GTAP-Power 10a Database: a Technical Note

By

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Abstract

The purpose of this note is to document changes introduced to the GTAP-Power 10a database construction process in addition to the GTAP-Power build approach developed in Peters (2016). First, in Peters (2016) output of the electricity and heat generation sector in GTAP was split using electricity generation data only. We use heat generation volumes to provide a more representative sectoral split and better concordance with GTAP sectoral definitions. Second, we introduce data on country and year-specific shares of transformation and distribution costs in electricity tariff for 80 countries. Finally, for every reference year, we update the levelized cost of electricity generation.

JEL classification: C61, D57, D58, L94, Q40.

Keywords: GTAP; GTAP-Power; Computable general equilibrium; Disaggregation.

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1. Treatment of the co-generation

In the GTAP 10a database, electricity sector ("ely") includes both electricity and heat generation (Aguiar et al., 2019). This sector combines heat and power plants (CHP), public heat plants, autoproducer heat plants, heat pumps, and CHP and heat plants (McDougall and Chepeliev, 2019).[2] For selected countries, mostly in Eastern and Northern Europe, share of the heat generation in aggregate electricity and heat production represents over 30%, while world average share is around 13% (Figure 1).

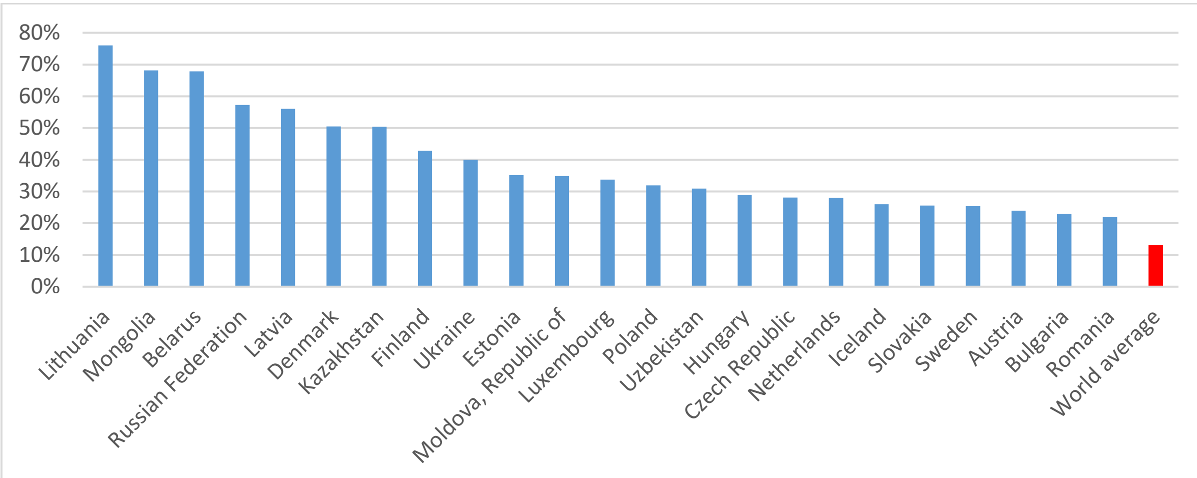

Figure 1. Share of heat generation in aggregate electricity and heat production by selected countries in 2014, %
Source: IEA (2015).

At the global level, 85% of heat is produced by coal and gas power plants (Figure 2). Though, in a small number of countries, 'Other base load' generation represents the largest share. For instance, this is the case of Switzerland, Norway, Iceland, Brazil and Chile. In the GTAP-Power 9a database construction process (Peters, 2016), output of the electricity and heat generation sector in GTAP was split using electricity generation data only. Overall, such approach did not have a significant impact on the representation of the GTAP 'ely' sector generation mix. At the same time, for some countries with high shares of heat generation (Figure 1), such assumptions might have led to substantial misrepresentation of the generation mix. In general, it would lead to the underrepresentation of the gas and oil generation and overrepresentation of other generation activities, in particular, hydro, solar, wind and nuclear - technologies that have a low share of heat generation.

[2] This information is retrieved from the International Energy Agency (IEA). For additional information, please refer to McDougall and Chepeliev (2019).

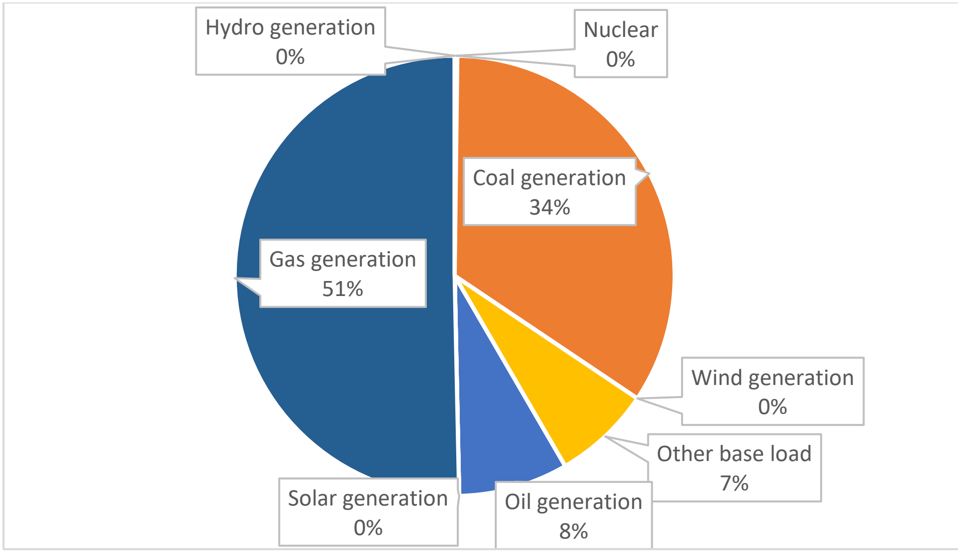

Figure 2. World average shares of heat generation by technologies
Source: IEA (2015).

Therefore, one of the steps introduced in the updated GTAP-Power build includes reliance on the heat generation data by countries and technologies in addition to the electricity generation data. Extended energy balances from International Energy Agency (IEA) are used to derive these data (2015a; 2015b). Such data are collected and processed for all four GTAP 10a reference years (2004, 2007, 2011 and 2014). For mapping of the heat generation volumes to the GTAP-Power sectoral classification, we use mappings developed in Peters (2016) and aggregate electricity and heat generation volumes for further processing.

