Development of the Non-CO_2 GHG Emissions Database for the GTAP Data Base Version 10A

By

Maksym Chepeliev[1]

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[1] Research Economist at the Center for Global Trade Analysis, Purdue University. Email: mchepeli@purdue.edu.
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[2] This is an updated version of the Research Memorandum No. 32 from February 2020. Key updates include use of the global warming potentials (GWPs) from the IPCC's Fourth Assessment Report (AR4) (compared to the GWPs from AR2 applied earlier), reporting of the GHG emissions from land use activities and minor changes to the mappings between emission drivers and emission sources.

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Abstract

The purpose of this note is to document data sources and steps used to develop the non-CO_2 greenhouse gas (GHG) emissions database for the GTAP Data Base Version 10A. Emissions are reported for three types of non-CO_2 GHGs – CH_4 (methane), N_2O (nitrous oxide) and the group of fluorinated gases (F-gases), and cover four reference years – 2004, 2007, 2011 and 2014. FAOSTAT dataset is used for sourcing agricultural non-CO_2 emissions, EDGAR v5.0 and v4.2 databases are used to source non-agricultural emissions. Each emission flow is associated with one of the four sets of emission drivers: output by industries, endowment by industries, input use by industries and consumption by households. Land use GHG emissions are reported separately without association with emission drivers.

JEL classification: C61, D57, D58, Q54, Q56.

Keywords: GTAP; Greenhouse gases; Non-CO_2 emissions; Computable general equilibrium.

Contents

1. Introduction

Standard GTAP 10a Data Base (Aguiar et al., 2019) provides estimates of CO_2 emissions produced from fossil fuel combustion. At the global level, as of 2010, these emissions represented less than 65% of total GHG emissions (IPCC, 2014). Non-CO_2 GHG emissions represented 24% of global GHG emissions, while CO_2 from forestry and land use accounted for the remaining 11% (Figure 1).

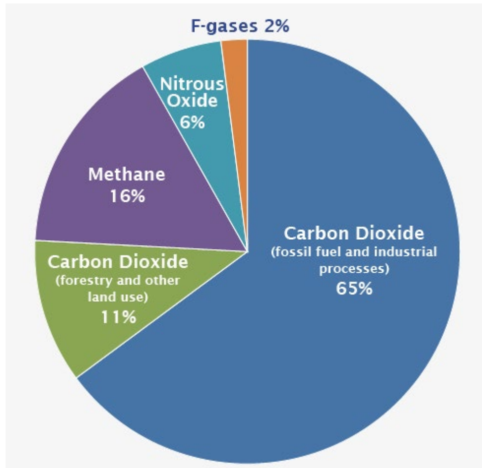

Figure 1. Global greenhouse gas emissions by gas in 2010, %
Source: IPCC (2014).

Due to the important contribution of non-CO_2 GHG emissions to climate mitigation pathways, since GTAP Version 6, a special version of the GTAP non-CO_2 emissions dataset has been constructed. GTAP 6 non-CO_2 dataset (Rose and Lee, 2009) with 2001 reference year was developed based on emission accounts provided in a detailed non-CO_2 and non-fossil fuel combustion CO_2 ("Other CO_2") greenhouse gas emissions database (Rose et al., 2007).

For the GTAP 7 and 8, non-CO_2 emission dataset was developed by an extrapolation of Rose et al. (2007) data to match each of the reference years. In GTAP 7, CH_4 and N_2O emission growth rates were used from US EPA (2006), while F-gases emission projections were based on output growth rates by regions from the GTAP database (Rose et al., 2010). For GTAP 8, however, applied emission growth rates are based on two data sources: EDGAR database for non-agricultural emissions and FAOSTAT for agricultural emissions (Ahmed et al., 2014).

GTAP 9 non-CO_2 GHG emissions dataset was developed using EDGAR Version 4.2 (JRC/PBL, 2011) dataset for non-agricultural activities and FAOSTAT emissions dataset for agricultural activities (Irfanoglu and van der Mensbrugghe, 2015). Emissions are directly sourced from the two sources listed above and mapped to three GTAP 9 reference years (2004, 2007 and 2011). As in EDGAR Version 4.2 the latest available data year is 2010, an emission growth approach was used to project emissions from 2010 to 2011 levels, assuming that 2010-2011 emissions growth rate equals 2007-2010 emissions growth rate.

For the GTAP 10a non-CO_2 emissions dataset construction we follow general approach outlined in Irfanoglu and van der Mensbrugghe (2015) with some further updates and modifications. We develop the dataset that covers four GTAP 10a reference years – 2004, 2007, 2011 and 2014. FAOSTAT (FAO, 2019) dataset is used to source agricultural non-CO_2 emissions, while EDGAR v5.0 and v4.2 databases are used to source non-agricultural emissions. Each emission flow is associated with one of the four sets of emission drivers: output by industries, endowment by industries, input use by industries and consumption by households. Figure 2 outlines general approach to the GTAP 10a non-CO_2 database construction. We additionally report land use GHG emissions without associating them with emission drivers.

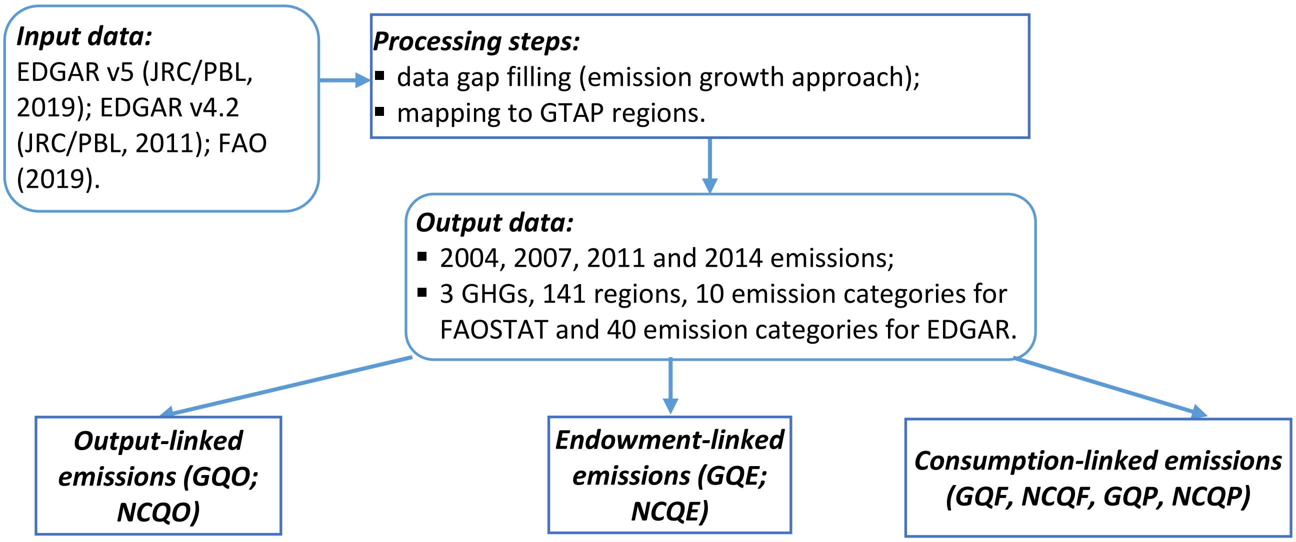

Figure 1. GTAP 10a non-CO_2 database construction process

Source: Authors

Note: In the final GTAP 10a non-CO_2 database emissions are provided in Gigagrams and mil. Mt of CO_2-eq.

