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Production Data for the Population-Environment-Technology (PET) Model

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Contents

Abstract

This report describes the production data serving as an input to the Population-Environment-Technology (PET) model (Dalton and Goulder, 2001; Dalton et al., 2008). The PET model is a multi-sector, multi-region computable general equilibrium model of the global economy. We describe the procedures used to develop regional production data for the model. GTAP (Global Trade Analysis Project) represents the major production data source. The document explains the structure of the data and the modifications we make to it, including modifications to the treatment of trade, physical energy quantities, and household consumption.

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Production Data for the Population-Environment-Technology (PET) Model

Regina Fuchs
Shonali Pachauri
Brian C. O'Neill

1. Introduction

This document describes the general structure of the production data employed in calibrating the Population-Environment-Technology (PET) model (Dalton and Goulder, 2001; Dalton et al., 2008), and also the modifications we make especially with respect to trade and energy quantities.

Section 2 describes the structure of the Global Trade Analysis Project (GTAP 6) data base (Dimaranan 2006), our main data source, and Input-Output (I-O) tables in detail. We explain how the different parts of an I-O table are built up and how GTAP data is constructed within the I-O framework. Section 3 deals with trade and transport margins. GTAP contains very detailed information on trade and transport, but it is not in a form directly useable by the PET model. For this reason we modified the data in order to meet the PET model requirements.

GTAP supplies energy volume data which is based primarily on the IEA energy balances (IEA 2003a, IEA 2003b). However, the original IEA energy quantity data is modified as part of the process of producing national I-O tables (Dimaranan 2006). We re-balance the GTAP I-O tables in order to be consistent with the original IEA energy quantities, given the high priority we place on accurate representation of energy quantities (and associated carbon emissions) in the PET model. This procedure is described in Section 4,

The GTAP production data only supplies household expenditures as a single consumption vector. In fact we are interested in the shift of demand across household consumption goods, and therefore split the consumption vector into several sub-categories of consumption goods via the so-called G-Matrix. The disaggregation of the household consumption data is described in Section 5.

2. GTAP Input-Output Tables

The Global Trade Analysis Project (GTAP) 6 Data Base aims to represent the world economy for the reference year 2001. GTAP 6 provides a set of files that contain flows of goods and services within and among regions based on regional Input-Output (I-O) Tables for 87 regions and 57 commodities. All terms are in money values, in millions of 2001 U.S. dollars. Except for energy, no volume data is supplied. The GTAP 6 Data Base is organized in 4 separate data packages which contain the file sets, parameters, main data and energy volume data.

Figure 1 shows the general structure of an I-O table. Each row describes the output of a particular industry (i.e., the value of the commodity it produces that is used by the other sectors of the economy) or, in the value added section of the table, the allocation of an endowment across sectors. K defines capital, L denotes labor and T includes any type of taxes. Each column describes the inputs to an industry (i.e., the value of the commodities or endowments it purchases as input to its production). Final demand includes private (C) and government (G) consumption, investment (I), exports (X) and imports (M). The total cost of production for a particular industry is represented by the column sums, and the total value of the output of a particular industry is represented by the row sums (including exports, minus imports).

GTAP data are based primarily on national I-O tables, but in the cases of energy, agriculture and food, trade, and import and export duties, values in the national tables are substituted by separately constructed data bases. This procedure is intended to ensure international consistency, particularly regarding the sectoral mapping of commodities, which is performed in different ways across countries in the original I-O tables.

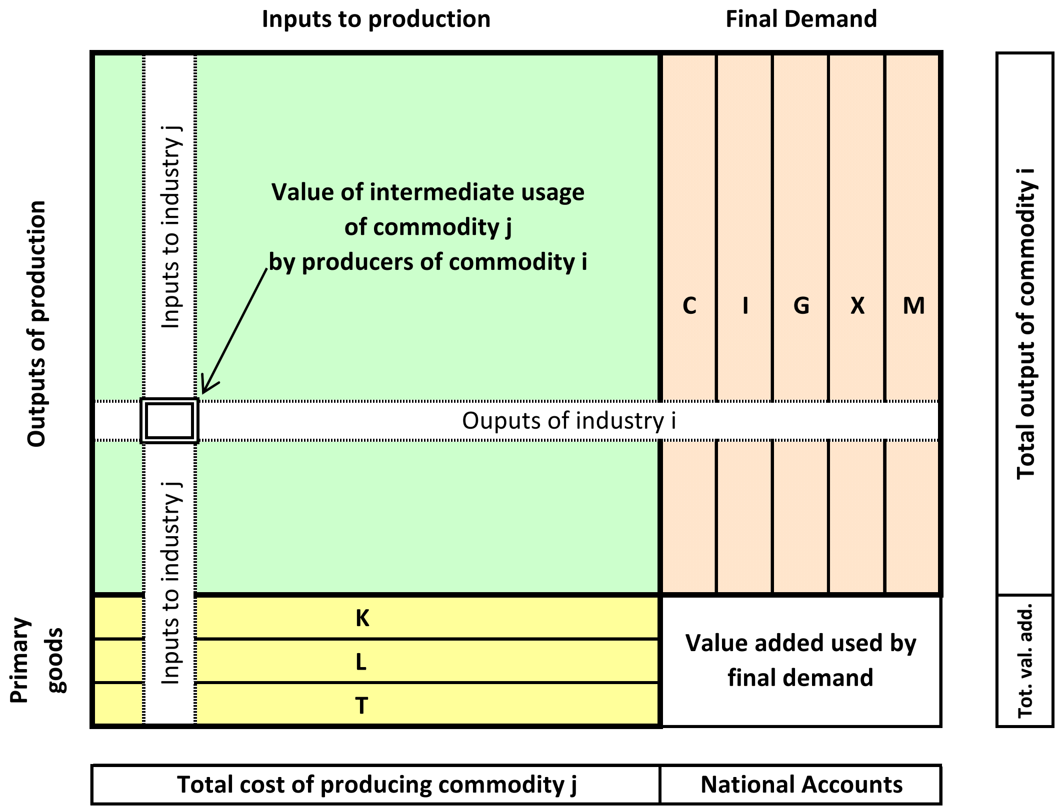

Figure 1. General structure of an Input-Output table.

2.1 Intermediate production

Since the GTAP database is designed primarily to support studies involving international trade, intermediate and final demand are divided into purchases from domestic sources and those purchased from abroad. Our interest is limited to the overall intermediate and final demand; for this reason we sum up imports and domestic purchases. Figure 2 shows a decomposition of a hypothetical intermediate production sector and the units in which data are supplied, in order to provide a basis for further discussion of the data.

