Academic Journal of Science and Technology
ISSN: 2771-3032 | Vol. 9, No. 3, 2024

Exploring the Synergistic Governance of Water Conservation and Carbon Reduction in Thermal Power Plants

Hongyu Ma, Zhi Su, Xiaowen Ding*

School of North China Electric Power University, Beijing, China
* Corresponding author

Abstract: In the industrial sector, thermal power plants not only use a lot of water, but also cause more carbon emissions. In today's era of carbon neutral carbon peaking and water scarcity in China, thermal power plants should not only do a good job of water conservation, but also reduce carbon emissions. But water-saving behaviours mostly consume more energy and cause more carbon emissions. This study explores how thermal power plants can save water and reduce carbon synergistically, and introduces a carbon footprint model to study the synergistic benefits of water saving and carbon reduction in thermal power plants, and takes a thermal power plant in the south as a typical case. Considering the environmental benefits of water conservation from a more systematic perspective helps to promote the synergistic effect of water conservation and carbon reduction.

Keywords: Thermal power plants; Water conservation; Carbon reduction; Carbon footprint.

1. Introduction

The enterprises in the thermal power generation industry, as one of the "high carbon emissions" methods of energy production, typically require a significant amount of water for processes such as circulating cooling and steam power generation during electricity generation. Additionally, substantial emissions of carbon dioxide and other greenhouse gases occur. These emissions can directly or indirectly contribute to global temperature rise, an increase in extreme weather events, and rising sea levels, among other issues. In the present scenario, thermal power plants are confronted with the dual pressures of water resource constraints and carbon emission limitations. Essentially, this necessitates thermal power generation enterprises to enhance water efficiency, conserve water, and reduce carbon emissions[1,2].

In 2021, ten Chinese ministries, including the National Development and Reform Commission (NDRC), jointly issued the "Guidance on Promoting the Utilization of Sewage Resources," which explicitly articulates the concept of "water conservation is pollution control." This concept expands beyond the reduction of water consumption and emphasizes the need for a systematic consideration of the impact of water conservation efforts on pollutant reduction, including the reduction of carbon dioxide emissions[3]. Particularly in the context of the current era of carbon peaking and carbon neutrality, water conservation should also be considered for its synergistic carbon reduction benefits.

2. Thermal Power Plant Water Reuse Technology

There are various water-saving technologies in thermal power plants, but generally thermal power plants adopt the use of treated tail water from sewage treatment plants in cities as feed water to replace fresh water, which can greatly reduce the consumption of water resources. However, the water quality standard of the tail water of the sewage treatment plant can not reach the water quality standard of the thermal power plant, the thermal power plant needs to carry out the secondary treatment of the tail water of the sewage treatment plant here, so that it can reach the water quality standard of the thermal power plant[4].

In addition to the use of tail water from wastewater treatment plants as fresh water, there are many parts of the internal water system of a thermal power plant where water reuse technology can be used.Thermal power plant internal water reuse technology mainly contains cooling water reuse, process wastewater treatment and reuse, desalination water reuse and reverse osmosis water reuse four aspects[5].

2.1. Cooling water reuse

In the thermal power industry enterprises, cooling water is usually used to cool heat-generating equipment, such as: boilers, turbines and condensers, etc. This part of the water flow consumption is usually very large, but due to the temperature increase after contact with the equipment, it is considered to be wastewater.

Cooling water reuse is the use of efficient water-saving cooling technologies, such as cooling towers or wet cooling systems, to treat cooling wastewater through physical and chemical processes, such as filtration and sedimentation, so that it can be converted into secondary water for reuse, thereby reducing the demand for limited freshwater resources; In addition, through the construction of the cooling water reuse system, it is also possible to reduce the consumption of related energy by enterprises in the thermal power generation industry, such as coal fuel and carbon energy, and to recycle and reuse part of the energy, so as to achieve the purpose of saving water and reducing carbon[6].

2.2. Process wastewater treatment and reuse

Process wastewater treatment and reuse is another key area. The use of advanced wastewater treatment technologies, such as biological treatment, chemical precipitation and membrane separation, helps to remove harmful substances and improve water quality.Treated wastewater can be used in other processes or recycling systems, thus reducing freshwater demand and contributing to water conservation.

2.3. Desalinated water reuse

Desalinated water is an important source of water used to supply boilers and involves a number of water-related systems in companies in the thermal power generation industry. The reuse of desalinated water is mainly through improved desalination techniques to improve water quality and reduce waste generation, thereby reducing the use of fresh water. Desalinated water can be used in all aspects of thermal power plants such as boiler feed water, cooling systems, equipment cleaning etc; Desalinated water is also a key component in the generation of steam, an important energy source used to drive turbine generators in thermal power plants; In addition, desalinated water can also be used in the steam circulation process in cooling systems.

