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Construction of Chinese Energy and Emissions Inventory

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Introduction

China's rapid economic growth and market liberalization has made China a major player in both the global economy and natural environment. A combination of China's large population, rapid urbanization, increased household wealth, and increased domestic production is placing unprecedented pressure on China's local environment (Liu and Diamond 2005). In addition, China is becoming an increasingly important contributor to global environmental problems.

A significant contributor to China's impressive economic performance is increased international trade. While the increased trade has improved the wealth and living standards of millions of Chinese, trade is also a key contributor to China's environmental challenges (Streets, Yu et al. 2006). Arguably, competitive prices are the driver behind China's increased trade, but as a consequence China's trading partners can reduce their own domestic pollution by importing the products from China. Due primarily to China's extensive use of coal, China's production is often more pollution intensive than China's trading partners. Consequently, while a country may reduce its own emissions, globally the pollution may in fact increase.

Given China's own environmental challenges and China's significant contribution to the world economy, there is a great need for tools to analysis the environmental repercussions of China's economic activities. One such tool is environmental input-output analysis (Leontief 1970). An important component of EIOA is energy and pollution data by industry sectors. Some studies have recently constructed Chinese energy and pollution data suitable for EIOA (Peters and Hertwich 2006), however this data has not been freely available or well documented. Given the recent interest in China, it is surprising that so few studies have constructed Chinese data for EIOA purposes.

This work explores the available sources of Chinese energy and pollution data and derives a comprehensive set of sectoral energy and emissions data for 1992, 1997 and 2002. This document outlines the data sources, manipulations, and assumptions used to construct the data. A series of spreadsheets contain the raw data and include our manipulations as outlined in this document. Whilst we have attempted to construct the energy and emissions data using the best available information it is possible that more accurate and up-to-date information is available. If you are aware of how we can improve the energy and emissions data, please contact one of the authors above and we will update the spreadsheets and documentation.

Data availability

As a general rule air emissions data by industry sector is not directly available, rather it is constructed from data on energy consumption by industry sector. This is the approach taken here. We have attempted to source most of the data from Chinese authorities, such as the Chinese National Bureau of Statistics (NBS), and where possible we have used country specific assumptions. NBS provides several formats of the energy data which are suitable for our needs. Most of the data is sourced from various version of the Energy Statistics Yearbook (ESYB). Three years of detailed

data are published in the ESYB and since the data is regularly updated we use the ESYB with the latest available data.

We constructed the 1992 energy data using:

- China Energy Databook v. 6.0 (Sinton 2004)
 - Table 4A.6.1. Industrial Sector End Use by Subsector and Energy Type, 1992
 - Table 4A.17-25. End Use and Inputs into Conversion

We constructed the 1997 energy data using:

- ESYB97-41
 - Energy Statistics Yearbook 1997-1999, Table 4-1, pg 66-69
 - The Energy Balance Sheet in 1997 in physical units
- ESYB97-52
 - Energy Statistics Yearbook 1997-1999, Table 5-2, pg 110-113
 - Final Energy Consumption in 1997 in physical units
- ESYB97-NCV
 - Energy Statistics Yearbook 1997-1999, pg 554
 - Net Calorific Values
- SNPESA
 - Sino-Norwegian Project on Environmental Statistics and Analysis (1998-2001)
 - We use the project documentation for cross checking

We constructed the 2002 energy data using:

- ESYB05-41
 - Energy Statistics Yearbook 2005, Table 4-4
 - The Energy Balance Sheet in 2002 in physical units
- ESYB05-52
 - Energy Statistics Yearbook 2005, Table 5-5
 - Final Energy Consumption in 2002 in physical units
- ESYB05-NCV
 - Energy Statistics Yearbook 2005, back page
 - Net Calorific Values

The other *main* sources of information came from:

- IPCC: “Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual” (IPCC 1996)
- CCCCS: “China Climate Change Country Study” (CCCCS 1999)
- IEA: Various sources for cross checking, including CO₂ Emissions from Fuel Combustion (2005 edition) and Energy Statistics of Non-OECD Countries (2005 edition)

It is also possible to use the Total Energy Consumption from the China Statistical Yearbook (usually Chapter 7). We found this data unsuitable for several reasons.

