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Proof of Concept for a U.S. Air Emissions Physical Flows Account

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Measuring the physical flows of resources and waste between the economy and environment is a central component of environmental-economic accounting as outlined in the *System of Environmental-Economic Accounting (SEEA)*, the United Nations standard for environmental accounting.

We present the first *SEEA*-consistent proof-of-concept air emissions physical flows account for the United States. Primary data on emissions come from the U.S. EPA's Greenhouse Gas Inventory (GHGI). The proof-of-concept account covers 2017 and presents tabulated emissions by industry along with examples of additional analytic indicators such as emissions per dollar value added.

Primary challenges in constructing this account are (1) adjusting the GHGI data from territory- to residency-based, and (2) attributing emissions to industries and institutional sectors. We use secondary measures of activity, like fuel purchases or output, and attribute emissions proportionally to these measures using a software tool called *FLOWSA* developed by researchers at EPA.

Keywords: *Air emissions, National accounting, Environmental accounting, Emissions inventories, SEEA*

JEL Codes: *E01, E20, I31, L92, L93, Q53, Q54, Q56*

1. Introduction

In countries around the world, national statistical agencies (such as the U.S. Bureau of Economic Analysis) maintain accounts of economic activity. Using these accounts, they compile and disseminate statistics such as gross domestic product (GDP) for use in government and private sector decision making.

But economic transactions—and the economy itself—do not exist in a vacuum. The economy exists within, draws resources from, and disposes of waste to, the environment. Understanding and measuring the effects of economic activity on the environment, including the physical flows of resources and waste, is crucial for good decision making by government leaders and other stakeholders. Consequently,

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measurements of these flows constitute one of the primary components of environmental-economic accounting.

In this paper, we focus on the physical flows of greenhouse gases emitted to the atmosphere by U.S. resident agents (enterprises and households). We present a proof-of-concept air emissions physical flows account for the U.S. that is consistent with international environmental-economic accounting standards.

2. System of Environmental-Economic Accounting

The *System of National Accounts (SNA)* is the international economic accounting standard promulgated by the United Nations (UN), in accordance with which BEA maintains the U.S. national economic accounts (United Nations Statistics Division, 2008). The *System of Environmental-Economic Accounting Central Framework (SEEA)* is the companion standard, also promulgated by the UN, for environmental-economic accounting (United Nations Statistics Division, 2012). Each system is designed for consistency in accounting methodology between countries and across years.

The broad goal of environmental-economic accounting is to measure the impact of economic activity on the environment, at a national scale, and to calculate reliable, relevant statistics expressing these impacts to aid in decision making by both government and private-sector stakeholders. To promote this goal, national environmental accounts must be comparable and consistent with national economic accounts in the definitions, boundaries, and accounting methods used. *SEEA* and the *SNA* are designed to work together in this way.

A. Types of SEEA Accounts

SEEA envisions three distinct areas or types of accounts: environmental flows (physical and monetary), economic activities related to the environment (referred to hereafter as environmental activities), and stocks of environmental assets (*SEEA* 2.6). Flows accounts track the movement of natural resources and residuals (namely, pollution and waste) between the economy and the environment; these flows may be expressed in either physical units (as we propose here for air emissions) or in monetary units. Environmental activity accounts measure the value of goods and services produced within the economy for the purposes of environmental protection or resource management; these accounts are unique among *SEEA* accounts in consisting of economic transactions already covered by the *SNA*. Environmental asset accounts focus on measuring the stocks of individual, specific environmental assets, such as water or timber; they are related to ecosystem accounts (which are covered by an extension to *SEEA*, known as *SEEA Ecosystem Accounting*) but with a narrower focus.

B. Important Definitions and Concepts

Two important principles that *SEEA* and the *SNA* have in common help define the set of economic (or environmental-economic) activities that are measured and included in the respective national accounts: the residency principle and the production boundary. The set of activities to be measured—and how they are to be attributed to industries and sectors—is further refined by *SEEA* through the definition of the environmental-economic boundary and *SEEA*'s treatment of own-account production activities (which differs slightly from their treatment in the *SNA*) and intertemporal issues (of particular importance for air emissions).

The residency principle states that national accounts, whether economic or environmental, should exclusively measure activities engaged in by agents resident in the country of interest. For example, all emissions from an airplane operated by Delta (a U.S. airline) on a route from New York City to London should be included in the U.S. air emissions account, including emissions occurring in international or foreign airspace. But if British Airways operates an airplane on the same route, none of that plane's emissions should be included in the U.S. air emissions account, even those emissions occurring in U.S. airspace (*SEEA* 2.122).

The production boundary defines activities to be included in the national accounts as productive economic activities engaged in by resident agents. Productive economic activities create, via a process under the control and management of the agent, a good or service that is (or could be) sold in a market. Therefore, the carbon dioxide and other emissions from an unintended forest fire are not included in the air emissions account since they do not result from a productive economic activity. On the other hand, methane emissions from cattle in a managed herd are included (*SEEA* 2.9).