The rest of the document is organized as follows. Section 2 discusses treatment of the agricultural emissions sourced from FAOSTAT. Section 3 outlines treatment of the non-agricultural emissions from EDGAR. Section 4 discusses treatment of the land use GHG emissions. Section 5 provides an overview of the constructed GTAP 10a non-CO_2 GHG database. Section 6 showcases an application of the constructed database to estimating GHG emissions embodied into final consumption of agricultural and food commodities. Finally, Section 7 concludes.

2. Treatment of the agricultural emissions from FAOSTAT

FAOSTAT dataset is used as a main source for agricultural non-CO_2 GHG emissions, excluding energy use emissions.[3] FAOSTAT emission data cover 1961-2017 timeframe, which enables explicit mapping to GTAP 10 reference years (2004, 2007, 2011 and 2014). Agricultural emissions in FAOSTAT are reported under 10 emission categories, which represent activities that produced such emissions. Appendix A provides a listing of such emission categories and their mapping to GHGs reported in the GTAP non-CO_2 database. FAOSTAT does not report agricultural emissions of fluorinated gases, but only N_2O and CH_4 emissions (Appendix A, column three). Three out of ten emission categories produce both GHGs, these include Burning crop residues, Burning savanna and Manure management, while seven remaining categories produce either nitrous oxide or methane.

[3] Non-CO_2 GHG emissions from fossil fuel combustion in agriculture are sourced from EDGAR dataset (see Section 3).

FAOSTAT reports data for 36 emission subcategories, which represent different agricultural commodities, types of land, etc. Their list is provided in Appendix B. 232 countries and territories reported by FAOSTAT are mapped to the GTAP country codes (FAO, 2019). To map the FAOSTAT data to GTAP Database, we first map each emission category to emission driver (Appendix A, column five). Then each emission subcategory is mapped to GTAP commodity (Appendix B, column four).

For instance, FAOSTAT (FAO, 2019) reports N_2O emissions from crop residues[4] ("CRES" category in Appendix A) for Barley by countries. Based on developed mappings, these emissions are associated with output of GTAP "Cereal grains nec" ("gro") sector. In this case, we use direct mapping, as no redistribution of emissions between sectors is performed. An example where redistribution of emissions is implemented includes N_2O emissions from synthetic nitrogen fertilizer application ("SNTF" category in Appendix A). These emissions are mapped to the eight GTAP agricultural sectors (listed in Appendix B) and are associated with intermediate use of "Chemical products" ("chm") by these sectors (Appendix B). We use the value of intermediate use of "chm" by these eight sectors to redistribute N_2O emissions. Such mapping approach is applied to all non-CO_2 GHG emission flows sourced from FAOSTAT.

3. Treatment of the non-agricultural emissions from EDGAR

Non-agricultural emissions and energy-related agricultural emissions are sourced from the EDGAR v5.0 and v4.2 databases (JRC/PBL, 2011; JRC/PBL, 2019). EDGAR reports emissions for six substances listed in Appendix C, which are mapped to three GHGs reported in the GTAP 10a non-CO_2 database. EDGAR v5.0 database covers 1970-2015 timeframe, but reports emissions of CH_4 and N_2O only, therefore it does not report emissions of F-gases. EDGAR v4.2 database reports F-gases, but has 2010 as the latest available data year. Therefore, the first step in the EDGAR non-CO_2 emissions data processing is to estimate emissions of F-gases for 2011 and 2014 reference years. We use an emission growth approach to extrapolate the dataset from years 2004-2010 to 2011-2014. In particular, we assume that the growth rate in emissions of F-gases between 2010 and 2014 equals an average growth rate between 2004-2010 (or shorter sub period if data for the whole period is not available). Historical emission growth rate is estimated using the formula:

$$egr(r,s,p)|_{n<2010} = \left(\frac{E_{2010}(r,s,p)}{E_n(r,s,p)}\right)^{\frac{1}{2010-n}},$$

where $egr(r,s,p)$ is region (r), source (s) and pollutant (p) specific emission growth rate; $E_t(r,s,p)$ is emission level in year t; and $n \in [2004;\ 2009]$ is the earliest year with non-zero emissions level. In case of $n > 2009$, $egr(r,s,p) = 1$ (emissions for 2011 and subsequent years equal 2010 emissions). To predict the data from 2010 to any future year t (in our case $t = 2011$), we use the formula:

$$E_t(r,s,p) = [egr(r,s,p)]^{t-2010} \cdot E_{2010}(r,s,p).$$

So if $E_{2010}(r,s,p) = 0$, then $E_t(r,s,p) = 0, \forall t > 2010$.

[4] Greenhouse gas (GHG) emissions from crop residues consist of direct and indirect nitrous oxide (N_2O) emissions from nitrogen (N) in crop residues and forage/pasture renewal left on agricultural fields by farmers.

Although this approach might introduce some uncertainty to the total level of non-CO_2 GHGs for 2011 and 2014 reference years, the share of F-gases in total non-CO_2 GHG emissions is less than 10% (Figure 10), so aggregate discrepancy should not be large.

EDGAR reports emissions for 231 countries (JRC/PBL, 2011; JRC/PBL, 2019), which are mapped to the GTAP country list. In addition, EDGAR database reports emissions from international aviation and international shipping. These emissions are reported at the global level. We redistribute these emissions by countries based on the value of exports reported in GTAP 10a for air transport ("atp") and water transport ("wtp") respectively, excluding exports of travelers' expenditures.

EDGAR reports emissions for 48 IPCC categories, which are mapped to emission drivers (Appendix D). As agricultural emissions are covered by FAOSTAT, they are discarded from the EDGAR data processing steps to avoid double counting.[5] EDGAR v5.0 uses IPCC 2006 codes (IPCC, 2006), while EDGAR v4.2, used for the F-gases reporting, is based on the IPCC 1996 codes (IPCC, 1997). Appendix D provides mapping between IPCC categories reported in EDGAR, GTAP emission drivers and emission agents. These mappings are used to associate EDGAR emissions with GTAP-based emission drivers and agents that produce these emissions, in the similar way as described in Section 2.

To provide the reallocation of emissions from combustion-related energy use (IPCC category 1A), we use volumes of combusted energy and emission factors. We estimate emission weights by multiplying combustion-related energy use by corresponding emission factors (Appendix E). For other IPCC categories, not included into 1A, we use corresponding GTAP values to assist with redistribution.