2. Transmission and distribution costs

In the previous release of the GTAP-Power database (Peters, 2016), a uniform transmission and distribution share in the total non-tax value of the electricity and heat generation was used for all regions. This share was assumed to be 21%, based on the data for United States (EIA, 2013). In reality, transmission and distribution shares largely vary between countries, depending on electricity grid structure, population density, electricity market model and other factors. In this update of the GTAP-Power release, we introduce transmission and distribution shares for 80 countries, which correspond to 65 GTAP regions.[3] In addition to the United States (EIA, 2013; EIA, 2018), transmission and distribution costs data cover African countries (Trimble et al., 2016), EU countries (Eurostat, 2019a) and a number of other countries discussed below. Upon data availability, year-specific transmission and distribution shares are estimated with mapping to the closest GTAP reference year.[4]

In the case of EU countries, Eurostat (2019a) reports shares of transmission and distribution costs in electricity price for household and non-household consumers, as well as for different consumption bands for both types of users. For households, we assume that a representative band

[3] See Appendix A for corresponding regional mapping.
[4] See Appendix A for data availability by years. For instance, in the case of Belgium, we map 2007 data to 2004 and 2007 reference years, 2011 to 2011 and 2014 to 2014.

is the group with annual electricity consumption between 2500 KWh and 4999 KWh.[5] For non-household consumers, we take a representative band with 500-1999 MWh of annual electricity consumption.[6] In addition, for both household and non-household users, Eurostat (2019a) reports data for the second part of each year, covering the 2007 to 2016 period.[7] First, we subtract the share of transmission and distribution-related losses from the transmission and distribution tariff based on the data provided in ENTSO-E (2017). We then estimate a weighted average share of transmission and distribution costs by household and non-household consumers. GTAP electricity and heat consumption volumes for household and non-household users are applied for weighting transmissions and distribution shares.

Transmission and distribution shares for six additional countries are estimated based on country-specific data sources.[8] In case of Ukraine, data for residential consumers are sourced from NERC (2015) and corresponds to the January 2015 tariff structure. Non-residential consumers data are sourced from NERC (2014) and is available for the 2009-2013 timeframe at an annual basis. Weighting of residential and non-residential transmission and distribution cost shares is performed using GTAP electricity and heat consumption volumes. For China, transmission and distribution shares are based on He et al. (2015). Transmission and distribution shares for Bhutan and Nepal are sourced from Siyambalapitiya (2018). In case of Nepal, further adjustment for losses is made using ADB (2010). In case of Russia, transmission and distribution share is sourced from EY (2018) and adjustments for electricity losses are based on WB (2019). Finally, data for Brazil are sourced from NEEA (2008).

Appendix A provides estimates of the shares of transmission and distribution in the total non-tax value of electricity output for selected countries, as well as data availability by years. For other countries and regions, not covered in Appendix A, year-specific shares[9] are estimated using GTAP electricity and heat generation volumes.

Figure 3 shows the shares of transmission and distribution in the total non-tax value of electricity output by countries in 2014.[10] These shares highly vary by countries – from as low as 4% in Seychelles to as high as 56% in Lesotho, with a global weighted average share of around 25.4%.

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[5] This is the most representative band according to EUROSTAT (2019b), as most residential consumers fall into this band.

[6] This is the most representative band for the EU non-household electricity consumers according to EUROSTAT (2019c).

[7] Starting from 2017 Eurostat is reporting annual average prices.

[8] These countries include Ukraine, China, Bhutan, Nepal, Russia and Brazil.

[9] These are weighted average shares.

[10] For several countries, we do not have 2014 data, in this case we use the closest available year. See Appendix A for data availability by years.

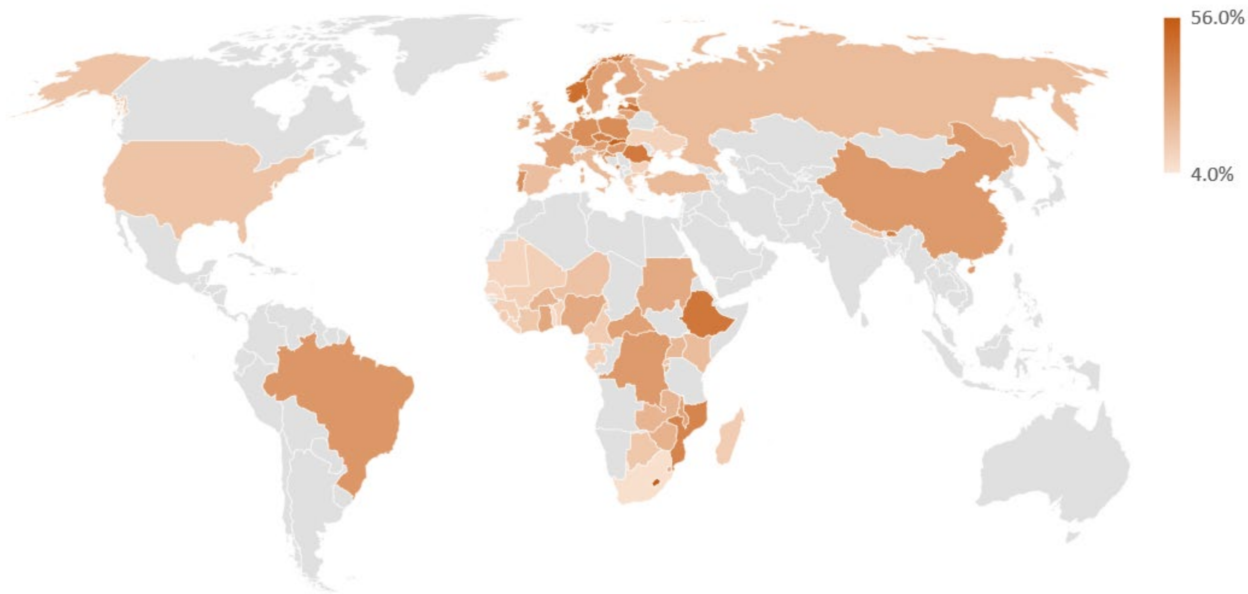

Figure 3. Shares of transmission and distribution in the total non-tax value of electricity output by countries in 2014 (or closest available year)

Source: Developed by author using EIA (2013), EIA (2018), Trimble et al. (2016), Eurostat (2019), ENTSO-E (2017), NERC (2015), NERC (2014), He et al. (2015), Siyambalapitiya (2018), ADB (2010), EY (2018), WB (2019) and NEEA (2008).

Note: Countries colored in grey do not have available data.

3. Levelized cost of electricity

To estimate the levelized cost of electricity (LCOE) for each cost type (i.e. investment, O&M, fuel, own-use, and effective tax), for each new sector (e.g., nuclear base load, hydro base load, coal base load, etc.) and region, GTAP-Power 9 database relied on the IEA/NEA (2010) (Peters, 2016). For the GTAP-Power 10a update, we use IEA/NEA (2010) to estimate LCOE for 2004, 2007 and 2011 reference years, while IEA/NEA (2015) is used to derive the LCOE for the 2014 reference year. As in the GTAP-Power 10a update we add heat generation to the targeted volumes of the GTAP 'ely' sector split, the LCOE of corresponding technologies are added to the set of levelized costs. Appendix B provides the mapping between IEA generation technologies identified in IEA/NEA (2015) and GTAP-Power sectors. It also identifies countries, where corresponding technologies are reported by IEA/NEA (2015).

IEA/NEA (2010) and IEA/NEA (2015) have a different country coverage. In particular, there are five countries reported in IEA/NEA (2010) that are not reported in IEA/NEA (2015): Canada, Mexico, Czech Republic, Sweden, Russia. On the other hand, IEA/NEA (2015) reports Denmark, Finland, New Zealand, Portugal, Spain and United Kingdom, which are not identified in IEA/NEA (2010). If the LCOE for a given country is reported by only one of the IEA/NEA reports, then this is used to derive the LCOEs for all reference years. To convert reported costs to the USD of the corresponding GTAP reference year, we use the US consumer price index (CPI). In cases, when several IEA technologies reported for a single country are mapped to the same GTAP-Power sector, a simple average of the corresponding cost components is estimated.

