MIT Joint Program on the Science and Policy of Global Change

Emission Inventory for Non-CO_2 Greenhouse Gases and Air Pollutants in EPPA 5

Caleb Waugh, Sergey Paltsev, Noelle Selin, John Reilly, Jennifer Morris, and Marcus Sarofim

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Caleb Waugh[*†], Sergey Paltsev[*], Noelle Selin[*], John Reilly[*],

Jennifer Morris[*], and Marcus Sarofim[‡]

Abstract

This technical note documents the inventory of non-CO_2 greenhouse gas (GHG) and traditional air pollutant emissions for the MIT Emissions Prediction and Policy Analysis model version five (EPPA 5). The non-CO_2 GHG species considered include methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Traditional air pollutants include carbon monoxide (CO), sulfur dioxide (SO_2), nitrous oxides (NO_x), ammonia (NH_3), black carbon (BC), organic carbon (OC), and non-methane volatile organic compounds (NMVOCs). In considering non-CO_2 GHG data sets, we evaluate bottom-up inventories from the Emissions Database for Global Atmospheric Research version 4.1 (EDGAR v4.1), the "U.S. Environmental Protection Agency Global Non-CO_2 Anthropogenic Emissions: 1990-2020" report (EPA 2006), and a recent inventory from the Global Trade Analysis Project (GTAP v7). For traditional air pollutants we consider EDGAR v4.1 and EDGAR-HTAP v1. Since EPPA 5 is also used in connection with the MIT Integrated Global System Model (IGSM) to study environmental effects, good agreement with measured GHG concentrations is crucial and we compare bottom-up and top-down estimates to gauge for consistency. We conclude that the EDGAR v4.1 inventory is best suited for benchmarking non-CO_2 GHGs in EPPA 5 due to good disaggregation between economic sectors and species, and because it provides the closest fit with top-down estimates.

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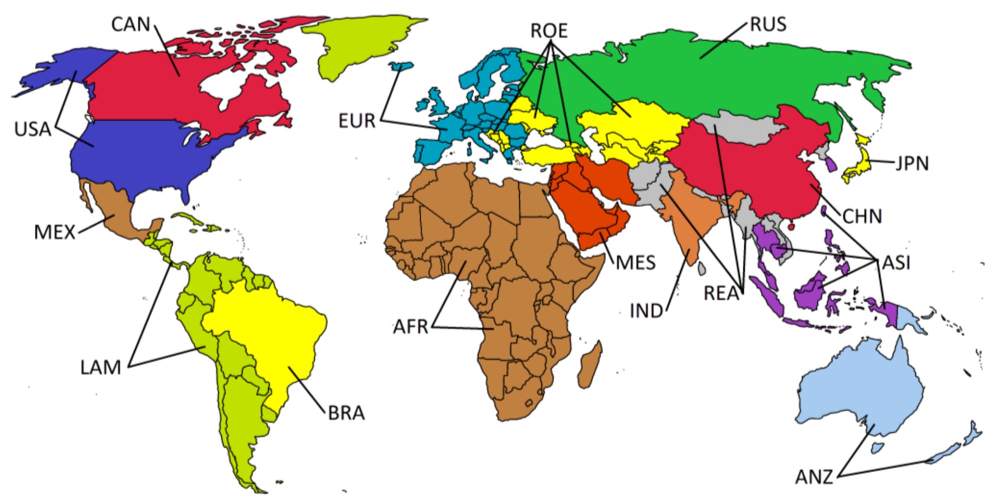
1. INTRODUCTION

This technical note documents the creation of a non-CO_2 greenhouse gas (GHG) and traditional air pollutant emissions inventory for the fifth version of the Massachusetts Institute of Technology (MIT) Emissions Prediction and Policy Analysis model (EPPA 5) (Paltsev *et al.*, 2011). EPPA 5 is a dynamically recursive multiregional general equilibrium model of the world economy that is used to study the effects of energy and environmental policy on the economy and on anthropogenic emissions of greenhouse gases and traditional air pollutants (Paltsev *et al.*, 2005). As a multiregional model, EPPA simulates the world economy by dividing the world into 16 regional economies that represent individual countries or groups of countries. As a general equilibrium model, EPPA simulates each regional economy using multiple economic sectors. In its base form, EPPA 5 contains 14 sectors, along with additional technological detail in energy sectors. A map of the EPPA 5 regions along with a table of the economic sectors and their abbreviation is given in **Figure 1**.For each region, sectoral output is used for intermediate use, final use, investment, and exports. In addition, we map some emissions to an aggregate final consumption rather than to a particular sectoral final use in the model. We denote those emissions as final demand (FD) emissions.



EPPA 5 Sectors	
LIVE	Livestock
CROP	Crops
FORS	Forestry
FOOD	Food
EINT	Energy Intensive Industry
HTRN	Household Transportation
TRAN	Other Transportation
OTHR	Other
SERV	Services
ELEC	Electricity
OIL	Oil
ROIL	Refined Oil
COAL	Coal
GAS	Gas

Figure 1. EPPA 5 Regions and Sectors.

As a dynamically recursive model, EPPA is calibrated to a base year which contains a snapshot of the world economy. The model then solves recursively from the base year in five year intervals producing projections of gross domestic product, final demand, energy consumption, and emissions of GHGs and traditional air pollutants. In addition to running as a standalone model, EPPA can also run jointly with the MIT Integrated Global System Model (IGSM) to study how changes in anthropogenic emissions impact various earth systems and the environment (Sokolov *et al.*, 2005). To account for anthropogenic emissions, the base year snapshot requires—in addition to economic data—an inventory of GHG and traditional air pollutant emissions for all sectors and regions.

The goal of this document is to explain the reasoning behind the choices made in selecting source data for the emissions inventory used in EPPA 5, and to make transparent any assumptions that were made when dealing with incomplete data. In EPPA 5 we account for the following GHGs: methane (CH_4), nitrous oxide (N_2O), hydroflurorcarbons (HFCs), perflurocarbons (PFCs), and sulfur hexafluoride (SF_6). We also consider the following traditional air pollutants: carbon monoxide (CO), sulfur dioxide (SO_2), nitrous oxides (NO_x), ammonia (NH_3), black carbon (BC), organic carbon (OC), and non-methane volatile organic compounds (NMVOCs).

Base year data for the economic parameters in EPPA come from the Global Trade Analysis Project (GTAP) database (Dimaranan and McDougall, 2002). Consequently, the base year for versions of EPPA coincides with the years that GTAP datasets have been released. For EPPA 5, we use GTAP version seven (GTAP v7) which has a base year of 2004 (Narayanan and Walmsley, 2008). In the past, the GTAP database only accounted for economic parameters and emissions inventories had to be compiled from other sources. For earlier versions of EPPA this was accomplished largely by building inventories from literature on individual GHG species (Mayer *et al*., 2000; Asadoorian *et al*., 2006). As interest in anthropogenic GHG and traditional air pollutant emissions has increased, comprehensive datasets for major species by region and source have been compiled making the task of creating emission inventories a matter of mapping these existing datasets into the EPPA regions and sectors. Two of the most prevalent datasets containing non-CO_2 GHG emissions include the Emissions Database for Global Atmospheric Research (EDGAR) (van Aardenne *et al.*, 2009), and the "U.S. Environmental Protection Agency Global Non-CO_2 Greenhouse Gas Emissions: 1990-2020" report (U.S. EPA, 2006). In addition to these inventories, GTAP has recently added its own GHG emissions inventory, based on the EPA inventory, as a supplement to its economic dataset (Rose *et al.*, 2010).

In general, estimates of non-CO_2 GHGs have been made using two approaches: bottom-up inventories and top-down estimates. Bottom-up inventories—such as those used to create the EDGAR, U.S. EPA, and GTAP datasets—are created by estimating anthropogenic GHG emissions based on economic activity within the sectors in each region, and by using emissions reporting data from the United Nations Framework Convention on Climate Change (UNFCCC, 2010). Top-down estimates are usually based on sampling concentrations of gases at various locations around the globe and then using inverse modeling to deduce anthropogenic emission from the concentration measurements. For a complete explanation on inverse modeling see Prinn, 2000. More recently, top-down approaches have also used GHG concentration measurement data from satellites. While both bottom-up and top-down methods are somewhat consistent, top-down estimates generally predict higher emissions than bottom-up. The top-down approach provides estimates of global GHG emissions that are consistent with observed concentrations, but are not sufficiently disaggregated by regions and economic sectors for direct use in an emissions inventory such as what is needed for EPPA 5. Consequently, we consider bottom-up databases as candidates for the EPPA 5 emissions inventory, but compare such datasets with top-down estimates to gauge for consistency.

For traditional air pollutant emissions, options of datasets for use in a global inventory are more limited. Although there is substantial literature on estimates of traditional air pollutant emissions, most estimates cover limited geographic areas and/or do not attribute emissions across multiple sources. Examples of data sets that give regional estimates include the European Monitoring and Evaluation Program (EMEP, 2010), emissions reporting to the United Nations Framework Convention on Climate Change (UNFCCC, 2010), the Regional Emissions Inventory in Asia (REAS, 2007), the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS, 2011) model by the International Institute for Applied Systems Analysis (IIASA, 2010), and various emissions monitoring data by the U.S. EPA.

For EPPA 5 we consider two potential datasets for traditional air pollutants. The first is an extension of the EDGAR v4.1 database that includes SO_2, NO_x, CO, NH_3, and NMVOCs. As with greenhouse gases, EDGAR v4.1 estimates emissions of traditional air pollutants using economic data by applying emissions factors and end-of-pipe abatement reductions. The second dataset we consider is the EDGAR-HTAP v1 dataset (HTAP, 2009), which uses emission estimates from the U.S. EPA, EMEP, UNFCCC, REAS, and GAINS as source data. Where data cannot be found in these datasets for some developing countries, EDGAR-HTAP v1 uses values from EDGAR v4.1.

In the remainder of this paper, we present the bottom-up inventories under consideration for GHGs and compare with literature on top-down estimates to gauge for consistency. After comparing bottom up and top down estimates we discuss the advantages and disadvantages of each dataset and explain any discrepancies. We then map the datasets from their original format into the EPPA 5 regions and sectors and provide a detailed comparison among bottom-up inventories. We also provide an overview of the datasets used for traditional air pollutants. We conclude that of the three datasets considered for non-CO_2 GHG emissions, the EDGAR v4.1 data is the best suited for creating a non-CO_2 emissions inventory for EPPA 5. This is largely due to EDGAR v4.1 being the least aggregated of the three in terms of economic sectors and GHG species, and because it most closely agrees with top-down estimates of CH_4 and SF_6. The later feature is important since it provides greater compatibility with the IGSM. Details of the method used to map the datasets and the resulting EPPA 5 emissions inventory are provided in the appendix. We also find the EDGAR-HTAP v1 data best suited for traditional air pollution emissions.

2. NON-CO_2 GREENHOUSE GAS INVENTORIES AND ESTIMATES

2.1 Bottom-Up Emissions Inventories

In considering bottom-up inventories for benchmarking non-CO_2 GHGs in EPPA 5, we are primarily interested in how each dataset aggregates/disaggregates data by region, source, and species since this largely affects our ability to map the dataset into the EPPA 5 regions and sectors. We also consider how well the data maps into the 2004 base year corresponding to the GTAP v7 economic benchmark data. The primary sources of the GHGs we consider are presented in **Table 1** and are listed by species and EPPA 5 sector.

Table 1. Sources of non-CO_2 GHGs by species and EPPA 5 sectors.

EPPA Sector	Description
Methane (CH_4) Emissions	
LIVE	Enteric fermentation from domesticated ruminants (cattle, buffalo, sheep, goats, and camels)
	Manure management of livestock
CROP	Rice patties and rice cultivation
	Incomplete biomass combustion of agricultural waste
FORS	Savannah and deforestation burning
FOOD	Food processing
EINT	Industrial sewage
	Paper and pulp production
	Misc. Production: Chemicals, iron and steel, metals, minerals, petrochemicals, silicon carbide (minor contributors)
OIL	Oil production, processing, flaring, and venting losses
COAL	Emissions due to coal seam leakage during coal mining
	Emissions due to incomplete combustion (minor contributor)
ROIL	Emission due to incomplete combustion (minor contributor)
GAS	Natural gas production, processing, transmission, and distribution losses
	Emissions due to incomplete combustion (minor contributor)
FD	Landfill waste decomposition
	Domestic wastewater
Nitrous Oxide (N_2O) Emissions	
LIVE	Manure management of livestock
CROP	Incomplete biomass combustion
	Agricultural soils: fertilizers, nitrogen-fixing crops, crop residues
FORS	Savannah and deforestation burning
EINT	Adipic and nitric acid production: used for producing synthetic fibers, coatings, plastics, urethane foams, elastomers, synthetic lubricants, polyesters, fertilizers, and explosives
COAL	Coal combustion
	Fugitive emissions (minor contributor)
ROIL	Refined oil products combustion
	Gasoline and diesel combustion
GAS	Fugitive emissions (minor contributor)
FD	Domestic wastewater
Hydrofluorocarbons (HFCs) Emissions	
OTHR	HFC-23: Production of halocarbons and SF_6, electronics manufacturing
	HFC-134a: Foam blowing and aerosols

	Other F-gas use: HFC-32, HFC-125, HFC-143a, HFC-152a, HFC-227ea, HFC-236fa, HFC-245fa, HFC-365mfc
FD	HFC-134a: Refrigeration and air conditioning
Perfluorocarbons (PFCs) Emissions	
EINT	CF_4, C_2F_6: Aluminum production (smelting)
OTHR	CF_4: Fire extinguishers, semiconductor and electronics manufacturing
	C_2F_6: Solvent, semiconductor and electronics manufacturing
	C_3F_8: Semiconductor and electronics manufacturing
	C_4F_8: Fire extinguishers, solvent, semiconductor and electronics manufacturing
	C_4F_{10}: Fire extinguishers, solvent
	C_6F_{14}, C_7F_{16}: Solvent
	Other F-gas use: C_2F_6, C_3F_8, C_4F_{10}
FD	C_2F_6, C_3F_8, C_5F_{12}: Refrigeration and air conditioning
Sulfur Hexafluoride (SF_6) Emissions	
EINT	Magnesium production
ELEC	Electrical switchgear
OTHR	Semiconductor and electronics manufacturing
	Other SF_6 use

2.1.1 Emissions Database for Global Atmospheric Research (EDGAR v4.1)

The most recent version of the EDGAR dataset is EDGAR v4.1 (van Aardenne *et al*., 2009). Previous versions of EDGAR include EDGAR v3.2 (Olivier *et al*., 2002; Olivier *et al*., 1999) and EDGAR v2.0 (Olivier *et al*., 1996), which have both been used in part in creating emissions inventories for previous versions of EPPA (Mayer *et al*., 2000; Asadoorian *et al*., 2006). The EDGAR v4.1 dataset offers full disaggregation among regions and accounts for each country individually. It also fully disaggregates each fluorinated gas species (F-gas) in accounting for HFCs, PFCs, and SF_6. For HFCs it considers emissions of HFC-23, HFC-32, HFC-125, HFC-134a, HFC-143a, HFC-152a, HFC-227ea, HFC-236fa, HFC-245fa, and HFC-365mfc. For PFCs it considers CF_4, C_2F_6, C_3F_8, C_4F_8, C_4F_{10}, C_5F_{12}, C_6F_{14}, and C_7F_{16}. EDGAR v4.1 also provides estimates in one year intervals from 1970 through 2005 and therefore contains estimates that directly map into the 2004 EPPA 5 base year. All emissions in EDGAR v4.1 are given in gigagrams per year (Gg/yr). The emission source categories in EDGAR v4.1 are broken down according to IPCC source codes for each source. Descriptions of the EDGAR v4.1 categories along with the corresponding EPPA 5 sectors they map into are given in **Table 2**.

In mapping the EDGAR v4.1 data into the EPPA 5 sectors, emissions associate with fuel use are mapped to the fuel category and not to the sector in which the fuel is used. For example, in using coal, natural gas, and oil in electricity production we map emissions associated with burning coal, natural gas, or oil to COAL, GAS, and OIL respectively and not to ELEC. Similarly, emissions associated with refined oil consumption in household transportation are attributed to ROIL and not HTRN. This approach is also used when mapping data from EPA

2006 and GTAP v7. The reason emissions are accounted for in this manner is that as policies and prices influence the demand of different fuels within each sector, we want to capture substitution effects between fuels as inputs to production. This can only be done if the emissions are attributed to the fuel itself as an input to production and not to the sector in which the fuel is used.

Table 2. EDGAR v4.1 mapped to EPPA 5 sectors and fuel use (descriptions are of the EDGAR categories).

EDGAR v4.1	EPPA 5	Description
1. Energy: Fuel Combustion (1A) and Fugitive emissions from fuel (1B)		
1A1a	COAL, GAS, OIL	Public electricity and heat production
1A1bc	COAL, GAS, OIL	Other Energy Industries
1A2	EINT	Manufacturing Industries and Construction
1A3a	ROIL	Domestic aviation
1A3b	ROIL	Road transportation
1A3c	ROIL	Rail transportation
1A3d	ROIL	Inland navigation
1A3e	ROIL	Other transportation
1A4	FD	Residential and other sectors
1B1	COAL	Fugitive emissions from solid fuels
1B2	OIL, GAS	Fugitive emissions from oil and gas
1C1	ROIL	Memo: International aviation
1C2	ROIL	Memo: International navigation
2. Industrial Processes (non-combustion) and 3. Product Use		
2A	EINT	Production of minerals
2B	EINT	Production of chemicals
2C	EINT	Production of metals
2D	OTHR, FOOD	Production of pulp/paper/food/drink
2E	OTHR	Production of halocarbons and SF6
2F1	FD	Refrigeration and Air Conditioning
2F2	OTHR	Foam Blowing
2F3	OTHR	Fire Extinguishers
2F4	OTHR	Aerosols
2F5	OTHR	F-gas as Solvent
2F7	OTHR	Semiconductor/Electronics Manufacture
2F8	ELEC	Electrical Equipment
2F9	OTHR	Other F-gas use
2G	OTHR	Non-energy use of lubricants/waxes (CO2)
3	OTHR	Solvent and other product use
4. Agriculture (including Savanna burning)		
4A	LIVE	Enteric fermentation

4B	LIVE	Manure management
4C	CROP	Rice cultivation
4D1	CROP	Direct soil emissions
4D2	LIVE	Manure in pasture/range/paddock
4D3	CROP	Indirect N_2O from agriculture
4D4	CROP	Other direct soil emissions
4E	FORS	Savanna burning
4F	CROP	Agricultural waste burning
5. Land Use Change and Forestry		
5A	FORS	Forest fires
5C	FORS	Grassland fires
5D	FORS	Decay of wetlands/peatlands
5F	FORS	Other vegetation fires
5F2	FORS	Forest fires-post burn decay
6. Waste		
6A	FD	Solid waste disposal on land
6B	FD	Wastewater handling
6C	FD	Waste incineration
6D	FD	Other waste handling
7. Other Anthropogenic Sources		
7A	COAL	Fossil fuel fires
7B	OTHR	Indirect N_2O from non-agricultural NO_x
7C	OTHR	Indirect N_2O from non-agricultural NH_3
7D	OTHR	Other sources

Overall, the EDGAR v4.1 source categories map directly into EPPA 5 sectors except for 1A1a: fossil fuel combustion from public electricity and heat production, 1A1bc: fossil fuel combustion from other energy industries, 1B2: fugitive emissions from oil and gas, and 2D: non-combustion emissions from the production of pulp, paper, food, and drink. These IPCC categories aggregate emissions that technically should fall into two or more EPPA 5 sectors. Of these four categories, only 1A1a and 1B2 have a large enough contribution of overall emissions to be significant. Since oil is the dominating source of N_2O emissions in 1A1a, and since the methane contribution is insignificant compared to overall methane emissions, we map 1A1a to the OIL sector. Category 1B2 is more difficult due to significant contributions coming from fugitive emissions of both oil and natural gas. We discuss the treatment of 1B2 later in this note.

