About the Supply Chain Greenhouse Gas Emission Factors v1.3 NAICS-6 Datasets

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# Summary

This document describes the Supply Chain Greenhouse Gas Emission Factors v1.3.0 NAICS-6 U.S. commodity datasets. Just like for the previous version, v1.2, the datasets comprise greenhouse gas (GHG) emission factors (Factors) for 1,016 U.S. commodities as defined by the 2017 version of the North American Industry Classification System (NAICS). However, a number of core updates were made: (1) the Factors are built with U.S. GHG emission data for 2022, (2) IPCC AR5 global warming potentials are used instead of AR4, (3) the underlying economic input-output model was updated to the 2017 benchmark, and (4) and the direct GHG emission sector attribution model was updated.

Factors are given for all NAICS-defined commodities at the 6-digit level except for electricity, government, and households. Each record consists of three factor types as in the previous releases: Supply Chain Emissions without Margins (SEF), Margins of Supply Chain Emissions (MEF), and Supply Chain Emissions with Margins (SEF+MEF). One set of Factors provides kg carbon dioxide equivalents (CO2e) per 2022 U.S. dollar (USD) for all GHGs combined using 100-yr global warming potentials to calculate the equivalents. In this dataset there is one SEF, MEF and SEF+MEF per commodity. The other dataset of Factors provides kg of each unique GHG emitted per 2022 dollar per commodity without the CO2e calculation. The dollar in the denominator of all factors uses purchaser prices.

# Background

The Supply Chain GHG Emission Factors estimate the GHG emissions indirectly and directly associated with a U.S. commodity or industry per dollar value over specific life cycle phases (Ingwersen and Li, 2020a). Sets of these Factors were originally published for years 2010-2016 and subsequently revised twice (Ingwersen and Li, 2020b; W. W. Ingwersen and Li, 2022, 2022-03-07). The v1.2 dataset, which was based on the 2019 GHG data, was released in 2023 (Ingwersen, 2023).

The Factors are created using a combination of two models - a sector attribution model for GHGs (SAM-GHG, formerly referred to as the National GHG Industry Attribution Model), and the U.S. Environmentally-Extended Input-Output (USEEIO) model. The SAM-GHG produces totals of the direct emissions by detailed industries and is used as an input into a selected USEEIO model. The USEEIO model produces the direct and then indirect emission intensities following data year adjustments and calculations. The final factors are adjusted to reflect purchaser prices, which are useful with expenditure data.

The first set of Factors described here, which are in CO2e, was created specifically at the request of the General Services Administration for use in estimating the Scope 3 GHG footprint of federal agencies. The Factors are intended for reporting GHGs embodied in purchases or what is referred to in the GHG Protocol standards as Scope 3, category 1 “Purchased goods and services” and category 2 “Capital goods” (USEPA, 2024; WRI and WBCSD, 2013). Some may choose to use them for other Scope 3 categories as well. The second set of Factors, provided by gas, are complimentary data that enable greater flexibility and resolution in accounting and reporting GHGs. Providing factors by gas allows users to track and report GHGs in expenditure data per gas. Leaving the gases in kg of mass allows users to choose global warming potentials of their choice in performing CO2e calculations.

The Factors are primarily intended for use in Scope 3 GHG accounting and reporting. They complement other GHG emission factors provided by the USEPA in the Emission Factor Hub for use in Scope 1 and 2 reporting. The basic use of the Factors is to match a Factor category with an item that has been purchased and multiply the respective Factor by the dollar amount spent. Such a calculation will result in direct and indirect GHG emissions associated with the given USD amount of a good or service.

# Methods

The Factors are derived using the methodology described in the 2020 report (Ingwersen and Li, 2020a), except where noted here.

The Factors are constructed using a more recent SAM-GHG model by NAICS-6 Industry (Young et al., 2024) that was applied to GHG emissions for year 2022 given by the most recent U.S. Greenhouse Gas Inventory (U.S. Environmental Protection Agency, 2024). This dataset includes emissions totals for carbon dioxide, methane, nitrous Oxide, carbon tetrafluoride, HFC-125, HFC-134a, HFC-143a, HFC-236fa, HFC-32, sulfur hexafluoride, HFC-23, hexafluoroethane, nitrogen trifluoride, perfluorocyclobutane, and perfluoropropane. All of these GHGs are used in Factor construction.

