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China's Water-Energy Nexus

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1. Introduction

China's recent growth experience has established new standards for economic growth among developing countries. Many low income economies aspire to the Chinese example and, although few are likely to replicate such sustained, rapid expansion, China's precedence for export and resource-intensive growth has given strong impetus to outward-oriented development strategies for industrialization and modernization. Even in China, however, the sustainability of this approach is open to question. Although China has maintained double-digit GDP growth over nearly three decades, serious constraints on water and energy resources have begun to emerge. A better understanding of these constraints will be essential for China's sustainable growth strategies and for other emerging economies to fully appraise the relevance of the Chinese example. For agricultural water use, the primary topic of this issue, intensified competition from burgeoning urban demand of the kind discussed in this paper will pose an unprecedented challenge for sustainable food, fiber, and biofuel production.

Water and energy resources are central to concerns over the sustainability of China's economic growth. While both issues have increasingly become prominent in domestic and international policy discourse, much less attention has focused on the water-energy nexus in China. In industrial economies, links between water and energy use are often extensive. For

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instance, energy is used to move water over distances great and small. Water is an indispensable component of the steam power cycles used in the vast majority of China's power plants. More indirectly, both energy and water are essential inputs in producing steel and cement, which in turn are used in building hydraulic infrastructure.

In this paper, we combine Chinese data on energy and water use with China's national economic input-output tables to examine water-energy linkages across the country's increasingly complex economy. Focusing on the energy implications of water use, we investigate three metrics of China's water-energy nexus: the energy intensity of non-agricultural water provision; energy-water price dynamics for non-agricultural use water; and the energy dimensions of water allocation. Section 2 of the paper provides a general overview of the water-energy nexus in China, focusing on the relationships between energy use and water quantity and quality. Section 3 outlines the methods used in the paper and particularly in analyzing input-output tables. In section 4 we explore the above three metrics in greater detail. A fifth and final section offers concluding remarks.

2. Background: The Water-Energy Nexus in China

Linkages between water and energy use pervade modern economies. Energy is required to move water over distances long and short, to meet the thermal requirements of water users, and to improve and maintain water quality. Water is used extensively as a coolant, particularly in power plants and vehicle engines. On a lifecycle basis, the links between water and energy are often complex. For instance, dams and other large-scale hydraulic infrastructure incorporate significant amounts of energy-intensive concrete and steel. Power plants that provide the electricity to operate water treatment facilities similarly require energy embodied in material inputs (e.g., concrete to build cooling towers) that is not captured in the water supply sector's consumption of electricity.

The nexus between water and energy use can be more fully understood in terms of three metrics: physical, monetary, and distributive. The first of these relates to energy intensity of water use and, conversely, the water intensity of energy use; the second, to dynamics interactions between energy and water prices. The third measures the energy implications of water allocation. Water quantity (i.e., intersectoral and interregional allocation) and quality (i.e.,

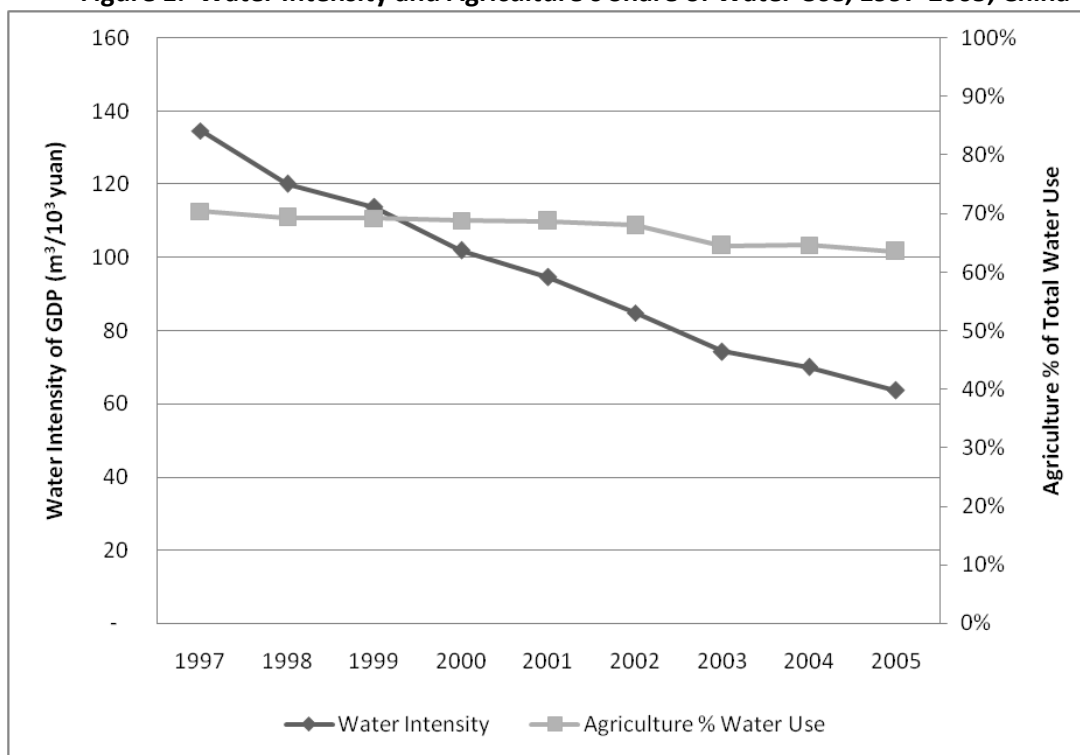
treatment) are central to water-energy interactions, and the remainder of this section is devoted to an overview of these two issues in China. In this paper our focus is predominantly on the energy implications of water use, rather than vice versa.