2.1.2 U.S. EPA Global Non-CO_2 GHG Emissions Report (EPA 2006)

The U.S. EPA report "Global Anthropogenic Non-CO_2 Greenhouse Gas Emissions:1990-2020" (EPA 2006) contains bottom-up projections of non-CO_2 GHGs similar to the EDGAR v4.1 dataset, except that the EPA report only gives projections in five year intervals with 2005 being the closest interval to the 2004 EPPA 5 base year (U.S. EPA, 2006). Assuming little change in emissions between 2004 and 2005, we consider the 2005 data. EPA 2006 provides good disaggregation among regions, and although not all countries are represented, the regions can be directly mapped into the EPPA 5 regions. All emissions are reported in megatons of CO_2 equivalent units ($MtCO_2eq$) based on the global warming potential (GWP) of each gas. The GWP values used in the report are based on the IPCC Second Assessment Report (SAR) (IPCC *et al.*, 1995). Although more recent GWP values are given in the IPCC Fourth Assessment Report (AR4) (IPCC, 2001), we continue to use SAR estimates to provide consistency with the EPA 2006 data and previous versions of EPPA. Values for GWP from the SAR are given in **Table 3**.

Table 3. Global Warming Potentials (GWP) from SAR.

Greenhouse Gas	GWP
Methane (CH_4)	21
Nitrous Oxide (N_2O)	310
Hydrofluorocarbons	
HFC-23	11,700
HFC-32	650
HFC-125	2,800
HFC-134a	1,300
HFC-143a	3,800
HFC-152a	140
HFC-227ea	2,900
HFC-236fa	6,300
HFC-245fa*	1,030
HFC-365mfc*	794
Perfluorocarbons	
CF_4	6,500
C_2F_6	9,200
C_3F_8	7,000
C_4F_{10}	7,000
C_4F_8	8,700
C_5F_{12}	7,500
C_6F_{14}	7,400
SF_6	23,900

*These values come from the 4AR.

While the EPA 2006 data disaggregates CH_4 and N_2O, the report uses $MtCO_2eq$ units to aggregate the PFCs, HFCs, and SF_6 across 11 categories. In addition, EPA 2006 also aggregates significantly across economic sectors that are disaggregated in EPPA 5. Although this does not completely rule out using the EPA 2006 data, it adds significant difficulty in that additional assumptions need to be made in mapping EPA 2006 data into EPPA 5. The EPA 2006 report does not assign any specific code to each category like EDGAR, but does uniquely reference the data in each category in the appendix. Henceforth, we will refer to each category by its appendix reference (appendix B for CH_4, appendix C for N_2O, and appendix D for the F-gases). The categories of the EPA 2006 data by appendix number along with their corresponding EPPA 5 sectors are given in **Table 4**.

Table 4. EPA 2006 mapped to EPPA 5 sectors (description are of EPA 2006 categories).

EPA 2006 Category	EPPA 5 Sector	Description
CH_4 Emissions		
B-1	GAS, OIL	Fugitives from Natural Gas and Oil Systems
B-2	COAL	Fugitives from Coal Mining Activities
B-3	ROIL, COAL, GAS	Stationary and Mobile Combustion
B-4	FD, CROP, OTHR	Biomass Combustion
B-5	EINT, OTHR	Other Industrial Non-Agricultural Sources
B-6	LIVE	Enteric Fermentation
B-7	CROP	Rice Cultivation
B-8	LIVE	Manure Management
B-9	CROP, FORS	Other Agricultural Sources
B-10	FD	Landfilling of Solid Waste
B-11	OTHR, FD	Wastewater
B-12	FD	Other Non-Agricultural Sources
NO_2 Emissions		
C-1	ROIL, TRAN	Stationary and Mobile Combustion
C-2	CROP, FD, OTHR	Biomass Combustion
C-3	OTHR	Adipic Acid and Nitric Acid Production
C-4	EINT	Other Industrial Non-Agricultural Sources
C-5	CROP	Agricultural Soils
C-6	LIVE	Manure Management
C-7	CROP, FORS	Other Agricultural Sources
C-8	OTHR, FD	Human Sewage
C-9	OTHR	Other Non-Agricultural Sources
HFCs, PFCs, and SF_6 Emissions		
D-1	OTHR	HFC and PFC Emissions from ODS Substitutes - Aerosols (MDI)
D-2	OTHR	HFC and PFC Emissions from ODS Substitutes - Aerosols (Non-MDI)
D-3	OTHR	HFC and PFC Emissions from ODS Substitutes - Fire Extinguishing
D-4	OTHR	HFC and PFC Emissions from ODS Substitutes - Foams

D-5	FD	HFC and PFC Emissions from ODS Substitutes - Refrigeration/Air Cond.
D-6	OTHR	HFC and PFC Emissions from ODS Substitutes - Solvents
D-7b	OTHR	HFC-23 Emissions from HCFC-22 Production
D-8b	ELEC	SF_6 Emissions from Electric Power Systems
D-9b	EINT	PFC Emissions from Primary Aluminum Production
D-10b	OTHR	HFC, PFC, SF_6 Emissions from Semiconductor Manufacturing
D-11b	EINT	SF_6 Emissions from Magnesium Manufacturing

As can be seen in Table 4, the EPA 2006 CH_4 and N_2O data is quite aggregated and often maps into two or more EPPA 5 sectors. In addition, the HFCs, PFCs, and SF_6 are also highly aggregated. F-gas categories D-1 through D-6 aggregate HFCs and PFCs, while D-10b aggregates HFCs, PFCs, and SF_6. Although many EPA 2006 categories aggregate across EPPA 5 species and sectors, there is generally one species or sector within each category that provides the largest contribution. Using this information, we map the EPA 2006 data into EPPA 5 based on which species and sources comprise the greatest contribution within each category. For example, for C-2 we expect the majority of N_2O emissions to come from agriculture and therefore map all of C-2 into CROP even though aggregate emissions come from CROP, FD, and OTHR.

2.1.3 Global Trade Analysis Project Emissions Inventory (GTAP v7)

One solution for dealing with the highly aggregated data in the EPA 2006 report is provided by GTAP. Although traditionally GTAP has only provided economic datasets, GTAP has recently created its own emission inventory using data related to the EPA 2006 dataset; however, they are not entirely the same. This effort is documented in Rose *et al*. (2010). Since—as discussed earlier—EPPA 5 is built on the GTAP dataset, this allows for seamless mapping of the GTAP v7 emissions inventory into EPPA 5. For a table outlining the mapping between GTAP v7 and EPPA 5 sectors, refer to Paltsev *et al.* (2011).

2.1.4 Overview of Bottom-up Inventories

Although each of the bottom-up inventories under consideration is fairly comparable in terms of global estimates, there remain significant differences particularly among estimates of CH_4 and the F-gases. A comparison of the global emissions from each inventory for CH_4, N_2O, HFCs, PFCs, and SF_6 is given in **Figure 2**. In the figure, CH_4 and N_2O are measured in teragrams per year (Tg/yr), while the HFCs, PFCs, and SF_6 are given in gigagrams per year (Gg/yr).

In aggregating the HFCs and PFCs in EDGAR v4.1, we convert all HFCs and PFCs into $MtCO_2eq$ units and then use CF_4 and HFC-134a as trace gases since they make up the largest component of the PFCs and HFCs respectively. Consequently, PFCs are given in gigagrams of CF_4 and HFCs are given in gigagrams of HFC-134a. As can be seen in Figure 2, EDGAR v4.1 has the highest estimates for CH_4, HFCs, and SF_6, while EPA 2006 gives the highest for N_2O and PFCs. Since GTAP v7 was based in part on the EPA 2006 data, we would expect the two inventories to be similar in aggregate, however, this is not the case. For CH_4 and N_2O, this is primarily because the GTAP v7 data does not include emissions from sources that are not uniquely anthropogenic. The omitted source categories in GTAP v7 include: biomass burning that is not uniquely attributed to anthropogenic sources, biomass burning from tropical forest deforestation, biomass combustion, and methane from underground storage and geothermal energy.

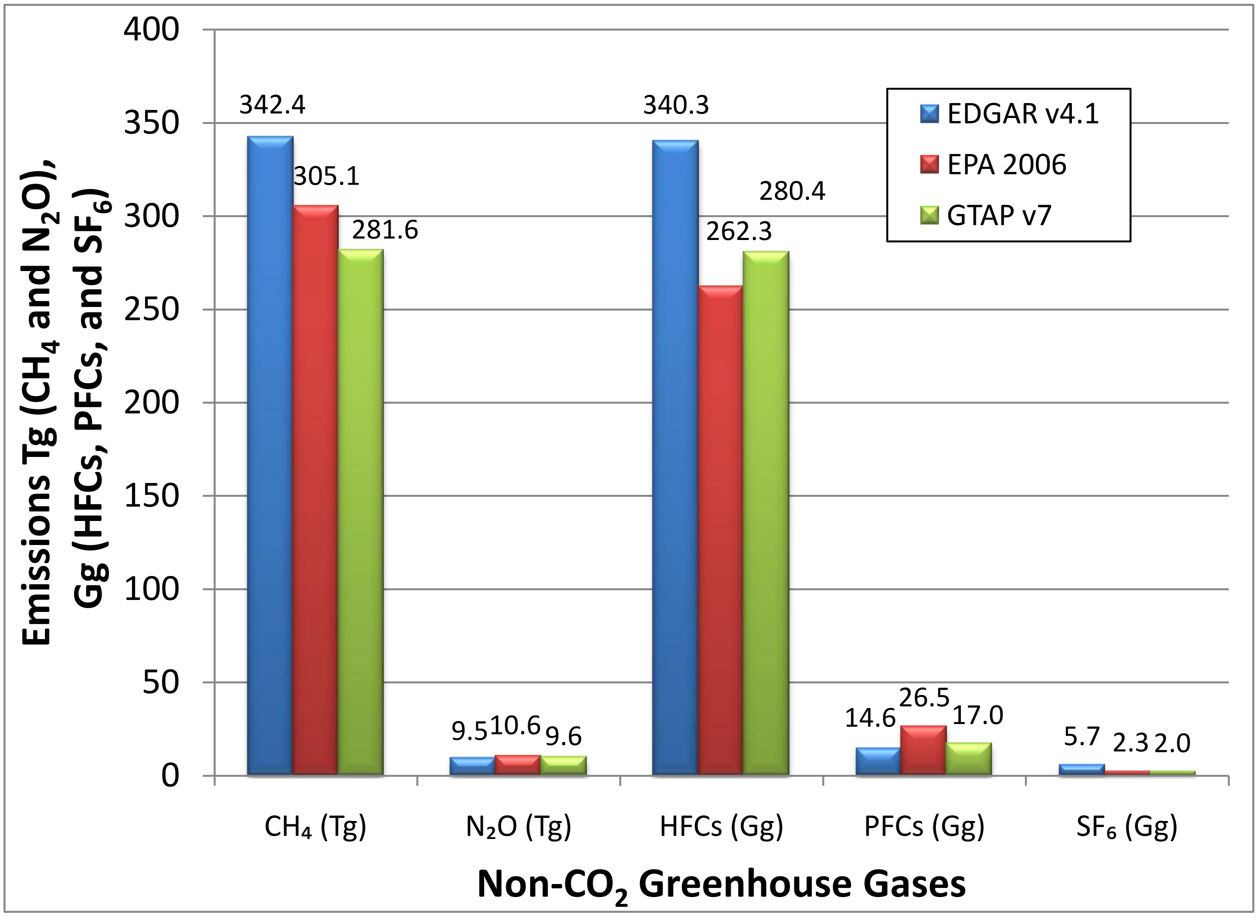


Figure 2. Comparison of non-CO_2 greenhouse gas emissions from EDGAR v4.1, EPA 2006, and GTAP v7 datasets. All inventories give estimates of annual emissions for 2004.

For the F-gases, the discrepancy between the GTAP v7 and EPA 2006 estimates can partially be explained due to differences in the way they allocate F-gas emission. As shown in Table 4, EPA 2006 contains 11 F-gas categories that aggregate across species. In contrast, the GTAP v7 data only contains six F-gas categories with some aggregation across species as well. Despite these differences, estimates of F-gas emissions carry a high degree of uncertainty so both estimates are within the range of uncertainty.

EDGAR v4.1 also differs significantly from the EPA 2006 and GTAP v7 HFC and PFC estimates. Since EDGAR v4.1 completely disaggregates HFCs, PFCs, and SF_6, we interpret this as signaling that our assumption for mapping the EPA 2006 data—based on the species and sector that contributed the most to each category—was not entirely reasonable. In other words, one cannot simply map according to which species and sources contribute the most within each category. As we do not use the EPA 2006 data in the end, this has no effect on the EPPA 5 emissions inventory.

2.2 Top-Down Emissions Estimates

Top-down estimates of non-CO_2 GHGs have been done for a variety of species. As mentioned in the introduction, top-down methods involve estimating emission levels based on measurements of atmospheric concentrations. Although some literature exists that considers global emissions, much of the literature limits consideration to a specific species in a particular region such as Europe or the U.S. In addition, the sampling period of concentrations in much of the literature ends prior to 2004. The literature for global estimates is fairly abundant for CH_4, less abundant but available for N_2O, very limited for SF_6, limited to only a few of the more significant species for PFCs (CF_4 and C_2F_4), and is nonexistent for HFCs except for regional estimates of HFC-134a and global estimates of HFC-152a and HFC-365mfc which constitute only a very small percentage of overall HFC emissions. Although some of the articles—particularly on methane—attempt to estimate emission sources, none do so in a consistent way so as to directly compare with bottom-up emissions from economic sectors. All these factors make it difficult to directly compare bottom-up inventories with the individual top-down estimates found in the literature. That said, in the following five subsections we survey a range of literature that most closely allows for comparison.

2.2.1 Methane (CH_4)

Methane is one of the more difficult gases to estimate due to a short lifetime, and has the greatest variance in emissions estimates among the literature. By using inverse modeling of concentration measurements obtained from satellite data, Bergamaschi *et al*. (2009) estimate total annual CH_4 emissions for 2004 to be 520 Tg/yr (Teragrams per year). However, *Bergamaschi et al.* do not distinguish between wetland and rice emissions so this number represents both anthropogenic emissions and natural emissions from wetlands. In a previous paper, Bergamaschi *et al*. (2007) attribute ~175 Tg/yr to wetlands. Accounting for this provides an estimate of 345 Tg/yr for anthropogenic emissions.

By using CH_4 concentration measurements from the Advanced Global Atmospheric Gases Experiment (AGAGE) obtained from 1996-2001, Chen and Prinn (2006) use inverse modeling to estimate total annual CH_4 emissions of 597 Tg/yr with anthropogenic emissions of 428 +/-34 Tg/yr in their baseline scenario. Similarly, Hein *et al*. (1997) use inverse modeling to estimate total annual methane emission from 1983-1989 of 592 Tg/yr with anthropogenic emission of 361 +/-39 Tg/yr. Finally, Mikaloff *et al*. (2004) estimate total annual emission from 1998-1999 to be 608 Tg/yr with 357 +/-42 Tg/yr coming from anthropogenic sources. The top-down estimated CH_4 emissions from all these studies is presented in **Figure 3**.

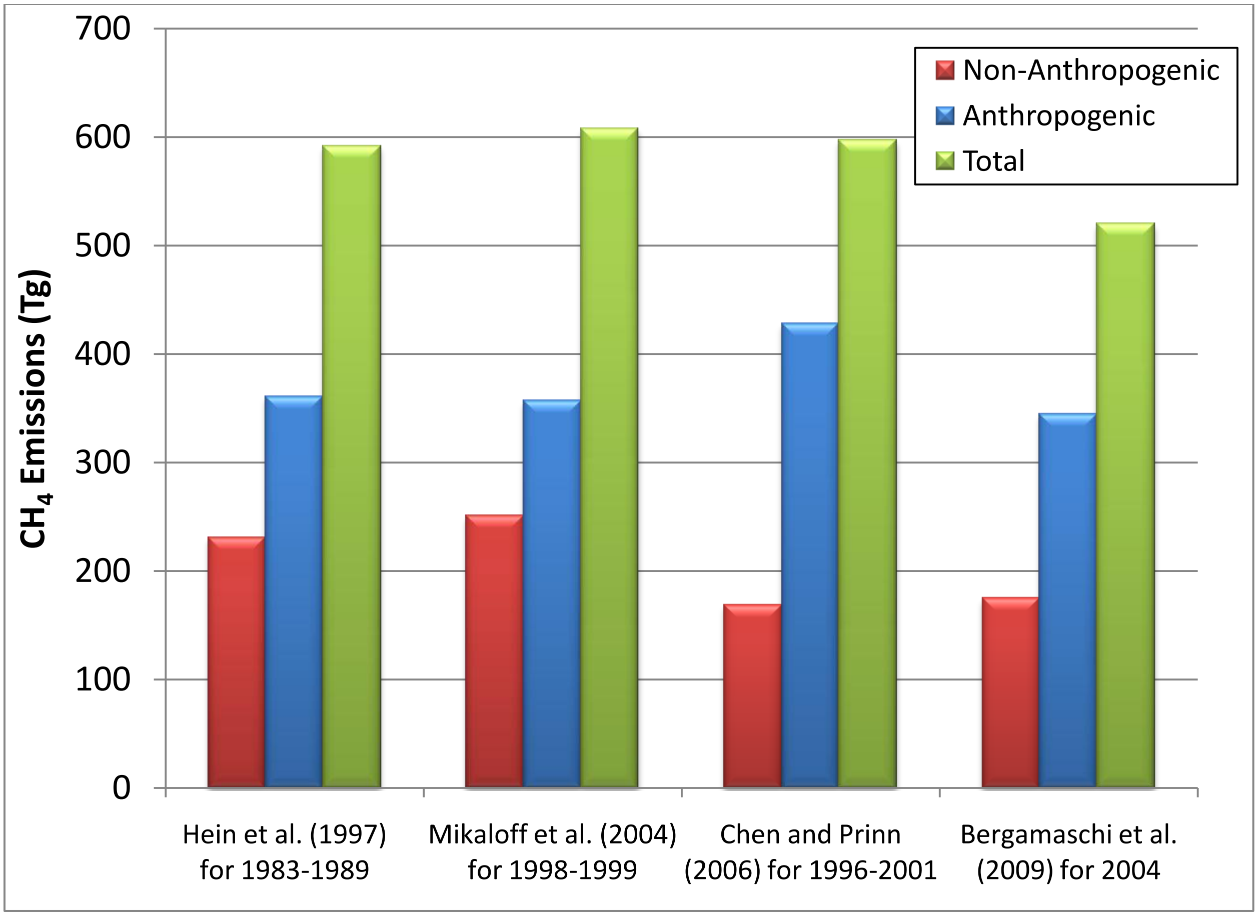


Figure 3. Comparison of total emissions and anthropogenic emissions of CH_4 top-down estimates. Values are yearly averages over the time periods indicated.

2.2.2 Nitrous Oxide (N_2O)

Nitrous oxide also has a relatively short life time—generally around 120 years—so that estimates based on inverse methodology also have some variability. By using inverse modeling on concentration measurements made by the Cooperative Global Air Sampling Network from 1998-2001, Hirsch *et al.* (2006) attribute 16.8 to 20.0 Tg/yr coming from land emissions and, assuming pre-industrial N_2O emission levels of 6.1-10.2 Tg/yr, predict anthropogenic N_2O emissions be around 6.6 -13.8 Tg/yr (in **Figure 4** we give the average of 10.2 Tg/yr). In contrast, Kroeze *et al.* (1999) offer a higher estimate of global anthropogenic emissions of 12.57 Tg/yr while Prather and Ehhalt (2001) provide a lower estimate of 9.0 Tg/yr.

2.2.3 Hydrofluorocarbons, Perfluorocarbons, and Sulfur Hexafluoride

The major contributors to global HFC emissions are HFC-23 and HFC-134a. Although some studies have considered inverse modeling of HFC emissions, the literature is sparse. Estimates of HFC-134a are found in O'Doherty *et al*. (2004) for concentration measurements obtained from 1998 to 2002, but consideration is limited to Europe. Global emissions are given for HFC-365mfc and HFC-152a in Stemmler *et al.* (2007) and Greally *et al.* (2007) respectively, but

HFC-mfc and HFC-152a only account for a minute portion of overall HFC emissions. Hence, there is little top-down work to compare with bottom-up global HFC inventories.

The major contributors to global PFC emissions are CF_4 and C_2F_6. Worton *et al.* (2007) and Harnicsh *et al.* (1996) give concentrations of both CF_4 and C_2F_6 but do not provide inverse modeling estimates of annual global emissions. In addition, Khalil *et al.* (2003) give a framework for addressing the sources of CF_4, C_2F_6, and C_3F_8, but do not use inverse modeling to calculate the amount of annual emissions from the concentrations.

