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Analysis on energy–water nexus by Sankey diagram: the case of Beijing

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ABSTRACT

We visualize water utilization in Beijing from source to service and onwards to destination using Sankey diagram to analyze the energy–water nexus at the city level. First, we describe the methodology, definition, and data and apply the Sankey diagram approach. Beijing faces highly constrained water resources and relies heavily on water that is energy-intensive to supply (such as underground water or water that must be conveyed over long distances. We find that the electricity required for water supply, treatment, utilization, and post-use utilization comprised about 5–7% of total electricity consumption in Beijing in 2009. We further find that water used in the energy-related sub-sectors accounted for about one-fourth of the water used in the whole industrial sector and about of 3% of the total fresh water used in Beijing in 2009. Among the energy related sub-sectors, the electricity sub-sector was found to be the largest contributor.

Keywords: Beijing; Water; Energy; Electricity; Sankey

1. Introduction

1.1. Recent focus on the energy–water nexus: challenges facing China

Water and energy are essential for human livelihood and the use of each is intimately intertwined. Water is withdrawn and consumed throughout the life cycle of almost all forms of energy, while energy is also consumed in the extraction, distribution, and utilization of water resources [1]. The invisible energy–water nexus has gained increasing attention among many researchers across a wide range of fields, including energy and water technology development, energy system analysis, water system analysis, and social management. These studies have analyzed the energy–water nexus from the point of water footprint assessment, analysis of energy return on water invested, analysis of water return on energy invested, and assessment of energy intensity of water and water intensity of energy [2–10].

Water and energy resource are central to concerns over the sustainability of economic development, and

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both issues have been emphasized significantly in the policy discussion in China and abroad. We investigate these issues in China, where there has been far less focus on quantitative analysis of the water–energy nexus.

While the National Bureau of Statistics of China publishes detailed annual data on sectoral physical energy inputs in its China Energy Statistical Yearbook [11], data on sectorial physical water inputs are not publicly available and must be estimated. Moreover, the sector defined as "water production and treatment" in [11] is also unclear about the system boundaries of this sector, and whether or not it includes water used in agriculture.

Ministry of Water Resource of China publishes annul physical water use (in cubic meter), broken down by "Agriculture," "Production," "Consumption" and "Biological protection" [12].

Some studies in recent years have emphasized the energy–water nexus (particularly the coal-water nexus). Analysis of the water footprint of various economic activities has been pursued primarily using input–output models. For example, the approach adopted in Kahrl and Roland-Holst [5] traced the relationships between energy and water resource through China's input–output table structure and drew conclusions focusing on the energy implications of water use. A similar study was undertaken by Zhao et al. [13]. Guan and Hubacek [14] and Wang et al. [15] analyzed water consumption at the inter-regional and district level, respectively.

To the best of our knowledge, research has not yet comprehensively described the energy–water nexus at the national level for China, nor has it analyzed these linkages at the regional or district level in depth to illustrate the situation of energy use throughout the water supply chain or water's role in the delivery of energy, such as how much energy is consumed in each stage of water sector, and how much water is consumed in the life-cycle of each type of energy).

1.2. Future constraints for Beijing

Beijing is the capital of PR China, and at the end of 2009, the city's population had reached 17.6 million (85% of which is concentrated in urban areas). Beijing also has the land area of 16,410.54 square km, 14% of which are plowed lands (2,316.88 square km) [16]. The plowed land is scattered over the sub-urban areas including the county and districts surrounding the central urban area of Beijing as shown in Fig. 1.

Beijing's GDP was 1,215.30 billion Yuan (178.7 billion US$) in 2009, with primary, secondary, and tertiary sectors accounting for 1.0, 23.5, and 75.5% of GDP, respectively. Overall, Beijing contributed 3.6% of China's total GDP this year [16].

Beijing's total energy consumption in 2009 was 65.7 million tce (ton of coal equivalent), or about 46.0 million toe (ton of oil equivalent), and end-use energy consumption was 63.27 million tce (44.29 million toe). Since 2001, Beijing's energy consumption per 10,000 Yuan has been decreasing as the rate of about 6% annually [16] as shown in Fig. 2.