Faced with supply constraints, managing energy demand growth has emerged as a key policy goal for China's central government. China's recent energy shortages have been driven largely by economic rather than physical constraints. Rapid economic growth, particularly after China's entry into the World Trade Organization (WTO) in December 2001, contributed to more than 14 percent annual energy demand growth from 2000-2005 (NBS, various years). While China's increasing dependence on imported oil is more widely discussed, the country's abundant coal resources have also been overstretched. Expected to increase by 220 million tons over 2001-2005, with much stronger than expected demand coal consumption grew instead by 890 million tons during this period (Fang, 2006), pushing up newly liberalized coal prices to more than double 1990 levels (Rosen and Houser, 2007). As a result of domestic supply constraints, China became a net coal importer for the first time in its history in early 2007.

Water scarcity in China, alternatively, has been driven by a combination of both economic and physical scarcity. The country's declining water resource base has been extensively documented elsewhere (Ma, 1999; Economy, 2004; Liu and Diamond, 2005). China's annual water deficit is roughly 40 billion cubic meters (m³) in normal years, about half of its cities are facing some degree of water shortage, and the decline in surface and groundwater resources has become an impediment to socio-economic development (NDRC, 2005).

Agriculture remains the dominant water user in China, though its share declined from 88 percent in 1980 to 65 percent in 2005 (NDRC, 2005; NBS, 2006). Competition for water among agricultural, industrial, and residential users has thus far been tempered by a significant increase in water use productivity in the Chinese economy. As Figure 1 shows, water intensity fell by nearly 50 percent from 1997-2005, offsetting 2.2 percent annual growth in non-agricultural water demand over this time period and limiting the decline in agriculture's share of water use to 6 percentage points. However, as China continues its transition from a rural, agriculture-based economy to an urban, industry-based and ultimately service-based economy, intersectoral competition for water will gradually grow. The World Bank (2001) projects that agriculture's share of water use in China will be around 50 percent of the country's total by 2050.

Figure 1. Water Intensity and Agriculture's Share of Water Use, 1997-2005, China



Sources: Energy data are from NBS (2006); 2000-2005 water consumption and agricultural water use data are from NBS (2006); 1997-1999 water consumption and agricultural use data are from MWR (various years).

Table 1: Water Availability and Use in China's 10 Main River Basins and River Groupings, 2004

River Basin (North/South)	Water Availability (billion m ³)	Total Use (billion m ³)	Use-Availability Ratio
Songhua (N)	118.99	36.96	0.31
Liao (N)	41.90	18.90	0.45
Hai (N)	29.96	37.00	1.23
Huang (N)	62.80	37.21	0.59
Huai (N)	75.22	55.64	0.74
Northwest (N)	130.04	59.97	0.46
Yangtze (S)	873.46	181.54	0.21
Pearl (S)	351.29	86.23	0.25
Southeast (S)	132.38	31.63	0.24
Southwest (S)	596.93	9.69	0.02

 National	2,412.96	554.78	0.23
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Note and Source: Southeast, Southwest, and Northwest include smaller river systems in those regions; all data from MWR (2004).

In addition to intersectoral competition for water resources, China is planning massive inter-basin water transfers that have the potential to create regional water competition. Much of the country's water scarcity is concentrated in the north. Eighty-three percent of China's water resources are located in provinces bordering or south of the Yangtze River, whereas 41 percent of the country's population, 56 percent of its cultivated land, and 42 percent of its GDP lie in provinces north of this region (NBS, 2005). Use-availability ratios in the country's northern river basins are distinctly higher than in southern river basins (Table 1). To alleviate regional water scarcity, China's second largest hydraulic engineering project (behind the Three Gorges Dam), the South-North Water Transfer Project, will divert water from the Yangtze River to northern China. By 2050 and at a projected cost of 500 billion yuan (US\$65 billion), the project is expected to transfer 44.8 billion m³ annually, nearly equivalent to the total utilization capacity of the Yellow River (Chen, 2005).

Both at a sectoral and a regional level, water quality poses a constraint for water quantity in China. Roughly one-third of the water in China's monitored rivers has limited or no usability because it does not meet minimum quality standards; in the north this proportion increases to 40-60 percent (World Bank, 2006a). Indeed, on major rivers water quality is uniformly worse in northern China — and particularly on the Hai and Huai Rivers — than in southern China (World Bank, 2006a). The World Bank estimates the cost of pollution-induced water scarcity to be 1-3 percent of local GDP in water scarce areas of China (World Bank, 2006b). Water quality is a particularly important constraint on residential water use, as less than half of China's cities have water treatment facilities (MoC, 2005).

Anticipating both quality- and quantity-related pressures on the country's water resources, China's central government set a near-term objective of no growth in agricultural water consumption, negligible growth in industrial consumption, and a gradual decrease in total urban per capita water consumption over the term of its 11th Five-Year Plan (2006-2010) (NDRC, 2005). Targets for increasing wastewater treatment are similarly ambitious. In 2007, the Ministry of Construction stipulated that at least 70 percent of the residential wastewater in towns and cities should be treated by 2010, a significant increase from the 45.7 percent treated in 2004 (MoC, 2005).