Constructed database reports GHG emissions in gigagrams (Gg) and million tons of CO_2 equivalent (MtCO2-eq.). In the latter case, to convert non-CO_2 GHG emission volumes to the CO_2-eq., we use global warming potentials (GWPs) from the IPCC's Fourth Assessment Report (AR4) (Forster et al., 2007). Though, IPCC's AR5 also provides GWPs, current UNFCCC guidelines require the use of the GWP values for the IPCC's AR4. GTAP 9 non-CO_2 GHG emissions dataset was using GWPs from the IPCC's AR2 (Irfanoglu and van der Mensbrugghe, 2015). All three referenced IPCC reports (AR2, AR4 and AR5) provide different GWPs. In the database files, we report GWPs from AR2, AR4 and AR5 by GTAP regions,[6] leaving users an opportunity to perform conversion to CO_2-eq. on their own. GWP values from the AR5, reported in the database files, do not include climate-carbon feedbacks. In those cases when GTAP regions do not emit any F-gases, global weighted average GWPs for F-gases are reported.

4. Land use GHG emissions

As was discussed earlier, CO_2 emissions from land use activities contribute around 11% of global GHG emissions (IPCC, 2014). As the standard GTAP database does not have detailed

[5] Fuel combustion emissions in agriculture are sourced from EDGAR.

[6] Though all GWPs are region-generic, F-gases category has different composition by regions thus resulting in region-specific GWPs. GWPs for CH_4 and N_2O are uniform across regions.

representation of the land use accounts,[7] GTAP 9 non-CO_2 GHG emissions dataset did not report land use emissions (Irfanoglu and van der Mensbrugghe, 2015). A number of previous efforts have been linking land use change emissions with the GTAP Land Use and Land Cover Data Base, which provides detailed accounting of the land use activities (e.g. Hertel et al., 2010). At the same time, accounting for all GHG emission sources is important for the proper tracking of the mitigation efforts and global warming estimates, for instance, in the case of linking of the GTAP simulations with the climate model.

In the current effort, we provide estimates of the land use GHG emissions by GTAP 10a regions based on the FAOSTAT database (FAO, 2019). We do not distribute these emissions by drivers and agents, but report them using FAOSTAT emission categories. Treatment of the land use emission changes is left up to the modelers, as different alternative assumptions could be implemented taking into account features of the applied model and specifics of the policy simulation. For instance, one can impose exogenous trends on land use emissions based on the additional data sources, e.g. using SSP database (IIASA, 2016), assume these emissions stay at the reference year level (e.g. within the static model runs) or link to the land use activities if such representation is available in the model.

Based on the FAO land use change GHG emissions data (FAO, 2019), we identify four emission categories and seven subcategories (Appendix F). We map land use GHG emissions reported by countries in the FAO database to the 141 GTAP 10a regions. In terms of land use emission sources, in 2014 burning biomass contributed around half of all emissions or 1718 $MtCO_2$-eq. (Figure 3). These included N_2O, CH_4 and CO_2 gases. Other three emission categories (forest land, cropland and grassland) produced CO_2 emissions only, with forest land being the second largest land use emissions contributor, followed by cropland (Figure 3). CO_2 accounted for 82.7% of all land use GHG emissions, followed by CH_4 with the share of 14.3%.

Forest land category is the only one that includes emission removals. With the global 2014 forest land GHG emissions of 1067 $MtCO_2$-eq., net forest conversion activities emitted 2920 $MtCO_2$-eq., while forest land has removed 1853 $MtCO_2$-eq. In some countries net emissions from forest land are negative, meaning that removals are larger than emissions from net forest conversion activities. Countries with net negative forest land emissions over 100 $MtCO_2$-eq. in 2014 include China, Malaysia, USA, Chile, Romania and Russia.

[7] GTAP 10a database reports payments for land as an endowment by sectors, but does not provide physical data on land use areas (e.g. cropland, forest land, grassland, etc.), afforestation/deforestation accounts or other land conversion activities.

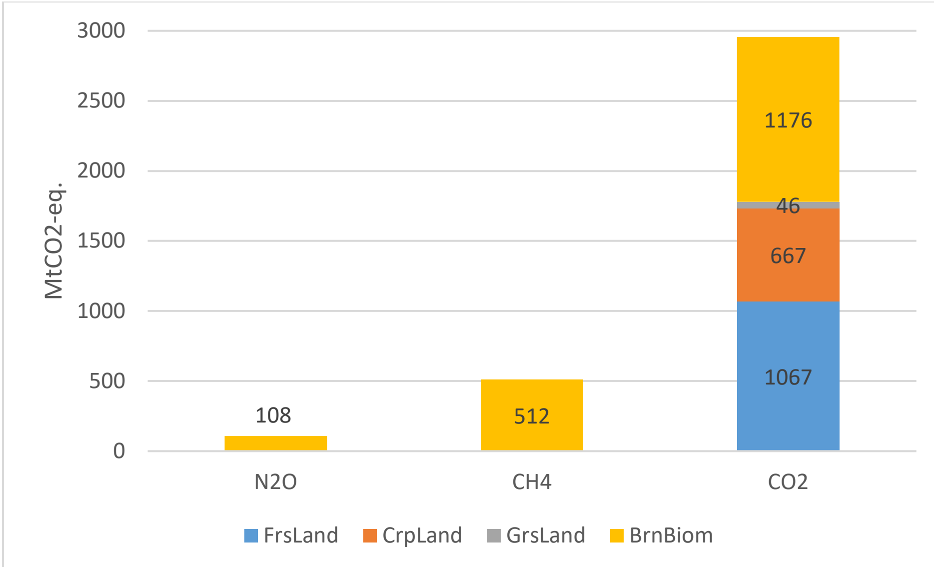

Figure 3. Distribution of global land use net GHG emissions in 2014 by gases and categories
Source: FAO (2019).

5. Overview of the GTAP 10a non-CO_2 database

In terms of emission drivers, out of 12.6 billion tCO_2-eq. of non-CO_2 GHG emissions in 2014,[8] over 51% are linked to output (Figure 4). CH_4 accounts for around 69% of global non-CO_2 GHG emissions, N_2O for around 22.9%, with the rest contributed by F-gases.

