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VIRTUAL WATER FLOW IN THE WEST–EAST ELECTRICITY TRANSMISSION PROJECT IN CHINA

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ABSTRACT

Owing to the rapid development of the global economy, the demand for energy and water resources is the main global challenge in the 21st century. This article focuses on the consumption and transfer of the water resources in China's West–East electricity transmission project. The input–output method is employed to construct a water footprint assessment model for this project. Results show that 606.4 billion kWh of electricity and 2.5 billion m^3 of virtual water were transferred from the western to eastern region in 2016. Coordinated policy making the optimal use of water resources for energy generation needs to be further discussed for promoting sustainable regional development.

Keywords: Virtual water, West–East electricity transmission project, water resources, China, water and energy nexus

1. INTRODUCTION

Electricity, an important component of energy demand, accounts for approximately 40% of the global primary energy consumption. The BP Statistical Review of World Energy 2018(2018) shows that in the recent years, the global annual electricity generation has gone through a sustained and rapid growth. In 2017, global electricity generation increased by 2.8%, a growth rate close to the 10-year average growth rate. Future global economic development, population growth, and innovations in electrification level indicate a sustained and rapid growth of power demand in the coming years. The demand for water has increased with an increase in the electricity consumption; therefore, water pollution has been become an increasingly significant issue.

As the world's largest developing country, China is a powerhouse of energy production and consumption. In 2017, China's energy consumption increased by more than 3% and the growth rate was much higher than the global average. The World Energy Outlook 2018 report(IEA, 2018) indicated that 20 percent of the global electricity demand growth will come from electric vehicles in China. However, the distribution of energy resources does not match the level of economic development and demand for energy. In China, the energy distribution is extremely uneven: coal resources are mainly distributed in the western and northern regions, where 69% of the coal resources are concentrated in western Shanxi, Shaanxi, and Inner Mongolia; 70% of the hydropower resources are distributed in the southwest. However, the primary energy consumption area is concentrated in the economically developed eastern coastal areas, where there is a lack of natural energy resources. In 2000, China officially launched the West–East electricity transmission project to alleviate negative environmental impacts in the eastern coastal areas and reduce the demand for coal. This project aimed to

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utilize China's coal and water resources in the northeast, northwest, and southwest regions for generating electricity, which can then be transmitted to the eastern coastal region, where electricity is scarce. Until recently, few researchers have evaluated the energy, economic, societal, and environmental effects of this power transmission from west to east. However, since the energy industry is a major water consumer owing to their industrial activities, the question of whether China's energy development will have sufficient water resources has gradually become the focus of many research scholars and policy makers.

Water footprint is a comprehensive evaluation indicator of water resource consumption; it offers a scientific basis for quantifying the impact of human activities on water resources. From the viewpoint of a system boundary evaluation, the water footprint boundary includes multiple stages of the entire life cycle of production, namely, production, transportation, sales, consumption, and reuse(Hoekstra & Hung, 2004). As a comprehensive indicator of the full span of human activities on the real consumption of water resources, water footprint closely links ultimate human consumption with water resource utilization. This footprint provides an important scientific basis for maintaining basin water resource security and improving regional water use efficiency. Therefore, it has become one of the predominant research fields of international water resource management.

Based on the in-depth studies on various theoretical methods of virtual water and water footprint assessment, this study constructs an energy water footprint assessment method to evaluate the relation between water consumption and energy gains during power generation, and the water footprint of the West–East electricity transmission project of China. The virtual water flow pattern has also been analyzed.

2. RESEARCH AREAS AND RESEARCH METHODS

2.1 West–East electricity transmission project in China

The West–East Power Transmission Project comprises three major routes (Figure 1). The southern route comprising the hydropower resources from the Wu River in Guizhou, Lancang River in Yunnan, Nanpan River, Beipan River, and Hongshui River at the junction of the provinces of Guangxi, Yunnan, and Guizhou, as well as the thermal power generated from pit thermal power plants in Yunnan, Guizhou, and Guangdong province. The central route comprising the hydropower generated from the Three Gorges Dam and Jinshajiang tributaries to the eastern region. The northern route comprising hydropower from the upper reaches of the Yellow River and thermal power from the pit thermal power plants in Shanxi and Inner Mongolia. The energy from this route is transmitted to the Beijing, Tianjin, and Tangshan areas.