After use, the desalinated wastewater can be treated and purified for reuse after ensuring that it meets the requirements of the boiler and other equipment, which not only helps to maintain the efficient operation of the boiler and other related equipment, but also helps to reduce the level of deposits and salts in the boiler and increase the life of the boiler equipment[7].

2.4. Reverse osmosis water reuse

Reverse osmosis water reuse is an efficient water treatment technology commonly used in companies in the thermal power generation industry. Advanced control systems and energy recovery systems are often used in this technology: The use of advanced control systems can help to monitor system performance and increase water yield, reducing wastewater discharge[8]. Energy recovery technologies, such as pressure energy recovery devices, are also used to reduce energy consumption, but their integration into reverse osmosis wastewater treatment systems will help to maximise the recovery of pure water and reduce wastewater discharges, resulting in water and carbon savings.

3. Carbon Footprint Calculation Model for Thermal Power Plants' Water-Related Segments

The present computational model was developed by referring to Tao Jiang ,Xianyue Duan[9]. And according to《 ISO 14067》,《GB/T 24044-2008》 and other standards and norms using carbon footprint model on the thermal power industry enterprises to save water and reduce carbon benefits research.

A carbon footprint is the total amount of greenhouse gas emissions produced over the life cycle of a business or product, usually expressed in carbon dioxide equivalent units. It includes both direct and indirect emissions and covers all stages from raw material collection to production, transport, use and disposal. Understanding the carbon footprint of a business or product helps organisations to identify the main sources of carbon emissions, develop mitigation strategies and reduce the risk of climate change.

3.1. Carbon Footprint Calculation Model

When calculating the carbon footprint of water-related processes of enterprises in the thermal power generation industry, the functional unit "power generation" can be selected. The carbon footprint of the water use process of a thermal power plant is calculated as follows:

$$CFW = \sum_i E_i = \sum_i (EF_i \times AD_i) \tag{1}$$

Eq.(1):

CFW—Carbon footprint of the functional unit water use process in kilograms of carbon dioxide equivalent ($kgCO_{2e}$).

i—Water resources life cycle stages, including water abstraction, water supply, water use, wastewater treatment, discharge and reuse, which should be selected appropriately according to the actual situation of the functional unit's water use process.

E_i—greenhouse gas emissions at a certain stage, in kilograms of carbon dioxide equivalent ($kgCO_{2e}$). In the actual calculation process, carbon emissions at each stage of the life cycle should be traced according to the water source and drainage destination of the water-using unit.

EF_i—Emission factor for water use or transfer behaviour at a given stage, in kilograms of carbon dioxide equivalent per cubic metre ($kgCO_{2e}/m^3$).

AD_i—Amount of water use or transfer behaviour at a given stage, in cubic metres (m^3).

3.2. Boundary range

The life cycle of a water resource begins when it is taken from a natural water body and ends when it is no longer used and is returned to nature, and the boundary of the carbon footprint of the water use process can be determined based on the scope of the process. The carbon footprint boundary of the water use process of a thermal power plant can be divided into four phases, namely the water extraction phase, the water supply phase, the water use phase, and the water discharge phase, which are illustrated in Figure 1.

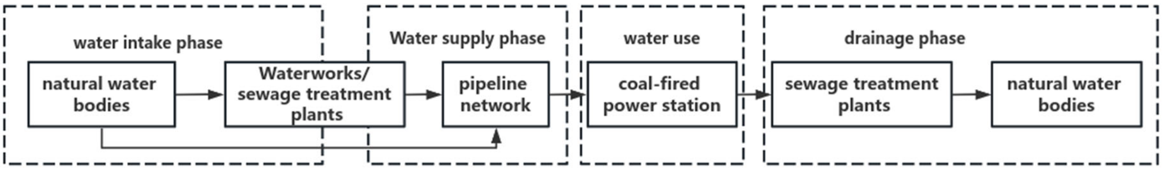

Figure 1. Carbon Footprint Boundary of Water-Related Processes in Thermal Power Plants

3.3. Assessment of synergistic benefits of water saving and carbon reduction in thermal power plants

By comparing the carbon emissions of water use behaviours of the same functional unit before and after the implementation of water saving measures, it can be understood whether the water saving behaviour has the synergistic benefit of carbon reduction generated.

$$CFW=CFW_{pre\text{-}saving} - CFW_{post\text{-}saving} \quad (2)$$

Eq.(2):

CFW—Change in carbon emissions from water saving behaviour, i.e. the difference in the carbon footprint of the water use process for the same functional unit before and after the implementation of water saving measures, in kilograms of carbon dioxide equivalent ($kgCO_{2e}$).

$CFW_{pre\text{-}saving}$—Carbon footprint of the water use process of a functional unit in kilograms of carbon dioxide equivalent ($kgCO_{2e}$) before the implementation of water saving measures.

