About the Supply Chain Greenhouse Gas Emission Factors v1.2 NAICS-6 Datasets

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Abstract

This document describes the Supply Chain Greenhouse Gas Emission Factors v1.2 NAICS-6 U.S. commodity datasets. The datasets are comprised of 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). The Factors are built with GHG emission data representing 2019. 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 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 dollar per commodity without the CO2e calculation. The dollar in the denominator of all factors uses purchaser prices in 2021 USD.

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; Ingwersen and Li, 2022-03-07, 2022). The previous Factors were provided in units of kg GHG/USD for Carbon dioxide, Methane, and Nitrous oxide - and in carbon dioxide equivalents (CO2e) for other GHGs. They 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 Factors are created using a combination of two models - the National Greenhouse Gas Industry Attribution Model (NGIAM), and the U.S. Environmentally-Extended Input-Output

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(USEEIO) model. The NGIAM produces totals of the direct emissions by detailed industries and is used as an input into a selected USEEIO model, from which the direct and then indirect emission intensities are then derived 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, were created specifically at the request of the White House Center for Environmental Quality and the General Services Administration in response to federal agencies GHG reporting obligations as described in the Executive Order 14057, commonly known as "Buy Clean" (CEQ, 2022). The Factors are intended for what is referred to in the GHG Protocol standards as Scope 3, category 1 "Purchased goods and services" and category 2 "Capital goods" (WRI and WBCSD, 2013). The second set of Factors provide complimentary data to 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 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 dollar 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 the NGIAM data product U.S. Greenhouse Gases by NAICS-6 Industry for 2019. This dataset includes totals of emissions 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) v1.0.8 (Ingwersen et al., 2021).

The USEEIO model created is USEEIO v2.1.19-GHG.
The economic components of the USEEIO model used to build the Factors are the same as those in the USEEIO v2.0 model (Ingwersen et al., 2022), although the input Bureau of Economic Analysis (BEA) datasets for industry output data and annual price indices were updated with more recent data from BEA (BEA, 2022; "Industry underlying estimates," 2022). The USEEIO model created is a commodity-based model, with a total requirements matrix prepared using the same modeling assumptions used for USEEIO v2.0.

For one set of Factors, the 100-yr global warming potentials (GWPs) from the IPCC 4th Assessment report (AR4) are used to convert GHGs into CO2e (Solomon, S. et al., 2007).

These GWPs are incorporated into the model 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+direct CO2e per commodity in kgCO2e/$. The other set of Factors that are presented in kg per GHG are drawn from the M matrix. The M matrix contains indirect+direct GHGs by gas per commodity in kg GHG/$. 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 2021 USD using the model Φ and ρ matrices in previously described procedures (Ingwersen and Li, 2020a).
The year 2021 is the most recent year for which detailed industry-specific chained-type price indices were available at time of Factor preparation. 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. The remaining factors are mapped from USEEIO code to NAICS 2017 6-digit codes (U.S. Census Bureau, 2021) using the following steps: Factors are associated with NAICS 2012 using the sector crosswalk associated with a USEEIO model (Li, Mo et al., 2022). The official concordance between the NAICS 2012 and NAICS 2017 classification is then used to further crosswalk each NAICS 2012 code to a NAICS 2017 code (Census Bureau, 2023). Where more than one USEEIO code maps to a single NAICS 2017 sector, an output-weighted approach is used to average the factors using the commodity output for the target year of 2019 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 previously v1.1.1 2016 Detail Commodity Factors (Ingwersen and Li, 2022-03-07) was performed for CO_2, N_2O, and CH_4. The current Factors were associated with their unique USEEIO codes (rather than the NAICS-6). Waste sector Factors (562*) were removed because of a difference in classification in the underlying USEEIO models used. For this comparison, the most recent Factors (v1.1.1) based on a USEEIO model closest in model type (Detail-Commodity) and year (2016) to the USEEIO model were selected in order to understand how the Factors differ from those used previously.
The previous Factors were reported in units of kg gas/$ for CO_2, N_2O, and CH_4 and in kg CO2e$ for Other gases. The analogous set of new factors (2nd dataset) was used for this comparison. Notably, the dollar years in the denominator are different – new Factors use 2021 USD, previous factors use 2018 USD - but this difference was left as is for this comparison, since the objective was to show the difference between published versions without further adjustment.