By all three metrics listed above — physical, distributive, and monetary — meeting the country’s goals for water quantity and quality will have implications for energy use. Increasing collection and treatment rates for wastewater will require higher electricity inputs for the water supply sector and will increase its energy intensity. Hydraulic infrastructure to transfer water over large distances will require significant amounts of concrete and steel, which in turn require large energy inputs and will increase the embodied energy intensity of water provision. Energy price transmission — both directly through electricity prices and indirectly through materials costs — will increase pressure on agricultural, industrial, and residential water prices.

3. Methods: Estimating Conjoint Water and Energy Requirements

This section provides an overview of three key methodological issues in the analysis: data sources and disaggregation; quantifying embodied water, energy, and costs; and direct and indirect water and energy use.

Data Sources and Disaggregation

Quantifying water and energy use at a sectoral level, both from an economic (e.g., costs) and a material (e.g., joules or m³) perspective, is an essential component of this analysis. While China’s National Bureau of Statistics (NBS) publishes detailed annual data on sectoral physical energy inputs in its *China Statistical Yearbook*, data on sectoral physical water inputs are not publicly available and must be estimated. This subsection discusses both the methods we use for estimation, and the data sources on which our estimates are based.

For both water and energy, we use the NBS national economic-input-output (I/O) tables as a distributional structure for converting from monetary to physical flows across economic activities, and to some extent vice versa. The NBS publishes national I/O tables every five years (1992, 1997, 2002), and updates these every two to three years based on the underlying structure of the five-year tables. To obtain a sense of both structure and change, we use

aggregated, 43-sector versions of the 1997 and 2004 tables here, referring to the 122-sector and 42-sector versions of the 2002 table when these provide insights that the other two tables do not.

China's Ministry of Water Resources (MWR) publishes annual physical water use data (in m³), broken down by "Agricultural," "Production," "Consumption," and "Biological Protection" uses. More recent data is available in the *China Statistical Yearbook*; pre-2000 data is available in the MWR's *China Water Resources Report* (中国水资源公报) series. Using the I/O tables to disaggregate these three categories by I/O sector is not entirely straightforward because "Water Production and Supply" in the I/O tables does not include agricultural use water. This is evidenced by the significant discrepancy between the share of physical agricultural water use (65-70 percent) in the MWR data and the share of agricultural expenditures for Water Production and Supply (just over 1 percent).

Indeed, it is not entirely clear where agricultural use water is included in the I/O tables. The 122-sector 2002 I/O table contains the sector "Water Conservancy," but "Crop Cultivation" comprises only 11 percent of the economy-wide expenditures for this sector, suggesting either that irrigation prices are orders of magnitude lower than non-agricultural sectors or that irrigation is located in another sector. For most other purposes (e.g., in the energy tables), the NBS includes agriculture-specific water within a broad definition of agriculture that includes conventional agriculture, forestry, livestock, and fisheries. For these reasons, we include agricultural use water in the agricultural sector's own purchases (e.g., the livestock sector's purchases from itself).

The share of irrigation water use within agricultural water use is not available for all years in MWR *Water Resources Reports*. Based on what data is available from 1997-2002, which range from 91-92 percent, we use an estimate of 92 percent for all three years that we examine. Shares for livestock and forestry water use are based on their shares of own expenditures. We assume that water use in inland fisheries is negligible relative to the other three categories. In many instances we aggregate the agricultural sector, and these assumptions thus do not have a significant bearing on our results.

Converting from I/O table expenditures on energy to physical energy units is more complex because of the many different kinds of energy carriers and double counting issues with primary and secondary energy. For calculating embodied energy, we use primary energy inputs by fuel

type (i.e., coal, crude oil, natural gas, and hydro, nuclear, and wind). These are converted from mass (tons) to energy (MJ) units using lower heating values in IPCC (2006). In cases where sectoring in the energy input tables is different than in the I/O table, we disaggregate based on sectoral primary energy expenditures.

Quantifying Embodied Energy, Water, and Costs

As noted above, the primary data source for the results reported in this paper is the NBS national I/O tables, and our analysis is based on a structural assessment of these tables. For the sake of brevity, we assume that the reader has a basic familiarity with Leontief methods. The basic approach is based on the commonly used intensity-based approach to input-output analysis,² where the multiplier matrix imputes a flow of normalized physical quantities across structural chains of intermediate transactions. More formally, this allocation takes the form

$$\varepsilon = \alpha'(I - A)^{-1}$$

where α is an intensity coefficient (e.g., MJ/unit output for energy), ε is a row vector of embodied intensity with its denominator in units of final demand value, I is the identity matrix, and A is the matrix of direct expenditure coefficients. Intuitively, multiplying the transpose of the vector α by the multiplier matrix takes each sector's energy intensity, multiplies it down the column of inputs, and then sums the column. The result is an embodied intensity that is essentially a sum of the sectoral intensities of a given sector's inputs scaled by the multiplier distribution.