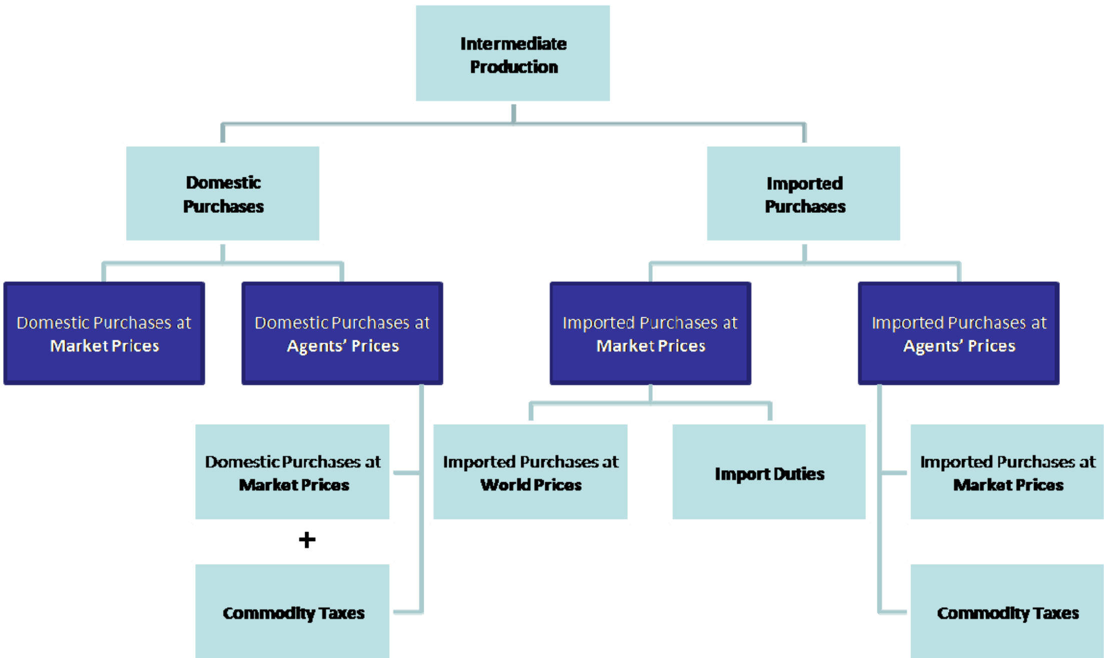

Figure 2. Decomposition of inputs to intermediate production into domestic and imported purchases. Different price measures employed are shown in blue boxes.

All intermediate flows of goods and services are available in terms of agents' and market prices. Agents' values of commodities are the sum of the market value of the respective commodity and net taxes (taxes minus subsidies). This applies to all goods in the market, for intermediate production as well as for primary production and final demand. We use market prices and include net taxes as additional row in the I-O table.

2.2 Primary factors and taxes on inputs and outputs

In Figure 1, we display labor and capital as the only endowment commodities. But in fact, GTAP distinguishes 5 different primary factors, namely skilled and unskilled labor, land, natural resources and capital. GTAP separates labor into skilled and unskilled labor on the basis of occupational classifications. In addition to GTAP 6 there is a separate land use data base which splits up land into agro ecological zones (AEZ's) and their use by the different industries.

GTAP provides figures on income tax, by factor and region (not by industry), as well as factor employment tax, by factor, industry and region, which is, again, the difference between market value and agents' value of output (Figure 2). In addition, there are taxes on outputs (ad valorem tax) by commodity (summed over industries). We include the net value of all taxes (also export and import taxes) as a single row in the value added portion of the I-O table.

2.3 Final demand

For investment goods, which are based on changes in physical capital stocks, GTAP creates a fictitious sector. Inputs to this sector represent imported and domestic purchases of goods used for investment (e.g. machinery, construction of buildings, etc.). Although GTAP provides data on investment for the economy as a whole broken down by commodities, it does not characterize investment undertaken by each sector.

Residential and government consumption, again, is split up into domestic and imported purchases, which can be easily summed up sector by sector.

2.4 Data aggregation

GTAP 6 is supported by GTAPAgg, a Windows program that aggregates several regions/commodities to one or more common regions/sectors and creates a data base of the selected collection of countries/commodities. Besides regions and sectors, primary factors can also be aggregated. GTAPAgg is very easy to use and provides an interface to specify the new (aggregate) regions/commodities you want to create out of the corresponding GTAP regions/commodities. Once the data is aggregated, it can be exported without any difficulties and manipulated by a spreadsheet program (e.g. MS Excel).

GTAPAgg aggregates countries by a simple addition of the elements of the I-O table from several countries to make a region. For example, in creating a European region, the value of energy inputs to Albania's transportation sector is added to the corresponding value for Bulgaria. This aggregation introduces an inconsistency regarding imported and domestic production. In GTAP, inputs to each sector are disaggregated into domestic and imported purchases. Adding these separately, as is done in the GTAPAgg program, leads to an overestimate of imported purchases (and underestimate of domestic purchases) in the aggregate region, because some portion of purchases previously defined as imported (e.g. from Albania to Bulgaria) should now be defined as domestic production (i.e. within Europe).

To adjust for this inconsistency in the aggregated data, the intra-regional trade has to be subtracted from each industrial sector's imported purchases and shifted to its domestic purchases. Because in the PET model we do not differentiate between domestic and imported inputs to production, we are not affected by this problem.

We apply the GTAP production data to the structure of the PET model. Our aim is to deploy up to 25 production sectors in the PET model (see Appendix Table 1) and up to 24 regions (see Appendix Table 2), but in the current version of the model we use 9 regions and 5 sectors: "coal", "oil and gas", "refined fuels", "electricity" and "materials". In principle one could use any aggregation of the 57 GTAP production sectors. Figure 2 gives the structure of the aggregated I-O table we employ in the PET model. Note that in addition to aggregating industries, we also aggregate taxes into a single net tax row, aggregate land, natural resources, and capital into a single capital row, and aggregate skilled and unskilled labor into a single labor row.

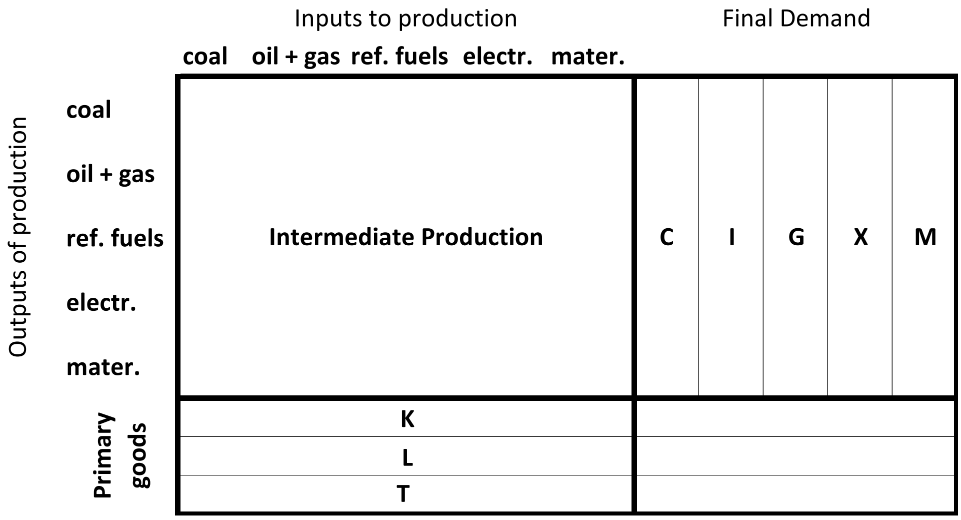

Figure 3. Structure of the Input-Output table currently used in the PET model.