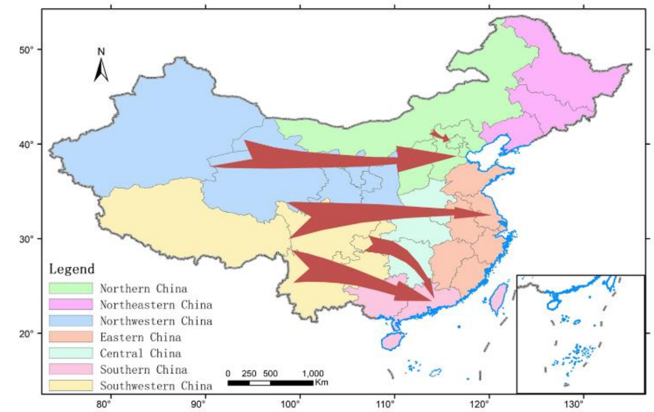

Fig 1 Route schematic of the West–East Power Transmission Project.

By 2017, the west–east power transmission capacity of China reached 229.11 million kW with the northern, central, and southern routes reaching 79.66, 106.63, and 42.82 million kW respectively. The cumulative transmission capacity was approximately 6.6 trillion kWh. Using ultra-high voltage transmission technology, 19 West–East Power Transmission Projects have been completed with a transmission capacity of 133.6 million kW and cumulative transmission capacity of 1.2 trillion kWh.

2.2 Water footprint assessment model for the West–East electricity transmission project

Herein, input–output method is used to construct an energy water footprint model. China's West–East Power Transmission Project mainly converts thermal power resources in the western and northern regions and hydropower resources in the southwest into electricity and transmits them to the eastern coastal areas, where electricity is scarce.

The power transmission data of the West–East Power Transmission Project comes from a compilation of statistics on the power industry published by the

China Electricity Council. The raw material input data of thermal power comes from the China Energy Statistical Yearbook published by the National Bureau of Statistics of China.

2.2.1 Water consumption of thermal power generation

Thermal power generation is still the main form of power generation in China, even though clean energy power generation has undergone rapid development in recent years. In 2016, coal-based thermal power generation accounted for 92% and 65.5% of thermal power and total power generation capacity, respectively. The established water footprint model of thermal power generation is as follows:

$$W_{i,t} = Q_{i,t} \times C_{i,t},$$

where $W_{i,t}$ is the water footprint of the i-th power station (m^3/kWh), $Q_{i,t}$ is the water consumption of thermal power generation (m^3/kWh), and $C_{i,t}$ is the power transmitted by the thermal power plant in the West–East Power Transmission Project (kWh).

2.2.2 Water consumption of hydropower generation

As a clean energy power generation method, hydropower plays a key role in promoting the circular economy and sustainable development. However, an increase in water retaining structures as a result of the development of hydropower has led to an increase in water area and evaporation, resulting in an increased loss of water resources. Unlike the calculation of water surface evaporation in the reservoir area of a traditional hydropower station, this study only considers the increase in water surface evaporation in the reservoir area caused by water storage power generation. While calculating the water footprint of a hydropower station, the new surface water evaporation in the reservoir area is regarded as the water loss caused by hydropower generation. The formula is as follows:

$$W_{j,h} = \Delta E_{j.h} \times Q_{j,h},$$

where $W_{j,h}$ is the water footprint (m^3) of the j-th hydropower station, and $\Delta\ E_{j,h}$ is the hydroelectric power generation (m^3/kWh) of the reservoir.

Herein, only the newly added water surface evaporation amount of the reservoir in comparison with the original river channel is calculated. $Q_{j,h}$ is the power transmission capacity (kWh) of the j-th hydropower station in the West–East Power Transmission Project (hWh).

3. RESULTS

3.1 Development of China's Electric Power grid

In recent years, power consumption in China has increased steadily. In 2018, the national power consumption was 6,844.9 billion kWh. Total generation capacity was 6,994 billion kWh with 1,232.9 and 4,921.3 billion kWh from hydropower and thermal power, respectively. The national power consumption increased by 87% and hydroelectric power generation increased by 116%, in comparison to that in 2009.

With the continuous development of the West–East Power Transmission project, the power transmission capability from west to east has grown from 4 million kW at the end of the last century to 140 million kW in 2015. Meanwhile, China's crossregional and interprovincial power exchange volume continues to grow. In 2018, Chinas crossregional and interprovincial power transmissions were 4,807 and 1,293.6 billion kWh, respectively, and the crossregional power transaction volume more than doubled in the past decade.

