Chapter 13
Emissions Data Base for GTAP

A CO_2 *Emissions from Fossil Fuels Combustion*

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A.1 Overview

Since GTAP 5 Data Base, a special satellite account that estimates CO_2 emissions from fossil fuel combustion has been developed (Lee 2008).[2] A corresponding approach to the estimation of emissions has remained unchanged since then and relies on the Tier 1 method of the 1996 IPCC Guidelines (IPCC/OECD/IEA 1997). However, a number of concerns regarding discrepancies between GTAP CO_2 emissions data and other international data sources, such as EDGAR and IEA, have been raised. In this paper, we compare GTAP CO_2 emissions data with other international data sources and quantify the revealed discrepancies. To address the identified differences, we develop and implement a revised emissions accounting framework based on the Tier 1 method of the 2006 IPCC Guidelines. Our revised approach includes estimation of emission factors at a more granular commodity level than implemented in the standard GTAP 10A Data Base. Two additional refinements include an updated accounting of emissions from blast furnaces and other recovered gases, as well as a more transparent treatment of CO_2 emissions from flaring. We implement an updated emissions accounting framework for the case of GTAP 11 energy database and show that it helps to substantially reduce discrepancies between GTAP and other international data sources both at the global and country levels.

A.2 Introduction

Since Global Trade Analysis Project (GTAP) 5 Data Base, a special satellite account that estimates CO_2 emissions from fossil fuel combustion has been developed and provided to the users together with the core accounts of the GTAP Data Base (Lee 2008). An originally developed methodology calculates the combustion-based CO_2 emissions from the GTAP energy volume data using Tier 1

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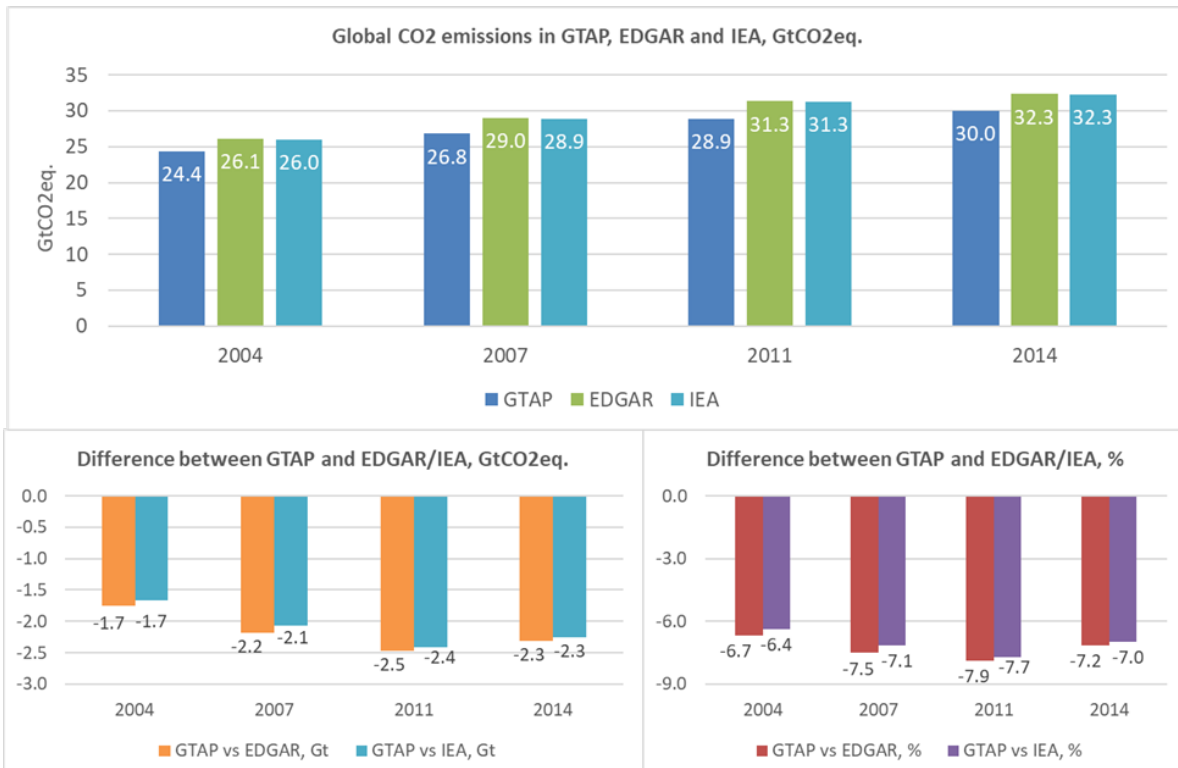
method of the International Panel on Climate Change (IPCC) 1996 Guidelines (IPCC/OECD/IEA 1997). A key motivation behind such approach (compared to an alternative of externally-sourced CO_2 emissions data) was to ensure an internal consistency between underlying GTAP energy volumes data and associated CO_2 emissions (Lee 2008).

