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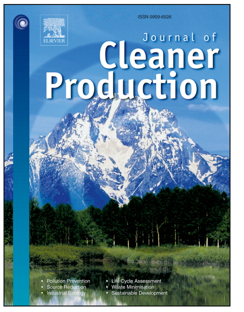

Freshwater costs of seawater desalination: Systems process analysis for the case plant in China

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Freshwater costs of seawater desalination: Systems process analysis for the case plant in China

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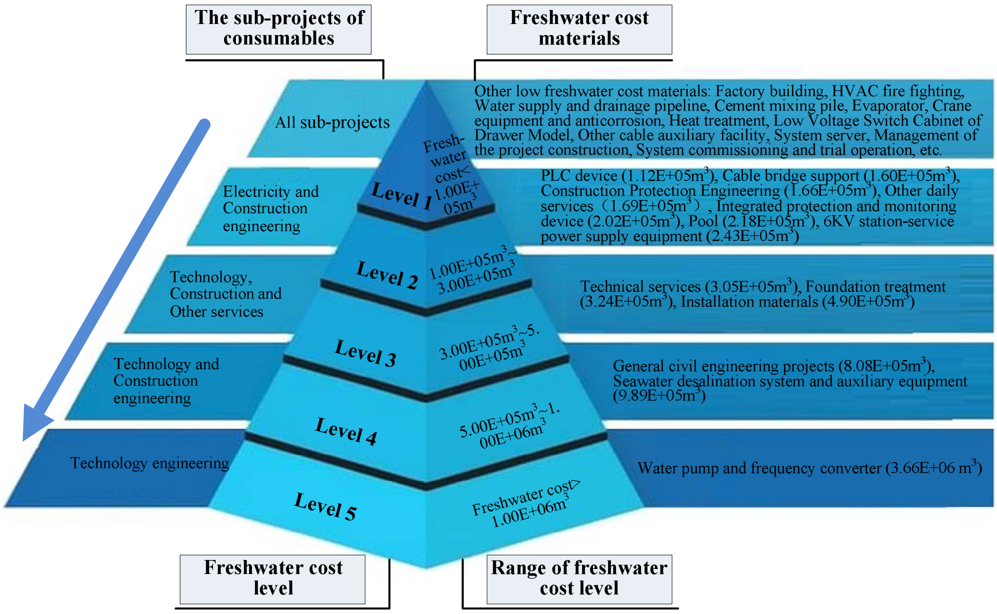
Graphical Abstract



The pyramid model of freshwater cost levels.

Freshwater costs of seawater desalination: Systems process analysis for the case plant in China

Abstract

Seawater desalination is one of the most essential strategies to solve freshwater shortage issues worldwide. Though having the possibility of providing abundant freshwater resources, desalination projects are also limited by the pressure of freshwater consumption. Based on the systems process analysis, the freshwater cost of seawater desalination is assessed with the case study of a 25,000 tons/day seawater desalination plant in Huanghua Port, Hebei Province, China. The total embodied water consumption is 9.02E+06 m^3, which is estimated in magnitude as five percent of the total freshwater production in the design cycle. Among all the sub-projects, the embodied water consumption in the technology system engineering represents the largest component, accounting for 60.12% of the total. The productivity level of the project is calculated to be 19.29, which highlights the potential of the desalination project for alleviating the shortage of freshwater. It is necessary to notice that the water yield of the project is calculated to be 9.12E+06 m^3, which could achieve the freshwater balance of the construction phase in the first year of operation. The comprehensive inventory and procedure of the embodied water accounting in this work are expected to provide useful references for rational allocation of water resources and optimal design for other desalination projects.

Keywords: Embodied water, Seawater desalination, Water resources, Systems process analysis

1. Introduction

Demand for water has been increasing due to continuous rapid growth of population and economy, leading to the global problems of water resource shortage. This increasingly affects global economic development and ecological environment, even leading to conflicts among countries and regions. One of the optimal solutions for solving the worldwide water crisis is to apply seawater desalination technologies for obtaining new water resources and increasing the total supply of freshwater (Khawaji et al., 2008; Mezher et al., 2011; Qiblawey and Banat, 2008). The roles of water production and consumption conceptually embodied in the construction phase of a seawater desalination project are thus critical for the operation and water saving of the project (Drouiche et al., 2011; Tsiourtis, 2001).

Generally, seawater desalination is regarded as a process of obtaining freshwater from seawater by physical, chemical or physical-chemical methods, which can provide continuous freshwater guarantee for people's livelihood, economic development and ecological maintenance in water-deficient areas. According to the National Seawater Utilization Report (2016), more than 100 seawater desalination projects have been completed in China by the end of 2016, with a water production scale of 1.89 million tons per day, with the largest seawater desalination project scale of 200,000 tons per day.

China is the site of the largest water shortage areas in the world, providing vast potential for the construction of seawater desalination projects. According to the progress of seawater desalination in recent years, much research focused on the economic cost accounting and evaluation of project investments (Blank, 2007; Dreizin, 2006; Eltawil et al., 2009; Fiorenza et al., 2003; Kim et al., 2013; Linares et al., 2016). Most of the existing literature paid attention to the relationship between the output of desalination projects and the unique local direct water demands, which contribute to the systematical comparison and construction of seawater desalination projects in general. There is however little research on the accounting and evaluation of freshwater costs in the construction phase of desalination projects, which still deserves further evaluation.

At present, there is relevant literature on indirect utilization of freshwater resources in the construction phase, which highlights the significance of indirect water use in the construction phase (Crawford and Pullen, 2011; Malça and Freire, 2006). Reasonable utilization of supply chains and whole water consumption to strengthen construction projects are effective options to fill this gap (Berger and Finkbeiner, 2010; Kotsovinos et al., 2011). In view of the rapidly increasing water consumption and shortage of water resources, the research on embodied water accounting is in progress (Berger et al., 2012; Chapagain and Hoekstra, 2007; Chen and Chen, 2012; Chen et al., 2012; Hoekstra et al., 2011; Jeswnai and Azapagic, 2011; Stoessel et al., 2012; Zhao et al., 2010).