- It does not include all energy sources
- It aggregates different types of coal by weight and not by energy content
- It uses a different method of allocation (see below)

Data reliability and uncertainty

Over recent years there has been considerable discussion on the reliability of Chinese energy statistics (Sinton 2001; US Embassy 2001; Sinton and Fridley 2002). The statistics most affected are coal use between 1996 and 2003, see Figure 1. There are several factors causing the unreliability of the statistics (Sinton 2001). First, in the late 1990's, the Chinese government closed down many privately owned coalmines. It is believed that many of these mines reopened illegally and consequently are not in the official statistics. Second, coal cleaning became more prevalent in the late 1990's and so less coal may be required for a given output of energy. Third, there may be errors in reporting. Recent satellite data has shown that the drop in coal consumption is probably unrealistic and the coal consumption data should not be used (Akimoto, Ohara et al. 2006). In our data set 1997 and particularly 2002 are likely to be affected. It is possible to improve the reliability of the energy statistics by triangulating with other statistics, such as industry outputs (Sinton and Fridley 2003). We have not attempted to modify the official statistics in any way and we leave it to the user of the data to make modifications if desired.

In this study, several factors contribute to uncertainty outside of the standard reporting uncertainties. First, biomass energy is not reported. Second, there are problems with misallocation (Sinton 2001). For instance, many state run industries provide services in addition to their main activities which may overestimate the energy use in those industries. Third, many industries provide their own transportation services which is not usually allocated to transportation. Consequently, not only is the total energy use uncertain, but also the distribution of energy consumption across industries.

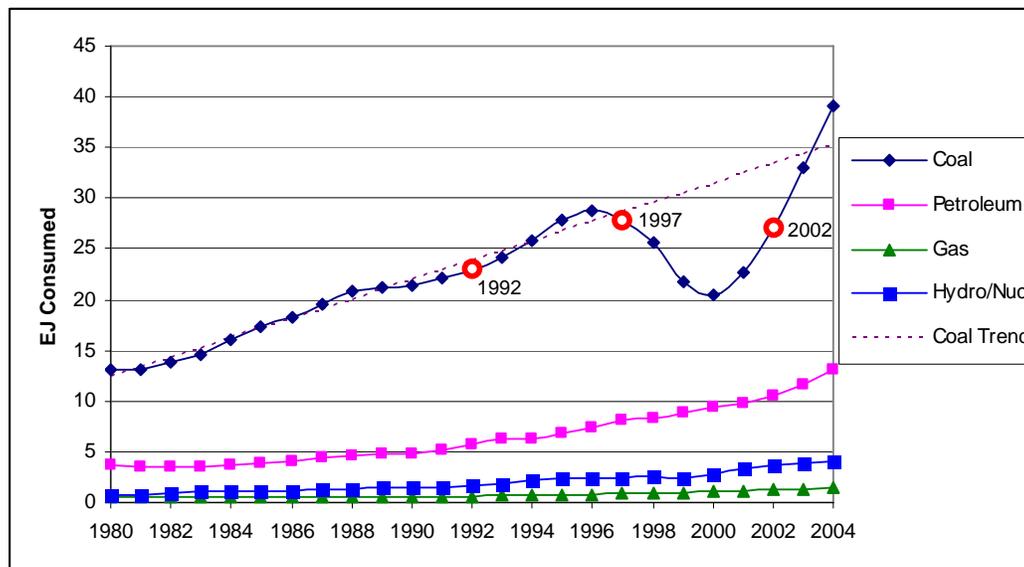


Figure 1: Chinese energy consumption from 1980 to 2004 showing the large dip between 1996 and 2003. Superimposed on the coal consumption is a historic trendline.

The transportation sectors in the energy data are highly aggregated and also include post and telecommunication. It is possible to disaggregate this “Transport, Storage, Postal & Telecommunications Services” sector based on the IO data. When linking with the IO data, the emission intensity of Post and Telecommunications will be too high, and the emission intensity of transportation will be too low. We have not made adjustments for this, but users of the data are free to do so.

Definitions

Some standard definitions used in the Chinese energy statistics are:

- Final Energy Consumption: The total energy consumption by industry and residential consumers, excluding losses and energy consumed in the conversion from primary to secondary forms of energy
- Loss: The total lost energy during the course of energy transport, distribution, storage, and any other objective reason.
- Transformation
 - Input: Primary energy forms used as an input to produce secondary forms of energy in transformation sectors. (e.g. coking coal, crude oil)
 - Output: Secondary energy forms produced from primary energy forms in transformation sectors (e.g. coke, coke oven gas, refined petroleum products)
- Total Energy Consumption: The overall value of energy consumed for combustion in the economy, including final consumption, loss, and transformation. Outputs are not included as we allocated the energy based on who combusts it.
 - Total Energy Consumption = Final Energy Consumption + Loss + Inputs
- Net Calorific Value (NCV): The energy content (in energy units) of an energy source per unit mass.
- Standard Coal Equivalent (SCE): 1 t SCE = 29.308 GJ

A Note on Allocation

An important consideration when constructing energy and emissions data is how to allocate primary and secondary energy and avoid double counting. The sectors most affected are the transformation sectors such as, coking, petroleum refining, and power generation.