Standard names for the GHGs are taken from the Federal LCA Commons Elementary Flow List (FEDEFL) v1.1.2 (Ingwersen et al., 2021).

The USEEIO model created, USEEIO v2.2.22-GHG,is a commodity-based model, with a total requirements matrix prepared using the same modeling assumptions used for USEEIO v2.0 (Ingwersen et al., 2022). The economic components of the USEEIO model were updated to use the 2017 benchmark detailed Make and Use tables, which became available as part of the 2023 comprehensive industry account updates (BEA, 2023).

v1.3 does not have unique Factors for different sub-industries of the Waste and Remediation sectors, for example for landfills. Waste sub-industry detail was provided for USEEIO v2.0 and for the v1.2 Factors, because data were available for disaggregation of the waste sector for the underlying 2012 detailed input-output tables. Equivalent data for disaggregation of the Waste and Remediation sector for the 2017 IO tables were not available in time to provide v1.3 Factors.

For one set of Factors, the 100-yr global warming potentials (GWPs) from the IPCC 5th Assessment report (AR5) are used to convert GHGs into CO2e (IPCC, 2014). The dataset of the GWPs used was part of a release of IPCC GWPs from the 4th through the 6th report (Young et al., 2023). These GWPs in the form of characterization factors that have already been aligned with the FEDEFL. These Factors are derived from the raw N matrix of the underlying USEEIO model. The N matrix contains indirect plus direct CO2e per commodity in kgCO2e per USD. The other set of Factors that are presented in kg per GHG are drawn from the M matrix. The M matrix contains indirect plus direct GHGs by gas per commodity in kg GHG per USD. The M and N matrices are further described in the USEEIO v2.0 documentation (Ingwersen et al., 2022).

The raw values from the underlying USEEIO model M or N matrices are adjusted to be in purchaser prices in 2022 USD using the model $Φ$ and $ρ$ matrices in previously described procedures (Ingwersen and Li, 2020a).
Commodities for which all factors have 0 values are dropped. Factors for USEEIO sectors representing government (G\*), special sectors used for input-output table balances (S\*), and those for the electricity sector (221100) are dropped. Government sectors were not needed for the designated use case, and electricity factors were dropped because estimation of GHG emissions from electricity is part of Scope 2 in the GHG Protocol, and these factors are intended, as specified above, for limited applications in Scope 3 accounting. The remaining factors are mapped from USEEIO code to NAICS 2017 6-digit codes (U.S. Census Bureau, 2021). Where more than one USEEIO code maps to a single NAICS 2017 sector, an monetary output-weighted approach is used to average the factors using the commodity output for the target year of 2022 as the weighting factor.

Model validation checks were performed for the USEEIO model underlying these Factors, following the same economic and environmental flows validation procedures used to validate the USEEIO v2.0 model (Ingwersen et al., 2022).

A comparison of the Factors to the previous version (v1.2) (Ingwersen, 2023) was performed. In order to compare the Factors, the following steps were taken:

1. Factors were associated with their unique USEEIO codes (rather than the NAICS-6).
2. Waste sector Factors (562\*) were removed because of a difference in classification in the underlying USEEIO models used.

The dollar years in the denominator of v1.3.0 and v1.2 are different – v1.3.0 Factors use 2022 USD, v1.2 factors use 2021 USD. However, this difference was left as is for this comparison, since the objective was to show the difference between published versions without further adjustment.

# Results

All tables can be found at the end of the text.

The dataset provides sets of factors including Supply Chain Emissions Factors (SEFs), Margin Emission Factors (MEFs), and Supply Chain Emission Factors + Margin Emission Factors (SEF+MEF) for commodities defined by unique 2017 6-digit NAICS codes. These represent 353 unique sets (SEF, MEF, SEF+MEF) of factors.

Table 1 shows the distributions of the SEFS, MEFs, and combined Factors. Among non-zero factors, the range of factor values is 0.029 - 3.924 kg CO2e/$, with a median value of 0.173 and a mean of 0.2819 indicating that most combined factors are < 0.2819 kg CO2e/$. 75% of SEFs are less than 0.32925 kg CO2e per USD. MEFs are non-zero for 45% of commodities. MEFs are in all cases less than the corresponding SEFS, and therefore the SEFs+MEFs are most influenced by the corresponding SEF.

Table 2 lists the 20 highest Factors.

