Chinese household consumption, energy requirements and carbon emissions

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Chapter for the China Update, 2008

Introduction

Much of the literature on Chinese energy focuses on the insatiable demand of China's rapidly growing industrial sector. Given that in 2005 industry accounted for close to 70 per cent of China's energy demand that is directly consumed by the various sectors of the economy, this focus is not unwarranted. Likewise, given that residential consumption accounted for only 11 per cent of this direct energy demand in 2005, perhaps it is not surprising that there has been so little research on this aspect of China's total energy demand.[1] What tends to be overlooked, however, is that whatever is produced within China is ultimately used for household and government consumption, investment and exports. This gives rise to a number of interesting questions regarding the end-users of energy. This paper focuses on one of those end-users, urban households, and considers the consequences of different household consumption patterns for energy requirements and carbon dioxide emissions (henceforth carbon emissions).

Drawing on national-level energy and output data for all production sectors and on the Urban Household Income and Expenditure Survey (UHIES) 2005, we address a three related issues. First, using national-level data, we extend the notion of

[1] Following an extensive literature search, Wei et al. (2007) and Liang (2007) are the only English papers we have found that focus explicitly on Chinese household energy consumption.

household energy consumption to include “indirect” energy requirements, defined in terms of the energy inputs used in the production of goods ultimately consumed by households. Adding this to direct energy consumption yields considerably higher total energy requirements, and therefore contributions to aggregate emissions, than accounting for direct energy requirements alone, supporting the findings of many others (Wei et al., 2007, Pachauri and Spreng, 2002, Cohen et al., 2005). This suggests that understanding household consumption patterns may be more important for understanding China’s future energy demand than has been previously recognised.

Second, using the urban household survey data, we examine the extent of variation in total energy requirements and emissions across households with different income levels. It seems obvious that richer households should generate more emissions, simply because they have more money to spend and virtually no expenditure is emission-free. More crucially though, we are concerned with household variations in energy requirements and emissions *per yuan*, that is, energy and emission intensities. Given that households with different levels of per capita income are likely to have different consumption bundles, and that different goods clearly require different quantities of energy in order to produce one yuan of output, variations are highly likely. A simple examination of how expenditure and emission shares of each sector vary across income brackets enables us to identify that while richer households do indeed emit more per capita, poorer households tend to be more emissions-intensive, that is, generating higher emissions per yuan spent. Their heavy reliance on coal as a source of direct energy also makes poorer households significantly less “energy green”, as reflected in higher emissions-energy ratios.

Third, econometric analysis provides estimates of the extent of variations in energy requirements and emissions that can be attributed to household variations in per capita income and a variety of other household-specific characteristics. Beyond per capita income, other variables of interest include household size and the level of education. Smaller households might be expected to emit more per capita based on economies of scale in the direct use of energy – electricity, fuel for cooking, and so on. It is possible – although perhaps overly optimistic – that higher levels of education may result in successful efforts reduce per capita emissions. Other factors that might impact on household variations include dwelling size, the age of household members, and the province in which households are located. The combined findings that emerge give rise to some critical policy implications.

Background

First, it is necessary to clarify some key terms. "Direct" energy requirements of households are defined as the consumption of energy carriers (coal, petroleum, natural gas and electricity) purchased by households in order to cater for energy services, such as space heating, heating tap water, lighting, appliances, cooking and motor fuel. "Indirect" energy requirements refer to the consumption of energy that occur in the production process of a good or service before its use (Weber and Perrels, 2000; Wei et al. 2007). Direct energy requirements are relatively easy to calculate. As long as physical quantities consumed of, say, petroleum, can be observed (which they can in the survey data used below), it is possible to convert those quantities into tonnes or grams of "coal equivalent" using the appropriate conversion factors. The carbon emissions associated with each form of energy can be readily derived using established "carbon coefficients", which are constants that vary across different energy forms (and across countries and over time as well).[2] Multiplying the petroleum quantity, expressed in tonnes of coal equivalent, by the appropriate carbon coefficient provides a measure of the total amount of carbon emissions associated with that quantity of petroleum consumption.

Calculating indirect energy requirements and their associated carbon emissions is more complex. Kok et al. (2005) survey the relevant literature and note the obvious but important point that different methods, all based on input-output (IO) analysis but using different data sources and different levels of aggregation, produce different results. They identify three basis methods. First, basic IO Energy Analysis draws on monetary data based entirely on national accounts. The indirect energy requirements of households are calculated by multiplying "sectoral cumulative energy intensities" with monetary data on the final demand of households, which are available from the IO table. Energy intensities do not include direct energy deliveries to households, which are calculated separately using physical energy data from energy statistics at the national level. Second, "IO plus household expenditure" differs from the basic method in that it relies on expenditure surveys rather than IO tables to determine household expenditures. Expenditure on each consumption item is multiplied with the corresponding value of energy intensity for that item. The direct energy requirements of households are also calculated separately, but here it is based on energy-use data collected at the household level. This is essentially the methodology adopted below, and has been used by many others (Weber and Perrels, 2000, Pachauri, 2004, Cohen et al., 2005, and Bin and Dowlatabadi, 2005). The third method is called hybrid energy analysis, which involves a combination of process and IO analysis. In

[2] By focusing on carbon intensities only, we overlook other greenhouse gases (GHGs), such as methane, nitrous oxide and chloroflurocarbons. While these other GHGs may be equally, or even more, important for certain environmental problems, data restrictions prevent a more holistic analysis at this stage.

process analysis, the lifecycle of a product is described in physical terms, delving in great detail into the various stages of the production process, such as distribution, storage, transport, waste and recycling, and so on. It is the most accurate and time-consuming method and, as a consequence, appears to have been used only for European analysis where such detailed data is available (see Reinders et al., 2003, for example). It is simply out of the question at this stage for a China-focused analysis.

This variety of methods (often referred to by different names) has been applied to address a variety of issues in single country and cross-country analyses.[3] Weber and Perrels (2000) assess the energy and emissions consequences of consumer activities in West Germany, the Netherlands and France, considering how alternative lifestyles – such as slower economic growth or the adoption of cleaner technologies – impact on projected household consumption patterns. Pachauri and Spreng (2002) use a 115 sector classification of IO tables for India in three different years, enabling them to conduct both cross-sectional and time-series analysis. They find that total energy consumption by Indian households is divided evenly between direct and indirect energy requirements and accounts for 75 per cent of total energy consumption in India. Their time-series analysis enables them to identify the main drivers of increasing energy requirements in total and per capita terms, namely growing expenditures per capita and increasing energy intensity in the food and agricultural sectors. Pachauri (2004) builds on this to consider cross-sectional variations in household energy requirements in 1993-94, finding that the size of the household dwelling, the number of members in the household, and the literacy level of the head of the household all effect household energy requirements: the first two positively, the last one negatively.

[3] Thus, for example, Kok et al.'s IO plus household expenditure approach is referred to by Bin and Dowlatabadi (2005) as "environmental IO life-cycle analysis", while Weber and Perrels (2000) refer to the same method as the "mixed monetary energetic approach".

Cohen et al. (2005) investigate the picture of equity that emerges within a developing country, using expenditure data on different income levels across 11 cities in Brazil. They show that 61 per cent of household energy is indirectly consumed and find that there are fairly constant energy intensities across income classes. Reinders et al. (2003) conduct a detailed examination of household energy intensities for a range of consumer goods in 11 European Union countries, showing that the direct energy share varies across countries, ranging from 34 to 64 per cent.

Wei et al's (2007a) analysis of China is closest in spirit to this paper. They first quantify the direct and indirect energy requirements and related carbon emissions of urban and rural residents between 1999 and 2002. They find that 26 per cent of China's total energy consumption and 30 per cent of its emissions are the "consequence of residents' lifestyles and economic activities to support these demands" (page 247). Using the IO plus expenditure approach, they find that for urban residents, the indirect contribution of energy consumption is 2.44 times greater than the direct contribution (accounting for 71 per cent of the total), while for rural residents it is actually smaller (accounting for 35 per cent of the total). The sectors covered are food, clothing, residence, household facilities and services, medicine and medical services, transport and communication services, education, cultural and recreation services, and miscellaneous commodities and services. While these sectors differ significantly from the ones used below, and the methodology is not identical, this paper provides a useful benchmark for comparison.