Typically, when constructing total energy consumption, the primary energy used as input into the transformation sectors is removed and the secondary energy produced is allocated to the different users of the energy. Thus, for example, the crude oil that is transformed in petroleum refining is not added as consumption in the refining sector, but the refinery products (secondary energy) are allocated to the different industry users such as agriculture, manufacturing, transport and services. Fossil-fuel power generation (electricity) is also an important example of energy transformations; the fossil-fuel is not allocated, but rather the electricity (secondary energy) is allocated to industry users. In some studies, the energy used as feedstock in power production is allocated to the consuming sectors in proportion to the fossil-fuel generated electricity. This method allows for the low efficiency of fossil-fuel power generation compared to hydropower or nuclear power.

Allocating energy based on the user of the secondary energy is not appropriate in environmental studies, particularly when using EIOA. Generally, most air emissions are caused by the combustion of fossil fuels. Air emissions are typically allocated to the industry emitting the pollution, not to the user of the secondary energy. Fossil-fuel power generation offers a good example. As described above, in many energy studies the energy from fossil-fuels used in power production is allocated to the user of

electricity (secondary energy). However, the emissions occur at the power plant and not at the site of electricity use. Consequently, air emissions in fossil-fuel power generation should be allocated to the power plant and not to the electricity use. On the other hand, for petroleum refining air emissions are allocated the same as for energy since the air emissions occur when the secondary energy is combusted. Overall, when constructing energy data to construct air emission data the energy should be allocated to the industry that *combusts* the fossil-fuel (not according to secondary energy use).

In the EIOA framework the IO table shows the relationship between different industry sectors. Power generation and petroleum refining are usually separate industry sectors. By applying standard EIOA methods the energy use and air emissions can be automatically allocated to the consumer or producer of the pollution. This can be demonstrated using the power series expansion (Miller and Blair 1985),

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

where F are the sectoral energy or air emission intensities, A is the normalized IO table, and y is the demand on the system. If a demand is placed on the aluminum sector then the first term in the expansion, Fy , gives the direct emissions at the site of the aluminum industry. The second term, FAy , contains all the first tier inputs including electricity production. Thus the second term reallocates the air emissions from fossil-fuel power generation to the aluminum industry. This approach inherently assumes that the price of the energy is the same for all industries. This assumption can be avoided by using the energy sectors in physical units (Miller and Blair 1985), producing a hybrid-unit A matrix of production. A generalization of the consumption and production perspectives and structural path analysis can be used for more detailed methods of allocation (Gallego and Lenzen 2005; Peters and Hertwich 2006).

Given that we are primarily interested in air emissions and applying EIOA it is important to allocate the energy data to the industry that combusts the fossil fuel. This is the method of allocation used in this article. Other users of the data may want different allocations and are free to reallocate the data if appropriate.

Data Manipulation

With comprehensive energy consumption data, the IPCC Tier 1 sectoral methodology can be utilized to derive an overall energy balance and emission inventories (IPCC 1996). Since we are primarily interested in air emissions from fuel combustion we construct the energy data first and then construct all air emissions based on the energy data. We include air emissions from major industrial processes (such as cement production). In the following, we assume the reader has familiarized themselves with the IPCC methodologies.

The following description is based on the 1997 data since we had access to a wider range of other data for cross checking. The 1992 and 2002 data is constructed using the same methodology. We occasionally refer to different spreadsheets that contain specific data and manipulations. A comprehensive list of the spreadsheets can be found in Appendix A.

Energy

In this section we explain each step to construct the total energy consumption by industry sector. We construct the energy data based on the final consumption values in ESYB97-41,52. We then add the energy used for transformation and deduct non-energy use which are both included in ESYB97-41.

Step 1: Construct final energy consumption by industry sector in energy units.