4. Comparisons for the GTAP-Power 9a database

Before moving to the overview of the GTAP-Power 10a database, we use updated data inputs (Sections 1-3 above) to produce a new GTAP-Power database for 2011 reference year and compare it against the GTAP-Power 9a database constructed by Peters (2016). In this way, we can better capture the impact of the updated data inputs and procedures, without interactions with other input data modifications (e.g. change in reference year, sectoral classification, etc.).

Introducing heat generation data to the GTAP-Power build changes the shares of electricity and heat generation technologies at the global level. As most heat generation is associated with gas base load generation (called "GasBL" in the database), the share of this technology at the global level increases by 4.6% (Figure 4). Another technology widely used for heat generation is oil peak generation ("OilP"), with corresponding global share increase by 1.6%. All other generation technologies experience moderate reductions (between 0.3% and 1.8%) or no significant changes (less than 0.1%) in the global electricity and heat generation mix (Figure 4). In general, global share of non-fossil fuel generation technologies (NuclearBL, WindBL, HydroBL, OtherBL, SolarP) reduces from 32% (in the v9a with initial inputs) to 26.9% (in the v9a with updated inputs). Indirectly, this also reduces carbon intensity of the fossil fuel generation technologies.

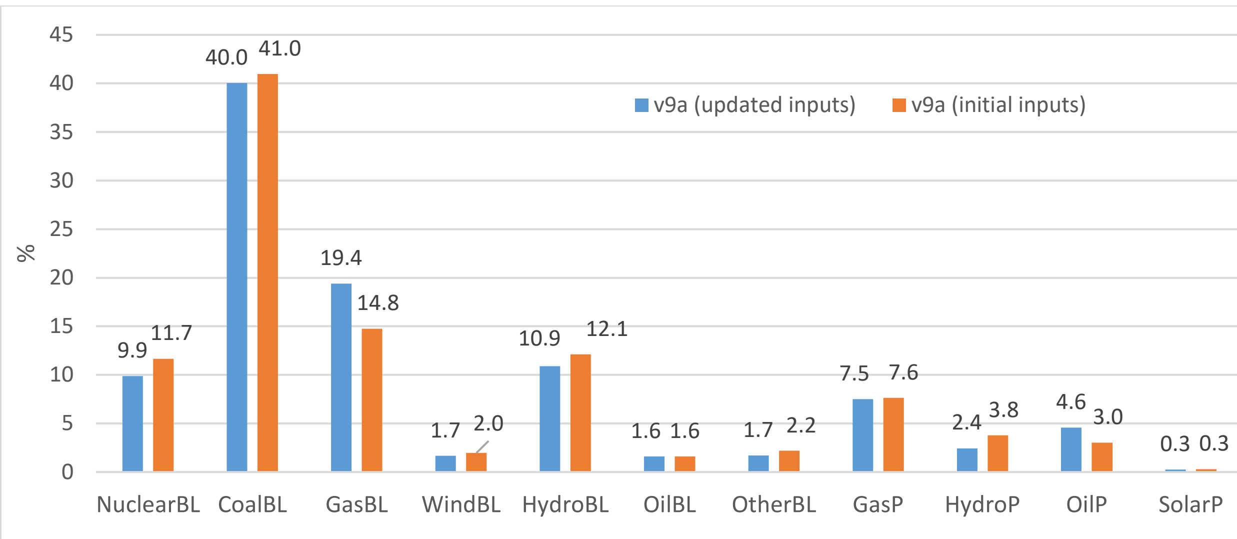

Figure 4. Shares of global electricity and heat generation from different technologies reported in GTAP-Power 9a for 2011 reference year under different input data assumptions, %

Source: GTAP-Power Data Base, erp.har, header: GWHR.

Note: "v9a (updated inputs)" corresponds to the database developed in this note; "v9a (initial inputs)" corresponds to the database developed in Peters (2016). In Peters (2016) only electricity generation is reported in the "GWHR" header.

Much larger relative changes are observed at the regional level, especially for countries with large shares of heat generation in aggregate electricity and heat production (Figure 5). For instance, in the case of gas base load generation, a number of countries experience at least 20% increase in corresponding shares – these include mostly Northern and Eastern European countries. Somewhat lower increases are observed for the oil peak generation share – between 8% and 15% for top 10 regions with the largest change (Figure 5). Most Eastern European countries experience large reductions in nuclear generation shares, reaching over 20% in the case of Ukraine. Hydro generation (both peak and base load) shows a more uniform reduction patterns around the world, with Asian, European and African countries among the top 10 impacted regions (Figure 5).

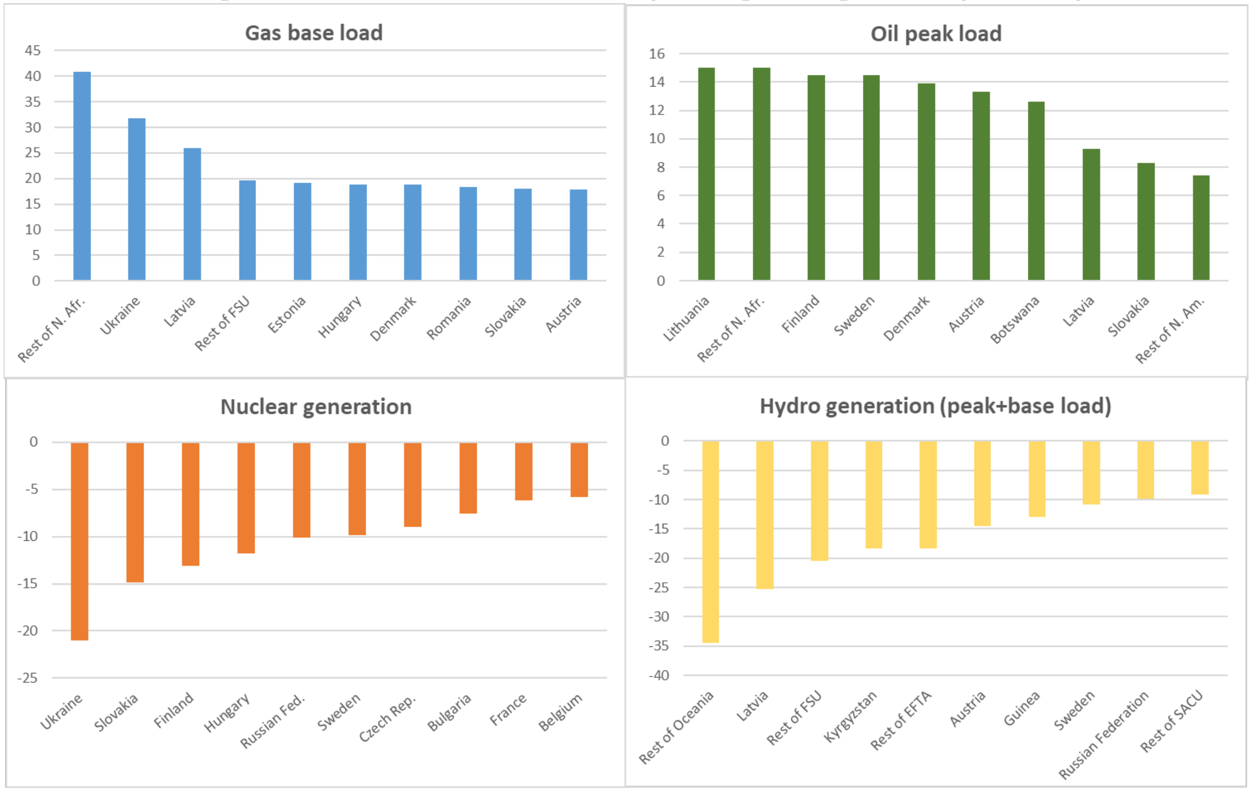

Figure 5. Change in shares of electricity and heat generation by technologies and regions for 2011 (new GTAP-Power vs original GTAP-Power)

Source: Estimates by author.