Before turning to detailed description of the methodology adopted in this paper, further clarification is required on at least two points. One regards the problem of using expenditure as the key variable for calculating energy and emissions intensities. As noted by Weber and Perrels (2000), calculating an average energy requirement per dollar spent on “food” does not allow a distinction between high and low quality product choices within that category. They argue that high quality usually comes at a high price, while the embodied energy increase is not commensurate, resulting in a lower energy intensity per money unit spent on high quality products. Regardless, to improve upon this “would require a much more detailed treatment”, and “such a level of detail is very difficult to combine with a dynamic description of consumption and production in a society” (page 552). Aside from the quality issue, high levels of aggregation are also problematic. If we had data on the energy inputs for, say, pork, eggs and milk, it would be (relatively) reasonable to assume that each of these is a homogeneous group and that price is also homogeneous within each group. Given that instead all we can do is aggregate these into “food”, because that is the extent of energy data available, it is true that we may overestimate or underestimate the energy and emissions intensities associated with each sub-group – pork, eggs and milk. Given data constraints, there is little to be done about this problem other than to emphasise that the discussion is necessarily about *average* intensities, and that the shortcomings of this approach are conceded.[4]

Other problems raised in the literature include the high level of uncertainty for countries that rely heavily on imports, where imports are assumed to be produced using same technology and structure as domestic industries and also the incompleteness of sectoral environmental statistics (for example, small and medium enterprises may only be registered in part and fail to be recorded accurately) (Suh et al. 2004). Hondo et al. (2002) identify numerous sources of uncertainty in carbon intensity calculations using input-output tables, including data errors, multiple goods in one sector, multiple prices of one good, multiple technologies of one good and

[4] See Suh et al. (2004) for further discussion on this point.

multiple producers of one good, presumably using different technologies. The household survey data used below does not indicate the share of imports in household expenditure and, likewise, it is beyond the scope of this paper to assess just how important these various sources of uncertainty might be. Instead, we simply acknowledge these issues and concede that the analysis is necessarily approximate rather than perfectly precise.

Finally, there is a related but distinct literature addressing ecological footprints and the potential impact of "greener" consumption patterns. An "ecological footprint" provides an estimate of the area of land required to support resource consumption of a defined population usually for a period of one year, and can be calculated at the city, regional, individual, national levels. Collins (2007), for example, considers the ecological footprint of food and drink consumption in the city of Cardiff, and ask questions such as what would happen to Cardiff's ecological footprint if there was an increase in the consumption of organic food? Carlsson-Kanyama (1998) analyses how changes in dietary choices – towards home-grown and low emissions food, for example – might impact on the green house gas emissions from food consumption in Sweden. Chen et al. (2007) assess the ecological footprint for China based on resource consumption between 1981 and 2001, demonstrating that the footprint per capita increased between 1981 and 1996, declining thereafter. Alfreddson (2004) explores the quantitative impact on energy use and carbon emissions if households were to adopt "green" consumption patterns. His conclusions are summarised in the title of the paper: "Green" Consumption – No Solution for Climate Change. Essentially, while he shows that "greener" consumption can reduce emissions, the impact is minimal and may even increase them, particularly when it is recognised that all types of consumption involve energy use and that as long as an economy is growing, emissions grow too. The ecological footprint methodology has become increasingly popular, as evidence by the Global Footprint Network, which provides extensive details on world and national ecological footprints, including China's.[5] The types of questions this line of research seeks to answer – about whether and how government policies might target "greener" consumption and what implications these might have for sustainability – are different from those posed here, where we seek to provide a quantitative assessment of just how much energy China's urban households consume and an analysis of the factors contributing to this consumption. Normative assessments about what our findings mean for "green" consumption policies are only touched upon as food for thought.

National-level Energy Requirements and Carbon Emissions

As shown in Table 1, China's direct energy consumption was 2.14 billion tonnes of coal equivalent (tce) in 2005. Industry (including mining and quarrying, manufacturing and the production and supply of electric power, heat power and water) accounted for the lion's share of this consumption, at 69.8 per cent. Residential consumption accounted for the next highest share at 10.9 per cent, with urban and rural residents accounting for 6.6 and 4.3 per cent respectively. This places aggregate residential direct energy consumption above transport, storage, postal and telecommunication services; agriculture; construction; and wholesale, retail trade and catering services. The dominance of industry in terms of direct energy consumption explains why much of the literature has focused on the relationship between China's rapid industrial development and energy demand.[6] However, this overlooks a critical

[5] See www.footprintnetwork.org

[6] See, for examples, Liao et al. (2007) and Fisher-Vanden et al. (2006).

point, which is that a large share of industry, and indeed other sectors as well, is ultimately consumed by China's households. This is where the notion of "indirect" energy consumption comes into play.

Table 1 **China's Direct Energy Consumption in 2005**

	Tonnes of coal equivalent (tce)	Share (%)
Total	2,144,793,700	100
Agriculture	79,782,800	3.7
Industry	1,496,389,400	69.8
Mining and Quarrying	118,283,300	5.5
Foodstuff	43,276,700	2.0
Textile, Sewing, Leather & Fur Products	58,416,200	2.7
Other Manufacturing	58,499,700	2.7
Production & Supply of Electric Power, Heat Power & Water	109,277,600	5.1
Coking, Gas and Petroleum Refining	104,715,200	4.9
Chemical Industry	244,744,100	11.4
Building Materials & Non-metal Mineral Products	215,151,000	10.0
Metal Products	462,770,400	21.6
Machinery and Equipment	81,255,000	3.8
Construction	34,110,700	1.6
Transport, Postal and Telecommunication Services	162,793,200	7.6
Wholesale & Retail Trades, Hotels & Catering Services	50,311,200	2.3
Other Services	86,911,500	4.1
Residential Consumption	234,495,100	10.9
Urban	142,205,300	6.6
Rural	92,289,800	4.3

Note: "Others" combines real estate, leasing and business services, banking and insurance and other services

Source: National Bureau of Statistics (2006)

Input-output tables provide the value of each productive sector used by the various sectors of the economy, which are: each of those productive sectors (agriculture, mining and quarrying, foodstuff, and so on); rural, urban and government consumption expenditure; gross fixed capital formation and changes in inventories; and net exports. The sum of these values is equal to the total output value for each productive sector. The shares of each sector's total output allocated to rural and urban consumption expenditure are listed in Table 2. Our notion of "indirect" energy consumption follows from observing these shares, which are as high as 49.5 per cent of the total in the case of foodstuff and average 16.8 per cent across all sectors. Given that the foodstuff sector, for example, used 43.3 million tce as direct energy inputs in the production process, households indirectly consumed 21.4 million tce through their consumption of foodstuff. In terms of total energy requirements then, in addition to the 10.9 per cent of total energy directly consumed by urban and rural households (as shown in Table 1), another 16.8 per cent of China's total energy, or 360 million tce, was indirectly consumed through their expenditure on other products (Table 3). This implies that 27.7 per cent of China's total energy can be traced to household consumption (very close to Wei et al.'s figure of 26 per cent). For urban households, indirect energy requirements of close to 248 million tce are 1.75 times higher than their direct energy requirements (accounting for 64 per cent of the total), while for rural households indirect requirements are 1.2 times higher (accounting for 55 per cent of the total). As urbanisation progresses in China, this is indicative that indirect energy demand will become an increasingly dominant source of China's consumer-driven emissions trends.

