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END USER ENERGY DEMAND AND CARBON EMISSION OF CHINA IN 2020 BASED ON THE ENERGY INPUT-OUTPUT ANALYSIS*

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Abstract

As the world's second largest energy consumer and top CO_2 emitter, China attracts widespread concerns about its energy issues. Given the increasing energy demands, one question that requires more specific attention is how much energy will be needed to meet people's satisfaction at a higher level of living standard? The basic energy demand for human livelihood and development is a rigid demand for socio-economic development, which is also the basis for energy and climate strategy. Based on a hybrid energy input-output model, the paper forecasts the household energy demand increment in China with reference to a national well-off goal of 2020. Results show a basic energy demand of 2.94 billion tce and CO_2 emission caused will reach 6.7 billion tons. To take the factor of energy transformation efficiency into account, the study updates the technology matrix of energy sectors based on the data of 2005. Results show it could save 16.3% of the primary energy demand increment. It indicates energy efficiency improvement would be a key solution in tackling the energy and climate change problem of China.

Key words: energy demand; carbon emission, well-off society; technology change; China

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End User Energy Demand and Carbon Emission of China in 2020 Based on the Energy Input-Output Analysis

XING Lu, ZOU Ji and SHI Lei

1. Introduction

With rapid economic growth, China is becoming the second largest consumer of energy and the top CO_2 emitter in the world today. Considering the ongoing industrialization and urbanization progresses, especially the large-scale infrastructure projects and lifetyle transformation of hundreds of millions of people, the increasing energy demand and CO_2 emissions caused have attracted widespread concerns.

Many researches have forecasted the energy demand of China. Most predictions before the year 2000 were proved to be far from reality mainly for two unexpected reasons: first is the rapid and long-lasting economic growth, second is the soaring electricity demand after 2000. Recent researches by Chinese official institutions such as the Environmental Protection Administration, the Energy Research Institution of the National Development and Reform Commission, and the Development Research Centre of the State Council, have generally predicted total energy demand to be within 3 billion tons of carbon equivalent (tce) by 2020, considering the constraints of resources and the environment as well as a potential improvement in energy efficiency. The latest studies by international institutions, such as the Asia Pacific Energy Research Centre, the International Energy Agency, and the Energy Information Administration have however forecasted a larger demand. APERC predicted the primary energy demand of China would reach 2.345 billion tons of oil equivalent (toe) (3.35 billion tce) in 2020 and 3.096 billion toe (4.42 billion tce) in 2030[1]; the EIA forecast it would be 119.5 terawatt-hours (twh (4.83 billion tce) in 2020 and 160.9 twh (6.5 billion tce) in 2030[2]; the prediction of the IEA was 3.819 billion toe (5.46 billion tce) in 2030[3].

However, these researches are all based on assumed economic growth, which seems to be wavering against the current background. One significant impact of the ongoing global financial crisis is the export plunge in China from the latter half of 2008. Given the increasing energy demands, the question this paper wants to discuss is the basic energy demand for human livelihood, that is, how much energy will be needed to meet the people’s satisfaction in eating, housing, clothing, travelling, education and sports entertainment at a higher level of living standard? This demand underlies the total energy demand, and is rigid due to socio-economic development, while its resultant CO_2 emissions could also be the rigid emission capacity of China. China has set its development target as to "realize a well-off society in 2020," which means a higher living standard for people in general. The energy required for this would increase not only by direct use but more significantly, the indirect use of energy caused by other products and services.

Households consume energy in two ways: directly and indirectly. Energy is consumed directly in the form of gasoline, electricity, natural gas, or fuel oil, and consumed indirectly as energy is used elsewhere in the economy to produce the goods and services purchased by consumers. Usually, an average household demands more energy indirectly than directly [4].

A number of studies have been carried out in developed countries to analyze total direct and indirect energy requirements in households. Studies specifically examining total (direct and indirect) energy requirements of households using input-output (I-O) analysis have been done for the USA [5], Norway [6], New Zealand [7], Finland [8] and Switzerland [9]. Studies extending the analysis to calculate total carbon emissions associated with household consumption have been conducted in the UK[10], Australia[11] and in other countries, and there are also some studies focusing on the energy and emissions flows embodied in household consumption[12].

However, such research for Asian countries is still limited. Park and Heo examine the direct and indirect household energy requirements in Korea from 1980 to 2000[13]. Shonali Pachauri and Daniel Spreng calculated total primary energy intensities of India along with private final consumption expenditures were used as a basis for determining the indirect energy requirements of Indian households[14]; and Shonali Pachauri examined changes in total energy requirements over the period from 1983-1984 to 1998-1999 using input-output analysis at the disaggregated 100 sector level[12]. Tuyet and Ishiharathe analyzed the change in embodied energy intensity in Vietnam from 1996 to 2000 by input-output analysis and structural decomposition [15].