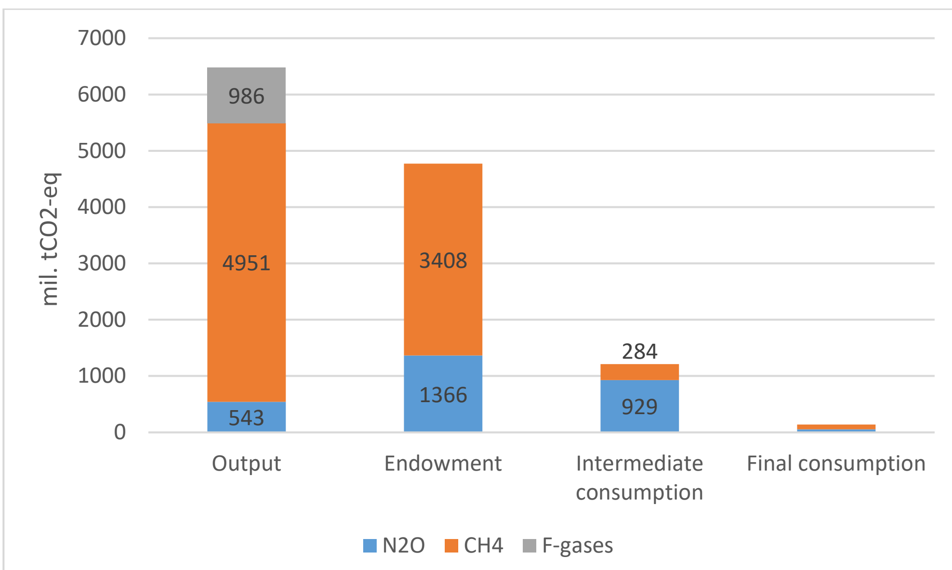

Figure 4. Distribution of non-CO_2 GHG emissions in 2014 by gases and drivers
Source: Estimated by authors based on GTAP 10a non-CO_2 database.

In terms of sectoral distribution, cattle sector accounts for almost quarter of all non-CO_2 GHG emissions at the global level, followed by water supply and sewage (16%) and coal (10%)

[8] In this section we consider only GHG emission from non-land use activities.

(Figure 5). Top eight sectors contribute over 78% of all non-CO_2 GHGs at the global level (Figure 5). Agricultural and food sectors account for 46% of all non-CO_2 GHG emissions.

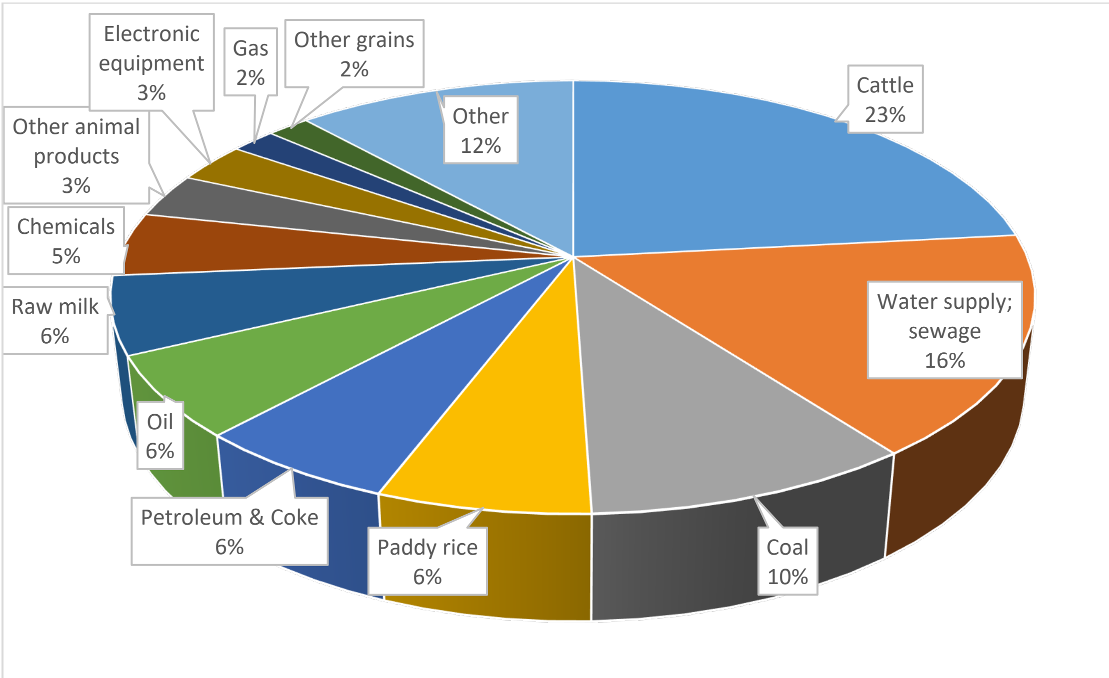

Figure 5. Distribution of global non-CO_2 GHG emissions by GTAP sectors in 2014, %
Source: Estimated by authors based on GTAP 10a non-CO_2 database.

In terms of changes over time, global non-CO_2 GHG emissions have been constantly increasing – from 10.8 billion tCO_2-eq. in 2004 to 12.6 billion tCO_2-eq. in 2014, with an annual average growth rate of around 1.5% (Figure 6).

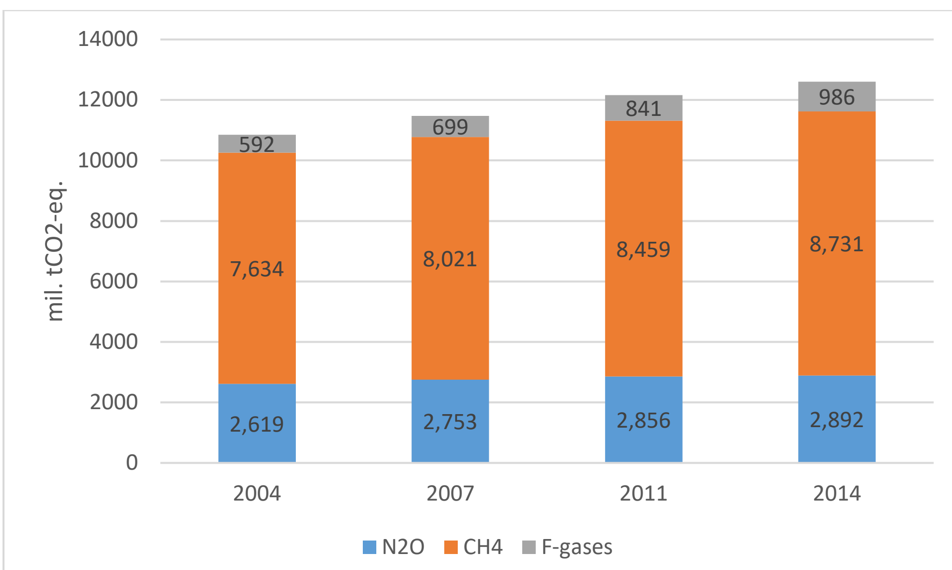

Figure 6. Global non-CO_2 GHG emissions by GTAP 10a reference years and gases
Source: Estimated by authors based on GTAP 10a non-CO_2 database.