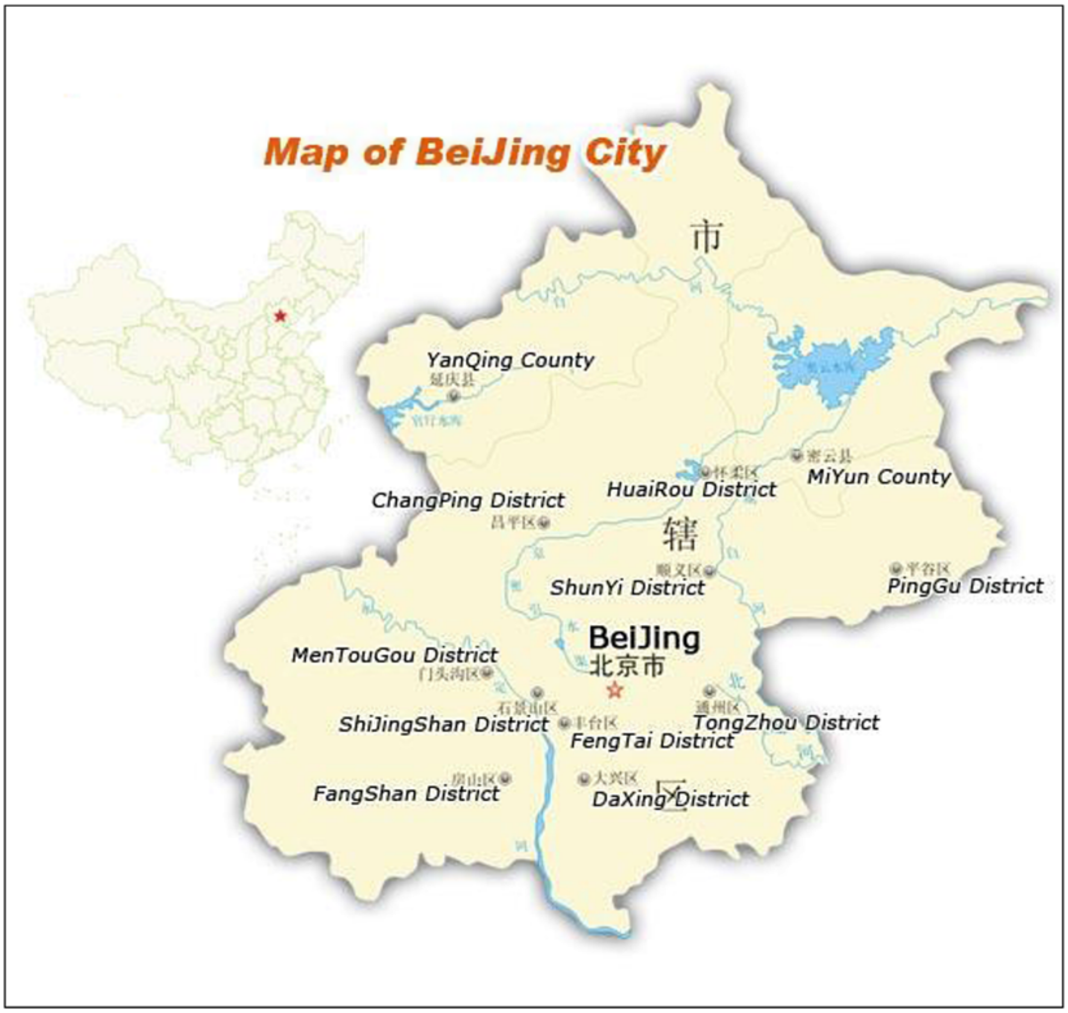
The annual per capita energy consumption in Beijing was 3.74 tce in 2009, which was higher than average level in China (2.31–2.39 tce) and in India (about 0.63 tce), but much lower than in US (about 7.9 tce) as shown in Table 1. The annual per capita residential consumption in Beijing is about 0.66 tce in 2009 [16], which is more than two times of the average level in China (0.25–0.26 tce).

The water supplied and consumed in Beijing in 2009 was 3,550 million cubic meter but the water resource was only 2,180 million cubic meters. Of this total, 31% was surface water and 69% was underground water, respectively. Though the annual water consumption per capita in Beijing (202 cubic meters) was lower than the average national levels of China (440–449), US (1,575), and even India (663), the annual household water consumption per capita was about 84 cubic meters in 2009 [16], which is higher than the average level in China (56–57 cubic meters) and in India (about 40 cubic meters), but lower than in US (about 630 cubic meters) as also shown in Table 1.

