Estimating energy accounts for WIOD 2016 (draft)

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1 Introduction

Addressing the problem of climate change has moved high up on the governments' agendas across the world. Effective strategies to reduce country-specific impacts require accurate and reliable environmental statistics. Such statistics should not only account for environmental pressures occurring within the borders of a country but should also allow to consider environmental pressures embodied in imports and exports.

Normally environmental impacts are calculated following production-based accounting (PBA) method. This method assigns the responsibility of a specific factor (e.g. CO2 or energy) to a country where the impact occurs. However, such method allows for the possibility of carbon leakage. With the rise in international trade, many scholars begun to question the effects of trade on the environment. One way to account for factor content embodied in trade and carbon leakage is to use the consumption-based accounting (CBA). Significant attention has been devoted to the use of consumption-based accounting principles in the past few decades.

Multi-regional input-output (MRIO) analysis has proved to be an ideal tool for this task. While MRIO models are a powerful tool for analysing the carbon footprints of countries, their data and computational requirements are often cited as barriers to timely, detailed and robust studies (Andrew et al., 2009). Many

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global input-output databases (EORA, WIOD2013, EXIOBASE) come with the environmental extensions that permit analyses such as estimation of carbon or energy footprints. However, in some cases, for instance, WIOD database released in 2016 does not contain such data.

This study aims to: i) demonstrate how data from the International Energy Agency (IEA) can be used to construct energy accounts that match WIOD 2016 sectoral classification, ii) present detailed comparison of WIOD2016 and WIOD2013 energy accounts, and iii) analyse global energy consumption based accounts (CBA) for the period 2000-2014.

2 Data

2.1 Energy data

Data for this study comes from two sources: i) International Energy Agency (IEA) and ii) World Input-Output Database (WIOD). IEA is the main source for energy data. Latest IEA 2017 edition provides World Energy balances for 178 countries and regional aggregates over the period 1960-2015 (OECD countries and regions) and 1971 -2015 (non-OECD countries and regions). For each year and country, energy balances cover 67 products 85 flows. For example, a flow " iron & steel" contains data of how much and what energy product (e.g., coal, oil) iron and steel industry used during a specific year. A final data extract from IEA has the following dimensions:

Year x country x flow x product = 14 years (2000-2014) x 44 countries x 63 products x 85 flows.

2.2 MRIO data

Multi-regional input-output (MRIO) tables come from WIOD 2013 (WIOD2013 hereafter) and WIOD 2016 (WIOD2016 hereafter) databases. WIOD2013 version is a system of MRIO tables, socioeconomic and environmental accounts. It covers 35 industries and 41 countries/regions, including 27 EU and 13 other major advanced and emerging economies, plus Rest of the World (ROW) region over the period 1995-2011 (environmental accounts only for 1995-2009).

A more recent WIOD2016 database provides data for 56 industries and 44 countries (28 EU, 15 other major countries and ROW region) for the period from 2000 to 2014. It also provides socio-economic accounts but it lacks environmental accounts.

The two databases overlap over the period from 2000 to 2009. WIOD 2016 estimates are compared to WIOD 2013 version over this period to test for the accuracy of the WIOD 2016 estimates. The aim here is to provide estimates that closely resemble those in WIOD 2013 so that the two databases could be linked to study the changes in environmental indicators over an extended period.

3 Methodology

This section outlines the allocation procedure of the 85 flows of the IEA energy balances into the corresponding WIOD 2016 sectors and final demand categories. The procedure to obtain energy accounts starting from energy balances involves a series of steps. Each step is explained in detail below, and all procedure is shown in figure 1. The allocation procedure follows the steps outlined in previous studies by Genty et al. (2012); Kuenen et al. (2013); Wiebe and Yamano (2016), Owen et al. (2017).