This approach can also be applied to costs within the transactions matrix. In this case, each entry a_{ij} in the i^{th} row of a given sector is normalized by gross output plus imports. The resulting row vector is multiplied by the multiplier matrix to produce an ε value with units of sectoral costs per unit final demand. Since both quantities share the same units, this measure is

² See, for example, Hendrickson et al. (1998) for the general methodology for environmental flows; see Casler and Wilber (1984) for the energy-specific case.

technically unit free and can be interpreted as a cost or expenditure elasticity of final demand for a given year. To compare results across years, we deflate all years to 2000 yuan using the IMF's deflator for China.

Total embodied use or cost can be found by multiplying ε by a final demand, or more specifically here household consumption (C), government expenditure (G), capital investment (I), and foreign exports (EX)

$$\varepsilon(C + G + I + EX)$$

Because we are interested in domestically consumed resources, we do not include imports in final demand. Both the transactions matrix and the final demand matrix in the I/O table do include import values, which we do not attempt to remove. Instead we assume that domestic energy consumption is caused by economic activity writ large, including imports. Energy intensities for sectors with higher imports will therefore be lower, all else equal. Additionally, imports do not have backward linkages through the economy and thus do not induce use or demand outside of the importing sector.

Direct and Embodied Energy in Water Use and Allocation

For productive water and energy requirements, we are interested in both direct and total embodied use. Direct use refers to the water or energy directly consumed by a given sector. Embodied use refers to direct use plus the water or energy consumed upstream of a given sector in the production and delivery of intermediate inputs in that sector. For example, direct energy use in the construction sector would include diesel fuel used to operate cranes; embodied energy use in the construction sector would include the energy used to produce steel used in buildings.

For water, direct use is simply equal to the water inputs into a given sector. For energy, the task is complicated by the distinction between primary energy (e.g., coal) and secondary energy (e.g., electricity). We calculate direct energy use from NBS estimates for total sectoral energy

consumption in their energy input tables, which include secondary energy estimates.³ The NBS data includes conversion efficiencies for non-fossil fuel electricity generation; we do not include these in our primary energy intensity calculations for α values. Although this discrepancy is less than 10 percent for the economy as a whole, for water production and supply it is somewhat larger because electricity comprises the bulk of energy inputs into the water production and supply sector. Thus we compare embodied and direct energy calculations with caution.

4. Results: Intensity, Price Dynamics, and the Energy Dimensions of Water Allocation

In this section we examine three broad trends at the nexus of water and energy use in China: the energy intensity of water provision; the interrelationships between energy and water prices; and the energy implications of water allocation.

Table 2. Water Consumption by Aggregate Sector (billion m³), 1997, 2002, 2004, China

	Agriculture	Production	Consumption	Biological Protection
1997	392.0 (70%)	112.1 (20%)	52.2 (9%)	n/a
2002	373.6 (68%)	114.2 (21%)	61.9 (11%)	n/a
2004	358.6 (65%)	122.9 (22%)	65.1 (12%)	8.2 (1%)

Source: 2002 and 2004 data are from NBS (2006); 1997 data are from MWR (1998).

We make extensive use of MWR aggregate water consumption data (Table 2) throughout this section, and make frequent reference to the MWR water use categories (column headings in Table 2). When we do make reference to these categories, we use capitalization.

³ By using NBS secondary energy data we thereby commit to a small discrepancy between our embodied use and direct use calculations.

Energy Intensity of Water Production and Supply

Because of the difficulty of isolating agricultural use water in the NBS I/O tables, the tables do not permit a reasonable estimate of the energy intensity of water use in agriculture. However, the I/O tables do include a “Production and Supply of Water” sector, which represents water utilities’ production and distribution of water and which we assume includes water in both the MWR’s “Production” and “Consumption” use categories. In reality, only part of the former is provided by water utilities, as industrial users in some cases have their own water supply. We thus assume that these extractions are small, or, in comparing intertemporal intensities, that they comprise a uniform share of total water use. Table 3 examines the energy intensity of water production and supply using three different metrics: direct energy intensity, embodied energy intensity, and volumetric energy intensity.

Table 3. Energy Intensity of Water Production and Supply, 1997, 2002, and 2004, China

	2004	2002	1997
Direct Energy Consumption in Water Production and Supply (WPS)			
Direct Energy Intensity of WPS	2.4 MJ/yuan	2.3 MJ/yuan	4.5 MJ/yuan
Economy-wide Average Energy Intensity	1.3 MJ/yuan	1.3 MJ/yuan	2.0 MJ/yuan
WPS Energy Consumption as a Percent of Total Energy Consumption	0.3%	0.4%	0.4%
Embodied Energy Consumption in Water Production and Supply (WPS)			
Embodied Energy Intensity of WPS	3.7 MJ/yuan	4.0 MJ/yuan	8.8 MJ/yuan
Economy-wide Average Embodied Energy Intensity of Demand	2.8 MJ/yuan	2.6 MJ/yuan	4.1 MJ/yuan
WPS Induced Energy Demand as a Percent of Total Induced Energy Demand	0.2%	0.3%	0.2%
Volumetric Energy Intensity of Water Production and Supply (WPS)			
Volumetric Direct Energy Intensity of WPS	1.0 MJ/m ³	0.9 MJ/m ³	1.0 MJ/m ³
Volumetric Electricity Intensity of WPS	93.1 Wh/m ³	79.4 Wh/m ³	79.4 Wh/m ³

