Embodied energy of Chinese Provinces

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Abstract

In order to counteract global resource depletion China is said to play a key role through reducing her own energy intensity of goods, products and services. Having just missed the target of 20% efficiency reduction per unit of GDP, effective policies need to be set in place that aim at reducing intensity of industries and sectors. We use energy consumption profiles of industries in three provinces in China as well as the latest economic input-output tables (2007) to construct a hybrid unit input-output model where primary and secondary energy sectors are represented in physical units (petajoules) and non-energy sectors in monetary units (RMB). We then analyze indirect- and direct energy embodied in industry production of the province Hubei, Zhejiang and Gansu. Each province has a very distinct economic make up, so that the study reflects the disparate socio-economic differences prevalent in China, its effect on embodied energy and the potential implication on energy policy. Focus of this conference paper is, for one, to give the rationale for using hybrid energy analysis: the opportunity in our case of sufficient data availability that allows us to apply the full hybrid method taking into account energy conservation rules to construct energy coefficients. The other focus of this work is on presenting the process of data collection and methodology. Results and discussion will be revealed in a later paper.

1 Introduction

Within the field of input-output analysis exists a technique for measuring the energy use in producing goods and services of an economy using physical (-energy) units for all primary and secondary energy sectors in an input-output matrix. Given sufficient data availability the so called full hybrid-unit analysis, which takes into account energy conservation conditions, is suitable to trace the energy needed for production of goods and services for delivery to final demand. The method shows the effect of consumer spending on direct and indirect energy use. For example, say a consumer buys a new car, this will have a direct effect on transactions among industries (manufacturer mainly) as well as an indirect effect (on the steel making industry as well as transport) in the interindustry matrix of the input-output table. The direct and indirect energy coefficients can be used to calculate the energy effects created by such transactions.

Ultimately energy input-output analysis gives an opportunity to link economic input-output tables with ecological and environmental research. Following the energy crisis in the 1970's, hybrid unit models have been used as a tool to give recommendations for appropriate design of energy policies (Wright, 1974, Bullard and Herendeen, 1975). The technique has been broadly applied to evaluate overall efficiency of production systems, to show effects of inter-fuel substitution on energy intensity, to investigate technological change, as well as to estimate different energy use due to changes in final demand (Costanza, 1981, Bullard et al., 1978, Hawdon and Pearson, 1995). Recently, in the light of climate change mitigation efforts and growing concerns of global resource scarcity, hybrid energy analysis has regained attention as a framework for energy policy analysis.

1.1 Challenges and motivation of research

The problem with hybrid energy analysis is that it relies on good data availability showing detailed levels of energy consumption of all industries within an economy. This data is not always available or easy to construct. Therefore, in many cases a simpler method for estimating the energy use per dollar's worth of output of each industrial sector is applied. This technique, referred to as the energy coefficient method, simply adds a set of linear energy coefficients to each industry (Miller and Blair, 1985). The major drawback of this method is that it conforms to physical energy conservation rules only when interindustry prices of energy are uniform across all sectors. This, however, is not the case in any large economy like China, instead we observe that sales prices of energy vary among industries (NSBC, 2007). We give an illustration of this problem. Say we have a power series expansion of the Leontief formulation:

$$F(I-A)^{-1}y = Fy + FAy + FA^2y + FA^3y + \dots$$

where F is the energy (coefficient) intensity, A is a normalized IO tables, and y the final demand. This standard environmental input-output formulation automatically allocates energy use (for example from power generation) to the consumer or producer.

The first term, Fy shows the direct energy embodied in production of a sector, the second term, FAy, contains all the first tier inputs including electricity production by the power generation sector. Thus, in the second term all energy use is reallocated from the power generation sector to all other industries. This step inherently assumes that the price of energy is the same for all industries. Using hybrid units, expressing the energy sectors in energy units would avoid this problem (Peters et al. 2004, Miller and Blair 1985).