3.1 IEA Allocation Procedure

3.1.1 Step 1

The IEA energy balances show the supply and the use of energy products by industries and final use categories as in table 1. The very first step in deriving energy accounts from IEA energy balances is to separate the use and the supply of energy products.

Energy use consists of the total final consumption by industry; the aviation and marine bunkers; the energy sector own use (with a changed algebraic sign) and transformation processes (with a changed algebraic sign).

Table 1 A simplified version of the IEA energy balances, (exemplified with data for Germany 2014)

		Energy Products				
		1	2	…	63	**Total**
Flow	**Total primary energy supply (TPES)**	…	…	…	…	**306790**
	Production	…	…	…	…	119734
	Imports	…	…	…	…	245472
	Exports	…	…	…	…	-49483
	International marine bunkers	…	…	…	…	-2282
	International aviation bunkers	…	…	…	…	-8038
	Stock changes	…	…	…	…	318
	Transfers	…	…	…	…	740
	Statistical differences	…	…	…	…	329
	Transformation processes	…	…	…	…	**-74243**
	Energy industry own use	…	…	…	…	**-16224**
	Total final consumption	…	…	…	…	**216322**
	Industry	…	…	…	…	54882
	Transport	…	…	…	…	54998
	Other	…	…	…	…	84323
	Non-energy use	…	…	…	…	22120

3.1.2 Step 2

The next step is to establish a correspondence key linking energy balance items and WIOD 2016 industries plus households. The correspondence matrix is displayed in table . Zero value "0" means no link and "1" represents a link between the IEA flow and WIOD sector(s). The columns containing only one entry represent one-to-one allocation, for example, column "International marine bunkers" is allocated to WIOD sector "Water transport". The IEA flows that contain multiple entries of "1" represent one-to-many allocation. For instance, the IEA flow "iron and steel" is allocated to two WIOD sectors "Manufacture of basic metals" and "Manufacture of fabricated metal products, except machinery and equipment".

3.1.3 Step 3

While one-to-one allocation is a straightforward task one-to-many allocation requires disaggregation of a specific IEA flow among several WIOD sectors. The splitting key is the input of energy-related sectors from the WIOD2016 IO tables in monetary terms.

3.1.4 Step 4

The above steps are combined to obtain the use of energy products by WIOD sectors and final demand categories using the following equation.

$$\mathbf{WEU} = \mathbf{EU} \times \mathbf{EUAM}$$

Where, **EU** is the IEA energy use table as explained in Step 1 with dimension 63 x 5355 (63 products x 85 flows). This matrix is obtained by diagonalising the 63x1 vector corresponding to each IEA energy flow and stacking it horizontally.

EUAM is the energy use allocation matrix as explained in steps 2 and 3 with dimension 5355 x 56. This matrix is obtained by diagonalising the 1x 57 (56 industries + households) vector corresponding to each column in the correspondence matrix and stacking it vertically.

WEU is the WIOD energy use matrix with dimension 63x57 representing the use of 63 energy products by 56 WIOD industries plus households.

To evaluate the accuracy of WIOD 2016 energy use estimates, the difference between WIOD2103 energy use and WIOD2016 energy was taken as a measure of estimation error (similar has been used by Olsen et al 2014 to estimate MRIO aggregation error The relative error ($\boldsymbol{\varepsilon}$) between WIOD2013 ($\mathbf{W1}$) and WIOD 2016 ($\mathbf{W2}$) for a given year (t) and country (r) is defines as:

$$\varepsilon_t^r = \frac{\mathbf{W2}_t^r - \mathbf{W1}_t^r}{\mathbf{W1}_t^r}$$

where $\mathbf{W1}$ and $\mathbf{W2}$ is total energy use (from production perspective) for WIOD 2013 and WIOD 2016 respectively.