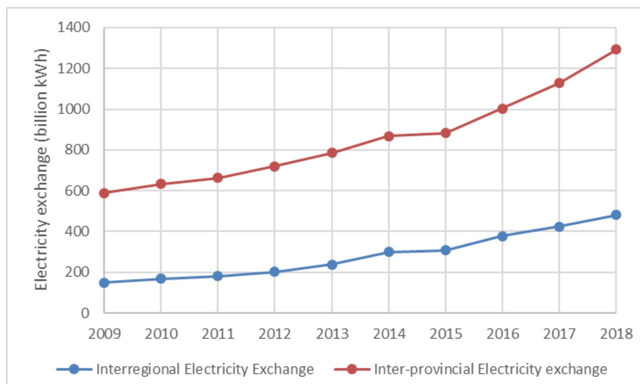

Fig 2 China's interregional and interprovincial power exchange in recent years

3.2 Virtual water footprint in West–East electricity transmission project

According to the statistics compiled from power industry statistics, in 2009, the northern route of the West–East Power Transmission Project was transmitting power mainly from Shanxi, Inner Mongolia, Liaoning and other places to Northern China with an annual transmission capacity of 1197 kWh. On the contrary, the central and southern routes transmitted 335 and 868 billion kWh to Central China and Guangdong, respectively. A total of 960 million m^3 virtual water was transferred from the western to eastern region.

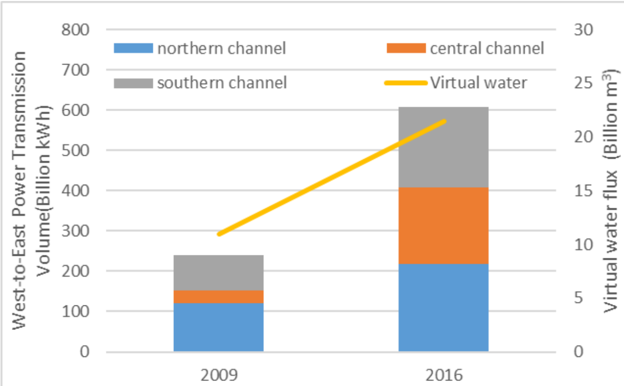

Fig 3 West–East power transmission and virtual water transfer

With the implementation of several ultra-high voltage transmission projects, the power transmission capacity of the West–East Power Transmission Project has doubled. In 2016, a total of 217.4 billion kWh of electricity was transmitted from Shanxi, Shaanxi, Inner Mongolia, Liaoning, and Xinjiang to Northern China. This electricity transmission mainly comprised thermal power, which would be the equivalent of transferring 320 million m^3 of virtual water from the western region to Northern China. Through the central route of West–East Power Transmission Project, a total of 191.2 billion kWh (thermal power and hydropower combined) was transmitted from Hubei, Sichuan, Shanxi, and Ningxia to Central China (Shanghai, Jiangsu, Zhejiang, Shandong, and Chongqing), which would be equivalent of transferring 1.1 billion m^3 of virtual water. Through the southern route of West–East Power Transmission Project, a total of 197.7 billion kWh was transmitted to Guangdong in 2016, which would be equivalent of transferring 1.09 billion m^3 of virtual water.

3.3 Prediction of Virtual water footprint for 2030

At the end of 2018, the National Energy Board of China announced that in the near future, nine key projects for transmission and distribution will be accelerated with a total transmission capacity of 57 million kW. It is expected that in 2030, the West–East power transmission by the state-owned power grid will reach 470 million kW, of which renewable energy would account for more than 70%. The water footprint output of the project will exceed 44 billion m^3, of which the water footprint output of the northwest water shortage area will be over 650 million m^3.

4. CONCLUSION

Since the 1990s, the rapid change in China's regional economy has been met with only a gradual change in the regional industrial pattern. The implementation of the West–East power transmission project not only effectively addresses the electricity demand in the eastern coastal areas of China but also effectively promotes the development of the western region. However, energy generation is a water-intensive industry, and a significant amount of water is being transferred to the eastern region in the form of virtual water for the generation and transmission of electrical energy. This indicates that the power transmission project may have an impact on the water resource sustainability and ecosystem stability in the water-scarce areas in the Northwest China. Therefore, it is necessary to reasonably regulate the use of water in the West–East power transmission project to avoid the excessive use of water resources.

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