Comparison of emission volumes by GHGs between GTAP 9 non-CO_2 (Irfanoglu and van der Mensbrugghe, 2015) and GTAP 10a non-CO_2 databases developed in this document has revealed some substantial differences (Appendix G). In particular, for the 2004 and 2007 reference years (these years do not undergo data gap-filling via emission growth approach), GTAP 9 non-CO_2 database reports on average 16% higher global non-CO_2 GHG emissions than GTAP 10a (Appendix G).[9] Higher differences are observed for the CH_4 emissions that differ by over 20% for 2004 and 2007 reference years. Additional comparisons between GTAP 9 non-CO_2 database and underlying EDGAR and FAOSTAT emissions data revealed that due to a processing error there was some double counting in emissions for selected categories. In particular, these included double counting of emissions from stationary and mobile combusting, which in the case of 2007 emissions led to the aggregate increase in CH_4 by around 19% relative to the source EDGAR and FAOSTAT data. Partly differences in emissions between GTAP 9 and GTAP 10a non-CO_2 databases are also driven by revisions of the underlying datasets. For instance, in the case of CH_4 emissions from waste water treatment (IPCC 2006 code "4D") in China for 2007, EDGAR v5.0 reports 13% higher emissions than EDGAR v4.2.

6. Numerical illustration

There are many aspects of the constructed GTAP non-CO_2 database that could be highlighted. In this section, we focus on GHG emissions (CO_2 and non-CO_2) embodied in final consumption of 21 GTAP agricultural and food commodities, including fishing industry.[10] Land use emissions are excluded from the estimates of GHG emissions embodied in final households' consumption. Country-specific GHG emissions per unit of output by industries are used to estimate emissions associated with final consumption flows. This method assumes that the production technology is based on fixed proportions (i.e. in a given sector and country, the same production technology is used to produce domestic and exported commodities) (Peters, 2008). This allows us to decompose emissions from domestic output into its sales disposition, i.e., exports or domestic sales. For every commodity, the total GHG emissions embodied in final households' consumption of region r (f_r) are estimated as

$$f_r = F_r(I - A_r)^{-1}e_r$$

where F_r is a vector of country-specific GHG emissions per unit of output by industries, I is the identity matrix, A_r is the technological matrix, which represents the industry requirements of domestically produced products in region r and e_r corresponds to the final households' consumption value in region r.

According to our estimation, cattle meat and other food products are by far the largest sectors with consumption-embodied food and agriculture GHG emissions (Figure 7). Out of 5.8 billion

[9] In GTAP 9 non-CO_2 database several categories were added to complement EDGAR-reported emissions. These included "Other Industrial Non-Agricultural Sources CH_4" (INCH), "Other Industrial Non-Agricultural Sources N_2O" (INN2), and "ODS Substitutes HFC-134a" (ODS). In the GTAP 10a database only EDGAR data were used to estimate non-agricultural emissions. Considering very small shares of these three categories, such differences should not impact general comparisons.

[10] For the purpose of current illustration, we include 21 GTAP sectors to the set of agricultural and food commodities – "pdr", "wht", "gro", "v_f", "osd", "c_b", "pfb", "ocr", "ctl", "oap", "rmk", "wol", "fsh", "cmt", "omt", "vol", "mil", "pcr", "sgr", "ofd", "b_t". Complete list of GTAP sectors and codes is provided in Aguiar et al. (2019).

tCO_2-eq. of GHG emissions (embodied into final consumption of food products), these two sectors correspond to 33.2% of global emissions. At the same time, raw commodity sectors, such as cattle, paddy rice and raw milk have much lower shares in terms of GHG emissions embodied into households' final consumption (compared with the direct emissions data). In this assessment, both combustion-related CO_2 emissions and non-CO_2 GHG emissions are reported under the GHG emissions embodied into final households' consumption.

In terms of global average carbon intensities, cattle meat, cattle, paddy rice and processed rice final consumption is associate with the highest emissions per USD (Figure 7). Production of other meat is on average over four times less carbon intensive than production of cattle meat. Wheat production is over 2.5 times less carbon intensive than processed rice.

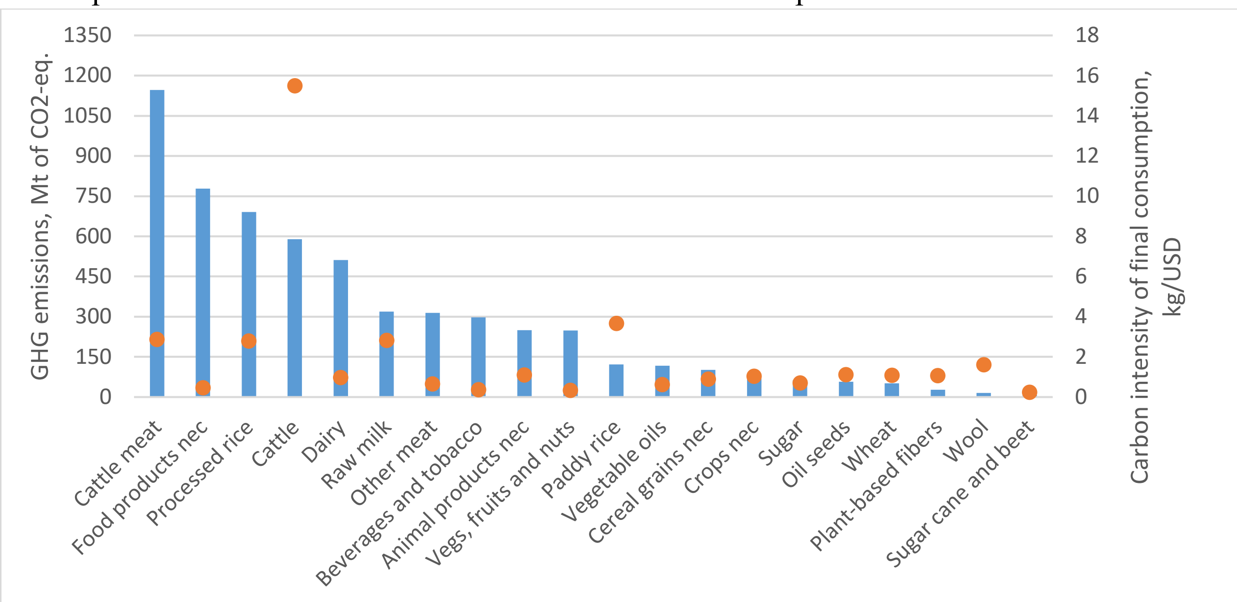

Figure 7. Global GHG emissions embodied into final households' consumption by GTAP agricultural and food sectors, 2014

Source: Estimated by authors based on GTAP 10a non-CO_2 database.

At the regional level, China has the largest food-related GHG emissions (16.6% of the global share), followed up by India (12.2%), USA (7.7%) and Brazil (5.9%). On the per capita basis, there is a high variation in emissions by regions (Figure 8). With a global average per capital GHG emissions from food and agricultural products final consumption of around 0.81 tCO_2-eq., per capita, emissions in a number of EU countries are below 0.7 tCO_2-eq. (e.g. Austria, Bulgaria, Czech Republic, Hungary, Netherlands, Romania, and Slovakia), emissions in other developed countries are much higher. For instance, they reach 1.3 tCO_2-eq. in Canada and 1.4 tCO_2-eq. in the U.S., 2.2 tCO_2-eq. in Australia and 2.5 tCO_2-eq. in New Zealand. Higher than global average level of per capita emissions from food and agricultural products final consumption are observed in Latin America countries. Countries in Northern Africa have on average lower levels of per capita emissions than in Sub-Saharan Africa (Figure 8).

