).
Step 3	Divide the company's biogenic CH_4 emissions by the national emissions data at the baseline year and multiply this decimal by the national emissions for each of the 20 years prior to the baseline year. This provides the "shadow company's" CH_4 emissions for years -1 through -20. Shadow company must be computed at the country of operation level. If the company operates in multiple countries, multiple shadow companies need to be computed.
Step 4	Apply the GWP* formula (i.e., 128 × Yrbaseline - 120 × Yr-20) to CH_4 emissions using Shadow company Yr-20 and the baseline year. This produces a GWP*, or a CO_2-we value, for biogenic emissions for the baseline year. Once the shadow companies are built and computed for all countries they can be added together to provide a global shadow company value.

Impacts of Using GWP* and GWP100 in Corporate GHG Inventory Reporting

When the developed methodology was applied to the Global Beef Company for the 2020 baseline year, GWP* presented an implied contribution to warming that was 41% lower than GWP100 (Figure 3). Over time, if CH_4 emissions continue to decrease at 1% annually GWP* would result in a negative value. The negative value does not suggest that a company no longer contributes to warming. Rapidly declining CH_4 emissions have a negative value because there is a declining temperature impact, relative to the warming caused by past SLCP emissions at a previous point in time (IPCC, 2021). Although not directly analogous, one way to view a negative GWP* value is temperature. For example, if on Monday the temperature is 85 and on Tuesday the temperature is 75, Tuesday is cooler than Monday by -10 degrees, but there is still a temperature. Therefore, although reductions in livestock CH_4 may result in a negative as long as livestock are producing emissions, there will still be an impact on climate. However, for a negative value to be possible, corporations would have to make substantial reductions in CH4 emissions across their supply chains. In countries with highly evolved beef production systems like in the US and Canada these types of reductions would be challenging. However, in countries like Brazil where age of cattle is decreasing and feedlot utilization is increasing these types of reductions could be possible (Abiec, 2023; FAO, 2023). In contrast, if companies continued to increase CH_4 emissions on an annual basis, GWP* would estimate a greater impact on warming compared to GWP100 (Figure 3). If CH_4 emissions neither increased nor decreased over time, GWP* would continue to present a lower value than GWP100.

Figure 3: Comparing Annual GWP* and GWP100 Methane Emissions



Dual Reporting of Emissions

To remain consistent with current corporate reporting guidelines and to improve the reporting precision of CH_4 impact on warming, the present methodology recommends dual reporting emissions, where both GWP* and GWP100 are reported. One recommended approach is split gas accounting, as first suggested by Lynch et al. (2016), where each GHG emission is reported separately (Table 4). In this reporting approach, CH_4, N_2O and CO_2 are first reported individually on a GWP100 basis then combined for CO2-e Total. Next, CH_4 is reported on a GWP* basis with the unit of CO_2-we. For direct CO_2-e and CO_2-we GHG total comparisons CH_4 CO_2-we can be added to N_2O and CO_2 using GWP100 for Total CO_2-we. For more reporting examples see Klopatek et al., 2026.

Table 4: Scope 3 Category 1a1 methane (CH_4), nitrous oxide (N_2O), carbon dioxide (CO_2) and total GHG emissions for Global Beef Company.

Global Beef Company Scope 3 Greenhouse Gas Emissions-Dual Reporting								
	Annual Emissions Report: Year 2021							
	AR 5 : GWP100, in units of CO2-e					GWP*, in units of CO2-we		
Scope 3	CO_2	CH_4	N_2O	Total Emissions	Total Emissions Intensity	CH_4	Total Emissions	Total Emissions Intensity
	(tCO_2)	(tCH_4)	(tN_2O)	(tCO_2e)	(tCO_2-e/t HCW)	(tCH_4-we)	(tCO_2-we)	(tCO_2-we/t HCW)
Annual Emissions	2.84	18.78	3.20	24.82	28.13	11.15	17.19	19.48

Reporting absolute emissions in corporate sustainability reports has been useful when demonstrating total changes in corporate emissions, but often, absolute emissions cannot express advances in supply chain system efficiency. Therefore, sustainability reports would be improved if both absolute and intensity metrics were incorporated into their reports. For GWP100 intensity Total GWP100 emissions are divided by annual production weight. For the Global Beef Company production weight was defined by kilograms of Hot Carcass weight. To use GWP*, Total CO_2-we can be divided by product production to form Total CO_2-we Intensity as seen in Table 4. For more information on calculating intensity metrics please see Klopatek et al., (2026).

Conclusion

The increased pressure and demand for food companies to accurately report emissions while continuing to improve supply chain resilience and food security has fueled the need for more holistic and nuanced reporting. For the first time a methodology has been developed to allow companies to dual report emissions on both a GWP100 and GWP* basis in their inventories. The creation of a shadow company has addressed the 20-years' worth of data obstacle for incorporating GWP* into corporate GHG inventories. Furthermore, reflecting the changes in biogenic CH_4 production for the shadow company at the national level decreased chances of misappropriating emissions and claims of greenwashing. Utilizing multiple metrics can enable companies to inclusively evaluate long-term and short-term impacts of their respective GHG emissions on climate and, ideally, allowing them to better assess their progress towards stated climate goals, such as commitments related to climate. The knowledge acquired during this evaluation process may better inform organizations on how and where to focus their financial resources for reducing emissions.

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Biographies

Sarah Klopatek

Dr. Sarah Klopatek is the Owner and Founder of Klopatek Livestock Solutions. In her role, Klopatek works on livestock system dynamics research, supply chain risk management, life cycle assessment development, and land use change. Klopatek continues to work alongside academic institutions and maintains a position at the University of Wisconsin as Honorary Faculty at the Nielson Institute for Environmental Studies and serves as an Adjunct Professor at Colorado State University in the Animal Science department.

Klopatek received her PhD and Post-doctoral education at University of California, Davis in Animal Science; a masters in Animal Science at Texas A&M, and a bachelors in Animal Science at the University of Arizona.

Matthew Beck

Matt graduated with a B.S. (2015) and M.S. (2017) in Animal Science from Oklahoma State University. He then completed his Ph.D. in Animal Science (2020) at Lincoln University, Christchurch, New Zealand. After school, Matt was then a Research Animal Scientist for the USDA-ARS located in Bushland, Texas for three years. Currently, Matt is an Assistant Professor of Beef Cattle Nutrition with the Texas A&M University, Department of Animal Science.

Logan Thompson

Logan grew up on a registered Horned Hereford ranch in central Texas which instilled a passion to improve the sustainability of beef production by developing practical solutions for producers. Logan started his bachelor's degree at Sam Houston State University in Huntsville, TX prior to completing his degree at Texas Tech University in 2015. Following this he earned a Masters in beef sustainability at Oklahoma State University in 2017 and a PhD in ruminant nutrition at Michigan State University in 2021. Prior to joining Kansas State University in August of 2022, he served as a post-doctoral fellow at Colorado State University.

Sarah Place

Dr. Sara E. Place is an Associate Professor at CSU AgNext. Previously Sarah was the chief sustainability officer at Elanco, where she provided customers with technical expertise on sustainability issues and supports Elanco's Healthy Purpose initiative. Prior to joining Elanco, Place served as the senior director for sustainable beef production research at the National Cattlemen's Beef Association and was an assistant professor in sustainable beef cattle systems at Oklahoma State University. Place received a doctoral degree in animal biology from the University of California, Davis; a bachelor's degree in animal science from Cornell University; and an associate's degree in applied science with a focus on agriculture business from Morrisville State College.