Methology and Case Study on Water Footprint of Gas-fired Power Generation Company

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Abstract. Scientific evaluation of the impact of human activities on water resources is a prerequisite for the sustainable use of water resources. Combined with the development status of China's thermal power generation industry, a water footprint accounting method for thermal power plants was constructed, and a typical gas-fired power generation company was used for empirical analysis. The results show that energy and material water footprints account for the largest proportion of the company's water footprint. Enhancing energy efficiency and selecting clean energy are the keys to reducing the water footprint of gas-fired power companies.

1. Introduction
With the effects of climate change, accelerated industrialization, and population growth, many countries around the world are facing severe conditions of water shortages and water pollution. How to solve the problem of water resources shortage and realize the sustainable use of water resources has become a global research hotspot. In 2002, Hoekstra put forward the concept of “water footprint” for the first time on the basis of research on ecological footprint and virtual water, which made people begin to notice the consumption of water resources implied in products and services. The water footprint originally refers to the total amount of water resources needed for all products and services consumed or produced by a country or a person[1]. It is a measure of water use. It is an indicator of the direct and indirect use of water, the amount of water consumed, the type of water source, and the amount of pollution.

Thermal power generation has long dominated China's power industry. In 2016, the amount of thermal power generation accounted for 74% of total power generation. Thermal power companies have huge water consumption and are the largest industrial water users. Mesfin[2] comprehensively analyzed the thermal power water footprint and pointed out that the water footprint of the supply chain must be comprehensively analyzed when accounting for the thermal power water footprint. Ali[3] analyzed the water footprints of different natural gas power plants in the United States, and found that the conversion efficiency of gas-fired power plants has an important impact on water use.

At present, the research on water footprint mainly focuses on agriculture, agricultural products, etc. The research on the water footprint of enterprises, especially on the water footprint of thermal power companies, is still at an exploratory stage. This paper first determines the scope of calculation, builds a water footprint assessment method based on the “Water Footprint Assessment Manual”, and conducts an empirical analysis of a gas-fired power generation company to discuss the factors affecting the water footprint of the company, and provides a method for the assessment of the water footprint of gas-fired power companies.
2. Research methods

2.1. Accounting range

There are many industrial chains involved in thermal power plants, and the scope of water footprint research is also very extensive. From the extraction of raw materials to the access to electricity, the entire process of power generation involves many fields such as industry and transportation, and each area has the consumption of water resources. Therefore, it is very difficult to calculate the water footprint of a thermal power plant, and it is necessary to establish a reasonable accounting limit. This study mainly focuses on the process of gas-fired power generation enterprises from the raw material extraction and transportation to the industrial production stage. The specific accounting limits are as follows:

1. The water footprint of thermal power companies includes the operational water footprint and the supply chain water footprint. Operational water footprint refers to the amount of freshwater consumed and contaminated by a company during its operations. For gas-fired power generation companies, the operational water footprint includes industrial living water systems, desalinated water systems, and circulating water systems. The operational water footprint of thermal power companies only considers the blue water footprint and gray water footprint.

2. The supply chain water footprint refers to the amount of fresh water consumed and contaminated by the energy and materials invested by the enterprise to produce the product. For gas-fired power generation companies, the supply chain water footprint includes the water footprints of the energy needed during transportation, purchased natural gas, and electricity.

3. In this study, the natural ecosystems consumed by thermal power generation companies and the products provided by agriculture, forestry, animal husbandry, and fishery are not included in the calculation of water consumption during the production process.

![Figure 1. Scope of the water footprint accounting of thermal power companies.](image)

2.2. Accounting method

Corporate water footprint refers to the amount of freshwater that is consumed or contaminated, either directly or indirectly, by supporting and operating companies. The water footprint of thermal power companies includes two parts: the operational water footprint and the supply chain water footprint. The operational water footprint of thermal power companies only considers the blue water footprint and the grey water footprint.

Unlike the common water footprint, the water footprint of thermal power plants does not include the green water footprint. Because the green water footprint mostly comes from the agricultural production process, the green water footprint of the thermal power plant accounts for a small proportion or is not used, and it is not practical to calculate the green water footprint of thermal power companies.

1. Blue water footprint calculation method

The blue water footprint of thermal power companies refers to the amount of fresh water consumed during the operation. Therefore, the calculation formula for the blue water footprint of thermal power
companies is:

$$WF_{blue} = E + P + R$$  \hspace{1cm} (1)$$

In the formula, WFblue is the blue water footprint, m$^3$; E is the evaporation loss of water in the operation of the thermal power plant, m$^3$; P is the amount of blue water combined to the product, m$^3$; R is the amount of backwater that cannot be reused, m$^3$.