3. Trade and Transport Margins

The focus of GTAP is trade. It combines detailed data on bilateral trade, transport margins and import and export duties/subsidies[1] with data from national I-O tables (as discussed above, separately constructed data on energy, food and agricultural products are also employed). However, the format in which trade data is supplied by GTAP 6 is not ready to be used directly in a multi-region CGE model such at the PET model in which international trade is not modeled as a separate industry. In this section, we describe the GTAP trade data, and our approach to adapting it for use in the PET model.

3.1 Trade

The main source for bilateral merchandise trade is the United Nations COMTRADE data of 2001, which covers only merchandise trade of goods (not services) and electricity. The second source is the IMF balance of payments statistics of September 2003.

In the GTAP database, imports and exports are available on a bilateral basis. Exports and imports are measured in two different prices, world and market prices, which differ in their treatment of taxes and transport margins (i.e., the cost of services

[1] GTAP contains a highly diversified data base on import and export taxes (Dimaranan, 2006, 16.A.2-16.A.4). In general export tax information from I-O tables comprises only ordinary export subsidies and does not take into account information on price undertakings, VERs (voluntary export restraints) and MFAs (Multi Fiber Arrangements). Similarly, import information typically includes ordinary import tariffs but not anti-dumping duties. GTAP tries to complete these informational arrays. Imported purchases in market prices are the sum of imports in world prices plus ordinary import duties and anti-dumping duties. Exports in terms of market prices consist of exports valued at world prices minus ordinary export duties, VERs, MFAs and price undertaking export tax equivalents.

used to transport goods for international trade). Figure 4 describes the relationship between price units, margins and taxes. Market prices reflect prices faced by agents within the markets of either an exporting or importing region. Therefore exports at market prices do not include either export or import duties, while imports at market prices include both. World prices reflect prices faced at the international level, after goods have been exported but before they have been imported. Therefore both exports and imports at world prices include export duties, but neither includes import duties. Imports and exports at world prices differ, however, in another respect. Transport services demanded for international trade (i.e., transport margins) are attributed to imports, and included in the world price for imports but not in the world price for exports. Thus the value of every imported good or service includes a transport margin used to ship the product.

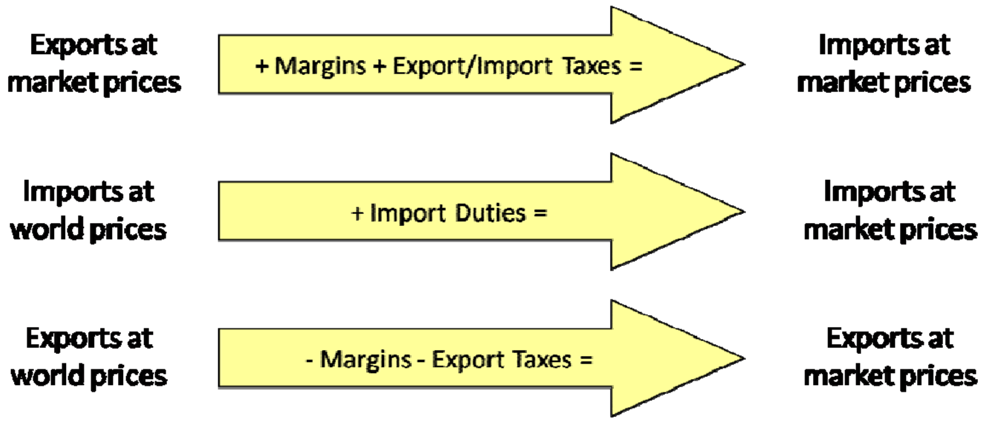

Figure 4. Relationship of exports / imports at market and world prices.

An example serves to clarify these relationships. Suppose there are $10,000 worth of fish in Norway at the market price there. If these fish are exported to Denmark, extra costs are incurred before they reach the market in Denmark: the cost of shipping ($1,000) and possible export taxes (or subsidies) ($100) imposed by Norway, and import duties imposed by Denmark ($200). Thus the market price in Denmark in this example will be $11,300, and therefore the value of exports from Norway will not equal the value of imports to Denmark in market prices. Exports and imports are also not equal when expressed in world prices. To get imports in world prices, import duties ($200) are subtracted from imports at market prices ($11,300), giving a value of $11,100, and to get exports in world prices export taxes ($100 total) are added to exports at market prices ($10,000), giving $10,100. The difference between exports in world prices and imports in world prices are the transport margins which account for $ 1,000. In a multi-region CGE model such as the PET model, the bilateral value of imports and exports must be equal. Our approach to establishing this condition is through the treatment of transport margins, described in the rest of this section.

3.2 Transport margins

Complete information on a margin includes the following dimensions:

(1) the margin service or mode of transport (air transport, sea transport, …),

(2) the country of origin of the transport service,

(3) the commodity to which the service is applied,

(4) the country of origin of the merchandise and

(5) the country of destination.

Returning to the example of fish imported by Denmark from Norway, a complete description might involve sea transport (1) supplied by a Polish company (2) of the fish (3) exported from Norway (4) to Denmark (5). GTAP provides two types of data regarding such margins: data on margin supply, and data on usage (or demand). Margin supply denotes the value of the transport services provided, and is associated with the country that supplies them, in this case Poland. Margin demand, or usage, is defined as the value of transport services used to import a particular commodity, and is associated with the country of destination, in this case Denmark.

In GTAP, margin supply is provided as a separate variable, and must be added to exports from the transport sector of the supplying region in order for the region's I-O table to balance. In our example, the $1,000 worth of fish transport services supplied by Poland must be added to the total exports from the Polish transport sector. Although GTAP provides a separate variable (VST) that gives the total value of all transport margin supply for a given country, it does not provide supply data by commodity or country of origin/destination of the traded good. So in the GTAP database for Poland, we know the total value of margin supply, but we don't know how much was used to transport fish, or how much was used for Norwegian exports or Danish imports. For that matter, we do not know how much of Polish margin supply was used to export from or import to Poland itself.

In contrast, margin demand in GTAP is available by both commodity and country of origin/destination of the traded good. So in our example, the GTAP data for Denmark would include not only the $1,000 transport margin for fish imports, but we would also know that that margin was associated with exports from Norway. It would also include the value of transport margins for fish imports from any other country, as well as imports of any other commodity. What is not included, however, is which country supplied the transport services for each bilateral trade flow, even if it was Denmark itself.

In summary, using the GTAP data it is only possible to identify a country's total transport margin supply to the international transport sector and the transport services associated with imports of each commodity. It is not possible to match transport supply with demand on a bilateral basis.

In order to describe these aspects of the data more formally, we present a short outline of the trade and price identities in the next paragraphs.