To reveal the relationship between household expenditure and final primary energy demand, a hybrid I-O energy analysis will be applied in this paper. I-O energy analysis is usually used to calculate the total energy required, direct and indirect, to produce one financial unit of product of each sector in the economy, also referred to as the energy intensity of the sector. This paper will forecast the household energy requirements under an assumed expenditure target based on these energy intensities.

2. Method and Data

2.1. Energy Input-Output Analysis

In general, process analysis and input-output (I-O) analysis are two ways to measure energy input for any economic activity. They theoretically require the same data and would yield the same result if a fully disaggregated data base were available. In the real world, nationwide problems are well suited to I-O analysis while process analysis is more suited to specific processes or products for which physical flows of goods and services are easy to trace [16]. The hybrid energy I-O analysis is in fact a combination of the two methods, or rather, a specific area of application of economic input-output analysis in which attention is concentrated on the primary energy requirements of production and consumption in an economy [12].

After Wassily Leontief developed the I-O analysis during the 1930s and 1940s, Bullard, Herendeen, Hannon and their colleagues pioneered in energy I-O analysis in the 1970s. They traced the flows of primary energy into and out of all the producing sectors to calculate the primary energy demanded, and solved the problem of non-uniform energy prices among different sectors of the economy by using physical energy flows data instead of converting financial data through energy tariffs. Thus the energy I-O analysis combines data on the primary energy use of every sector in physical units with traditional information on inter-industry monetary flows contained within the I-O transactions table of an economy [12].

To divide all the sectors in the I-O table into two parts- energy sectors and non-energy sectors, see table 1. A is the technology matrix, E refers to energy sector and I refers to non-energy sector, Y is final product, and X is the sum of intermediate and final production. Specially, A_{EE} is the converting efficiency between energy sectors, with unit of tce/tce; A_{EI} refers to energy intensity of non-energy sectors, the unit is yuan/tce; A_{IE} is the efficiency of non-energy sector input to energy sectors, with unit of tce/yuan; and A_{II} is converting efficiency between non-energy sectors, the unit is yuan/yuan.

Table 1 **Framework of I-O energy table (n sectors)**

Output / Input			**Intermediate product**								**Final product**		Total
			Energy sector				Non-energy sector				Consumption	Ex/Import	
			1	2	..	k	1	2	..	n-k			
	Energy sector	1	A_{EE}				A_{EI}				Y_E		X_E

		2				
		..				
		k				
	Non-energy sector	1	A_{IE}	A_{II}	Y_I	X_I
		2				
		..				
		n-k				

As

$$X_E=A_{EE}*Y_E+A_{EI}*Y_I+Y_E \quad \text{(eq. 1)}$$

$$X_I = A_{IE}*Y_E + A_{II}*Y_I + Y_I \quad \text{(eq. 2)}$$

We could calculate XE by eq. 3 as following

$$X_E=[I-A_{EE}-A_{EI}(I-A_{II})^{-1}A_{IE}]^{-1} * [Y_E+A_{EI}(I-A_{II})^{-1}Y_I] \quad \text{(eq. 3)}$$

Since technology matrix A is fixed by the established I-O energy table, Y is exogenous and X is endogenetic in these equations, we could establish eq. 4 about the increment based on eq. 3.

$$\Delta X_E=[I-A_{EE}-A_{EI}(I-A_{II})^{-1}A_{IE}]^{-1} * [\Delta Y_E+A_{EI}(I-A_{II})^{-1}\Delta Y_I] \quad \text{(eq. 4)}$$

Eq. 4 is what exactly we will use for calculating the primary energy requirements increment according to the assumed expenditures growth.

2.2. I-O energy table and data

The National Bureau of Statistics of China publishes the national I-O tables every five years, and the latest 2002 I-O table, which included 122 sectors, was published in 2006[17]. In addition to I-O data, the calculation also requires data on energy transactions in the economy in physical units. Since energy statistics are collected in aggregative way -- energy consumption of 39 sectors was published in the 2004 Energy Statistics [18] (with energy statistics of year 2002) -- this paper aggregates the 122 sectors in the I-O table into 42 ones: 8 energy sectors and 34 non-energy sectors.