The blue water footprint of a thermal power plant can be reduced to the sum of water withdrawals for each system minus the displacement. Its formula is:

$$WF_{blue} = Abstr - Effl_0$$  \hspace{1cm} (2)$$

In the formula, Abstr is the sum of water withdrawals for each system, m$^3$; Effl0 is the displacement of the thermal power plant, m$^3$.

(2) Gray water footprint calculation method

The large amount of waste water discharged from the production process of a thermal power plant must be treated before being discharged. Calculate the gray water footprint produced by the thermal power plant production process to reflect the water pollution burden from the perspective of water consumption. In this study, chemical oxygen demand (COD) was selected as the pollutant index of the company’s gray water footprint. According to the “Surface Water Environmental Quality Standard” (GB3838-2002), the maximum allowable concentration of pollutants was assumed to be V, and the concentration of pollutants in natural water was 0.

The calculation formula for grey water footprint of thermal power enterprises is:

$$WF_{grey} = \frac{L}{c_{max} - c_{nat}} = \frac{Effl_1 \times c_{effl_1} - Abstr \times c_{act}}{c_{max} - c_{nat}}$$  \hspace{1cm} (3)$$

In the formula, WFgrey is the gray water footprint, m$^3$; L is the pollution load, mg; Effl1 is the pollutant discharge, m$^3$; Abstr is the water withdrawal, m$^3$; cact is the geological concentration of the water intake, mg/m$^3$; cmax is the water environmental quality standard corresponds to the maximum allowable concentration of pollutants, mg/m$^3$; cnat is the natural water body water concentration, mg/m$^3$.

(3) Energy and material water footprint calculation method

The energy and material water footprint includes the water footprint of energy and materials invested by thermal power plants to produce products. For gas-fired power generation enterprises, the energy and materials required by the enterprise mainly include the energy required for transportation, purchased natural gas, and electricity. The calculation method is shown in (4):

$$WF_{virtual} = \sum_{i=1}^{n} M_i k_i$$  \hspace{1cm} (4)$$

In the formula, WFvirtual is the energy and material water footprint, m$^3$; Mi is the amount of the ith energy or material used; ki is the water footprint factor of the ith energy or material.

3. Empirical analysis

3.1. Empirical corporate status and data sources

Company A is located in Guangdong Province and engages in natural gas power generation. It is a representative of similar domestic companies. The company’s power supply in 2014-2016 was 2.60×10$^9$ kWh, 2.35×10$^9$ kWh and 2.46×10$^9$ kWh, respectively.

This research investigates gas-fired power generation companies and refers to existing data to understand the types of energy and materials commonly used by gas-fired power generation companies. The relevant energy and material water footprint coefficients are shown in Table 1.

3.2. Production data used for the water footprint accounting

The production data used for the water footprint accounting is derived from the statistical data and daily monitoring information of the A company, including fresh water usage, displacement, energy and material usage, water quality monitoring data of the discharged wastewater, and power supply in each process system.

| Energy type                      | Unit       | Water footprint factor$^a$ |
|---------------------------------|------------|---------------------------|
| Natural gas                     | m$^3$/GJ   | 0.1                       |
| Outsourcing power (Southern Grid)| m$^3$/kW·h | 0.0037                    |
Pipeline transportation
Standard Coal

\[ \text{m}^3/\text{km} \times 3.11 \times 10^{-8} \]
\[ \text{m}^3/\text{tce} \times 3.56^{[4]} \]

LNG shipping

\[ \text{tce/ thousand tons of nautical miles} \times 48.7 \text{ (Year 2013)} \]
\[ \text{tce/ thousand tons of nautical miles} \times 46.27 \text{ (Year 2014)} \]
\[ \text{tce/ thousand tons of nautical miles} \times 43.95 \text{ (Year 2015)} \]

\[ \text{m}^3/\text{thousand tons of nautical miles} \times 0.173 \text{ (Year 2013)} \]
\[ \text{m}^3/\text{thousand tons of nautical miles} \times 0.165 \text{ (Year 2014)} \]
\[ \text{m}^3/\text{thousand tons of nautical miles} \times 0.156 \text{ (Year 2015)} \]

\[ \text{a The data of outsourced power and pipeline transportation comes from the eBalance database; the data of LNG ship transportation is calculated according to the data of the energy consumption of liquefied gas carriers in the 2013 Development Statistics Bulletin of the Transport Industry, combined with the data of standard coal, assuming the annual reduction rate of unit consumption of liquefied gas carriers is 5%} \]

3.2. Accounting results and analysis
The water footprints of Year 2014, 2015, and 2016 for Company A were statistically analyzed. The results are shown in Tables 2 and 3.