As mentioned earlier, Beijing has very constrained water resources and is over-reliant on its underground water resources as shown in Table 2 [17]. In recent years, recycled water is becoming very important water supplying in Beijing. Water delivered via the South-to-North Water Transfer Project (SNWTP) has also begun to alleviate water constraints in Beijing. Furthermore, the government has provided for supplies of water to be diverted to Beijing from other provinces if needed to supply the national capitol in the event of an emergency.

1.3. Structure of this analysis

In this study, we analyze water flows from source to service and onwards to destination for the case of Beijing using the Sankey diagram as a visualization tool. In Section 2 we outline our methodology, which is Sankey diagram analysis. Section 3 provides a detailed description of the data we use in this



(Source: http://www.chinafacttours.com/photo/maps/map-of-beijing.html)

Fig. 1. The map of Beijing of China.

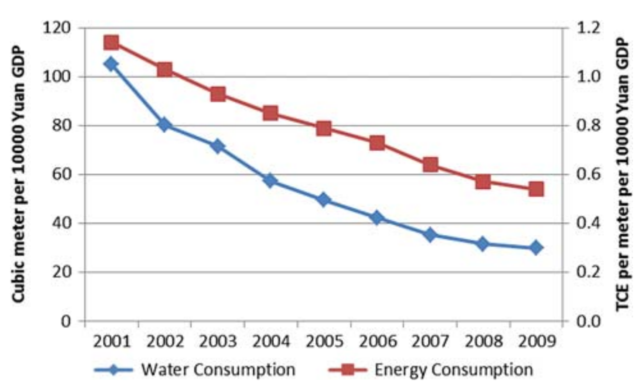


Fig. 2. Energy and water consumption per GDP in Beijing (2001–2009).

research. In Section 4, we describe the results of our analysis. Section 5 offers conclusions and directions for future work.

2. Methodology

2.1. Water Sankey diagram from source to service and destination

The Sankey tool (http://www.e-sankey.com/en/) has been used to describe energy flows widely [18–20] by visually mapping the source, destination, and quantity of each kind of energy embodied in each stage of the energy supply chain. We choose to focus on Beijing mainly due to data availability, as there is no consistent national data set for water utilization and data is missing for many provinces. Many of the references we use here are only available for Beijing. Nevertheless, our study establishes the application of the Sankey methodology to analyze the water–energy nexus in Beijing and provides a foundation for future studies focused on other parts of China or on the nation as a whole.

Table 1
Energy and water use per capita in Beijing, China, US and India

Quantity	Beijing (2005)	Beijing (2009)	China (2009)	China (2010)	US (2009)	India (2009)
1. Annual permanent population (million)	15.38[a]	17.55[a]	1328.1[c]	1361.8[c]	306.2[c]	1147.7[c]
2. Energy consumption						
Total energy consumption (million tce)	55.22[a]	65.7[a]	3066.47[c]	3249.39[c]	2409.143[c]	717.8143[c]
Total residential energy consumption (million tce)	8.14[a]	11.67[a]	–	–	–	–
Energy consumption per capita (tce)	3.59[b]	3.74[b]	2.31[c]	2.39[c]	7.87[b]	0.63[b]
Residential energy consumption per capita (tce)	0.53[b]	0.66[b]	0.25[c]	0.26[c]	–	–
3. Water consumption						
Total water consumption (billion km^3)	3.45[a]	3.55[a]	596.5[d]	599.8[d]	482.2[e]	761[e]
Total household water consumption (billion km^3)	1.34[a]	1.47[a]	75.2[d]	76.58[d]	193[e]	46[e]
Water consumption per capita (m^3)	224[b]	202[b]	449[b]	440[b]	1,575[e]	663[e]
Household water consumption per capita (m^3)	87[b]	84[b]	57[b]	56[b]	630[e]	40[e]

[a]Data source: [16].
[b]Data source: calculated by authors.
[c]Data source: [11].
[d]Data source: [12].
[e]Data source: http://www.worldwater.org/datav7/data_table_2_freshwater_withdrawal.xlsx.