In our paper we take opportunity of the dataset on energy consumption available from the Chinese Energy Yearbook (ESYB) of the year 2007. We used this data to construct detailed energy consumption profiles of all industries in 30 Chinese provinces. We then apply a full hybrid energy input output analysis to three Chinese Provinces using the most recent national and province level commodity by commodity input-output tables from the year 2007. Energy intensity research on China using input-output so far has focused solely on a simpler analysis than applied here, the energy coefficient method, mainly revolves around assessing energy embodied in international trade and does not assess interregional differences (see Lin and Polenske, 1995, Fisher-Vanden et al. 2003, Liu et al. 2010). Our contribution is twofold: for one, we construct the full hybrid energy model to Chinese input-output tables as a fundamental analysis to be able to trace the direct and indirect energy embodied in production of industry structures of different regions in China. We do have the data availability, an issue that usually sets a limitation to apply a full hybrid analysis. Our work ought to be used to build on. For example, the methodology for expressing hybrid unit IO tables for provinces needs to be fully integrated into a Multi-region input-output model (MRIO) in order to account for embodied energy within interregional trade linkages so that one can see the effect of trade on indirect embodied energy.

Secondly, by contrasting provinces from different socio-economic background our work fits into the general discussion on how to design emerging economies like Central and Western China in a low carbon and energy efficient way. Energy analysis and policy design has recently gained in importance for emerging economies, in particular China (Ma and Stern, 2006). Past economic growth and increased international trade has been fuelled by dependency of energy – mainly coal, oil and gas. Although China is still far away from decoupling its economy from reliance on fossil fuels, it has put in place first steps to reduce energy intensity nationwide (Wang et al. 2010). Also, the Government recently implemented several policies to help western and central China to catch up economically with the rest of China. In front of this background we find it useful to analyse energy use patterns in selected provinces and compare them Our paper is motivated by the questions 1) are there any significant differences in energy intensity between regions in China. 2) If so, what production structures are most energy intense and how much indirect energy is embodied in products?

2 Energy Intensity in China

Since China's economic reform started in 1978 its growth has been coupled with huge demand of energy. Electricity has been produced primarily by firing of fossil fuels, and this trend is continuing with coal currently accounting for 80% of China's primary energy resources (Liu and Gallagher, 2009). If no prohibitive policies are set in place then energy resource use is predicted to increase drastically from about 2200 MT_{oec} in the year 2010 to over 4000 MT_{oec} in 2030 (World Energy outlook, 2010). Although the Chinese Government implemented several policies for energy intensity reduction, for example a decision to close all coal fired power stations with less than 100MW capacity, officials of the National Development and Reform Commission (NDRC) had to admit in December 2010 that China will fail to reach a 20% reduction of energy consumption per unit of GDP, a goal stated initially in its 11th 5-year plan, and instead conceded a slight increase over the last year[1].

China's own decisions on energy use to carry their economy have, of course, effects on global energy demand and CO_2 levels: the World Energy Outlook (2010) states that limiting the global concentration of CO_2 to 450 ppm, a goal that is consistent with the 2-degree target, will be impossible to reach if the current energy pathway in China is followed with no further course correction (WEO, 2010). Part of China's growth can be attributed to its strong international trade activities, and studies have shown that China is a net exporter of energy (Hong et al., 2006). Between 1992 and 2005 the energy embodied in intl. trade has increased and could not be completely offset by domestic efforts to reduce energy intensity. China's increased international trade has led to overexploitation of resources and caused dependency on energy imports (Liu et al., 2010). Also, it has been reported that since 2003 China's overall energy intensity has been increasing again for the first time since thirty years (Ma and Stern 2006). It is therefore worthwhile to investigate ways to improve China's own domestic energy use for production processes, as done in this paper, because it will help to lower resource dependency, as well as contribute to global resource depletion and CO_2 emissions.