3.3 Measures of imports and exports including transport margins

The following definitions are consistent with GTAP notation and will be used to refer to terms of trade in the data. i denotes a good transported from source region r to destination region s:

$$VXWD(i,r,s) = VXMD(i,r,s) + XTAX(i,r,s)$$

Exports at world price = Exports at market price + export taxes

In other words, the price of a good on the world market (i.e., in world prices or in terms of f.o.b. (free on board)) is its market price in the country of origin modified by the corresponding export taxes. Note that exports at world prices do not include the cost of transport. For imports, we have:

$$VIMS(i,r,s) = VIWS(i,r,s) + MTAX(i,r,s)$$

Imports at market prices = Imports at world prices + import taxes

The value of imports at world prices includes both export duties and the cost of transport, and the cost of import duties is added as well in order to arrive at market prices in the importing country. Thus, the difference between exports at world prices (f.o.b.) and imports at world prices (or in c.i.f. terms) is the international transport margin $VTWR(i,r,s)$:

$$VXWD(i,r,s) = VIWS(i,r,s) - VTWR(i,r,s)$$

Since exports at world prices from r to s equal imports at world prices minus transport margins from r to s we get:

$$VIMS(i,r,s) = VXMD(i,r,s) + VTWR\ (i,r,s) + XTAX(i,r,s) + MTAX(i,r,s)$$

Imports at market price = Exports at market price + transport demand + export duties + import duties

This identity describes transport margin demand associated with imported goods. GTAP 6 provides an extra data array for transport supply $VST(r)$ that denotes transport i supplied by region r -- i.e., the value provided by a country's transport sector for transporting goods internationally, whether it is for exporting goods, importing them, or transporting them between two other countries[2]. As described above, transport

[2] Transport supply is also differentiated by mode of transport (land, water, or air) in the GTAP data, but we do not use that distinction in our analysis.

supply is not disaggregated by the commodity which employs transport services for exports. Nonetheless, transport margin supply and demand equal when summed over all indices, but not necessarily for bilateral transport since the transport services can be provided by a third country.

3.4 Treatment of trade margins in the PET model

The PET model requires the value of exports from a source region to be equal to the value of imports in a destination region. In GTAP, bilateral imports and exports are not of equal value, because even when measured in world prices, they differ by the value of transport margins. In general there are two options for establishing this equality: either include transport margins in the value of both exports and imports, or include margins in neither. We choose the approach of including transport margins in both exports and imports, in order to ensure that the economic activity associated with transport services for internationally traded goods, which can be substantial particularly for some energy goods, is captured within the model.

Since margins are already included in the value of imports, we need a method to incorporate their value in bilateral exports as well. Ideally, the method would also preserve the total value of margins supplied by each region as a whole. As discussed above, GTAP provides data on total margin supply by region, but it is not disaggregated by sector or region of origin/destination of the traded goods, which is essential for producing balanced trade flows. In brief, our method produces an estimate of margin supply disaggregated by sector and region based on a set of simplifying assumptions. It consists of the following steps:

1) Assume all margins are supplied by the country of origin of the traded goods. Margin data associated with imports are available by sector and country of origin/destination, so we add the value of these margins to exports of the origin countries.
2) Rebalance the I-O table by adding corresponding transport service inputs to each sector that has had transport margins added to the value of its exports. In addition, adjust the region's exports from the transport sector to reflect the redistribution of margin supply in the I-O table.
3) Adjust bilateral trade flows so that they are consistent with any change in aggregate transport sector exports, and preserve bilateral trade balances.

These steps are explained in more detail below, related to our hypothetical example of fish exports from Norway to Denmark, and expressed analytically.

3.4.1 Allocating margin supply to regions of origin

The first step of allocating margin supply to the country of origin of traded goods has two main benefits: it provides a means of capturing the economic activity associated with trade margins (as compared to ignoring margins completely), and it is the simplest and most direct means of balancing bilateral trade flows.

In our fish trade example, this approach would assume that the $1,000 in transport services for exporting fish from Norway to Denmark were supplied by

Norway, and would be added to the value of Norwegian exports from the fish industry. This would produce a value of exports of $11,200 ($10,000 market price + $1,000 margins + $200 export duties), which would be equal to the value of imports to Denmark. The inaccuracy is that, in this case, we know that transport services were actually supplied by a third country, namely Poland. Because of the construction of the GTAP data and our model structure, we are not able to assign the value of these margins to bilateral trade with Poland because in the Polish margin supply data we do not know the origin or destination of the product being transported.

Analytically, we add to the value of each sector's exports the sum of margins associated with trade to each destination region:

$$VXWD'(i,r) = VXWD(i,r) + \sum_{s} VTWR(i,r,s)$$

where $VXWD'$ is the adjusted value of exports from region r, and we have suppressed the index s in $VXWD$ to $VXWD'$ indicate aggregate exports summed over all destination countries.

3.4.2 Rebalancing the I-O table

A consequence of allocating margin supply to exports from the regions of origin is that the GTAP I-O tables for each region become unbalanced: the value of sector outputs has been increased by the value of margin supply added to exports, but the value of sector inputs has remained the same. To restore the equality between inputs and outputs, we adjust the transportation industry inputs to each sector by an amount equal to the margin supply added to exports of that sector. In terms of our example, the value of transport inputs to the fish sector in Norway is increased by $1000, reflecting the payments by the fish industry made to the transport industry to export the product to Denmark. The value of this transport input is already reflected in the value of the fish exports, based on the adjustment we made in the previous section. Analytically, we adjust the transport sector outputs according to:

$$OUT'(TRAN,j,r) = OUT(TRAN,j,r) + \sum_{s} VTWR(i,r,s), \quad i = j$$

where $OUT(TRAN,j,r)$ is the output of the Transport sector in region r that is consumed by sector j and OUT' is its adjusted value. This re-establishes the balance between inputs and outputs in the I-O table in all sectors except the Transport sector. In that sector, one further step is required. Recall that to balance the I-O table, the total value of all transport margins (VST) supplied by a region must be added to the exports of the transport sector. We have now included some amount of that total margin supply in the value of services supplied to other sectors for the transport margins associated with the exports of those sectors themselves. We therefore need to adjust the VST variable to account for the fact that some of the transport margin supply it reflects is now represented in other parts of the table. The adjusted margin supply to the export market, T' , is

$$VST'(r) = VST(r) - \sum_{i,s} VTWR(i,r,s)$$

We refer to $VST'(r)$ as excess margin supply (>0) or demand (<0), since it represents the transport margins supplied by a region in addition to the amount that we have accounted for in the exports of specific sectors. Exports from the transport sector are then increased by this excess supply or demand, rather than by the original VST variable, in order to balance the I-O table.

In terms of our example, suppose that Norway's transport margin supply (i.e., its VST) were $50,000. In adjustments made above, we have already added $1000 of transport margins to exports from the fish industry (and to transport inputs to that industry). We therefore need to reduce the value of transport margin supply that will be added to the exports of the transport sector, so that excess margin supply (VST') for Norway is $49,000. Its total margin supply is still $50,000, we have just accounted for it differently in its I-O table by associating some of that supply with the exports of specific industries rather than with exports of the transport industry.

3.4.3 Assigning transport exports bilaterally

As a final step, the excess supply of or demand for transport margins must also be allocated bilaterally so that bilateral trade balances in the transport sector are maintained. There is no information in the GTAP data on which to base assumptions about the destination of transport supplied to the international market. We introduce an algorithm that allocates excess transport margins from net suppliers to net demanders in the simplest manner. In short, we start with regions that have excess margin supply, and in each case allocate it to trade with regions that have excess margin demand, in proportion to their excess demand.

For example, expand our two country illustration to five, and assume Denmark and Italy are net suppliers of transport services. Norway, Germany and Poland are net demanders:

$$VST'(r) > 0 \qquad if \quad r = Denmark, Italy$$

$$VST'(r) < 0 \qquad if \quad r = Norway, Germany, Poland$$

Total excess margin supply equals the sum of excess margin demand across regions. In order to allocate excess margin supply from Denmark, we distribute across the three countries with excess demand according to their shares of excess demand. Therefore, the modified transport service supply from Denmark to Norway is

$$VST'(DEN, NOR) = VST'(DEN) * \frac{VST'(NOR)}{\sum_{i,r} VST'(r) \; if \; VST' < 0}$$

By applying this procedure to any of the bilateral trade relationships, we come up with balanced bilateral trade flows among all regions.