2.2. *Water consumption for energy production and supply*

Water is withdrawn and consumed throughout the life cycle of every energy pathway. We assess all the water consumption stage-by-stage to determine how much water for energy production and supply is utilized in a specific region. Beijing is a special case because it imports some energy from other provinces and much water has been consumed in the course of the upstream of the energy. We note that data are patchy or unavailable to calculate the water requirement for upstream energy production located in other provinces, and so we do not include this quantity in our analysis.

2.3. *Energy consumption for water production and supply*

Energy is consumed for the extraction, distribution, and end-use of water resources. In the water Sankey diagram, the energy use rates are assessed individually as described in Section 3. An additional distinguishing feature of Beijing is that the city obtains some of its water from the SNWTP, which is the biggest inter-basin water transfer pipeline in the world. The water delivered to Beijing has been transported over 300 km [21] and as a result much energy has been embodied in the water when supplied to Beijing. To calculate energy embodied in water transited into in Beijing, we have to set up different cases in which the energy embodied in the water due to transfer via the SNWTP is included or omitted from the calculation.

3. Definition and data

3.1. *Definition for water sources, usage, and destination*

The definition of water source is shown in Table 3.

The definition of water usage is shown in Table 4.

The definition of water destination is shown in Table 5.

3.2. *Data on energy for water*

Based on expert opinion and a review of the literature, we get the energy intensity factors for specific water processes in Table 6 and describe them in detail as follows.

3.2.1. *Water from SNWTP*

Beijing received water from Hebei province via the SNWTP (about 310 km distance) [21] and the electricity consumption for the long-distance conveyance is about

Table 2
Water resource and consumption in Beijing (2005–2010)

Item (unit: 0.1 billion km^3)	2005	2006	2007	2008	2009	2010
Total volume of water resource in the year	23.2	24.5	23.8	34.2	21.8	23.1
Volume of surface water resource	7.6	6.0	7.6	12.8	6.8	7.2
Volume of underground water resource	18.5	18.5	16.2	21.4	15.1	15.9
Total volume of water supplied and consumed in the year	34.5	34.3	34.8	35.1	35.5	35.2
By source						
Surface water	7.0	6.4	5.7	6.2	3.8	4.6
Underground water	24.9	24.3	24.2	22.9	19.7	21.2
Recycled water	2.6	3.6	5.0	6.0	6.5	6.8
SNWTP water	0	0	0	0	2.6	2.6
Emergent water supply	0	0	0	0	2.9	0
By purpose						
Water used by farming	13.2	12.8	12.4	12.0	12.0	11.4
Water used by industry	6.8	6.2	5.8	5.2	5.2	5.1
Water used by households	13.4	13.7	13.9	14.7	14.7	14.7
Water used by environment	1.1	1.6	2.7	3.2	3.6	4.0

Note: data source: [12].

2.04 kWh, if we assume SNWTP has similar electricity consumption rate per unit water transported (ton-km) as a northern California state water project whose energy consumption is 16,000 kWh/MG (6.56 kWh/cubic meter) for about 400 miles conveyance [9], resulting in an electricity intensity of 2.04 kWh/cubic meter [6.56 kWh/cubicmeter × [310 km/(400 mile × 1.609 km/mile)].

3.2.2. Surface water

Power is required to get surface water from the river or the lake to the factory for direct use or to the water plant for further treatment. According to the analysis of Wang [22], the electricity use rate is 0.19 kWh/cubic meter of water supplied.

3.2.3. Underground water

Most of Beijing's water comes from underground sources. According to the field survey and calculations made by Wang et al. [23], the energy use rate from groundwater pumping in Beijing was 0.44 kWh/cubic meter with the underground water level at a 19.14 m depth. We can update the energy use rate to 0.49 kWh/cubic meter with the water level was changed to a depth of 24.07 meters in 2009 [17].

3.2.4. Recycled water

After the wastewater is discharged and treated, it can be reclaimed for future use at an energy use rate of about 0.20 kWh per cubic meter, based on the average electricity intensity reported by the US DOE [7]: 800 kWh/cubic meter.

3.2.5. Water treatment and distribution

Once water is extracted, there are two pathways to treat it depending on the purpose: direct use or through a water treatment company. There is only 0.004 kWh of electricity require to treat one ton of water before it is supplied directly for industrial or domestic use with an energy use rate of 0.18 kWh/cubic meter [23], but as much as 0.12 kWh [24] of electricity to treat 1 ton of water in water company before the water is distributed with the energy use rate is 0.20 kWh, which is a low value for California considering that Beijing's water supply system is a relatively new, compact, and efficient one [7].