Specific to *SEEA* is the definition of the environmental-economic boundary. Physical or monetary flow accounts are to exclusively measure flows that cross the boundary between the environment and the economy. For example, if the methane produced by decomposition in a landfill is captured and used in a productive process, rather than being emitted to the atmosphere, this flow of methane is considered a flow within the economy and is not included in the air emissions account. Similarly, methane emitted by wild animals is considered a flow within the environment and is not included in the air emissions account (*SEEA* 3.243).

SEEA differs slightly from the *SNA* in its treatment of own-account production by industries and households. In the *SNA*, such own-account production is not directly recorded (except in certain situations such as own-account capital formation or flows related to ancillary activities), but (for own-account production by industries) its value is reflected in the measure of output for the producing industry. In *SEEA*, the flows resulting from any own-account production by industries or households are to be measured and attributed to the industry or household that produces them.[1] For instance, enterprises in many industries own and operate trucks for own-account production of transportation services. The emissions from the operation of these trucks should be included in the air emissions account, even though the value of the transportation services provided would not be directly recorded in the economic accounts. Within the air emissions account, these emissions should be attributed to the industries that own and operate the trucks (*SEEA* 1.42).

Finally, some emissions may occur because of productive economic activities undertaken in previous periods. For example, suppose that household consumption in period 1 results in solid waste being generated. The decomposition of this waste in period 2 generates emissions of methane and other gases. These emissions cannot be attributed to household consumption in period 2 since they do not result from period 2's household consumption. For the same reason, they cannot be attributed to the waste management industry. Consequently, *SEEA* directs that such emissions are to be recorded in a separate category called "accumulations" (*SEEA* 3.252).

3. Related Work

Three existing strands of work by EPA, BEA, and the U.S. Geological Survey (USGS) are related to this effort. EPA's Greenhouse Gas Inventory (GHGI) also measures U.S. emissions of greenhouse gases in accordance with international standards set by the Intergovernmental Panel on Climate Change (IPCC). BEA and USGS have worked together to produce *SEEA*-consistent proof-of-concept water and land accounts. Finally, EPA's U.S. Environmentally Extended Input-Output (USEEIO) model attributes environmental impact data to industries and integrates this data with BEA Input-Output data.

A. EPA Greenhouse Gas Inventory

The GHGI measures U.S emissions of greenhouse gases in accordance with the standards established by the Intergovernmental Panel on Climate Change (IPCC) to satisfy U.S. obligations under the UN

[1] Indeed, this is precisely because the value of such own-account production is included in the value of output for the industry. The accounting principle here is to match emissions with the productive activity that generates them.

Framework Convention on Climate Change (UNFCCC) treaties. The IPCC standards differ from *SEEA* standards in several ways, due at least in part to the different purposes of the two standards (Intergovernmental Panel on Climate Change, 2006).

Most importantly, the IPCC standards require measuring greenhouse gas emissions on a territory basis: those that occur in U.S. territory (including U.S. waters) (IPCC 8.2.1). *SEEA* requires measuring emission by U.S. resident agents, wherever those emissions occur. In general, the results of measuring emissions according to a residency basis instead of a territory basis are most noticeable in the various transportation industries and in the fishing industry (*SEEA* 3.240, 3.255).

Other areas of divergence between IPCC and *SEEA* standards are their treatment of carbon sequestration (or removals) and of marine and aviation emissions. Carbon sequestration[2] is to be accounted for under the IPCC (IPCC 8.2.1) but not under *SEEA* (*SEEA* 5.392; Eurostat 2.92, 2.100). On the other hand, emissions from fuel used by ships or aircraft traveling internationally are not included in any country's inventory under IPCC standards; SEEA requires that these emissions be included in the air emissions account of the country whose resident owns the ship or airplane.

B. BEA/USGS Proof-of-Concept *SEEA*-Consistent Water and Land Accounts

Researchers from BEA and USGS have compiled initial proof-of-concept accounts for physical flows of water, water productivity, water quality, and water emissions (Bagstad, et al., 2020). The physical flows and water productivity accounts are compiled for the years 2000, 2005, 2010, and 2015, water quality accounts for 2002 and 2012, and water emissions accounts for 2015, with selected years reflecting availability of data.

The physical flows accounts for water are the most detailed, with state-level data. Using these accounts, the authors derive several useful statistics, including water use by state, change in water use by state, proportion of water use by industry by state, and so on, demonstrating the value that well-kept environmental accounts can have in providing the data needed for good decision making. The water emissions account is compiled from a single regulatory database (EPA's PCS-ICIS database), due to the lack of a national emissions inventory for water. It is therefore incomplete in its coverage, and the authors discuss what data would need to be collected to maintain more complete water emissions accounts.