Table 2 **Shares of Household Consumption Expenditures in Total Output (%)**

	Rural	Urban	Subtotal
Total	5.2	11.6	16.8
Agriculture	17.3	19.4	36.6
Mining and Quarrying	0.8	2.0	2.8
Foodstuff	17.2	32.3	49.5
Textile, Sewing, Leather & Fur Products	4.2	16.5	20.7
Other Manufacturing	1.8	7.8	9.6
Prod. & Supply of Electric Power, Heat Power & Water	2.7	12.3	15.0
Coking, Gas and Petroleum Refining	0.6	3.9	4.5
Chemical Industry	2.3	4.4	6.7
Building Materials & Non-metal Mineral Products	1.7	7.9	9.6
Metal Products	0.4	1.5	1.8
Machinery and Equipment	1.4	5.3	6.6
Construction	0.0	0.0	0.0
Transport, Postal and Telecommunication services	3.2	8.9	12.1
Wholesale & Retail Trades, Hotels & Catering Services	5.8	20.0	25.8
Real Estate, Leasing and Business Services	12.8	18.9	31.7
Banking and Insurance	7.3	12.9	20.2
Other Services	5.4	21.1	26.5

Source: National Bureau of Statistics (2007)

Table 3 **Indirect Energy Requirements for Rural and Urban Households (tce)**

	Rural Households	Urban Households	All Households
Total	111,346,660	248,396,863	359,743,523
Agriculture	13,771,037	15,441,121	29,212,157
Mining and Quarrying	892,686	2,376,610	3,269,296
Foodstuff	7,440,270	13,998,298	21,438,568
Textile, Sewing, Leather & Fur Products	2,428,034	9,643,341	12,071,374
Other Manufacturing	1,037,221	4,550,680	5,587,901
Prod. & Supply of Electric Power, Heat & Water	2,952,497	13,470,711	16,423,208
Coking, Gas and Petroleum Refining	674,286	4,066,234	4,740,520
Chemical Industry	5,653,267	10,774,117	16,427,385
Building Materials & Non-metal Mineral Products	3,688,929	17,060,760	20,749,688
Metal Products	1,639,769	6,874,557	8,514,326
Machinery and Equipment	1,127,616	4,271,539	5,399,155
Transport, Postal & Telecommunication services	5,220,209	14,515,674	19,735,883
Wholesale & Retail, Hotels & Catering Services	2,930,965	10,053,672	12,984,637
Other Services	6,952,920	16,773,920	23,726,840

Note: "Other services" combines real estate, leasing, business, banking, insurance and other services

Source: Tables 1 and 2 and authors' calculations

In order to look more closely at the energy requirements and carbon emissions of households in China in the following section, it is first necessary to calculate the "energy intensity", defined as energy requirements per yuan of output in each sector, and the "carbon intensity", defined as the carbon emissions per yuan of output in each sector. Dividing the total energy consumed in each sector by the gross value of output in that sector gives sector-level energy intensities, which are provided in Table 4 below in terms of grams of coal equivalent (gce) per yuan for each of the sectors for which data is available in 2005.[7] One point that is immediately clear is that energy intensities vary substantially across sectors, ranging from 1,178 grams per yuan in the "Mining of other ores", to just 5.47 grams per yuan in the "Manufacturing of Communication, Computers and Other Electronic Equipment". In aggregate, the construction sector has the lowest energy requirements per yuan of output at 9.87

[7] Unfortunately, this precludes "Transport, postal and telecommunication services", "Wholesale and retail trades, hotels and catering services" and "Other services", as the gross value of output for these sectors is not available. Expenditure on transport will be accounted for in the "direct" energy calculations, discussed further below. However, services are omitted from the analysis as there is no alternative given data availability at this stage.

grams, compared with 20.22 grams in agriculture, 58.25 grams in manufacturing and 79.36 grams in mining.[8]

Calculating the carbon intensities is a little more involved because not all forms of energy are associated with the same carbon emissions. To resolve this, we first need to know how much of each type of energy is used by each production sector. This data is available from the *China Energy Statistical Yearbook* and provides the energy requirements (that is, direct energy inputs) for production in 48 sectors. Eighteen different fuels are specified, which are then aggregated into six categories: coal, coking products, petroleum products, natural gas, heat and electricity.[9]

Since the data is measured in consistent units, it is then possible to calculate the share of energy from each category used in production in each of the 48 sectors.[10] For example, agriculture consumed 79.8 million tce in 2005. Of that, 30.1 per cent was coal, 1.5 per cent was coking products, 50.4 per cent was petroleum products, 0 per cent was natural gas, 0.05 per cent was heat and 17.9 per cent was electricity. Based on the International Energy Agency's (IEA) data, Table 5 provides the Carbon Emission Coefficients for China in 2005, measured in tonnes of carbon equivalent (tcae).[11] It is then straightforward to calculate the carbon intensity for each sector by multiplying each emission coefficient by the proportion of each fuel used in

[8] As mentioned earlier, the sectors are not directly comparable to those used by Wei et al (2007). However, note that they calculate energy and carbon intensities in their "food" sector of 28 grams and 23 grams per yuan respectively. This sector incorporates the food processing, manufacturing and beverages sectors used above, and taking simple averages across these sectors reassuringly puts our calculations in the same ball park as their's.

[9] Coal includes raw coal, clean coal and other washed coal. Coking products include coke, coke oven gas, other gas and other coke products. Petroleum products include crude oil, gasoline, kerosene, diesel oil, fuel oil, petroleum liquid gas, refinery gas and other petroleum products. Natural gas, heat and electricity stand alone.

[10] To complicate matters slightly, the relevant table in the *China Energy Statistical Yearbook* reports total final energy consumption in each sector in two consistent forms – coal equivalent calculation and calorific value calculation. However, it only provides the breakdown of energy sources in terms of calorific value calculations and so we use these to calculate the shares of each source. In terms of shares, the results are equivalent whichever measure is used.

[11] The electricity coefficient is a weighted sum of the coal, oil and gas coefficients, based on the shares of coal, oil and gas used in China's electricity generation being 78 per cent, 2.4 per cent and 1 per cent respectively (International Energy Agency, 2007). The remainder of China electricity is fueled by hydropower (16 per cent), nuclear (2.1 per cent), and wind, biomass and other renewables (0.5 per cent). These are all assumed to have zero carbon coefficients. Coking products and heat are assumed to have the same carbon coefficient as coal.

production and summing over all fuels, giving the emissions intensities in grams of carbon per yuan reported in Table 4. Given that different sectors use different types of energy in different proportions, there is not a perfect correlation between energy intensity and emissions intensity. Although the correlation at this sectoral level is extremely high at 0.999, a closer look at the household data reveals important differences in across income deciles, as the subsequent analysis reveals.

Table 4 **Energy and Carbon Intensities by Sector in 2005**

	Energy Intensity (grams/yuan)	Carbon intensity (grams/yuan)
Agriculture	20.22	11.51
Industry	**59.47**	37.68
Mining and Quarrying	**79.36**	48.13
Mining and Washing of Coal	98.95	66.32
Extraction of Petroleum and Natural Gas	57.09	28.57
Mining and Processing of Ferrous Metal Ores	95.75	57.54
Mining and Processing of Non-Ferrous Metal Ores	58.27	34.63
Mining and Processing of Nonmetal Ores	114.13	72.04
Mining of Other Ores	1178.23	665.47
Manufacturing	**58.25**	37.09
Processing of Food from Agricultural Products	19.21	12.36
Manufacture of Foods	30.97	20.24
Manufacture of Beverages	28.50	18.90
Manufacture of Tobacco	8.38	5.34
Manufacture of Textile	39.33	25.22
Manufacture of Textile Wearing Apparel, Footware and Caps	11.00	6.74
Manufacture of Leather, Fur, Feather and Related Products	8.97	5.34
Processing of Timber, Manufacture of Wood Products	37.83	24.43
Manufacture of Furniture	9.04	5.29
Manufacture of Paper and Paper Products	78.80	51.97
Printing, Reproduction of Recording Media	19.04	11.00
Manufacture of Articles For Culture, Education & Sport Activity	13.23	7.47
Processing of Petroleum, Coking, Processing of Nuclear Fuel	87.26	47.17
Manufacture of Raw Chemical Materials and Chemical Products	134.52	80.93
Manufacture of Medicines	26.43	17.17
Manufacture of Chemical Fibers	51.50	32.12
Manufacture of Rubber	49.20	30.40
Manufacture of Plastics	28.59	16.71
Manufacture of Non-metallic Mineral Products	206.47	136.47
Smelting and Pressing of Ferrous Metals	171.72	117.28
Smelting and Pressing of Non-ferrous Metals	90.49	55.30
Manufacture of Metal Products	33.91	19.90
Manufacture of General Purpose Machinery	19.49	12.13
Manufacture of Special Purpose Machinery	20.43	12.80
Manufacture of Transport Equipment	12.41	7.53
Manufacture of Electrical Machinery and Equipment	8.58	4.92
Manufacture of Communication & Other Electronic Equipment	5.47	3.01
Manufacture of Measuring Instruments and Office Machinery	6.99	4.02
Manufacture of Artwork and Other Manufacturing	61.17	37.31
Recycling and Disposal of Waste	11.67	6.99
Electric Power, Gas and Water Production and Supply	**57.88**	35.85
Production and Distribution of Electric Power and Heat Power	54.94	34.46
Production and Distribution of Gas	90.05	49.53
Production and Distribution of Water	119.52	76.78
Construction	9.87	5.25