While delivering a consistent set of CO_2 emission estimates across countries and sectors, it has been revealed that the applied approach results in a relatively substantial discrepancies between GTAP-based fossil fuel combustion CO_2 emissions and corresponding data from other international data sources. Figure 13.1 provides a comparison between GTAP 10A (Aguiar et al. 2019), EDGAR v5.0 (Crippa et al. 2019) and International Energy Agency (IEA2022) databases at the global level.

Figure 13.1: Comparison of the global fossil fuel combustion CO_2 emissions from different data sources



Notes: Only fossil fuel combustion CO_2 emissions are reported on the figure. For the case of IPPC 2006 classifications from EDGAR v5.0, these correspond to the "1.A" code. For the case of IEA reporting, emissions from non-fossil fuel sources (industrial waste and non-renewable municipal waste) are excluded from reporting. Figures from all data sources include emissions from international aviation and navigation. "$GtCO_2$eq." stands for Gigatons (billion metric tons) of CO_2 equivalent.
Source: Developed by author based on Aguiar et al. 2019, Crippa et al. 2019 and IEA 2022.

As can be seen from the comparison across four reported reference years, while discrepancies between EDGAR and IEA emission estimates are relatively minor (in a range of 0.1 $GtCO_2$eq. or 0.2%-0.4%), GTAP emissions database systematically underestimates global fossil fuel combustion CO_2 emissions relative to these two international data sources. Observed discrepancies show consistent patterns over time and are in a range of 1.7-2.5 $GtCO_2$eq. or 6.4%-7.9%, depending on the database and year choice (figure 13.1). This suggests the presence of a consistent pattern of under-reporting of the fossil fuels combustion CO_2 emissions in the GTAP Data Base at the global level.

In the current update, we attempt to address the identified differences by developing a revised emissions accounting framework based on the Tier 1 method of the 2006 IPCC Guidelines. Our revised approach also includes estimation of emission factors at a more granular commodity level than implemented in the standard GTAP 10A Data Base. Two additional modifications include an updated accounting of emissions from blast furnaces and other recovered gases, as well as a more transparent treatment of CO_2 emissions from flaring. We implement an updated emissions accounting framework for the case of GTAP 11 energy database and show that it helps to substantially reduce discrepancies between GTAP and other international data sources both at the global and country levels.

A.3 Revisions to the fossil fuels combustion CO_2 emissions' accounting framework

To address the discrepancies between GTAP and other international data sources, we introduce three major modifications to the GTAP CO_2 emissions database construction process. In this section we first provide a brief overview of the currently used approach and then describe the introduced updates.

Current approach to estimating fossil fuels combustion CO_2 emissions in GTAP

The approach applied in the earlier versions of the database, including GTAP 10A Data Base (Aguiar et al. 2019), relies on the Tier 1 method from 1996 IPCC Guidelines (Lee 2008). CO_2 emissions from the use of energy commodity i by agent j in region r ($CO_2^{i,j,r}$) are estimated as follows:

$$CO_2^{i,j,r} = (FC_{i,j,r} * CC_i * (1 - CST_{i,j,r}) * EF_i * FOC_i * \frac{44}{12})/1000, \tag{13.1}$$

where $FC_(i,j,r)$ stands for the fuel consumption of energy commodity i by agent j in region r (measured in 1000 tonnes of oil equivalent (toe)); CC_i corresponds to the conversion coefficient for energy commodity i (TJ per 1000 toe); $CST_(i,j,r)$ is a ratio of carbon stored of energy commodity i by agent j in region r; EF_i is an emission factor of energy commodity i (tons of carbon (tC) per TJ); and FOC_i is a fraction of carbon oxidized for energy commodity i.

Tables 13.1 and 13.2 provide values of the corresponding coefficients from equation 13.1 as implemented for the CO_2 emissions accounting in the GTAP 10A Data Base. Fuel consumption volumes ($FC_{i,j,r}$) from equation 13.1 are based on the estimates from GTAP energy database (McDougall and Chepeliev 2021).