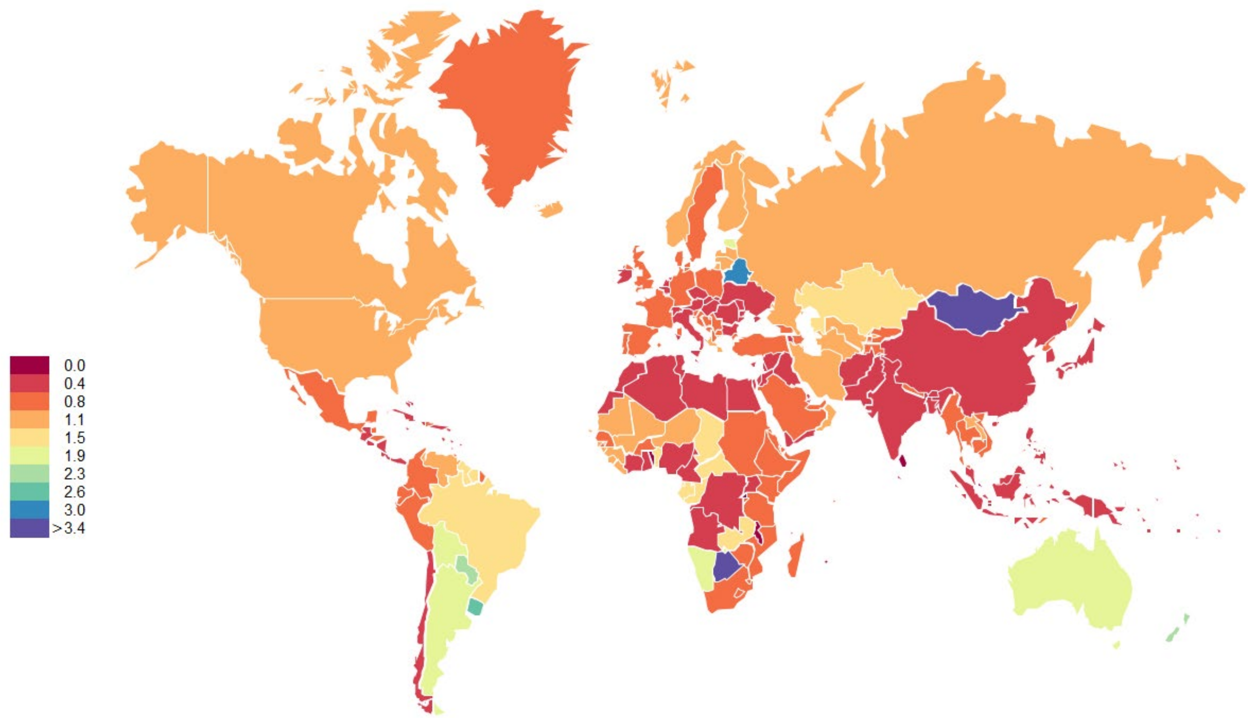

Figure 8. Per capita GHG emissions embodied into households' final consumption of food and agricultural commodities by GTAP 10a regions in 2014, tons/capita/year
Source: Estimated by authors based on GTAP 10a non-CO_2 database.

7. Summary

Considering the important contribution of non-CO_2 GHG emissions to the representation of climate mitigation pathways, a special version of the GTAP non-CO_2 emissions dataset has been constructed since GTAP Version 6. This document outlines an approach to the construction of GTAP 10a non-CO_2 GHG emissions database, which covers emissions of CH_4, N_2O and the group of fluorinated gases (F-gases).

The general approach follows that outlined in Irfanoglu and van der Mensbrugghe (2015) with some further updates and modifications. The newly developed database covers four GTAP 10a reference years – 2004, 2007, 2011 and 2014. FAOSTAT (FAO, 2019) dataset is used for sourcing agricultural non-CO_2 emissions, while EDGAR v5.0 and v4.2 databases (JRC/PBL, 2011; JRC/PBL, 2019) are used to source non-agricultural emissions. Each emission flow is associated with one of the four sets of emission drivers: output by industries, endowment by industries, input use by industries and consumption by households. For each emission category reported in FAOSTAT and EDGAR, mapping to GTAP emission drivers and agents is developed. These mappings are used to redistribute emissions based on value or volume flows. In the case of emissions from fossil fuel combustion, non-CO_2 GHG emission factors are used to assist with emissions redistribution. In addition, land use GHG emissions are reported separately without association with emission drivers.

We showcase an application of the newly constructed GTAP 10a non-CO_2 GHG emissions database by estimating GHG emissions embodied into final consumption of agricultural and food commodities in 2014 (excluding land use emissions). We show that in terms of emission intensities of food products, cattle meat and processed rice have the highest global average carbon footprint – over 2.7 kgCO_2-eq. per USD. At the regional level, China has the largest food-related GHG emissions (16.6% of the global share), followed up by India (12.2%), USA (7.7%) and Brazil (5.9%). On the per capita basis, there is a high variation in food-related GHG emissions by countries, with a global average of around 0.81 tCO_2-eq. While a number of European countries have food-related GHG emissions below 0.6 tCO_2-eq. (e.g. Czech Republic, Hungary, Netherlands, Slovakia), emissions in other developed countries are much higher. For instance, they reach 1.3 tCO_2-eq. in Canada, 1.4 tCO_2-eq. in the U.S., 2.2 tCO_2-eq. in Australia and 2.5 tCO_2-eq. in New Zealand.

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Appendix A. FAO emission categories mapped to GHGs and emission drivers

No.	Emission category code	Emission category description	Reported GHGs	Emission driver
1.	BCRS	Burning crop residues	N_2O, CH_4	Output
2.	BSAV	Burning savanna	N_2O, CH_4	Land
3.	CLOS	Cultivation of organic soils	N_2O	Land
4.	CRES	Crop residues	N_2O	Output
5.	MPAS	Manure left on pastures	N_2O	Capital
6.	MASL	Manure applied to soils	N_2O	Capital
7.	SNTF	Synthetic fertilizers	N_2O	Input use of chemical products ("chm")
8.	RICC	Rice cultivation	CH_4	Land
9.	MMNG	Manure management	N_2O, CH_4	Capital
10.	EFRM	Enteric fermentation	CH_4	Capital

Source: Developed by authors based on FAO (2019).