Global annual emissions of SF_6 have been estimated by Levin *et al*. (2009) using inverse modeling for concentration samples taken from 1978 to 2008. From this, Levin *et al.* provide a global annual 2004 estimate of 5.84 Gg/yr. Annual emissions of SF_6 are also estimated by Rigby *et al.* (2010) for 2004 at 5.7 Gg/yr. In addition, both Levin *et al.* and Rigby *et al.* compare their estimates with bottom-up inventories and time trends from EDGAR and find relatively good agreement.

2.3 EPPA 5 Inventory Comparisons

Having considered both bottom-up inventories and top-down inverse modeling estimates, we now compare the global estimates of both techniques. We begin by giving an overall comparison of the three bottom-up inventories—EDGAR v4.1, EPA 2006, and GTAP v7—with the top-down estimates for CH_4, N_2O, and SF_6. We then present the results of mapping each bottom-up inventory into EPPA 5 and discuss any discrepancies among the bottom-up inventories by region and sector. We find that the discrepancies are primarily of two kinds: (1) discrepancies due to legitimate differences between the inventories, and (2) discrepancies arising from trying to map aggregated source data into the more disaggregated EPPA 5 sectors.

2.3.1 Overall Comparison

Comparison between the bottom-up inventories and top-down inverse modeling estimates for CH_4, N_2O, and SF_6 is given in Figure 4. Comparison with PFCs and HFCs is not given due to unavailability of literature to compile global estimates as mentioned earlier.

In the figure we see that the previously stated assertion—that top-down estimates exceed bottom-up inventories—generally holds for all three gases. For CH_4 and SF_6, EDGAR v4.1 is in closest agreement with top-down estimates. Top down estimate are also largely consistent for both CH_4 and SF_6 except for the Chen and Prinn (2006) estimates of CH_4 which are considerably higher than the other top-down CH_4 estimates. For N_2O, we see all three bottom-up estimates within the range given by the top-down methods.

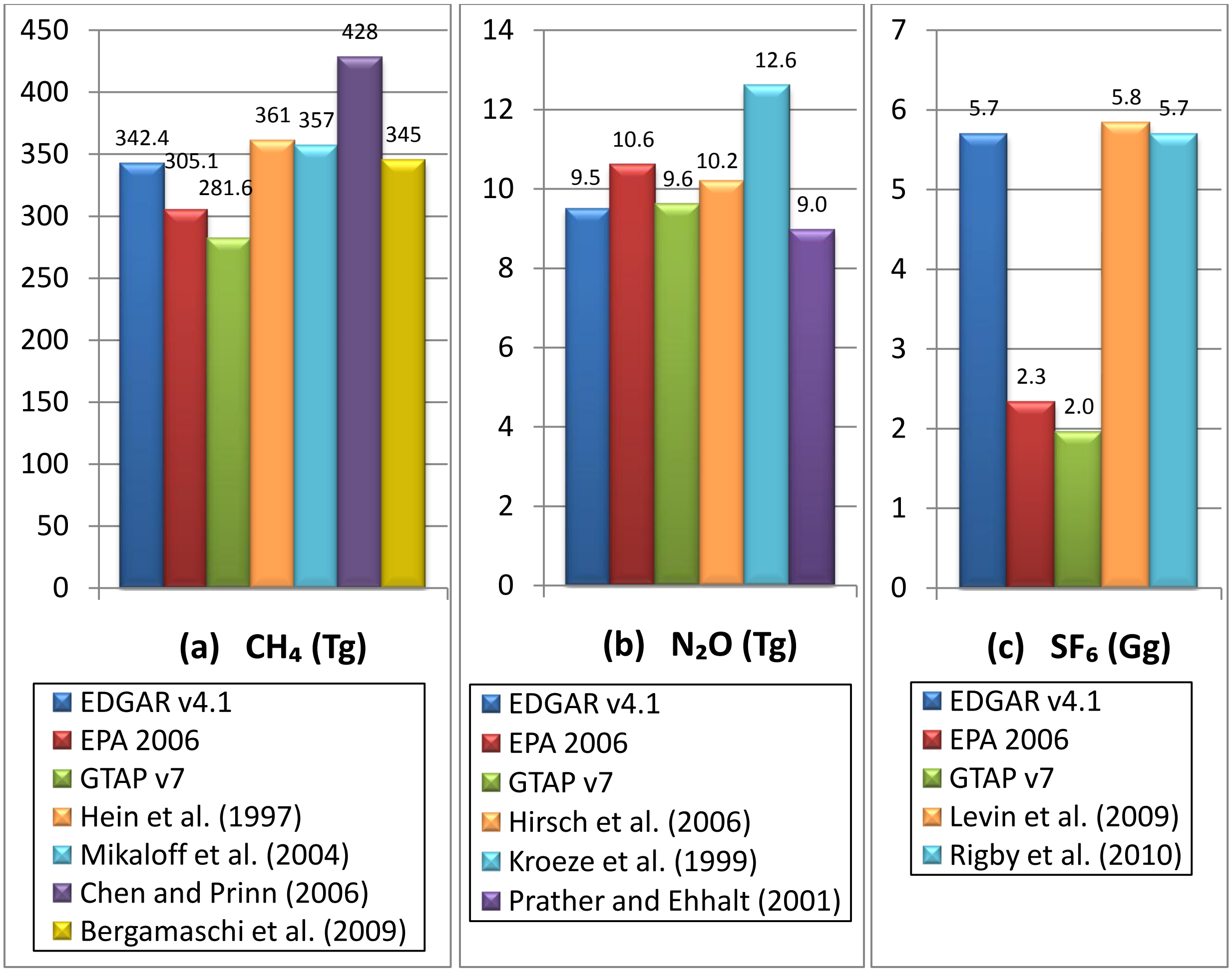


Figure 4. Comparison between the bottom-up inventories (EDGAR v4.1, EPA 2006, and GTAP v7), and top-down estimates taken for (a) CH_4 (Bergamaschi *et al.*, Chen *et al.*, Hein *et al.*, and Mikaloff *et al.*), (b) N_2O (Huang *et al.* and Hirsch *et al.*), and (c) SF_6 (Levin *et al.* and Rigby *et al.*).

2.3.2 Methane (CH_4)

Comparison between the three bottom-up inventories for CH_4 by region shows relatively good agreement and can be found in **Figure 5**. Here we see GTAP v7 closely following EPA 2006 although estimates are not entirely the same. As mentioned earlier, this is largely due to GTAP not considering certain emissions that cannot uniquely be attributed to anthropogenic sources. The major deviations are between the EPA 2006/GTAP v7 and EDGAR v4.1 data and are for ASI, CHN, and RUS. In China the difference is primarily found in fugitive coal emissions with EDGAR v4.1 attributing 20.4 Tg compared to 6.46 Tg from EPA 2006. For ASI, the difference is mainly found in waste water handling with EDGAR v4.1 attributing 8.59 Tg compared to 1.26 Tg from EPA 2006. In Russia, the difference lies in fugitive emissions from natural gas with EDGAR v4.1 attributing 18.51 Tg compared to 8.22 Tg from EPA 2006. These differences can also be used to help explain discrepancies in CH_4 estimates across sectors, which are given in **Figure 6**.

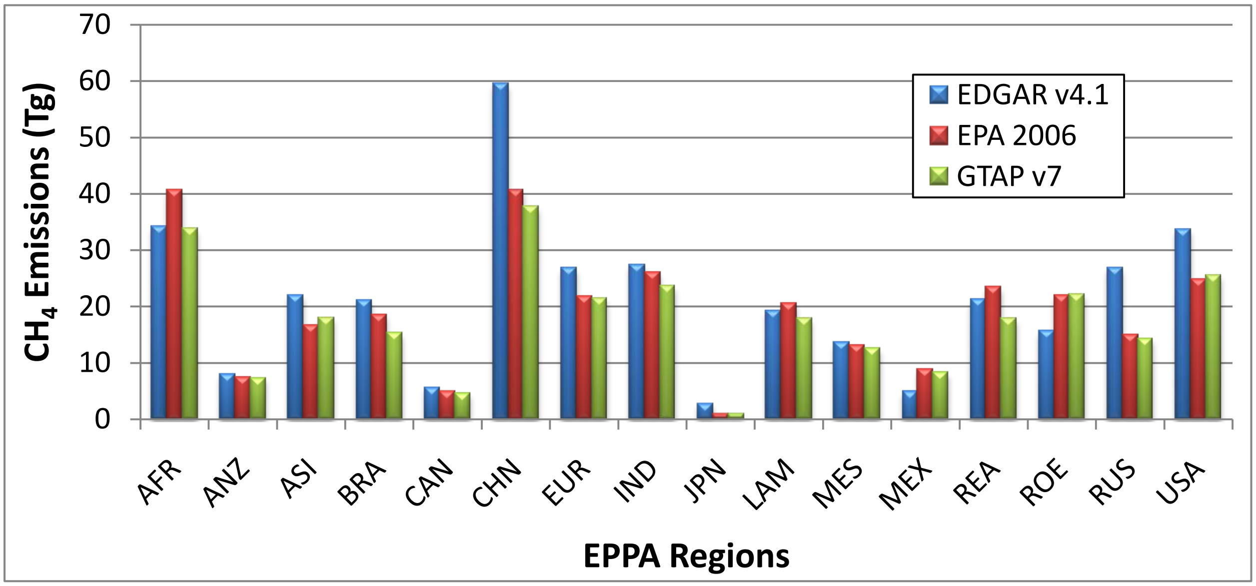


Figure 5. Comparison of bottom-up inventories for CH_4 as mapped into EPPA 5 regions.

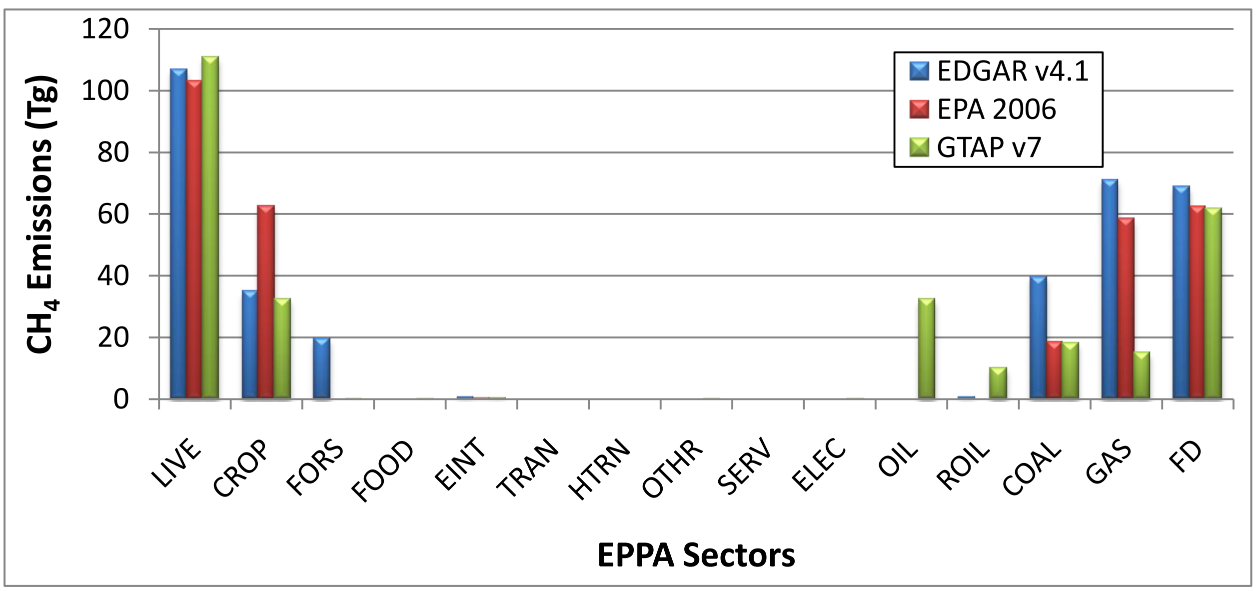


Figure 6. Comparison of bottom-up inventories for CH_4 as mapped into EPPA 5 sectors without adjustment for oil and gas aggregation in EDGAR 4.1 inventory.

Almost all of the difference in COAL between EDGAR v4.1 and GTAP v7/EPPA 2006 can be attributed to an additional 13.94 Tg of fugitive coal emissions that EDGAR v4.1 assigns to China. The difference in FD (final demand) between EDGAR v4.1 and GTAP v7/EPPA 2006 can be attributed largely to an additional 7.33 Tg that EDGAR v4.1 attributes to wastewater handling in ASI. The difference in CROP between EPA 2006 and EDGAR v4.1/GTAP v7 is a result of EPA 2006 aggregating CROP and FORS emissions. In the GTAP v7 data, the FORS contribution is minimal due to the non-consideration of certain biomass burning as mentioned previously.

The most difficult differences to account for are the differences among OIL and GAS estimates. Because the sources for these emissions are generally aggregated in the inventories—category 1B2 in EDGAR v4.1 and B-1 in EPA 2006—they will be considered jointly. Although 10.29 Tg of the EDGAR v7 total can be attributed to the additional fugitive natural gas emissions coming from Russia making it virtually equal to the EPA 2006 value, the primary issue is that both EDGAR v4.1 and EPA 2006 aggregate fugitive emissions from oil and natural gas. Since natural gas is largely comprised of methane, it was initially assumed in mapping the EDGAR v4.1 and EPA 2006 data that fugitive emissions from gas would dominate so that the aggregated oil and gas emissions were mapped into GAS. However, by comparing with GTAP v7 we see that the contribution of oil should be significant. This can largely be attributed to oil production processing and gas flaring. However, in a previous version of EDGAR (EDGAR 3.2 FT 2000), fugitive emissions from oil and gas were disaggregated and estimated emissions of fugitive oil and fugitive gas were given of 10.46 Tg and 49.37 Tg respectively (Olivier *et al.*, 2005). Assuming growth rates among nations stayed relatively the same from 2000 to 2004, we use the EDGAR 3.2 FT 2000 data to disaggregate. The modified EDGAR v4.1 emissions are given in **Figure 7**.The improved mapping of GTAP v7 and EDGAR v4.1 estimates to the EPPA sectors reduces, but does not eliminate, differences.

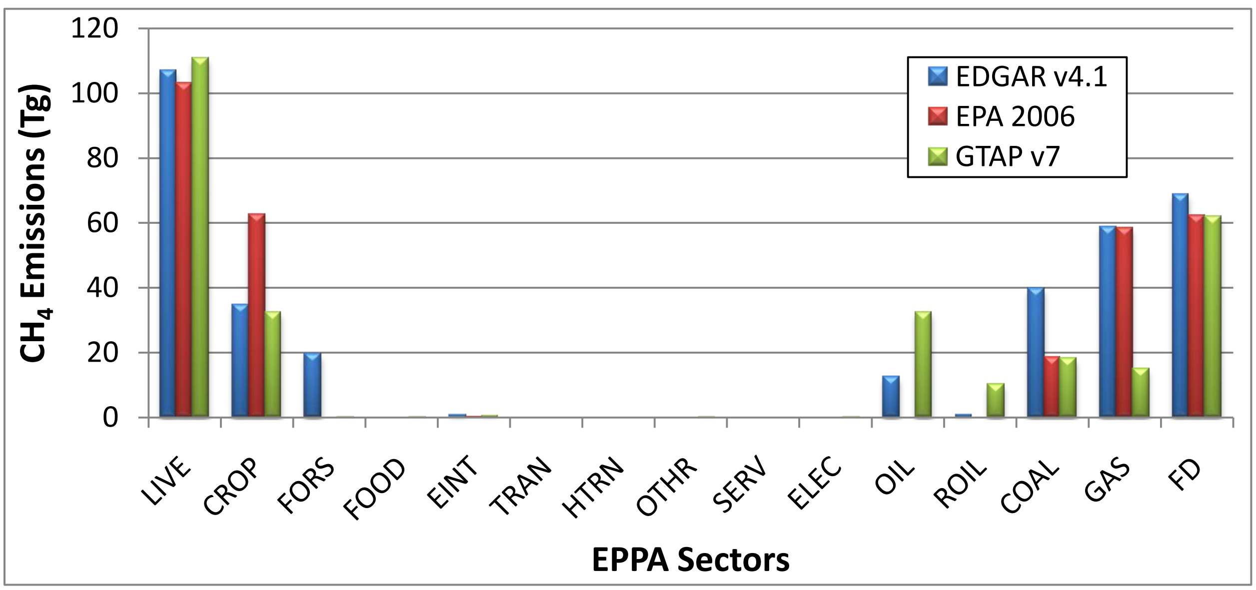


Figure 7. Comparison of bottom-up inventories for CH_4 as mapped into EPPA 5 sectors including adjustment for oil and gas aggregation in the EDGAR 4.1 inventory.

2.3.3 Nitrous Oxide (N_2O)

Emissions of N_2O also have fairly good agreement across regions, as shown in **Figure 8**, except for ASI, CHN, EUR, IND, and USA. The higher estimate of ASI emissions by EDGAR v4.1 can be attributed largely to forestry and land-use change with EDGAR v4.1 attributing 0.31Tg compared to none from EPA 2006 or GTAP v7. The difference in CHN emissions is due almost entirely to emissions from agricultural soils with EDGAR v4.1 attributing 0.59 Tg compared to 1.75 Tg from EPA 2006. The difference in EUR emissions between EDGAR v4.1 and EPPA 2006/GTAP v7 also comes from agricultural soils emissions with EDGAR v4.1 attributing 0.35 Tg compared to 0.80 Tg from EPA 2006. The difference in IND emissions is also found in agriculture soils emissions, except that the trend is reversed with EDGAR v4.1 attributing 0.47 Tg compared to 0.19 Tg from EPA 2006. Finally, the difference in USA estimates between EDGAR v4.1 and EPA 2006 also comes mainly from agricultural soils estimates with EDGAR v4.1 attributing 0.28 Tg compared to 0.85 Tg from EPA 2006.

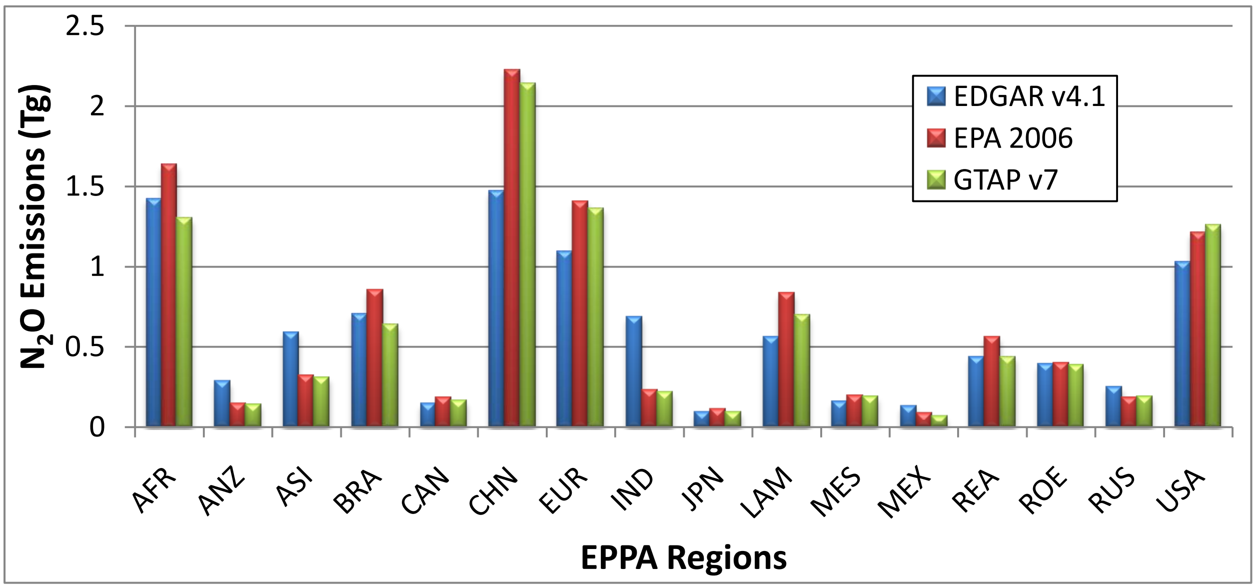


Figure 8. Comparison of bottom-up inventories for N_2O as mapped into EPPA 5 regions.