Source*:* National Bureau of Statistics (2006, 2007) and own calculations.

Table 5 **Carbon Coefficients by Fuel**	
Coal	0.7018
Oil	0.4876
Gas	0.3999
Electricity	0.5631

Source: International Energy Agency (online) and own calculations

Urban Household Energy Requirements and Carbon Emissions

The data used in this section is drawn from the Urban Household Income and Expenditure Survey (UHIES) 2005. Although the survey comprises all 31 provinces in China, we only have access to the data for 16 provinces. In the survey, household expenditure is divided into 7 categories: current period consumption; expenditure on housing building or purchasing; transfer expenditure (including tax, donations, buying lotteries, paying for expenditure of non-co-residing family members (parents or children), expenditure on non-saving insurances, and other transfer expenditures); interest only mortgage repayments; social welfare savings; saving and mortgage repayments (principles only); and end-of-period cash-in-hand. The part of household expenditure that we are able to convert into direct and indirect energy consumption and carbon emissions is the first category: current period consumption, which, on average, accounts for 75 per cent of total household expenditure (see column 5 in Appendix Table A1). To the extent that any of the other categories require energy inputs and therefore generate emissions, the calculations below will underestimate households' indirect contributions to China's energy demand. The survey provides details of household current period consumption on a range of highly disaggregated goods. We aggregate these according to the sectors in Table 4, and are thus able to calculate the urban household energy requirements and carbon emissions that occur indirectly via each household's consumption bundle.[12] This is the notion of "indirect energy" introduced above, but now applied to household level expenditure data. In addition to these indirect energy requirements, each household also consumes energy directly, in the form of coal, gas, petroleum and electricity. The Survey data provides the quantities of each of these consumed by each household, which are readily converted into tonnes of coal equivalent, from which the carbon emissions can be obtained. We also have expenditure data on each of these forms of direct energy consumption, from which emission intensities can be obtained.

Three important assumptions are made in calculating household energy consumption and carbon emissions. First, a sizeable amount of household food consumption comprises eating out. We assume that one third of the cost of eating out is due to food consumption, while the remainder is service cost.[13] We further assume that half of the cost of food eaten out stems from food processed from agricultural products, while the other half stems from manufactured food. Second, we assume that 25 per cent of total expenditure on public transportation fees, such as expenditure on taxi, bus, air and train tickets, is related to petrol consumption, while the rest is attributed to services. Third, all services fees are assumed to be energy free, due to data limitations. Excluding services costs, the proportion of current period consumption which is counted for as direct and indirect energy consumption is around 73 per cent of the current period consumption and 55 per cent of the per capita total household expenditure (see Appendix Table A1). As with the above excluded categories in total household expenditure, omitting services from the analysis will

[12] See Table A2 in the Appendix for details. Due to the data limitations discussed in previous footnotes, not all sectors in Table 4 are included in the analysis in this section.

[13] Although the nutrition literature normally assumes a 50 per cent premium to reflect processing margins, studies also find that this assumption is not sensitive to the estimated income elasticity of nutrition intake (see, for example, Deaton, 1996 and Gibson and Rozelle, 2002).

mean that we underestimate households' indirect contributions to China's energy demand.

Table 6 presents summary statistics by income decile for urban households' total energy consumption, carbon emissions, direct and indirect emissions, per capita energy consumption and carbon emissions, and direct emissions by different energy sources. The table shows that the surveyed urban Chinese households consume an average of 1.71 tonnes of coal equivalent (tce) per annum, which in turn generate an average of 0.90 tonnes of carbon emissions (tcae). Average per capita energy consumption across all households is 0.61 tce per annum, which generates 0.32 tcae. Energy consumption and carbon emissions are much higher for richer households than for poorer ones. Households in the top 10 percentile income group (the 10th decile) consume an average of 2.48 tce, some 86 per cent more than the amount consumed by households in the poorest group (the 1st decile) at 1.28 tce. Similarly, the richest decile on average emits 66 per cent more carbon than the poorest.

By separating total energy consumption into direct and indirect sources, it is revealed that only 32 per cent of household energy consumption is from direct sources.[14] Nevertheless, with regard to carbon emissions, indirect sources account for a larger proportion, especially for the richest decile, where close to 40 percent of carbon emissions are from indirect sources.[15] This compares with just 20 per cent for

[14] This is quite a departure from the aggregate figures in the preceding section, which showed that direct energy demand only accounted for 36 per cent of urban households' total energy demand. Two obvious reasons why we understate indirect energy demand is that we do not incorporate all sectors or all expenditure in our analysis. The figure also differs significantly from Wei et al. (2007), who find that direct energy accounts for just 29 per cent of urban household energy requirements. Their figure is at the lowest end of the literature surveyed in the previous section, while ours here is towards the high end. One reason for the discrepancy may stem from the different consumption categories that we assess, particularly as we divide consumption into over 20 categories compared with their eight. Another clear difference is that in Wei et al., the "Residence" category dominates urban indirect energy demand, accounting for over 60 per cent of it. Included in this category are the production and supply of electric power, steam, hot water and gas, all of which are assumed to be direct energy demand in our analysis.

[15] In addition, given that richer households spend a higher proportion of their income on services, and these are largely excluded from our story here, the share of energy and emissions that can be attributed to indirect sources is likely to be understated more for rich than poor. On average, our sample households spend 2,243 yuan per capita on services, which accounts for 27 per cent of per capita current period consumption. For the poorest group,

the poorest decile (see Appendix Table A3). Why does indirect energy demand account for a higher proportion of total emissions generated by richer households than by poorer ones? When comparing carbon emissions across income groups, it is clear that rich households emit more per capita than poor households. However, if comparing direct emissions, the poor generate only slightly less carbon than the rich. Further investigation shows that the high direct emissions for poor households are mainly due to their relatively high levels of coal consumption – the least "green" or most emission-intensive form of energy. The poorest income decile's carbon emissions from coal consumption are around seven times as high as the richest decile's. This, in turn, is due to the fact that the price for coal is one third of the price for gas, one ninth of the price for electricity, and one tenth of the price for petrol, as shown in Table 7.

A closer look at the data reveals some interesting points regarding variations in the level of carbon emissions per unit of energy consumed across households. This emissions-energy ratio provides a measure of the extent of the carbon intensity of energy, or "energy greenness", with lower levels implying that energy use is relatively energy green. To sum up the discussion of Table 6 and further examine this energy efficiency, we present a group of graphs which provide visual relationships between energy and emissions on the one hand and income on the other. Figure 1 presents per capita total energy consumption, carbon emissions and the ratio of carbon emissions over energy consumption, by income percentile. The figure shows that while rich households consume more energy and produce more carbon emissions per capita,

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service expenditure is 727 yuan per capita, accounting for 23 per cent of the total current period consumption, while for the richest group this figure is 5,592 yuan, accounting for 30 per cent of the current period consumption (see columns 3 and 6 in Appendix A).

their emissions-energy ratio is lower than poor households'. That is, richer households are relatively energy-green.