Generally speaking, the accounting methods for a case project mainly involve two kinds of methods. The process analysis starts from tracking the input data to the output data in the life cycle of the project to account for the resource utilization and environmental impacts (Dixon et al., 2003; Proença and Ghisi, 2010; Wong and Mui, 2008). This analysis attempts to trace the resource utilization and environmental emissions of all the production processes, though it is hard to cover all the processes with the limited steps (Arpke and Hutzler, 2006; Cabeza et al., 2014; Emmerson et al., 1995). On the contrary, the input-output method reflects the relationships among different economies by adopting a top-down perspective, which is applicable to carrying out the accounting analysis for a particular department or region. This method has been generally applied at the macro-scale of resource utilization and environmental emissions (Velázquez, 2007; Xia et al., 2015, 2016; Yang et al., 2010), while it is unnecessary to assess the specific engineering assessment due to the uniqueness of an individual case (Hondo et al., 2002; Miller and Blair, 2009).

With the advantages of the above mentioned methods, a hybrid analysis was proposed by Bullard et al. (1978), taking into account the rationality and comprehensiveness of the assessment results (Kramer et al., 1999; Lenzen, 1999, 2002). Based on the above studies and derived from the systems ecology, Chen et al. (2011b) proposed the systems process analysis integrating the above mentioned methods and taking low-carbon buildings as an example for the pursuit of systems accounting evaluation (Chen et al., 2013; Han et al., 2015b). With the continuous improvement of the accounting method, it was further applied in the evaluation of ecological factors (energy consumption, environmental emissions and water usage) of construction, electricity and wetland projects (Chen et al., 2009; Han et al., 2013, 2014; Liu et al., 2016; Meng et al., 2013, 2014; Shao and Chen, 2013, 2016; Wu and Chen, 2017).

Generally, the seawater desalination plant is considered as a type of significant water production system with regard to its ability to deliver fresh water. Existing studies on resources accounting have contributed extensively to the related assessment work (Malça and Freire, 2006). With the emergence of literature on the analyses of the embodied water consumption of seawater desalination, particularly where the productivity assessments are deficient, a comprehensive evaluation of embodied water of seawater desalination and the productivity levels of the related projects is necessary.

In this context, a systematic analysis of embodied water assessments on seawater desalination is comprehensively performed with the systems process analysis. By quantifying the freshwater costs of the Huanghua Desalination Project in Hebei Province, the water production and consumption of the desalination project covering 5 sub-projects are systematically analyzed, and the construction phase is comprehensively assessed with the comparisons of different types of water use. With the detailed classification of the basic materials, the measures for rational allocation and utilization of water resources in the desalination projects are discussed. The rest of this paper is as follows. Section 2 provides a description of the methodological approach. Section 3 describes the overall results obtained, Section 4 provides further discussion, and Section 5 concludes.

2. Method and data sources

Details of the systems process analysis, data sources and case description are presented below.

2.1 Systems process analysis

This study applies the systems process analysis combined with the process analysis and the input-output analysis to pursue a systems accounting of the embodied water in the seawater desalination project. In order to improve the operability of the method and enhance the data accuracy, the study was carried out according to the first-hand data based on the data list (Hebei Guohua Cangdong Power Generation Co. Ltd, 2013). According to the specific requirements and specifications of the seawater desalination project, all the involved items and economic costs are listed and categorized into three types (equipment, materials and labor).

2.1.1. Production industry and embodied water

In the calculation of embodied water consumption, each project could be traced back to its corresponding production industry through the supply chains. Denoted as the total water use for final demand, embodied water intensity refers to the direct and indirect water use per economic output in the production processes (Han et al., 2015b). Based on the corresponding inventory and economic costs, the consumption of embodied water can be calculated in each project. For the convenience of the calculation, each sub-project with the same materials was merged into the same economic industry as the overall economic costs in the whole engineering system.

2.1.2. Embodied water of sub-projects

According to the material inputs and embodied intensity of each project and combining with the actual water usage of the case project (Liu et al., 2017), the multi-scale and multi-type embodied water usage of the case project can be calculated:

$$W_{required} = \sum_{i=1}^{n} W_i = \sum_{i=1}^{n} (\varepsilon_i \times I_i) \quad (1)$$

where I_i is the economic cost of the corresponding sector *i* in the input list of the seawater desalination project, ε_i denotes the multi-type embodied intensity of sector *i*, and W_i is the embodied water use of sector *i*. By calculating the total consumption of each sub-project, the whole project's embodied water in the supply chain can be summed.

2.1.3. Embodied water assessments of seawater desalination projects

Based on the above process, the net water production $W_{procduction}$ in this work is to assess the impact of water production on the supply of local water resources, which could be obtained as:

$$W_{production} = W_{desalted} - W_{required} \quad (2)$$

Since seawater desalination is devised as a technology for alleviating the shortage of freshwater resources, the investment rate $R_{investment}$ of the seawater desalination project can be measured by the seawater desalted in embodied water investment:

$$R_{investment} = W_{required} / W_{desalted} \quad (3)$$

Furthermore, in order to reflect the freshwater production capacity of the case project, the productivity level $L_{productivity}$ of the desalination project can be calculated as follows:

$$L_{productivity} = (W_{desalted} - W_{required}) / W_{required} \quad (4)$$

Detailed equations and symbols are presented in Table 1 for reference.

Table 1

Assessments of the seawater desalination system.

Index	Content	Definition	Equation
$W_{desalted}$	Desalted water	Total water desalted through the desalination project	
$W_{required}$	Embodied water	The embodied water required to desalted water	
$W_{production}$	Water production	The desalted water volume after removing the freshwater costs	$W_{desalted} - W_{required}$
$R_{investment}$	Investment rate	The embodied water requirement to the desalted seawater volume	$W_{required} / W_{desalted}$
$L_{productivity}$	Productivity level	The net water production in embodied water requirement	$(W_{desalted} - W_{required}) / W_{required}$

2.2 Case description and data sources

2.2.1 Case description

The LT-MED third-phase project located in Hebei Province was developed in 2013 by the Huanghua Power Plant, which processes 25.00 thousand tons/day of fresh water and chosen as the study case in this work. With the third phase project, the capacity of daily water production of the Huanghua Power Plant increased from 32.50 to 57.50 thousand tons, and the capacity of the external water supply increased from 18.80 to 40.00 thousand tons, ranking it as first place in China. According to the calculation of the operating phase of 20 years, the total amount of freshwater produced is 1.83E+08 m^3.

