Extending GTAP Data for Climate Policy Analysis

Paper Reference 2172

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Abstract

The Global Trade Analysis Project (GTAP) at Purdue University provides a global set of social accounting matrices used by trade and environmental modelers throughout the world. However, there are several ways to extend the GTAP data set to make it more suitable for analysis of climate policy. We describe methods developed at Pacific Northwest National Laboratory for using and extending the GTAP data set as the foundation of an updated benchmark data set for the Second Generation Model (SGM). The data development process for SGM is under revision to (1) take advantage of economic data provided by the Global Trade Analysis Project; (2) allow for timely updates of the model base year; (3) enforce consistency with energy balances published by the International Energy Agency (IEA); and (4) maintain a role for international experts.

For some types of global analysis, the GTAP data set may be sufficient. However, analysis of climate policy can benefit from a finer level of detail for fuels and energy processes than is available in GTAP. We demonstrate these procedures using the GTAP 6 data set and 2001 energy balances from the IEA. First, the IEA energy balances are aggregated to the desired set of fuels. Second, an aggregation of the GTAP data set is combined with the energy balances in a way that maintains strict adherence to IEA energy quantities and allows for additional energy carriers such as coke and heat. Third, the electricity generating sector is expanded into a set of generation technologies, including advanced technologies such as coal integrated gasification combined cycle (IGCC), and carbon dioxide capture and storage (CCS).

Our objective is to automate the construction of a benchmark data set for the Second Generation Model for any desired country or aggregation of countries. The final data set takes the form of a "use table" which is essentially an input-output table with more production activities than intermediate goods. Anyone with subscriptions to the GTAP data set and to the IEA energy balances can use these procedures to construct a benchmark data set with an extended representation of the energy system.

1. Introduction

There is a general consensus among economic modelers that information from economic input-output tables should be combined with data on energy quantities for analysis of energy and climate policy. However, at least three different approaches are in use: procedures developed by the Global Trade Analysis Project (GTAP); procedures developed for the Second Generation Model (SGM; Sands and Fawcett, 2005); and the GTAP-EG approach documented by Rutherford and Paltsev (2000). Each of these modeling groups uses energy balances from the International Energy Agency (IEA).

For some types of global analysis, the GTAP data set may be sufficient. However, analysis of climate policy can benefit from a finer level of detail for fuels and energy processes than is available in GTAP. In this paper, we describe procedures for extending the GTAP data set to (i) expand the set of fuels, and (ii) include production data for specific electricity generating technologies.

We demonstrate these procedures using the GTAP 6 data set, 2001 energy balances from the International Energy Agency, and engineering descriptions of electricity generating technologies from various sources. First, the IEA energy balances are aggregated to the desired set of fuels. Second, an aggregation of the GTAP data set is combined with the energy balances in a way that maintains strict adherence to IEA energy quantities and allows for additional energy carriers such as coke and heat. Third, the electricity generating sector is expanded into a set of generation technologies, including advanced technologies such as coal integrated gasification combined cycle (IGCC), and carbon dioxide capture and storage (CCS).

Our objective is to automate the construction of a benchmark data set for the Second Generation Model for any desired country or aggregation of countries. The final data set takes the form of a "use table" which is essentially an input-output table with more production activities than intermediate goods. Anyone with subscriptions to the GTAP data set and to the IEA energy balances can use these procedures to construct a benchmark data set with an extended representation of the energy system.

The data development process for SGM is under revision to (1) take advantage of economic data provided by the Global Trade Analysis Project; (2) allow for timely updates of the model base year; (3) enforce consistency with energy balances published by the International Energy Agency (IEA); and (4) maintain a role for international experts.

For some regions, GTAP is the only source of economic data available to us. The first step is to construct a benchmark input-output table using GTAP, but combine this table with IEA energy balances to restore full consistency with IEA balances and expand the number of energy carriers. After that, national accounts data from GTAP are used to complete a benchmark social accounting matrix for each region. This provides a default or basic benchmark data set for any desired country or aggregation of countries for the GTAP base year, presently 2001. This part of the process is complete.