Within China's border energy consumption and production processes are spatially decoupled as a result of existing economic and social regional disparities. Energy embodied in products follows trade patterns, mainly from production sites in the West and Central region to the East, a wealthy region with growing demand of consumer goods (Ma et al. 2008). Energy-intensive primary industries are to a large extent located in the western parts of the country. As seen in table 1 province Gansu, located in the West has the lowest per capita GDP followed by Hubei (Central Region) and Zhejiang. Gansu economy is dominated by coal production, as well as crude petroleum and natural gas.

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[1] according to http://www.atimes.com/atimes/China_Business/HL20Cb01.html, accessed on 3.1.11

	Zhejiang	**Hubei**	**Gansu**
GDP per capita	**105.01**	**47.67**	**26.92**
Generation Capacity (TWh)			
Hydro	**13.00**	**93.30**	**18.9**
Fossil fuels	**172.30**	**60.90**	**42.4**
Nuclear	**22.70**	**0.00**	**0.00**
Wind	**0.05**	**0.00**	**0.31**
Other	**0.00**	**0.00**	**0.3**
Coal production (MT)	**0.13**	**12.30**	**38.23**
Coal consumption (MT)	**113.34**	**96.52**	**39.59**

Table 1. Comparison of provinces analysed in this study.

In order to allow the Western region of China to catch up economically with the rest of the country the Government implemented several regional policies, with the flagship policy being the Western Development Program (Tian, 2002). Up to this point interregional trade within China was rather low. However, according to Duchin (2005) the Government realized the economic benefit China obtained from international trade with other countries, and thus applied this idea within its own border and encouraged interregional trade by implementing several respecitve policies (Duchin, 2005). It is because of the differences in economic development as well as prevalent trade linkages among provinces that we chose the three provinces. As of now, however, our analysis on embodied energy is reduced to domestic production without any specification on trade linkages. Yet, we regard our comparison as sufficient for discussion of the hybrid unit methodology as well as a basic comparison of the provinces.

3 Literature review

Early work on hybrid energy analysis started in the late 1960’s and 1970’s, after economies experienced acute energy shortage stemming from the international energy crisis. Research was primarily driven by a need for a robust framework for energy policy analysis. Cumberland (1966) developed an inter-industry regional model in which he included environmental (ie.:energy use) relationships in order to assess externalities that have not been given much attention in previous models. Hannon (1973) introduced the concept of hybrid unit energy analysis to US input-output accounts. This work was followed by several other authors analysing energy use of production with US national accounts: Wright (1974) used hybrid energy analysis to trace back several industry inputs to their requirements of primary energy, Bullard and Herendeen (1975) evaluate the amount of primary energy input to all sectors of the economy, taking into consideration different energy sales prices per sector, and Bullard and Sebald (1976) tested effects of technological change and uncertainty on energy use in US input-output models. Notably Wright as well as Bullard and Herendeen used slightly different techniques for estimating embodied energy, and thus also found different results. Wright estimated energy intensity coefficients from each energy sector that are then used as multipliers for the industry rows of the input-output matrix to calculate the amount of embodied energy. Although this method is frequently applied in the literature because of its simplicity and straightforward data availability, it actually has methodological and practical limitations which are described in detail in Miller and Blair (1985) and have been mentioned in our introduction. One of the weaknesses is that this formulation only produces internally consistent results if energy prices hare held constant across all sectors. Bullard and Herendeen (1975) solve this problem by defining energy coefficients that inherently conform to a set of energy conservation conditions, ensuring consistency of accounting for physical energy flows in the economy. In our work we use a full hybrid analysis taking into account conditions of energy conservation. This approach was also applied by Costanza (1980) to calculate embodied energy for a 92 sector economy in which he included primary factors of economic production, labor and government. Through this inclusion he found a strong dependency between embodied energy and the dollar value.