The largest combined factor is for *Cement Manufacturing* (327310); the next largest factors are for *Cattle farming and feedlot* sectors (112\*), followed by *Lime and Gypsum manufacturing* (3274\*) sectors and *Pipeline transportation* (486\*). Other animal raising and chemical products round out the top 20.

The underlying USEEIO model passed model validation checks, including the check that the total GHGs per industry can be recalculated from the model using total US production in the demand vector, using Equation 28 in Ingwersen et al. (2022).

## Comparison to Previous Factors

We compared the SEFs with the previous release based on common USEEIO codes. 1016 USEEIO codes were in common between the underlying models for v1.2 and v1.3.0, and SEFs based on these codes were compared.

Table 3 shows a statistical summary of the relative change both for the factors in CO2e and for the factors by gas for the Supply Chain Emission Factors with Margins. Data are shown as fractional change.

The median change in the CO2e SEFs was -18%. 75% of the SEFs The majority of SEFs for carbon dioxide have decreased between 8 % and 32 %, with a median value of change being -19. Methane and nitrous oxide SEFs have on average decreased as well. Methane has decreased for most SEFs between 19 % and 38 %. Nitrous oxide has decreased for most SEFs between -8% and 26%.

Of the 1016 Supply Chain Emission Factors with Margins, 139 increased by more than 5%, and 796 decreased by more than 5%.

Table 4 and Table 5 show the commodities with the greatest increase and decreased in their SEF+MEF. The waste sectors commodities changed significantly due to the absence of waste disaggregation in the USEEIOv2.2.22-GHG model used in comparison with the USEEIOv2.1.19-GHG model. In the current version all NAICS sectors starting with 562\* have the same Factors. The agricultural and mining sector Factor decreases are most driven by economic output from 2019 to 2022 increasing more than GHG emissions.

Data on change by commodity, GHG for each SEF type are provided in the RelativeChangefromv1.2tov1.3.0inSEFsinCO2e.csv and RelativeChangefromv1.2tov1.3.0inSEFsbyGHG.csv supporting documents.

# Usage Notes

Users of these Factors for estimating GHGs associated with purchased goods or services should follow the following steps. This assumes the goods and services are valued in USD, and not mass or physical quantities.

1. Associate each good or service with the closest NAICS code using NAICS code descriptions.
2. OPTIONAL but RECOMMENDED. Adjust the dollar year of the selected Factors to match the dollar year of the spend data. For instance, to adjust any SEF from the given 2022 year to 2023, use the following equation:

$$SEF\_{c\$2023}=SEF\_{c\$2022}\*\frac{CPI\_{c,2022}}{CPI\_{c,2023}}$$

where the $CPI$ is a annual commodity-specific price index for commodity $c$. This calculation is equivalent to the $ρ$ matrix adjustment described in the USEEIO v2 documentation used for USEEIO v2.0 (Ingwersen et al., 2022), where the CPI data used are the industry-specific chain-tyoe prices published by the BEA as part of the industry account underlying detail data (BEA, 2022), which are then transformed into commodity-form using a market shares approach. The supply-chain-factors code can be executed to generate all the Factors in a user-provided dollar year to perform this change using the factor adjustment functionality built into useeior (Li, Mo et al., 2022). As of the time of publication, detailed level chain-type prices were not available after 2022.

1. Multiply dollars spent for a good or service by its matched Factor to get kg of a GHG or CO2e the total direct + indirect GHG emissions for a given good or service, depending on the unit of the given Factor. If users wish to convert GHGs into CO2e using IPCC global warming potentials, they can access a set GWPs from various IPCC reports and for 20 and 100-year time horizons that match with the GHG names used in this dataset in the IPCC GWPs for FEDEFL v1 dataset (Young et al., 2023).

Do not add the results of the calculation of SEF and/or MEF to the result of the SEF+MEF, since this will be duplicative.

Table 1. Distributions of Factor values by Factor Types.

| **Factor Type** | **Min.** | **1st Qu.** | **Median** | **Mean** | **3rd Qu.** | **Max.** |
| --- | --- | --- | --- | --- | --- | --- |
| Supply Chain Emission Factors without Margins | 0.026 | 0.103 | 0.159 | 0.2650 | 0.3022 | 3.846 |
| Margins of Supply Chain Emission Factors | 0.000 | 0.000 | 0.000 | 0.0169 | 0.0302 | 0.125 |
| Supply Chain Emission Factors with Margins | 0.029 | 0.108 | 0.173 | 0.2819 | 0.3292 | 3.924 |