Table 13.1: Values for selected coefficients from equation 13.1 used for estimating CO_2 emissions in GTAP 10A Data Base

Energy commodity	Conversion coefficient (CC), TJ/1000 toe	Emission factor (EF), tC/TJ	Fraction of carbon oxidized (FOC)[a]
Coal	41.868	25.80	0.980
Crude oil	41.868	20.00	0.990
Natural gas	41.868	15.30	0.950*
Petroleum products	41.868	19.00	0.990
Liquefied petroleum gas	41.868	17.20	0.995

Notes: * in the original IPCC 1996 guidelines the value of FOC for natural gas is 0.995. A processing error in the GTAP implementation led to the application of the 0.95 value (this implies to all GTAP 10A reference years).
Source: developed by author based on Aguiar et al. 2019 and Lee 2008.

[a] In the 2006 IPCC guidelines, this is referred to as "carbon oxidization factor" (IEA 2019).

Table 13.2: Value for the ratio of carbon stored coefficient from equation 13.1 used for estimating CO_2 emissions in GTAP 10A Data Base

Mode of use	CST value
Energy consumption	0.0
Transformation	1.0
Own use	0.0
Non-energy consumption	1.0

Notes: In the original implementation (Lee 2008), CST coefficient included country-specific shares of energy commodities used as a feedstock in the petrochemical industry. Currently used IEA's extended energy balances (IEA 2021) report volumes of non-energy use across sectors as a separate category, thus this aspect (feedstock use) is explicitly captured in the used energy balances.
Source: developed by author based on Aguiar et al. 2019.

Transitioning from 1996 to 2006 IPCC Guidelines

As a first methodological update in GTAP 11, we implement an emissions accounting framework based on the Tier 1 methodology from 2006 IPCC Guidelines (IEA 2019). For estimating emissions, we still rely on equation 13.1, but update values of the coefficients used to estimate emission volumes, as well as apply values of the corresponding coefficients at a more granular commodity level.

First, following the 2006 IPCC Guidelines, we update the carbon content values (EF_i).[3] Carbon content represents a quantity of carbon per unit of energy for a given fuel (IEA 2019). Some of the carbon content values have been revised in the 2006 IPCC Guidelines compared to the 1996 revision. One of the specific features introduced in the 2006 IPCC Guidelines is a provision of default carbon content value for each commodity, as well as lower and upper limits corresponding to the 95 percent confidence intervals. In the current update we rely on the default values from the 2006 IPCC Guidelines.

Differences in the updated carbon content values range between -13.7 percent for refinery gas to +7.3 percent for blast furnace gas (Table 13.3). For many commodities, however, the value remained unchanged. At the same time, in the current update, we not only implement the 2006 IPCC values for the carbon content, but also specify them at the disaggregate commodity level – individually for all 42 commodities identified in the GTAP energy database (McDougall and Chepeliev 2021).

Table 13.3: Comparison of carbon content values

Fuel Type	GTAP 10A value, kg/GJ	1996 Guidelines, kg/GJ	2006 Guidelines, kg/GJ	Percent Change (2006 vs 1996 Guidelines)
Anthracite	25.8	26.8	26.8	0%
Coking Coal	25.8	25.8	25.8	0%
Other Bituminous Coal	25.8	25.8	25.8	0%
Sub-Bituminous Coal	25.8	26.2	26.2	0%
Lignite	25.8	27.6	27.6	0%
Patent Fuel	25.8	25.8	26.6	3.1%
Coke oven coke	19	29.5	29.2	-1%
Gas Coke	19	29.5	29.2	-1%
Coal Tar	19	..	22	x
BKB	25.8	25.8	26.6	3.1%
Gas Works Gas	15.3	..	12.1	x
Coke Oven Gas	19	13	12.1	-6.9%
Blast Furnace Gas	0	66	70.8	7.3%
Other recovered gases	0	..	49.6	x
Peat	25.8	28.9	28.9	0%
Oil shale	20	29.1	29.1	0%

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[3] In the 1996 IPCC Guidelines carbon content is referred to as the carbon emission factor.