Notes and sources: Energy data used in calculating direct energy intensities are from the Production and Supply of Water’s “total energy consumption” column in NBS (1999, 2004, 2006) energy input tables; the denominator in energy intensity calculations is based on Production and Supply of Water output from the I/O tables. To be consistent, “economy-wide average energy intensity” is calculated as the total energy consumption for the entire economy divided by the sum of our sectoral outputs; note that this is not equivalent to energy intensity measured as energy per unit GDP. Embodied energy intensities (ϵ) are calculated using the methods described above; induced energy demands simply ϵ multiplied by total final

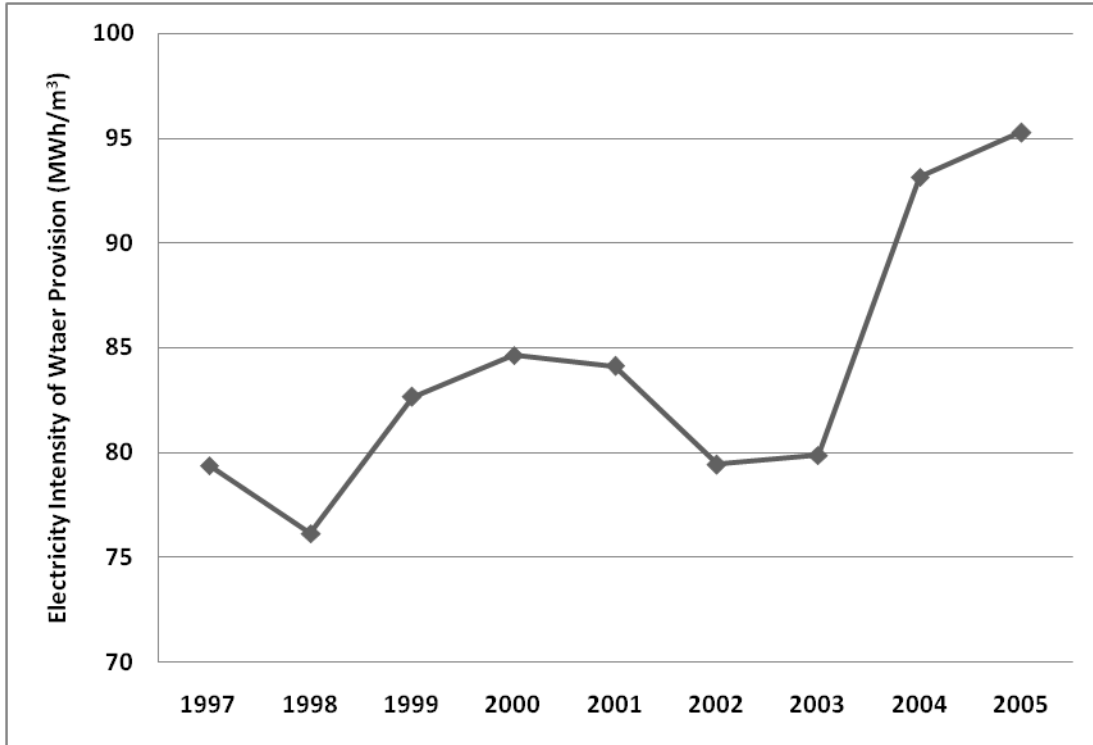
demand excluding imports. Physical energy intensity is sectoral energy consumption divided by total "Production" and "Consumption" water use from MWR (1998) and NBS (2006).

As described in more detail in the methods section, "direct energy consumption" in Table 3 is the energy used directly in the production and supply of water. The direct energy intensity of water production and supply is the amount of energy (primary and secondary) that the sector uses in per unit output. Embodied energy in Table 3 is the energy used throughout the total process of producing and supplying water, which includes, for instance, the energy produced to make concrete for hydraulic infrastructure or plastic for pipes.

Table 3 illustrates two trends in the energy intensity of water production and distribution in China. First, direct energy intensity declined substantially from 1997 to 2004, consistent with a 2.4 percent annual decline in the aggregate energy intensity of the Chinese economy over the same time period (NBS, various years). Second, from 2002-2004 the direct and volumetric energy intensities of water provision increased, driven at least in part by higher per cubic meter electricity inputs. Curiously, however, embodied energy intensity declined during this time period as the water production and supply sector underwent an expenditure shift away from electricity and heavy industrial inputs and toward less energy intensive equipment and services.

Higher volumetric electricity intensity of water provision after 2002 may have been driven by the build out of water treatment facilities to meet rising national standards for water quality. By 2005, China's 661 cities had 708 treatment facilities with a combined capacity of 49.12 million m³/day, a more than doubling of 2000 capacity (MoC, 2005). However, many water treatment facilities are not being used because municipal governments do not have the funds to operate them (MoC, 2005), which means that energy requirements for treatment could be relatively needs. As Figure 2 shows, the electricity intensity of water provision appears to have experienced a stepwise increase from 2003-2004.

Figure 2. Electricity Intensity of Water Production and Supply, 1997-2005, China



Sources: Electricity data is from NBS (1997-2005) energy input tables; electricity input data for 1998 were not available and we estimated this quantity based on the 1997 ratio of electricity to total energy inputs; 2000-2005 water use data is from NBS (2006); 1997-1999 water use data is from MWR (1997-1999).