$CFW_{post\text{-}saving}$—Carbon footprint in kilograms of carbon dioxide equivalent ($kgCO_{2e}$) generated by the functional unit's water use process after the implementation of water conservation measures.

There are three possible scenarios for changes in carbon emissions from water saving processes that can be used to determine whether water saving behaviour produces synergistic benefits in terms of carbon reduction:

(1) CFW is greater than 0. Under the same functional unit, the carbon emission generated by the water consumption behaviour after water saving is smaller than that before water saving, and the synergistic benefit of carbon reduction is obtained at the same time of water saving effect, and such water saving measures should be focused on promotion and application.

(2) CFW is less than 0. Under the same functional unit, the water consumption behaviour after water saving has added a certain amount of carbon emission than before water saving, which is a case of "exchanging carbon for water".

(3) CFW is equal to 0. There is no change in carbon emissions from water use behaviour before and after water saving for the same functional unit.

4. Case Study

A thermal power plant in a southern city was selected as a case study for analysis, and firstly, the carbon emission factors of each water-related link of its thermal power plant were established, which are shown in Table 1 Mean value of carbon emission in each stage of water system in a southern city[10].

Table 1. Average carbon emissions of water systems in a southern city by stage

Sequence	Stage	Emission factors /$kgCO_{2e} \cdot m^{-3}$
1	Water intake phase	0.3194
2	Water supply phase	0.2646
3	Water use phase	note①
4	drainage phase	0.2771
note①：The discharge factors need to be calculated on a case-by-case basis, as each water-related process is different at this stage.		

The thermal power plant in the water intake stage of the construction of recycled water industrial use project, the use of ABFT depth treatment process, the depth of the treatment of the tail water used as power plant circulating water make-up water, boiler make-up water, etc., the total design scale of 60,000m^3 / d. Here the effectiveness of the process in saving water and reducing carbon will be verified by calculating the difference in carbon footprint (CFW) before and after the adoption of ABFT process in this thermal power plant.

It is assumed that the thermal power plant has not built the ABFT deep treatment process, which will have 60,000 m^3 of water taken from fresh water sources per day, i.e., the amount of fresh water used ($AD_{fresh\ water}$) is 60,000 m^3, Considering that the water use stage process is the same regardless of whether reclaimed water is withdrawn or not, the carbon footprint at the water use stage is ignored. Combining the data in Table 1 and bringing it into Eq.(1) yields a carbon footprint of 19,164 $kgCO_{2e}$ at the water intake stage ($CFW_{Pre\text{-}saving\ water\ collection}$), 15,876 $kgCO_{2e}$ at the water supply stage ($CFW_{Pre\text{-}saving\ water\ supply}$), and 16,626 $kgCO_{2e}$ at the water discharge stage ($CFW_{Drainage\ before\ water\ saving}$), which translates into a carbon footprint ($CFW_{pre\text{-}saving}$) of 51,666 $kgCO_{2e}$ for every 60,000 m^3 of fresh water prior to the adoption of the ABFT process. Since CO_2 has a relative molecular mass of 44 and carbon has a relative molecular mass of 12, i.e. 0.27kg of carbon in 1kg of CO_2, the carbon footprint (before $CFW_{pre\text{-}saving}$) is about 13.95 tonnes of CO_2 per 60,000m^3 of fresh water used.

Now the thermal power plant introduces 60,000m^3 of tail water per day from the sewage treatment plant, to be used by the thermal power plant after ABFT deep treatment. By invoking this process, the carbon consumption of water taken from fresh water source is reduced, but the carbon consumption during the operation of ABFT deep treatment process is extra. Now, the carbon consumption of 60,000m^3 of tail water per day is calculated to be introduced to the power plant after the thermal power plant adopts the ABFT deep treatment process. As mentioned above, the carbon footprint of the water-use phase is ignored, considering that the water-use phase process is the same regardless of whether reclaimed water is taken or not. Combined with the data in Table 1, and brought into Equation 1, it can be obtained that the carbon footprint in the water supply stage ($CFW_{Post\text{-}saving\ water\ supply}$) is 15876 $kgCO_{2e}$, and the carbon footprint in the drainage stage ($CFW_{Post\text{-}saving\ drainage}$) is 16626 $kgCO_{2e}$. (Since there is no need to fetch water from the fresh water source after adopting the ABFT process, the carbon footprint calculation ignores the carbon footprint calculation of the fetching stage in calculating the carbon footprint).