2.2.1 Energy sectors: There are 4 primary energy sectors and 4 secondary energy sectors inclusive in the energy sectors. Primary energy sectors include Coal mining and dressing (code 06007), Hydro and nuclear power (separated from Power generation and heat supply whose code is 44086), Petroleum extraction and Natural gas extraction (they are divided from Petroleum and natural gas extraction with code 07008). Secondary energy sectors are Thermal power (from Power generation and heat supply, code 44086), Heating supply (from Power generation and heat supply, code 44086), Petroleum processing (code 25036 Petroleum and nuclear fuel processing) and Coking (code 25037 Coking and code 45087 Fuel gas production and supply).

Two principles are applied here to re-organize these sectors:

- Keep coherence in data collection and sector category design between the I-O table and Energy Balance sheet. Energy Statistic Book 2004 provided explicit input and output of energy transformation, while aggregative final energy consumption of industrial sectors. To make the most use of the data to enhance accuracy, this study reorganized several key energy sectors.
- Provide convenience to make final household expenditure corresponding. For example, indoor heating, electricity and fuel gas uses are direct energy requirements and could be collected from statistics, thus corresponding energy sectors were separated under the condition of data availability.

2.2.2 Non-energy sectors: Non-energy sectors are coherent with those for energy statistics, because the sector category is more aggregative than that in I-O table. For example, housing, education, health care and entertainment are aggregated as "Other." Some sectors, such as Metals mining and dressing, Petroleum extraction, are not directly for final consumption, thus their final demand is 0 and only be considered producers of intermediate production. Details about the sectors and final consumption corresponding could be found in table 2.

2.2.3 Data: I-O table is from the "2002 Input-Output Table of China" published by the National Bureau of Statistics of China in 2006. The unit of the monetary I-O table is 10 thousand yuan, which is also the monetary unit of the I-O energy table. Energy statistics are from the "Energy Statistics Book 2004" published by the National Bureau of Statistics of China in 2006.

Element of A_{EE}, a_{ij}, refers to the fraction of total output of sector j that is derived from inputs from sector i. Input from primary energy sector i includes energy transformation to secondary energy sector j and final consumption of j; while secondary energy could only be used as final consumption by other energy sectors. Final energy consumption for Hydro and nuclear power, Thermal power and Heating supply sectors is divided according to their output (the three sectors are aggregated in the final energy consumption statistics), as well as the Petroleum extraction and Natural gas extraction sectors, and Petroleum processing and Coking.

This study focuses on energy requirement caused by household expenditure increment. So export and import, capital goods and investment, government consumption are not taken into account, their changes are assumed to be 0.

3. Well-off society goal in 2020 and energy demand increment

3.1. Well-off society indicators

In 2007, President Hu Jintao pledged in the Communist Party's 17th National Congress that China would build a well-off society that ensures balanced economic growth, improvement in people's well-being and social justice by 2020. Though a few official institutes proposed measures in special area, such as income, average size of housing, there are no existed indicator system to identify a well-off society. Therefore, choosing a well-off reference is what we need to do first.

Considering that household expenditures in different economy sectors are interrelated, a set of coherent data is more rational than combination of separate indicators. As the first province to establish explicit indicators to measure its own well-off society goal in 2003, Jiangsu province announced that 18 out of a total of 25 indicators had been achieved by 2006, while all these indicators had been achieved in the south of the province by then. So this paper has chosen the urban household expenditures of Jiangsu in 2006 to be the target national expenditures as a well-off society goal in 2020. Compared with Beijing and Shanghai, Jiangsu is more representative of the whole country. The average expenditures of Jiangsu in 2006 are shown in table 2 as 2020 expenditures. The population is assumed to be 1.5 billion in 2020.

For direct energy demand, coal for living consumption, household heating, fuel gas (natural gas for living consumption, liquefied petroleum gas and gas as household fuel gas) demanded in 2020 are calculated linearly based on the growth rate of 1990-2002. Because different parts of China vary greatly in direct energy use, for example, the southeastern part of the country lacks energy resources thus they consume more natural gas than coal than the those in the west. The northern region has household heating while the south uses cooling appliances. It is more reliable to forecast the direct energy demand by historic data.

It is agreed in many researches that direct electricity demand per capita will reach 700 kHz/year in 2020[19]. According to China's "Middle and long term program of renewable energy development" published in 2007, renewable energy mainly constituted by hydro and nuclear power will account for 20% of the total electricity generation. So the final demand of electricity is divided by this proportion.