Note: Top 10 regions with the largest changes in shares are reported for each technology. Comparisons are based on GTAP-Power v9a.

One of the issues identified in the GTAP-Power 9a database and reported by Larry Liu, included an unusually large input of petroleum products ("p_c") to the Electricity transmission and distribution sector ("TnD") in Russia. In particular, the volume of petroleum products used by "TnD" in Russia in 2011 was even larger than "p_c" inputs to the oil peak generation. Using updated data inputs in the new version addresses this issue for all reference years.

Appendix C reports comparisons between GTAP-Power database constructed by Peters (2016) and the new version. The comparison method ranks the differences between the two datasets, in decreasing order, by showing large changes in large values first. The entropy measure is a product of absolute and relative difference (in logarithms).

According to the comparison (Appendix C), the largest change is associated with the reduction of "p_c" use in the "TnD" sector in Russia (as previously discussed). This is followed by an increase in "GasBL" output in Ukraine due to the introduction of heat generation and reduction in "TnD" output in Russia due to the use of country-specific transmission and distribution shares. Other large changes include reductions in hydro peak and base load generation and changes (either increase of decrease) in the transmission and distribution sector output.

There are number of other changes identified by the comparison, indirectly linked the input data updates (e.g. inclusion of the heat generation to the LCOE estimates). These include an increase in the "OilBL" generation in Japan – from less than 1% of the total oil-based generation (in the original GTAP-Power) to around 12.5% in the new GTAP-Power. As neither IEA nor EIA data provide the split between base and peak load, such mix is decided based on initial assumption and costs by generation technologies (Peters, 2016). Another case with relatively large difference between two databases includes change in the "p_c" used by "CoalBL" in China. In the case of the new GTAP-Power, "CoalBL" consumes almost exclusively coal, while relatively larger volume of "p_c" goes to the oil-based power and heat generation.

5. Overview of the GTAP-Power 10a database

Using data inputs described in Sections 1-3 and methodological approach developed in Peters (2016), we construct the GTAP-Power 10a database for all four reference years – 2004, 2007, 2011 and 2014 of the GTAP 10a database (Aguiar et al., 2019).[11] In this Section, we provide a brief overview of the GTAP-Power 10a database and showcase an application that tracks CO_2 emissions embodied into the final consumption of electricity focusing on the 2014 reference year.

Looking into the generation mix at the global level, coal and gas power generation contribute almost 66% of total electricity and heat generation (Figure 6). Renewable energy sources (wind, solar, hydro and other base load) contribute around 19.3%, with hydro accounting for almost three quarters of the latter. Electricity and heat generation mix highly varies across countries (Figure 7). For instance, in Brazil over 63% of total electricity and heat generation is coming from hydro, while in South Africa 93% is coal-based. Costs of power and heat generation also significantly differ by countries and technologies. Introduction of the country-specific transmission and distribution costs increased this variation relative to the GTAP-Power 9a database (Peters, 2016).

[11] GTAP 10 being one of the core data inputs.

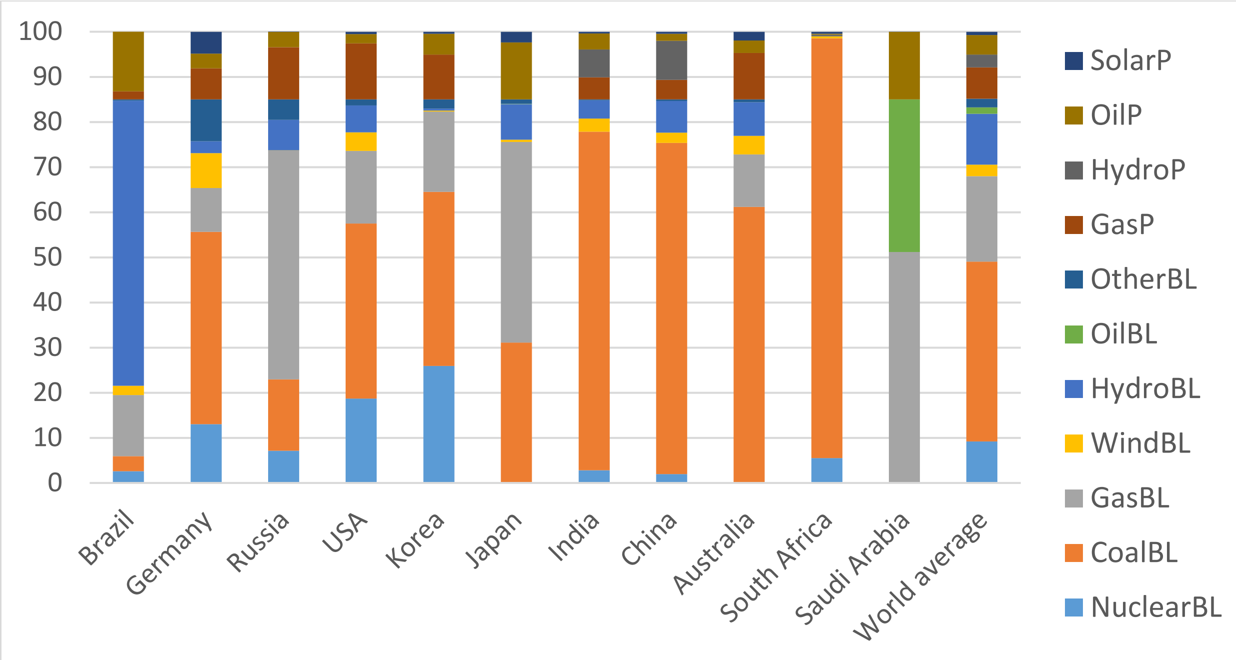

Figure 6. Shares of electricity and heat generation by technologies and selected countries in 2014, %

Source: GTAP-Power 10a database.

There are other aspects of the GTAP-Power database that can be highlighted. We focus on CO_2 emissions embodied into final consumption of electricity generated by different technologies. Following Peters (2008), CO_2 emissions per unit of output by countries and industries are used to estimate emissions associated with final consumption. 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). For every commodity, the total CO_2 emissions associated with fossil-fuels combustion and embodied into final consumption in region r (f_r) are estimated as

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

where F_r is a vector of country-specific CO_2 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 c_r corresponds to the final consumption.