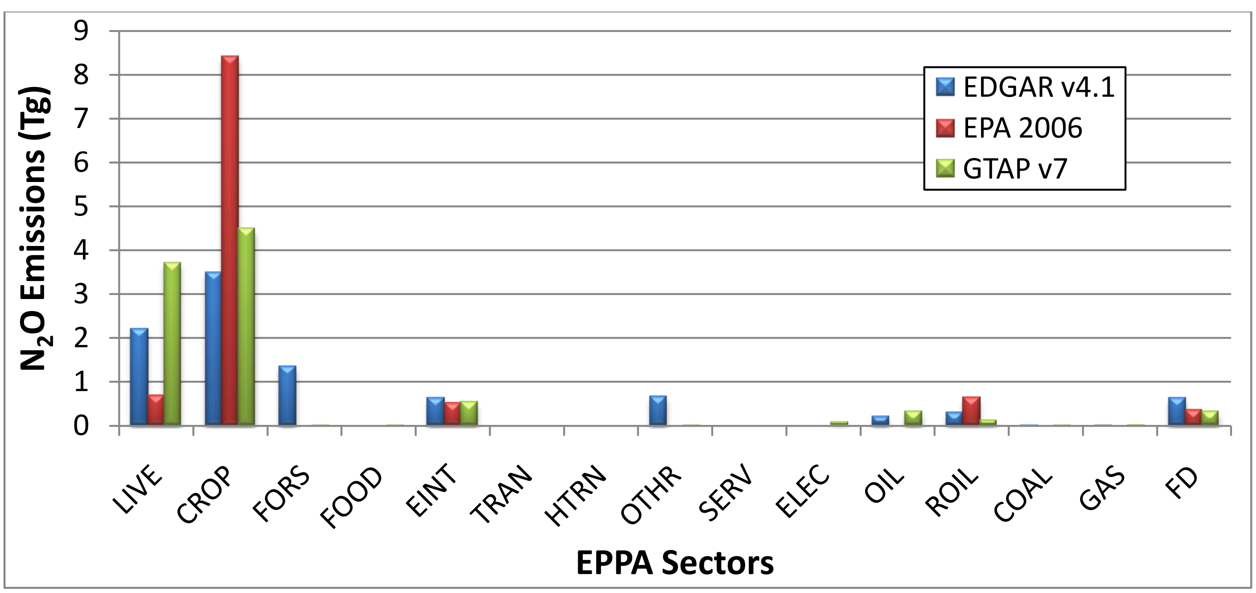


Figure 9. Comparison of bottom-up inventories for N_2O as mapped into EPPA 5 sectors.

The differences highlighted in the regional comparison explain most of the differences between the three inventories when looking at sectors. A breakdown of N_2O emissions by sector is given in **Figure 9**. In the figure we see a larger contribution of agricultural soils emissions by EPA 2006 compared to EDGAR v4.1 in CROP. However, the GTAP v7 CROP emissions are significantly lower than EPA 2006. This is due to EPA 2006 aggregating agricultural soils emissions from both commercial fertilizers and manure as a fertilizer. In GTAP v7 and EDGAR v4.1 these sources are disaggregated between CROP and LIVE respectively. What we see then are both GTAP v7 and EDGAR v4.1 having proportionately the same emissions in LIVE and CROP except for GTAP v7 being greater in magnitude. For FORS, the EPA 2006 forestry contribution is aggregated with CROP. For the GTAP data, we directly see the result of not including sources of biomass burning since the FORS contribution is almost zero.

2.3.4 Hydrofluorocarbons (HFCs)

In general it is difficult with F-gases to distinguish between differences among datasets and differences that result from mapping highly aggregated data. While the EDGAR v4.1 data treats F-gases individually, EPA 2006 aggregates species across 11 source categories while the GTAP v7 data lumps F-gases into 6 source categories. As can be seen in Figure 2, EPA 2006 estimates of HFCs are lower, and estimates of PFCs are higher in comparison to EDGAR v4.1. Since EDGAR v4.1 accounts for each F-gas individually, much of this difference may be due to attributing to PFCs emissions that should be HFCs. In comparing HFCs across regions, as shown in **Figure 10**, all three inventories are qualitatively similar with CHN, JPN, EUR, and USA being the primary emitters. Despite EDGAR v4.1 estimates being the highest, the only real difference comes from EUR and JPN where the EPA 2006 estimates are significantly lower than GTAP v7 and EDGAR v4.1.

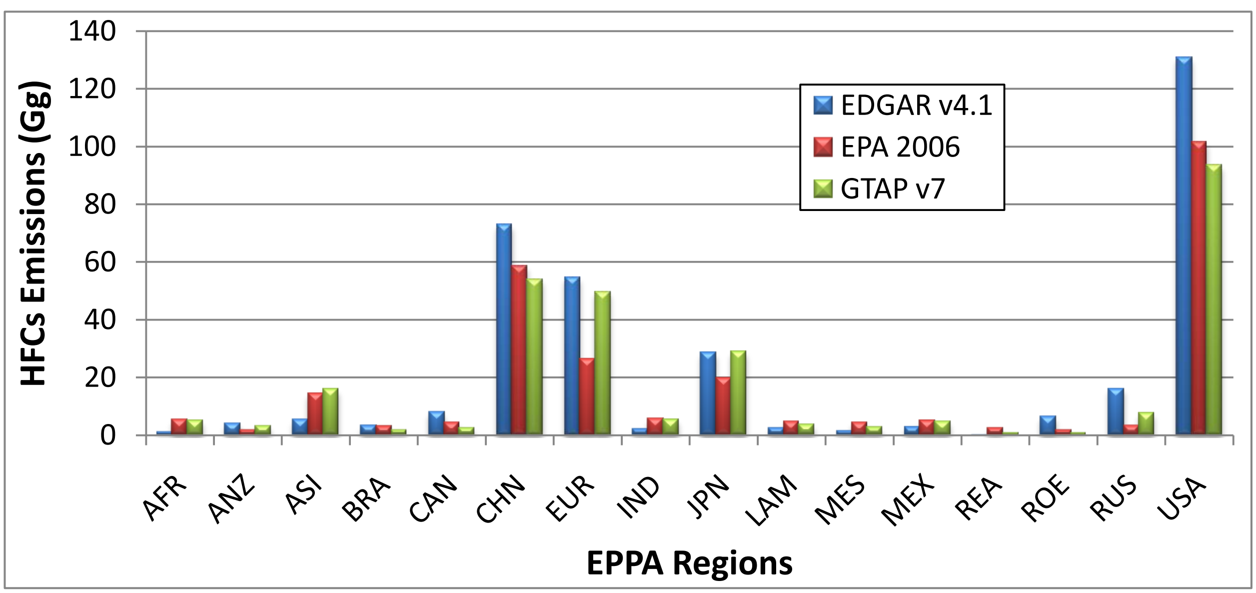


Figure 10. Comparison of bottom-up inventories for HFCs as mapped into EPPA 5 regions.

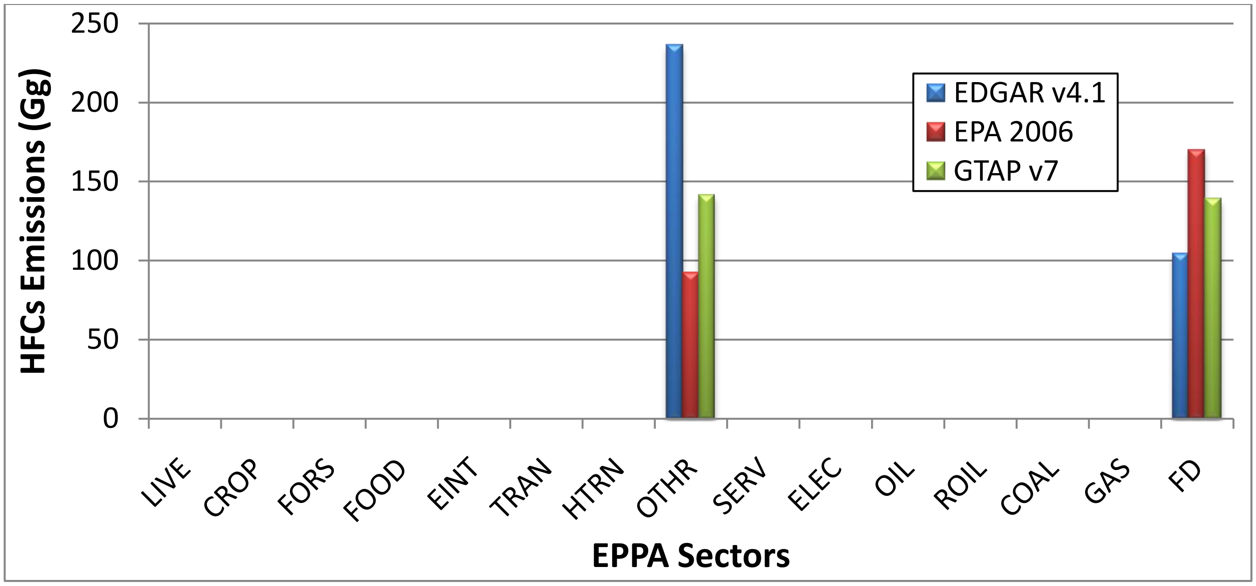


Figure 11. Comparison of bottom-up inventories for HFCs as mapped into EPPA 5 sectors.

As shown in **Figure 11**, the only sectors contributing to HFC emissions in EPPA 5 are OTHR and FD. Again sectoral differences are in opposite directions for the different data sets, and so some portion of them may be due to how emission are attributed to sectors.

2.3.5 Perfluorocarbons (PFCs)

As is shown in **Figure 12**, there are significant differences among the three inventories in estimates of PFCs by region. Overall, the estimates from EPA 2006 are much higher and, as was mentioned in the previous section, this is most likely because some of the aggregate emissions really should be attributed to HFCs.

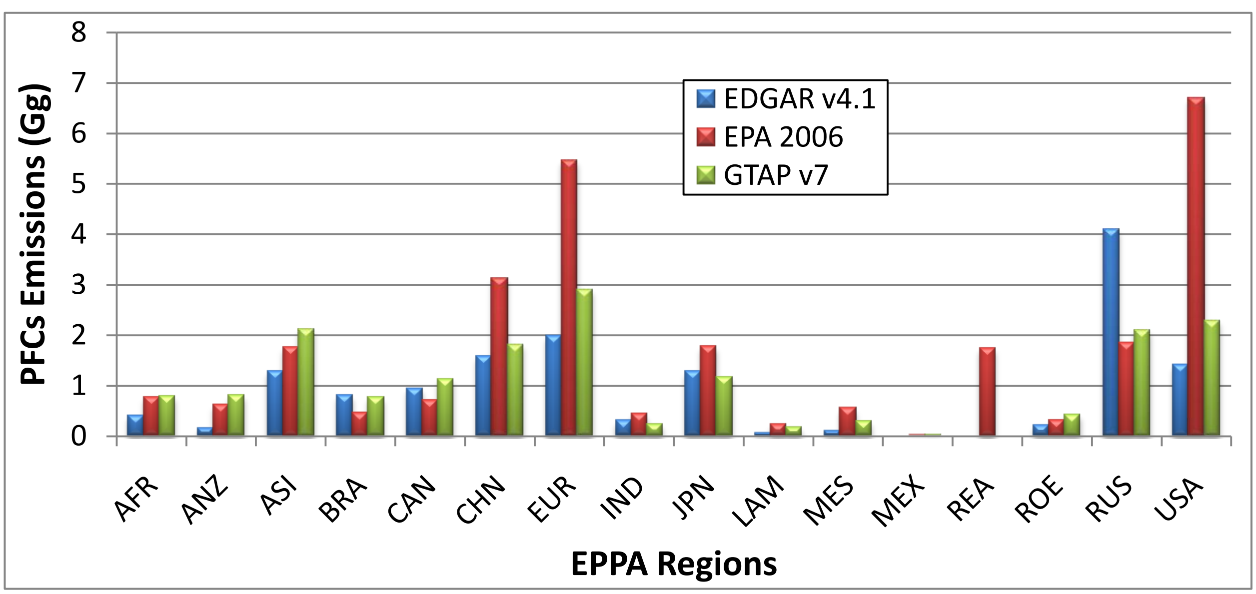


Figure 12. Comparison of bottom-up inventories for PFCs as mapped into EPPA 5 regions.

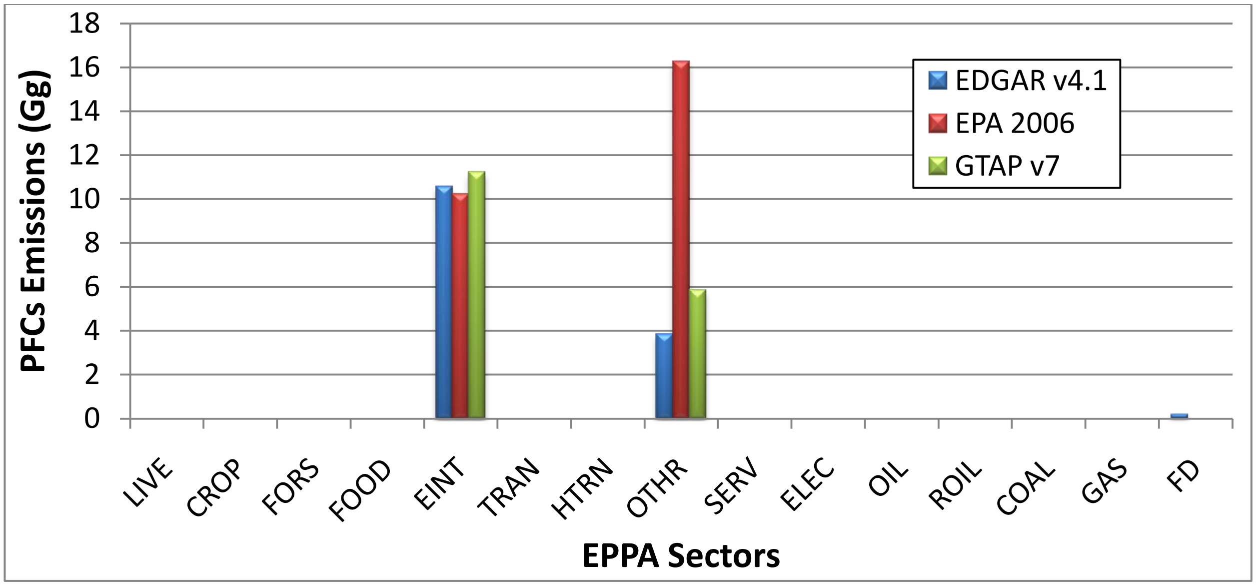


Figure 13. Comparison of bottom-up inventories for PFCs as mapped into EPPA 5 sectors.

There are also two specific features that stand out. First, the EDGAR v4.1 estimates for RUS are much higher than the other inventories, and second, EPA 2006 attributes a large portion of emissions to REA which does not occur in the other inventories.

A sectoral comparison of PFCs as shown in **Figure 13** reveals good agreement among all three inventories for EINT. For OTHR, the estimate from EPA 2006 is much higher than the others. If we look back at F-gas emission categories on Table 4, this makes some sense. Only EPA 2006 category D-9b is mapped to EINT, and there was no aggregation across species (all emissions came from PFCs used in aluminum production). OTHR, on the other hand, included seven EPA 2006 categories that were aggregated between HFCs and PFCs. This observation is consistent with the previous one that a good amount of emissions attributed to PFCs, if the data were disaggregated by species, likely would be attributed to HFCs.

2.3.6 Sulfur Hexafluoride (SF_6)

In **Figure 14** we see that the regional emissions of SF_6 show good agreement between EPA 2006 and GTAP v7. The EDGAR v4.1 estimates however are much higher. In **Figure 15** we see that this is largely due to EDGAR v4.1 attributing emissions to OTHR while EPA 2006 and GTAP v7 predict no emissions in this sector. If we look at Table 2 these OTHR emissions come from EDGAR v4.1 source categories 2E, 2F7, and 2F9. Because the EDGAR v4.1 SF_6 inventory is in good agreement with the top-down estimates, and because it has complete disaggregation among F-gas species, the inventory shows a clear advantage over EPA 2006 and GTAP v7.

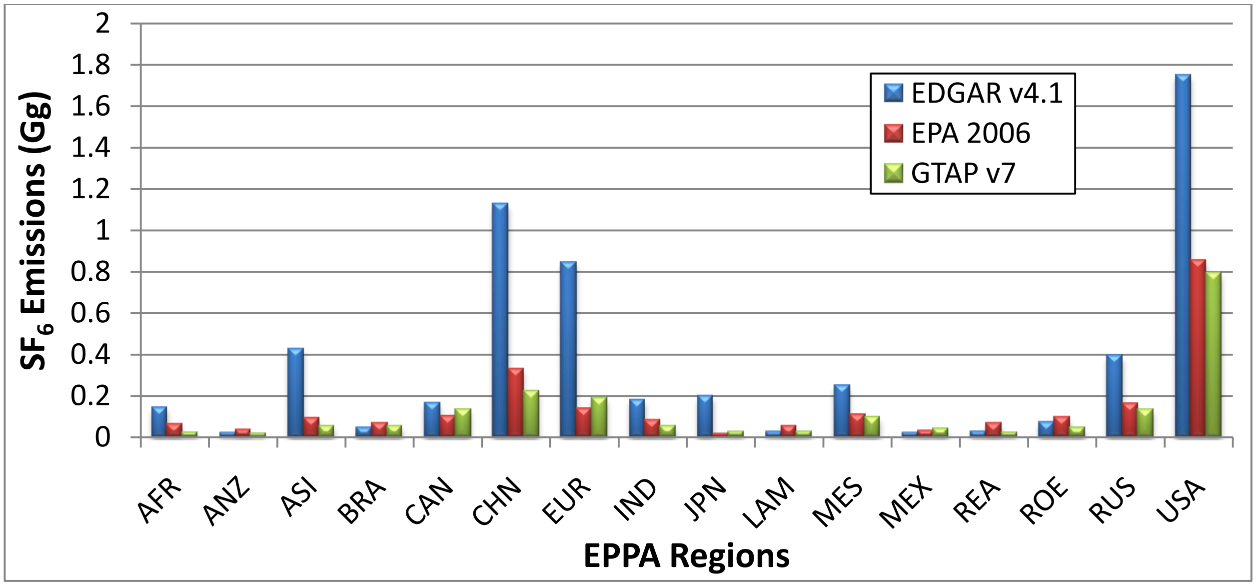


Figure 14. Comparison of bottom-up inventories for SF_6 as mapped into EPPA 5 regions.

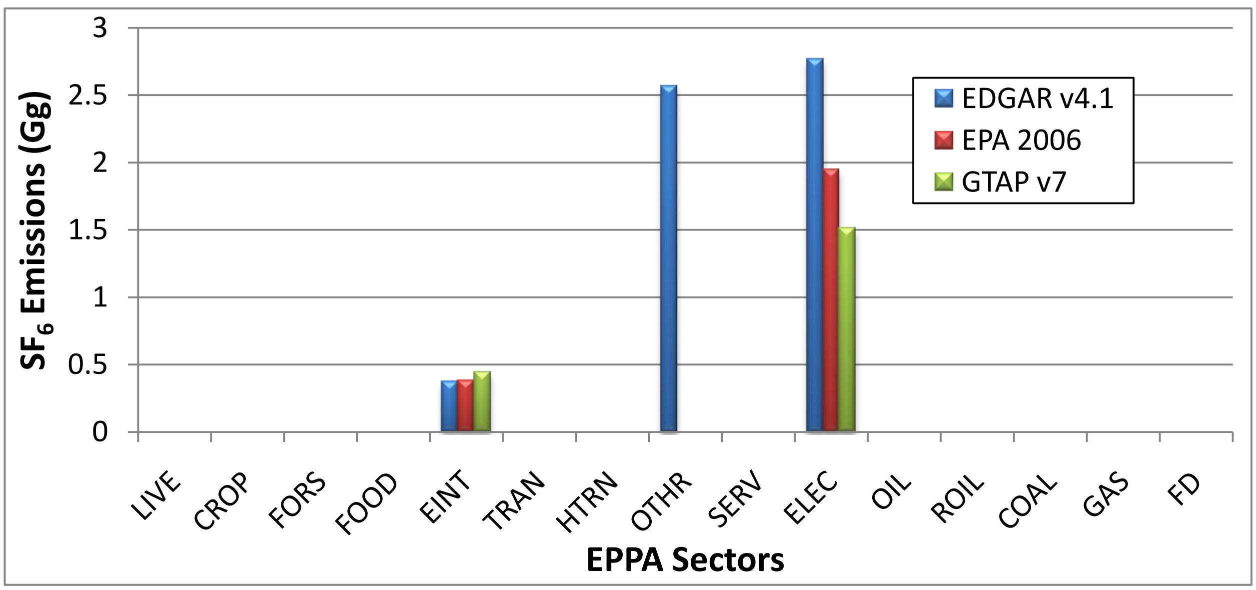


Figure 15. Comparison of bottom-up inventories for SF_6 as mapped into EPPA 5 sectors.