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[2] The removal of carbon from the atmosphere. This may occur through either natural means, as by plants transforming atmospheric carbon dioxide into biomass through photosynthesis, or artificial means, such as by storing carbon dioxide underground.

BEA and USGS have also collaborated to compile proof-of-concept accounts for land cover, land use, and land value (Wentland, et al., 2020). The land cover accounts are compiled for 2001, 2006, 2011, and 2016 and the land use accounts are compiled for 2000; these selections again reflect data availability. The land value account is compiled using a large microdata set from Zillow, which could, in principle, have supported higher frequency estimates. However, the authors aggregate the microdata into three groups: 2002-2006, 2007-2011, and 2012-2016 and compile accounts for each group of years, to correspond more closely with the other land accounts. As with the water accounts, the authors derive several statistics valuable for decision making, including the change in urban, forest, and agricultural land cover over time and the relationship between land use and price and how that relationship differs by region and across time.

Both the water and land accounts highlight the importance of the underlying source data, and the extent to which it dictates what *SEEA*-consistent accounts can be compiled, how thorough they can be, and how frequently they can be updated.

C. EPA U.S. Environmentally Extended Input-Output Model

The US Environmentally Extended Input-Output (USEEIO) models are a family of environmental-economic models of U.S. goods and services production (Ingersen, Li, Young, Vendries, & Birney, 2022). Using USEEIO, the environmental life cycle impacts of more than 400 commodities can be calculated.[3] The primary divergence between the USEEIO models and the proof-of-concept *SEEA* air emissions account is that USEEIO is designed to capture both direct and indirect environmental impacts of each industry, while the proof-of-concept *SEEA* account is focused on capturing direct emissions *only* by each industry. Many of the environmental data tables used in the USEEIO model, including those which identify direct environmental impacts of each industry, are generated using a tool also developed by EPA called FLOWSA. As described in more detail later, we also use this tool in creating the data tables that underly the proof-of-concept *SEEA* air emissions account.

4. Methodology

Our process for compiling the proof-of-concept air emissions account for the U.S. mirrors the process suggested by Eurostat for European countries constructing similar accounts (Eurostat, 2015):

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[3] These mainly correspond to the commodities found in the BEA 2012 Detail IO tables, with some additional disaggregation.

1. Begin with primary source data on emissions from the appropriate national emissions inventory; in this case, EPA's Greenhouse Gas Inventory (GHGI), as detailed below.
2. Attribute emissions to industries (for business) and other institutional sectors including households. Typically, this is done using secondary data, such as data on fuel purchases or output, as described in section 4.B.
3. Align emissions with the residency basis and production boundaries described in *SEEA*. This is also typically done using secondary data sources, as described in section 4.C.
4. Assemble the final estimates in tabular form, as seen in section 7.

A. Primary Data Sources

The primary data source for this proof-of-concept air emissions account is the Greenhouse Gas Inventory (GHGI), discussed above. EPA produces the GHGI every year to satisfy the requirements of the UNFCCC, in accordance with the IPCC international standards for the compilation of national greenhouse gas inventories. As a result of adherence to these standards, the GHGI represents an internally consistent time series of estimated greenhouse gas emissions for the U.S. (U.S. Environmental Protection Agency, 2019).

As discussed above, the IPCC standards EPA follows in compiling the GHGI focus on emissions generated within U.S. territory, regardless of residency. Consequently, we need to adjust the emissions reported in the GHGI to the residency basis of *SEEA*. This is most important in industries such as transportation, where U.S. resident enterprises (in contrast to foreign affiliates of U.S. multinational enterprises) conduct meaningful operations abroad and foreign resident enterprises (in contrast to U.S. affiliates of foreign multinationals) conduct meaningful operations in the U.S.

One unique challenge for compiling an air emissions account for the U.S. based on the GHGI is that IPCC standards require emissions to be reported according to an International Standard Industrial Classification (ISIC) based classification of emissions sources (IPCC table 8.2) which does not map readily to the North American Industrial Classification System (NAICS) based industry classification used by BEA in compiling the national economic accounts. For consistency with the economic accounts, it is necessary that the air emissions account follow the same industrial classification. For this reason, rather than using the GHGI common reporting format tables submitted to the UN as our primary data source, we use the GHGI Inventory Report (U.S. Environmental Protection Agency, 2019), which provides greater detail than the tables submitted to the UN. This additional detail is useful for attributing emissions to NAICS-based industries.

In the inventory report, emissions are broken down by type of emitting activity. Some emitting activities, such as manure spread over fields for fertilizer, are specific to certain industries. Other activities, such as coal combustion for stationary applications or operating trucks, are not specific to any one industry, so emissions from these activities must be attributed to specific industries using other data sources.

