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Review and prospects of desalination as a water supply method in China

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ABSTRACT

With the development of urbanization and deterioration of water environment, the fresh water shortage in eastern coastal cities of China is more and more serious. Desalination, as the only way to increase the amount of fresh water, should be more applied in this region, while the actual development is not as expected for some reasons. The study reviews the desalination status in China from the perspective such as driving force, investment, cost, policy, safety and energy. The analysis of problems makes the recommendations how to develop desalination market and make desalination as a safety water supply. In addition, the study compares desalination with wastewater reuse in water quality, cost, management, public acceptance and so on and discusses the proposal for integrated utilization of different unconventional water sources.

Keywords: Desalination; Cost and investment; Technology; Energy; Management and policy

1. Introduction

China is a serious drought and water shortage country, listed as one of thirteen countries that are most water-poor in the world. The total amount of renewable fresh water supply is $2.8 \times 1.0^{12}\,m^3$/year in 2008 equivalent to a theoretical per capita freshwater resource of 2,220 m^3 [1], accounting for 6% of the average value of the world and ranking fourth in the world. But China is a populous country, so the freshwater resource per capita is one-fourth of the world's mean value (8,840 m^3), ranking 121 in the world. Further, the practically available freshwater resources per capita, excluding flood run-off and groundwater resources in remote areas, are only about 900 m^3, with extremely uneven distribution [2]. By the end of twentieth century, among more than 600 cities in the country, more than 400 cities had existed problems of inadequate water supply and some 110 cities faced serious water shortage. The bigger city, the bigger is the challenge. In the 32 megalopolis with population over one million, there are 30 cities long plagued by water shortage [3]. At the same time of being confronted with water shortage, water pollution is increasingly aggravating. With the rapid development of economic construction and the population on the increase, particularly rapid expansion of the urban population, sewage and waste emission increases as well. According to China's Environment Bulletin, only one-fifth of the municipal and industrial wastewater is

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properly treated. The rest is more or less untreated and directly drained into the waters, causing a large area of water pollution and resulting in deterioration of water environment [1]. Despite large flows, the waters of seven major river systems are moderately polluted, and eutrophication is the prominent problem of lakes (reservoirs) [1].

Even if water treatment plants were developed thoroughly over the country, additional water supplies are needed to meet the growing water demand of the urban areas. Desalination has been proven to be an important method for freshwater supply in the world. The rapid growth of desalination in the recent decades allowed the social and economic development to continue and grow also in arid and semi-arid areas. The installed desalination capacity has increased rapidly worldwide, from 8,000 m^3/d in 1970 to about 77.4 million m^3/d installed or contracted production capacity with over 16,000 industrial-scale desalination unites by 2012 [4]. A variety of desalting technologies has been developed over the years, primarily thermal and membrane processes. The cost of desalination per produced water volume is roughly inversely proportional to the production capacity of the plant. The market is also driven by the falling costs of desalination, which are due to the technological advances in the desalination process [5].

Since China is a water shortage country with huge marine resources, desalination should be an important additional water sources and should have a board space for development in the country. Research on technology of water desalination in China started with ED in 1958, in a co-operation between the navy and the Chinese Academy of Sciences; the research on RO started in 1965; the research on large- and medium-sized distillation started in 1975. In 1981, the first ED desalination station with capacity 200 m^3/day was officially put into operation in Yongxing Island of Xisha (Paracel) Islands [6]. After more than 40 years development, desalination in China has made considerable progress and achievements, gradually forming a comprehensive technology subject and water treatment technology industry [7]. Especially in recent years, with the increased deterioration of fresh water resources and the increased attention and investment on water conservation, the development of desalination in China has been accelerating. Data from the Ministry of Science and Technology showed that as of September 2011, the total capacity of seawater desalination in China had reached 660,000 m^3/day, which was more than 13 times of the level in 2005 (50,000 m^3/day) [8]. In Fig. 1, the capacity of desalination in China for the years 1981–2007 is presented. Up to 2007, 41% of the desalinated water is used for municipal, 38% for industrial and 21% for power production purposes [9–12].