Carbon consumption will be generated from the electricity consumption of the operation process due to the adoption of the ABFT process. Here, based on the relevant data in the "13th Five-Year Plan" Provincial People's Government's Assessment Measures on the Target Responsibility for Controlling Greenhouse Gas Emissions" and the "Letter from the Ministry of Ecology and Environment on the Request to Provide a Self-Assessment Report on the Implementation of the Target Responsibility of Provincial People's Governments for Controlling Greenhouse Gas Emissions in 2018", the carbon emission factor of the electricity consumption process is determined to be 0.5246 $kgCO_2/kWh$.According to the relevant data research, the thermal power plant in the ABFT process operation process, aeration fan power consumption 110 kW/h, a total of one; lifting pumping station power consumption 90 kW/h, a total of two; UV decontamination equipment power consumption 25.6 kW/h, a total of two, the thermal power plant in the depth treatment of 60,000 m^3 from the tail water of sewage treatment plant, the ABFT process one day of power consumption of about 8188.8 kW. Therefore, the carbon footprint of the ABFT process ($CFW_{Water\text{-}saving\ post\text{-}}$

$_{\text{processes}}$) is 4295.8 kgCO$_{2e}$. Combined with the previous calculations, the carbon footprint of the thermal power plant after adopting the ABFT process (CFW$_{\text{post-saving}}$) is 36797.8 kgCO$_{2e}$, i.e., 9.94 tonnes of CO$_2$ are consumed for each 60,000 m^3 of tail water treated after the introduction of this process.

The above calculation data, brought into the Eq(2), calculated that, after taking the ABFT process daily water saving carbon footprint (CFW) is 4.01 tonnes of CO$_2$. by CFW is greater than 0 it can be seen that, under the same functional unit, the use of ABFT deep treatment process produces less carbon emissions, in the water saving effect at the same time, also get carbon reduction synergies, to achieve water saving and carbon reduction "win-win" situation, this water saving measure should be promoted. At the same time of water saving effect, the synergistic benefit of carbon reduction is also obtained, which achieves a "win-win" situation of water saving and carbon reduction, and this water saving measure should be promoted and applied.

5. Conclusion and Outlook

Against the backdrop of water scarcity and carbon neutral carbon peaking in China, the thermal power generation industry is facing greater pressure to save water and reduce carbon. The concerted promotion of water conservation and carbon reduction in thermal power plants is conducive to the thermal power industry's advancement on the road of clean, low-carbon and green transformation. At the same time, the combination of water conservation and the "dual carbon" goal will be more conducive to explaining the environmental benefits and practical significance of water conservation.

The carbon footprint model in this study can be further used to collect basic data on the carbon emission behaviours of different cities, subjects and scenarios in the water use and water conservation process, and improve the calculation methods and technical details, so that it can be applied to a wider range of water conservation scenarios.

References

[1] Jia Luyu,Wang Yanhua,Wang Ke . Synergistic carbon dioxide emission reduction effect of air pollution control measures Assessment [J]. Environmental Protection Science, 2020, 46 (6): 19-26.

[2] Wang Yibing, Zhang Jiangtao, Jiao Hanyu et al. Methodology for developing technical routes for water conservation and wastewater management in thermal power plants[J]. Thermal Power Generation, 2018, 47(07): 125-132. DOI:10.19666/j.rlfd.201710100.

[3] Guo Cha, Chen Guang, Ma Yan. Analysis of factors affecting carbon emission in the key links of urban water system and Countermeasure Suggestion [J]. Water Purification Technology, 2021, 40(10):113-117.

[4] Zhu Fahua, Xu Jingxin, Pan Chao, et al. Opportunities and Challenges for Coal Power Generation in Achieving Carbon Neutrality and Challenges in achieving carbon neutrality [J]. Power Technology and Environmental Protection, 2022, 38(2): 79-86.

[5] Shao Guohua, Fang Di. Application of zero-discharge technology for positive osmosis membrane concentration of power plant desulphurisation wastewater [J]. Industrial Water Treatment,2016,36(08):109-112.

[6] Tang Xiaoliang,Liu Qing . Analysis of Carbon Emission Policies in Power Generation Industry and Response Countermeasures of Thermal Power Enterprises [J]. Pollution Prevention Technology, 2020,33(2): 81-83.

[7] Shi Xi,Dang Xiaojie. Technical measures for water conservation in thermal power plants[J]. Shandong Metallurgy, 2011,04:47-48.

[8] SUN Hui,SUN Xinge,DAI Jiagang et al. Response surface methodology and particle size analysis to optimise the pre-treatment of urban reclaimed water reused in power plants[J]. Inner Mongolia Power Technology, 2023, 41(04):9 4-100.DOI:10.19929/j.cnki.nmgdljs.2023.0061.

[9] Jiang Tao, Duan Xianyue, Cai Yuling. Research on carbon emission behaviour of water conservation process and its benefit assessment method [J]. Chinese Paper Industry, 2023, 44(08): 1-5.

[10] Li Linjun, Qiu Guoyu. Energy consumption of urban water resources development and utilisation and its economic analysis--Taking Shenzhen as an example[J/OL]. Ecological Economy:1-16[2023-03-11].