The distillation technology in this project is regarded as one of the most widely used desalination technologies, which has been widely used in various seawater desalination projects. Distillation desalination technology includes multi stage flash distillation (MSF), multi effect distillation (MED) and mechanical vapor compression (MVC). The low temperature multi effect distillation (LT-MED) was developed in 1980s, with the process flow diagram shown in Fig. 1. This technology shows its advantages in high-quality desalted water, simple equipment structure, no limit by the original seawater concentration and no special requirements for pretreatment. The case project co-produces both electricity and desalinated water, which is an ideal option for the construction of large-scale desalination plants.

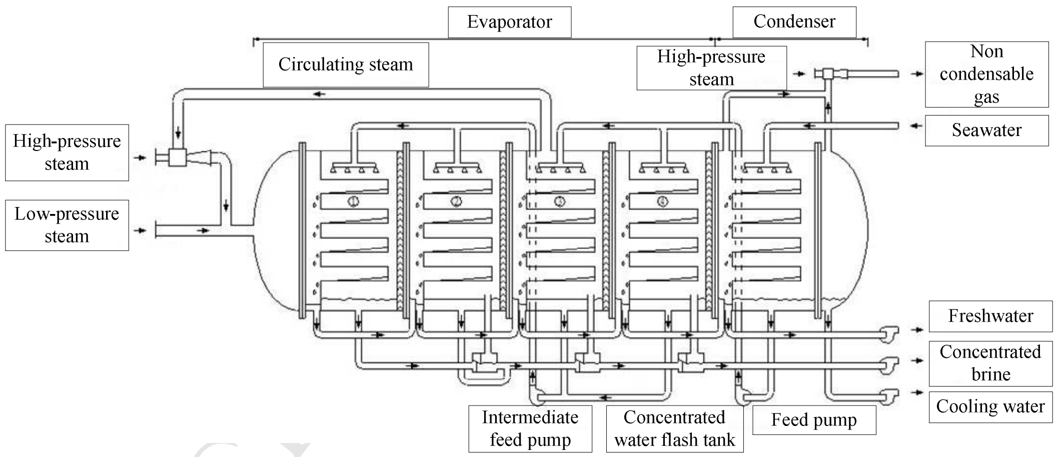


Fig. 1. The flow diagram of the case seawater desalination project.

As shown in Table 2, the construction phase of seawater desalination project can be further divided into three major projects (construction engineering, installation engineering, and other services), in which the installation engineering can be divided into three sub-projects (technology system engineering, electrical system engineering, and thermal control system engineering). Details are given in Appendix A and B, and the full names and abbreviations of the sub-projects are listed in Table 2 for reference.

Table 2

The full names and abbreviations of the sub-projects.

No.	Projects	Sub-projects	Abbrev.
1	Construction engineering		Construction engineering
2	Installation engineering		Installation engineering
3		Technology system engineering	Technology system
4		Electrical system engineering	Electrical system
5		Thermal control system engineering	Thermal control system
6	Other services		Other services

2.2.2 Data sources

The systems assessments of embodied water for seawater desalination projects require an appropriate embodied water intensity inventory database, which covers all economic products corresponding to the production industry. For different types of projects, the embodied water intensity database has been derived based on the systems input-output analysis (Chen et al., 2011a, c, 2013; Chen and Han, 2015a, b; Han et al., 2015a, 2018; Li and Han, 2018). Based on the data of Hebei Province's input-output table and the systems analysis, the embodied water intensity inventory of Hebei Province in 2012 has been obtained, which provided the most accurate and detailed data for Hebei Province (Liu et al., 2017; Han et al., 2017). The unit of the database is cubic meters/million CNY, and the full names and abbreviations of the relevant input-output sectors are presented in Table 3 for reference.

Table 3

The full names and abbreviations of the relevant input-output departments.

Sector code	Full name	Abbrev.
12	Chemical Products Related Industry	Chemical
13	Nonmetal Mineral Products	Nonmetal Mineral
15	Metal Products	Metal
16	Ordinary Machinery, Equipment for Special Purpose	Special equipment
18	Electric Equipment and Machinery	Electricity
19	Electronic and Telecommunications Equipment	Electronic communication
20	Instruments, Meters, Cultural and Office Machinery	Instruments and meters
23	Electric Power/Steam and Hot Water Production and Supply	Electricity and heat
25	Water Production and Supply Industry	Water
26	Construction Industry	Construction
29	Information Transmission, Computer Service and Software Industry	Computer Service
36	Polytechnic Services	Technology

3. Results

3.1 Embodied water of sub-projects in seawater desalination

Fig. 2 presents the consumption structure of the construction phase. To conduct a detailed analysis, the detailed results of the embodied water of 5 sub-projects in the construction phase of the case project are presented below. Detailed data can be referred in Appendix C.

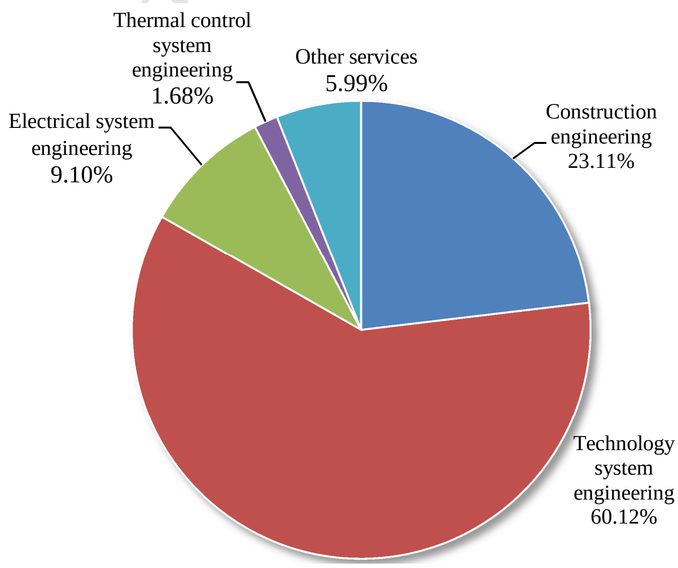


Fig. 2. Embodied water structure in the construction phase.