B. Attribution to Industries

Attributing emissions recorded in the GHGI across industries is a two-step process. First, we map activities in the GHGI to industries, which are defined using NAICS codes. We largely use NAICS 3-digit codes, with some codes in the manufacturing and professional services industries further disaggregated to the NAICS 4-digit level (to enable aggregating our results to the BEA summary level industries). For many activities, there is a one-to-one mapping.

For those activities that map to multiple industries, emissions are attributed to those industries in proportion to some measure of polluting activity. For example, if the GHGI reports that industries A and B (which produce emissions mainly by burning fuel), emit 9 tons of CO2 in aggregate, and industry A purchases twice as much fuel as industry B, 6 tons of CO2 will be attributed to industry A while 3 tons will be attributed to industry B. In this proof-of-concept account, emissions from coal combustion in manufacturing are attributed proportional to each industry's consumption of coal for energy, as given in the Energy Information Administration (EIA) Manufacturing Energy Consumption Survey (MECS) (U.S. Energy Information Administration, 2018). Emissions from other industrial or commercial coal combustion are attributed proportional to each industry's coal purchases, as given in the BEA Use table.

In selecting measures of polluting activity to use as secondary data sources to attribute emissions proportionally, the ideal measure is related as closely as possible to the polluting activity. For example, when the activity reported in the GHGI is a form of fuel combustion, the ideal measure is the quantity of fuel consumed, since this is most closely tied to the quantity of emissions released. For this reason, as in the example above, EIA's MECS survey is used where possible. To attribute emissions from fuel combustion to industries not covered by the MECS, we use purchases of the relevant fuel commodity from the BEA Use table. Much of the work involved in compiling the air emissions account consists of identifying and selecting the measures of polluting activity to use in attributing emissions.

C. Residency Adjustments

The GHGI estimates emissions on a territory basis: it measures emissions that occur in U.S. territory regardless of the residency of the agent performing the polluting activity. Adjusting these estimates to the residency basis required by *SEEA* can be done in one of three ways, depending on the data available for making the adjustment.

In some cases, emissions by U.S. residents can be estimated directly. Doing so requires data on fuel consumption for a particular activity by U.S. residents. We multiply fuel consumption by a multiplier called an emissions factor[4] to arrive at an estimate of total emissions for that activity by U.S. residents. This estimate then replaces reported emissions for that activity from the GHGI. For example, the air transport industry requires a residency adjustment, since U.S. airlines operate many flights into and out of foreign airports (and vice versa). For this adjustment, we use data from the Bureau of Transportation Statistics (BTS) Fuel Cost and Consumption for U.S. Carriers, which provides the quantity of fuel consumed by U.S. residents air transport carriers, both domestically and abroad. Since this data lines up precisely with the residency principle of *SEEA*, we multiply by an emissions factor for jet fuel obtained from EPA and replace the GHGI's estimate of emissions from jet airplanes.

If data on fuel consumption that conform to the residency basis are not available, we may be able to directly estimate the emissions that need to be added (subtracted) from GHGI emissions estimates to arrive at *SEEA* consistent emissions estimates. The emissions to be added are those by U.S. residents abroad, while those to be subtracted are those from foreign residents in the U.S. For example, marine shipping requires a large adjustment to align with the residency basis. Complete data on marine fuel consumption by U.S. residents are not available; however, BEA collects data on fuel expenditures by U.S. marine carriers abroad, and by foreign carriers in the U.S. Combining these data with data on world average prices for marine fuel oil, we will be able to estimate the quantity of fuel consumed by each group; multiplying these quantities by an emissions factor for marine fuel oil gives estimated emissions for each group, which we will add and subtract (respectively) from the GHGI estimated emissions from marine shipping[5].

Finally, if no estimate of fuel use or expenditure is available, we may be able to make an adjustment based on a measure of output. For example, we lack a measure of fuel consumption by U.S. trucks operating in Canada or Mexico (and vice versa), so we make the residency adjustment for truck transportation by multiplying the emissions reported in the GHGI and attributed to the truck

[4] Emissions factors are drawn from the EPA GHG Emissions Factors Hub (U.S. Environmental Protection Agency, 2022).

[5] Note that due to delays in obtaining data, this adjustment is not incorporated in the current version of the account, as discussed briefly in section 8.B.

transportation industry by the ratio of U.S. truck transportation output to output plus net exports of truck transportation services (this turns out to be a small adjustment, percentagewise).

D. Treatment of Specific Activities

Some activities reported in the GHGI require special treatment under *SEEA* or extra care in attribution to industries. For instance, as discussed in section 2.B, emissions reported under activities associated with trucking cannot all be assigned to the truck transportation industry, since truck transportation services are produced by enterprises in many industries for their own use (on own account). To properly attribute emissions from trucking activities we use the BTS Transportation Satellite Accounts (TSAs) (U.S. Bureau of Transportation Statistics, 2022), which provide estimates of the value of transportation services produced on own account by each industry, as well as by for-hire transportation industries. Trucking emissions are attributed to industries proportional to the value of truck transportation services produced by that industry.