3.2. Results of energy demand increment

On the condition of realizing the well-off society goal indicated by the above expenditures in 2020, total energy demand caused by household final consumption will increase 1.416 billion tce compared with that in 2002. According to the Chinese Statistic Book 2004, energy consumption was 1.518 billion tce in 2002, thus energy demand in 2020 will at least rise to 2.934 billion tce. Applying eq. 4 to energy sectors, we also find that direct energy demand accounts for 33.5% of the total energy increment. Details are shown in table 3.

[Table 2 and Table 3 about here]

Results show that the energy demand in 2020 almost doubles in contrast to 2002, and annual growth reaches 3.7%. It is comparable with some other researches from international institutions: the IEA forecasted in 2007 that the energy demand of China during 2005-2030 would grow at a rate of 3.2%[3]; in the same year, the EIA predicted the annual growth rate to be 3.9% from 2005 to 2030[2]; and APERC's prediction in 2006 was 3.2% for the period 2002-2030[1].

From the experience of developed countries, energy demand per capita exceeds 3.5 toe (5 tce) after GDP per capita reaches 3000 US dollars. Today in Beijing and Shanghai, where the GDP per capita is beyond 3000 US dollars, energy demand per capita exceeds 4 tce. Dai assumed that urban population in China could reach the 4 tce standard by 2020, then the total energy demand would be more than 40 billion tce. The result from this paper shows an energy demand of 2 tce per capita in China at least, under the structure and technology conditions of 2002.

Table 2 Expenditure indicators and expenditure increments

	Sector	Indicator	Expenditure in 2002		Expenditure in 2020[c]		Increment
			Per capita	Sum	Per capita	Sum	(tce)/(yuan)
E	Coal mining and dressing	coal for living consumption		4824		1708	-3116
	Petroleum extraction	-		0		0	0
	Natural gas extraction	natural gas for living consumption		680		1680	999
	Hydro and nuclear power	household electricity use		470		2581	2111
	Thermal power			1990		10324	8334
	Heating supply	household heating		908		4104	3196
	Petroleum processing	liquefied petroleum gas		2457		9237	6780
	Coking	gas		610		892	282
I	Food processing and production	food	1149.1	147604334	2245.8	336871739	189267405
	Textile industry	bedding	14.6	1872103	55.6	8336467	6464364
	Clothing and relative products	clothing	294.9	37884707	942.2	141328790	103444083
	Furniture manufacturing	furniture material	1.9	238992	3.9	578696	339704
	Cultural, educational and sports articles	consumer goods for recreational use	130.6	16781005	529.2	79387255	62606250
	Electric equipment and machinery	durable consumer goods[a]	53.0	6807284	165.5	24820596	18013312
	Electronic and telecommunica tions equipment		53.0	6807284	165.5	24820596	18013312
	Other manufacturing industry	indoor ornament, daily consumer goods	65.4	8396579	226.1	33919896.0	25523317
	Transportation,	transportation	323.0	41491174	1262.7	189404740	147913566

storage, post and telecommunication services	and telecommunication					
Wholesale, retail trade and catering services	eating outside	255.7	32845443.0	714.7	107206043	74360600
Other	housing, medicine and medical services, education& cultural and recreation services, miscellaneous commodities and services, travelling[b]	1313.8	168760251.0	3216.7	482501632	313741381

a Expenditures on durable consumer goods are evenly divided by sectors *Electric equipment and machinery* and *Electronic and telecommunications equipment;*

b Since there is no provincial statistics on travelling expenditure, the 2020 expenditure on domestic travelling uses the national average expenditure on domestic travelling by urban citizens in 2006.

c All the prices have been processed by the commodity price index from 2002-2006.

Table 3 **Energy demand increment caused by household final consumption**

	Energy demand (tce)		Direct demand percentage (%)	Average annual growth rate 2002-2020 (%)
	Total in 2002[a]	Increment in 2020		
Coal	97294	87811	36.1	3.6
Crude oil	31964	44142	26.1	4.9
Natural gas	3697	4380	36.3	4.4
Hydro/nuclear power	3993	5288	50.7	4.8

a The primary energy consumption here is from the Energy Statistics Book 2004, the sum of the four has a statistical error of about 2% with the total energy consumption from the Chinese Statistic Book 2004.

Though coal has the lowest growth rate among the primary energy categories, it still accounts for more than 60% of them. However, coal demand for living consumption has been decreasing rapidly, see table 2. Oil and electricity have increased rapidly, while electricity demand increment is largely attributed to final use while all of the oil demand is in intermediate production. The direct energy demand percentage also varies among primary energy categories: half of electricity requirement is caused by household direct use, and only 26.1% of crude oil is used for secondary energy production. Because of rapid electricity demand growth, coal demand for direct use still accounts for 36.3% and even the coal demand for living consumption is at a low proportion.