4. Energy Balancing

As mentioned in section I, the GTAP Data Base provides regional I-O tables and international trade flows in monetary values, but also includes a separate energy volumes database. This database, the GTAP Energy Data Set (EDS) (McDougall and Huey-Lin Lee 2006), is based on data primarily from the International Energy Agency's (IEA's) energy statistics and balances, but also draws on energy price data from several sources. It is produced jointly with the GTAP I-O and trade tables for each region and this joint production process leads to changes in both the energy quantities and the economic values relative to the original data from which they are derived. In our applications, we place high value on employing the best estimates of energy quantities (and associated carbon emissions), and we therefore prefer that the I-O tables be consistent not with the EDS data, but with the original IEA energy quantity data. We therefore carry out our own balancing procedure to establish this consistency. The following sections describe the format of the IEA energy balances and the procedures we follow to energy re-balance the GTAP I-O tables.

Previous efforts at such energy re-balancing of I-O tables follow two broad approaches: calibrating I-O monetary values either to both energy quantity and energy price data, or to energy quantity data alone. In fact, since only two out of three variables (price, quantity, and value) can be regarded as independent, it is problematic to incorporate both energy price and quantity data in a recalibration (Rutherford and Paltsev, 2000). We follow the approach outlined in Sands and Fawcett (2005) that aims to maintain full consistency between the monetary values in the I-O tables and the physical energy volume flows represented in the IEA energy balances.

An energy balance is a two dimensional table that presents all inputs, outputs and uses of different forms of energy inside a given national or regional territory. It is used to record the flows associated with every energy commodity from the point when new energy enters the system of the national/regional energy supply, its transformation and losses that occur in that process, up until all its final end uses. The IEA energy balances that we use for re-balancing the GTAP I-O tables are arranged with all energy commodities on one dimension of the table and all processes or flows, including supply, transformation and end-uses on the second dimension (see Figure 5). Commodities in the IEA energy balances include all energy goods and are classified as either primary (extracted or captured directly from natural resources) or secondary (all energy goods that are not primary but are produced or transformed from primary goods). Flows in the IEA balances are defined as all the processes between the first appearance and final disappearance of energy commodities and include supply, transformation, own use and losses, and final consumption.

Energy Flows	Primary Energy Commodities				Secondary Energy Commodities			
	Coal	Crude Oil	Solid Biomass	...	Kerosene	Coke	Electricity	...
Production								
Trade								
Total Primary Energy Supply (TPES)								
Transformation								
Energy sector own use and losses								
Total Final Consumption (TFC)								
Total Industry Total Transport Total Others Total Non-energy use								

Figure 5. A simplified schematic overview of the IEA energy balances

We undertake the following steps to energy re-balance the GTAP I-O tables using the IEA energy balances:

- Reconstruct the IEA energy balances to match the PET regional and sector classification
- Carry out the energy re-balancing procedure on the GTAP I-O tables using the re-constructed IEA energy balances such that key desirable properties of the I-O tables are maintained.

The sections below provide a more detailed description of these procedures.

4.1 Reconstructing the IEA energy balances

We use the IEA's "Extended Energy Balances" (2008 edition) for OECD and Non-OECD countries as the basis for all the physical energy quantities data that we use in the energy re-balancing of the I-O tables. The IEA databases include detailed energy balances for over 30 OECD and 100 non-OECD countries. The balances have the same structure as that described in Figure 5 above, but include data for over 50 energy commodities accounting for a very detailed set of energy flows. The first set of steps required to carry out the energy re-balancing therefore requires a re-aggregation of the IEA's extended energy balances to match the PET regional and sector classification. This involves:

1. Mapping the IEA countries and regions to GTAP regions.
2. Aggregating the IEA energy commodities to the PET energy sectors.
3. Mapping the IEA energy flows to match the PET sectors.
4. Checking to ensure that energy supply equals energy use in the reconstructed energy balances.

We use the information provided by McDougall and Huey-Lin Lee (2006) and Rutherford and Paltsev (2000) to map IEA countries and regions to the GTAP classification (see Table 2 in the Appendix). We aggregate the IEA energy commodities to the PET energy sectors largely by following the mapping rules provided in McDougall and Huey-Lin Lee (2006) that describe how the IEA energy commodities are aggregated in the GTAP's EDS. The GTAP EDS, however, discards certain energy commodities for which data are provided in the IEA balances. For the purposes of the PET model, in order to carry out a full accounting of all energy, we adjust the mapping rules and carry out certain further modifications and aggregations to map the IEA energy commodities to the PET energy sectors (see Table 3 in the Appendix for the exact matching rules).

We also re-classify the IEA energy flows to match the PET sectors, largely following EDS industry classification as elaborated in McDougall and Huey-Lin Lee (2006). We carry out certain further refinements again to ensure that all flows are accounted for and matched to the PET sectors. The details of the rules used for mapping the IEA energy flows to the PET sectors are summarized in Appendix Table 4. The level of detail included in the IEA's extended energy balances allow for a one-for-one match between the energy flows and the PET sectors in almost all cases. Two exceptions occur in the case of (1) agricultural and food sectors, and (2) services and water sectors. In the PET model, we disaggregate the primary agricultural & forest, and manufactured food sectors into 'rice', 'other crops', 'animal products', and 'forestry', with the first three of these including both primary and manufactured products associated with each sector. Within the IEA extended energy balances, there exists only a single final consumption sector representing 'agriculture and forestry', and another for 'food products'. We therefore aggregate the agriculture and forestry sector with the food products sector in the energy balances. In order to split out the final energy consumption from this aggregated sector to the four PET sectors mentioned above, we use the shares of expenditures on the specific energy commodities in monetary values from the GTAP I-O table. This approach makes a simplifying assumption that the energy intensity of production of each of these four sectors is identical. A similar procedure is applied to split the energy flows to the 'other services' and 'water' sectors in the PET sector classification, since the IEA balances only provide information for the single final consumption sector 'commercial and public services' that includes water.

Finally, we carry out a balance check to ensure that energy supply for each of the aggregated energy commodities matches energy use or demand in the re-constructed energy balances. The general structure of the IEA energy balances are maintained in the reconstruction, but the table is ultimately transposed so that it resembles the general structure of the GTAP I-O table.

4.2 The energy re-balancing procedure

Once we have the re-constructed IEA energy balances for our PET regions, we use these to rebalance the GTAP I-O tables to maintain full consistency between the monetary values in the I-O and the physical energy volume flows represented in the energy balances. The re-balancing procedure involves the following steps:

1. Construct a hybrid I-O table by substituting physical energy flows from the reconstructed energy balances for the monetary values in the energy rows of the I-O tables and treat all values except those for the value added components (i.e.

primary factors and taxes) and imports and exports in the hybrid I-O table as quantities.
2. Estimate prices for each PET sector. Prices are calculated as simple unit values by taking the ratio of total output in monetary values from the original I-O to the total physical quantity from the reconstructed energy balance for each respective energy sector. For non-energy sectors, assume the original prices are unitary.
3. Solve the set of linear equations represented in the table by equating value of output (quantity*price) for each sector with the total value of inputs – i.e., equating every row sum to the corresponding column sum. The solution to this set of equations determines a new set of prices for each sector that rebalances the table.
4. Create the new re-balanced I-O by multiplying all quantities with the newly determined prices derived in the previous step.