More recently, energy analysis in input-output analysis has gained renewed attention to evaluate the (CO2-) emission embodied in products and trade. For example, Casler and Blair (1997) apply the hybrid method to a number of emission pollutants embodied in products using 1985 input-output data of the US Economy. Besides applying hybrid energy analysis to issues related to climate change, the technique is also combined with material flow analysis and structural decomposition analysis (Hawkins et al. 2006, Jacobsen 2000). This gives opportunity to explore energy flows induced for production of single products and tracing them through the economy, enabling to assess the energy embodied in specific products’ life cycle. A number of authors use Structural decomposition analysis (SDA) together with hybrid-unit energy input-output analysis to investigate drivers of energy use in a period of time (see: Jacobsen, 2000; De Haan, 2001; Hoekstra and Van den Bergh, 2002; Kagawa and Inamura, 2001). Dietzenbacher (2006), however, warns that in some cases the hybrid unit approach in SDA leads to arbitrary results because during intermediate steps of the calculation a mix of units is used.

There are several studies on embodied energy in China and they either focus on international trade and the simple energy coefficient method is used for evaluating embodied energy, or the studies analyse trends over time via application of SDA. Studies on embodied energy in trade of China include work by Liu et al., 2010 and Hong et al., 2006. Liang et al. (2007) used a Multi-region model for China to detect differences in regional CO_2 emissions stemming from production activities and also calculates energy intensity vectors for those regions. They find a strong need for efficiency improvements in Central China and the Northwest because also inter-regional transfer of energy out of these regions is relatively high. Application of SDA or Index Decomposition analysis has been conducted by Zha et al., 2007, Fisher-Vanden et al., 2003 and Liu, 2010. Findings by Ma et al. (2006) included that the remarkable decline in overall energy intensity of China between 1980 and 2003, in contrast to a steadily growing GDP, is mainly due to technological change, inter-fuel substitution and inter-industry change. China currently is a net exporter of energy and the energy embodied in exports is increasing over time as the absolute volume of exports increase.

Albeit static in its nature, because we use only one year (2007) in our study, a full hybrid energy analysis of Chinese provinces is useful to obtain a detailed understanding of China’s domestic energy uses for production. Detailed energy consumption data from the Energy Yearbook as well as sales data to industry (Electricity Yearbook) were available to us and therefore we see opportunity to apply a fundamental and basic analysis of embodied energy to China. Also, no research to date has been done on comparing provincial or regional differences in embodied energy using hybrid unit analysis.

4 Data collection and preparation

We use two sets of data:

1) monetary commodity by commodity input-output tables of the year 2007 for the provinces Gansu, Hubei and Zhejiang provided by the National Bureau of Statistics of China (NBSC, 2007).
2) Chinese Energy final consumption data by industry, available through the ESYB, as well as Energy Balance Sheets of 2007 (NBS, 2007).

The tables were aggregated to represent a 42 sector economy of each province. Final demand is disaggregated to Household, Government consumption, fixed capital formation, Inventory increase, domestic and overseas exports. As explained in more detailed in the methodology section we had to strip imports from final demand. Exports are not specified by province or country destination. The issue of reliability of Chinese energy statistics has been discussed, in particular in context of potential underreporting of Coal use between 1996 – 2003 (Sinton

2001, Akimoto, Ohara et al. 2006). This specific problem does not affect the data 2007. Although we cannot guarantee for complete accuracy of the dataset made available to us we did not attempt to modify it.

From the dataset on energy we constructed the Chinese energy consumption inventory, in peta-joules (PJ) for 2007. The detailed description of this exercise can be found in Peters et al. (2004), and won't be repeated here. As a result we obtained the energy consumed by 46 sectors allocated by combustion of 20 fuels (biomass energy is not reported). By allocating energy based on the user of the primary energy we made to avoid double counting. Typically when constructing energy consumption accounts primary energy used as input into transformation sectors (for example the electricity generation sector) is allocated to the different users of the energy. For example, the energy from fossil-fuels used in power production is allocated to the user of electricity, although the emissions of burning primary energy, and converting it into secondary energy actually occurs at the power plant (Peters et al. 2004). Therefore we allocate the energy data to the industry that combusts the fossil fuel.