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Fuel Type	GTAP 10A value, kg/GJ	1996 Guidelines, kg/GJ	2006 Guidelines, kg/GJ	Percent Change (2006 vs 1996 Guidelines)
Natural Gas	15.3	15.3	15.3	0%
Crude Oil	20	20	20	0%
Natural Gas Liquids	15.3	17.2	17.5	1.7%
Refinery Feedstocks	19	20	20	0%
Orimulsion	x	22	21	-4.5%
Refinery Gas	19	18.2	15.7	-13.7%
Ethane	19	16.8	16.8	0%
Liquefied petroleum gases (LPG)	19	17.2	17.2	0%
Motor Gasoline excl. biofuels	19	18.9	18.9	0%
Aviation Gasoline	19	18.9	19.1	1.1%
Gasoline type jet fuel	19	18.9	19.1	1.1%
Kerosene type jet fuel excl. bio	19	19.5	19.5	0%
Other Kerosene	19	19.6	19.6	0%
Gas/Diesel Oil excl. biofuels	19	20.2	20.2	0%
Fuel Oil	19	21.1	21.1	0%
Naphtha	19	20	20	0%
Lubricants	19	20	20	0%
Bitumen	19	22	22	0%
Petroleum Coke	19	27.5	26.6	-3.3%
Non-specified oil products	19	20	20	0%
Other hydrocarbons	19	20	20	0%
White Spirit & SBP	19	20	20	0%
Paraffin Waxes	19	20	20	0%

Notes: In addition to central values (reported in the table), 2006 IPCC guidelines also report the lower and upper limits of 95 percent confidence intervals, assuming lognormal distribution. In the 1996 IPCC Guidelines carbon content is referred to as the carbon emission factor. In the case of GTAP 10A Data Base, emission factors are defined at an aggregate commodity level (Table A.1), therefore are uniform across the subsets of disaggregated commodities energy that belong to the same aggregate commodity. For the cases of blast furnace gas and recovered gases, the GTAP 10A carbon content value is assumed to be "0" to reflect the point that the energy flows of these commodities are discarded in the GTAP energy database.
Source: developed by author based on Aguiar et al. 2019, Lee 2008 and IEA 2019.

In the GTAP 10A implementation (Aguiar et al. 2019; Lee 2008), emission factors were identified at an aggregate commodity level – for five broad energy commodity groups (Table 13.1) – and thus such treatment did not account for a country/region-specific energy mix within each commodity category. Since, for instance, gasoline, kerosene, jet fuel, diesel, etc. use within an aggregate petroleum products category varies across countries/regions, consideration of the commodity-specific emission factors provides a more consistent approach to estimating CO_2 emissions.

A small portion of the carbon contained in the energy commodity is not oxidized within the combustion process (in general, around 1-2 percent) (IEA 2019). To account for this fact, 1996 IPCC Guidelines suggested to subtract this amount from the volume of combusted fuel using a specific share – FOC_i coefficient in equation 13.1 – with the corresponding values represented in

Table 13.2. However, considering that in most cases, emissions inventory compilers have no "real" information as to whether such correction was actually applied, 2006 IPCC Guidelines suggest to use the default value of 1 for all fuels. Such update results in the increasing volume of CO_2 emissions (relative to the 1996 IPCC Guidelines) – by 0.5-2 percent depending on fuel type.

Accounting for emissions from blast furnace gas and other recovered gases

In the process of the GTAP energy database construction, a special treatment is applied to selected commodities. In particular, to avoid recognizing energy production by industries that predominantly produce non-energy goods (e.g. blast furnace gas production by ferrous metals industry), some energy commodity flows are re-classified or discarded (McDougall and Chepeliev 2021). Two particular examples of such commodities include blast furnace gas and other recovered gases – both to a large extent being by-products of the metals industry and also being self-consumed (though a substantial share of blast furnace gas is also used in the electricity and heat generation). In the GTAP energy database construction process, to avoid the conversion of iron and steel sector into an energy supplying industry, corresponding energy volume flows (of blast furnace gas and other recovered gases) are discarded.

At the aggregate level, these flows represent a relatively small share of energy supply – global average share is under 1 percent. At the same time, combustion of the corresponding energy commodities is largely concentrated in two sectors – ferrous metals and electricity generation – thus the impacts of discarding these energy flows are very sector-concentrated. In addition, compared to other energy sources, blast furnace gas and other recovered gases have much higher carbon content values – around 2-3 times higher than coking coal (Table 13.3). Thus, discarding corresponding energy flows reduces global CO_2 emission in a range of 2 percent. To take into account corresponding emissions, we revise the treatment of energy flows within the GTAP energy database (Chapter 12) and introduce corresponding emission factors for blast furnace gas and other recovered gases based on values reported in Table 13.3.