Combining Table 2 and Table 3, it can be seen that the water yield per unit production of Company A in 2014-2016 was \(8.59 \times 10^4 \text{ m}^3/\text{kW} \cdot \text{h}\), \(8.42 \times 10^4 \text{ m}^3/\text{kW} \cdot \text{h}\) and \(8.51 \times 10^4 \text{ m}^3/\text{kW} \cdot \text{h}\), respectively. Compared with the power water footprint factor, the output water footprint of a typical gas-fired power plant A company is only about 23%, indicating that gas-fired power generation is a power generation method that consumes little water resources. Combining the unit production blue water footprint and unit output water footprint accounting results, it can be seen that since 2014, the unit production blue water footprint has decreased year by year, indicating that water saving measures are effective. Company A uses the river water to cool in the water-water exchanger, boiler sewage expansion container, water spray temperature-reduction system, and water-saving appliances for most of the end-use water appliances in the company.

Table 2. Water footprint of A company from 2013 to 2015.

| Year  | Supply-chain water footprint (m³) | Operational water footprint (m³) |
|-------|----------------------------------|----------------------------------|
|       | Energy and material water footprint* | Transport water footprint | Blue water footprint | Grey water footprint | water footprint (m³) |
| Year 2014 | 1949852.48 | 171220.42 | 37480.08 | 33038.06 | 2191591.05 |
| Year 2015 | 1777393.02 | 148183.70 | 32995.60 | 39630.16 | 1998202.48 |
| Year 2016 | 1860893.51 | 147609.94 | 33168.96 | 34993.10 | 2076665.51 |

* Energy and material water footprint in Table 2 does not include transport water footprint.

Table 3. Water footprint per unit output of A company from 2013 to 2015.

| Year | Output (kW·h) | Supply-chain water footprint per unit output (m³/kW-h) | Operational water footprint per unit output (m³/kW-h) |
|------|---------------|------------------------------------------------------|------------------------------------------------------|
|      | Energy and material water footprint per unit output* | Transport water footprint per unit output | Blue water footprint per unit output | Grey water footprint per unit output | water footprint per unit output (m³/kW-h) |
|      |                                                           |                                                      |                                                      |                                                      |                                                      |
| Year | Supply-chain water footprint (%) | Operational water footprint (%) | Blue water footprint (%) | Grey water footprint (%) | Water footprint (%) |
|------|---------------------------------|---------------------------------|-------------------------|-------------------------|---------------------|
|      | Energy and material water footprint<sup>a</sup> | Transport water footprint | Blue water footprint | Grey water footprint |                     |
| 2014 | 88.97%                          | 7.81%                          | 1.71%                  | 1.51%                  | 100.00%             |
| 2015 | 88.95%                          | 7.42%                          | 1.65%                  | 1.98%                  | 100.00%             |
| 2016 | 89.61%                          | 7.11%                          | 1.60%                  | 1.69%                  | 100.00%             |

<sup>a</sup> Energy and material water footprint in Table 4 does not include transport water footprint.

4. Conclusion
This paper establishes a water footprint accounting method for thermal power generation companies and conducts empirical research with a typical gas-fired power generation company. The following conclusions have been obtained:

(1) The water footprint accounting method and related parameters of gas-fired power generation companies established in this study can reflect the water footprint intensity of gas-fired power generation companies, have good operability and accuracy, and provide method support for gas-fired power generation enterprises' water footprint assessment.

(2) The unit production water footprint of a typical gas-fired power plant A in 2014-2016 was $8.59 \times 10^4$ m$^3$/kW·h, $8.42 \times 10^4$ m$^3$/kW·h and $8.51 \times 10^4$ m$^3$/kW·h, respectively. Compared with the power water footprint factor, the output water footprint of a typical gas-fired power plant A company is only about 23%, indicating that gas-fired power generation is a power generation method that consumes little water resources.

(3) From the perspective of the composition of the water footprint of gas-fired power companies, the energy and material water footprints of the water footprint of the supply chain account for a large proportion, which indicates that energy types and energy utilization efficiency are decisive factors influencing gas-fired power generation enterprises. The transportation water footprints accounted for the second place, while blue water footprints and gray water footprints in corporate water footprints accounted for relatively small.

(4) From the analysis of the accounting results, for gas-fired power generation companies, the key to reducing water footprint is to improve energy efficiency and use clean energy. In addition, although
the water footprint of the operation accounts for a relatively small proportion of the entire company's water footprint, the blue water footprint and the gray water footprint are subject to increasingly stringent restrictions on the use of water quotas and environmental protection requirements. Enterprises need to strengthen water management in industrial production processes, improve the utilization rate of water recycling between processes, improve the technical and management level of water saving in the process, strengthen wastewater treatment, reduce drainage and improve drainage quality.

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