Table 3
Definition of water source

Water source	Description
SNWTP water	Water that is imported inter-basin into Beijing through SNWTP
Surface water	Renewable surface water that is available for use
Groundwater	Renewable groundwater resources
Recycled water	Water which has been treated from wastewater

Table 4
Definition of water usage

Water usage	Description
Environment use	Water that is either left in rivers or physically distributed to rivers to maintain ecosystems
Agriculture use	Water that is used for irrigation purposes to produce crops/milk and meat products
Village life use	Water that is used in village residential housing units (households)
City life use	Water that is used in city residential housing units (households)
Manufacture	Manufacturing, processing and other industrial plant water uses
Electricity production and supplying	Water consumption that is used for the electricity generation and supplying (the water consumption per kWh of electricity generation is much lower than water withdraw)
Heat supplying	Water that is used for the heat production and supplying
Leakage	Leakage in the distribution network
Fuel production	Water that is used for the solid, liquid and gas fuel production and supplying
Civil public use	Water that is used in city by public, that is, public toilet

Table 5
Definition of water destination

Water destination	Description
Outflow	Water flows to outside (including clean water and dirty water)
Consumed	Water consumed, including water contained in human/livestock body, and goods and water to air/earth through evaporation, evapotranspiration and percolation
Recycled water	Water recycled from wastewater collection and treatment

Table 6
Energy intensity for specific water processes in Beijing

Item	Energy use factor (kWh/ton)
1. Energy for water withdraw	
Embodied in water of SNWTP	2.04
To get surface water	0.19
To get ground water	0.49
To reclaim recycled water	0.20
2. Energy for water used directly	
To treat water for industry and domestic direct use	0.004
To distribute water for industry and domestic direct use	0.18
3. Energy for water through water company	
To treat water in water company	0.12
To distribute water from water company	0.20
4. Energy for water utilization	
Agriculture	0.58
Civil public and landscape	0.23
For city life	6.42
For village life	3.21
5. Energy for sewage	
Sewage collection	0.1
Sewage treatment	0.6

Note: data sources are explained in detail in the Sections 3.2.1–3.2.7.

3.2.6. Water utilization

We were unable to find any data on the energy used during the water utilization phase at either the macro- or micro-level in China (or in Beijing). Agricultural water is primarily considered using the combined sprinkler and furrow technology widely used in Beijing, with an energy usage rate of 0.58 kWh per cubic meter of water [25]. Civil public and landscape water is considered using the booster pumping technology, assuming an energy use rate of 0.23 kWh per cubic meter of water [26]. Tap and shower use accounts for most of the municipal household water use in Beijing, as washing machines using warm water or dish washer is highly uncommon. An energy use rate of 6.42 kWh per cubic meter of water is associated with this water utilization [26]. In rural village households, the energy usage rate is set as half of that in the city life in Beijing.

There is an open question over whether or not energy required to support water use in domestic life (both village and city life), even the energy used when the water is utilized in a public environment, should be included or not in the calculation of the total energy for water chain. In the base case in this analysis, we only consider the energy used when the water is consumed in agriculture and public environment and then consider additional cases that consider alternative assumptions as described in Section 4.3.1.

3.2.7. Sewage collection and treatment

The wastewater treatment rate in Beijing was about 80% in 2010 [17], higher than the nation average level (77%) in China in 2010 [27]. Since we do not have data for China, we assume electricity intensities of water use based on the US situation [7], where about 0.1 and 0.5 kWh of electricity are used to collect and treat one ton of wastewater, respectively.

3.3. Data on water used in energy delivery

Since 2001, the composition of water end uses has changed significantly. As Fig. 3 shows, the contribution of water use by industry to the total water consumption in Beijing has decreased gradually from 23.6 to 14.7% over the period from 2001 to 2009 [17].

We calculated the water used in energy-related industries based on the following method: water use amount equal to the water use factor times the energy output or energy conversion losses.

We also disaggregate three sub-sections (solid/liquid/gaseous fuel production, electricity generation/supply and heat generation/supply) within the industrial sector, which we refer to as the energy sub-sectors. The water used in other industries is designated as manufacturing use.