CO_2 emissions from flaring

Flaring emissions in the IPCC accounting framework are included to the fugitive emissions category and thus are separated from the fuel combustion activities (IPCC 2008). In the IEA's extended energy balances, energy flows that are flared are also not reported (IEA 2021). In the GTAP energy database construction process, however, additional energy flows that correspond to flaring are introduced. As a result, previous versions of the GTAP CO_2 emissions data accounts for flaring emissions as part of the fossil fuel combustion emissions. At the same time, flaring-related energy flows introduced in GTAP are based on historical estimates and are different from country-specific flaring data reported by other international data sources (e.g. CEC 2021). In the current update, we discard the energy flows associated with flaring from the GTAP energy database, to be consistent with the IEA energy balance accounting as well as IPCC definition of the fossil fuel combustion emissions. For the consistency of greenhouse gas (GHG) emissions accounting within the overall GTAP emissions framework, corresponding flaring emissions are included to the complementary GHG emissions database together with fugitive and process emissions (Chapter 13B). Such treatment would assure that flaring-related energy and emission flows are aligned with the corresponding estimates form international data sources. This would also provide an explicit separation between fuel combustion and non-combustion emissions in consistence with an IPCC reporting framework (IPCC 2008).

A.4 Overview of the updated fossil fuels combustion CO_2 emission estimates

Comparisons at the global level

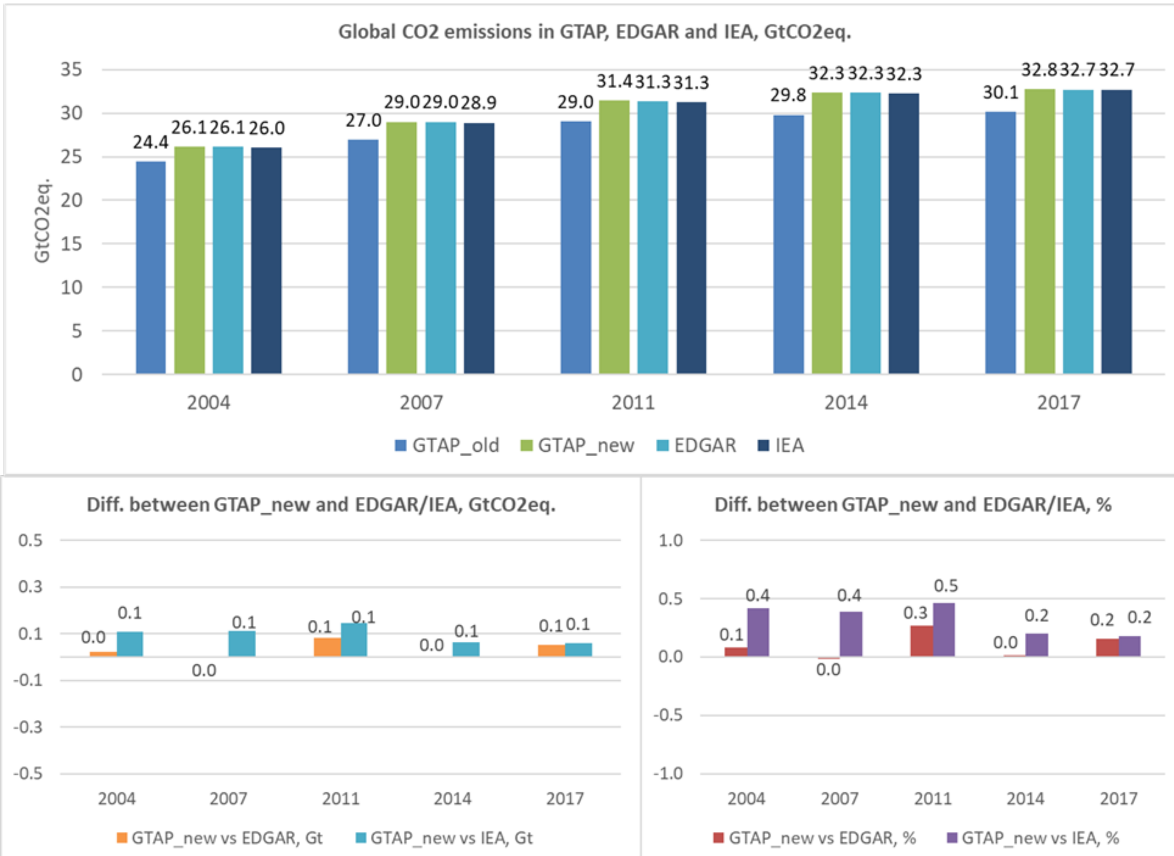
A revised CO_2 emissions accounting framework is applied to the GTAP 11 energy database, which covers five reference years – 2004, 2007, 2011, 2014 and 2017. Within the GTAP energy database construction process, IEA's extended energy balances are gap-filled and preprocessed first, then they are mapped to a more aggregate GTAP categories followed by additional reconciliations and adjustments (Chapter 12). For the emissions estimation process implemented in this paper, we rely on the energy balances obtained after the first step described above, i.e.,pre-processed and gap-filled, but not yet aggregated. This allows for a more transparent comparison between obtained emission estimates from GTAP and other international data sources at a sectoral and country level. For instance, within an aggregation process in GTAP, energy flows and emissions from international aviation and navigation activities are distributed across countries, while in the EDGAR and IEA databases these emission categories are treated separately. Figure 13.2 below provides a comparison of global CO_2 emissions between IEA, EDGAR and GTAP. For the case of GTAP, two estimation approaches are reported: "GTAP_old" estimates follow a method used in GTAP 10A Data Base, while "GTAP_new" estimates are based on the approach discussed in this document and applied to GTAP 11.