Another activity requiring careful attention is emissions from waste stored in landfills. As indicated in section 2.B, emissions from waste in landfills should be attributed to accumulations, since they result from the economic activity of prior periods. Doing so requires identifying which "activities," as reported in the GHGI, correspond to emissions from decomposition of the waste itself and which correspond to emissions from the operation of the landfill. Emissions from the current period operation of the landfill are attributed to the waste management industry in the current period.

5. Data

A. Greenhouse Gas Inventory

The primary source of greenhouse gas emissions data for this proof-of-concept account is the Greenhouse Gas Inventory (GHGI) (U.S. Environmental Protection Agency, 2019). EPA produces the GHGI every year to satisfy the requirements of the United Nations Framework Convention on Climate Change (UNFCCC), which sets international standards for the construction of greenhouse gas inventories.[6] As a result of adherence to these standards, and because EPA re-estimates all earlier years when methodological improvements are made, the GHGI represents an internally consistent time series

[6] The GHGI has a two-year publication lag; as of this writing, the most recent data year published is 2019. Note that there may be an increased delay in production of the GHGI for 2020 and beyond due to the need for some models to be redeveloped to address structural changes resulting from the COVID-19 pandemic.

of estimated greenhouse gas emissions for the U.S. This allows us to compile a multi-year proof of concept air emissions account that is also internally self-consistent.

B. Secondary Data Sources

i. BEA Use Table

BEA's Use table is a broadly useful secondary data source, with data on purchases of commodities by industries. Commodities such as coal and petroleum products are good proxies for industries' use of related fuels. Since the Use table contains data for the whole economy, we use it as a fallback data source when more detailed sources of data do not have adequate coverage (for example, the EIA MECS survey is more detailed, but only covers manufacturing industries) (U.S. Bureau of Economic Analysis, 2017).

ii. BTS Transportation Satellite Accounts

To properly attribute emissions from trucking, an activity which is carried out by many industries, we use the BTS Transportation Satellite Accounts (TSAs). The TSAs are compiled for the purpose of measuring the value of transportation services produced by both the for-hire transportation industries and by other industries on own account (referred to as "in-house use" in the TSAs). These accounts are compiled using data on intermediate inputs specific to producing transportation services, combined with data on the employment of transportation employees. Emissions from trucking are attributed to industries proportional to the value of truck transportation services produced (either for hire or on own account) by those industries (U.S. Bureau of Transportation Statistics, 2022).

iii. BLS Quarterly Census of Employment and Wages

The BLS Quarterly Census of Employment and Wages (QCEW) is conducted quarterly and provides data on employment by industry and by county, using records from each state's unemployment insurance accounting program. Each employer in a state submits quarterly reports with employment and wage data for each of their establishments within the state. Because the QCEW data is very disaggregated in terms of industries, we use it as a backup data source for attribution when other data sources are too aggregated. The implicit assumption when doing so is that employment is a reasonable proxy for industry size and emissions, especially when comparing closely related industries (U.S. Bureau of Labor Statistics, 2012).

iv. EIA Manufacturing Energy Consumption Survey

The EIA tracks energy use by manufacturing industries through the Manufacturing Energy Consumption Survey (MECS), published every four years. The MECS data is used to proportionally allocate methane and carbon dioxide emissions from coal and natural gas manufacturing and distillate fuel, hydrocarbon gas liquid, coke and breeze, natural gas, and other petroleum feedstocks to the appropriate industries. When necessary, BLS QCEW employment data is used to disaggregate MECS data to a finer degree of industry specificity, before attributing emissions flows to industries (U.S. Energy Information Administration, 2018).

v. BTS Fuel Cost and Consumption for U.S. (Air) Carriers

BTS collects and reports data on the quantity of fuel consumed by major commercial carriers, on all flights worldwide (U.S. Bureau of Transportation Statistics, 2022). Since this conforms closely to the *SEEA* residency principle, we use these data to directly estimate emissions from U.S. air transportation, by multiplying the quantity of fuel consumed by an emissions factor obtained from EPA (U.S. Environmental Protection Agency, 2022), for each of the relevant greenhouse gas emissions (carbon dioxide, methane, and nitrous oxide).

6. Tools

The data tables underlying the proof-of-concept U.S. *SEEA* air emissions account are generated in FLOWSA, a Python tool developed by EPA for environmental impact to industry (and non-business economic sector) attribution modeling (Birney, et al., 2022). FLOWSA is open-source[7] and allows for transparent and reproducible modeling of industry air emissions. The source data import process is automated, allowing models compiled in FLOWSA to be easily updated as new source data become available.

FLOWSA's operation can be summarized in three steps: 1) source data import, 2) activity to industry mapping, and 3) attributing environmental impacts, as found in the source data, to industries.