The final energy consumption comes directly from a combination of ESYB97-41 and ESYB97-52. ESYB97-41,52 are available in both physical units and SCE. Taking a ratio of the tables in the different units shows that the NCVs can vary across industries. The variations seem more like errors and consequently we chose to use ESYB97-41,52 in physical units (sheet E-Phy) and apply NCVs to convert the physical units to energy units. There are several different data sources for Chinese NCVs. Some of the data sources are incomplete and the NCVs vary between the data sources. We took the NCVs, in order of priority, from the ESYB, implied values from ESYB97-41,52, and CCCCS. The sheet E-Factors gives a comparison of several data sources for Chinese NCVs. The unadjusted final energy consumption in PJ is found in sheet E-PJ (1).

Step 2: Account for losses

The final energy consumption does not include losses which are included in ESYB97-41. The losses are generally small, but to account for them we scale up the final energy consumption in each sector by the energy lost. We distribute the energy loss in each sector in proportional to the energy source consumed by that sector. The sheet E-Loss gives the energy losses and E-PJ (2) gives the final energy consumption including losses.

Step 3: Account for non-energy uses

Some of the energy is used as feedstock into different industrial processes. ESYB97-41 gives the total non-energy use in the industrial sectors. Based on CCCCS and SNPESA, we assume that all the non-energy use is in the chemical sectors. We distribute the feedstock evenly across the five chemical sectors except for “Other Petroleum Products” and “Other Energy” which are assumed to be completely non-energy use. All coke use in smelting of metals is calculated using industrial process emissions and thus, the coke in those sectors is deducted as non-energy use. Based on SNPESA we assume that coal is not used as a reducing agent in the smelting of metals. The distribution of non-energy use is shown in E-NE.

Step 4: Account for transformations

Some of the primary energy is converted into secondary forms of energy. As discussed earlier, we allocate the energy according to the industry that combusts the energy. Thus inputs into refining, coking, and coal cleaning are not include in the total energy consumption. On the other hand, adjustments must to be made for electricity. We add the thermal power and heating supply inputs from ESYB97-41 to the “Electric Power, Steam and Hot Water Production and Supply sector”. This assumes that all heat and power is produced in this sector (that is, there are no autoproducers). IEA data shows that autoproducers are responsible for about 1.5% of electricity and 5-

6% of heat in 1997 and 2002. Consequently, the energy use for these autoproducers is not allocated correctly.

Since we have allocated fossil-fuel inputs to total energy consumption we must remove the electricity and heat sectors in order to avoid double-counting. According to ESYB97-41 all heat is produced by fossil-fuels and about 80% of electricity is produced by fossil-fuels. To be consistent with GDP, adjustments must be made for international bunker fuels (United Nations 2003). We modify the transport sector by including the fuels purchased by Chinese airplanes and ships abroad and deducting the fuels purchased by foreign airplanes and ships in China. The manipulations for transformations are shown in sheet E-Trans.

Step 5: Adding together the values from sheet E_PJ (2), the non-energy use values from E_NE and the transformations from E_Trans, we achieve a final Total Energy Consumption profile for each sector and fuel. This is presented in the sheet E.

Air Emissions

The emissions data is constructed based on the prepared energy data (sheet E). Since the air emissions are primarily due to combustion we assume the same feedstock and non-energy use for all the air emissions. Generally, the emissions are calculated by multiplying the energy data by an emission factor (IPCC 1996).

CO₂

To construct the CO₂ emissions data, two major data are required: the carbon emission factor of each fuel and the fraction of carbon oxidized for each fuel in each sector. We used several data sources when collecting this information (Wu and Chen; IPCC 1996; CCCCS 1999)

Where possible we have used Chinese specific values for the emission factors (EFs) and the fraction of oxidized carbon (FOC). We use sector specific values for FOC for coal (CCCS 1999) which vary between 80-95% and so are lower than the IPCC default value of 98%. The sheet CO₂-Factors gives details of the values we have used and the IPCC default values.

We also included process emissions according to the IPCC guidelines and where the data was available. All process emissions were based on production volume data from various statistical yearbooks and the US Geological Survey (for 1992). Processes included were:

- Raw chemicals: Ammonia production, Soda ash use
- Nonmetal mineral products: Cement production
- Smelting and pressing of ferrous metals: Iron and steel, coke as a reducing agent
- Smelting and pressing of nonferrous metals: Coke as a reducing agent

SO₂

The SO₂ emissions are directly related to the sulfur content of the fuels and the use of abatement technologies. The calculations were based on the IPCC guidelines using country specific values where available. In our spreadsheet we have used a default of 0% efficiency for abatement technologies. While this is certainly an underestimate,

we do not have the necessary data. Consequently, the SO₂ emissions are likely to be an overestimate.