Implementation of the proposed updates substantially reduces the discrepancies between GTAP, IEA and EDGAR. At the global level differences do not exceed 0.1 $GtCO_2eq.$ or 0.5 percent across all analyzed years (Figure 13.2), which is comparable to the level of differences observed between IEA and EDGAR. For the case of 2017 year, discrepancies between revised GTAP emission estimates and both IEA and EDGAR are under 0.2%.

Country-level comparisons

At the country level, an updated CO_2 emissions accounting also leads to the substantial reduction in discrepancies between GTAP and both IEA and EDGAR (Figure 13.3). Focusing on the top 20 global emitters, under "GTAP_old" approach mean of the absolute deviations from EDGAR is 7.5 percent, while for the case of IEA it is 6.8 percent. Under the "GTAP_new" approach, corresponding numbers reduce to 2.7 percent and 0.8 percent respectively. When comparing across countries, "GTAP_new" estimates are especially close to the IEA CO_2 emissions, as the deviation for any country among top 20 emitters is under 4 percent, while for the case of top 10 emitters the difference does not exceed 1.5 percent. These comparisons suggest that the implemented CO_2

Figure 13.2: Comparison of the global fossil fuel combustion CO_2 emissions from different data sources and emission estimation approaches



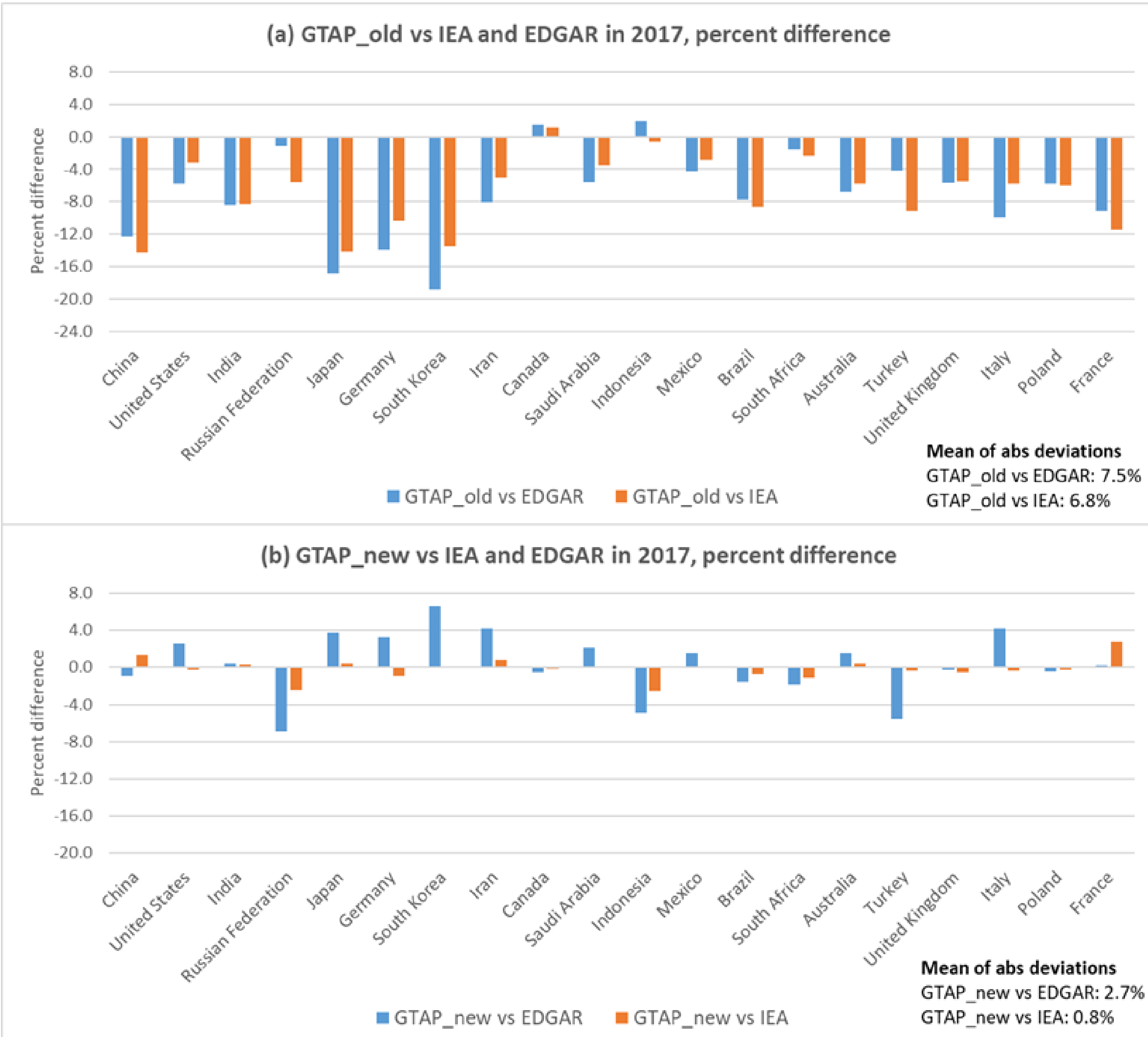
Notes: Only fossil fuel combustion CO_2 emissions are reported on the figure. For the case of IPPC 2006 classifications from EDGAR v5.0, these correspond to the "1.A" code. For the case of IEA reporting, emissions from non-fossil fuel sources (industrial waste and non-renewable municipal waste) are excluded from reporting. Figures from all data sources include emissions from international aviation and navigation. "GtCO_2eq." stands for Gigatons (billion metric tons) of CO_2 equivalent. For the case of GTAP, emission estimates are based on the GTAP 11 energy database. "GTAP_old" label corresponds to the emissions' estimation approach applied in GTAP 10A. "GTAP_new" label corresponds to the emissions' estimation approach proposed in this study.