As shown in Table 7 and explained below, we have collected estimated water use factors based on expert opinion, governmental regulation, and a review of the literature; on the basis of the specific energy output or throughout amount in 2009 [16] in Beijing, the water use amounts for the energy sub-sectors are calculated.

In Beijing, most of the coal is extracted through underground rather than surface mining [16], which differ significantly in their water intensity. Surface mining requires 0.3–1.1 cubic meters per ton, while underground mining requires 2.3–3.1 cubic meters per ton [28]. The number (2.3 cubic meter per ton) is near the upper range of estimates for the US (1–8 gal/MMBtu) [6].

For water consumed in power generation, 2.45 kg per kWh in 2010 has been reported [29] as the national average level in China, which is lower than the number used in Pan et al. (2.85 kg per kWh) [28] and is similar to the number reported on the internet for the Jingneng company, one of five major power generation companies in Beijing: 2.46 kg per kWh (http://218.247.239.221/gybSearch/viewnews.jsp?id = 259465). This number (2.45 kg per kWh) for thermal power generation is also near the upper end of the range of US estimates (300–510 gal/MWh) as described in [6] and (394–664 gal/MWh) for subcritical coal power generation with tower cooling in the report by NREL of US [30].

There are government guidelines published (http://www.bjpc.gov.cn/zt/125ny/nyzc/201105/t802659.htm; http://wenku.baidu.com/view/121c933383c4bb4cf7ecd1b6.html) in Beijing to regulate the water consumption level for the specific sub-sectors: for oil refining subsector, the upper limit is 1.62 cubic meter per 10,000 Yuan output. Given that the price of refined products is about

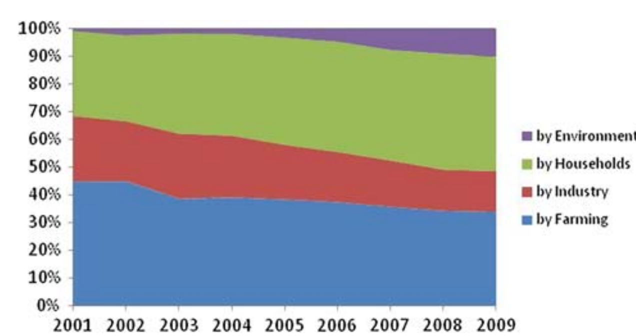


Fig. 3. Structure of water use by purpose in Beijing (2001–2009).

Table 7
Water energy-use factors and results showing water used in energy production in Beijing in 2009

Item	Factor	Unit	Output or throughout amount in 2009	Unit	Water use (million cubic meter)
1. Water for fuel production					
Coal	2.3	m^3 per ton	0.8	Million ton	1.84
Petroleum	2.2	m^3 per ton	3.5	Million ton	7.70
Subtotal					9.54
2. Water for electricity					
Generation	2.45	kg per kWh	27	Billion kWh	66.15
Supplying	0.34	kg per kWh	71	Billion kWh	24.14
Subtotal					90.29
3. Water for heat generation and supplying	0.47	m^3 per ton steam	45.73	Million ton steam	21.05
4. Total energy production and supplying					120.88

7,500 Yuan per ton, we estimate the water consumption level at 2.2 cubic meter per ton output; for the electric power sector, the upper limit is 6.74 cubic meter per 10,000 Yuan output. Assuming an electricity price of 0.50 Yuan per kWh, water consumption intensity is estimated at 0.34 kg per kWh during the distribution; for heat production and distribution, the upper limit is 35 cubic meter per 10,000 Yuan output, and the price of heat is 135 Yuan per ton, yielding a water consumption level of 0.47 cubic meter per ton of steam. It is found that the number (2.2 cubic meter per ton) for oil refining is near the upper range of US estimates (7–13 gal/MMBtu) [6].