3.2 Calculation of Energy CBA

A standard environmentally extended Leontief model is applied to calculate energy footprint for WIOD 2013 and WIOD 2016. The basic Leontief model can be expressed as:

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{Y} = \mathbf{LY}$$

where, $\mathbf{x}$ is the vector of output, $\mathbf{A}$ is the matrix of technical coefficients, $\mathbf{Y}$ is the matrix of final demands and $(\mathbf{I} - \mathbf{A})^{-1} = \mathbf{L}$ is the total requirement matrix representing interdependencies between industries. The IO model in equation 1 is extended to incorporate energy use as:

$$\mathbf{E} = \mathbf{eLY}$$

where, $\mathbf{E}$ is the total energy requirements and $\mathbf{e}$ is the direct energy intensity vector representing energy use per unit of output for a given country.

4 Results (preliminary)

4.1 WIOD 2016 allocation results

The difference between WIOD2016 energy use estimates in comparison with WIOD2013 for selected years and the average for the period 2000-2009‡ are

‡ The average for the period 2000-2009 is calculated taking absolute difference ignoring any negative values.

presented in table 2. The results indicate that for most countries WIOD2016 estimates are very similar to WIOD2013. For most countries the estimates vary between 1-4% per cent and in most cases the difference is positive. This implies that WIOD2016 energy use estimates are on average higher than WIOD2013. But there are also some exceptions e.g., Denmark, the Netherlands, Germany.

For Denmark, Malta , Belgium and Luxembourg the estimates display greater discrepancies and vary between 10-20%. For Denmark and Luxembourg the results are underestimated and for Malta and Belgium overestimated. For China and Austria WIOD2016 energy use estimates are on average 7-9 % greater than WIOD2013.

Switzerland, Croatia and Norway were not included in WIOD2013 release thus it was not possible to present the estimation error for these countries.

Table 2 Estimation error of WIOD 2016 Energy Use accounts, selected years

	2000 ε_{00} (%)	2005 ε_{05} (%)	2009 ε_{09} (%)	2000-2009 $\lvert\varepsilon_{00-09}\rvert$ (%)
Denmark	-11,0	-19,9	-23,2	18,8
Malta	14,4	8,2	29,3	14,7
Belgium	9,1	13,1	10,7	13,8
Luxembourg	-10,4	-9,2	-18,5	11,3
China	7,3	10,1	8,6	9,1
Austria	7,7	9,1	7,0	8,3
Slovakia	4,9	5,9	5,6	5,4
Rest of World	3,4	4,4	5,6	4,5
Spain	5,0	4,2	4,4	4,4
Finland	5,5	5,0	3,3	4,4
Netherlands	-6,4	-4,3	-1,0	3,9
Taiwan	-1,9	-3,2	-5,4	3,3
Brazil	3,2	3,0	2,7	3,2
Ireland	1,2	-2,8	-8,8	3,2
Romania	1,8	4,4	2,1	3,1
Czech Republic	3,0	2,9	2,5	3,0
Greece	5,5	-2,9	-2,3	2,8
Bulgaria	2,9	2,8	1,3	2,6
Latvia	-1,4	-1,7	5,3	2,2
Cyprus	1,2	3,1	-1,4	1,9
Russia	2,1	1,7	1,1	1,7
Poland	1,6	1,6	1,5	1,6
Sweden	2,0	1,2	1,7	1,6
Estonia	-2,6	-1,2	-0,1	1,4
France	1,6	1,4	1,1	1,4
Portugal	1,7	1,0	1,2	1,4
Great Britain	1,0	1,1	1,2	1,3
Italy	0,3	1,7	1,9	1,3
Canada	0,6	1,5	1,6	1,2
Hungary	0,7	1,4	0,8	1,2
Australia	0,4	-1,6	1,8	1,1
Germany	-0,2	-0,9	-1,0	1,0
Mexico	-0,6	-0,1	0,5	1,0
Indonesia	0,2	-0,4	0,5	0,9
India	-0,9	-0,2	1,0	0,7
South Korea	0,9	0,6	-0,4	0,7
Lithuania	0,1	1,1	1,5	0,7
Japan	-0,3	-0,5	-1,0	0,6
Slovenia	0,2	0,1	1,7	0,4
Turkey	-0,1	-0,1	-1,0	0,4
United States	0,2	0,3	-0,5	0,2
Switzerland	n/a	n/a	n/a	n/a
Croatia	n/a	n/a	n/a	n/a
Norway	n/a	n/a	n/a	n/a