This basic data set can then be extended in several ways. First, the electricity sector can be disaggregated into specific technologies using engineering data. Second, our international collaborators can be called on to compare the GTAP-based data to locally available input-output tables and energy balances. Of particular concern are energy prices and the representation of pre-existing energy taxes or subsidies. There may be further adjustments to the benchmark data set as the result of this comparison to local data.

This paper is focused on methodology and Section 2 goes through the steps for constructing an extended hybrid input-output table based on GTAP data and IEA energy balances. Section 3 describes how data on energy technologies can be added to the benchmark data set. The paper concludes with discussion in Section 4.

2. Methodology

This section begins with descriptions of the two data sets used: GTAP data and IEA energy balances. We provide an example with an intermediate level of aggregation of the GTAP data (16 production sectors). The methodology of combining information from both data sets relies on the distinction between use and make tables, and Section 2.3 provides some background. Data extensions in this paper rely on two computational methods: (1) combining use and make tables into a commodity-by-commodity table; and (2) rebalancing the input-output table so that row sums equal column sums in value terms. The actual computations are described in Sections 2.4 and 2.6. The representation of natural gas can cause confusion, and Section 2.5 provides some discussion. Further adjustments to the social accounting matrix are described in Section 2.7.

2.1 GTAP input-output table

We begin by constructing input-output tables for a set of global regions from the GTAP 6 data set. We work with a set of production sectors with an intermediate level of detail as shown in Table 1. This aggregation retains all six energy carriers in the GTAP 6 data set and these are highlighted in bold in Table 1. These sectors were chosen to retain full level of energy detail in GTAP, but limit the number of non-energy sectors to those that have IEA energy consumption data.

[Table 1]

The six GTAP energy sectors capture some, but not all, of the energy detail available from IEA. The GTAP definitions of crude oil, coal, and electricity match up well with IEA. However, the petroleum and coal products sector (P_C) is a combination of many energy carriers and the methods described in this paper allow one to split this sector into its components. We have chosen to split this GTAP sector into three components: refined petroleum, coke, and gases from coal transformation. It would be possible to further split refined petroleum into the fuels available in the IEA balances (e.g., gasoline, diesel), especially if transportation is the focus of a study. GTAP provides two natural gas sectors (GAS and GDT), while IEA has just one.

Our first step was to construct an aggregation of the GTAP 6 data set with 18 regions and 16 production sectors. We then used the seehar.exe utility in batch mode to extract various GTAP tables from BaseData.har and create a BaseData.csv file for further processing in a matrix programming language. The GTAP tables and how they are organized into an input-output table are shown in Figure 1.

[Figure 1]

Table 2 provides a list of the 18 regions we have constructed from the GTAP data set. This is similar to the original set of regions for the Second Generation Model but provides further disaggregation of the original “rest of world” sector in SGM. We use the GTAP data set because it is the only readily available source of economic data for some of these regions, and is a source of consistent trade data across the regions.

[Table 2]

2.2 IEA energy balances

An important source of global energy data is the set of energy balances published by the International Energy Agency (IEA). This provides a consistent set of energy production, transformation, consumption, and trade data across countries. These energy balances are derived mostly from energy balance tables provided by member countries. An energy balance table can be thought of as an energy input-output table, although some initial work is needed to separate the energy balance table into energy use and make tables.

We start with the extended IEA balances for year 2001, aggregate the balances into the regions listed in Table 1, aggregate the energy carriers to a manageable set, and separate the energy balances into energy use and make tables. An energy make table has all energy production and transformation activities as rows, and all fuels as columns. Table 3 contains a 2001 energy make table for China as an example. We have aggregated the fuels, or energy carriers, to eight. However, the IEA extended energy balances contain much more detail for products of refined petroleum. Others may want to keep some of this detail and the methods here could be extended to retain that detail.

[Table 3]

Note that this aggregation of fuels provides some energy detail beyond that retained in GTAP (coke, gases from coal transformation, heat). However, the IEA balances make no attempt to split natural gas consumption into the two GTAP categories for natural gas.