The country specific values were obtained from:

- China Environmental Statistical Yearbook 2003
- Various Chinese sources

The following process emissions were included in a similar way to CO₂:

- Raw chemicals: Ammonia and Sulfuric Acid production
- Nonmetal mineral products: Cement Production
- Smelting and pressing of ferrous metals: Iron and Steel Production
- Smelting and pressing of nonferrous metals: Aluminum Production
- Metal Products: Steel rolling

NO_x

The NO_x emissions are based on the IPCC guidelines and are technology dependent. Country specific data was used where available (Tian, Hao et al. 2001; Chen and Wang 2005). The country specific values are disaggregated into nine broad industry sectors. These values were similar in value, but generally lower, than the IPCC default values. Where sufficient data was not available we used the “industry” values as a default. We also assumed that all the minor fuels were the same as natural gas. Since these minor fuels contribute to only a small share of total NO_x emissions they have a minor effect on the total sectoral NO_x emissions.

The following process emissions were included in a similar way to CO₂:

- Raw chemicals: Ammonia production
- Smelting and pressing of ferrous metals: Iron and Steel Production, Steel rolling
- Smelting and pressing of nonferrous metals: Aluminum Production
- Metal Products: Steel rolling

Water

Sectoral fresh water use and waste water produced is available from a separate study (Guan and Hubacek 2006).

Conclusion

In this article we have described how we have constructed the 1992, 1997 and 2002 energy data and key air emissions CO₂, SO₂, and NO_x for China. Fresh water and waste water data is available from another study. The spreadsheets containing the data and our assumptions are freely available for use and modification. If you have any suggestions for improvements then please notify one of the authors so the data can be updated in future releases.

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Appendix A: Spreadsheet Data Key

The data are presented in a series of spreadsheets, as detailed above. The following list summarizes what is found on each sheet.

- 1) E-Phy: The original energy consumption data in physical units (unit is given in each column) from ESYB97-41,52.
- 2) E-Factors: A list of all net calorific values (NCVs) from various data sources, used to convert physical energy data into energy units. The value that is used is found in row 13.
- 3) E-PJ (1): The original energy consumption data in energy units, after conversion, using sheets 1) and 2).
- 4) E-Loss: An adjustment to the data to account for losses in transmission and transportation, based on loss data from ESYB97-41.
- 5) E-PJ (2): Energy consumption data in energy units, after adjusting for transport and transmission losses, using sheets 3) and 4).
- 6) E-NE: Amounts of energy consumed by each sector that is used as a feedstock or other non-energy use. It is assumed that non-energy use only occurs in chemical sectors.
- 7) E-Trans: Amounts of energy consumed by each sector that is used in transformation processes to produce secondary energy and adjustment for international bunkers. Transformation and bunkers data from ESYB97-41 is shown below the sectors.
- 8) E: Final estimate of energy consumption by sector, allocated by final combustion of primary or secondary energy, after adjustments for non-energy use, transformation, and international bunkers. 8) uses sheets 5), 6), and 7).
- 9) CO₂-Factors: Carbon emission factors and fraction oxidized estimates by sector. Fraction oxidized data are by sector, while emissions factors are assumed constant through all sectors.
- 10) CO₂: Total amounts of CO₂ emitted from each sector by each energy type, followed by process emissions and total emissions.
- 11) SO₂-Factors: Sulfur content and retention data for each fuel type and derived emissions factors for SO₂. Note that abatement efficiency is set at a default level of 0% but this may be adjusted by the user.
- 12) SO₂: Total amounts of SO₂ emitted from each sector by each fuel energy type, followed by process emissions and total emissions.
- 13) NO_x-Factors: Assumed NO_x emission factors with a comparison to IPCC default values, broken up by aggregate sector type. The factors used in the calculation are in rows 23 to 31.
- 14) NO_x: Total amounts of NO_x emitted from each sector by each fuel energy type, followed by process emissions and total emissions.

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3/2006	John Amund Karlsen	<i>Resultatundersøkelsen 2005 for Stiftelsen Miljøfyrtårn</i>

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The Industrial Ecology Programme (IndEcol) is a multidisciplinary university programme established at the Norwegian University of Science and Technology (NTNU) in 1998 for a period of minimum ten years. It includes a Master of Science programme launched in 2004 and a significant number of doctoral students as well as research projects geared towards Norwegian manufacturing, energy and building industries. The activities at IndEcol have a strong attention to interdisciplinary research and teaching, bridging technology, natural and social sciences in the search for sustainable solutions for production and consumption of energy and resources.



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