As the fundamental sub-project, the embodied water consumption of the construction engineering is 2.09E+06 m^3, accounting for 23.11% in the construction phase of the case project. Specific to each component, general civil engineering projects account for nearly 40% of the total embodied water of construction engineering, followed by foundation treatment (15.52%) and pool (10.43%) as shown in Fig. 3.

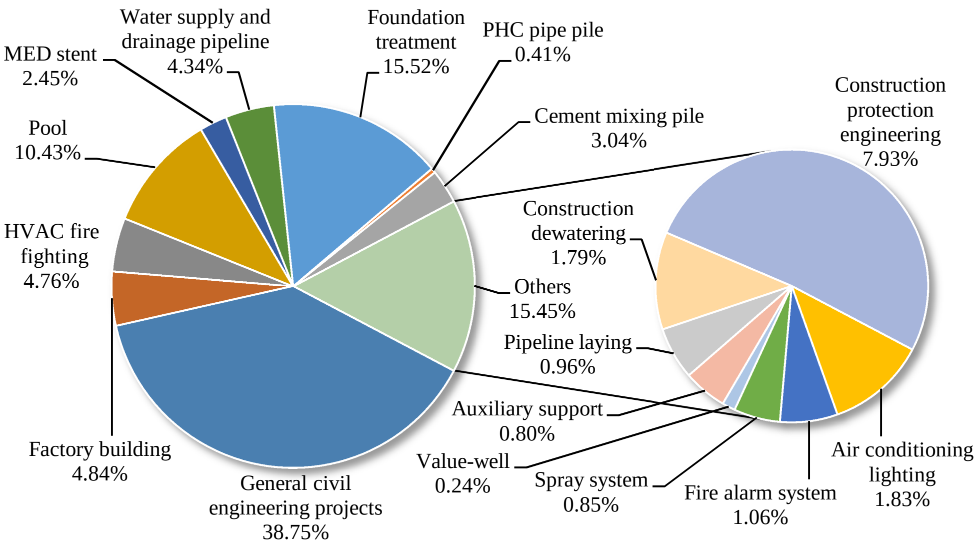


Fig. 3. Embodied water structure of construction engineering.

Technology system engineering is the largest embodied water consumption project in the construction phase, with the total amount reaching 5.42E+06 m^3. Water pump and frequency converter are the main components (3.66E+06 m^3), accounting for 67.46% of the total in this sub-project. As shown in Fig. 4, the auxiliary equipment and system device of the seawater desalination occupy large proportions as well, representing 13.32% and 4.93% of the total, respectively. In addition, other accessories and materials account for about 10%, in which other installation materials account for the largest proportion in this component.

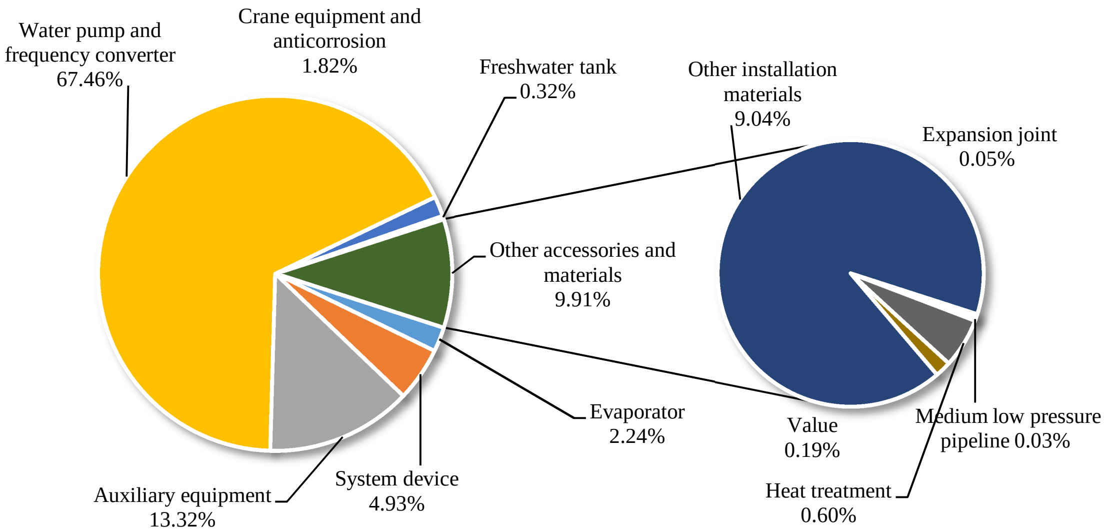


Fig. 4. Embodied water structure of technology system engineering.

The input list of the electrical system engineering mainly includes the power supply equipment, auxiliary materials and facilities and equipment installation. The embodied water consumption of 6KV station-service power supply equipment is 2.43E+05 m^3, accounting for nearly 30% of the total in the electrical system engineering. Besides, the embodied water consumption of the cable bridge support is 1.60E+05 m^3, accounting for nearly 20% of the total in this sub-project. Other auxiliary materials and facilities account for the largest proportion, reaching approximately 37.47% as shown in Fig. 5.

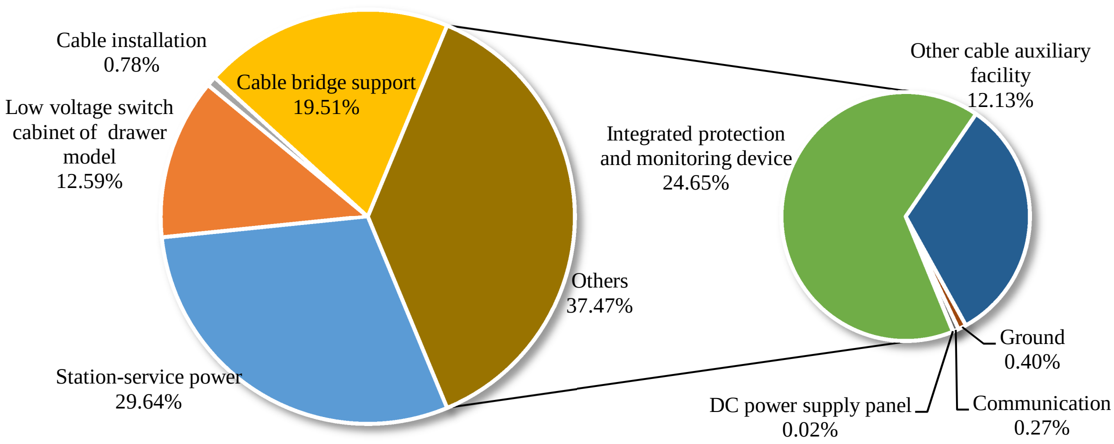


Fig. 5. Embodied water structure of electrical system engineering.