The IEA energy balances capture a large amount of detail beyond that shown in the make table, especially for energy transformation and consumption. Table 4 provides part of the energy use table for China, covering energy transformation processes. For example, Table 3 shows the amount of electricity generated (126.6 mtoe), but Table 4 shows the fuels consumed in electricity generation, which for China is mostly coal.

Formally, a make table has dimensions of activities by commodities, while a use table has dimensions of commodities by activities. Therefore, Table 4 is actually the transpose of the energy transformation part of a use table.

[Table 4]

An interesting feature of these energy use and make tables is the "heat" energy carrier, which is usually doesn't appear in economic input-output tables, but is more common in energy balance tables. In China, a significant amount of coal is used for heat and the information provided by energy balances allows the modeler to choose how to represent heat. We could model heat as another energy carrier with its own price, or instead have end users purchase the fuels that produce heat.

2.3 Background on use and make tables

The original data for economic input-output tables are often collected first as use and make tables, and then later combined. The following discussion applies to either economic data or energy data and is based on Miller and Blair (1985).

Use tables contain one column for each industry, with each row showing the amount of each commodity purchased in a given year. Make tables contain one row for each industry, showing the amounts produced of each commodity. Therefore, use tables have dimensions of commodity-by-industry and make tables are industry-by-commodity. Because of joint production, output by industry is different than output by commodity, and row sums do not equal column sums in the use or make tables.

There are at least four ways to combine use and make tables into a single input-output table where row sums match column sums. We can create either commodity-by-commodity or industry-by-industry tables. Further, each of these two types of tables can be constructed using commodity-based or industry-based technology assumptions. None of this would be necessary if each industry produced only one commodity. In that case the make table would be diagonal, providing no new information beyond the use table.

<u>Commodity-Based Technology</u>. Each commodity is produced using the same value shares of inputs, regardless of what industry produced the commodity.

<u>Industry-Based Technology</u>. A commodity is produced using input value shares that are an average across the industries producing it.

The assumption of commodity-based technologies is difficult to work with because a matrix inversion is required, often yielding negative input-output coefficients. Computation of input-output tables using the assumption of industry-based technologies is much simpler, with no negative coefficients.

For the SGM, we have constructed commodity-by-commodity input-output tables using the assumption of industry-based technologies. (This is the same way that the Indian government combines its use and make tables.) Commodity-by-commodity tables are preferred because the units of output are pure, and not a mix of commodities. Each column in the resulting input-output table is actually a hypothetical industry that produces just one commodity. The use table is post-multiplied by a normalized make table to obtain a commodity-by-commodity input-output table.

2.4 Hybrid input-output table

In this section we describe the construction of an input-output table with hybrid units: all of the energy rows are in units of joules, while all of the other rows are in 2001 US$. See Miller and Blair (1985) for background on the motivation for using input-output tables with both energy and economic units. The resulting hybrid input-output table should be viewed first as a table of quantities. In the following section, we will apply prices to each commodity so that we can quickly convert between quantities and values.

Figure 2a describes the components needed to construct a hybrid input-output table. All data above the dashed line in Figure 2a are derived from energy balances and are in units of joules. All data below the dashed line in Figure 2a are in units of 2001 US$ and are derived from GTAP input-output tables. The structure of the final hybrid input-output table is shown in Figure 2b. Equations in this section describe the transformation from the original data in Figure 2a to the final table in Figure 2b.

Sub-matrices U^{11}, U^{12}, and U^{13} are all derived from IEA energy balances. U^{11} is the transpose of data from Table 4. The other two energy use tables contain data on energy consumption for non-energy production activities and final demand. All of these sub-matrices have have eight rows, one for each energy carrier (the columns in Table 4). Only one of these sub-matrices, U^{11}, needs further transformation.

Other sub-matrices in Figure 2a below the dashed line are all taken from GTAP input-output tables. They include all the non-energy and value-added rows from the GTAP input-output table. Some of them, matrices U^{22}, U^{23}, and U^{32}, need no further transformation. What we have essentially done is replaced the energy rows of the GTAP input-output table with energy quantities from the IEA energy balances. Since the GTAP data do not contain as many energy carriers, we will need to expand the remaining GTAP sub-matrices, U^{21} and U^{31}, so they have as many columns as there are energy carriers (eight).