Nevertheless, compared with the Middle Eastern countries, desalination in China is still not as much applied as might be expected. The total installed capacity since 1945 is only ranked sixth in the world [4] and daily output is only about 1% of the global production. Besides comparatively high price, there are also other problems existing, such as policy and management, which delay the pace of development. In 2012, the issue of 'The views on accelerating the development of the desalination industry' (Document No. 13, 2012) by the office of State Council identifies the desalination industry to the national strategic level [13]. Information from China Desalination Association (CDA) shows that during '12th Five-Year' period, investment for desalination is expected to reach 200 billion Yuan RMB [8]. Desalination in China is facing unprecedented opportunities for development yet many challenges remain.

The article reviews the desalination status in China from the perspective of general driving forces, management, investment and price system, policy, safety and energy. Through the analysis of problems, it is possible to make recommendations how to develop the Chinese desalination market and to use desalination for a safety water supply. In addition, the article compares desalination with wastewater reuse in terms of water quality, cost, management, policy and public acceptance and discusses the proposal for comprehensive and optimized utilization of different water sources.

2. Driving force for Chinese desalination market – Why desalination needed in China?

The most fundamental driving force for desalination is a freshwater shortage for all the countries using this method. There is no exception for China as previously described. The total water shortage in urban area is 6 billion m^3. The output value impacted by urban water shortage is up to more than 2.0×1.0^{11} RMB Yuan/a, with about 40 million population affected [3]. The prediction is that the water resources per capital will decrease to 1,760 m^3 by 2030, which is calculated according to the population increasing to 1.6 billion [14]. The value is closed to 1,700 m^3 per capital, which is the internationally recognized water stressed standard.

For China, another reason is the advantage of desalination to other ways of getting fresh water. At present, besides local surface water source, the main modes of access to fresh water are exploitation of groundwater, remote water diversion and desalination, in which the last one is the only method that can increase the total amount of freshwater. In the situation of surface water serious polluted, the exploitation

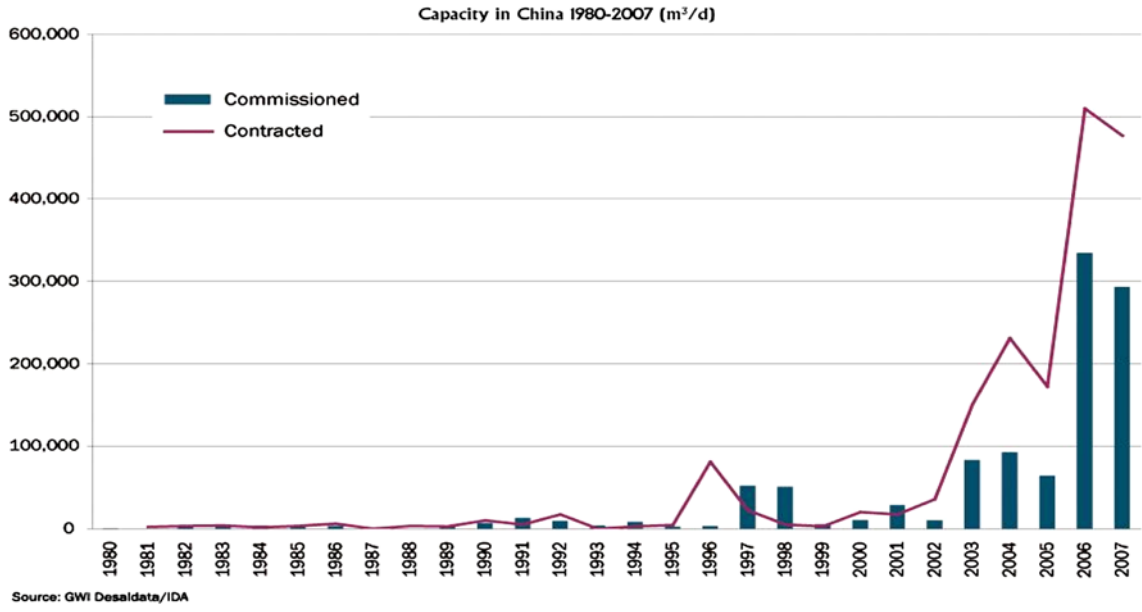

Fig. 1. The change of desalination capacity in China from 1980 to 2007 [9–12].

of groundwater has been a regular way to get fresh water. About 400 out of 657 cities are using groundwater as water source, and the amount is up to 18% of total water supply in 2001 [15]. As there is not enough management and monitoring, the over-exploitation of groundwater takes place in almost all large- and middle-sized cities, which leads to ground subsidence, seawater intrusion for coastal locations, salinization of land, drained wetlands, dried watercourses and lakes and other ecological damages. Besides the over-exploitation, groundwater in 76 cities is seriously polluted to a level where the water is unsuitable for water supply. To alleviate water depletion in the north of China, the Chinese government developed a plan of remote water diversion called 'South-North water transfer project' in 2002. However, the fresh water available from the Yangtze River basin is insufficient and the impact of the water transfer project on the ecosystem is hard to estimate [16]. The project will also lead to forced migration for hundreds of thousands of people. In addition, the total investment will reach 486 billion Yuan RMB, suggesting that the cost of remote water diversion is much higher than the cost of desalination.