4.2 PBA and CBA results for WIOD216 vs WIOD2013

WIOD2016 energy use estimates from the previous step have been applied to calculate energy footprint (CBA) for the period 2000 to 2014. The results for selected countries (China, Germany, Japan and the US) are displayed in figures 1-4 together with WIOD 2013 results for the period 1995-2009. Two databases overall over the period 2000-2009 so it can be used to see how the differences between WIOD2013 and WIOD2016.

Figure 1 display CBA and PBA results for the USA. PBA results are virtually the same when calculated using WIOD2013 and WIOD2016 version. On the other hand, CBA results are greater when calculated using WIOD2016 especially during the period 2000-2006. Finally, we can see that energy use has stabilised in the US after 2008 for both PBA and CBA measures.

The same results are displayed for China in figure 2. Here, we can see that WIOD2016 results are greater for both PBA and CBA measures, but they follow the same trend as WIOD2013. The results for the period after 2009 show that energy use in China continues to increase.

The results for Japan are displayed in figure 3. In general the results for Japan are similar to those of the USA. PBA energy use is virtually the same when calculated using WIOD2013 and WIOD2016 data. Whereas, CBA is larger when calculated with WIOD2016 than with WIOD2013. Since 2009 energy use in Japan have declined according to both PBA and CBA measures.

The results for Germany displayed in figure 4 show a different story. PBA estimates are virtually the same according to both WIOD2013 and WIOD2016 calculations. CBA results are different in the sense that WIOD2016 display lower values than WIOD2013 which is opposite from those seen for the US and Japan.