Matrices U^{21} and U^{31} have only four columns, even though the GTAP data include six energy activities. Here, we have combined some GTAP activities for consistency with IEA energy balances. Note that the IEA balances (see Table 3 or Table 4) always combine oil and natural gas extraction as a single activity. Also, the EIA data do not distinguish between natural gas production and natural gas distribution. Therefore, the GTAP data are first collapsed to four energy activities by combining the GAS, OIL, and GDT sectors into a single sector.

[Figure 2]

Let M be the energy make table (14 by 8) from Table 3. This is used to transform U^{11} to the dimensions needed in the final commodity-by-commodity table:

$$C^{11} = U^{11}\overline{M} \tag{1}$$

where $\overline{M}$ is a normalized energy make table. Each element of M is divided by its column sum, so that each column of $\overline{M}$ sums to 1 and each element is equal to the share of output by energy production or transformation activity.

$$\overline{M}_{ij} = \frac{M_{ij}}{\sum_k M_{kj}} \tag{2}$$

The normalized make table can also be used to transform the parts of the input table that correspond to non-energy inputs into the production or transformation of energy. The same transformation can be applied to both the U^{21} and U^{31} sub-matrices.

$$C^{21} = U^{21} G \overline{M} \tag{3}$$

$$VA^{1} = U^{31} G \overline{M} \tag{4}$$

Equations (3) and (4) use a grouping matrix G of ones and zeros to collapse the number of rows of the energy make table from 14 to 4, and keeps the matrices in these equations conformable. No further transformation is needed for the other matrices in Figure 2a.

$$C^{12} = U^{12} \tag{5a}$$

$$C^{22} = U^{22} \tag{5b}$$

$$VA^{2} = U^{32} \tag{5c}$$

$$FD^{1} = U^{13} \tag{5d}$$

$$FD^{2} = U^{23} \tag{5e}$$

The grouping matrix *G* in Equations 3 and 4 aggregates the IEA energy activities into four categories to better match GTAP activities: (1) oil and gas extraction, gas works; (2) coal mining;

(3) activities that primarily produce electricity or heat; (4) activities that transform coal or crude oil into other fuels. Transformations using *G* are simply allocating production costs, from GTAP data, across the eight energy carriers in the final data set.

To summarize, we have a constructed a hybrid input-output table where the energy rows are in units of joules and are based on IEA energy balances. The remaining rows are in units of 2001 US$ and are derived from GTAP input-output tables. Transformation of the energy columns is needed so that the number of energy columns is equal to the number of energy rows (eight). This hybrid table should be viewed as an input-output table expressed in quantities. Section 2.6 will describe how the quantity table is converted to a balanced value table.

2.5 Natural gas

One point of possible confusion is the distinction between the “natural gas” and “distributed gas” sectors. IEA energy balances make no such distinction, but many input-output tables include separate sectors. In our work, we have taken the view that the “natural gas” sector provides bulk natural gas directly to energy transformation (especially electricity), but that other end users purchase natural gas from the “distributed gas” sector and pay higher distribution costs. Therefore, we use this distinction to allow for two prices of natural gas in the data set, a lower price for large end users and a higher price for other end users.

If one decides to include a distributed gas sector in the data set, then there is one more energy carrier (nine energy rows instead of eight) and one more energy transformation activity (natural gas to distributed gas). The same sort of distinction can also be applied to electricity, where there would be two prices for electricity, busbar electricity and distributed electricity.

2.6 Rebalancing the input-output table

After the transformations described in Section 2.4 are complete, we have an input-output table with units of joules in the energy rows and real currency in the remaining rows. At this point, we need to rebalance the input-output table by solving for a set of row multipliers (the value added section of the input-output table does not need to be rebalanced) that provide a balanced table in values, where row sums equal column sums. Multipliers for the energy rows are interpreted as energy prices in units of US$ per gigajoule (GJ) and can be used to convert between energy values and quantities.