Despite uncertainties in volumetric energy intensity and apparent declines in embodied energy intensity, both metrics intuitively appear set to increase. Even with the large expansion in water treatment capacity noted above, more than half of urban residential wastewater in China remained untreated, and 297 cities had no treatment facilities as of 2004 (MoC, 2005). Without energy efficiency improvements, meeting medium-term goals for treatment capacity would result in an increase in the energy intensity of existing water supply.

In addition, the need for increasingly energy- and materials-intensive hydraulic projects to alleviate regional water scarcity will raise both the volumetric and embodied energy intensity of water production and supply. The South-North Water Diversion project, for instance, will require massive amounts of concrete to build its three main canals, as well as large quantities of

electricity to run the pumps that move water along these canals. The energy and materials requirements of large-scale hydraulic infrastructure are likely to be captured under “construction” in the I/O tables, but are unlikely to show up in the water sector’s costs because they are financed by the central government. Adding more detailed lifecycle assessment for these projects regarding the energy requirements for water supply could substantially increase water energy’s share of the Chinese economy’s total energy consumption. By our estimates, construction sector embodied energy accounted for 19 percent of China’s total energy consumption in 2004.

As it stands, although both the direct and embodied energy intensity of the water supply sector are roughly twice the economy-wide average, the total amount of energy required to supply water — again both directly and on a lifecycle basis⁴ — is less than one half of a percent of China’s total energy consumption. Despite 14 percent growth in its electricity consumption from 2003-2005, the water supply sector accounted for less than one percent of the growth in China’s electricity consumption over the same period (NBS, various years; EBCEPY, various years). Including the energy embodied in agricultural use water would only raise this share by at most, and most likely less than, three percentage points (agricultural embodied energy’s share of total energy consumption).

Energy Costs and Water Prices

Through its use in powering pumps and running water treatment equipment, electricity represents a significant share of the cost of water provision. At a national level, electricity costs ranged from 33 percent (2004) to 39 percent (1997) of the cost of producing and distributing water in China during the three years we examine. As electricity and energy prices in China rise, attendant pressures on water prices will emerge. Assuming that these costs will be passed on at some level, understanding water use and exposure to water prices by final demand source is important for managing energy-water price dynamics.

⁴ Note here that the embodied energy share is lower than direct energy share because of the discrepancy in methods between NBS secondary energy calculations and our embodied energy calculations.

Table 4 shows water use in the Chinese economy by final demand source, and including different water uses. For instance, in 2004 exports accounted for 30.9 billion m³, or 25 percent, of the Chinese economy's induced demand for "Production" water (row 1). When "Consumption" water is added to household use (row 2) exports' share of total water use falls to 16 percent. Finally, when agricultural use water is included in embodied water use calculations (row 3) exports' share of total induced water use increases to 19 percent.

Table 4. Embodied Water Consumption by Final Demand Sector (billion m³ and percent total)

	HH	GOV	INV	EX	TOTAL
Embodied Water Use (Production)	35.1 (29%)	15.1 (12%)	41.0 (33%)	30.9 (25%)	122.9
Embodied Water Use (Production) and Direct Residential Use	101.0 (54%)	15.1 (8%)	41.0 (22%)	30.9 (16%)	188.0
Embodied Water Use (Production and Agriculture) and Direct Residential Use	289.2 (53%)	46.1 (8%)	107.7 (20%)	103.6 (19%)	546.6

Notes: HH is household consumption; GOV is government expenditure; INV is capital investment; EX is foreign exports.

Several characteristics of induced water use shown in Table 4 are noteworthy. Although household consumption of Production water is only slightly higher than foreign (export) consumption, households accounted for more than half of China's total water consumption in 2004. Service-intensive government consumption was not a major source of induced water demand. Investment was the largest source of Production water demand, with the construction sector accounting for 60 percent of investment's embodied water use, and thus 12 percent of China's total water use (excluding Biological Protection) in 2004. At nearly 20 percent of the country's total water use, exports are a major driver in China's water use.

Because each final demand category faced different water prices, shares of embodied water use do not translate into shares of upstream water costs. Table 5 shows Production water cost elasticities of final demand (*see Methods*) for each sector, and disaggregates households into rural and urban households. As Table 5 indicates, there is not a significant difference

between any final demand sectors in terms of the upstream increase in Production water costs due to a unit increase in final demand. In other words, all five sectors had roughly the same cost vulnerability to Production water price increases in 2004.

Table 5. Water and Electricity Cost Elasticities of Final Demand

	RurHH	UrbHH	GOV	INV	EX
Water Cost Elasticity of Final Demand (basis points)	0.26	0.26	0.30	0.28	0.26
Electricity Cost Elasticity of Final Demand (basis points)	6.2	5.8	5.6	7.9	7.9

Notes: RurHH is rural household consumption; UrbHH is urban household consumption; GOV is government expenditure; INV is capital investment; EX is foreign exports.

In Table 5 we also include electricity cost elasticities to illustrate two points. First, embodied electricity costs exhibit much more variation among sectors than do embodied water costs. Second, a comparison between water and electricity cost elasticities demonstrates how small embodied water costs are relative to embodied electricity costs. A unit increase in rural household demand causes a 0.062 yuan increase in upstream electricity expenditures, but only a 0.0026 yuan increase in upstream water expenditures.