Figure 1. The USA PBA and CBA energy use, WIOD2013 vs WIOD2016

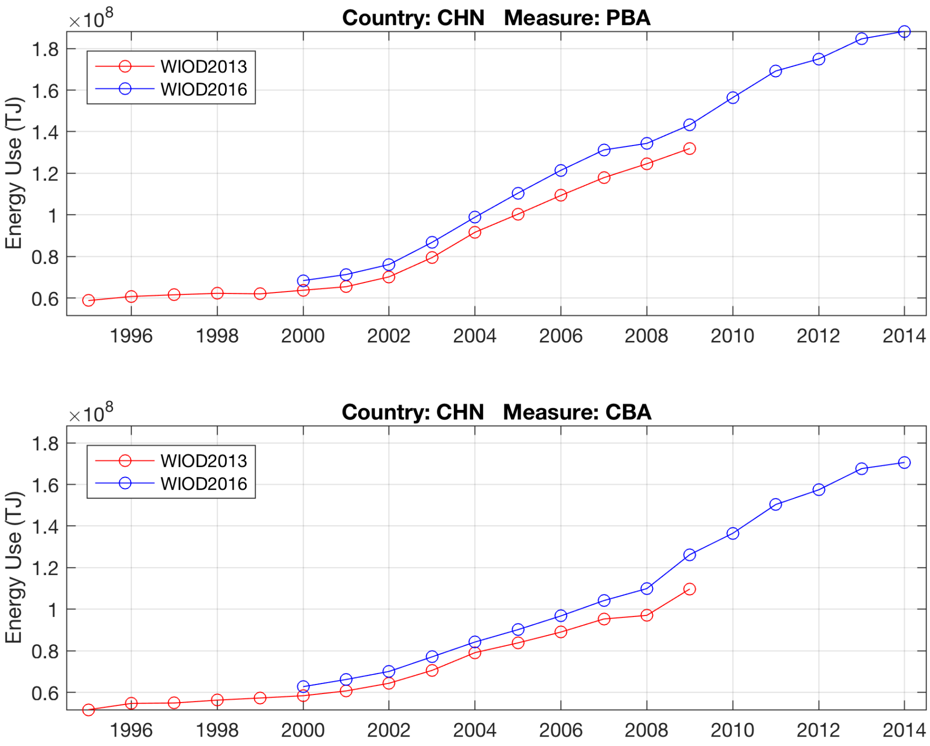


Figure 2. China PBA and CBA energy use, WIOD2013 vs WIOD2016

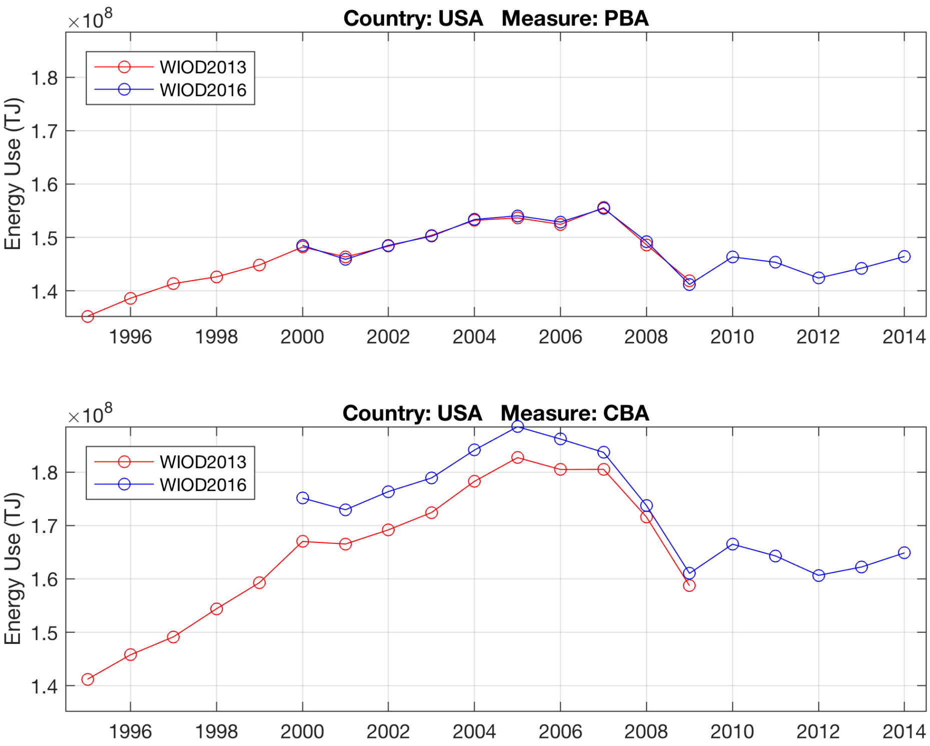


Figure 3. Japan PBA and CBA energy use, WIOD2013 vs WIOD2016