The rebalancing procedure is simple: in this case there are 19 unknown row multipliers and 19 linear equations, which can be solved directly for the 19 unknowns. Some countries (e.g., India) have no data for the heat energy carrier, so there are 18 unknowns in those countries. Table 5 displays the row multipliers (one for each commodity) that balance the hybrid input-output table in value terms. For the energy carriers, these multipliers are prices in units of US$ per GJ. For the other commodities, the multipliers have no particular significance except to show how much these rows need adjustment to balance the input-output table. We prefer that these multipliers remain close to 1.

The row multipliers for non-energy goods are not actually applied to all elements in the row. The trade values (imports and exports) remain in their original values to maintain trade consistency between regions. The original GTAP data are perfectly balanced in terms of global trade values and we want to retain this balance. The original IEA energy data are very close to balance across regions, so we adjust energy production in one region as a correction.

[Table 5]

Since the economic data used to construct the hybrid input-output table are based on GTAP data, the coal prices generally reflect the coal prices implicit in the GTAP 6 data set. One number that stands out is the very low coal price for China, which is well below international prices for coal. The baseline price of coal is especially important for analysis of climate policy, as this provides the base price upon which a carbon price would be added.

We also assume that all regions face the same price for crude oil and natural gas. In this case the price of the fuel is known in advance, but there is an adjustment term to value added in each region for the production of these fuels.

2.7 Social Accounts

GTAP data provide information on social accounts beyond the input-output table and these can be compactly represented in a condensed social accounting matrix (SAM). Some of these numbers will have changed through our transformation and rebalancing procedures, and that means that some further adjustment is needed to the social accounting matrix. It turns out that the primary adjustment terms is savings by the representative household.

3. Further extensions

We have learned over 15 years of modeling alternative climate policies the importance of including key technologies, especially for electricity generation. Therefore, in all of our analysis, we have always had at least the following set of electricity generation technologies: oil-fired, gas-fired, coal-fired, nuclear, and hydro. Several single-country versions of SGM also include the following advanced generating technologies: natural gas combined cycle (NGCC), coal integrated gasification combined cycle (IGCC), and the option of including carbon dioxide capture and storage (CCS) in electricity generation. Including these technologies involves disaggregation of the electricity generation sector into separate technologies based on engineering performance data. Advanced generating technologies were introduced into SGM-USA and then adapted for use in single-country versions of SGM for Japan and Germany. We are working to automate this process so that it can be applied to all SGM regions as part of the data construction process. Our experience has shown that a lot of the mitigation potential for carbon dioxide is in the electricity generation sector, and these technologies are essential for simulations of alternative climate policies. See Sands (2004) for an application to SGM-USA.

It is also possible to apply this approach to energy-intensive industries such as iron and steel. We have done this for only one country so far (Germany) and our experience shows that this approach for iron and steel provides more realism in simulating climate policy, but this must be balanced against the added cost to assemble the engineering data in a form consistent with an input-output table (Schumacher and Sands, 2007).

Figure 3 demonstrates how a benchmark input-output table can be extended to include information on specific energy technologies. This table include five electricity generating technologies and three steel technologies. This table for Germany was not constructed with GTAP data, but shows possible ways to extend an input-output table.

[Figure 3]

4. Discussion

Previously, data sets for the Second Generation Model were constructed country-by-country with help from international collaborators and the use of local input-output tables and energy balances. This type of data construction is labor-intensive and may still be appropriate for single-country versions of SGM. However, this has become prohibitively expensive to repeat for an update of a global SGM data set from 1990 to something closer to the present. Therefore, we have developed methods to extend the GTAP data set in a way that makes the best of use of GTAP and IEA energy balances.

However, we believe there remains a role for international collaborators in this revised data development process. At a minimum, we can ask our international collaborators to compare GTAP information on prices and energy taxes to locally available data. We are especially interested in finding a representative price for coal and how taxes on refined petroleum are represented in the indirect tax structure. We would also like to determine the best way to incorporate more recent input-output tables into the data development process. Fore example, a 2002 input-output table is now available for China and we would like to take advantage of more recent data for China.

The original SGM data development process retained local currencies where possible. We still prefer to model China's economy in yuan and India's economy in rupees. Fortunately, the conversion from local currency to US$ is fairly transparent in the GTAP data set, which allows us to convert back to local currency using base-year market exchange rates.