Table 2. Top 20 Supply Chain Emission Factors with Margins. Unit is kg CO2e per USD 2022.

| **2017 NAICS Code** | **2017 NAICS Title** | **Supply Chain Emission Factors without Margins** | **Margins of Supply Chain Emission Factors** | **Supply Chain Emission Factors with Margins** |
| --- | --- | --- | --- | --- |
| 327310 | Cement Manufacturing | 3.846 | 0.078 | 3.924 |
| 112111 | Beef Cattle Ranching and Farming | 2.847 | 0.045 | 2.893 |
| 112112 | Cattle Feedlots | 2.847 | 0.045 | 2.893 |
| 112130 | Dual-Purpose Cattle Ranching and Farming | 2.847 | 0.045 | 2.893 |
| 112120 | Dairy Cattle and Milk Production | 1.682 | 0.042 | 1.724 |
| 327410 | Lime Manufacturing | 1.560 | 0.063 | 1.623 |
| 327420 | Gypsum Product Manufacturing | 1.560 | 0.063 | 1.623 |
| 486110 | Pipeline Transportation of Crude Oil | 1.619 | 0.000 | 1.619 |
| 486210 | Pipeline Transportation of Natural Gas | 1.619 | 0.000 | 1.619 |
| 486910 | Pipeline Transportation of Refined Petroleum Products | 1.619 | 0.000 | 1.619 |
| 486990 | All Other Pipeline Transportation | 1.619 | 0.000 | 1.619 |
| 325120 | Industrial Gas Manufacturing | 1.163 | 0.048 | 1.211 |
| 325193 | Ethyl Alcohol Manufacturing | 1.166 | 0.018 | 1.184 |
| 325194 | Cyclic Crude, Intermediate, and Gum and Wood Chemical Manufacturing | 1.166 | 0.018 | 1.184 |
| 325199 | All Other Basic Organic Chemical Manufacturing | 1.166 | 0.018 | 1.184 |
| 325311 | Nitrogenous Fertilizer Manufacturing | 1.114 | 0.023 | 1.137 |
| 325312 | Phosphatic Fertilizer Manufacturing | 1.114 | 0.023 | 1.137 |
| 325314 | Fertilizer (Mixing Only) Manufacturing | 1.114 | 0.023 | 1.137 |
| 112210 | Hog and Pig Farming | 1.077 | 0.051 | 1.128 |
| 112410 | Sheep Farming | 1.077 | 0.051 | 1.128 |

Table 3. Summary Statistics of Relative Change from v1.2 to v1.3 by GHG for Supply Chain Emission Factors without Margins.

| **GHG** | **Min.** | **1st Qu.** | **Median** | **Mean** | **3rd Qu.** | **Max.** |
| --- | --- | --- | --- | --- | --- | --- |
| CO2e | -0.91 | -0.28 | -0.16 | -0.13 | -0.04 | 5.25 |
| Carbon dioxide | -0.88 | -0.31 | -0.17 | -0.15 | -0.05 | 1.51 |
| Methane | -0.94 | -0.38 | -0.28 | -0.07 | -0.14 | 49.50 |
| Nitrous oxide | -0.88 | -0.24 | -0.08 | -0.02 | 0.13 | 4.32 |

  *Table 4. Commodities with Greatest Relative Increase from v1.2 to v1.3 in SEF+MEF.*