Results

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 1016 commodities defined by unique 2017 6-digit NAICS codes. These represent 373 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 0.013 - 10.989 kg CO2e/$, with a median value of 0.208 and a mean of 0.386 indicating that most combined factors are < 0.386 kg CO2e/$. 75% of SEFs are less than 0.4 kgCO2e/$. 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 1: Distributions of Factor values by Factor Types

	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
Supply Chain Emission Factors without Margins	0.013	0.1230	0.187	0.3579	0.4015	10.989
Margins of Supply Chain Emission Factors	0.000	0.0000	0.000	0.0282	0.0490	0.270
Supply Chain Emission Factors with Margins	0.013	0.1288	0.208	0.3860	0.4483	10.989

Table 2 lists the 10 highest Factors.

Table 2: Top 10 Supply Chain Emission Factors with Margins. Unit is kg CO2e per USD 2019.

2017 NAICS Code	2017 NAICS Title	GHG	Unit	Supply Chain Emission Factors without Margins	Margins of Supply Chain Emission Factors	Supply Chain Emission Factors with Margins	Reference USEEIO Code
562212	Solid Waste Landfill	All GHGs	kg CO2e/2021 USD, purchaser price	10.989	0.000	10.989	562212
327310	Cement Manufacturing	All GHGs	kg CO2e/2021 USD, purchaser price	3.768	0.090	3.858	327310

2017 NAICS Code	2017 NAICS Title	GHG	Unit	Supply Chain Emission Factors without Margins	Margins of Supply Chain Emission Factors	Supply Chain Emission Factors with Margins	Reference USEEIO Code
112111	Beef Cattle Ranching and Farming	All GHGs	kg CO2e/2021 USD, purchaser price	3.227	0.071	3.298	1121A0
112112	Cattle Feedlots	All GHGs	kg CO2e/2021 USD, purchaser price	3.227	0.071	3.298	1121A0
112130	Dual-Purpose Cattle Ranching and Farming	All GHGs	kg CO2e/2021 USD, purchaser price	3.227	0.071	3.298	1121A0
111130	Dry Pea and Bean Farming	All GHGs	kg CO2e/2021 USD, purchaser price	2.874	0.134	3.007	1111B0
111140	Wheat Farming	All GHGs	kg CO2e/2021 USD, purchaser price	2.874	0.134	3.007	1111B0
111150	Corn Farming	All GHGs	kg CO2e/2021 USD, purchaser price	2.874	0.134	3.007	1111B0
111160	Rice Farming	All GHGs	kg CO2e/2021 USD, purchaser price	2.874	0.134	3.007	1111B0
111191	Oilseed and Grain	All GHGs	kg CO2e/2021	2.874	0.134	3.007	1111B0

2017 NAICS Code	2017 NAICS Title	GHG	Unit	Supply Chain Emission Factors without Margins	Margins of Supply Chain Emission Factors	Supply Chain Emission Factors with Margins	Reference USEEIO Code
	Combination Farming		USD, purchaser price				

The largest combined factor is for Solid Waste Landfills (562212); the next largest factors are for grain farming sectors followed by Cement Manufacturing (327310) and Cattle farming and feedlot sectors.

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

Table 3, Table 4, and Table 5 show a statistical summary of the relative change by gas for each of the SEF types. Data are shown as fractional change.
Because Methane and Nitrous oxide MEFs represent a relatively small contribution to the CO2e for SEFs with margins for all sectors, they are not included in Table 4.

The majority of SEFs for Carbon dioxide have decreased between 6% and 18%, with a median value of change being -13% (a 13% reduction). Nitrous oxide and Methane SEFs have on average decreased for more commodities. More than 75% of Methane SEFs decreased, with a median decrease of 35%. Methane decrease can largely be explained by a decrease in intensity of Dairy and Cattle feedlot methane that propagated through to food products as well as decrease in emission intensity of petrochemical products.

However, individual commodity factors themselves have decreased by as much as 65% or increased as much as 117%. The CO_2 SEF+MEF for Petrochemicals (325110) and Other Basic Inorganic Chemicals (325180) increased by 117% and 68%, respectively. The largest CO_2 SEF+MEF decrease was 49% for Medicinal and botanical ingredients (325411) followed by 46% for Couriers and Messengers (492000).