Table 6. **Average Energy Consumption and Carbon Emissions by Income Decile**

	Household Emissions (tcae)	Household Energy (tce)	Per Capita Emissions (tcae)	Per Capita Energy (tce)	Direct Energy (tce)	Indirect Energy (tce)
1st decile	0.77	1.34	0.24	0.42	1.09	0.24
2nd decile	0.81	1.46	0.26	0.47	1.15	0.31
3rd decile	0.84	1.54	0.28	0.51	1.18	0.35
4th decile	0.80	1.51	0.28	0.52	1.13	0.38
5th decile	0.85	1.61	0.30	0.57	1.19	0.41
6th decile	0.86	1.63	0.31	0.59	1.19	0.44
7th decile	0.90	1.74	0.33	0.64	1.26	0.48
8th decile	0.93	1.80	0.35	0.68	1.28	0.53
9th decile	1.00	1.95	0.39	0.76	1.36	0.59
10th decile	1.28	2.48	0.50	0.97	1.68	0.80
Average	0.90	1.71	0.32	0.61	1.25	0.45
	Direct Emissions (tcae)	**Indirect Emissions (tcae)**	**Emissions (coal) (tcae)**	**Emissions (oil) (tcae)**	**Emissions (electric.) (tcae)**	**Emissions (gas) (tcae)**
1st decile	0.61	0.16	0.35	0.02	0.07	0.17
2nd decile	0.61	0.20	0.28	0.03	0.08	0.22
3rd decile	0.61	0.23	0.24	0.04	0.09	0.24
4th decile	0.56	0.24	0.17	0.04	0.10	0.25
5th decile	0.59	0.26	0.17	0.05	0.10	0.27
6th decile	0.57	0.28	0.13	0.06	0.11	0.28
7th decile	0.59	0.30	0.11	0.06	0.12	0.31
8th decile	0.60	0.34	0.09	0.06	0.12	0.32
9th decile	0.63	0.37	0.07	0.09	0.13	0.34
10th decile	0.77	0.50	0.05	0.18	0.16	0.38
Average	0.61	0.29	0.17	0.06	0.11	0.28

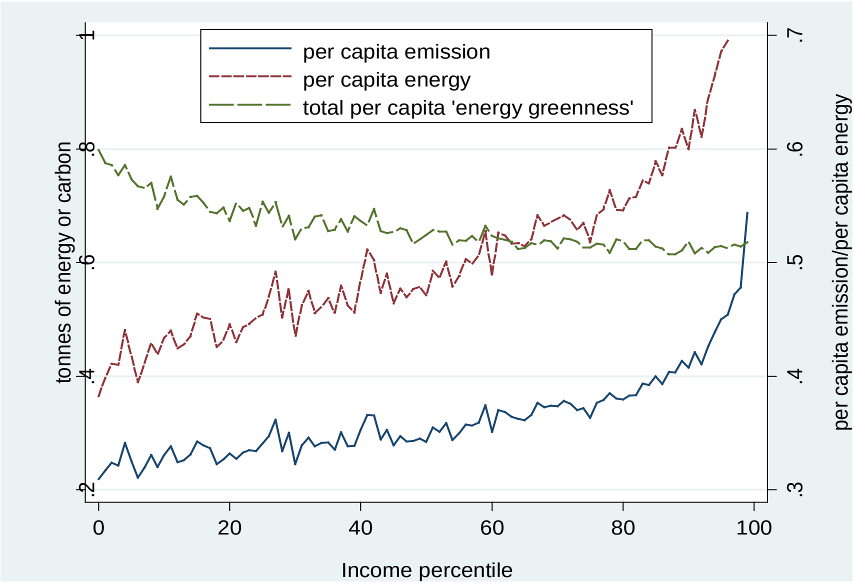
Source: UHIES (2005) and authors' calculations

Table 7. **Price per tonne of coal equivalent**

	Yuan/tonne	Proportion of coal price
Coal	374	1
Gas	1,070	2.9
Electricity	3,246	8.7
Petrol	4,033	10.8

Source: Derived from UHIES, 2005

Figure 1 **Total energy, carbon emissions and 'greenness' by income**



We then separately plot direct and indirect energy, emissions, and their ratio in Figures 2 and 3a. The two figures indicate that the major source of lower energy greenness for the poor is direct energy consumption, which generates substantially more emissions for the poor than for the rich. For indirect energy consumption and emissions, there is almost no difference across income groups.

The data presented in Table 6 indicate that the main reason for high levels of direct energy consumption and carbon emissions for people in poor households is due to their high levels of coal consumption. We therefore exclude coal from direct energy consumption and consequent emissions and plot the remaining direct energy and emissions by income group again (see Figure 3b). The new figure shows almost the same level of energy greenness for poor and rich households. In fact, there is a slightly higher emissions-energy ratio for the top income decile compared with the other income groups.