We had to perform several modifications to the energy dataset to make it compatible for a hybrid version with the input-output tables:

- **Aggregate the 20 fuels into a set of primary- and secondary energy sectors**

  The 20 fuel types described in the ESYB can be categorized according to Table 2 in into three primary and two secondary energy sectors: coal mining, crude oil production, natural gas production, Electricity generation and petroleum processing. These 5 sectors can be found in the monetary input-output tables, and will in a later step be replaced with physical units. The table 2 below shows the energy sectors as labelled in the input-output matrix

Coal mining and processing	**Petroleum & Gas extraction**	**Petroleum Processing**	**Electricity and Heat Production and Supply**	**Gas Production**
Primary Sector	***Primary Sector***	***Secondary Sector***	***Secondary Sector***	**Primary Sector**
Raw coal **Cleaned Coal** **Other Washed Coal** **Briquettes** **Coke** **Coke Oven Gas** **Other Gas and Coking Products**	**Crude oil**	**Gasoline** **Kerosene** **Diesel Oil** **Fuel Oil** **LPG** **Refinery Gas** **Other Petroleum Products**	**Non –fossil Eelctricity** **Non-fossil Heat**	**Natural Gas**

Table 2: Allocation of fuels to primary and secondary energy sectors.

- **Convert the 46 energy consumption matrix from the ESYB to a 42x 42 sector matrix compatible with the input-output tables**.

  Both tables are aggregated slightly different. Here we use an aggregation process described by Peters (2006) using a concordance matrix to obtain a 42 sector matrix.

- **Estimate energy consumption of disaggregated final demand categories**

The energy data from the ESYB contains only information on energy consumption of the inter-industry matrix. However, for a hybrid-unit model final demand expressed in physical unit is necessary. In order to estimate energy consumption of all final demand categories we first calculated, for each sector, the ratios of intermediate use to final demand categories in the monetary table That same ratio was then used to estimate the deliveries to final demand in physical units.

5 Methodology:

We develop a hybrid unit input-output model in which we substitute the rows in the input-output matrix that represent the primary and secondary energy sector with rows of physical units. The inter-industry flow between energy sectors, and energy- to non-energy sectors is thus shown in energy units, peta joules (PJ), while inter-industry flow between non-energy sectors remains in monetary units (10.000 RMB).

Say we have a traditional input-output accounting identity, measured in monetary terms of the form

$$Z_i + f = X \qquad (1)$$

where Z is the matrix of interindustry transactions, f is the vector of total final demands and X the vector of total outputs. In input-output models a direct proportionality between inputs to a particular sector and its outputs are assumed for any industry in the model. Thus, for any industry we can write:

$$X_{ij} = a_{ij} X_j \qquad i,j = 1,2 \qquad (2)$$

and

$$\sum_{i=1}^{2} X_{ij} = X_j \qquad j = 1,2 \tag{3}$$

Xij in this case is the unit of good i absorbed by sector j; i,j = 1,…42,
Xj units of output of sector j; j = 1,…42,
aij = units of input of good I per unit of output of good j; i,j = 1,..42

(3) shows that the value of all inputs to any sector is equal to the value of the output produced by that sector. Energy input-output takes the same assumption. The balance equation (3) is changed to energy units by pre-multiplying each of the inputs X_{ij} by respective energy intensity coefficients ε_i and the output X_j by ε_j. This indicates that the energy equivalent of the input $_i$ into $_j$ plus the energy equivalent of the second input, $_j$ into $_j$ is equal to the total energy embodied in the output of the industry $_j$. We need to add the external direct energy input, E_j, to the energy balance equation because all processing activities need some form of suitable input of resources from the earth (note that when dealing with monetary values this input can be ignored, but when working with energy units this additional input to the system from the earth for in accordance to the law of conservation of energy). Therefore we write our energy balance equation in general terms as follows:

$$\sum_{i=1}^{n} \varepsilon_{ik}X_{kj} + E_{ij} = \varepsilon_{ij}X_j \qquad j = 1,2\ldots n \quad \text{and } i = 1,2,\ldots,m \tag{4}$$