3. TRADITIONAL AIR POLLUTANT EMISSIONS INVENTORY

For traditional air pollutants we compare estimates given by EDGAR v4.1 and EDGAR-HTAP v1. Although both inventories were developed at least in part by the EDGAR team, the methodologies behind each inventory are different. For EDGAR v4.1 the estimates were made by applying emissions factors to economic activity such as statistics provided by the International Energy Agency (IEA, 2010), and the Food and Agricultural Organization of the United Nations (FAO, 2010). For the EDGAR-HTAP v1 dataset, multiple sources were used in the following descending order of priority: 1) US EPA and Environment Canada, 2) EMEP, 3) UNFCCC, 4) REAS, 5) GAINS (for China), and 6) EDGAR v4.1. For our purposes we accept the EDGAR-HTAP v1 dataset as the preferred one since it already takes into account judgments regarding preferential treatment of source data, but we compare the estimates with the EDGAR v4.1 estimates to illustrate differences between the methodologies.

3.1 SO_2, NO_x, CO, NH_3, and NMVOC Estimates

For emission of SO_2, a comparison between EDGAR v4.1 and EDGAR-HTAP v1 estimates are given in **Figure 16** and **Figure 17** by EPPA 5 regions and sectors respectfully.

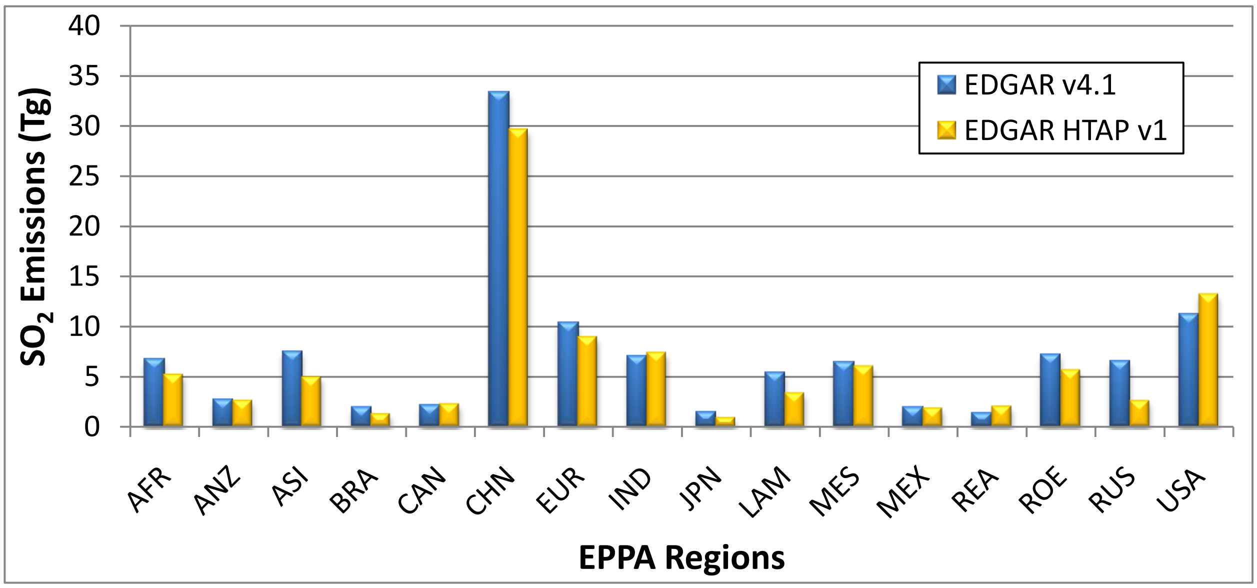


Figure 16. Bottom-up inventories for SO_2 as mapped into EPPA 5 regions.

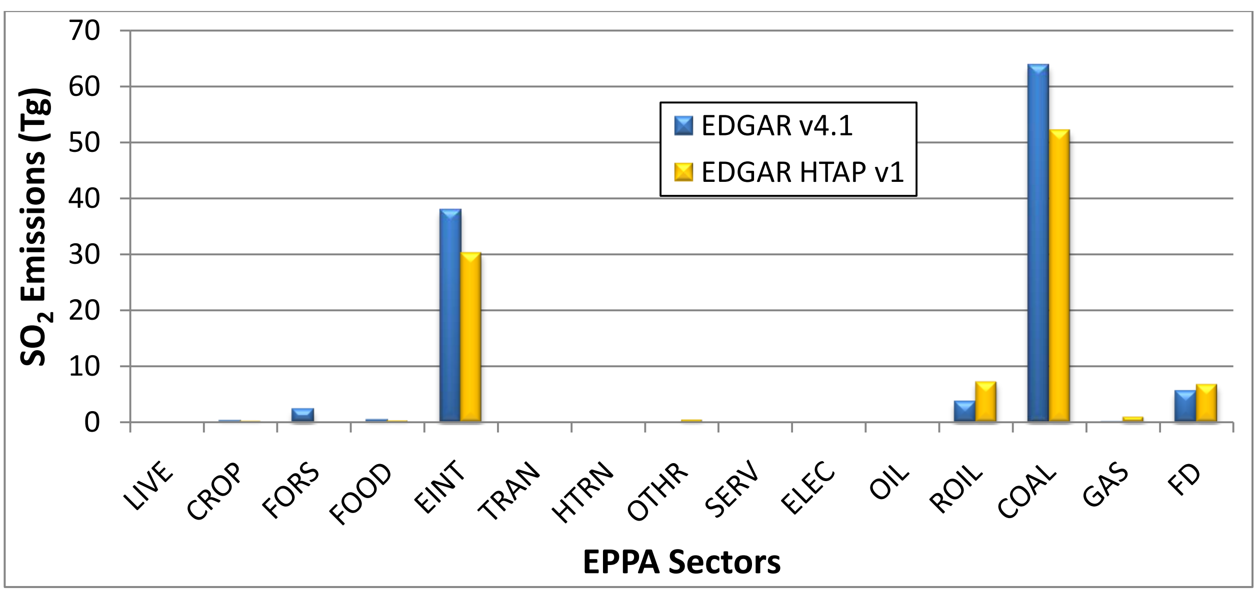


Figure 17. Bottom-up inventories for SO_2 as mapped into EPPA 5 sectors.

Overall, we see relatively good agreement with estimates by EDGAR v4.1 being slightly higher than EDGAR-HTAP v1. The regional allocation is largely what would be expected with most emissions coming from China which has relatively less stringent emissions regulation, while other large industrial regions such as the USA and Europe emit much less which is a result of already stringent SO_2 emissions regulation in those regions. By sector we also see emissions coming from economic activity as would be expected with the vast amount of emissions coming from fossil fuel combustion in COAL and EINT.

For NO_x we see in **Figure 18** that the two datasets are very similar except for increased estimates of emission in China and Africa by EDGAR v4.1 relative to EDGAR-HTAP v1. When looking at the sectoral breakdown in **Figure 19** we see that this is largely due to higher estimates of COAL emissions by EDGAR v4.1 and by estimates of emissions coming from FORS that are present in the EDGAR-HTAP v1 data. Overall the NO_x trend is similar to SO_2 with China being the primary emitter, but we see much more emissions from Europe and the USA. Fossil fuel emissions from COAL and EINT remain high with additional emissions coming from ROIL.

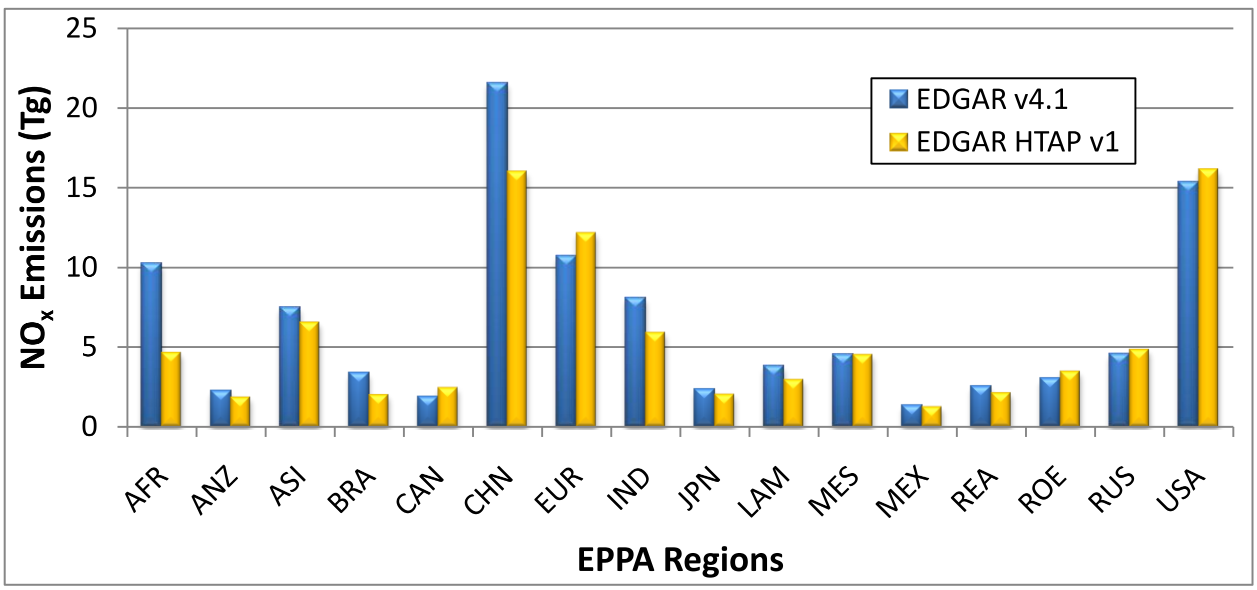


Figure 18. Bottom-up inventories for NO_x as mapped into EPPA 5 regions.

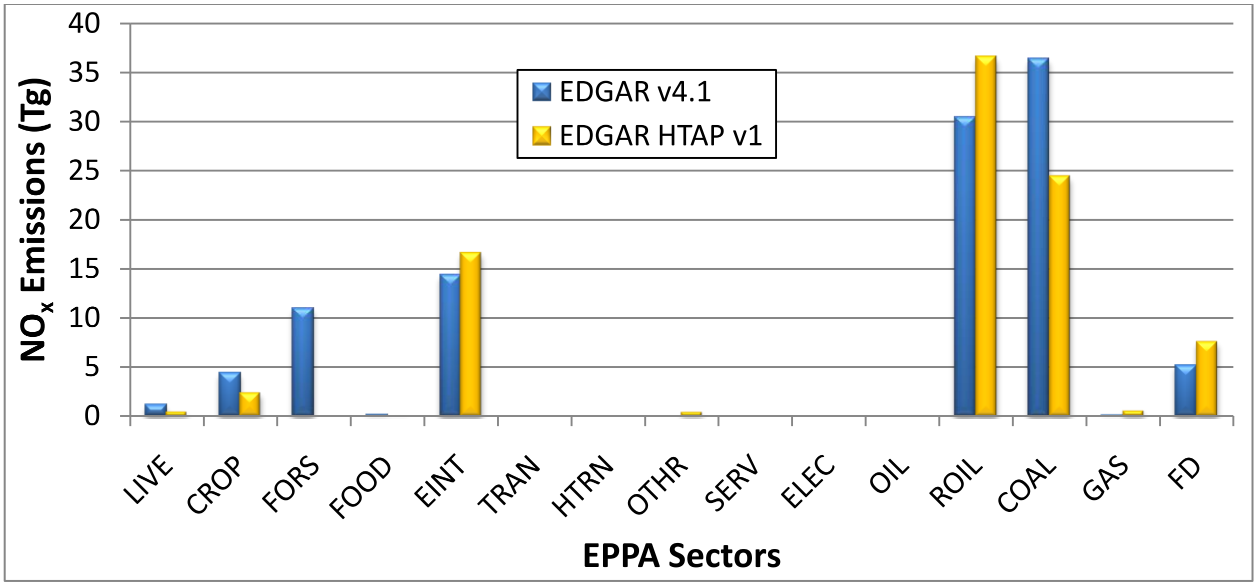


Figure 19. Bottom-up inventories for NO_x as mapped into EPPA 5 sectors.

For emissions of CO, we see in **Figure 20** much discrepancy between regional estimates especially in Africa. This is largely explained in the sectoral breakdown in **Figure 21** where the majority of emissions from EDGAR v4.1 come from FORS which includes savannah burning and forest fires. When comparing the raw data between the two datasets we see large differences between IPCC categories 4E (savannah burning), 4F (agricultural waste burning), 5A (forest fires), and 5C (grassland fires). While EDGAR-HTAP v1 only has 50.82 Tg of CO emissions coming from these categories (all from 4F), EDGAR v4.1 has 440.46 Tg coming from these categories with 170.7 Tg from 4E, 50.16 Tg from 4F, 195.92 Tg from 5A, and 23.68 Tg from 5C.

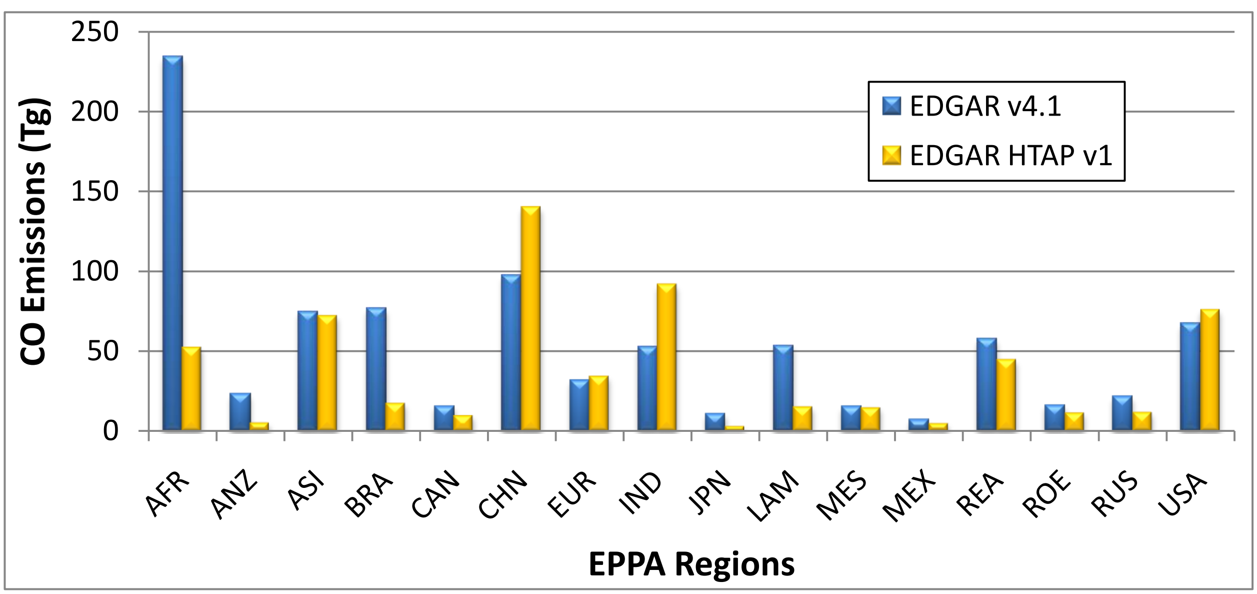


Figure 20. Bottom-up inventories for CO as mapped into EPPA 5 regions.

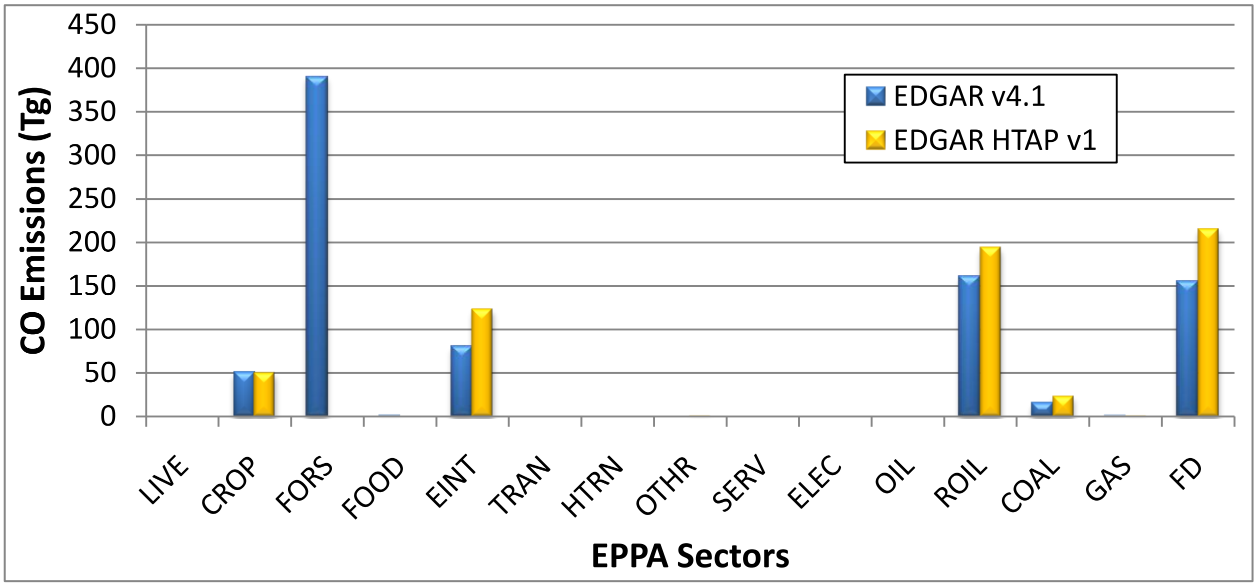


Figure 21. Bottom-up inventories for CO as mapped into EPPA 5 sectors.

For NH_3 we see in **Figure 22** and **Figure 23** the majority of emissions coming from LIVE and CROP in China, Africa, Europe, and India. In LIVE, the primary source of these emissions is livestock manure both in manure management facilities and from pasture or rangeland. In CROP, the primary source of emissions comes from direct soil emissions with some additional emissions coming from agricultural waste burning. Overall, estimates are similar except for higher emissions in Africa from the EDGAR v4.1 data due to FORS, and higher emissions in China and India from the EDGAR-HTAP v1 data due to greater emission from COAL.

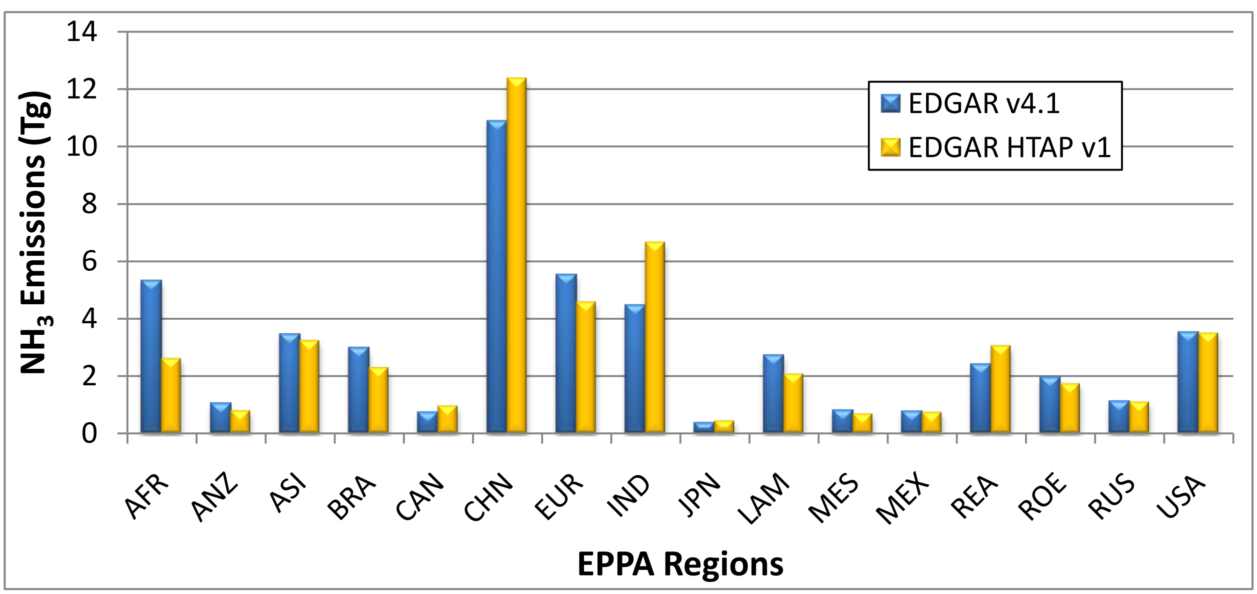


Figure 22. Bottom-up inventories for NH_3 as mapped into EPPA 5 regions.