Figure 2 **Indirect energy, carbon emissions and 'greenness' by income**

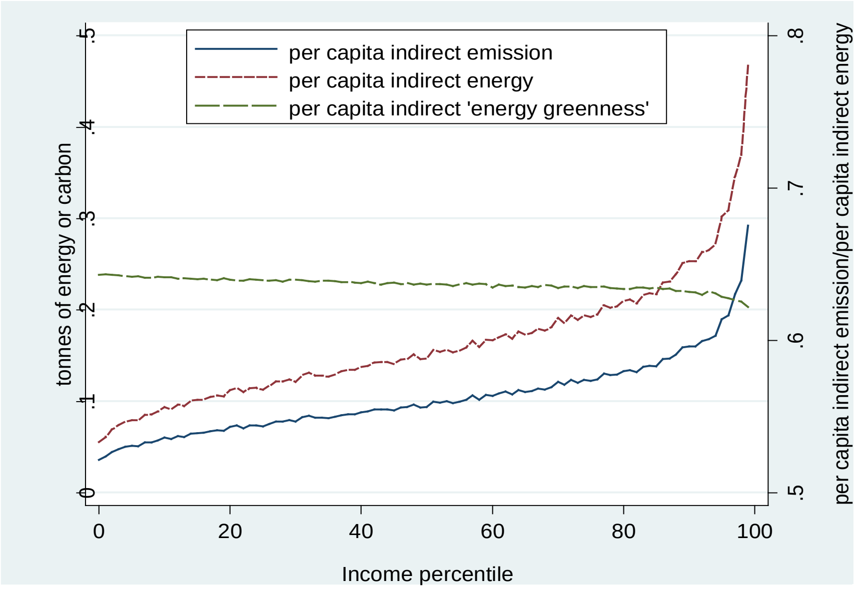


Figure 3a **Direct energy, carbon emissions and ‘greenness’ by income**

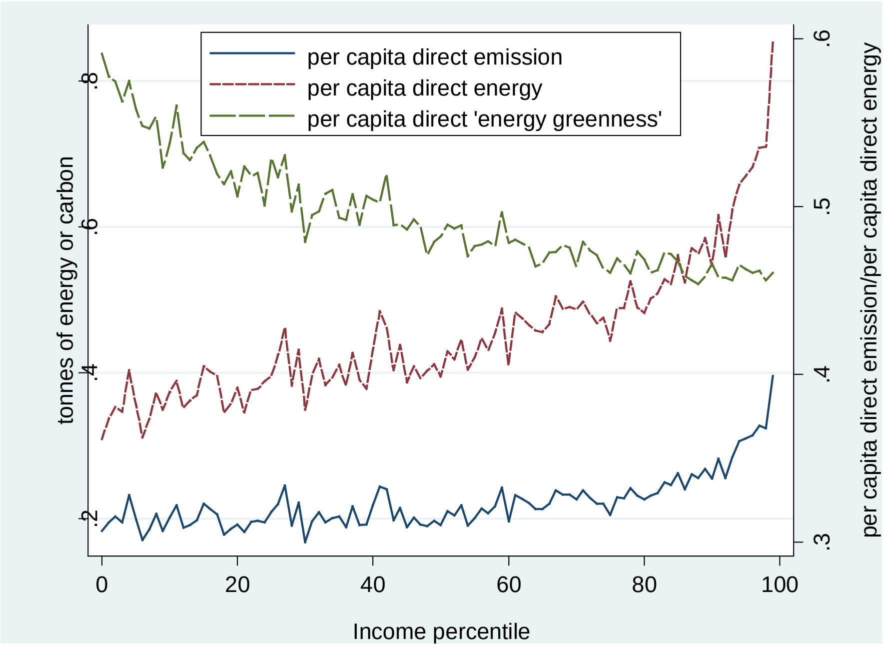
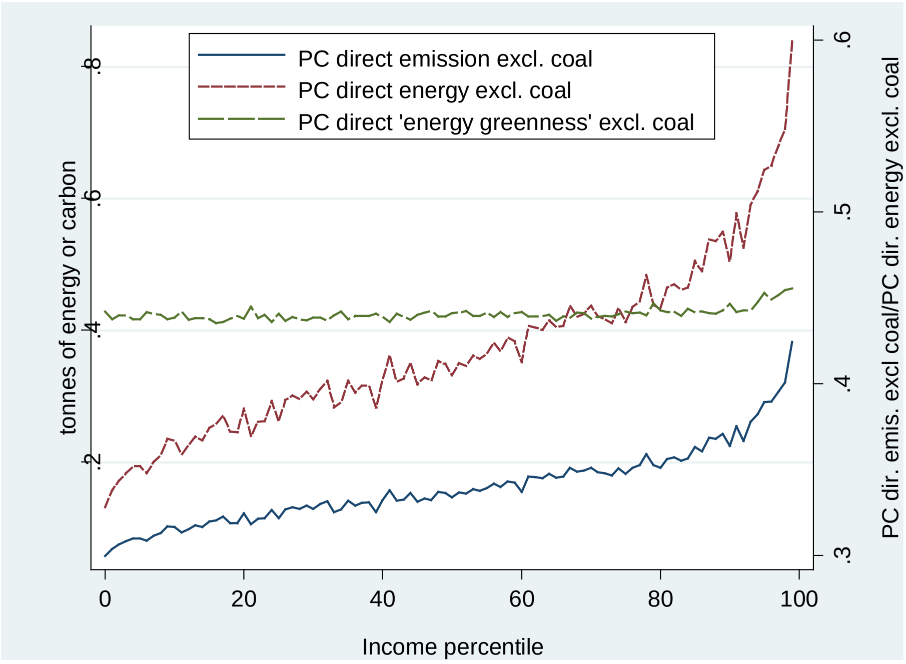


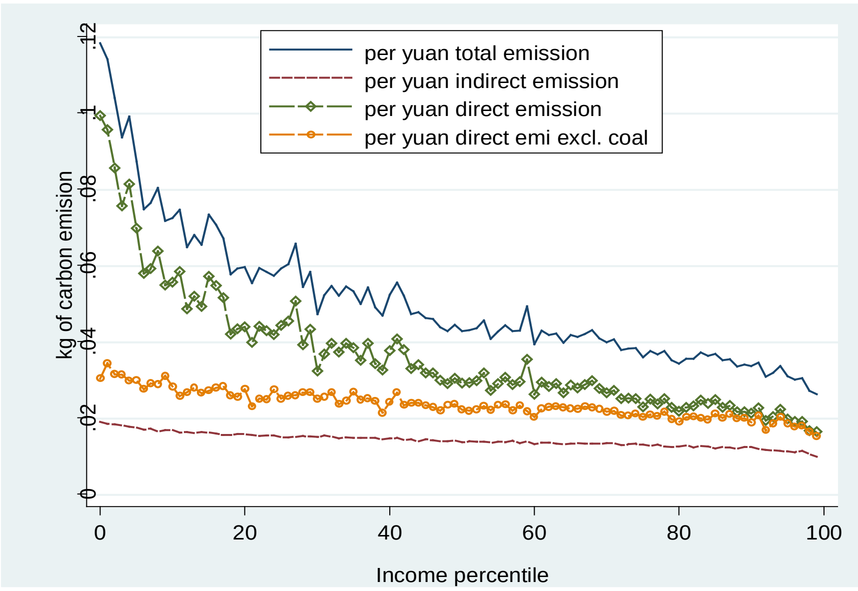
Figure 3b **Direct energy, carbon emissions and 'greenness' excl. coal by income**



The next question of interest us is whether there is any variation in rich and poor household's per yuan carbon emissions. Figure 4 plots average emissions divided by total expenditure per household. The top solid line in Figure 4 is total emissions per yuan. The figure indicates that every yuan spent by the poorest household generates 0.12 kilograms of emissions, while one yuan spent by the richest household only generates 0.02 kg carbon. Almost the entire difference in these emissions intensities is due to direct energy consumption, as can be seen by the fact that the direct emissions per yuan curve follows the total emissions curve closely while the indirect emissions per yuan curve is almost flat. This, in turn, is due to the high level of coal consumption by the poor (as seen by the curve for direct emissions excluding coal, which is also very flat). In other words, the most important discrepancy between rich and poor households lies in the different shares of expenditure allocated to direct coal consumption and the emissions generated as a result.

This is not to say that the sources of indirect emissions do not vary across income brackets. For example, food (processed from agriculture, manufactured and eating out combined) accounts for 75 per cent of the poorest decile's emissions, compared with just 48 per cent for the richest decile, while 10 per cent of the richest decile's indirect emissions stem from manufactures of raw chemicals and chemical materials, compared with 5 per cent for the poorest decile. However, these differences do not amount to significant differences in emissions per yuan spent for each of these income groups. Instead, it is all about direct emission shares, and those generated from coal consumption in particular: 58 per cent of the poorest household's direct emissions stem from coal consumption compared with just 6.5 per cent for the richest households.[16] Thus while rich households consume more energy and produce more carbon emission than poor households, more importantly, poor households produce more emissions per unit of energy consumption and more emissions per yuan spent than rich households.

Figure 4 **Per yuan carbon emissions by income percentile (kilograms)**



[16] See Appendix Table A3 for details.

An econometric analysis

The above analysis is based entirely on simple averages by income group. Energy consumption and emissions may also be affected by other factors, such as household composition and dwelling size. Further, households' location of residence may also have a significant effect due to weather conditions and regional energy price variations. In this section we estimate simple energy and emission determination equations, which allow us to tease out other factors and to identify the pure income effect of urban household energy requirements and emissions.

In our econometric model, in addition to per capita income and its squared term we control for household size, the gender, age and years of schooling of the household head, a group of household composition variables relating to gender and age, dwelling size, and dummy variables for each of the 15 provinces other than Beijing, which is the benchmark province, and therefore the omitted dummy variable.

Insert Table 8 HERE.

Table 8 presents the results for the determinants of per capita energy consumption. On average, larger households consume less per capita energy, verifying an economies of scale effect. Cooking for five people should consume less energy than cooking for one person five times. Similarly, five people watching TV requires the same amount of energy as one person watching TV. Our results also show that males and older household heads are associated with higher energy consumption, while households with more educated heads consume less energy. This latter effect, however, is only applicable to total energy and direct energy consumption.[17] This lends some support to the optimistic claim that people with higher levels of education are more aware of the impact of their energy consumption on total emissions and account for this in their consumption decisions. The household composition variables indicate that relative to the omitted category (male and female adults aged 20 to 65), children of most age groups consumes less energy, while older people (male and female above 65) consume more energy. This may be related to the fact that old people spend more time at home. Further, the larger the size of the house, the more energy consumed. On average, every 100 square meter requires 44.3 kg total coal equivalent energy. This is mainly due to direct energy consumption, and in particular, coal consumption; although, larger housing is associated with higher indirect energy consumption as well.