Source: Developed by author based on revised GTAP energy database, Crippa et al. 2019 and IEA 2022.

emissions accounting framework helps to address the systematic under-reporting in the GTAP emissions database and substantially reduces discrepancies with other international data sources.

A.5 Summary and conclusions

Addressing the identified discrepancies in fuel combustion CO_2 emissions between GTAP and other international data sources, we have implemented three major updates to the GTAP 11 fossil fuels combustion CO_2 emissions accounting framework. First, a revised emissions accounting framework based on the Tier 1 method of the 2006 IPCC Guidelines has been introduced. The

Figure 13.3: Comparison of the fossil fuel combustion CO_2 emissions across different data sources and emission estimation approaches for top 20 emitters in 2017, percent difference



Source: Developed by author based on revised GTAP energy database, Crippa et al. 2019 and IEA 2022.

updated approach also includes estimation of emission factors at a more granular commodity level than implemented in the GTAP 10A Data Base. Second, an updated accounting of emissions from blast furnaces and other recovered gases has been incorporated. Finally, a more transparent treatment of CO_2 emissions from flaring that includes their reclassification with fugitive emissions was implemented. These updates helped to reduce differences (GTAP vs IEA and EDGAR) in the estimates of global fossil fuels combustion CO_2 emissions for 2017 reference year from over 8 percent (in the case of the standard GTAP 10A approach) to less than 0.2 percent under the updated treatment. Country-specific differences are also reduced substantially.

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