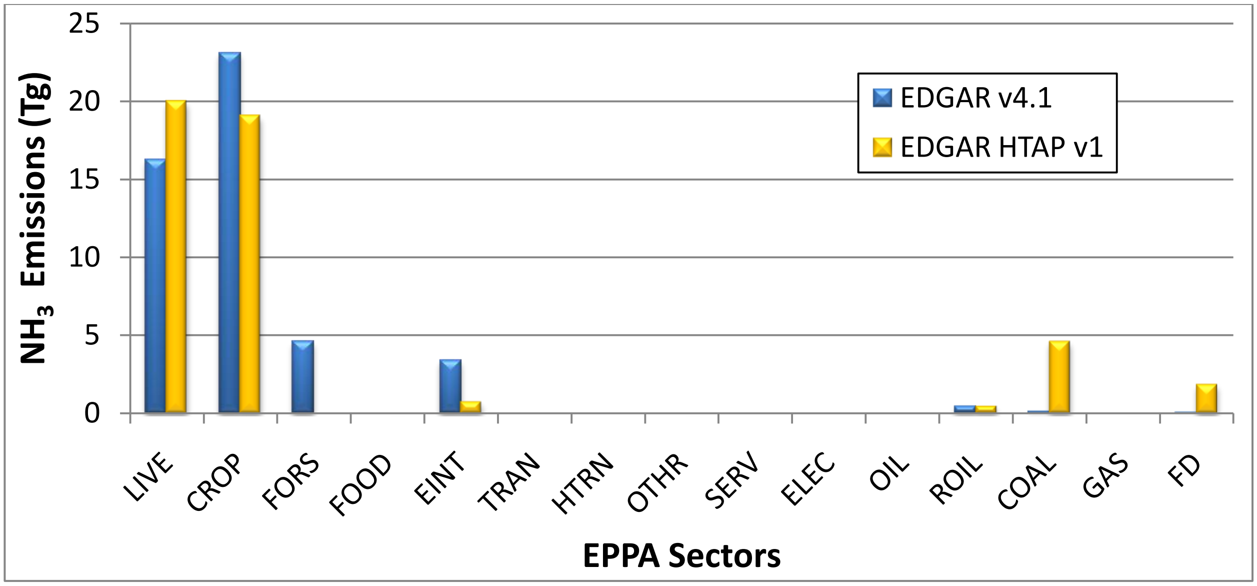


Figure 23. Bottom-up inventories for NH_3 as mapped into EPPA 5 sectors.

In **Figure 24** and **Figure 25** we see the emissions of NMVOCs spread much more evenly across all regions with good agreement except in estimates made for China and Africa. The main sources of NMVOCs include FORS, OTHR, ROIL, GAS, and FD. In Africa the difference between EDGAR v4.1 and EDGAR-HTAP v1 is largely due to emissions from FORS where EDGAR v4.1 estimates 25.72 Tg coming from IPCC categories 4E, 4F, 5A, and 5C, while EDGAR-HTAP v1 only estimates 4.23 Tg coming entirely from 4F. Once again, as was the case with CO emissions, the primary difference between datasets is due to savannah burning and forest fires not being included in the EDGAR-HTAP v1 data.

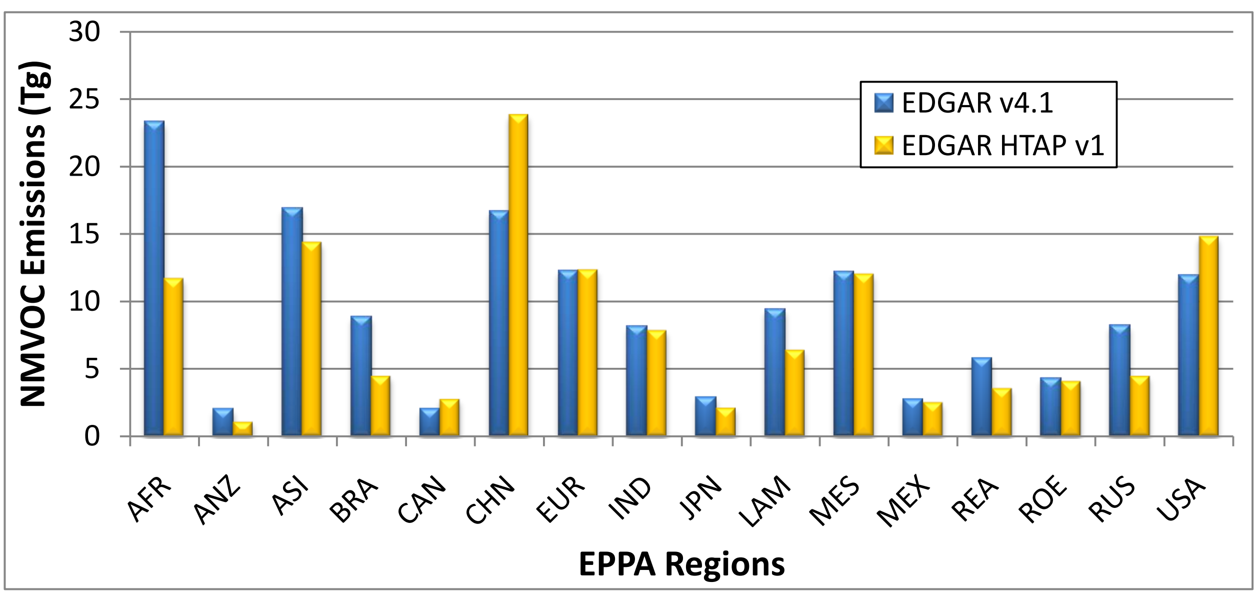


Figure 24. Bottom-up inventories for NMVOC as mapped into EPPA 5 regions.

For OTHR, the source is mainly from solvents such as those used in producing paint and formaldehyde. Emissions for ROIL mainly come from petroleum used in the transportation sector. For GAS, emissions are largely due to fugitive emissions from oil and gas production.

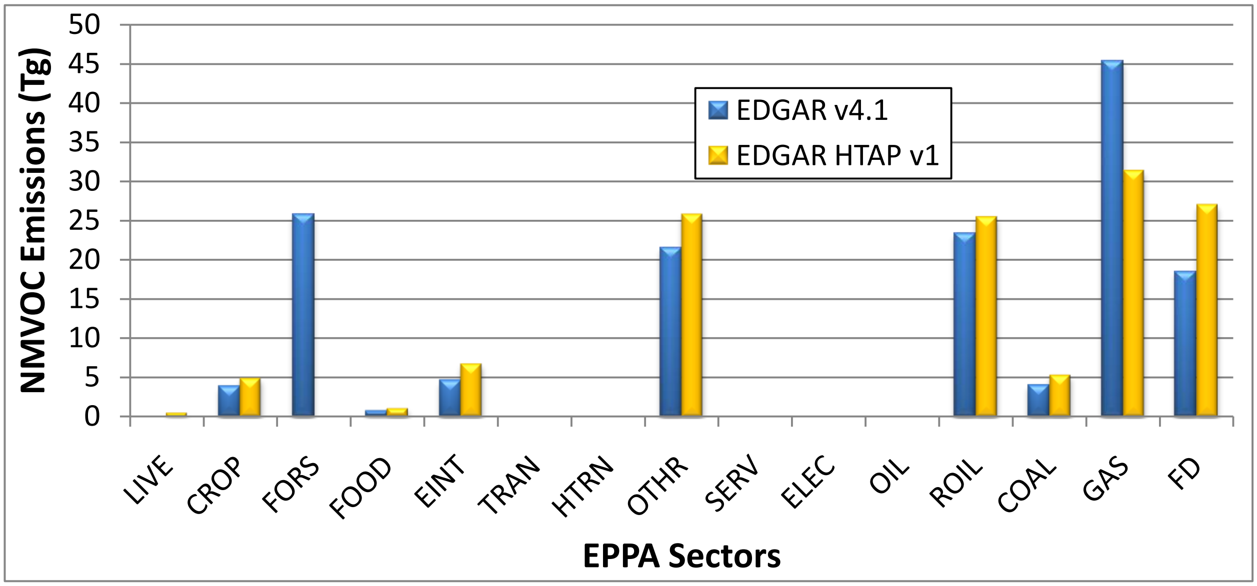


Figure 25. Bottom-up inventories for NMVOC as mapped into EPPA 5 sectors.

3.2 BC and OC Estimates

For black carbon (BC) and organic carbon (OC) estimates we consider only data from EDGAR-HTAP v1 since neither BC nor OC estimates are available from EDGAR v4.1.

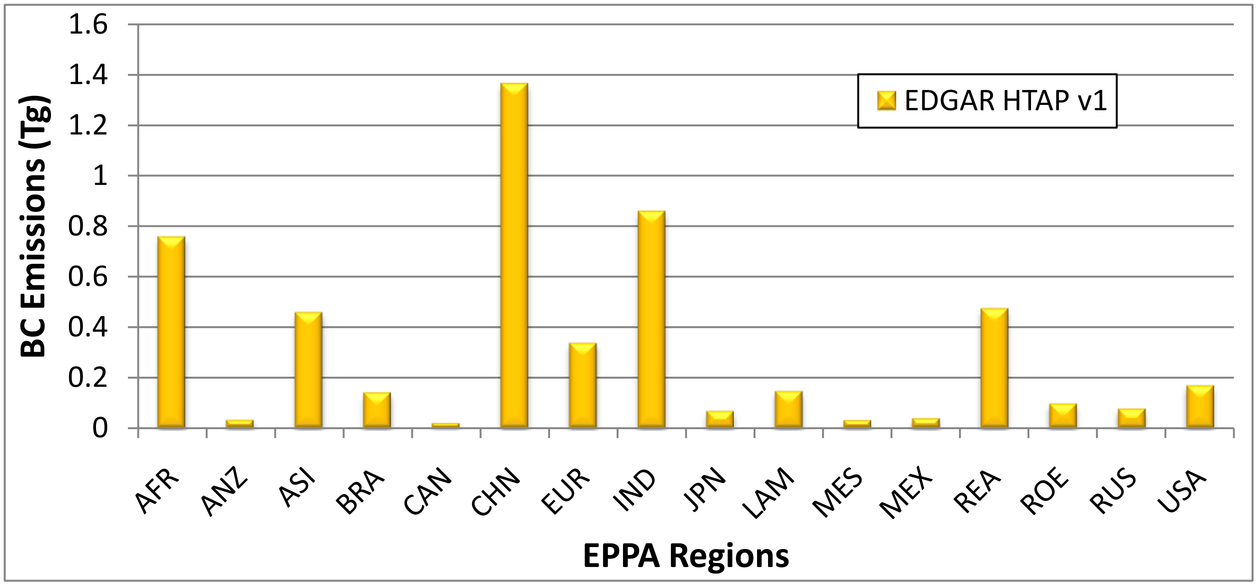


Figure 26. Bottom-up inventories for BC as mapped into EPPA 5 regions.

In the previous version of EPPA (EPPA 4), data for BC and OC was obtained from Bond *et al.*, 2004. For BC and OC, the primary inventories that were used in EDGAR-HTAP v1 were REAS, GAINS, and EDGAR, but these inventories were also compared to the observational data provided by Bond *et al.* and were checked for consistency with particulate matter (PM) estimates. Estimates for BC are provided by region and sector in **Figure 26** and **Figure 27** respectfully. As can be seen, the majority of emissions come from developing countries in regions such as AFR, ASI, CHN, IND, and REA. This is largely accounted for by final demand (FD) which includes fuel combustion in the residential sector.

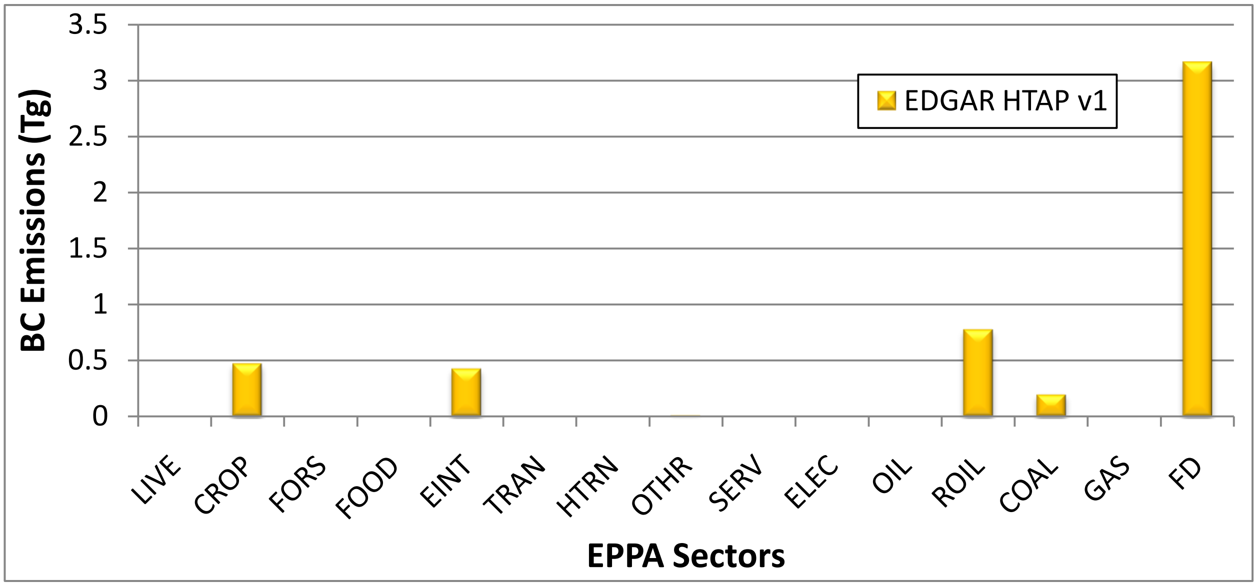


Figure 27. Bottom-up inventories for BC as mapped into EPPA 5 sectors.

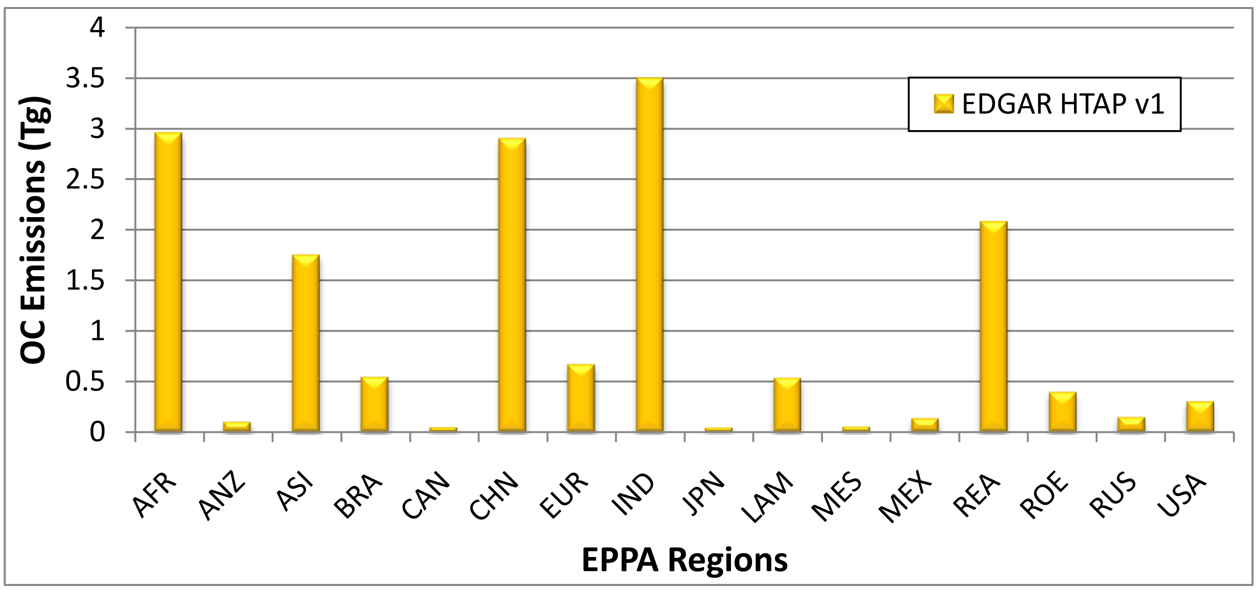


Figure 28. Bottom-up inventories for OC as mapped into EPPA 5 regions.

For OC, we see the same trend as with BC with developing countries having the highest emissions. This is once again due largely to fuel combustion in FD from residential use. Regional and sectoral estimates for OC are given in **Figure 28** and **Figure 29** respectfully.

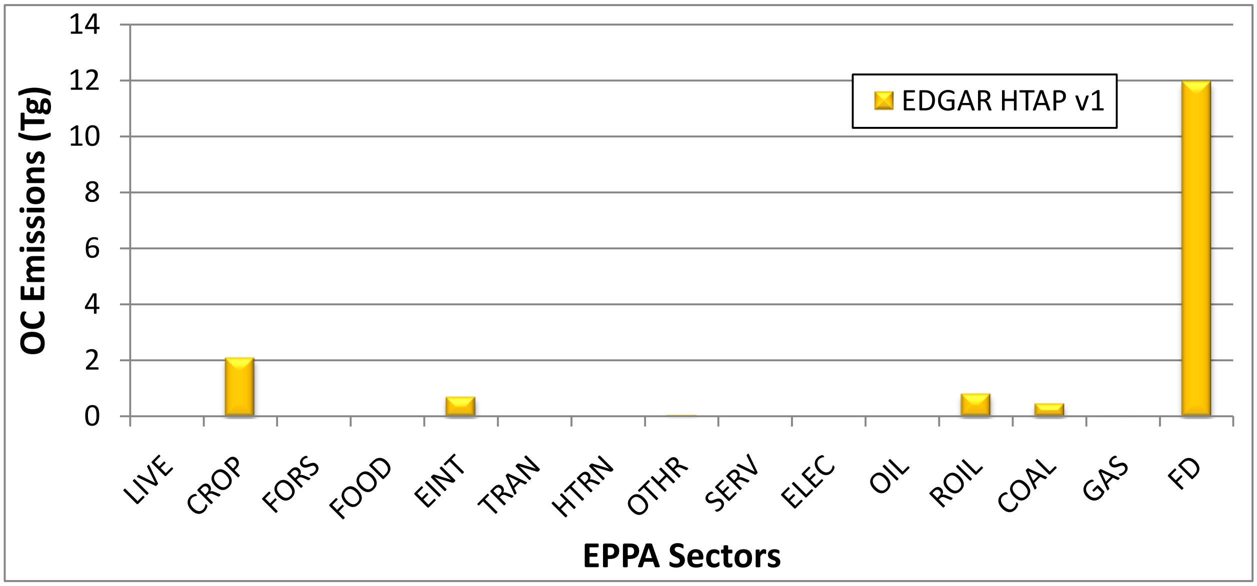


Figure 29. Bottom-up inventories for OC as mapped into EPPA 5 sectors.

4. CONCLUSION

In summary, after evaluating the three GHG datasets for use in an emissions inventory for EPPA 5, we found that the EDGAR v4.1 database was best suited for this purpose. While there are differences among the inventories, discrepancies in our estimates of emissions from EPPA sectors can also arise from trying to map aggregated data into the more disaggregated sectors. For the HFCs, PFCs, and SF_6, EDGAR v4.1 showed a clear advantage because it was the only dataset that fully disaggregated F-gas species and it also provided the closest agreement with top-down estimates of SF_6 and CH_4. For our consideration this was particularly important because it allows for better coupling of EPPA 5 with the IGSM. For N_2O, there appeared to be no real advantage with any of the three datasets. Because there are clear advantages to using EDGAR v4.1 for CH_4 and the F-gases, and because there is no real advantage of one dataset over the others for N_2O, we use EDGAR v4.1 for N_2O as well.

For traditional air pollutants we considered both the EDGAR v4.1 dataset and EDGAR-HTAP v1. Aside from the differences in methodology, the only significant difference was that EDGAR v4.1 included in its estimates emissions from savannah burning and forest fires. Because EDGAR-HTAP v1 takes into account preferential treatment of source data from the U.S. EPA, Environment Canada, EMEP, UNFCCC, REAS, and GAINS in addition to EDGAR v4.1 we consider it as the more thoroughly compiled source for benchmarking EPPA 5 traditional air pollutants.