The final part of Table 8 presents results for the provincial dummy variables. Relative to Beijing, the following provinces (cities) consume more energy (in descending order): Shanxi, Shanghai, Chongqing, Sichuan, Heilongjiang, Henan, Liaoning and Anhui. This order is almost the same for direct energy consumption. For non-coal direct energy consumption, there is a slight difference in consumption orders. For example, Shanghai ranks first, while Shanxi ranks second. In terms of indirect energy consumption, only Guangdong and Shanghai exceed Beijing, while the remaining provinces all consume less direct energy than Beijing. These energy consumption differences across provinces may be related to the differences in energy price level and resource reserves across regions. For example, it is understandable that households in Shanxi would consume more energy, especially coal. Richer regions

[17] However, when only non-coal direct energies are included, the effect of education of the household head switches sign and becomes positive and statistically significant. These contradictory results are puzzling, but are perhaps related to high correlations between per capita income and education levels in combination with the high coal content of poorer households' direct energy consumption.

appear to be the largest consumers of indirect energy, as evidenced by the positive coefficients on Shanghai and Guangdong in the final column. This compounds the earlier claim that as Chinese households and regions become richer, indirect energy patterns will become increasingly important.

The estimated carbon emission equations are presented in Table 9, where we observe almost the same pattern of carbon determinants as in the energy consumption equation. We, therefore, do not reiterate our results. The discussion below will focus entirely on the effect of income.

Insert Table 9 HERE.

To capture potential diminishing marginal energy requirements and carbon emissions as income increases, we include a squared term for the latter in the regressions. The results indicate that the relationship between energy consumption/carbon emissions and income for urban Chinese households is essentially linear over the income range of our sample. For example, with regard to total per capita energy consumption, every additional yuan of income increases energy consumption by 0.02 kg of coal equivalent but the rate of increase falls by just 0.00000006 kg of coal equivalent. For indirect energy consumption, the diminishing point is not reached until 158,000 yuan per capita, which is more than five times the current average per capita income level. For total energy consumption, the point of diminishing marginal energy requirements and carbon emissions are reached at income levels of 174,000 and 363,000 yuan respectively. To visualise the estimated relationship between energy consumption/carbon emissions and income, Figures 5 and 6 plot the predicted relationship for 99 per cent of the range of income levels in our sample (100 to 42,100 yuan). The figures show that within our sample income range, the relationship between income and all types of energy/emission is almost linear. Comparing the two figures, the only difference observed is that income has the lowest effect on indirect energy consumption, while it has the lowest effect on direct carbon emissions. One of the most interesting results is that income has a stronger effect on non-coal direct energy consumption and carbon emissions than on direct energy consumption and carbon emission, confirming yet again that coal is mainly a poor people's energy.

Figure 5 **Predicted relationship between household per capita energy consumption and income**

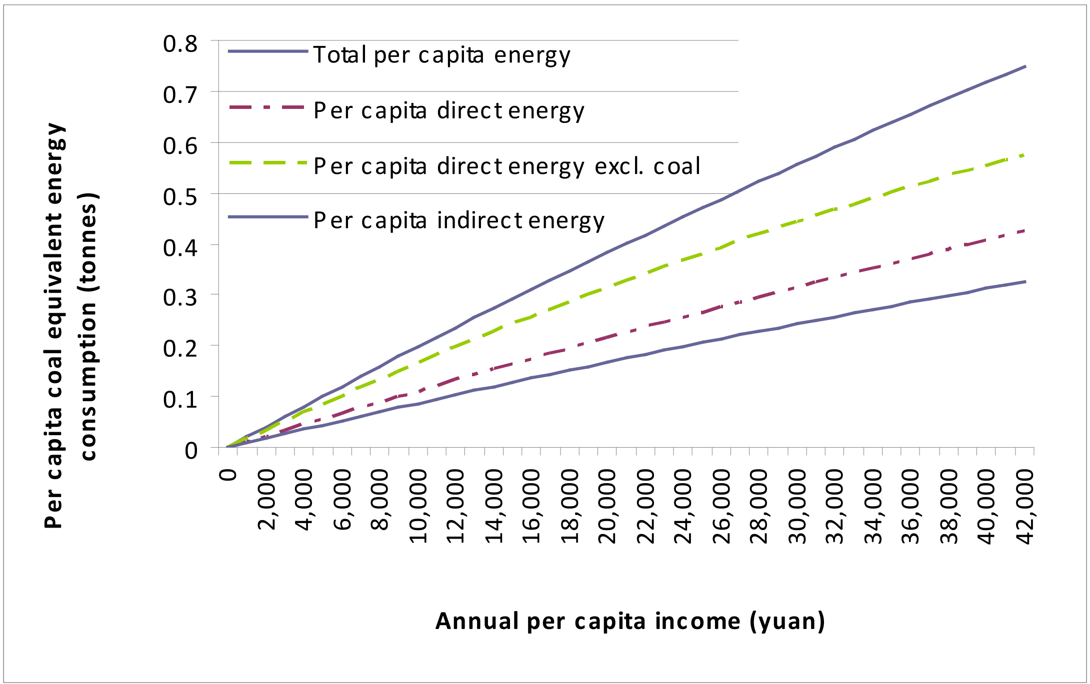
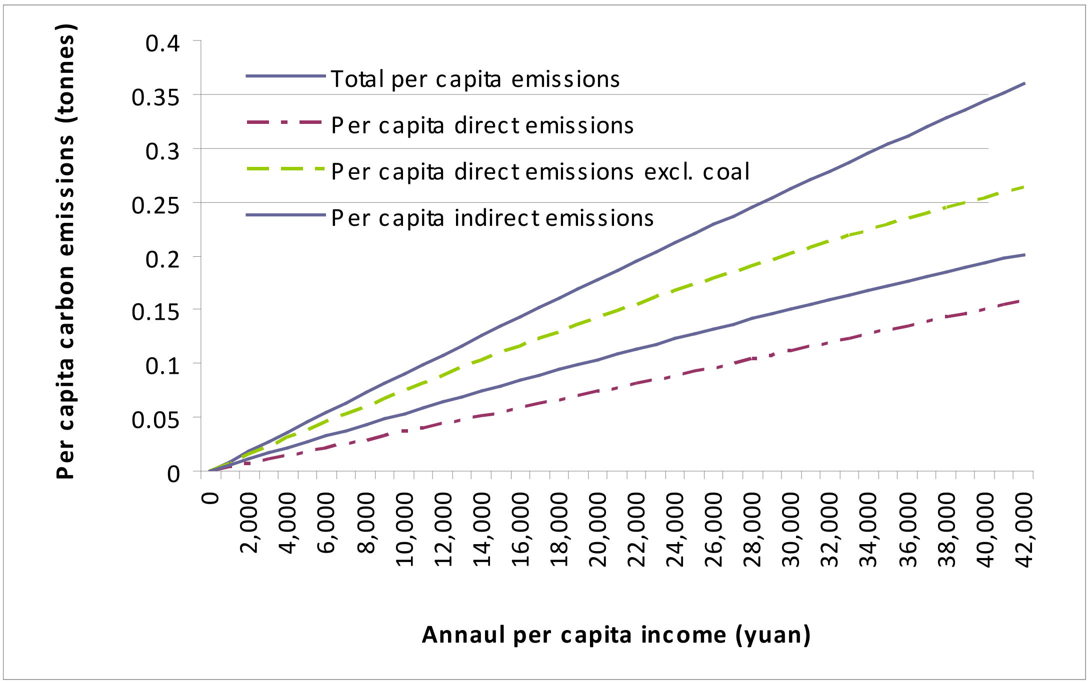


Figure 6 **Predicted relationship between household per capita carbon emission and income**



Conclusions

This chapter focused on three inter-related issues. First, we drew on national-level data to establish the notion that the total energy requirements of households are substantially higher when their indirect energy requirements are added to their direct energy consumption. Indeed, the calculations showed that this allocated an additional 16.8 per cent of China's total energy demand to households, 11.2 per cent of which was attributed to urban households. If the 11th Five Year Plan succeeds in its objective of shifting the Chinese economy towards consumption-led growth, indirect energy shares are likely to rise in the future, thereby becoming increasingly important for understanding future energy demand and consumer-driven emissions trends.