This energy balance equation is for the i^{th} energy type in the j^{th} industry for an economy with *n* industries and *m* energy producing industries and no secondary products. ε_{ik} is the energy unit of the i^{th} energy type per renmimbi unit of output of industry *k* and E_{ij} represents the amount of the i^{th} type of energy taken directly from the earth by sector *j*. In short, the energy embodied in any sector output equals the amount of energy embodied in all that sector's input plus the primary energy input. This equation determines the energy conservation conditions. In matrix notation we would get:

$$\varepsilon A \hat{X} + E = \varepsilon \hat{X}, \tag{5}$$

where

$$\varepsilon(1,2,\ldots m), \quad A = \begin{bmatrix} a_{11} & a_{12} & .. & a_{1n} \\ a_{21} & a_{22} & .. & a_{2n} \\ .. & .. & .. & .. \\ a_{n1} & a_{n2} & .. & a_{nn} \end{bmatrix}, \quad \hat{X} = \begin{bmatrix} X_1 & 0 & .. & 0 \\ 0 & X_n & .. & 0 \\ .. & .. & .. & .. \\ 0 & 0 & .. & X_n \end{bmatrix}, \quad E = [0_{(1,\ldots n)} \; E_{(1,..,m)}]$$

Solving after energy intensity gives:

$$\varepsilon = E \hat{X}^{-1} (I-A)^{-1} \qquad (6)$$

and we note that $E \hat{X}^{-1} = [0\ 1] = e$, therefore:

$$\varepsilon_i = e_i(I-A)^{-1} \qquad (7)$$

where e_i is an 1 *x* n row vector of zeros except for a one in the i^{th} location. (7) gives the total energy requirement matrix in hybrid units. Direct energy requirement is defined as

$$\varepsilon_d = e_i A \qquad (8)$$

Indirect energy ε_{id} requirement of a sector is then simply

$$\varepsilon_i - \varepsilon_d = \varepsilon_{id} \qquad (9)$$

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Annex 1

Table 1 Categorization of fuel types into primary and secondary energy sector

Coal mining	Petroleum & Gas extraction	Petroleum Processing	Electricity and Heat Production and Supply	Gas Production
Raw coal	Briquettes	Gasoline	Eelctricity	Natural Gas
Cleaned Coal	Coke	Kerosene	Heat	
Other Washed Coal	Coke Oven Gas	Diesel Oil		
	Other Gas	Fuel Oil		
	Other Coking Products	LPG		
	Crude oil	Refinery Gas		
		Other Petroleum Products		

Table 2: Modifying a 43 sector input-output table in the Energy Yearbook to a 42 sector input-output table:

43 sector energy table	42 sectors Input-output tables
Nonferrous Metals Mining and Dressing	Non-metal mineral mining
Food Processing Food Production Beverage Production Tobacco Processing	Manufacture of food products and tobacco processing
Logging and Transport of Wood and Bamboo Timber Processing, Bamboo, Cane Furniture Manufacturing	Sawmills and Furniture
Raw Chemical Materials and Chemical Products Medical and Pharmaceutical Products Chemical Fiber	Chemicals
Rubber Products Plastic Products	Scrap and Waste
Smelting and Pressing of Ferrous Metals	Metals smelting and Pressing

Smelting and Pressing of Nonferrous Metals	
Transportation, Storage, Post and Telecommunication Services	Transports and warehousing Post Telecommunication and IT Services
Wholesale, Retail Trade and Catering Services	Wholesale and retail trade Eating and drinking places, and hotels
Others	Finance and insurance Real estate Rentings and other commercial services Scientific Research General technical services Water conservancy, environmental and public facilities management Residential and other services Education Health services and social welfare Culture, sports and entertainments Public administration and other sectors