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APPENDIX A

This appendix presents an overview of the spreadsheets used to map the primary data from each emissions inventory into the EPPA 5 regions and sectors. For those affiliated with the Joint Program and have access to the Joint Program wiki, the Excel spreadsheets can be found at https://wikis.mit.edu/confluence/display/globalchange/Emissions+Inventory+for+EPPA+5 and are in the zip file Emissions_Inventories.zip. Inside the zip file there is a hierarchy of folders and interconnected Excel worksheets that reference values in other worksheets. Because of the interconnected structure, the hierarchy of folders and Excel sheets should not be changed. A tree view of the folders in the zip file is given in **Figure A1**.

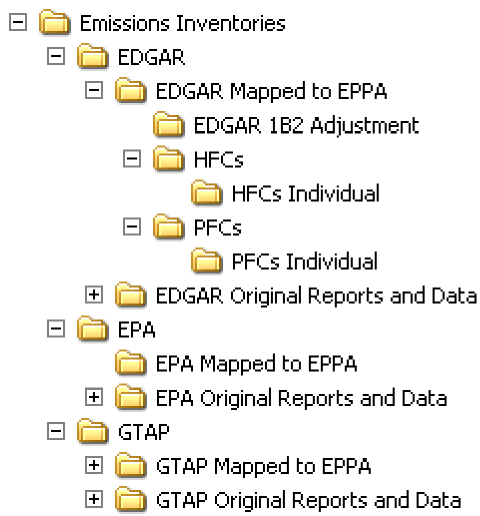

Figure A1. Hierarchy of Excel folders

As can been seen, the 'Emissions Inventories' folder contains three folders for each bottom-up dataset: 'EDGAR,' 'EPA,' and 'GTAP.' Within each of these folders are two folders, one containing the system of Excel worksheets that maps a particular dataset into EPPA 5 (i.e. 'EDGAR Mapped to EPPA,' 'EPA Mapped to EPPA,' and 'GTAP Mapped to EPPA'), and another that contains the original data for each dataset.

Although each dataset is formatted differently, the method for mapping is relatively the same. For each dataset there is a mapping worksheet that defines the rules for mapping the regions and sectors into EPPA 5, and also contains variables that are used by other Excel worksheets. The main idea is that instead of having to go in and manually change variables in all the individual Excel worksheets, those values are centrally located in the mapping sheet. Therefore, the only values that should be changed in the system of Excel worksheets are those in the mapping sheet. To illustrate, for the EDGAR dataset the Excel worksheet that defines the mapping rules is 'EDGAR to EPPA Mapping Sheet.xlsx.' Inside the worksheet are four spreadsheets: 'Region Mapping,' 'Sector Mapping,' 'PFC and HFC GWPs,' and 'Compare Data.' 'Region Mapping' contains two columns 'Name of Country,' and 'EPPA Region.' In the 'Name of Country' column are all the countries found in the EDGAR v4.1 original data. The second column 'EPPA

Region' contains the region that the country is to be mapped to. Similarly, the 'Sector Mapping' spreadsheet contains two columns: 'EDGAR Sector,' and 'EPPA Sector.' 'EDGAR Sector' contains the sectors found in the original EDGAR v4.1 data and 'EPPA Sector' provides the corresponding EPPA sector that the EDGAR sector is to be mapped to. Once these mapping rules are defined, they are used as a look-up table for mapping all the EDGAR GHG species. The other two folders—'PFC and HFC GWPs' and 'Compare Data'—contain variables that are used by other worksheets. 'PFC and HFC GWPs' contain the GWPs for all GHG species to allow for conversion between Gg or Tg and MtCO2eq. 'Compare Data' contains variables that are used by a macro that allows for quick comparison between mapping schemes. The mapping worksheets for the EPA and GTAP datasets are essentially identical to EDGAR.

Other than the mapping worksheets, the majority of the other Excel sheets for each dataset contain the mapping of a specific GHG species into EPPA5. There are 21 species for EDGAR, 5 for EPA, and 3 for GTAP. The reason for the difference in number is that the original EDGAR data disaggregates all HFCs and PFCs, while the GTAP data aggregates all HFCs, PFCs, and SF6 into a single F-gas category. The EDGAR species are mapped into EPPA 5 regions and sectors in the following worksheets: 'EDGAR CH4 2004.xlsx,' 'EDGAR N2O 2004.xlsx,' 'EDGAR SF6 2004.xlsx,' 'EDGAR HFC_23 2004.xlsx,' 'EDGAR HFC_32 2004.xlsx,' 'EDGAR HFC_125 2004.xlsx,' 'EDGAR HFC_134a 2004.xlsx,' 'EDGAR HFC_143a 2004.xlsx,' 'EDGAR HFC_152a 2004.xlsx,' 'EDGAR HFC_227ea 2004.xlsx,' 'EDGAR HFC_236fa 2004.xlsx,' 'EDGAR HFC_245fa 2004.xlsx,' 'EDGAR HFC_365mfc 2004.xlsx,' 'EDGAR PFC_C2F6 2004.xlsx,' 'EDGAR PFC_C3F8 2004.xlsx,' 'EDGAR PFC_C4F8 2004.xlsx,' 'EDGAR PFC_C4F10 2004.xlsx,' 'EDGAR PFC_C5F12 2004.xlsx,' 'EDGAR PFC_C6F14 2004.xlsx,' 'EDGAR PFC_C7F16 2004.xlsx,' 'EDGAR PFC_CF4 2004.xlsx.' The EPA species are mapped into EPPA 5 in: 'EPA CH4 2005.xlsx,' 'EPA N2O 2005.xlsx,' 'EPA HFCs 2005.xlsx,' 'EPA PFCs 2005.xlsx,' and 'EPA SF6 2005.xlsx.' The GTAP species are mapped to EPPA 5 in: 'GTAP CH4 2004.xlsx,' 'GTAP N2O 2004.xlsx,' and 'GTAP FGAS 2004.xlsx.' In addition, the EDGAR mapping contains two additional worksheets—'EDGAR HFCs Aggregate.xlsx' and 'EDGAR PFCs Aggregate.xlsx'—that are used to aggregate the individual HFCs and PFCs. This is done by converting each HFC or PFC into $MtCO_2eq$ units, summing those in terms of $MtCO_2eq$ and then converting the aggregated HFCs and PFCs into Gg of a trace gas (HFC-134a for HFCs, and CF_4 for PFCs).

Each worksheet that maps a specific GHG species contains three main spreadsheets. First is a spreadsheet containing the original dataset data, second is a spreadsheet that maps the original data into EPPA regions, and finally there is a spreadsheet that maps the regional data into sectors. For example, in worksheet 'EDGAR CH4 2004.xlsx,' spreadsheet 'ch4_v40_2004' contains the original EDGAR data for CH_4. In 'EDGAR CH4 Totals,' the data from 'ch4_v40_2004' is mapped into EPPA 5 regions with the original EDGAR sectors. In 'CH4 EPPA Mapping,' the data from 'EDGAR CH4 Totals' is then mapped into EPPA 5 sectors. In some of the worksheets for individual species, there is an additional spreadsheet called 'Compare Data.' This sheet provides a template for comparing data with mapping results and can be used to compare different mappings and/or troubleshoot and look for errors. The way it works is by placing emissions values that are to be compared into the ‘Compare Data’ spreadsheet. In the earlier example for the ‘EDGAR CH4 2004’ worksheet, the spreadsheet is ‘Compare CH4 Data.’ After the data is inputted, one simply returns to the ‘CH4 EPPA Mapping’ spreadsheet and clicks on the ‘Compare Data’ button. Doing so will run a macro that compares the mapped data with the inputted values and changes the color of each cell based on the difference between the mapped value and the inputted value. The idea is that instead of having to manually go through and compare emissions data cell by cell, the ‘Compare Data’ macro simply highlights how much the data differs by assigning the cell a color.

We have now considered all worksheets that involve mapping the emissions inventory datasets into EPPA 5. Two final worksheets are given that provide quick comparison between EDGAR, EPA, and GTAP. The first is ‘EDGAR_EPA_GTAP Sector Mapping.xlsx’ which provides a description of each of the EDGAR, EPA, and GTAP sectors and illustrates how each sector is mapped into EPPA 5. The second worksheet is ‘EDGAR_EPA_GTAP_Inversion Comparison.xlsx’ which graphs the results from all the dataset mappings to allow for easy comparison. We emphasize that all graphs in the worksheet are linked to the individual species worksheets and are updated automatically. In the worksheet are multiple charts that compare emissions for each dataset by species, country, and region. In addition, there is a total emission graph that compares the datasets with top-down estimates for CH_4, N_2O, and SF_6.

APPENDIX B

The following appendix contains the complete non-CO_2 greenhouse gas and traditional air pollutant emissions inventory for EPPA 5.

In mapping the EDGAR v4.1 data into the EPPA 5 sectors, be aware that emissions associated with fuel use are mapped to the fuel category and not to the sector in which the fuel is used. For example, in using coal, natural gas, and oil in electricity production we map emissions associated with burning coal, natural gas, or oil to COAL, GAS, and OIL respectively and not to ELEC. Similarly, emissions associated with refined oil consumption in household transportation are attributed to ROIL and not HTRN. The reason emissions are accounted for in this manner is that as policies and prices influence the demand of different fuels within each sector, we wish to capture substitution effects between fuels as inputs to production. This can only be done if the emissions are attributed to the fuel itself as an input to production and not to the sector in which the fuel is used.

Table B1. EPPA 5 CH_4 emission inventory by region and sector (units in Tg).

	LIVE	CROP	FORS	FOOD	EINT	TRAN	HTRN	OTHR	SERV	ELEC	OIL	ROIL	COAL	GAS	FD	Region Total
AFR	12.6268	1.0971	8.2785	0	0.0456	0	0	0	0	0	2.0607	0.0309	1.7778	0.9879	7.3006	34.206
ANZ	4.3048	0.0547	0.6685	0	0.0078	0	0	0	0	0	0.2878	0.0146	1.5119	0.1711	0.9674	7.989
ASI	2.4271	6.3921	1.9183	0	0.0531	0	0	0	0	0	0.5292	0.0803	1.0739	3.8476	5.6510	21.973
BRA	13.2170	0.4746	3.4950	0	0.0927	0	0	0	0	0	0.2997	0.0286	0.3696	0.1037	2.9989	21.080
CAN	1.2101	0.0084	0.4314	0	0.0177	0	0	0	0	0	0.3886	0.0109	0.0955	1.9599	1.5046	5.627
CHN	10.9866	13.0336	0.0404	0	0.1350	0	0	0	0	0	0.6571	0.0723	21.2376	0.4650	12.8451	59.473
EUR	10.5218	0.1408	0.0348	0	0.0730	0	0	0	0	0	0.6883	0.1234	2.9971	3.9517	8.2949	26.826
IND	13.7371	4.0086	0.0682	0	0.0512	0	0	0	0	0	0.1516	0.0322	1.6919	0.4787	7.1465	27.366
JPN	0.6934	0.7657	0.0035	0	0.0257	0	0	0	0	0	0.0031	0.0162	0.0688	0.7546	0.4518	2.783
LAM	10.3616	0.7427	2.3068	0	0.0381	0	0	0	0	0	1.4038	0.0480	0.3192	1.1803	2.7660	19.167
MES	1.5057	0.1719	0.0011	0	0.0217	0	0	0	0	0	2.1516	0.0582	0.0449	8.0368	1.5611	13.553
MEX	2.4752	0.0410	0.0774	0	0.0058	0	0	0	0	0	0.7671	0.0149	0.0365	0.4857	1.0333	4.937
REA	7.2220	7.3317	1.7016	0	0.0106	0	0	0	0	0	0.1493	0.0126	0.4589	0.4529	3.9067	21.246
ROE	4.5863	0.1428	0.1263	0	0.0198	0	0	0	0	0	0.3788	0.0251	1.2684	6.0088	3.0011	15.557
RUS	2.5113	0.0654	0.3571	0	0.0197	0	0	0	0	0	1.3673	0.0275	2.0941	17.5495	2.9480	26.940
USA	8.5050	0.4062	0.0755	0	0.0787	0	0	0	0	0	1.1594	0.1182	4.6961	12.1714	6.4849	33.696
Sector Totals	106.892	34.877	19.585	0	0.696	0	0	0	0	0	12.443	0.714	39.742	58.606	68.862	342.417

Table B2. EPPA 5 N_2O emission inventory by region and sector (units in Tg).

	LIVE	CROP	FORS	FOOD	EINT	TRAN	HTRN	OTHR	SERV	ELEC	OIL	ROIL	COAL	GAS	FD	Region Total
AFR	0.4512	0.1447	0.6562	0	0.0111	0	0	0.08187	0	0	0.0040	0.0053	0.0005	0.0009	0.0677	1.424
ANZ	0.1269	0.0561	0.0616	0	0.0090	0	0	0.01484	0	0	0.0034	0.0050	0.0009	0.0000	0.0053	0.283
ASI	0.0560	0.2626	0.1403	0	0.0303	0	0	0.04736	0	0	0.0090	0.0083	0.0005	0.0002	0.0378	0.592
BRA	0.2702	0.1898	0.1836	0	0.0137	0	0	0.02705	0	0	0.0006	0.0037	0.0003	0.0000	0.0178	0.707
CAN	0.0145	0.0605	0.0253	0	0.0112	0	0	0.01185	0	0	0.0023	0.0141	0.0002	0.0001	0.0068	0.147
CHN	0.2837	0.8203	0.0034	0	0.0625	0	0	0.11933	0	0	0.0459	0.0160	0.0035	0.0000	0.1166	1.471
EUR	0.1440	0.4710	0.0033	0	0.2308	0	0	0.07679	0	0	0.0429	0.0385	0.0007	0.0001	0.0817	1.090
IND	0.1698	0.3326	0.0072	0	0.0163	0	0	0.04564	0	0	0.0125	0.0039	0.0004	0.0000	0.0980	0.686
JPN	0.0051	0.0220	0.0003	0	0.0156	0	0	0.01552	0	0	0.0074	0.0127	0.0001	0.0000	0.0172	0.096
LAM	0.2148	0.1820	0.1049	0	0.0091	0	0	0.02581	0	0	0.0012	0.0050	0.0002	0.0002	0.0204	0.564
MES	0.0604	0.0506	0.0001	0	0.0039	0	0	0.02391	0	0	0.0019	0.0065	0.0003	0.0004	0.0144	0.162
MEX	0.0507	0.0477	0.0062	0	0.0045	0	0	0.00774	0	0	0.0008	0.0049	0.0001	0.0001	0.0095	0.132
REA	0.1230	0.1353	0.1109	0	0.0037	0	0	0.02049	0	0	0.0006	0.0018	0.0000	0.0000	0.0416	0.437
ROE	0.0727	0.1757	0.0120	0	0.0743	0	0	0.02281	0	0	0.0045	0.0036	0.0001	0.0002	0.0265	0.392
RUS	0.0262	0.0863	0.0313	0	0.0482	0	0	0.02789	0	0	0.0061	0.0059	0.0002	0.0004	0.0168	0.249
USA	0.1265	0.4514	0.0058	0	0.0841	0	0	0.09483	0	0	0.0550	0.1610	0.0008	0.0001	0.0501	1.030
Sector Totals	2.196	3.489	1.353	0	0.628	0	0	0.66372	0	0	0.198	0.296	0.009	0.003	0.628	9.463

Table B3. EPPA 5 HFCs emission inventory by region and sector (units are in Gg of HFC-134a equivalent).

	LIVE	CROP	FORS	FOOD	EINT	TRAN	HTRN	OTHR	SERV	ELEC	OIL	ROIL	COAL	GAS	FD	Region Total
AFR	0	0	0	0	0	0	0	0.54951	0	0	0	0	0	0	0.4375	0.987
ANZ	0	0	0	0	0	0	0	2.28604	0	0	0	0	0	0	1.8342	4.120
ASI	0	0	0	0	0	0	0	3.9892	0	0	0	0	0	0	1.3936	5.383
BRA	0	0	0	0	0	0	0	2.85512	0	0	0	0	0	0	0.4761	3.331
CAN	0	0	0	0	0	0	0	4.44611	0	0	0	0	0	0	3.5616	8.008
CHN	0	0	0	0	0	0	0	72.1329	0	0	0	0	0	0	0.7646	72.897
EUR	0	0	0	0	0	0	0	33.0112	0	0	0	0	0	0	21.7061	54.717
IND	0	0	0	0	0	0	0	2.02659	0	0	0	0	0	0	0.0000	2.027
JPN	0	0	0	0	0	0	0	16.1519	0	0	0	0	0	0	12.3871	28.539
LAM	0	0	0	0	0	0	0	1.95832	0	0	0	0	0	0	0.4561	2.414
MES	0	0	0	0	0	0	0	0.87059	0	0	0	0	0	0	0.6646	1.535
MEX	0	0	0	0	0	0	0	2.42948	0	0	0	0	0	0	0.4538	2.883
REA	0	0	0	0	0	0	0	0.10327	0	0	0	0	0	0	0.0697	0.173
ROE	0	0	0	0	0	0	0	3.62852	0	0	0	0	0	0	2.7237	6.352
RUS	0	0	0	0	0	0	0	13.4698	0	0	0	0	0	0	2.7194	16.189
USA	0	0	0	0	0	0	0	76.3165	0	0	0	0	0	0	54.4400	130.757
Sector Totals	0	0	0	0	0	0	0	236.225	0	0	0	0	0	0	104.088	340.313

Table B4. EPPA 5 PFCs emission inventory by region and sector (units are in Gg of CF_4 equivalent).

	LIVE	CROP	FORS	FOOD	EINT	TRAN	HTRN	OTHR	SERV	ELEC	OIL	ROIL	COAL	GAS	FD	Region Total
AFR	0	0	0	0	0.4052	0	0	0	0	0	0	0	0	0	0.0000	0.405
ANZ	0	0	0	0	0.1481	0	0	0.00666	0	0	0	0	0	0	0.0043	0.159
ASI	0	0	0	0	0.0189	0	0	1.26772	0	0	0	0	0	0	0.0000	1.287
BRA	0	0	0	0	0.8051	0	0	6.8E-05	0	0	0	0	0	0	0.0000	0.805
CAN	0	0	0	0	0.9402	0	0	0.00482	0	0	0	0	0	0	0.0002	0.945
CHN	0	0	0	0	1.4428	0	0	0.13761	0	0	0	0	0	0	0.0000	1.580
EUR	0	0	0	0	1.5285	0	0	0.35992	0	0	0	0	0	0	0.0905	1.979
IND	0	0	0	0	0.3003	0	0	0.0009	0	0	0	0	0	0	0.0000	0.301
JPN	0	0	0	0	0.0065	0	0	1.24386	0	0	0	0	0	0	0.0207	1.271
LAM	0	0	0	0	0.0602	0	0	0.00012	0	0	0	0	0	0	0.0000	0.060
MES	0	0	0	0	0.0855	0	0	0.01779	0	0	0	0	0	0	0.0000	0.103
MEX	0	0	0	0	0.0000	0	0	0	0	0	0	0	0	0	0.0000	0.000
REA	0	0	0	0	0.0000	0	0	0	0	0	0	0	0	0	0.0000	0.000
ROE	0	0	0	0	0.1920	0	0	0.01285	0	0	0	0	0	0	0.0099	0.215
RUS	0	0	0	0	3.9346	0	0	0.1297	0	0	0	0	0	0	0.0232	4.088
USA	0	0	0	0	0.7061	0	0	0.6514	0	0	0	0	0	0	0.0477	1.405
Sector Totals	0	0	0	0	10.574	0	0	3.83341	0	0	0	0	0	0	0.196	14.604

Table B5. EPPA 5 SF_6 emission inventory by region and sector (units in Gg).