| **2017 NAICS Code** | **2017 NAICS Title** | **v1.2** | **v1.3.0** | **Relative Change** |
| --- | --- | --- | --- | --- |
| 562920 | Materials Recovery Facilities | 0.158 | 0.988 | 5.2532 |
| 562910 | Remediation Services | 0.163 | 0.988 | 5.0613 |
| 562111 | Solid Waste Collection | 0.197 | 0.988 | 4.0152 |
| 711510 | Independent Artists, Writers, and Performers | 0.013 | 0.033 | 1.5385 |
| 336415 | Guided Missile and Space Vehicle Propulsion Unit and Propulsion Unit Parts Manufacturing | 0.146 | 0.294 | 1.0137 |
| 336419 | Other Guided Missile and Space Vehicle Parts and Auxiliary Equipment Manufacturing | 0.146 | 0.294 | 1.0137 |
| 236116 | New Multifamily Housing Construction (except For-Sale Builders) | 0.116 | 0.221 | 0.9052 |
| 425110 | Business to Business Electronic Markets | 0.051 | 0.092 | 0.8039 |
| 425120 | Wholesale Trade Agents and Brokers | 0.051 | 0.092 | 0.8039 |
| 325414 | Biological Product (except Diagnostic) Manufacturing | 0.085 | 0.150 | 0.7647 |
| 531110 | Lessors of Residential Buildings and Dwellings | 0.019 | 0.033 | 0.7368 |
| 524113 | Direct Life Insurance Carriers | 0.030 | 0.051 | 0.7000 |
| 562119 | Other Waste Collection | 0.632 | 0.988 | 0.5633 |
| 562219 | Other Nonhazardous Waste Treatment and Disposal | 0.632 | 0.988 | 0.5633 |
| 562991 | Septic Tank and Related Services | 0.632 | 0.988 | 0.5633 |
| 562998 | All Other Miscellaneous Waste Management Services | 0.632 | 0.988 | 0.5633 |
| 561311 | Employment Placement Agencies | 0.033 | 0.051 | 0.5455 |
| 561312 | Executive Search Services | 0.033 | 0.051 | 0.5455 |
| 561320 | Temporary Help Services | 0.033 | 0.051 | 0.5455 |
| 561330 | Professional Employer Organizations | 0.033 | 0.051 | 0.5455 |

Table 5. Commodities with Greatest Relative Decrease from v1.2 to v1.3.

| **2017 NAICS Code** | **2017 NAICS Title** | **v1.2** | **v1.3.0** | **Relative Change** |
| --- | --- | --- | --- | --- |
| 562212 | Solid Waste Landfill | 10.989 | 0.988 | -0.9101 |
| 212230 | Copper, Nickel, Lead, and Zinc Mining | 1.165 | 0.324 | -0.7219 |
| 111130 | Dry Pea and Bean Farming | 3.007 | 0.848 | -0.7180 |
| 111140 | Wheat Farming | 3.007 | 0.848 | -0.7180 |
| 111150 | Corn Farming | 3.007 | 0.848 | -0.7180 |
| 111160 | Rice Farming | 3.007 | 0.848 | -0.7180 |
| 111191 | Oilseed and Grain Combination Farming | 3.007 | 0.848 | -0.7180 |
| 111199 | All Other Grain Farming | 3.007 | 0.848 | -0.7180 |
| 111411 | Mushroom Production | 1.043 | 0.307 | -0.7057 |
| 111419 | Other Food Crops Grown Under Cover | 1.043 | 0.307 | -0.7057 |
| 111421 | Nursery and Tree Production | 1.043 | 0.307 | -0.7057 |
| 111422 | Floriculture Production | 1.043 | 0.307 | -0.7057 |
| 325130 | Synthetic Dye and Pigment Manufacturing | 1.382 | 0.432 | -0.6874 |
| 324110 | Petroleum Refineries | 0.859 | 0.270 | -0.6857 |
| 112310 | Chicken Egg Production | 1.171 | 0.438 | -0.6260 |
| 112320 | Broilers and Other Meat Type Chicken Production | 1.171 | 0.438 | -0.6260 |
| 112330 | Turkey Production | 1.171 | 0.438 | -0.6260 |
| 112340 | Poultry Hatcheries | 1.171 | 0.438 | -0.6260 |
| 112390 | Other Poultry Production | 1.171 | 0.438 | -0.6260 |
| 813110 | Religious Organizations | 0.197 | 0.076 | -0.6142 |

# For more guidance on using the Factors see the webinar on Using the Supply Chain GHG Emission Factors (W. Ingwersen and Li, 2022)

# Code Availability

The source code for producing the Factors can be found in the [USEPA/supply-chain-factors repository](https://github.com/usepa/supply-chain-factors). A model specification file for the USEEIO v2.2.22-GHG model is present under model-specs. The *CalculateEmissionFactors.Rmd* R markdown notebook along with supporting R scripts are used to generate the Factor datasets. This notebook draws on [useeior](https://github.com/USEPA/useeior) to build and calculate the USEEIO model. The 2022 GHG direct emission totals by sector dataset, prepared using [FLOWSA](https://github.com/USEPA/flowsa), is automatically retrieved upon building the model for the first time and stored locally for the user. The matching global warming potential factors for the IPCC GWP were prepared using the [LCIA Formatter](https://github.com/USEPA/LCIAformatter), and are likewise retrieved and stored locally upon first build of the model. The supply-chain-factors repository provides additional guidance on use of the source code.

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