At the global level, around 3.3 Gt of CO_2 emissions are embodied into final domestic electricity consumption by households, which constitutes 11% of the global CO_2 emissions from fossil fuel combustion. Coal generation is by far the largest contributor (Figure 7), with the global share of almost 64% in CO_2 emissions embodied into final domestic electricity consumption by households. Gas-based electricity and heat generation (both base and peak load) accounts for 26.7% of CO_2 emissions embodied into final domestic electricity consumption.

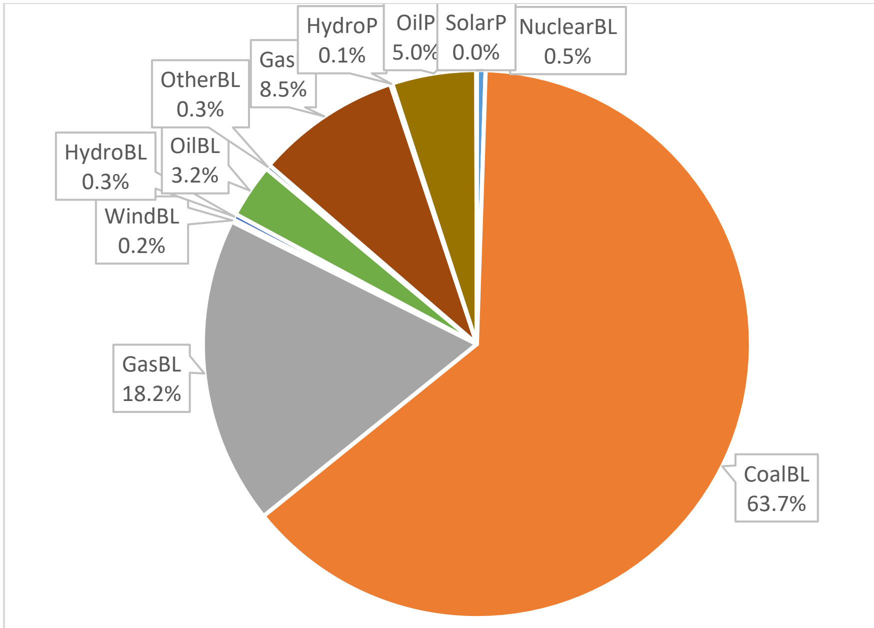

Figure 7. Distribution of the global CO_2 emissions embodied into the final consumption of electricity and heat in 2014 by generation technologies, %

Source: Authors' estimates based on the GTAP-Power 10a database.

In terms of emission intensities, coal generation is by far the dirtiest technology, followed by oil base load generation and gas peak load generation (Figure 8). Hydro base load is the cleanest technology, emitting around 1% of coal base load generation per Kwh of generated electricity.

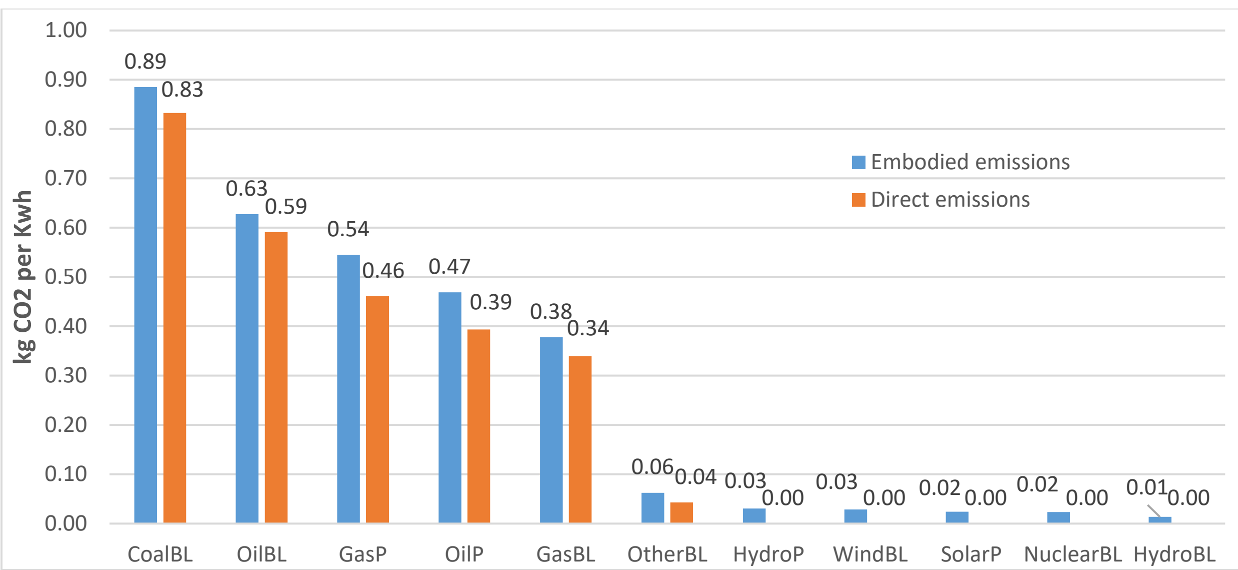

Figure 8. Global average intensities of the CO_2 emissions embodied into the final consumption of domestic electricity and heat in 2014 by generation technologies, kg CO_2 per Kwh

Source: Author's estimate based on the GTAP-Power 10a database.

When we consider direct emissions from fossil fuel combustion only, all renewable generation technologies are carbon neutral (Figure 8), while when we account for the CO_2 emissions embodied into electricity production through the entire value chain, renewable technologies turn to produce between 10 and 30 grams of CO_2 emissions per Kwh of generated electricity. Inclusion of the embodied emissions into the estimates also increases carbon intensity of the fossil fuel-based electricity and heat generation (Figure 8). In the cases of gas and oil peak load generation carbon intensities increase by 18%-19%.

Finally, there is a high variation in intensities of the CO_2 emissions embodied into the final consumption of electricity and heat by countries. For instance, in the case of coal base load generation, CO_2 emissions embodied into the final consumption of domestic electricity and heat vary between less than 0.5 kg per Kwh (e.g. in Estonia, Finland, Sweden) to over 1.5 kg per Kwh (in Zimbabwe, Botswana and the Rest of Central Africa). While in many cases, carbon intensity of the domestic coal-based electricity consumed by households is lower in the developed countries than in the transition economies, it is not the general case. For instance, China's coal generation is less carbon intensive than the one in Australia, Canada and the United States (Figure 9).