4. Results

4.1. Water Sankey diagram for Beijing

Based on water supply, utilization and wastewater treatment data from the Beijing Water Resources Bulletin [17] and the report on Beijing Water Flow in 2009 completed earlier by the authors [31], the water from source to service and to destination in Beijing in 2009 is shown in Fig. 4. The diagram clearly illustrates the energy–water nexus: (1) those points at which energy is required for water provision are shown in red color and used to calculate the energy use for the water supply chain in Beijing, and (2) three

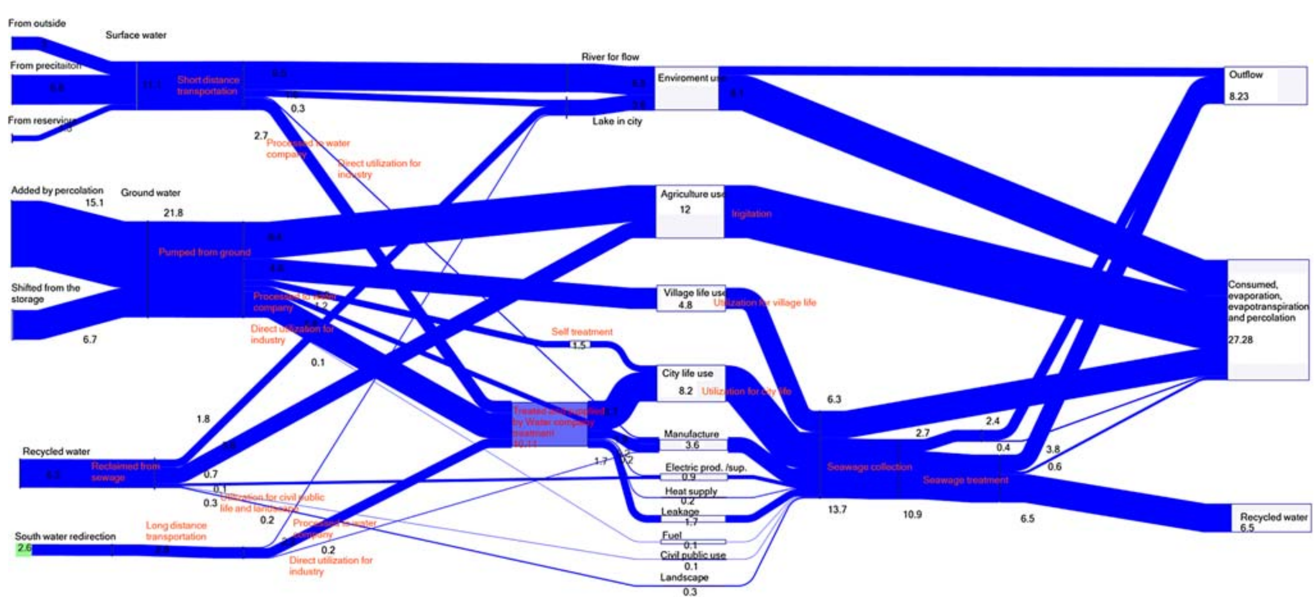


Fig. 4. Water Sankey diagram for Beijing in 2009 (unit: 0.1 billion m^3).

energy-related sub-sectors (electricity, heat, and fuel sub-sectors are subtracted from the industry sector to show that how much water is consumed in the course of supplying energy in Beijing. The details of these linkages are described in Section 4.2.

4.2. The energy–water nexus in Beijing: detailed description

4.2.1. Energy for water provision

When we consider the energy embodied in the water from SNWTP and also the energy used when water is consumed for agriculture and public environment use, the electricity for water chain in Beijing accounts for about 14.2% of its locally produced electricity and 5.5% of its total electricity consumption in 2009. If we omit the embodied energy in the water from SNWTP, the numbers will decrease to 12.3 and 4.7%, respectively.

The contribution of each water process to the total energy consumption for water chain is shown in Fig. 5. The water supply and conveyance stage dominates the contribution to total energy consumption, followed by post-use treatment.

4.2.2. Water for energy

It is found that about one-fourth of water use in the industrial sector is used by the energy sub-sector, as shown in Table 8. Water used in electricity accounts for the biggest component of overall water used to supply energy in Beijing.

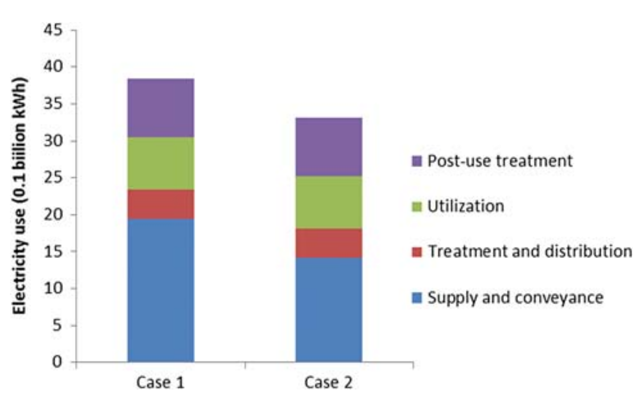


Fig. 5. Contribution of each process to energy consumption for the Beijing water chain in 2009. (Case 1: Energy embodied in water from the SNWTP is included; and Case 2: Energy embodied in water from the SNWTP is not included.)