The first step in generating the air emissions account is to import datasets for all primary and secondary data sources. The source datasets are imported with the original terminology, units, and activities and formatted into standardized tables. These standardized tables simplify the process of harmonizing the data and allow for data sets which are used repeatedly to be used consistently each time they are used. The most recent release of FLOWSA, v1.2.2, provides pre-imported tables for approximately 50 common environmental and economic data sources.

[7] Hosted on GitHub, at https://github.com/USEPA/flowsa

As the primary and secondary datasets are published with diverse terminology to describe activities, the second step is to create activity to industry mapping files that capture the relationship between the original dataset terminology (e.g., "Natural gas manufacturing") and industries, generally 3- or 4-digit NAICS codes. These crosswalks are created for each primary and secondary activity dataset and used to standardize industry terminology. The crosswalks do not capture how the data should be attributed, only which industries relate to each activity in a data source.

EPA provides crosswalks for datasets already imported into FLOWSA, but users may also define their own crosswalks. Crosswalks are developed using activity to industry mapping files provided by data publishers, through discussions with data publishers, and the definitions of source data activities and NAICS codes.

The final step of compiling the proof-of-concept air emissions account is building the industry attribution model. Each model is created from a unique methodology file containing instructions for how each primary data source activity should be attributed to industries, either directly or proportionally, using secondary data sets. The method files for the data tables underlying the proof-of-concept *SEEA* air emissions account capture the residency basis and production boundaries discussed earlier in the paper. All method files used to generate this proof-of-concept air emissions account are hosted in the FLOWSA GitHub repository.

7. Results

Table 1 gives a physical supply and use table for air emissions, aggregated to the NAICS 2-digit level. In the supply-use framework, "uses" of emissions (by the environment) represent the emissions flowing into the atmosphere, not any use by economic units; indeed, any flows of gases to other economic units for their use would be considered flows within the economy, and outside the scope of this account. Therefore, the two columns in the Use portion of the table are identically equal by construction, both to each other and to the total supply column of the Supply section.

Table 1. Physical Supply and Use of Air Emissions in the U.S., at NAICS 2-Digit Level

Pollutant\Industry	Agriculture[1]	Mining	Utilities	Construction	Manufacturing	Wholesale	Retail	Transportation
Carbon Dioxide	13.21	91.09	2,062.44	37.78	917.96	66.11	90.67	610.30
Methane	251.10	207.02	34.45	0.02	1.36	0.04	0.04	33.94
Nitrous Oxide	347.52	1.87	51.25	0.22	19.72	0.40	0.57	6.84
F-GHGs	-	0.04	-	8.48	87.50	1.10	0.62	6.41
Sulfur Hexaflouride	-	-	4.20	-	1.70	-	-	-
Nitrogen Triflouride	-	-	-	-	0.60	-	-	-
Total GWP	611.83	300.02	2,152.34	46.49	1,028.84	67.66	91.91	657.49

1. "Agriculture" includes forestry and fishing

Pollutant\Industry	Information	Finance	Real Estate	Professional[2]	Management	Administrative[2]	Education	Health Care
Carbon Dioxide	6.73	9.52	23.23	14.89	9.72	64.71	6.82	16.91
Methane	0.01	0.03	0.12	0.01	0.01	112.03	0.01	0.04
Nitrous Oxide	0.04	0.02	0.50	0.10	0.06	2.83	0.04	4.39
F-GHGs	1.32	0.04	0.18	0.79	0.01	1.04	0.14	1.51
Sulfur Hexaflouride	-	-	-	-	-	-	-	-
Nitrogen Triflouride	-	-	-	-	-	-	-	-
Total GWP	8.10	9.61	24.03	15.79	9.79	180.61	7.00	22.85

2. "Professional" includes scientific and technical services; "Administrative" includes support and waste management services

Pollutant\Industry	Entertainment[3]	Hospitality[3]	Oth. Services	Government	Households	Total Supply	Environment	Total Use
Carbon Dioxide	2.25	33.00	18.13	31.93	1,056.19	5,183.58	5,183.58	5,183.58
Methane	0.03	0.03	0.03		4.20	644.52	644.52	644.52
Nitrous Oxide	0.18	0.19	0.18	0.27	6.70	443.89	443.89	443.89
F-GHGs	0.08	1.42	0.53	1.05	41.11	153.37	153.37	153.37
Sulfur Hexaflouride	-	-	-	-	-	5.90	5.90	5.90
Nitrogen Triflouride	-	-	-	-	-	0.60	0.60	0.60
Total GWP	2.54	34.64	18.88	33.25	1,108.21	6,431.87	6,431.87	6,431.87

3. "Entertainment" includes art and recreation; "Hospitality" includes accommodation and food services

All figures are reported in Mt CO2 equivalent (1 unit anywhere in the table represents global warming potential (GWP) equal to one megatonne of carbon dioxide)

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The patterns of emissions by industry observed in this proof-of-concept account, as displayed in figure 1, generally conform to what might be expected: the highest emissions of carbon dioxide come from electric generation; of methane and nitrous oxide, from agriculture; of fluorinated greenhouse gases (HFCs and PFCs), from manufacturing; with sulfur hexafluoride and nitrogen trifluoride being narrowly restricted to the electronics manufacturing (and electric distribution, for sulfur hexafluoride) industries.