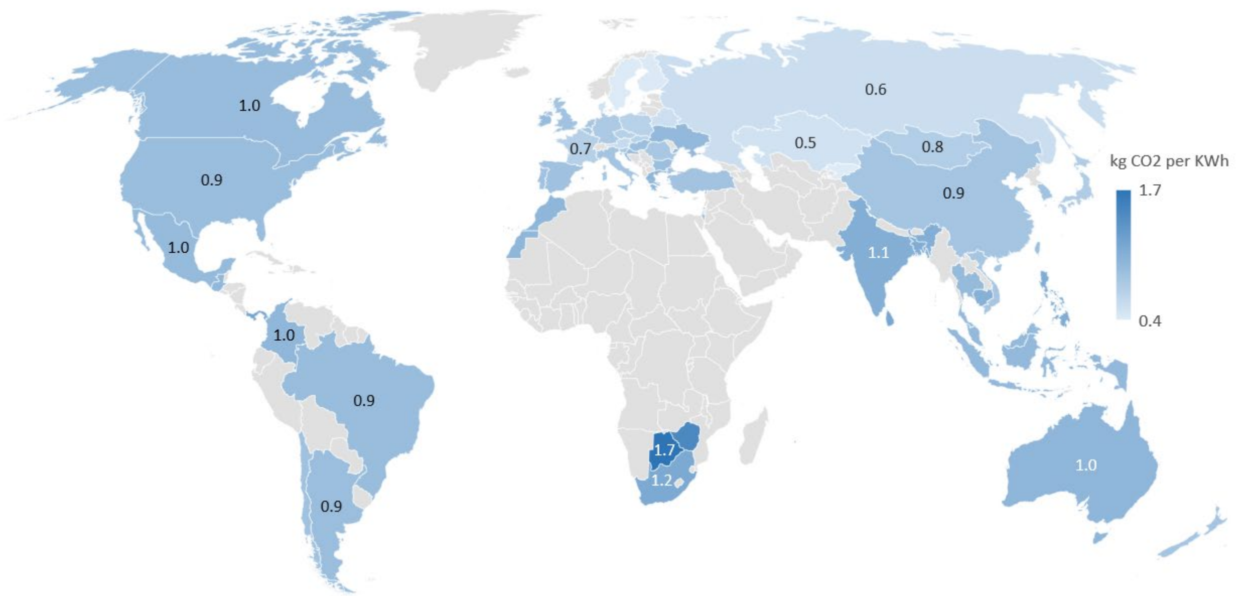

Figure 9. Intensities of the CO_2 emissions embodied into the final consumption of domestic electricity and heat from coal base load generation in 2014 by countries, kg CO_2 per Kwh

Source: Author's estimate based on the GTAP-Power 10a database.

Note: Only individual countries with coal base load generation over 100 GWh are plotted on the map. Countries colored in grey do not have available data or have coal base load generation below 100 GWh per year.

6. Summary

This note documents the changes introduced to the GTAP-Power 10a database construction process. We address a number of limitations identified in Peters (2016). In particular, we discuss three key updates.

First, in the original GTAP-Power database developed by Peters (2016), the output of the electricity and heat generation sector in GTAP was split using electricity generation data only. In this note, we add heat generation volumes data to provide a more representative sectoral split and better concordance with GTAP definitions. Introduction of the heat generation data to the GTAP-Power build changes shares of electricity and heat generation technologies at the global level. As most heat generation is associated with gas base load generation, share of this technology at the global level increases by 4.6% (based on the 2011 reference year comparisons). Another technology widely used for heat generation is oil peak generation ("OilP"), with corresponding global share increase by 1.6%. All other generation technologies experience moderate reductions or no significant changes in the global electricity and heat generation mix.

Second, we add data on country and year-specific shares of transformation and distribution costs in electricity tariff. In the previous release of the GTAP-Power database, this share was assumed to be 21%, based on the data for United States (EIA, 2013). In reality, transmission and distribution shares largely vary by countries, depending on electricity grid structure, population density, electricity market model and other factors. In this update of the GTAP-Power release, we introduce transmission and distribution shares for 80 GTAP countries, which correspond to 65 GTAP 10 regions. These shares highly vary across countries – from as low as 4% in Seychelles to as high as 56% in Lesotho, with global weighted average share of around 25.4%.

Finally, we update the levelized costs of electricity generation and make these data year-specific. For the GTAP-Power 10a update, we use IEA/NEA (2010) to estimate LCOE for 2004, 2007 and 2011 reference years, while IEA/NEA (2015) is used to derive LCOE for the 2014 reference year. As in the GTAP-Power 10a update we add heat generation to the targeted volumes of the GTAP 'ely' sector split, LCOE of corresponding technologies are added to the set of levelized costs.

We showcase an application of the newly constructed GTAP-Power database by estimating CO_2 emissions embodied into final consumption of electricity generated with different technologies. We show that in terms of emission intensities, coal generation is by far the dirtiest technology, followed by oil base load generation and gas peak load generation. Hydro base load is the cleanest technology, emitting around 1% of coal base load generation per Kwh of generated electricity. At the same time, even within the same generation technology emission intensities highly vary across countries. For instance, in the case of coal base load generation, CO_2 emissions embodied into the final consumption of domestic electricity and heat vary between less than 0.5 kg per Kwh (e.g. in Estonia, Finland, Sweden) to over 1.5 kg per Kwh (in Pakistan and Botswana).

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Appendix A. Share of the transmission and distribution sector in the total non-tax value of electricity sector output for selected countries, %

No.	Country code	Country name	Region code	T&D share				Available data years
				2004	2007	2011	2014	
1	aut	Austria	aut	27.9	27.9	27.9	30.8	2011, 2014
2	bdi	Burundi	xec	23.7	23.7	23.7	23.7	2014
3	bel	Belgium	bel	29.3	29.3	34.2	36.2	2007, 2011, 2014
4	ben	Benin	ben	12.0	12.0	12.0	12.0	2013
5	bfa	Burkina Faso	bfa	21.7	21.7	21.7	21.7	2014
6	bgr	Bulgaria	bgr	27.9	27.9	21.7	11.1	2007, 2011, 2014
7	bra	Brazil	bra	33.1	33.1	33.1	33.1	2006
8	btn	Bhutan	xsa	33.2	42.2	42.7	42.7	2015
9	bwa	Botswana	bwa	14.5	14.5	14.5	14.5	2013
10	caf	Central African Republic	xcf	29.3	29.3	29.3	29.3	2014
11	chn	China	chn	32.0	32.0	32.0	32.0	2011
12	civ	Cote d'Ivoire	civ	15.1	15.1	15.1	15.1	2014
13	cmr	Cameroon	cmr	13.4	13.4	13.4	13.4	2014
14	cog	Congo	xcf	31.8	31.8	31.8	31.8	2012
15	com	Comoros	xec	10.7	10.7	10.7	10.7	2012
16	cpv	Cape Verde	xwf	8.9	8.9	8.9	8.9	2012
17	cyp	Cyprus	cyp	14.2	14.2	14.2	16.3	2011, 2014
18	cze	Czech Republic	cze	32.7	32.7	36.7	41.2	2007, 2011, 2014
19	deu	Germany	deu	30.9	30.9	29.0	36.2	2007, 2011, 2014
20	dnk	Denmark	dnk	44.5	44.5	32.5	37.4	2007, 2011, 2014
21	esp	Spain	esp	32.2	32.2	32.2	18.6	2011, 2014
22	est	Estonia	est	35.2	35.2	37.2	33.8	2007, 2011, 2014
23	eth	Ethiopia	eth	45.2	45.2	45.2	45.2	2012
24	fin	Finland	fin	26.1	26.1	25.4	27.2	2007, 2011, 2014
25	fra	France	fra	28.1	28.1	28.1	28.1	2014
26	gab	Gabon	xcf	11.7	11.7	11.7	11.7	2014
27	gbr	United Kingdom	gbr	27.5	27.5	24.7	26.0	2007, 2011, 2014
28	gha	Ghana	gha	26.8	26.8	26.8	26.8	2013
29	gin	Guinea	gin	11.9	11.9	11.9	11.9	2013
30	gmb	Gambia	xwf	10.1	10.1	10.1	10.1	2014
31	grc	Greece	grc	17.5	17.5	17.5	13.7	2011, 2014
32	hrv	Croatia	hrv	39.4	39.4	34.8	37.2	2007, 2011, 2014
33	hun	Hungary	hun	33.7	33.7	33.1	33.1	2007, 2014
34	irl	Ireland	irl	27.1	27.1	27.1	26.0	2011, 2014