4. CO_2 emission from energy increment

Increasing energy demand not only challenges national energy security, but also contributes to global climate change. Energy demand in 2020 calculated above would be transformed into CO_2 emission through the following coefficients in table 4.

Table 4 **CO_2 emission coefficients of different energy** [20] (tCO_2/tec)

Data source	Coal	Oil	Natural gas
Department of Energy/ EIA	2.574	1.753	1.426
Institute of Energy Economics, Japan	2.772	2.149	1.646
National program on climate change, China	2.662	2.138	1.500
Xu Guoquan	2.741	2.136	1.624
Average	2.687	2.044	1.550

By using the average emission coefficients of primary energy (CO_2 emission of hydro and nuclear power is considered to be 0), primary energy demand in 2020 will emit 6.655 billion tons of CO_2, which is 24.5% of global CO_2 emission in 2005. In this case, CO_2 emission per capita of China in 2020 will reach 4.44 tons (equal to 1.33 tons carbon emission).

Nicholas Stern proposed a global target for climate mitigation, that is, 2 tons of carbon emission per capita by 2020. As for China, the incomplete energy demand for household final demand will account for 66.5% of the proposed target. If we take the investment and capital goods, huge export and government consumption into consideration, the actual emission is likely to exceed the target. According to the expenditure indicators in this study, energy demand caused by household final consumption only accounts for 41.4% of the total in 2002.

5. Impact of technology change

With the constraint of rigid energy demand, the prime solution for saving energy and control CO_2 emission is to improve energy technology. The household energy demand increment calculated above is discussed in a static condition without technological and economic structure changes. Since China is now at the intermediate stage of industrialization and will not complete it before 2020, economic structure change is not considered in this paper. Besides, the newly-launched national stimulus package are aimed at large-scale infrastructure projects, it makes the low-carbon transformation even harder. Therefore, energy technology improvement becomes the key element to reduce energy requirement.

For data limitation, here we only consider energy transformation efficiency improvement. Update the technology matrix of energy sectors A_{EE} with the energy data of 2005, according to the Energy Statistic Book 2006[21]. By comparing the two in 2002 and 2005, we find that most coefficients in the 2005 technology matrix is smaller than those in 2002 matrix, which means technology improvement in the energy sectors.

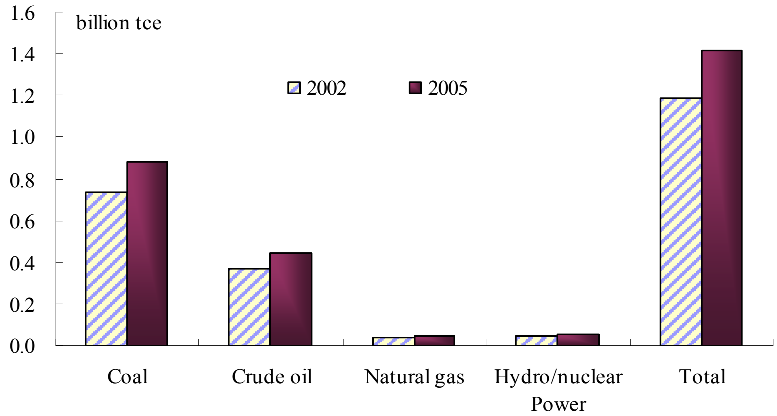

Fig. 1 **Energy demand increment with A_{EE2002} and A_{EE2005}**

Applying the 2005 technology matrix AEE2005 to calculate the energy demand increment caused by household consumption in 2020, results show a saving of 0.23 billion tce which accounts for 16.4% of the increment, that's nearly 8% of the total demand in 2020, see in figure 1. Specially, coal and crude oil could save 16.6% and 16.3% respectively, hydro/nuclear power will save 15.6%, and natural gas has the lowest saving of 13.4%. It indicates a great potential of energy saving in China.

6. Conclusion

This paper predicts direct and indirect energy demand increment caused by household consumption under a well-off society goal. Results show that energy demand at a higher living standard will double in 2020, using the more developed Jiangsu province as a reference. CO_2 emission then will reach 6.7 billion tons, which makes it hard to meet the proposed global climate change target of 2 tons carbon emission per capita. Considering the rigid energy requirement and development stage of China, technology is the key to deal with energy and climate issues. The energy transformation technology improvement during 2002 and 2005 could save 16.4% of the energy demand increment, which means China has a great potential for energy saving depending on energy technology development.

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