The thermal control system is mainly composed of the PLC device, servers, main instruments, control equipment, cables, auxiliary facilities and other installation materials. Fig. 6 depicts the detailed structures of the embodied water consumption of the thermal system engineering. The PLC control system is the core component of this sub-engineering, whose consumption is 1.12E+05 m^3, with 73.87% of the total in this project. The system server and cables and ancillary facilities also account for large shares in the sub-project, with the proportions of 12.65% and 7.78% respectively as shown in Fig. 6.

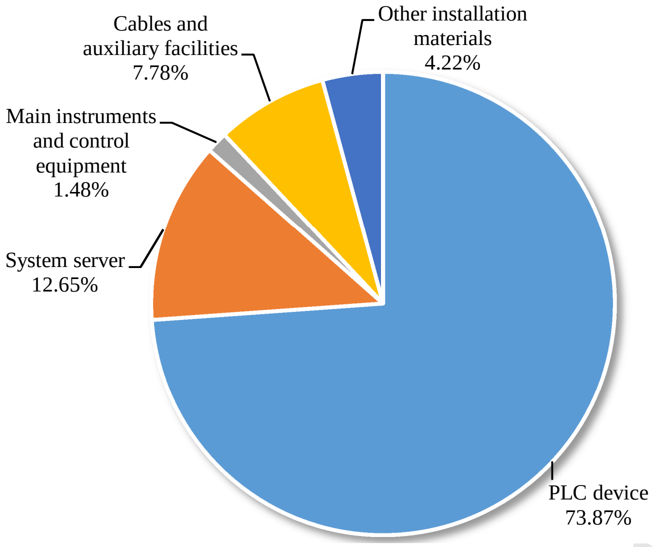


Fig. 6. Embodied water structure of thermal control system engineering.

Other services include the management and technical services of the project construction, the costs of system commissioning and trial operation and other expenses. The technical services of the project construction are the largest embodied water consumption component in this sub-project, whose consumption is 3.05E+05 m^3, accounting for 56.46% of the total. Besides, the embodied water consumption of the management in the project construction accounts for about 9.04% as well, as shown in Fig. 7.

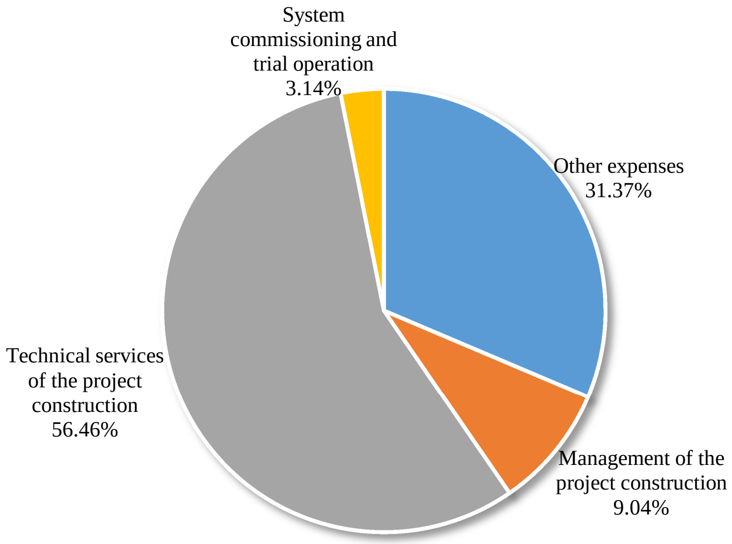


Fig. 7. Embodied water structure of other services.

3.2 Multi-types of embodied water in the construction phase

The embodied water intensity database applied in this study is composed of four types of water use, namely agricultural production, industrial production, household use and biological protection. With the obtained database, the four proportions of embodied water consumption in the construction phase are calculated as 3.54%, 54.22%, 41.80% and 0.43%, respectively. Among them, the industrial production and household use account for the large proportions of the total. Detailed data of five sub-projects are listed in Table 4.

Table 4

Embodied water consumption of sub-projects in construction phase.

Sub-projects \ **Types of water use**	**Agricultural production**	**Industrial production**	**Household use**	**Biological protection**	**Total consumption**
Construction engineering	5.33E+04 m^3	1.13E+06 m^3	8.98E+05 m^3	8.53E+03 m^3	2.09E+06 m^3

Sub-projects \ Types of water use	Agricultural production	Industrial production	Household use	Biological protection	Total consumption
Install engineering	2.44E+05 m^3	3.48E+06 m^3	2.64E+06 m^3	2.81E+04 m^3	6.39E+06 m^3
Technology system	2.06E+05 m^3	2.95E+06 m^3	2.24E+06 m^3	2.40E+04 m^3	5.42E+06 m^3
Electrical system	2.79E+04 m^3	4.50E+05 m^3	3.39E+05 m^3	3.38E+03 m^3	8.20E+05 m^3
Thermal control system	1.04E+04 m^3	8.06E+04 m^3	5.95E+04 m^3	7.34E+02 m^3	1.51E+05 m^3
Other services	2.14E+04 m^3	2.87E+05 m^3	2.30E+05 m^3	2.45E+03 m^3	5.40E+05 m^3
Total consumption	3.19E+05 m^3	4.89E+06 m^3	3.77E+06 m^3	3.91E+04 m^3	9.02E+06 m^3

Fig. 8 further depicts the constituents of embodied water of 5 sub-projects in the construction phase. The technology system engineering is regarded as the sub-project with the largest embodied water consumption in the construction phase. The proportions of the four types of embodied water in the sub-project are 3.83%, 54.42%, 41.32% and 0.44%, corresponding to agricultural production, industrial production, household use and biological protection respectively.