No.	Country code	Country name	Region code	T&D share				Available data years
				2004	2007	2011	2014	
35	isl	Iceland	xef	12.9	12.9	12.9	12.9	2014
36	ita	Italy	ita	20.5	20.5	20.5	20.1	2011, 2014
37	ken	Kenya	ken	19.2	19.2	19.2	19.2	2015
38	lbr	Liberia	xwf	9.7	9.7	9.7	9.7	2014
39	lie	Liechtenstein	xef	46.8	46.8	46.8	46.8	2014
40	lso	Lesotho	xsc	55.7	55.7	55.7	55.7	2010
41	ltu	Lithuania	ltu	42.9	42.9	38.7	29.0	2007, 2011, 2014
42	lux	Luxembourg	lux	29.7	29.7	28.3	29.9	2007, 2011, 2014
43	lva	Latvia	lva	41.5	41.5	39.3	48.8	2007, 2011, 2014
44	mdg	Madagascar	mdg	13.3	13.3	13.3	13.3	2014
45	mli	Mali	xwf	11.5	11.5	11.5	11.5	2014
46	mlt	Malta	mlt	20.1	20.1	12.7	14.2	2007, 2011, 2014
47	mne	Montenegro	xer	39.8	39.8	39.8	40.3	2011, 2014
48	moz	Mozambique	moz	39.8	39.8	39.8	39.8	2014
49	mrt	Mauritania	xwf	9.8	9.8	9.8	9.8	2013
50	mus	Mauritius	mus	12.7	12.7	12.7	12.7	2013
51	mwi	Malawi	mwi	28.5	28.5	28.5	28.5	2014
52	ner	Niger	xwf	16.7	16.7	16.7	16.7	2014
53	nga	Nigeria	nga	26.3	26.3	26.3	26.3	2014
54	nld	Netherlands	nld	21.8	21.8	22.7	26.5	2007, 2011, 2014
55	nor	Norway	nor	47.1	47.1	45.9	47.9	2007, 2011, 2014
56	npl	Nepal	npl	17.0	17.0	17.0	17.0	2014
57	pol	Poland	pol	56.7	56.7	32.8	37.1	2007, 2011, 2014
58	prt	Portugal	prt	12.0	12.0	32.5	36.2	2007, 2011, 2014
59	rou	Romania	rou	39.6	39.6	38.0	43.9	2007, 2011, 2014
60	rus	Russian Federation	rus	19.5	19.5	19.5	19.5	2016
61	rwa	Rwanda	rwa	17.5	17.5	17.5	17.5	2013
62	sdn	Sudan	xec	26.2	26.2	26.2	26.2	2014
63	sen	Senegal	sen	7.9	7.9	7.9	7.9	2013
64	sle	Sierra Leone	xwf	12.6	12.6	12.6	12.6	2012
65	srb	Serbia and Montenegro	xer	25.7	25.7	25.7	25.7	2014
66	stp	Sao Tome and Principe	xcf	9.5	9.5	9.5	9.5	2014
67	svk	Slovakia	svk	42.2	42.2	49.0	54.4	2007, 2011, 2014
68	svn	Slovenia	svn	25.5	25.5	25.5	28.7	2011, 2014

No.	Country code	Country name	Region code	T&D share				Available data years
				2004	2007	2011	2014	
69	swe	Sweden	swe	24.3	24.3	26.3	29.5	2007, 2011, 2014
70	swz	Swaziland	xsc	25.3	25.3	25.3	25.3	2014
71	syc	Seychelles	xec	3.9	3.9	3.9	3.9	2014
72	tgo	Togo	tgo	7.9	7.9	7.9	7.9	2013
73	tur	Turkey	tur	18.1	18.1	18.1	19.8	2011, 2014
74	tza	Tanzania, United Republic of	tza	20.0	20.0	20.0	20.0	2015
75	uga	Uganda	uga	20.6	20.6	20.6	20.6	2014
76	ukr	Ukraine	ukr	15.5	15.5	13.6	10.8	2009, 2011, 2013
77	usa	United States of America	usa	13.4	13.3	15.8	16.5	2004, 2007, 2011, 2014
78	zaf	South Africa	zaf	6.0	6.0	6.0	6.0	2014
79	zmb	Zambia	zmb	21.5	21.5	21.5	21.5	2014
80	zwe	Zimbabwe	zwe	23.0	23.0	23.0	23.0	2012
81	**Weighted average**			24.8	24.7	24.9	25.4	-

Source: Developed by authors using EIA (2013), EIA (2018), Trimble et al. (2016), Eurostat (2019), ENTSO-E (2017), NERC (2015), NERC (2014), He et al. (2015), Siyambalapitiya (2018), ADB (2010), EY (2018), WB (2019) and NEEA (2008).

Note: In case of data availability for both residential and non-residential users, data years are reported for the type of consumers with the largest number of available years.

Appendix B. Mapping between IEA generation technologies and GTAP-Power 10a sectors

No.	IEA generation technologies	GTAP-Power sector	Reported countries
Nuclear generation			
1	Nuclear - ALWR	NuclearBL	China, Japan, Korea, USA, France, Hungary, Finland, UK
2	Nuclear – gen III projects		Belgium
3	Nuclear - LWR		Slovak Republic
Coal base load generation			
4	Coal - ultra-supercritical	CoalBL	China, Japan, Belgium, Netherlands
5	Coal – supercritical pulverised		USA
6	Coal - pulverised		Korea, South Africa, Portugal
7	Coal – hard coal		Germany
8	Coal – lignite		Germany
9	Combined heat and power (CHP) large - coal		Denmark
Gas base load generation			
10	Combined-cycle Gas Turbine (CCGT)	GasBL	China, Japan, Korea, Belgium, France, Germany, Hungary, Netherlands, New Zealand, Portugal, UK
11	CHP medium – natural gas		Denmark
12	CHP large – natural gas		Denmark
13	CHP engine		Spain
14	CHP gas turbine		Spain
Wind base load generation			
15	Onshore wind	WindBL	China, Japan, Korea, USA, Austria, Belgium, France, Germany, Hungary, Italy, Netherlands, South Africa, Denmark, New Zealand, Portugal, UK
16	Offshore wind		Korea, USA, Belgium, France, Germany, Netherlands, Denmark, Portugal, UK
Hydro base load generation			
17	Hydro – non-power dams	HydroBL	USA
18	Hydro – new stream development		USA
19	Large hydro – run of river (Large hydro)		Brazil, Germany, Switzerland, Spain
20	Small hydro – run of river		Austria, Germany, Italy, Switzerland, Spain
21	Large hydro		UK
Oil base load generation			
22	-	OilBL	-
Other base load generation			
23	Biomass	OtherBL	USA, UK
24	Solar thermal – 12 hrs storage		USA
25	Geothermal - flash steam		USA
26	Geothermal - binary rankine cycle		USA