Table 3: Summary Statistics of Relative Change from v1.1.1 2016 to v1.2 2019 by GHG for Supply Chain Emission Factors without Margins

	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
Carbon dioxide	-0.57	-0.19	-0.13	-0.13	-0.06	0.61
Methane	-0.68	-0.48	-0.35	-0.33	-0.21	0.27
Nitrous oxide	-0.54	-0.32	-0.22	-0.20	-0.06	0.15

Table 4: Summary Statistics of Relative Change from v1.1.1 2016 to v1.2 2019 by GHG for Margins of Supply Chain Emission Factors

	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
Carbon dioxide	-0.44	-0.19	-0.1	-0.09	-0.01	0.87

Table 5: Summary Statistics of Relative Change from v1.1.1 2016 to v1.2 2019 by GHG for Supply Chain Emission Factors with Margins

	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
Carbon dioxide	-0.52	-0.19	-0.13	-0.12	-0.07	0.53
Methane	-0.68	-0.47	-0.36	-0.35	-0.24	0.14
Nitrous oxide	-0.53	-0.31	-0.21	-0.20	-0.05	0.16

Table 6: Commodities with Greatest Relative Change from v1.1.1 2016 to v1.2 2019

Commodity Code	Commodity Name	GHG	v1.1.1-2016	v1.2-2019	Relative Change
423600	Household appliances and electrical and electronic goods	Methane	0.001	0.00032	-0.6819
312200	Tobacco products	Methane	0.001	0.00033	-0.6744
334290	Communications equipment	Methane	0.001	0.00034	-0.6606
441000	Vehicles and parts sales	Methane	0.001	0.00034	-0.6596
334300	Audio and video equipment	Methane	0.001	0.00035	-0.6493
334512	Automatic controls for HVAC and refrigeration equipment	Methane	0.001	0.00037	-0.6315
325412	Pharmaceutical products (pills, powders, solutions, etc.)	Methane	0.001	0.00037	-0.6303
336411	Aircraft	Methane	0.001	0.00038	-0.6244
334112	Computer storage device readers	Methane	0.001	0.00038	-0.6211
812900	Pet care, photofinishing, parking and other sundry services	Methane	0.001	0.00039	-0.6132

Three high resolution figures showing comparisons of SEFs, MEFs, and SEF+MEFS between the v1.1.1-2016 and the v1.2-2019 datasets are provided separately. These figures provide more detailed visualization of Factor changes.

1. `SEFv1.1.1-2016_tov1.2-2019Compare.png`

2. `MEFv1.1.1-2016_tov1.2-2019Compare.png`
3. `SEF+MEFv1.1.1-2016_tov1.2-2019Compare.png`

The figures are not embedded in this document due to their large size. For each figure values of commodity Factors from each dataset are shown for each of the GHGs in three panels. Squares represent the v1.1.1-2016 values, and circles represent the v1.2-2019 values.

Data on change by commodity and gas are provided in `RelativeChangefromv1.1.1-2016to1.2-2019inSEFsbygas.csv`.

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 2021 year to 2022, use the following equation:

$$SEF_{c\$2022} = SEF_{c\$2021} * \frac{CPI_{c,2021}}{CPI_{c,2022}}$$

where the CPI is a annual commodity-specific price index for commodity c. The supply-chain-factors code can be executed to generate all the Factors in a user-provided dollar year to perform this change in mass, using the factor adjustment functionality built into useeior (Li, Mo et al., 2022).

3. Multiply dollars spend 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.

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.

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. A model specification file for the USEEIO v2.1.19-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 to build and calculate the USEEIO model. The 2019 NGIAM dataset, prepared using 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, 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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Appendices

Appendix 1 - Check of NAICS mapping

Load in 2012 to 2017 NAICS crosswalk. Check number of records.

```
## [1] 1069
```

How many unique 2012 codes are there?

```
## [1] 1065
```

How many unique 2017 codes are there?

```
## [1] 1057
```

Merge this in with the SEF table, check number of rows

```
## [1] 1234
```

There are multiple 2017 NAICS for these 2012 NAICS

Filter out rows where both NAICS 2017 and the SEF values are repeated. Re-check length

```
## [1] 1225
```

Separate out records where multiple records for NAICS 2017. How many of these are there?

```
## [1] 234
```

What are they:

```
##  [1] 236117 236210 236220 237210 238110 238120 238130 238140 238150 238160
## [11] 238170 238190 238210 238220 238290 238310 238320 238330 238340 238350
## [21] 238390 238910 238990 335220 531110
```

These 25 are all construction sectors where there are multiple USEEIO per NAICS, except for 33522*, major household appliances, which is split into 4 sectors in 2012 and 53111*, lessors of buildings, where there are two sectors in 2012.