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Table 1. GTAP sector aggregation

No	New sector	GTAP sectors	Description
1	PAG	pdr wht gro v_f osd c_b pfb ocr ctl oap rmk wol frs fsh	Primary agriculture
2	**COL**	coa	coal
3	**OIL**	oil	crude oil
4	**GAS**	gas	natural gas
5	FPR	cmt omt vol mil pcr sgr ofd b_t	processed food
6	WPP	lum ppp	wood and paper products
7	**P_C**	p_c	petroleum and coal products
8	CRP	crp	chemicals, rubber, and plastic
9	NMM	nmm	non-metallic minerals
10	I_S	i_s	iron and steel
11	NFM	nfm	non-ferrous metals
12	OID	omn tex wap lea fmp mvh otn ele ome omf wtr cns	other industry
13	**ELY**	ely	electricity
14	**GDT**	gdt	gas distribution
15	TPT	otp wtp atp	transport
16	SVS	trd cmn ofi isr obs ros dwe	services

Table 2. GTAP region aggregation

No	New region	Comprising (GTAP sectors)	Description
1	usa	usa	USA
2	can	can	Canada
3	weu	aut bel dnk fin fra deu gbr grc irl ita lux nld prt esp swe che xef	Western Europe
4	jpn	jpn	Japan
5	aus	aus nzl xoc	Australia/New Zealand
6	fsu	est lva ltu rus xsu	Former Soviet Union
7	eeu	alb bgr hrv cyp cze hun mlt pol rom svk svn tur xer	Eastern Europe
8	chn	chn	China
9	ind	ind	India
10	mex	mex	Mexico
11	kor	kor	(South) Korea
12	mde	xme mar tun xnf	Middle East/N. Africa
13	bra	bra	Brazil
14	arg	arg	Argentina
15	xam	xna col per ven xap chl ury xsm xca xfa xcb	Rest of Americas*
16	xss	bwa zaf xsc mwi moz tza zmb zwe xsd mdg uga xss	Sub-Saharan Africa
17	sea	idn mys phl sgp tha vnm xse bgd	Southeast Asia
18	xas	hkg twn xea lka xsa	Rest of Asia

* Most are located in Central and South America

Table 3. 2001 energy **make table** for China (million tons oil equivalent)

				Coal Transformation				
	Crude Oil	Natural Gas	Coal	Coke	Gases	Refined Petroleum	Electricity	Heat
Oil and Gas Extraction	164.1	31.4						
Coal Mining			698.8					
Coke Ovens				82.5	11.6			
Blast Furnaces					16.5			
Petroleum Refineries						201.8		
Petrochemical Industry								
Gas Works		3.8		0.6				
Liquefaction Plants								
Other Transformation				3.3				
Public Electricity Plants							124.5	
Autoproducer Electricity Plants							2.1	
Heat Plants								36.6
CHP Plants								
Electric Boilers								

Table 4. Part of 2001 China energy **use table** (million tons oil equivalent)