4.3. Results summary and key insights

4.3.1. Ratio of energy use in the water supply chain

As analyzed earlier, if the energy embodied in the SNWTP water is not included, about 4.7% of electricity consumption in Beijing was used in the water supply chain (including original supply, utilization for agriculture and public environment, and treatment) in this area. Moreover, if the energy for water utilization for agriculture and public environment are not included, the aforementioned ratio changes to about 3.7%, which is a little lower than the situation in US: about 4% of US power generation was used for "water supply and treatment," which was comparable with several other industrial sectors such as "paper and pulp," "chemicals," and "petroleum refining" [7].

Among the share of 3.7% (ratio of electricity for water chain to total electricity consumption) in Beijing, water supply and conveyance stage accounts for 2.0%, treatment and distribution stage is 0.6%, and post-use stage is 1.1%, respectively.

Information on energy use in China's water sector at the national level is scarce. However, based on the data published by central government [11], the share of energy consumption in *water production and distribution sector* of total energy consumption in China can be calculated out to be about 0.3% and the share of electricity consumption in this sector relative to total electricity consumption in China can be calculated out to be about 0.7%, which is roughly similar to the electricity consumption ratio only by the treatment and distribution stage of water chain in Beijing (0.6%).

If the energy embodied in the SNWTP water is included, the share of electricity used in the water chain in Beijing increases to 4.5%, which is very close to that of California (5%) where water is seriously scarce and great efforts have been taken to ensure sustainable supplies [9].

4.3.2. Ratio of water use for energy supply

About 38% of electricity was produced locally in Beijing and the rest was imported from other locations [16]. As shown in Fig. 4, the sub-sector of electricity production and supply in Beijing accounted for 2.5% of total freshwater consumption in Beijing. The ratio is relatively lower than the situation in US: thermoelectric power accounted for 3.3% of total freshwater consumption US in 1995 [32].

At the same time, the sub-sector of electricity production and supplying accounted for about 22.4% of total freshwater withdrawals in Beijing and the ratio is also relatively lower than the situation

Table 8
Water use for energy in industrial subsectors in Beijing in 2009

Sub-sector	Water consumption (0.1 billion cubic meter)	Share of water for industry use (%)	Share of total water use (%)
1. Manufacturing	3.55	68.3	10.0
2. Energy	1.22	23.2	3.4
2.1 Fuel	0.21	1.8	0.3
2.2 Electricity production and supply	0.90	17.3	2.5
2.3 Heat supply	0.21	0.21	0.6
3. Leakage and loss during distribution to industry	0.44	8.5	1.2

Note: Water withdrawals for the electricity sub-sector are about 10 times the water consumption amount for this sub-sector.

in US. In the US in 2000, thermoelectric power generation accounted for 39% of all freshwater withdrawals [33].

If we also consider the water used or withdrawn to support the generation of the electricity imported from other provinces to Beijing, the aforementioned ratios of water consumption or withdrawals for electricity production in Beijing should be larger than those observed in the US.

5. Conclusions

China's water resources are unevenly distributed and Beijing faces serious urgent challenges to the sustainability of its water supply [34]. Based on the research on water–energy nexus for Beijing, we arrive at the following key findings:

(1) The majority of water consumption is household usage, in large part due to the relatively advanced level of Beijing's economic development;
(2) The electricity used in Beijing's water supply chain was about 4–6% of its total electricity consumption in 2009, which is line with observations from other water-scarce regions such as California in US;
(3) Though less than half of electricity is produced locally, the electric power sub-sector consumed 2.5% of the total freshwater in Beijing, which is close to the situation in the US (3.3%);
(4) If we also consider the water used or withdrawn to support upstream supply activities outside of Beijing, as well as electricity that is imported from other provinces to Beijing, the ratios of water consumption and withdrawal to electricity production in Beijing should be larger than those observed in the US.

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