Ideally, all final demand components including imports and exports should be energy re-balanced as well. However, we exclude imports and exports from the re-balancing procedure so as to maintain the bilateral trade balances in the GTAP I-O tables assured through the procedures described in section 3, which are required for the PET model to operate.

The key characteristics of the re-balancing procedure we use are that it ensures adherence to the energy balances, preserves energy quantities in the base year, and maintains energy balances as the PET model operates through time. In addition, the procedure also has certain other appealing properties. The rebalancing we carry out for the PET model calibration is also designed to enforce the law of one price for each energy commodity. Finally, as we mentioned above, value added components are unchanged from the values in the original GTAP I-O table and therefore this implies that the identity between Aggregate Final Demand and Value Added is also maintained.

5. Disaggregating Household Consumption

The GTAP I-O tables represent household consumption as a single column of expenditures. This column includes separate expenditures on goods produced by each of the production sectors. However, we are interested in applying the PET model to questions in which shifts in demand across different types of goods may be important, and for that purpose, we require splitting the single column of expenditures into several sub-categories of goods so that they may be separately modeled. We do this through the development of a matrix, which we call the “G-Matrix” (where “G” stands for goods). This matrix is used to split the payments that households make to various industries into multiple columns. In general our aim is to be able to include up to 16 consumption goods in the model, although current applications employ four. A detailed description of these consumption categories is given in the Appendix (see Table 5; Zigova et al. forthcoming).

5.1 Basic structure of the G-Matrix

In the current version of the PET model there are 5 production sectors and 4 consumption categories, “energy”, “food”, “transport” and “other” (basically everything else), so we use this model configuration as an illustration of the matrix structure. The

G-Matrix links the production sectors to the consumption categories via a 5x4 Matrix (Figure 6) that multiplies the consumption column in the I-O table (see section I.A.), yielding 4 consumption columns representing expenditures on four different consumption good categories. This operation is performed by a row-wise scalar multiplication.

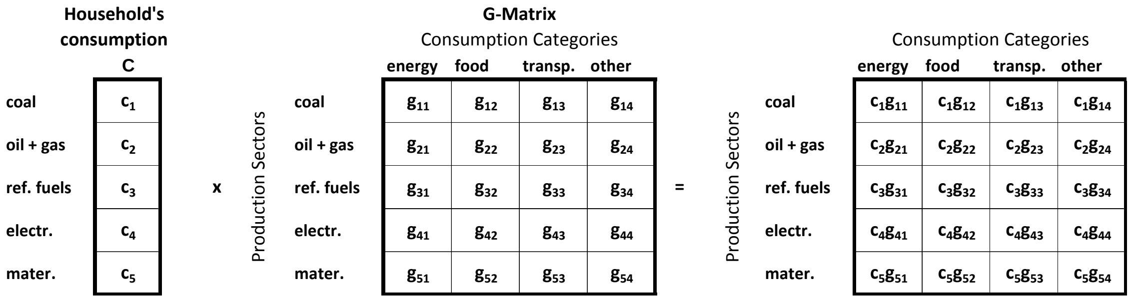

Figure 6. Illustration of use of the G-matrix.

Each row of the G-matrix consists of shares that sum to 1.0, which act to divide the payments by households to a given industry into payments to that industry associated with each of the disaggregated goods. This structure ensures that the resulting expenditures on the set of disaggregated goods are identical to expenditures represented by the original single consumption column, in terms of both total expenditures and payments to particular industries. The main substantive issue is the derivation of these shares constituting the elements of the matrix in order to represent expenditures on alternative goods as accurately as possible.

5.2 Deriving elements of the G-matrix

The steps required to derive elements of the G-matrix depend on the degree of correspondence between consumption goods and production sectors. Ideally we could define the consumption goods in one-to-one correspondence to the production sectors. In that case, the G-Matrix would be an Identity-Matrix (1s on the diagonal, 0s off-diagonal). For example, assume we only have 2 production sectors, "energy" and "other," as well as 2 consumption categories, "energy" and "other". The G-Matrix would look as follows:

	energy	**other**
energy	1	0
other	0	1

Payments by households for the energy good they consume would be made entirely to the energy sector, and payments for the "other" good would be made entirely to the "other sector". Determining that goods and sectors corresponded exactly would be done by inspection of the subsectors included in the aggregate "energy" and "other" production sectors, and comparing them to the definition of the two consumption goods. This comparison allows determination of whether there is complete correspondence between a consumption good with a production sector.

To take a slightly more complicated example, we return to our previous example of 5 production industries and 4 consumption sectors as used in the current PET model version. In that case, the G-matrix would have the following illustrative structure:

	energy	food	transp.	other
coal	1	0	0	0
oil + gas	1	0	0	0
ref. fuels	0.9	0	0.1	0
electr.	1	0	0	0
mater.	0	0.33	0.33	0.33

Here, the matrix elements that are 1's and 0's are determined in the same way as above: by examining (in the GTAP data) the sub-sectors of the five aggregate industries, and comparing them with the definitions of the four consumption goods. This allows one to determine, for example, that all of the output of the coal industry that is consumed by households is consumed as part of the aggregate energy good (and none of it as part of the food, transport, or other good). The same also applies for the household consumption of output of the oil and gas, and electricity sectors.

In some cases, the correspondence of an industry to a single good is not exact, but the correspondence to more than one good combined, is. For example, in the case of the refined fuels sector, some of the outputs of that sector might be transport fuels (part of the transport good), and the rest used for other purposes such as household heating that are part of the energy good (in the the GTAP data we are not actually so fortunate in the case of transport fuels, but it serves as a useful hypothetical example). Such cases can be handled by examining the disaggregated sub-sectors making up the refined fuels industry, separating those that produce transport fuels from those that produce other fuels, and deriving shares for the relevant G-matrix row (0.9 and 0.1 in the illustration above) based on the payments by households to these sub-sectors. GTAP 6 disaggregates the economy into 57 production sectors. In most cases this level of disaggregation provides sufficient detail for determining G-matrix elements.

Nonetheless there are cases where the correspondence between industries and goods is inexact and we need an alternative strategy. The most important of these cases occurs when there is insufficient disaggregation in the available production data to cleanly divide household payments to an aggregate industry among different consumption goods. Examples in the GTAP data include coal products and petroleum products, which are part of a single industry within GTAP but are part of separate consumption goods according to our 16-good configuration. Similarly, transport fuels are not distinguished in GTAP from other fuels.

In these types of cases we employ one of two strategies to further disaggregate the GTAP data:

1. Use information from the energy balances (IEA 2008a, IEA 2008b). Since the IEA data includes more disaggregation in some cases than the GTAP data, we use the shares of energy use between two industries as a proxy for the share of payments to those two industries by households. So, for example, the GTAP data does not explicitly distinguish fuels consumed for transport from other uses of fuels. We therefore use the share of energy consumption for transport as distinguished in the IEA data in order to split payments for transport fuels from payment for fuels in general in the GTAP data.
2. Use information from the household surveys. If disaggregated IEA data are not available, we use data from the household expenditure surveys to further disaggregate the GTAP production data. For example, we use the share of expenditures on processed food found in the expenditure surveys to estimate the share of the output of the agricultural sectors in the GTAP data that are associated with processed food production.