Part of the reason for this order of magnitude difference is that, in all intermediate sectors except water production and supply, direct water expenditures are a tiny fraction (less than 0.3 percent in 2004) of total, average sectoral inputs. Similarly, for final demand sectors (predominantly rural and urban households) water outlays were less than one percent of total direct expenditures in 2004. For both rural and urban households, induced energy demand from the water production and supply sector was 0.5 and 0.7 percent, respectively, of total induced energy demand in 2004. For Production water, at current levels neither water prices nor energy price transmission to water prices has major implications for final demand sectors at a macro level.

The Energy Implications of Water Migration

By two orders of magnitude, agriculture has the lowest output per unit of direct water use of any sector in the Chinese economy aside from water production and supply (Table 6). Allowing water to migrate out of agriculture and into higher value added uses will be a necessary condition for sustaining growth in the Chinese economy.

Table 5. Characteristics of Water and Energy Use by Sector

	Output/Direct Water Use (yuan/m ³)	Embodied Energy Intensity (MJ/yuan)	Embodied Water Intensity (m ³ /yuan)	Energy- Water Use Ratio (MJ/m ³)
Agriculture	10	1.4	132.4	10
Mining	421	5.1	8.3	614
Manufacturing	527	2.3	43.2	54
Chemicals	284	5.7	15.1	375
Building Materials & Metals	371	5.3	10.3	506
Equipment	553	2.9	8.7	330
Electronics & Instruments	984	1.6	5.8	273
Electricity & Gas	285	17.0	13.6	1,246
Refining & Coking	475	15.2	5.8	2,623
Water	13	3.7	87.1	43
Construction	553	3.7	22.7	161
Transport & Telecom	310	3.7	11.0	339
Trade	290	1.8	11.9	154
Restaurants	182	1.8	37.5	48
Services	285	1.5	10.3	141
Average	99	2.8	25.1	110

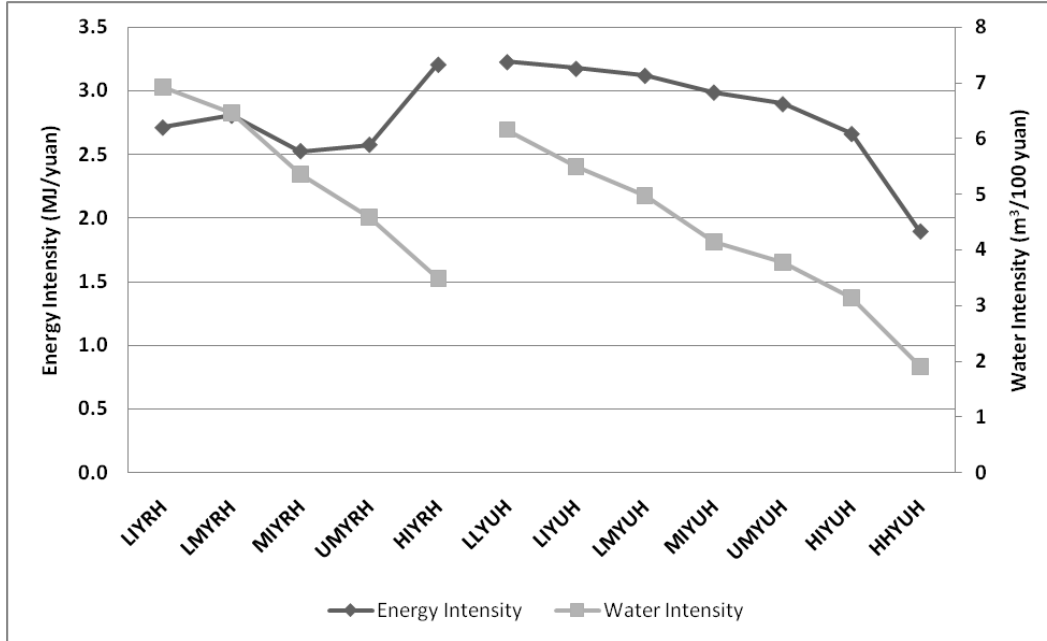
As the second and third columns of Table 6 show, there is an energy dimension to this water migration. As water transits from agricultural to non-agricultural uses it moves to sectors that are either more (e.g., chemicals) or less (e.g., services) energy intensive vis-à-vis agriculture. In Table 6, more energy-intensive sectors have higher sectoral energy-water use (MJ/m³) ratios (e.g., chemicals). Alternatively, sectors with lower energy-water use ratios all have relatively high embodied water intensities (e.g., manufacturing).

Although these energy-water use ratios do not necessarily reflect the energy intensity of water use per se, they do provide insight into some of the trade-offs facing policymakers in energy-water-related decision-making. For instance, while the services industry is the least energy intensive non-agricultural sector in the Chinese economy, its water intensity is on par with the building materials and metals industries. Encouraging sector rotation from industry to services might thus lower the Chinese economy's energy intensity, but at the same time raise its water intensity.

Table 6 also illustrates the merit of a lifecycle perspective for evaluating sector resource use. Whereas the construction sector has one of the highest output/water use ratios in the table, its embodied water intensity is the fifth largest in the Chinese economy, and induced demand from the construction sector accounted for 14 percent of China's total water use in 2004.

A final point to add to this discussion is that neither water migration nor its energy implications is strictly a rural-urban issue. A number of industry types in Table 6, including both the light industry commonly found in township village enterprises (TVEs) and heavy industry, operate in rural areas. From an industry perspective, water reallocation is predominantly a transition from agricultural to non-agricultural water use rather than a rural-urban transition. In reality, a significant share of industry is located in cities. In China's contemporary urban planning regime, both light and heavy industry have clustered in urban areas, a phenomenon that may become less prevalent as China's cities evolve.