27	Biogas – engine		Italy, Spain
28	Solid biomass – turbine		Italy
29	Solid waste incineration		Italy, Netherlands
30	Solid waste incineration - turbine		Spain
31	Geothermal		Italy, New Zealand, UK
32	Biomass - turbine		Spain
33	CHP biogas		Austria
34	CHP solid biomass		Austria
35	CHP biomass		UK
36	CHP engine - biogas (digester)		Germany
37	CHP engine - biogas		Germany
38	CHP engine - mine gas		Germany
39	CHP steam turbine - solid biomass		Germany
40	CHP Geothermal		Germany, UK
41	CHP biogas/fermentation		Netherlands
42	Co-firing of wood pellets		Netherlands
43	CHP medium - wood chips		Denmark
44	CHP medium - straw		Denmark
45	CHP large - wood pellets		Denmark
46	Solar thermal (CSP) – molten salt storage		South Africa
Gas peak generation			
47	Open-cycle Gas Turbine (OCGT)	GasP	Belgium, Germany, New Zealand, UK
Hydro peak generation			
48	Large hydro – reservoir	HydroP	Switzerland, Portugal, Spain
49	Small hydro - reservoir		Spain
50	Large hydro – pumped storage		Switzerland, Portugal
Oil peak generation			
51	-	OilP	-
Solar peak generation			
52	Solar PV- large, ground-mounted	SolarP	China, Japan, Korea, USA, France, Germany, Hungary, Italy, Denmark, Portugal, Spain, UK
53	Solar thermal – 6 hrs storage		USA
Discarded technologies			
54	Solar PV - commercial rooftop	Not mapped to the GTAP	China, Korea, USA, Austria, Belgium, France, Germany, Hungary, Italy, Netherlands, Switzerland, Denmark, Portugal, Spain
55	Solar PV - residential rooftop		Japan, Korea, USA, Belgium, France, Germany, Hungary, Italy, Denmark, Portugal, Spain, UK

Source: Developed by authors based on IEA/NEA (2015).

Appendix C. A comparison between GTAP-Power 9a database constructed in Peters (2016) and GTAP-Power 9a with updated data inputs

C.1. Methodological note

The comparison program employs an entropy-based methodology developed by Robert McDougall. This method ranks the differences between two datasets, in decreasing order, by showing large changes in large values first. The entropy measure is a product of absolute and relative difference (in logarithms). It is applicable to non-negative data – we focus on usage of commodities as represented in the nonnegative tax-free and tax-paid usage values. This is done in multiple iterations: comparing array elements, array totals, rank 1 sub-totals, rank 2 sub-totals, etc.

For each comparison, all features including array elements, totals and sub-totals are compared, to identify the most divergent feature. The dataset is then re-scaled to eliminate that divergence and then comparisons of all features are carried out again and this process is repeated several times.

Table C.2. Comparisons between GTAP-Power 9a constructed with initial and updated data inputs

Commodity	Usage	Region	Entropy	Values, mn USD	
				GTAP-Power 9a	GTAP-Power 9a_upd
p_c_d	TnD	rus	49752	15372	20
GasBL_d	All	ukr	34770	0	8365
TnD_d	All	rus	26433	29117	3644
OilBL_d	All	jpn	26248	0	6314
p_c_d	CoalBL	chn	21691	8881	63
HydroP_d	All	All	21320	74829	29301
All	OilBL	jpn	20280	0	5755
All	HydroP	All	19430	70764	28193
All	GasBL	ukr	18743	0	8331
OilP_d	All	chn	17070	3158	21108
All	OilP	chn	16252	3013	20142
GasP_d	All	jpn	13451	3236	0
All	GasP	jpn	12087	2909	0
GasP_d	All	All	11845	222344	152982
HydroBL_d	All	fra	10920	0	2627
OtherBL_d	All	rus	10488	135	5749
All	GasP	All	10254	204674	142418
All	OtherBL	rus	9843	127	5394
OtherBL_d	All	bra	8330	6262	368
GasBL_d	All	fin	8059	0	1939
GasBL_d	GasBL	ukr	7999	0	86

Commodity	Usage	Region	Entropy	Values, mn USD	
				GTAP-Power 9a	GTAP-Power 9a_upd
All	OtherBL	bra	7441	5596	329
All	HydroBL	fra	7114	0	2259
TnD_d	All	chn	7089	63446	96679
All	TnD	chn	6535	60540	92251
GasP_d	All	fin	6081	2189	0
OilP_d	All	blr	5952	0	1432
GasBL_d	All	rou	5925	0	1425
OilP_d	All	xnf	5318	0	1279
OtherBL_d	All	All	5287	88596	60388
All	OtherBL	All	5261	76214	50473
HydroP_d	All	swe	5111	3549	0
All	GasP	fin	4840	1725	0
OilP_d	All	All	4831	176199	242794
GasP_d	All	dnk	4687	1669	0
All	TnD	rus	4668	27318	3419
GasP_d	All	xnf	4621	1645	0
All	GasP	xnf	4576	1627	0
All	OilP	blr	4492	0	1394
All	OilP	All	4458	164323	223860
gas_m	GasBL	fin	4437	0	1067
OilP_d	All	rus	4434	14503	28003
p_c_d	OilP	xnf	4374	0	1052
All	GasBL	fin	4288	0	1488
p_c_d	OilP	All	4200	99875	145112
All	OilP	rus	4163	13607	26273
All	OilP	xnf	4142	0	1260
GasP_d	All	aut	3968	1414	0
OilBL_d	All	fin	3857	0	928
p_c_d	OilP	rus	3843	12473	24132
All	HydroP	swe	3744	2551	0
OilP_d	All	usa	3629	6751	15474
All	GasP	aut	3437	1224	0
All	HydroP	ukr	3433	2343	0
HydroP_d	All	ukr	3425	2380	0
All	OilP	usa	3401	6416	14650
GasBL_d	All	All	3327	312981	372621
TnD_d	All	usa	3317	93346	69964
OilBL_d	All	blr	3282	790	0
GasP_d	hhld	dnk	3208	1141	0

Commodity	Usage	Region	Entropy	Values, mn USD	
				GTAP-Power 9a	GTAP-Power 9a_upd
gdt_d	GasP	xnf	3207	1139	0
p_c_d	TnD	rus	49752	15372	20
GasBL_d	All	ukr	34770	0	8365
TnD_d	All	rus	26433	29117	3644
OilBL_d	All	jpn	26248	0	6314
p_c_d	CoalBL	chn	21691	8881	63
HydroP_d	All	All	21320	74829	29301
All	OilBL	jpn	20280	0	5755
All	HydroP	All	19430	70764	28193
All	GasBL	ukr	18743	0	8331
OilP_d	All	chn	17070	3158	21108
All	OilP	chn	16252	3013	20142
GasP_d	All	jpn	13451	3236	0
All	GasP	jpn	12087	2909	0
GasP_d	All	All	11845	222344	152982
HydroBL_d	All	fra	10920	0	2627
OtherBL_d	All	rus	10488	135	5749

Source: developed by author.

Note: "_d" in the commodity name corresponds to the domestic component; "_m" in the commodity name corresponds to the imported component. "GTAP-Power 9a" corresponds to the database constructed in Peters (2016); "GTAP-Power 9a_upd" corresponds to the database constructed using inputs described in this note.