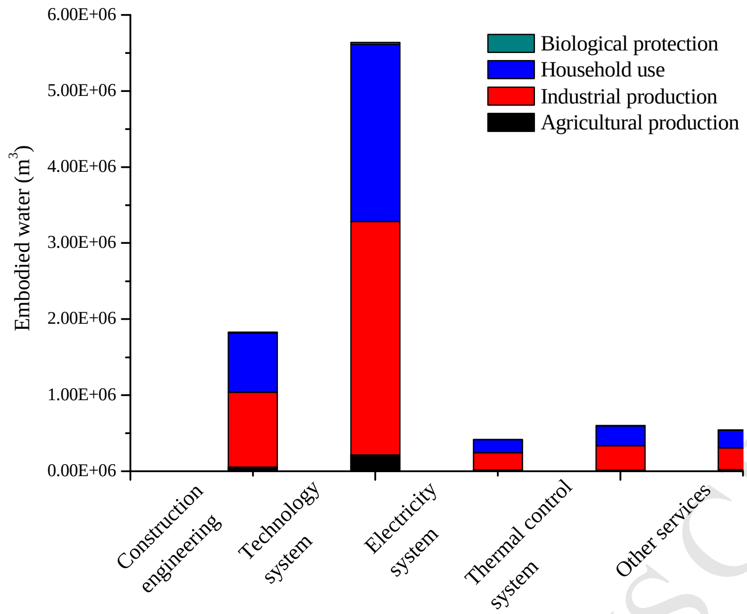


Fig. 8. The multi-type embodied water of 5 sub-projects in the construction phase.

Meanwhile, Fig. 9 shows the constituents of four types of embodied water of 3 projects in the construction phase, among which the installation engineering is the largest embodied water consumption project. With the detailed results of the 3 projects, the proportions in the installation engineering regarding agricultural production, industrial production, household use and biological protection are 3.68%, 54.37%, 41.52% and 0.43% respectively.

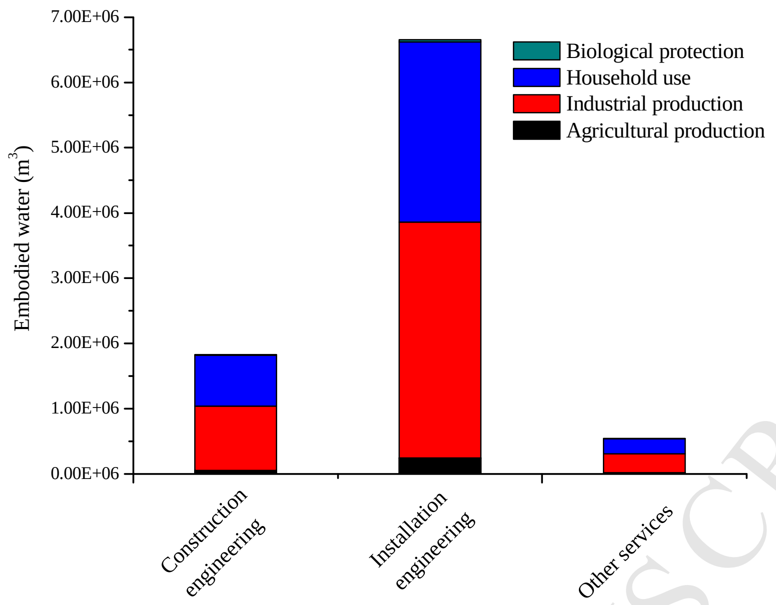


Fig. 9. The multi-type embodied water of 3 sub-projects in the construction phase.

The above results present that technology system engineering is the largest embodied water sub-project in the construction phase when it is divided into 5 sub-projects, and installation engineering is the largest embodied water consumption project in the construction phase when divided into 3 projects. The proportion of the four types of water use of embodied water in these two projects is close to the proportion of the total amount of embodied water. Among all types of water use, the proportions of industrial water and household water are with large quantities. As for the other sub-projects in this phase, agricultural and biological water are less involved in the construction phase of the seawater desalination project. Detailed data can be referred in Appendix C.

4. Discussion

The case project in Huanghua, Cangzhou covers an area of about 33 thousand square meters, and the direct water consumption W_{direct} is estimated to be 1.60E+05 m^3. Based on the results, the embodied water consumption $W_{required}$ in the construction phase of the case project is calculated as 9.02E+06 m^3. From the results, the amount of embodied water consumption is 56 times higher than the direct water consumption when considering the indirect water consumption in this phase. The total freshwater production $W_{desalted}$ in operation life cycle is 1.83E+08 m^3, which is 20.29 times of the total freshwater consumption in the construction phase. After removing the freshwater costs in the construction phase, the net water production $W_{production}$ can reach 1.74E+08 m^3, which means the average net water production per year $w_{production}$ is 8.70E+06 m^3, almost equivalent to the local average water supply in 20 years.

Among all the sub-projects, the embodied water consumption in the technology system engineering represents the largest component, accounting for 60.12% of the total embodied water consumption. Followed is construction engineering, accounting for 23.11% of the total. Taking the installation project (including technology system engineering, electrical system engineering, and thermal control system engineering) as a whole, the embodied water consumption of installation engineering in the construction phase is much larger than in the other sub-projects, accounting for 70.90% of the total.

Overall, the investment rate $R_{investment}$ of the case project is calculated as 20:1, and the productivity level $L_{productivity}$ of the case project is calculated as 19.29, far greater than 1, indicating that desalination water production is much higher than the embodied water consumption in the construction phase. In the first year of operation, the water yield of the project is calculated to be 9.12E+06 m^3, which could achieve the freshwater balance in the construction phase. According to the statistics of Cangzhou Statistical Bureau (2014) and Hebei Water Resources Bulletin (2013), there were 1993 industrial enterprises above the designated size, and the total annual industrial water demand per year in Cangzhou area is 2.68E+08 m^3. With the design standard of the case project, it is expected to meet the water demands of 8 enterprises in Cangzhou New Area. With the supply ability of the desalination project, the total industrial water demands of 8 enterprises in Cangzhou New Area is about 1.08E+06 m^3, which accounts for 12.4% of the total annual net water output of the case project. After removing the industrial water and household water used in the power plant where the project is located, there is still about 85% of the net water output available for other enterprises, greatly alleviating the local water demands at the local economy. Detailed indicators are listed in Table 5 for reference.