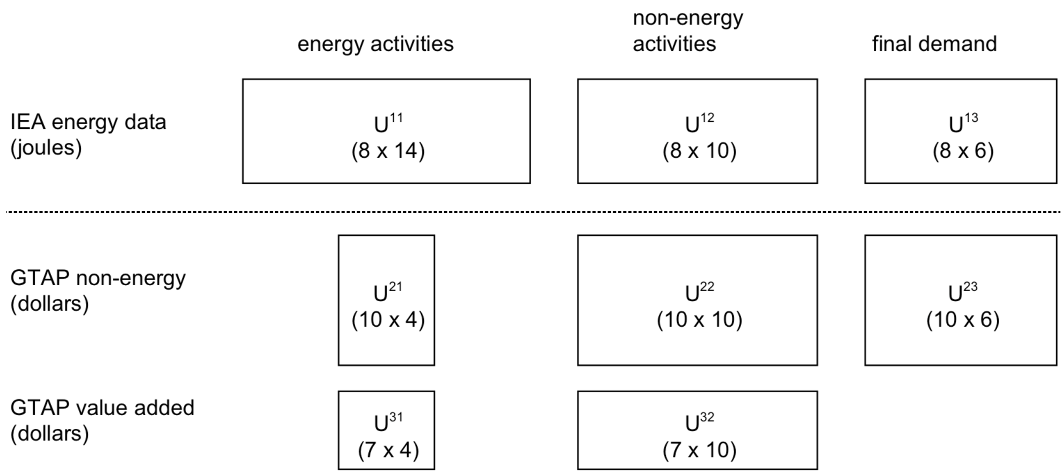
	Crude Oil	Natural Gas	Coal	Coal Transformation: Coke	Coal Transformation: Gases	Refined Petroleum	Electricity	Heat
Oil and Gas Extraction								
Coal Mining								
Coke Ovens			98.3					
Blast Furnaces				57.8				
Petroleum Refineries	204.1							
Petrochemical Industry								
Gas Works			5.3			0.2		
Liquefaction Plants								
Other Transformation			3.7					
Public Electricity Plants		1.3	288.8			8.4		
Autoproducer Electricity Plants	0.8				2.2	2.7		
Heat Plants	0.1	1.7	34.9		1.1	4.1		
CHP Plants								
Electric Boilers								

Table 5. Multipliers to balance hybrid input-output table for selected countries

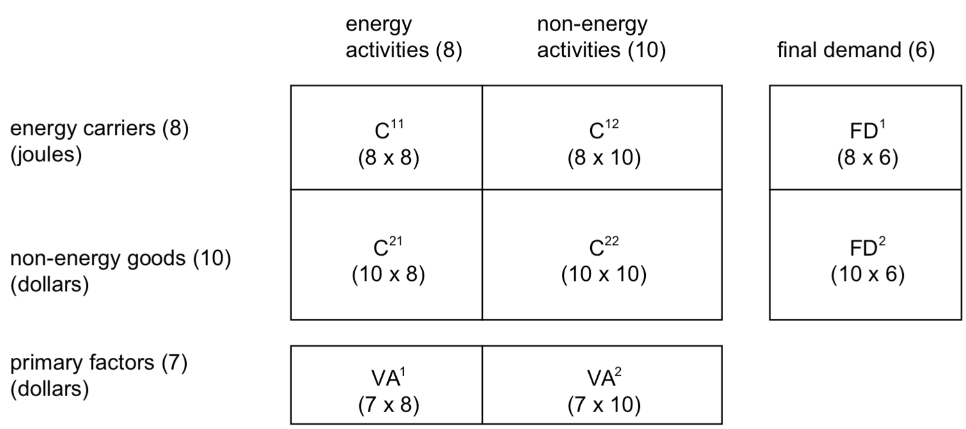
		USA	Canada	Japan	Mexico	China	India	Brazil
1	coal	1.39	1.56	1.54	1.58	0.38	0.52	1.54
2	crude oil	2.82	2.82	2.82	2.82	2.82	2.82	2.82
3	natural gas	2.82	2.82	2.82	2.82	2.82	2.82	2.82
4	coke	2.17	2.44	3.84	2.03	2.18	1.07	2.80
5	gases from coal transformation	5.67	4.61	9.03	5.13	5.27	3.20	7.58
6	refined petroleum	3.31	3.63	5.32	3.27	5.12	3.38	4.22
7	electricity	19.51	14.44	47.38	7.91	12.86	24.20	20.42
8	heat	9.46	6.85	10.60		3.88		2.54
9	distributed gas	4.68	4.83	3.03	5.35	4.41	5.20	5.35
10	primary agriculture (PAG)	1.00	1.01	1.00	1.00	1.01	1.00	1.00
11	processed food (FPR)	1.00	1.00	1.00	1.00	1.01	0.99	1.00
12	wood and paper products (WPP)	1.00	1.01	0.99	1.00	1.00	0.87	1.00
13	chemicals, rubber, plastics (CRP)	1.02	1.03	0.99	1.00	1.03	0.93	1.00
14	non-metallic minerals (NMM)	1.01	0.99	0.98	1.00	1.01	0.88	0.99
15	iron and steel (I_S)	1.00	1.01	1.00	1.00	1.02	0.90	1.03
16	non-ferrous metals (NFM)	1.02	1.04	0.98	0.98	1.02	0.84	1.01
17	other industry (OID)	1.01	1.02	1.01	1.01	1.01	1.03	1.00
18	transport (TPT)	1.03	1.03	1.01	1.02	1.05	0.97	1.07
19	services (SVS)	1.00	1.01	1.00	1.00	1.01	1.00	1.01