Get the rest of the table where NAICS 2017 factors are unique. How many rows?

```
## [1] 991
```

Confirm that matches the number of unique 2017 NAICS codes

```
## [1] 991
```

What NAICS 2017 codes are present without matching factors?

```
##  [1] 221111 221112 221113 221114 221115 221116 221117 221118 221121 221122
## [11] 331314 814110 921110 921120 921130 921140 921150 921190 922110 922120
## [21] 922130 922140 922150 922160 922190 923110 923120 923130 923140 924110
## [31] 924120 925110 925120 926110 926120 926130 926140 926150 927110 928110
## [41] 928120
```

221* is electricity and 92* are gov, which have intentionally been excluded. 331314 is secondary smelting and alloying of aluminum which is not a USEEIO commodity. 814110 is household business for which SEF is 0.

For NAICS 2017 with multiple factors, use USEEIO commodity output to calculate a weighted average. For this an allocation table is created.

Check that all allocation factors are 1.

```
## [1] 1
```

Merge in allocation factors, check length

```
## [1] 234
```

Are any duplicated?

```
## [1] 0
```

Confirm there are no SEFs that are not present in the merged dataset

```
## character(0)
```

Apply allocation factors and aggregate up to 2017 NAICS

Add back in full NAICS 2017 set to get industry names. Also add in original USEEIO codes for reference. Finally check to see if expected NAICS are present. This list should match the list of known excluded codes.

```
##  [1] 221111 221112 221113 221114 221115 221116 221117 221118 221121 221122
## [11] 331314 814110 921110 921120 921130 921140 921150 921190 922110 922120
## [21] 922130 922140 922150 922160 922190 923110 923120 923130 923140 924110
## [31] 924120 925110 925120 926110 926120 926130 926140 926150 927110 928110
## [41] 928120
```

Appendix 2 - Model Validation

The standard validation of the USEEIOv2.1.19-GHG model is performed. The model was built using the source code and model specification file in the supply-chain-factors repository.

Validate the underlying USEEIO model

```
model <- readRDS(here::here("data/USEEIOv2.1.19-GHG.rds"))
library(useeior)
useeior::printValidationResults(model)
```

```
## [1] "Validate that commodity output can be recalculated (within 1%) with
the model total requirements matrix (L) and demand vector (y) for US
production"
## [1] "Number of sectors passing: 409"
## [1] "Number of sectors failing: 2"
## [1] "Sectors failing: S00402/US, S00300/US"


## [1] "Validate that commodity output can be recalculated (within 1%) with
model total domestic requirements matrix (L_d) and model demand (y) for US
production"
## [1] "Number of sectors passing: 409"
## [1] "Number of sectors failing: 2"
## [1] "Sectors failing: S00402/US, S00300/US"


## [1] "Validate that flow totals by commodity (E_c) can be recalculated
(within 1%) using the model satellite matrix (B), market shares matrix (V_n),
total requirements matrix (L), and demand vector (y) for US production"
## [1] "Number of flow totals by commodity passing: 6576"
## [1] "Number of flow totals by commodity failing: 0"
## [1] "Validate that flow totals by commodity (E_c) can be recalculated
(within 1%) using the model satellite matrix (B), market shares matrix (V_n),
total domestic requirements matrix (L_d), and demand vector (y) for US
production"
```

```
## [1] "Number of flow totals by commodity passing: 6576"
## [1] "Number of flow totals by commodity failing: 0"
## [1] "Sectors with flow totals failing: "
```

```
## [1] "Validate that commodity output are properly transformed to industry
output via MarketShare"
## [1] "Number of flow totals by commodity passing: 409"
## [1] "Number of flow totals by commodity failing: 2"
## [1] "Sectors with flow totals failing: S00402/US, S00300/US"
```

```
## [1] "Validate that commodity output equals to domestic use plus production
demand"
## [1] "Number of flow totals by commodity passing: 410"
## [1] "Number of flow totals by commodity failing: 1"
```

The only commodities failing any validation tests are the IO tables balancing commodities which have no impact and are not used to create Factors.