Table 5

Basic indicators of the case project.

Index	**Data**	**Index**	**Data**
W_{direct}	1.60E+05 m^3	$L_{productivity}$	19.29
$W_{required}$	9.02E+06 m^3	$R_{investment}$	20 : 1
$W_{desalted}$	1.83E+08 m^3	$Y_{investment}$	1st year
$W_{production}$	1.74E+08 m^3	N_{supply}	8 enterprises

Fig. 10 further summarized the different levels of freshwater cost materials in the basic seawater desalination project based on the above results. Five levels of freshwater costs are classified according to the magnitude of embodied water consumption. Generally speaking, the inputs in the construction phase of seawater desalination project include general civil engineering projects, foundation treatment, seawater desalination pump and frequency converter, seawater desalination system and auxiliary equipment, technical services of seawater desalination project, other installation materials and 6KV station-service power supply equipment. From Fig. 10, the general civil engineering projects, foundation treatment, seawater desalination pump and frequency converter, seawater desalination system and auxiliary equipment, technical services of seawater desalination project, other installation materials are classified in the higher level of freshwater costs, which mainly concentrate in the technology system engineering and construction engineering. In addition, components including evaporator, water supply and drainage pipeline, PLC device, cable bridge and other cable auxiliary facilities belong to the lower level of freshwater costs, which are always regarded as the indispensable components for desalination projects as well.

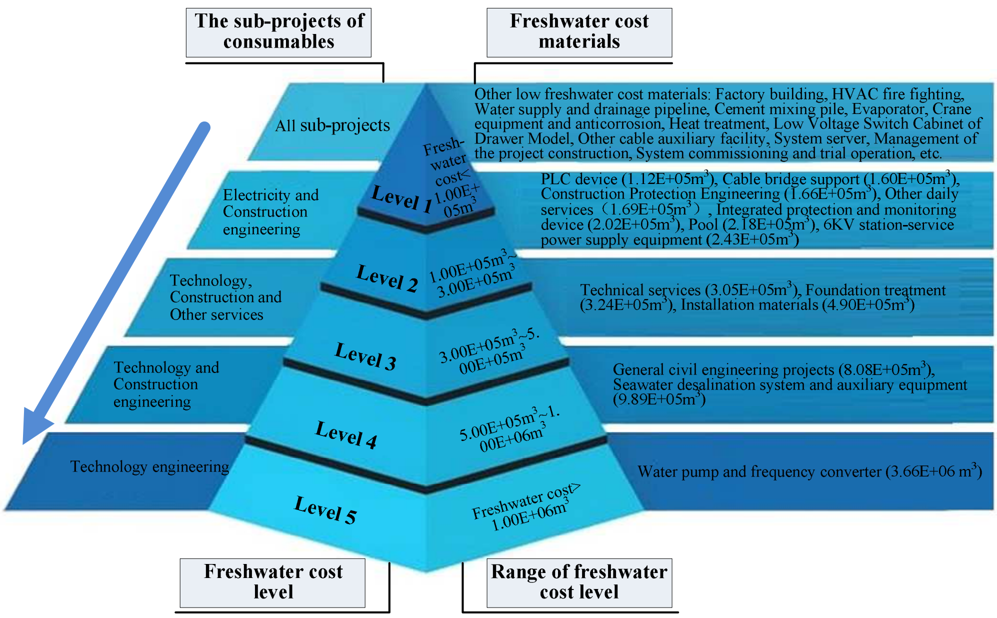


Fig. 10. The pyramid model of freshwater cost levels.

In recent years, the seawater desalination technology has made great progresses around the world. As one of the most water shortage countries in the world, China has huge requirements for the desalination construction to ease the water crisis. For a clear presentation, the distribution of key water shortage areas and the distribution scales of existing desalination in China are depicted in Fig. 11. According to the National Seawater Utilization Report (2016), more than 100 seawater desalination projects have been completed in China, with a water production scale of nearly 2 million tons per day. According to the 13th Five-Year Plan for the Utilization of Seawater in China (2016), the total scale of seawater desalination in China will reach more than 2.20 million tons per day by 2020, which means most of the coastal areas would vigorously conduct the construction and upgrading of seawater desalination projects.