Appendix B. Emission subcategories reported in the FAOSTAT database and mapping to GTAP sectors

No.	Emission subcategory code	Emission subcategory description	GTAP sectors[11]
1.	56	Maize	gro
2.	27	Rice, paddy	pdr
3.	156	Sugar cane	c_b
4.	15	Wheat	wht
5.	44	Barley	gro
6.	79	Millet	gro
7.	116	Potatoes	v_f
8.	176	Beans, dry	v_f
9.	75	Oats	gro
10.	71	Rye	gro
11.	236	Soybeans	osd
12.	83	Sorghum	gro
13.	6760	Savanna	ctl, oap, rmk
14.	6789	Woody savanna	ctl, oap, rmk
15.	6791	Closed shrubland	ctl, oap, rmk
16.	6792	Open shrubland	ctl, oap, rmk
17.	6794	Grassland	ctl, oap, rmk
18.	6727	Cropland organic soils	pdr, wht, gro, v_f, osd, c_b, pfb, ocr
19.	6728	Grassland organic soils	ctl, oap, rmk
20.	1107	Asses	ctl
21.	1126	Camels	ctl
22.	960	Cattle, dairy	rmk
23.	961	Cattle, non-dairy	ctl
24.	1016	Goats	ctl
25.	1096	Horses	ctl
26.	1110	Mules	ctl
27.	976	Sheep	ctl
28.	946	Buffaloes	ctl
29.	1051	Swine, breeding	oap
30.	1049	Swine, market	oap
31.	1177	Llamas	ctl
32.	1053	Chickens, broilers	oap
33.	1052	Chickens, layers	oap
34.	1068	Ducks	oap
35.	1079	Turkeys	oap
36.	3107	Synthetic Nitrogen fertilizers	pdr, wht, gro, v_f, osd, c_b, pfb, ocr

Source: Developed by authors.

[11] Description and codes of the GTAP 10a sectors can be found here https://www.gtap.agecon.purdue.edu/databases/v10/v10_sectors.aspx#Sector65

Appendix C. Emission substances reported in EDGAR and their global warming potential

No.	Emission substances	Global warming potential	Mapping to the reported GHGs
1.	CF_4	7390	F-gas
2.	CH_4	25	CH_4
3.	HFC134A	1430	F-gas
4.	HFC23	14800	F-gas
5.	N_2O	298	N_2O
6.	SF_6	22800	F-gas

Source: Developed by authors based on Foster et al. (2007), JRC/PBL (2011) and JRC/PBL (2019).
Note: 100-year global warming potentials are reported in the table following IPCC AR4 (Foster et al., 2007).

Appendix D. Mapping between EDGAR emission categories and GTAP emission drivers

No.	IPCC 2006 category code	IPCC 1996 category code	Category description	GTAP emission drivers	GTAP emission agents
1	1A1A		Fuel Combustion Activities: Main Activity Electricity and Heat Production	coa, oil, gas, p_c, gdt	ely
2	1A1BC		Fuel Combustion Activities: Petroleum Refining; Manufacture of Solid Fuels and Other Energy Industries	coa, oil, gas, p_c, gdt	coa, oil, gas, p_c, gdt
3	1A2		Fuel Combustion Activities: Manufacturing Industries and Construction	coa, oil, gas, p_c, gdt	oxt, cmt, omt, vol, mil, pcr, sgr, ofd, b_t, tex, wap, lea, lum, ppp, chm, bph, rpp, nmm, i_s, nfm, fmp, ele, eeq, ome, mvh, otn, omf, cns
4	1A3A		Fuel Combustion Activities: Civil Aviation	coa, oil, gas, p_c, gdt	atp
5	1A3B		Fuel Combustion Activities: Road Transportation	coa, oil, gas, p_c, gdt	otp, HHs[12]
6	1A3C		Fuel Combustion Activities: Railways	coa, oil, gas, p_c, gdt	otp
7	1A3D		Fuel Combustion Activities: Water-borne Navigation	coa, oil, gas, p_c, gdt	wtp
8	1A3E		Fuel Combustion Activities: Other Transportation	coa, oil, gas, p_c, gdt	otp
9	1A4		Fuel Combustion Activities: Other Sectors	coa, oil, gas, p_c, gdt	pdr, wht, gro, v_f, osd, c_b, pfb, ocr, ctl, oap, rmk, wol, frs, fsh, wtr, trd, afs, whs, cmn, ofi, ins, rsa, obs, ros, osg, edu, hht, dwe, HHs[13]
10	1A5		Fuel Combustion Activities: Non-Specified	coa, oil, gas, p_c, gdt	wtr, trd, afs, whs, cmn, ofi, ins, rsa, obs, ros, osg, edu, hht, dwe
11	1B1		Fugitive Emissions from Fuels: Solid Fuels	Output	coa
12	1B2		Fugitive Emissions from Fuels: Oil and Natural Gas	Output	oil, gas, p_c, gdt
13	2B		Industrial processes and product use: chemical Industry	Output	chm
14	2C		Industrial processes and product use: Metal Industry	Output	i_s, nfm
15	2C3		Process emissions of primary aluminium production	Output	nfm

[12] In the case of households, 1A3B emissions are linked to the "p_c" use only.
[13] In the case of households, 1A4 emissions are linked to the use of "coa", "oil", "gas" and "gdt".

No.	IPCC 2006 category code	IPCC 1996 category code	Category description	GTAP emission drivers	GTAP emission agents
16	2C4A		Process emissions of SF6 used in aluminium production	Output	nfm
17	2C4B		Process emissions of SF6 used in magnesium foundries	Output	nfm
18		2E	Byproduct emissions of production of halocarbons and sulphur hexafluoride	Output	chm
19		2F1A	Consumption of halocarbons and sulphur hexafluoride: refrigerator and air conditioning	Output	ele
20		2F2	Consumption of halocarbons and sulphur hexafluoride: foam blowing	Output	chm
21		2F3	Consumption of halocarbons and sulphur hexafluoride: fire extinguishers	Output	chm
22		2F4	Consumption of halocarbons and sulphur hexafluoride: aerosols	Output	chm
23		2F7A	Consumption of halocarbons: semiconductors manufacturing	Output	ele
24		2F7B	Consumption of halocarbons: flat panel display production	Output	ele
25		2F7C	Consumption of halocarbons: photovoltaic cells manufacturing	Output	ele
26		2F8	Consumption of halocarbons: electrical equipment	Output	eeq,
27		2F8B	Consumption of halocarbons: electrical equipment use	Output	eeq,
28		2F9	Other F-gas use and SF6	Output	ele, eeq, ome
29		2F9A	Other F-gas use and SF6: adiabatic prop: shoes and others	Output	lea
30		2F9B	Other F-gas use and SF6: adiabatic prop: tires	Output	rpp
31		2F9C	Other F-gas use and SF6: sound proof windows	Output	rpp
32		2F9D	Other F-gas use and SF6: accelerators	Output	eeq
33		2F9E	Other F-gas use and SF6: AWACS, other military, misc.	Output	eeq
34		2F9F	Other F-gas use and SF6: unknown SF6 use	Output	ele, eeq, ome