Figure 1. Total Emissions (in Global Warming Potential) by Industry

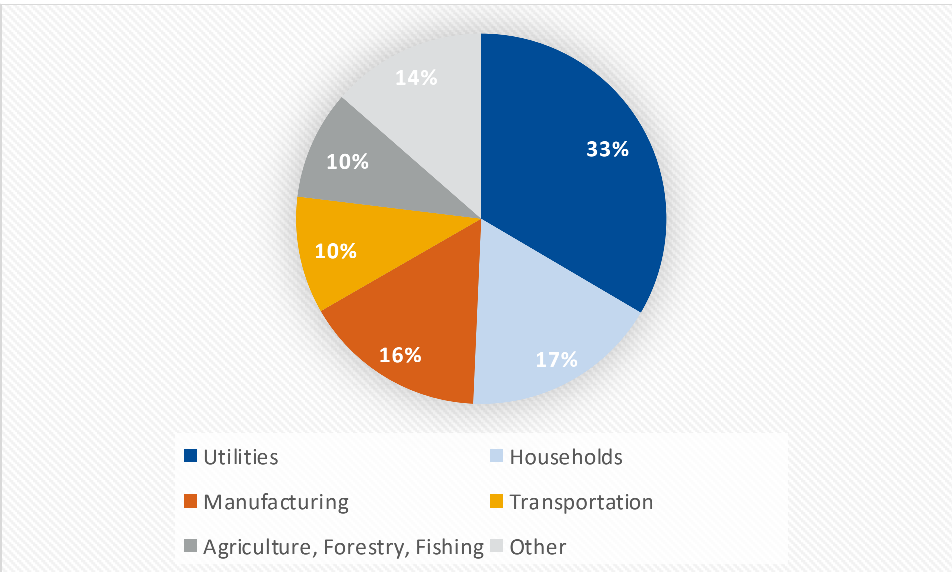

Figure 2 shows emissions intensities by industry, in kg-carbon-dioxide-equivalent units per dollar contributed to GDP. The first thing to notice in this figure is the wide variation of magnitudes across industries. Utilities (primarily due to electric generation) have by far the highest emissions intensity per dollar, double that of their nearest rival (agriculture).[8] Only utilities, agriculture, mining, and transportation have emissions per dollar greater than 1 kg CO_2e/$. Many other industries have emissions per dollar a hundred or even a thousand times smaller.

[8] It should be noted that "dollars contributed to GDP," or dollars of value added, should not be considered a measure of an industry's true value to society, for reasons too numerous to discuss here. This is particularly true in the case of utilities, which are most commonly operating under heavily regulated prices, not at a competitive market equilibrium.

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Figure 3. Emissions Intensity by Industry (kg CO_2 equivalent/dollar)