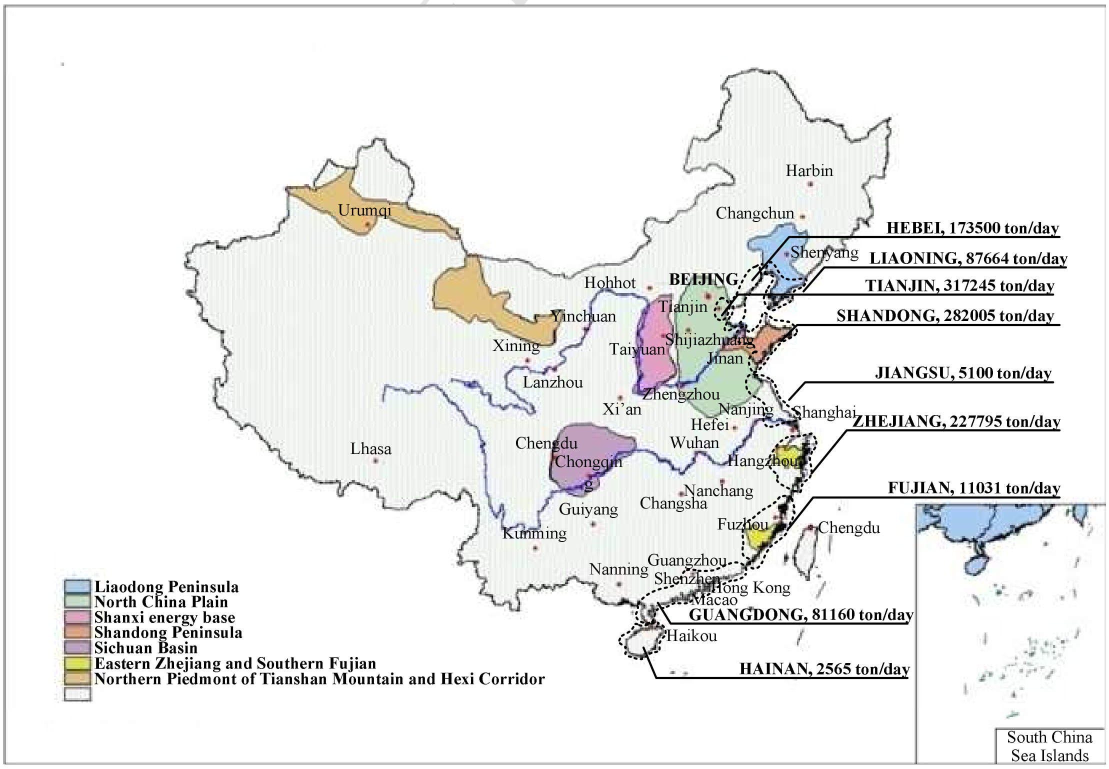


Fig. 11. Water shortage areas and seawater desalination distribution in China.

Besides, the different desalination projects in the previous studies among the world are also compared in Table 6. The economic investments of these projects were always evaluated; however few studies focused on the freshwater cost evaluation on the desalination projects. Generally, the economic costs are highly related to production capacity, while the production capacity of the case project almost ranks in the first place among these projects. With the obtained item inputs from the Huanghua Power Plant, the freshwater costs are systematically assessed with detailed material evaluation. On the one hand, this assessment could provide fundamental references for plant design improving and engineering operation optimizing from the freshwater cost perspective. On the other hand, it can effectively avoid the inefficient water use and achieve the reasonable water allocation for regional collaborated development.

Table 6

Comparisons of seawater desalination plants.

Location	**Country**	**Plant capacity**	**Reference**	**Suitable RE-desalination combination**	**Unit product**
---	---	1500 m^3/day	Nafey et al., 2008	Solar thermal-MEE–MVC	1.24 $/$m^3$
Near Dead Sea	Israel	3000 m^3/day	European Commission, 1998	Solar thermal-MEB	---
Safat	Kuwait	10 m^3/day	European Commission, 1998	Solar thermal-MSF	---
Almeria	Spain	72 m^3/day	Zarza, 1991	Solar thermal-MED-TVC	---
University of Ancona	Italy	30 m^3/day	Caruso and Naviglio, 1999	Solar thermal-MEB	---
Ranau	Malaysia	20000 m^3/day	Chiam and Sarbatly , 2013	Geothermal-VMD	0.50 $/$m^3$

Location	**Country**	**Plant capacity**	**Reference**	**Suitable RE-desalination combination**	**Unit product**
Isola di Pantelleria	Italy	4110 m^3/day	Manenti et al., 2013	Geothermal-MED	2.30 \$/m^3
Split and Dalmatia	Croatia	100 m^3/day	Vujcic and Krneta, 2000	Wind-RO	---
Ténès	Algeria	5000 m^3/day	Dehmas et al., 2011	Wind-RETScreen free	---
Huanghua Port	China	25000 m^3/day	This paper	Water-electricity cogeneration-LT-MED	0.95 \$/m^3

In order to improve the utilization of seawater desalination, it is necessary to strengthen the supervision of high-level water consuming materials, optimize process operation systems, and improve the investment rate and productivity level of the desalination projects. Among the basic components, the desalination materials including desalination pumps and frequency converter, desalination systems and auxiliary equipment, desalination project technical services deserve further attention. Besides, the construction of seawater desalination project requires a systematic accounting system for life cycle measurement for water-saving cooperation and reasonable allocation. Overall, there are still huge potentials to improve the optimization of seawater desalination from the upstream and downstream of the supply chains, which could have positive effects on the productivity of seawater desalination plants and provide necessary references for water saving strategies.

5. Conclusion

This study focused on Hebei Guohua Huanghua Power Plant's desalination project and assessed the freshwater costs to obtain detailed embodied water inventory of the desalination materials in the construction phase. The water production and consumption of the desalination project covering 5 sub-projects are systematically analyzed, and the construction phase is comprehensively assessed with the comparisons of different types of water use. This work applies the systems accounting for the freshwater cost assessments of a seawater desalination project from the embodied perspective for the first time, laying a solid foundation for systems water accounting of the Huanghua power plant as well as other possible projects in water shortage areas.

Overall, the total embodied water consumption $W_{required}$ in construction phase is 9.02E+06 m^3, which is 56 times higher than the direct water consumption W_{direct} in the phase. The total water production $W_{production}$ is expected to be 1.83E+08 m^3 in the 20 year life cycle and the net water production per year $w_{production}$ can reach 8.70E+06 m^3. The embodied water consumption of technology system engineering is 5.42E+06 m^3, which is the highest among sub-projects. The seawater desalination productivity level $L_{productivity}$ of the case project are 19.29, which represents the fact that it greatly alleviates the shortage of freshwater resources and makes a certain contribution to the water-saving strategy in China.

This work clearly provides a set of freshwater cost accounting and assesses the desalination productivity of desalination projects. It is the first time to apply the systems process analysis to the freshwater cost assessment of seawater desalination, which fills the blank in the field of freshwater accounting and evaluation. Meanwhile, the study conducts a system accounting on the construction of new seawater desalination projects and the management of freshwater operation of existing projects. With the comprehensive inventory of the embodied water consumption, the detailed analyses in this work provide a detailed profile for the freshwater cost assessments of seawater desalination projects, presenting a great ability to alleviate the shortage of freshwater resources and to extend this research to other desalination projects.

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Highlights

The freshwater costs of the Huanghua Seawater Desalination are 9.02E+06 m^3.

The productivity of the project is 19.29 m^3 net water/m^3 required water.

Materials with different levels of freshwater costs are compared and assessed.

The net freshwater volume per year of the project reaches 8.70E+06 m^3.

The water demands of 8 enterprises in Cangzhou are meet by the project.

Construction and technology materials are essential for embodied water conservation.