Figure 3. Rural and Urban Household Embodied Water and Energy Intensity, 2004, China



In addition, as Figure 3 illustrates, agricultural water’s migration to urban vis-à-vis residential water use does not imply a transition toward higher energy consumption. Figure 3 shows the water and energy intensities of 5 rural and 7 urban income groups based on NBS classifications. Although NBS data does not provide sufficient information to determine how many households are within each grouping, energy-water ratios increase for rural households and fall for urban households as income increases. In other words, as water moves from agriculture into the goods and services consumed by rural and urban households, by moving into urban rather than rural consumption it does not necessarily move into consumption bundles that are more energy intensive.

5. Conclusions

As China continues to sustain high rates of economic growth, it is important for both the country’s own policymakers and those in other developing economies to better understand patterns of resource use within the Chinese economy and the vulnerability of its growth to resource scarcity. Over the last decade, energy and water constraints have indeed emerged as

important sustainability issues for China's economy, and have become the subject of greater scholarly, policy, and media attention, both within China and abroad. Much less attention has focused on the linkages between energy and water use in China. This paper attempts to begin to fill that gap from an economy-wide perspective, focusing on the energy implications of water use.

In examining the energy dimensions of water use in China, we take a lifecycle perspective. That is, our primary interest is in water and energy flows throughout the Chinese economy and embodied in the goods and services that make up final demand, rather than simply the water and energy directly used by economic sectors. To capture these linkages we combine and analyze several different data sets, including China's National Bureau of Statistics (NBS) energy input data, Ministry of Water Resources (MWR) water use data, and NBS national input-output (I/O) tables. We examine the energy implications of water use through three metrics: physical (energy intensity), monetary (energy-water price interactions), and distributive (energy implications of water allocation).

Based on this analysis, we draw four overarching conclusions. First, both direct and embodied energy used to supply non-agricultural water account for less than half of a percent of China's total water use. Adding the direct energy to supply agricultural water might increase this by one to two percentage points at most. However, these shares do not include the energy embodied in large-scale hydraulic infrastructure, such as dams that provide irrigation water or conveyance systems that transfer water from water abundant to water scarce regions. Given China's plans for extensive large dam (e.g., the Three Gorges Dam, scheduled for completion in 2009) and massive inter-basin water transfer projects (e.g., the South-North Water Diversion Project), the embodied energy requirements of hydraulic infrastructure at the margin are likely considerable.

While the I/O tables do not facilitate a direct assessment of the energy requirements of large hydraulic infrastructure, it is noteworthy that, despite its low direct energy inputs, on a lifecycle basis the construction sector accounted for 19 percent of energy use in the Chinese economy, as well as 14 percent of its water consumption, in 2004. As managing energy demand becomes an increasingly urgent task for China's policymakers, more detailed lifecycle analysis is needed to evaluate the total energy and water requirements of large-scale hydraulic infrastructure vis-à-vis less resource-intensive alternatives.

Second, although energy is a significant share of the cost of non-agricultural water provision, because water prices are comparatively low as a percentage of aggregate sector inputs, energy-water price interactions are largely shielded from the broader economy. Even as the water supply sector grows more energy intensive through, for instance, requirements for improved water quality, pressure on water prices through energy price increases will be comparatively modest. As we demonstrate, final demand sectors are an order of magnitude more vulnerable to electricity prices than non-agricultural water prices, and two orders of magnitude more vulnerable to direct electricity prices than the electricity costs embodied in these water prices. Nor would there be significant variability in the impacts of energy price-driven water prices increases among aggregate final demand sectors. Cost vulnerability to non-agricultural water prices, and thus the exposure to energy price transmission through water prices, is roughly uniform across sources of final demand. If and when the need for cost recovery for large hydraulic infrastructure and water treatment facilities arises, water prices in China would presumably experience a sustained increase, and the energy-water price relationship would become more important at an economy-wide level.

Third, the “migration” of agricultural water from agriculture to other uses has significant implications for aggregate energy and water use. Agriculture has by significant measure the lowest output-water use ratio in the Chinese economy, and allowing water to continue to transit from agriculture to other uses is important for sustaining economic growth. As water migrates from agriculture to higher value added uses, it moves to sectors that are more (e.g., chemicals) or less (e.g., services) energy intensive. While this migration provides a window of opportunity to influence trajectories of resource use through encouraging and discouraging certain sectors, trade-offs between energy and water intensity are part of this process. Light manufacturing and restaurants, for instance, are significantly less energy intensive than the chemicals industry, but significantly more water intensive. Using policy instruments to steer water toward less energy-intensive sectors, such as light manufacturing, could decrease the Chinese economy’s energy intensity while increasing its water intensity.

Nor are the energy implications of water allocation neatly divided along rural-urban grounds. Small-scale industry has been a feature of rural China since the 1980s, and larger-scale industry may increasingly shift to rural areas as China’s cities evolve. From a household consumption standpoint, as water transits from agriculture to rural and urban residential use it

does not necessarily move to more energy-intensive consumption in urban vis-à-vis areas. In short, addressing the energy implications of water allocation requires attention to both rural and urban water and energy use, and not simply the interface between them.

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