Another type of special case occurs if a production sector is not part of the definition of any consumption good; e.g. crude oil, other minerals, etc. This is a reasonable outcome since private households rarely consume products like crude oil but rather consume refined petroleum products. In such a case, we either ignore this sector (if household consumption of its output is zero), or assign it to the consumption category that it is most closely related to (if its household consumption is positive).

6. Discussion

Previously data used to calibrate the PET model in its application for individual country case studies came largely from national data sources, including national I-O tables and energy balances and statistics. The calibration of a new global version of the PET model, however, requires a consistent set of production accounts and energy quantity data for all world countries and regions. Data of this type can of course be constructed on country-by-country bases from local national data sources. However, this is an extremely data intensive and laborious exercise. Therefore, we employ the use of international data sets, in particular, GTAP data and IEA energy balances, for calibrating the PET global version. There are, however, some limitations to using such international data sets, and this report presents some of the methods developed and modifications we have undertaken to extend and make the best use of the GTAP production data and IEA energy balances. In future work and developments of the PET model, however, we still envisage using some national data sources for specific countries. In particular, we would like to take advantage of national data sources for large emerging countries, like India and China, where input-output tables have been published that are more recent than those employed in the GTAP data.

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Appendix:

5 Production sectors	25 Production sectors
1. Coal	1. Coal
	2. Biomass
2. Oil and gas	3. Oil
	4. Gas
3. Refined fuels	5. Petroleum products+
	6. Coal products+
	7. Methanol+
	8. Ethanol+
	9. Syngas+
	10. H2*
4. Electricity	11. Electricity**
	12. Nuclear***
	13. Renewables***
5. Materials	14. Forestry
	15. Rice
	16. Other crops
	17. Animal products
	18. Fish
	19. Other Processed Food
	20. Transportation equipment
	21. Transportation services
	22. Mining
	23. Manufacturing
	24. Water
	25. Other services

+ not available seperately in GTAP, merged to "Petroleum and Coal products"

* H2 for transport only

** includes co-generated heat and H2 for industrial use.

*** discarded in GTAP, but accounted for in energy balancing.

Table 1. Composition of production sectors in the PET Model

4 SRES Regions	9 Regions	24 Regions	GTAP regions	IEA regions	Inconsistencies
1. OECD-Countries (OECD)	1. USA (US)	1. USA (US)	usa	USA	IEA includes data for American Samoa, Guam, Puerto Rico & Northern Mariana Islands, Virgin Islands partially in this region
	2. EU27+	2. EU27+	aut, bel, dnk, fin, fra, deu, gbr, grc, irl, ita, lux, nld, prt, esp, swe, che, xef, cyp, cze, hun, mlt, pol, rom, svk, svn, est, lva, ltu, bgr, xna	EU27 + ICELAND+NORWAY	Lichtenstein &, Greenland missing; Bermuda and Saint Pierre & Miquelon are in OTHERLATIN; France includes Monaco; Italy includes San Marino and Vatican; Portugal includes Azores and Madeira; Spain includes Canary Islands
		3. Japan (JPN)	jpn	JAPAN	
		4. S. Korea (KOR)	kor	KOREA	
		5. Hong Kong (HKG)	hkg	HONGKONG	
		6. Canada (CAN)	can	CANADA	
		7. Singapore, Taiwan (ST)	sgp, twn	SINGAPORE+TAIPEI	
	3. Other Industrialized Countries (OIC)	8. Australia, New Zealand (ANZ)	aus, nzl	AUSTRALI+NZ	
2. Reforming Economies (REF)		9. Russia (RUS)	rus	RUSSIA	
	4. Transition Countries (TC)	10. Other Transition Countries (OTC)	xer, alb, hrv, xsu	ALBANIA+ BOSNIAHERZ+ CROATIA+ ARMENIA+ AZERBAIJAN+ BELARUS+ GEORGIA+ KAZAKHSTAN+ KYRGYSTAN+ MOLODOVA+ SERBIA+ TAKIKISTAN+ TURKMEINST+ UKRAINE+ UZBEKISTAN	Andorra, Faroe Islands, Montenegro missing
3. Asia (ASIA)	5. China (excl. Hong Kong) (CHN)	11. China (excl. Hong Kong) (CHN)	chn	CHINA	
	6. India (IND)	12. India (IND)	ind	INDIA	
		13. Indonesia (IDN)	idn	INDONESIA	
		14. Vietnam (VNM)	vnm	VIETNAM	
		15. Malaysia & Phillippines (MP)	mys, phl	MALAYSIA+PHILIPPINE	
		16. Turkey (TUR)	tur	TURKEY	
		17. Middle East and North Africa (MENA)	xme, mar, tun, xnf	MOROCCO+ TUNISIA+ ALGERIA+ EGYPT+ LIBYA+ BAHRAIN+ IRAN+ IRAQ+ ISRAEL+ JORDAN+ KUWAIT+ LEBANON+ OMAN+ QUATAR+ SAUDIARABI+ SYRIA+ UAE+ YEMEN	Palestinian Territory, Occupied missing
	7. Other Developing Countries (ODC)	18. Other Developing Countries (ODC)	xoc, xea, tha, xse, bgd, lka, xsa	THAILAND+ BANGLADESH+ SRILANKA+ OTHERASIA+ KOREADPR+ MYANMAR+ NEPAL+ PAKISTAN	Brunei Darussalam, Timor Leste, Marshall Islands, Nauru, Norfolk Island, Niue, Palau, Tokelau, Tuvalu, Wallis and Futuna missing. Some Islands in xoc are in USA
4. Africa and Latin America (ALM)		19. Mexico (MEX)	mex	MEXICO	
		20. Brazil (BRA)	bra	BRAZIL	
		21. Pacific South America (PSA)	per, xap, chl	PERU+ CHILE+ BOLIVIA+ ECUADOR	
	8. Latin America and Carribean (LAC)	22. Other LAC (OLAC)	col, ven, arg, ury, xsm, xca, xfa, xcb	COLUMBIA+ VENEZUELA+ ARGENTINA+ URUGUAY+ OTHERLATIN+ COSTARICA+ CUBA+ DOMINICANR+ ELSALVADOR+ GUATEMALA+ HAITI+ HONDURAS+ JAMAICA+ NANTILLES+ NICARAGUA+ PANAMA+ PARAGUAY+ TRINIDAD	Ariguilla missing; OTHERLATIN includes Bermuda and St Pierre et Miquelon; US Virgin Islands and Puerto Rico are included in USA
		23. South Africa (SA)	zaf	SOUTHAFRIC	
	9. Sub-Saharan Africa (SSA)	24. Rest of Sub-Saharan Africa (OSSA)	bwa, xsc, mwi, moz, tza, zmb, zwe, xsd, mdg, uga, xss	ANGOLA+ BOTSWANA+ MOZAMBIQUE+ TANZANIA+ ZAMBIA+ ZIMBABWE+ OTHERAFRIC+ BENIN+ CAMEROON+ CONGO+ CONGOREP+ ERITREA+ ETHIOPIA+ GABON+ GHANA+ KENYA+ NIGERIA+ SENEGAL+ SUDAN	Cote d'Ivoire, Mayotte, Saint Helena, Togo missing