	LIVE	CROP	FORS	FOOD	EINT	TRAN	HTRN	OTHR	SERV	ELEC	OIL	ROIL	COAL	GAS	FD	Region Total
AFR	0	0	0	0	0.0000	0	0	0.01767	0	0.12743	0	0	0	0	0	0.145
ANZ	0	0	0	0	0.0000	0	0	0.00195	0	0.01954	0	0	0	0	0	0.021
ASI	0	0	0	0	0.0043	0	0	0.12851	0	0.29268	0	0	0	0	0	0.425
BRA	0	0	0	0	0.0035	0	0	0.00227	0	0.04026	0	0	0	0	0	0.046
CAN	0	0	0	0	0.0082	0	0	0.099	0	0.06183	0	0	0	0	0	0.169
CHN	0	0	0	0	0.0900	0	0	0.1795	0	0.85746	0	0	0	0	0	1.127
EUR	0	0	0	0	0.0740	0	0	0.59808	0	0.17455	0	0	0	0	0	0.847
IND	0	0	0	0	0.0004	0	0	0.00018	0	0.18018	0	0	0	0	0	0.181
JPN	0	0	0	0	0.0405	0	0	0.10979	0	0.0496	0	0	0	0	0	0.200
LAM	0	0	0	0	0.0000	0	0	0.00073	0	0.02526	0	0	0	0	0	0.026
MES	0	0	0	0	0.0123	0	0	0.01342	0	0.22404	0	0	0	0	0	0.250
MEX	0	0	0	0	0.0011	0	0	0.00372	0	0.01662	0	0	0	0	0	0.021
REA	0	0	0	0	0.0000	0	0	0	0	0.0297	0	0	0	0	0	0.030
ROE	0	0	0	0	0.0006	0	0	0.00036	0	0.07177	0	0	0	0	0	0.073
RUS	0	0	0	0	0.0000	0	0	0.3819	0	0.011	0	0	0	0	0	0.393
USA	0	0	0	0	0.1344	0	0	1.02998	0	0.58561	0	0	0	0	0	1.750
Sector Totals	0	0	0	0	0.369	0	0	2.56707	0	2.76755	0	0	0	0	0	5.704

Table B6. EPPA 5 SO_2 emission inventory by region and sector (units are Tg).

	LIVE	CROP	FORS	FOOD	EINT	TRAN	HTRN	OTHR	SERV	ELEC	OIL	ROIL	COAL	GAS	FD	Region Total
AFR	0	0.0081	0	0.00513	1.1869	0	0	0	0	0	0	0.2662	3.2606	0.0003	0.5191	5.246
ANZ	0	0.0000	0	7.5E-05	1.8908	0	0	0	0	0	0	0.0642	0.6813	0.0030	0.0192	2.659
ASI	0	0.0518	0	0	1.8288	0	0	0	0	0	0	1.0539	1.8511	0.0000	0.2073	4.993
BRA	0	0.0317	0	0.0235	0.6973	0	0	0	0	0	0	0.2525	0.2170	0.0000	0.0977	1.320
CAN	0	0.0000	0	0.018	0.9510	0	0	0.009	0	0	0	0.1620	0.9713	0.1370	0.0560	2.304
CHN	0	0.0279	0	0.124	11.9219	0	0	0	0	0	0	0.4753	14.7000	0.1400	2.2012	29.590
EUR	0	0.0041	0	0.02571	1.4905	0	0	0.04146	0	0	0	0.8338	5.4455	0.2381	0.8989	8.978
IND	0	0.0335	0	0	1.7520	0	0	0	0	0	0	1.1816	3.8920	0.0000	0.5500	7.409
JPN	0	0.0001	0	0.00121	0.3216	0	0	0	0	0	0	0.1663	0.1822	0.0000	0.2589	0.930
LAM	0	0.0178	0	0.01068	1.3840	0	0	0	0	0	0	0.2659	1.5527	0.0001	0.1708	3.402
MES	0	0.0013	0	0.00063	1.6834	0	0	0	0	0	0	0.6510	3.3706	0.0001	0.3841	6.091
MEX	0	0.0049	0	0.00042	0.2165	0	0	0	0	0	0	0.2854	1.3106	0.0000	0.0865	1.904
REA	0	0.0346	0	0	0.9964	0	0	0	0	0	0	0.3614	0.4578	0.0000	0.2258	2.076
ROE	0	0.0021	0	0.00425	1.0383	0	0	0.02266	0	0	0	0.1606	3.8045	0.0646	0.5876	5.685
RUS	0	0.0000	0	0.0719	0.9467	0	0	0	0	0	0	0.4880	0.9540	0.1810	0.0000	2.642
USA	0	0.0000	0	0	2.0070	0	0	0.373	0	0	0	0.5862	9.5300	0.2200	0.5197	13.236
Sector Totals	0	0.218	0	0.28551	30.313	0	0	0.44612	0	0	0	7.254	52.181	0.984	6.783	98.465

Table B7. EPPA 5 NO_x emission inventory by region and sector (units in Tg).

	LIVE	CROP	FORS	FOOD	EINT	TRAN	HTRN	OTHR	SERV	ELEC	OIL	ROIL	COAL	GAS	FD	Region Total
AFR	0.1867	0.1563	0	0.00201	0.4949	0	0	0	0	0	0	1.4971	1.8351	0.0374	0.4778	4.687
ANZ	0.0053	0.0209	0	0	0.4674	0	0	0	0	0	0	0.5408	0.6978	0.0014	0.1459	1.879
ASI	0.0009	0.2236	0	0	0.9114	0	0	0	0	0	0	3.3911	1.7372	0.0000	0.3178	6.582
BRA	0.1044	0.3870	0	0.00895	0.4272	0	0	0	0	0	0	0.9218	0.1287	0.0017	0.0612	2.041
CAN	0.0000	0.0000	0	0.024	0.1980	0	0	0.016	0	0	0	1.2970	0.7830	0.0850	0.0880	2.491
CHN	0.0000	0.0260	0	0	6.9730	0	0	0	0	0	0	2.9451	4.4040	0.0576	1.6226	16.028
EUR	0.0148	0.1917	0	0.02101	1.8924	0	0	0.02181	0	0	0	6.0410	2.3228	0.0291	1.6449	12.179
IND	0.0000	0.6900	0	0	0.6520	0	0	0	0	0	0	1.7177	2.1985	0.0000	0.6850	5.943
JPN	0.0062	0.0164	0	0.0003	0.5141	0	0	0	0	0	0	0.9919	0.2371	0.0000	0.2957	2.062
LAM	0.0903	0.2497	0	0.00411	0.5407	0	0	0	0	0	0	1.1715	0.8008	0.0055	0.1255	2.988
MES	0.0321	0.0482	0	0.00024	0.6091	0	0	0	0	0	0	2.4662	1.2261	0.0151	0.1644	4.562
MEX	0.0254	0.0813	0	0.00016	0.0544	0	0	0	0	0	0	0.7778	0.2852	0.0032	0.0473	1.275
REA	0.0002	0.2408	0	0	0.1940	0	0	0	0	0	0	1.0810	0.3096	0.0000	0.3403	2.166
ROE	0.0230	0.0674	0	0.00089	0.5248	0	0	0.02184	0	0	0	1.2020	1.2398	0.0338	0.3925	3.506
RUS	0.0000	0.0000	0	0.0069	0.3586	0	0	0	0	0	0	1.2843	2.6500	0.0117	0.5670	4.878
USA	0.0000	0.0391	0	0	1.8740	0	0	0.4	0	0	0	9.2864	3.5900	0.3160	0.6618	16.167
Sector Totals	0.489	2.439	0	0.06856	16.686	0	0	0.45965	0	0	0	36.613	24.446	0.598	7.638	89.435

Table B8. EPPA 5 CO emission inventory by region and sector (units in Tg).

	LIVE	CROP	FORS	FOOD	EINT	TRAN	HTRN	OTHR	SERV	ELEC	OIL	ROIL	COAL	GAS	FD	Region Total
AFR	0	1.8561	0	0.00837	1.4532	0	0	0	0	0	0	7.2628	4.4627	0.2057	37.4972	52.746
ANZ	0	0.4487	0	0	0.3434	0	0	0	0	0	0	3.6088	0.0829	0.0081	1.0528	5.545
ASI	0	11.9126	0	0	15.0357	0	0	0	0	0	0	19.5539	7.1140	0.0000	18.8909	72.507
BRA	0	7.3000	0	0.0488	2.9820	0	0	0	0	0	0	3.4492	1.7104	0.0092	2.3110	17.811
CAN	0	0.0000	0	0.086	1.1083	0	0	0.03	0	0	0	7.3930	0.7390	0.1460	0.7080	10.210
CHN	0	5.5800	0	0.0239	66.7713	0	0	0.553	0	0	0	17.0290	4.3547	0.0179	45.9025	140.232
EUR	0	0.5981	0	0.0182	6.7750	0	0	0.0349	0	0	0	15.1751	0.7004	0.0863	11.2223	34.610
IND	0	7.7110	0	0	18.2300	0	0	0	0	0	0	8.6261	1.8280	0.0000	55.6000	91.995
JPN	0	0.1700	0	0	1.5700	0	0	0	0	0	0	1.2688	0.1060	0.0000	0.1709	3.286
LAM	0	4.0878	0	0.02016	0.8918	0	0	0	0	0	0	5.0118	0.4809	0.0305	5.0016	15.525
MES	0	0.2962	0	0.00132	0.4636	0	0	0	0	0	0	13.6539	0.1690	0.0830	0.4186	15.086
MEX	0	1.1203	0	0.00087	0.1290	0	0	0	0	0	0	2.6725	0.0388	0.0173	1.2600	5.239
REA	0	7.9700	0	0	3.4244	0	0	0	0	0	0	4.8847	0.9002	0.0000	27.8409	45.020
ROE	0	0.9053	0	0.00326	1.0333	0	0	0.06455	0	0	0	6.7881	0.1288	0.0815	2.8401	11.845
RUS	0	0.0000	0	0.0258	1.1070	0	0	0	0	0	0	9.2761	0.4640	0.0176	1.2200	12.110
USA	0	0.8790	0	0	2.2720	0	0	0.572	0	0	0	68.4641	0.5980	0.3210	3.1567	76.263
Sector Totals	0	50.835	0	0.23668	123.590	0	0	1.25444	0	0	0	194.118	23.878	1.024	215.094	610.029

Table B9. EPPA 5 NH_3 emission inventory by region and sector (units in Tg).

	LIVE	CROP	FORS	FOOD	EINT	TRAN	HTRN	OTHR	SERV	ELEC	OIL	ROIL	COAL	GAS	FD	Region Total
AFR	1.7793	0.7770	0	0	0.0436	0	0	0	0	0	0	0.0044	0.0031	0.0000	0.0103	2.618
ANZ	0.4474	0.3349	0	0	0.0045	0	0	0	0	0	0	0.0125	0.0013	0.0000	0.0002	0.801
ASI	0.6179	1.5895	0	0	0.0740	0	0	0	0	0	0	0.0391	0.7291	0.0000	0.1947	3.244
BRA	1.2892	0.9802	0	0	0.0210	0	0	0	0	0	0	0.0063	0.0024	0.0000	0.0008	2.300
CAN	0.3417	0.5620	0	0.004	0.0225	0	0	0.003	0	0	0	0.0190	0.0110	0.0020	0.0030	0.968
CHN	5.8500	5.4410	0	0	0.1681	0	0	0	0	0	0	0.0188	0.7793	0.0000	0.0882	12.345
EUR	2.8486	1.0492	0	0.00409	0.0661	0	0	0.00615	0	0	0	0.0818	0.4325	0.0001	0.0941	4.583
IND	0.8223	3.2689	0	0	0.1860	0	0	0	0	0	0	0.0001	1.7717	0.0000	0.6080	6.657
JPN	0.1583	0.1683	0	0	0.0006	0	0	0	0	0	0	0.0152	0.1046	0.0000	0.0008	0.448
LAM	1.0908	0.9427	0	0	0.0300	0	0	0	0	0	0	0.0096	0.0054	0.0000	0.0014	2.080
MES	0.2497	0.4094	0	0	0.0180	0	0	0	0	0	0	0.0118	0.0087	0.0000	0.0005	0.698
MEX	0.3545	0.3818	0	0	0.0028	0	0	0	0	0	0	0.0124	0.0034	0.0000	0.0003	0.755
REA	0.7255	1.1819	0	0	0.0177	0	0	0	0	0	0	0.0188	0.7733	0.0000	0.3440	3.061
ROE	1.3667	0.3145	0	0	0.0149	0	0	0.00114	0	0	0	0.0024	0.0023	0.0057	0.0330	1.741
RUS	0.5670	0.0000	0	0	0.0410	0	0	0	0	0	0	0.0000	0.0000	0.0000	0.5010	1.109
USA	1.4985	1.6782	0	0	0.0603	0	0	0	0	0	0	0.2363	0.0217	0.0000	0.0050	3.500
Sector Totals	20.007	19.079	0	0.00809	0.771	0	0	0.01029	0	0	0	0.488	4.650	0.008	1.885	46.908

Table B10. EPPA 5 NMVOCs emission inventory by region and sector (units in Tg).

	LIVE	CROP	FORS	FOOD	EINT	TRAN	HTRN	OTHR	SERV	ELEC	OIL	ROIL	COAL	GAS	FD	Region Total
AFR	0.0000	0.1411	0	0.01809	0.0370	0	0	1.6527	0	0	0	1.2040	1.4474	3.4074	3.7996	11.707
ANZ	0.0000	0.0258	0	0.06117	0.0471	0	0	0.22678	0	0	0	0.3842	0.0125	0.1955	0.1370	1.090
ASI	0.0000	0.9067	0	0.02049	2.0846	0	0	2.14335	0	0	0	2.0295	0.4755	5.5195	1.2188	14.398
BRA	0.0000	0.5560	0	0.0288	0.0660	0	0	0.6387	0	0	0	0.8106	0.5189	1.5600	0.3034	4.482
CAN	0.3004	0.2090	0	0.028	0.0822	0	0	0.57483	0	0	0	0.6330	0.0330	0.7500	0.1640	2.774
CHN	0.0000	1.0500	0	0.13906	2.1945	0	0	4.45344	0	0	0	2.6055	0.1193	1.1200	12.1355	23.817
EUR	0.2626	0.4392	0	0.31599	0.5369	0	0	3.75584	0	0	0	2.6624	2.1503	0.9089	1.3171	12.349
IND	0.0000	0.5860	0	0.00289	0.2091	0	0	0.6561	0	0	0	1.0440	0.0796	2.0400	3.2416	7.859
JPN	0.0000	0.0017	0	0.0264	0.2682	0	0	1.3094	0	0	0	0.1447	0.0049	0.2470	0.1332	2.136
LAM	0.0000	0.3109	0	0.01544	0.0731	0	0	1.10784	0	0	0	0.8839	0.1365	3.2501	0.6234	6.401
MES	0.0000	0.0225	0	0.00219	0.0265	0	0	0.60525	0	0	0	2.5312	0.0471	8.6704	0.1346	12.040
MEX	0.0000	0.0852	0	0.00601	0.0180	0	0	0.2894	0	0	0	0.3152	0.0056	1.6400	0.1676	2.527
REA	0.0000	0.6061	0	0.00088	0.0105	0	0	0.37596	0	0	0	0.4475	0.0970	0.4259	1.6088	3.573
ROE	0.0060	0.0346	0	0.14723	0.4667	0	0	0.7567	0	0	0	1.2020	0.1291	0.9551	0.3960	4.093
RUS	0.0000	0.0000	0	0.347	0.3082	0	0	1.731	0	0	0	1.7431	0.0807	0.1210	0.1590	4.490
USA	0.0000	0.0000	0	0	0.3927	0	0	5.521	0	0	0	6.8246	0.0441	0.5330	1.4923	14.808
Sector Totals	0.569	4.975	0	1.15963	6.821	0	0	25.7983	0	0	0	25.465	5.382	31.344	27.032	128.546

Table B11. EPPA 5 BC emission inventory by region and sector (units in Tg).

	LIVE	CROP	FORS	FOOD	EINT	TRAN	HTRN	OTHR	SERV	ELEC	OIL	ROIL	COAL	GAS	FD	Region Total
AFR	0	0.0139	0	0	0.0118	0	0	0	0	0	0	0.0179	0.0354	3.7E-07	0.6771	0.756
ANZ	0	0.0082	0	0	0.0003	0	0	0	0	0	0	0.0068	0.0004	3.9E-09	0.0155	0.031
ASI	0	0.0895	0	0	0.0238	0	0	0	0	0	0	0.1326	0.0102	0	0.2002	0.456
BRA	0	0.0547	0	0	0.0011	0	0	0	0	0	0	0.0314	0.0124	1.7E-08	0.0411	0.141
CAN	0	0.0021	0	0	0.0004	0	0	0	0	0	0	0.0071	0.0002	2.4E-08	0.0080	0.018
CHN	0	0.1030	0	0	0.3015	0	0	0.013	0	0	0	0.0924	0.1021	1.8E-05	0.7500	1.362
EUR	0	0.0112	0	0	0.0293	0	0	0	0	0	0	0.1284	0.0034	5.3E-08	0.1634	0.336
IND	0	0.0578	0	0	0.0328	0	0	0	0	0	0	0.1137	0.0123	0	0.6410	0.858
JPN	0	0.0002	0	0	0.0076	0	0	0	0	0	0	0.0419	0.0086	2.3E-10	0.0083	0.067
LAM	0	0.0307	0	0	0.0021	0	0	0	0	0	0	0.0181	0.0035	5.5E-08	0.0904	0.145
MES	0	0.0022	0	0	0.0009	0	0	0	0	0	0	0.0190	0.0021	1.5E-07	0.0058	0.030
MEX	0	0.0084	0	0	0.0002	0	0	0	0	0	0	0.0052	0.0007	3.2E-08	0.0235	0.038
REA	0	0.0598	0	0	0.0057	0	0	0	0	0	0	0.0598	0.0026	0	0.3444	0.472
ROE	0	0.0161	0	0	0.0012	0	0	0	0	0	0	0.0145	0.0008	8.9E-08	0.0635	0.096
RUS	0	0.0067	0	0	0.0085	0	0	0	0	0	0	0.0063	0.0026	1.6E-07	0.0508	0.075
USA	0	0.0097	0	0	0.0017	0	0	0	0	0	0	0.0812	0.0016	3.4E-08	0.0733	0.168
Sector Totals	0	0.474	0	0	0.429	0	0	0.013	0	0	0	0.776	0.199	1.9E-05	3.156	5.047

Table B12. EPPA 5 OC emission inventory by region and sector (units in Tg).

	LIVE	CROP	FORS	FOOD	EINT	TRAN	HTRN	OTHR	SERV	ELEC	OIL	ROIL	COAL	GAS	FD	Region Total
AFR	0	0.0666	0	0	0.0222	0	0	0	0	0	0	0.0102	0.2315	3.1E-06	2.6212	2.952
ANZ	0	0.0391	0	0	0.0001	0	0	0	0	0	0	0.0023	0.0023	3.3E-08	0.0560	0.100
ASI	0	0.4281	0	0	0.0444	0	0	0	0	0	0	0.2568	0.0077	0	1.0120	1.749
BRA	0	0.2619	0	0	0.0221	0	0	0	0	0	0	0.0113	0.0847	1.4E-07	0.1640	0.544
CAN	0	0.0103	0	0	0.0001	0	0	0	0	0	0	0.0035	0.0001	2E-07	0.0310	0.045
CHN	0	0.3250	0	0	0.2870	0	0	0.0577	0	0	0	0.1908	0.0740	0	1.9600	2.895
EUR	0	0.0535	0	0	0.0586	0	0	0	0	0	0	0.0448	0.0161	4.4E-07	0.4955	0.668
IND	0	0.2768	0	0	0.0973	0	0	0	0	0	0	0.0903	0.0041	0	3.0200	3.489
JPN	0	0.0008	0	0	0.0053	0	0	0	0	0	0	0.0178	0.0073	1.9E-09	0.0122	0.043
LAM	0	0.1466	0	0	0.0020	0	0	0	0	0	0	0.0086	0.0158	4.6E-07	0.3596	0.533
MES	0	0.0106	0	0	0.0003	0	0	0	0	0	0	0.0165	0.0030	1.3E-06	0.0214	0.052
MEX	0	0.0401	0	0	0.0000	0	0	0	0	0	0	0.0024	0.0002	2.6E-07	0.0931	0.136
REA	0	0.2853	0	0	0.0103	0	0	0	0	0	0	0.1320	0.0016	0	1.6468	2.076
ROE	0	0.0769	0	0	0.1457	0	0	0	0	0	0	0.0077	0.0051	7.5E-07	0.1599	0.395
RUS	0	0.0321	0	0	0.0173	0	0	0	0	0	0	0.0063	0.0132	1.3E-06	0.0788	0.148
USA	0	0.0464	0	0	0.0010	0	0	0	0	0	0	0.0282	0.0010	2.8E-07	0.2260	0.303
Sector Totals	0	2.100	0	0	0.714	0	0	0.0577	0	0	0	0.830	0.468	8.3E-06	11.958	16.126

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