	Sectors	HH	Govt	Invest	Export	Import
	VIFM+VDFM	VIPM+ VDPM	VIGM+ VDGM	VIFM(cgd)+ VDFM(cgd)	VXMD	-VIMS
Value added	VFM					
Product tax	-OSEP					
IBT	(VIFA-VIFM) + (VDFA-VDFM) + (EVFA-VFM)					

Figure 1. Structure of input-output table constructed from GTAP 6 data set



(a) Data used to construct hybrid input-output table



(b) Structure of hybrid input-output table with energy

Figure 2. Hybrid input-output table and its components

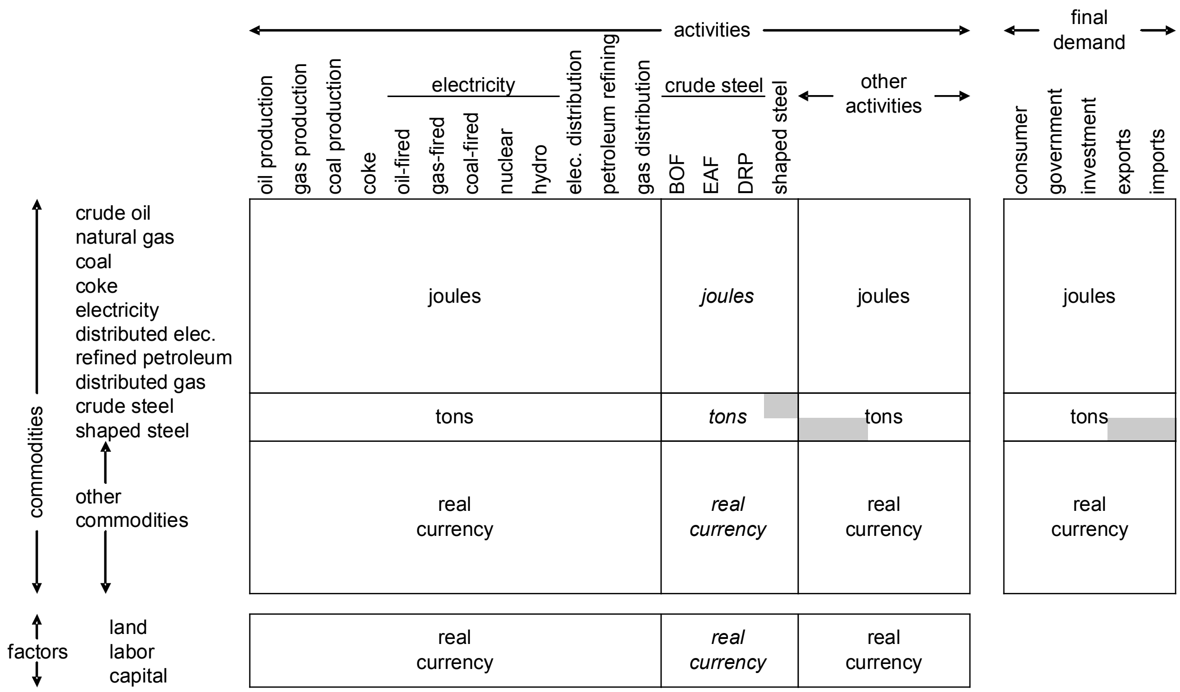


Figure 3. Organization of benchmark use table for Germany in 1995. Each row is a distinct commodity and each column represents production activities. Three distinct activities (technologies) are available for crude steel production: basic oxygen furnace (BOF), electric arc furnace (EAF), and direct reduction process (DRP).