Table 2. Composition of regions in the PET model

PET Energy Sectors	IEA Energy Commodities
1. Coal	Hard coal
	Brown coal
	Anthracite
	Coking coal
	Other bituminous coal
	Sub-bituminous coal
	Lignite/brown coal
	Peat
	Patent fuel
	Primary solid biomass
	Charcoal
2. Oil and gas	Crude oil
	Natural gas liquids
	Additives/blending components
	Other hydrocarbons
	Natural gas
	Industrial waste
	Municipal waste (renew)
	Municipal waste (non-renew)
	Biogas
3. Refined fuels	Coke oven coke and lignite coke
	Gas coke
	Coal tar
	Coke oven gas
	Refinery feedstocks
	Refinery gas
	Ethane
	Liquefied petroleum gases (LPG)
	Motor gasoline
	Aviation gasoline
	Gasoline type jet fuel
	Kerosene type jet fuel
	Kerosene
	Gas/diesel oil
	Heavy fuel oil
	Naphtha
	White spirit & SBP
	Lubricants
	Bitumen
	Paraffin waxes
	Petroleum coke
	Non-specified petroleum products
	BKB/peat briquettes
	Gas works gas
	Blast furnace gas
	Oxygen steel furnace gas
	Biogasoline
	Biodiesels
	Other liquid biofuels
	Non-specified combust. renewables + wastes
4. Electricity	Elec/heat output from non-spec. manuf. gases
	Electricity
	Heat
	Heat output from non-specified comb fuels
	Nuclear
	Hydro
	Geothermal
	Solar photovoltaics
	Solar thermal
	Tide, wave and ocean
	Wind
	Other renewable electricity sources

Table 3. Correspondence between IEA and aggregate PET energy commodities

IEA EEB ENERGY FLOWS CLASSIFICATION	GTAP EDS CLASSIFICATION	PET CLASSIFICATION
Production	Production	Production
Imports	Imports	Imports
Exports	Exports	Exports
International marine bunkers	Exports	Exports
Stock changes	Discarded	Discarded
Total primary energy supply	TPES	TPES
Transfers	If positive added to TPES of respective energy commodity, if negative added to REF	If positive added to TPES of respective energy commodity, if negative added to REF
Statistical differences	Discarded	Discarded
Transformation sector	SUBTOTAL	SUBTOTAL
Main activity producer electricity plants	ELY	ELY
Autoproducer electricity plants	ELY	ELY
Main activity producer CHP plants	ELY	ELY
Autoproducer CHP plants	ELY	ELY
Main activity producer heat plants	ELY	ELY
Autoproducer heat plants	ELY	ELY
Heat pumps	ELY	ELY
Electric boilers	ELY	ELY
Chemical heat for electricity production	ELY	ELY
Blast furnaces	REF	REF
Gas works	GAS	REF
Coke ovens	REF	REF
Patent fuel plants	REF	REF
BKB plants	REF	REF
Petroleum refineries	REF	REF
Petrochemical industry	REF	REF
Coal liquefaction plants	REF	REF
Gas-to-liquids (GTL) plants	REF	REF
For blended natural gas	REF	REF
Charcoal production plants	Discarded	COAL
Non-specified (transformation)	Add to own consumption of respective energy commodity	Add to own consumption of respective energy commodity
Energy sector	SUBTOTAL	SUBTOTAL
Coal mines	COAL	COAL
Oil and gas extraction	Split between OIL&GAS in proportion of total production	Split between OIL&GAS in proportion of total production
Blast furnaces	REF	REF
Gas works	GAS	REF
Gasification plants for biogas	Discarded	GAS
Coke ovens	REF	REF
Patent fuel plants	REF	REF
BKB plants	REF	REF
Petroleum refineries	REF	REF
Coal liquefaction plants	REF	REF
Liquefaction (LNG)/regasification plants	REF	REF
Gas-to-liquids (GTL) plants	REF	REF
Own use in electricity, CHP and heat plants	ELY	ELY
Used for pumped storage	ELY	ELY
Nuclear industry	Discarded	ELY
Charcoal production plants	Discarded	COAL
Non-specified (energy)	Add to own consumption of respective energy commodity	Add to own consumption of respective energy commodity
Distribution losses	Add to own consumption of respective energy commodity	Add to own consumption of respective energy commodity
Total final consumption	SUBTOTAL	SUBTOTAL
Industry sector	SUBTOTAL	SUBTOTAL
Iron and steel	Iron&Steel	Iron&Steel
Chemical and petrochemical	Chemical and petrochemical	Chemical and petrochemical
Non-ferrous metals	Non-ferrous metals	Non-ferrous metals
Non-metallic minerals	Non-metallic minerals	Non-metallic minerals
Transport equipment	Transport equipment	Transport equipment
Machinery	Machinery	Machinery
Mining and quarrying	Mining and quarrying	Mining and quarrying
Food and Tobacco	Food and Tobacco	Food and Tobacco
Paper, pulp and print	Paper, pulp and print	Paper, pulp and print
Wood and wood products	Wood and wood products	Wood and wood products
Construction	Construction	Construction
Textile and leather	Textile and leather	Textile and leather
Non-specified (industry)	Non-specified (industry)	Non-specified (industry)
Transport sector	SUBTOTAL	SUBTOTAL
International aviation	Transport services	Transport services
Domestic aviation	Transport services	Transport services
Road	Part retained in Transport services, and part shifted to Residential	Part retained in Transport services, and part shifted to Residential**
Rail	Transport services	Transport services
Pipeline transport	Transport services	Transport services
World marine bunkers	Transport services	Transport services
Domestic navigation	Transport services	Transport services
Non-specified (transport)	Transport services	Transport services
Other sectors	SUBTOTAL	SUBTOTAL
Residential	C	C
Commercial and public services	Services	Services
Agriculture/forestry	Agriculture/forestry	Agriculture/forestry
Fishing	Fishing	Fishing
Non-specified (other)	Services	Services
Non-energy use	SUBTOTAL	SUBTOTAL
Non-energy use industry/transformation/energy	Non-specified (industry)	Non-specified (industry)
Non-energy use in transport	Transport services	Transport services
Non-energy use in other sectors	Services	Services

Note** We apportion the amount of flows of Motor gasolene and Gas/Diesel oil to the ROAD sector between Transport Services and Residential sector using shares calculated from the GTAP tables of private consumption of transport equipment to that of the total of private and commercial (intermediate sector) consumption

Table 4. Correspondence between GTAP, IEA and PET energy commodities

4 Consumption sectors	16 Consumption sectors
1. Energy	1. Electricity
	2. Gas
	3. Petroleum products
	4. Coal
	5. Coal products
	6. Biomass
2. Food	7. Rice
	8. Other crops
	9. Meat and dairy
	10. Fish
	11. Processed food
3. Transportation	12. Transport fuels
	13. Transport equipment
	14. Transport services
4. Other	15. Other Services
	16. Other Goods

Table 5. Composition of consumption sectors in the PET Model