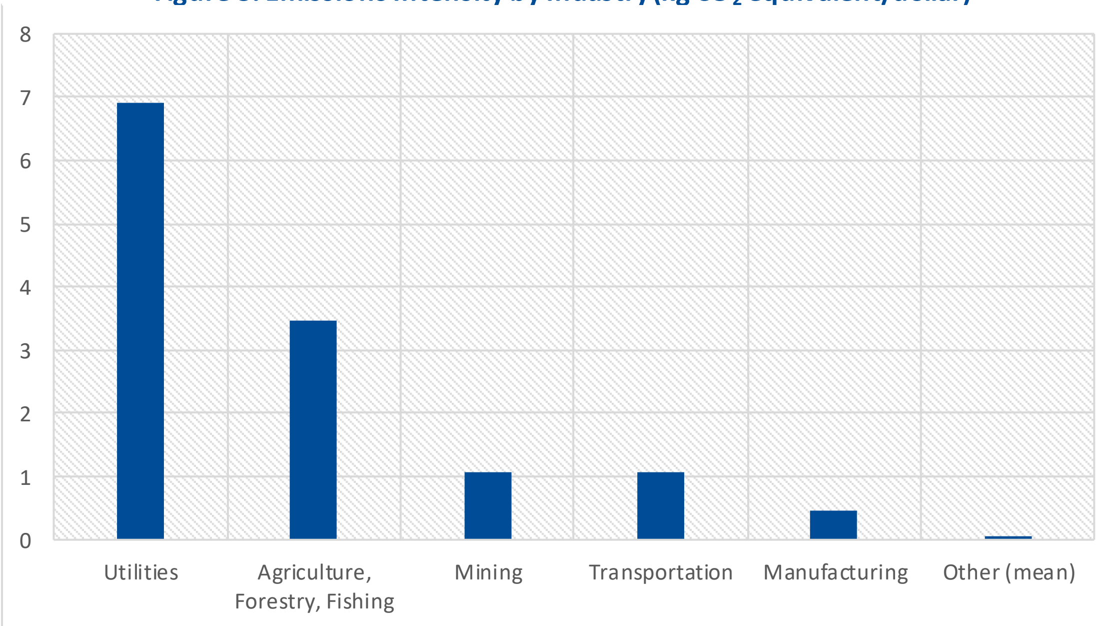
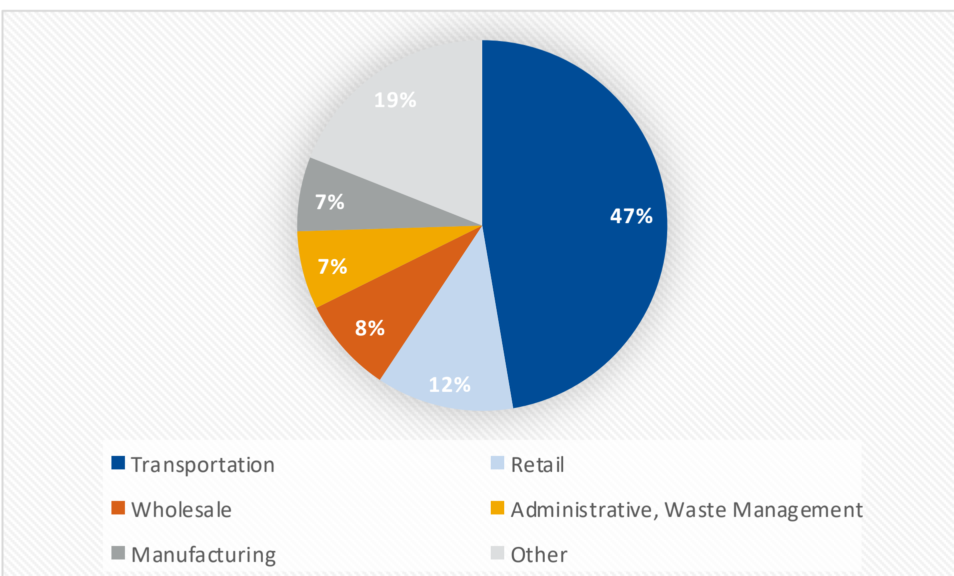


Figure 3 shows how emissions from trucking (as an activity) are attributed across different industries. While the for-hire truck transportation industry is by far the largest single source of trucking emissions, it is outweighed by the total emissions due to various industries operating trucks for their own use. This serves as an example of how *SEEA*-consistent air emissions accounting can be used to provide valuable understanding and data for both public and private decision makers, beyond what is available from the GHGI alone.

Figure 2. Attribution of Trucking Emissions to Industries



8. Challenges and Further Work

A. Data Gaps

The biggest data gaps encountered in preparing a *SEEA*-consistent air emissions account for the U.S. lie in areas not adequately covered by the GHGI due to the difference between the territory basis of the GHGI and the residency basis of *SEEA*. The largest such gap is in marine transportation. It is known that ships burn a large quantity of fuel, producing a correspondingly large quantity of emissions. However, since these emissions are not included in the GHGI, we will have to estimate those emissions directly, using data on fuel expenditures by U.S. owned ships operating abroad and foreign owned ships operating in the U.S., together with data on world average fuel prices. It would be strongly preferable to have data on quantity of fuel consumed by U.S. owned ships, like the data on fuel consumption by U.S. air carriers collected by BTS. However, BTS does not currently collect such data for ships.

A similar gap exists in truck transportation. U.S. trucks operate in Canada and Mexico, and Canadian and Mexican trucks operate in the U.S. However, data on fuel consumed by U.S. trucks abroad, or Canadian and Mexican trucks in the U.S., are not available. In this proof-of-concept account, we make an adjustment based on the ratio of truck transportation service imports and exports to domestic truck transportation output, but data on fuel consumption (again, like the BTS data on air carrier fuel consumption), would enable more accurate accounting for these emissions.

A gap which we were not able to address even partially in this account concerns the use of passenger cars by businesses. Under *SEEA*, the emissions from cars operated by businesses should be attributed to the industries to which those businesses belong. However, we have not been able to identify a source of data that would allow us to make this attribution. Consequently, in this proof-of-concept account, all emissions from passenger cars are attributed to household consumption.

B. Further Work

Further work on refining this proof-of-concept U.S. *SEEA* air emissions account will include making the residency adjustment for marine transportation, properly attributing emissions from accumulated wastes to accumulations, and searching for a way to properly attribute emissions from passenger car use by businesses.

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