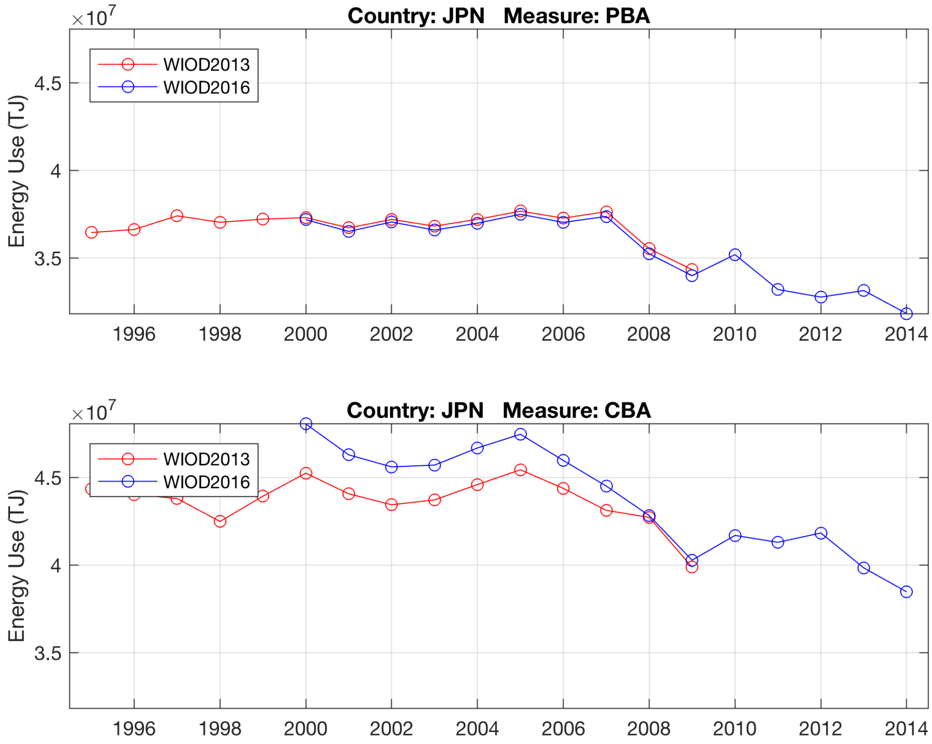
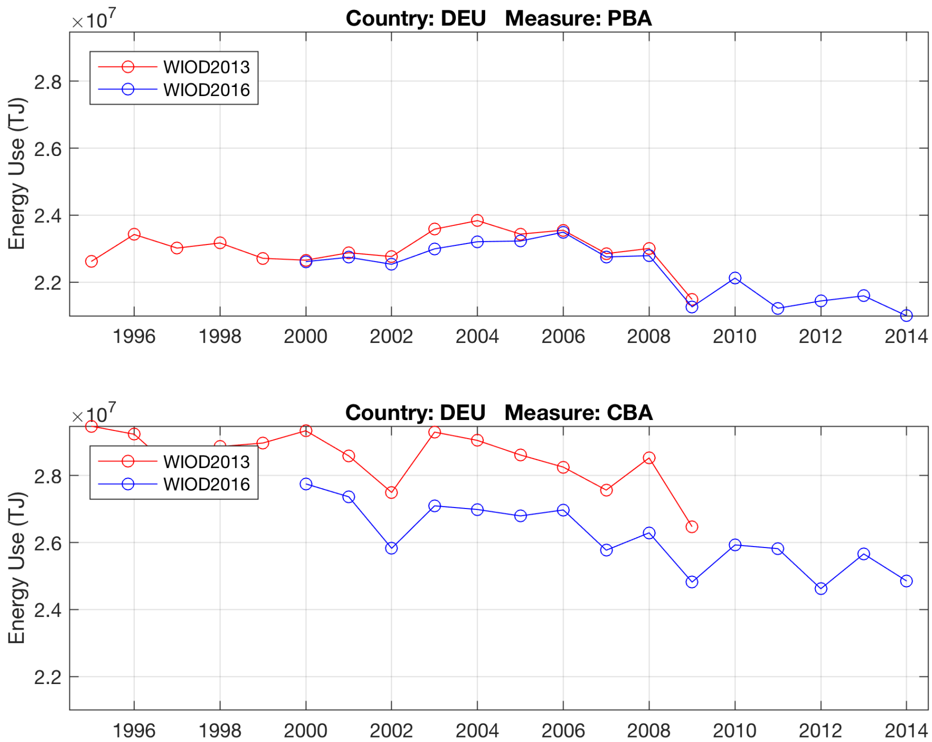


Figure 4. Germany PBA and CBE energy use, WIOD2013 vsWIOD2016



5 Discussion and Conclusion

To be added.

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