No.	IPCC 2006 category code	IPCC 1996 category code	Category description	GTAP emission drivers	GTAP emission agents
35	2G		Other Product Manufacture and Use	chm, bph	ofd, hht
36	3A1		Enteric Fermentation	NA	NA
37	3A2		Manure Management	NA	NA
38	3C1		Emissions from biomass burning	NA	NA
39	3C4		Direct N_2O Emissions from managed soils	NA	NA
40	3C5		Indirect N_2O Emissions from managed soils	NA	NA
41	3C6		Indirect N_2O Emissions from manure management	NA	NA
42	3C7		Rice cultivations	NA	NA
43	4A		Solid Waste Disposal	Output	wtr
44	4B		Biological Treatment of Solid Waste	Output	wtr
45	4C		Incineration and Open Burning of Waste	Output	coa, oil, gas, oxt, cmt, omt, vol, mil, pcr, sgr, ofd, b_t, tex, wap, lea, lum, ppp, p_c, chm, bph, rpp, nmm, i_s, nfm, fmp, ele, eeq, ome, mvh, otn, omf, wtr
46	4D		Wastewater Treatment and Discharge	Output	wtr
47	5A		Indirect N_2O emissions from the atmospheric deposition of nitrogen in NO_x and NH_3	NA	NA
48	5B		Other	Output	coa, oil

Source: Developed by authors based on IPCC (1997), IPCC (2006), JRC/PBL (2011), JRC/PBL (2019).
Note: “NA” corresponds to agricultural emission categories. These emissions are sourced from FAOSTAT dataset (FAO, 2019), therefore we do not process these emission categories from EDGAR dataset.

Appendix E. Emission factors for selected GHGs, g per mmBtu

Fuel type	GTAP sectors	CH_4 factor	N_2O factor
Coal and coke	coa	11	1.6
Natural gas	gas, gdt	1.0	0.1
Petroleum products	p_c, oil	3.0	0.6

Source: US EPA (2018).

Appendix F. Land use GHG emission categories reported in the FAOSTAT database

No.	Emission category (code)	Emission subcategory (code)	Reported GHGs
1.	Forest land (FrsLand)	Forest land (FrsLand)	CO_2
2.	Forest land (FrsLand)	Forest conversion (FrsConv)	CO_2
3.	Cropland (CrpLand)	Cropland organic soils (CrpSoil)	CO_2
4.	Grassland (GrsLand)	Grassland organic soils (GrsSoil)	CO_2
5.	Burning – biomass (BrnBiom)	Humid tropical forest (TropFrs)	N_2O, CH_4
6.	Burning – biomass (BrnBiom)	Other forest (OthFrs)	N_2O, CH_4
7.	Burning – biomass (BrnBiom)	Organic soils (OrgSoil)	CO_2, N_2O, CH_4

Source: FAO (2019).

Appendix G. Comparisons between GTAP 9 non-CO_2 emissions database and GTAP 10a non-CO_2 emissions database

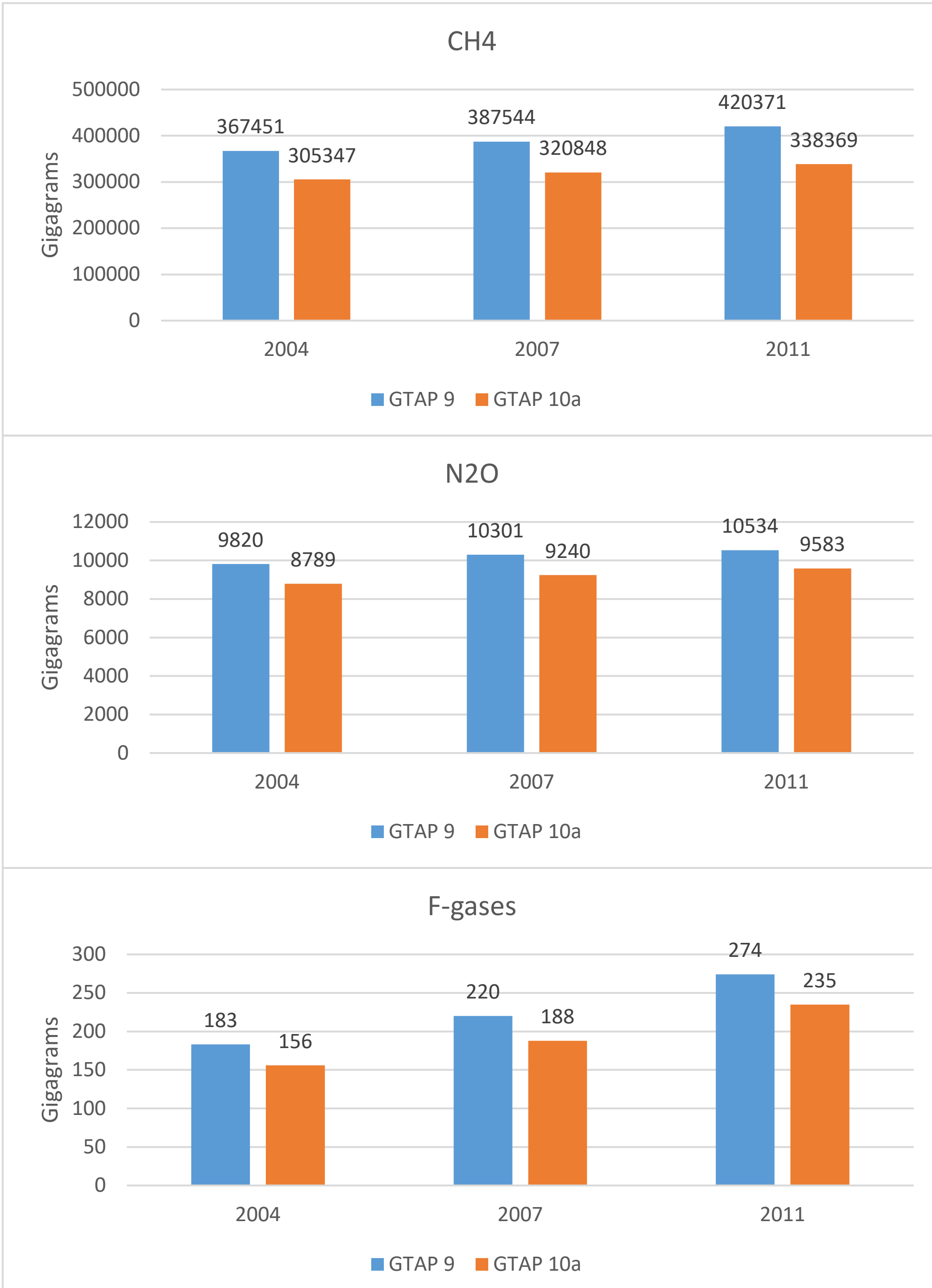

Figure G.1. GHG emissions in GTAP 9 non-CO_2 emissions database and GTAP 10a non-CO_2 emissions database

Source: estimated by authors based on GTAP 10a non-CO_2 database and Irfanoglu and van der Mensbrugghe (2015).
Note: Land use emissions are excluded from the comparison, as they have not been reported in the GTAP 9 non-CO_2 database. To avoid discrepancies driven by differences in applied global warming potentials in GTAP 9 and 10a non-CO_2 databases, emissions are reported in gigagrams.