Second, using urban household survey data, we examined the extent of variation in total energy requirements and emissions across households with different income levels. While there were clear differences in the shares of indirect emissions attributable to different consumption bundles of rich and poor households, these were overshadowed by overwhelming evidence that the share of emissions attributed to direct energy consumption matters most: poorer households are more emissions-intensive because of their heavy dependence on coal. The most critical policy implication to emerge from this is to ensure that poor households are encouraged to shift away from coal and towards cleaner energy sources in the near future.

The survey-based analysis produced a share of indirect energy for urban households of 32 percent, just half the share that we found using national-level aggregate data. This discrepancy stemmed from a number of issues, including the need to use per capita consumption rather than expenditure and the exclusion of services from the survey-based analysis (Appendix Table A1). Moreover, throughout the chapter, we overlook the processes that deliver final goods to household doorsteps, including the storage and distribution of goods, all of which require considerable energy inputs. These inadequacies only strengthen the claim that the indirect energy requirements of Chinese households matter more to the future of China's contributions to global environmental pressures than many people realise, and that more detailed research in this area is therefore warranted.

Third, the econometric analysis focused on the determinants of variation in per capita energy requirements and emissions. The virtually linear relationship between per capita income and energy demand is indicative of the challenges facing China as per capita incomes continue to grow, since there is no indication of diminishing marginal energy requirements happening over the wide range of current income levels. This finding stresses the need for policymakers to promote ways to reduce the emission-intensities of all of the goods consumed by Chinese households (and for that matter, used by the other end-users as well). The higher energy requirements of richer provinces even after controlling for per capita income further compounds this need, as poorer provinces continue to grow and strive towards living standards comparable to their richer neighbours. While there was some evidence that households with higher levels of education consume less energy per capita, this result did not hold up in the regression using indirect energy only. Whether or not education has a role to play in promoting cleaner consumption patterns in the future therefore remains open to question, although it is hard to think that such efforts would prove detrimental. This point extends to thoughts about whether "green" consumption policies stand any chance of reducing China's emissions path below current trajectories.

To end on a bright note, assuming that services are relatively energy-green (which is certainly the case compared to direct coal consumption) and noting the above evidence that richer Chinese households spend a higher share of their income on services, the future for China may well look cleaner if incomes can be raised across the board to the point where services dominate consumption patterns. That future cannot arrive quickly enough.

Appendix

Table A1 **Breakdown of Per Capita Expenditure**

	Total PC expenditure	Current period PC consumption	PC service cost	PC cons. excl. services	PC current period cons. as % of PC exp.	PC service cost as % of per capita current period cons.	PC current period cons. excl. services as % of PC total exp.
	(1)	(2)	(3)	(4)	(5)=(2)/(1)	(6)=(3)/(2)	(7)=(4)/(1)
decile 1	3,655	3,095	727	2,369	0.85	0.23	0.65
decile 2	5,200	4,323	1,039	3,284	0.83	0.24	0.63
decile 3	6,438	5,211	1,285	3,926	0.81	0.25	0.61
decile 4	7,402	5,934	1,513	4,421	0.80	0.25	0.60
decile 5	8,694	6,872	1,790	5,082	0.79	0.26	0.58
decile 6	9,973	7,687	2,021	5,666	0.77	0.26	0.57
decile 7	11,639	8,843	2,421	6,422	0.76	0.27	0.55
decile 8	13,562	10,015	2,723	7,292	0.74	0.27	0.54
decile 9	16,390	11,827	3,316	8,511	0.72	0.28	0.52
decile 10	27,303	18,845	5,592	13,252	0.69	0.30	0.49
average	11,026	8,265	2,243	6,022	0.75	0.27	0.55

Table A2 **Aggregation of Survey Sectors into Table 4 Sectors**

Table 4 Sector	**Survey Sectors included**
Processing of Food from Agricultural Products	grain, starch, meat, poultry, eggs, seafood, vegetable, fruits
Manufacture of Foods	manufacture of grain, bean, meat, poultry, eggs, seafood, sugar,vegetable, fruits, milk, cake, canned food and semi-cooked food plus 1/3 of eating out expenses
Manufacture of Beverages	alcohol and drinks
Manufacture of Tobacco	tobacco
Manufacture of Textiles	clothing materials
Manufacture of Textile Apparel, Footware & Caps	clothes, shoes, bed-clothes, textile decoration
Processing of Timber and Wood Products	furniture materials
Manufacture of Furniture	furniture
Manufacture of Paper and Paper Products	papers and stationery
Printing, Reproduction of Recording Media	newspapers, magzines, books, textbooks, education softwares
Manufacture of Articles for Culture, Education & Sports	sports equipment, electronic dictionaries, audio & video products, culture decorations
Manufacture of Raw Chemical Materials & Chemical Products	detergent and cosmetic goods for hair-dressing and bathing
Manufacture of Medicines	medicine, nutriments
Manufacture of Metal Products	lighting, cutlery, tea sets, small tools
Manufacture of Transport Equipment	cars, bikes, motors, and their components
Manufacture of Electrical Machinery and Equipment	electric, medical and health equipment
Manufacture of Measuring Instruments & Office Machinery	pianos, other musical instruments, body-building equipment, watches
Manufacture of Artwork and Other Manufacturing	jewellry and other miscellaneous items
Production and Distribution of Water	water
Construction	housing decoration and building materials
Services	services: sewing, housekeeping, medical treatment, communication fee, recreation fee, education fee, rent, imputed rent, housing management fee ; transportation fee*0.75; eating out expenditure*0.67

Table A3 **Emission shares of consumption goods by income decile**

	Share of total emissions		Share of indirect emissions	
	1st	10th	1st	10th
Indirect emissions				
Processing of Food from Agricultural Products	0.045	0.046	**0.223**	**0.117**
Manufacture of Foods	0.104	0.123	**0.513**	**0.312**
1/3 of eating out	0.003	0.019	**0.015**	**0.048**
Manufacture of Beverages	0.004	0.011	0.021	0.027
Manufacture of Tobacco	0.002	0.003	0.008	0.007
Manufacture of Textile	0.000	0.001	0.002	0.002
Manufacture of Textile Wearing Apparel, Footwear, and Caps	0.007	0.026	0.036	0.065
Processing of Wood Products	0.000	0.000	0.000	0.001
Manufacture of Furniture	0.000	0.004	0.001	0.009
Manufacture of Paper and products	0.002	0.002	0.009	0.006
Printing and Recording Media	0.002	0.003	0.008	0.009
Manufacture of Articles For Culture, Education and Sport Activity	0.000	0.003	0.002	0.009
Manufacture of Raw Chemical Materials and Chemical Products	0.011	0.041	**0.052**	**0.103**
Manufacture of Medicines	0.001	0.014	0.005	0.036
Manufacture of Metal Products	0.001	0.003	0.003	0.008
Manufacture of Transport Equipment	0.001	0.023	0.002	0.059
Manufacture of Electrical Machinery and Equipment	0.001	0.005	0.002	0.012
Manufacture of Communication, Computers and Electronics	0.000	0.004	0.001	0.011
Manufacture of Measuring Instrument, Cultural & Office Machinery	0.000	0.001	0.000	0.002
Manufacture of Artwork and Other Manufacturing	0.009	0.038	0.045	0.097
Production and Distribution of Water	0.010	0.015	0.050	0.039
Construction	0.001	0.009	0.003	0.024
			Share of direct emissions	
Direct emissions				
Coal	**0.459**	0.040	**0.576**	0.065
Petrol	0.029	0.144	0.036	0.237
Gas	0.222	**0.295**	0.279	**0.487**
Electricity	0.087	0.128	0.109	0.211
Share of direct emissions in total	0.797	0.606		

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