On the other hand, China has 32,000 km of coastline and 3,000,000 km^2 of marine areas, which contain abundant seawater resources [16]. The littoral resides 40% of the total population and contribute to 70% GDP of China in the 13 provinces with coast. China's population and economy are concentrated in the coastal zone, which makes desalination a viable alternative source of water, as many coastal cities face serious fresh water shortage [17]. Furthermore, desalination is less influenced by geology and climate than groundwater abstraction or remote water diversion. Desalination has less impact on surrounding residents. That means that desalination is a safer method for water supply. Whether from cost or from impact on ecology and environment perspective, desalination should be a better way to provide fresh water to these water-shortage areas instead of over-exploitation of groundwater or transferring water from long way.

3. The problems and proposals for development

Desalination is not as widely used as it could be for water supply. Although there is some progress after more than 40 years of development, desalination in China is still in the initial stage and has the features of immature technology, such as small-scale plants, slow development, high costs and difficult promotion [18].

In Fig. 2, the distribution of installed capacity by plant size and the top 10 plants by capacity is presented. Most of the desalination plants of China are still small- or medium-scale plants. Large capacity plants only account for 4.7% of the production. Desalination has not reached the economic scale in China. In a market economy, the demands decide markets. The small-scale means there is little demands for desalination. The users do not have enough awareness and

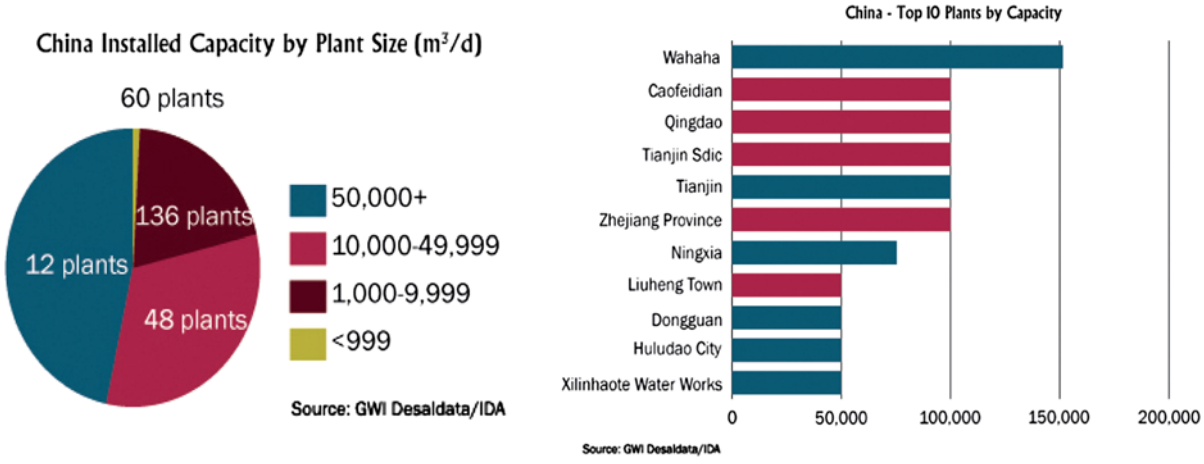

Fig. 2. China installed capacity by plant size [9–12].

acceptance for desalinated water, combined with high cost and no enough support from government. At present, there are not enough benefits for investors to be involved in the desalination industry. Technology, price and policy, which have some correlation to each other, are the most important points for the development of desalination in China.

3.1. Technology and energy

There are three main types of desalination methods used throughout the world, named Membrane Systems (such as RO and ED), Thermal Processes (such as MSF, MED and VC), and others (such as MD). Of all methods, RO has the largest share of the Chinese desalination market (Fig. 3). Reverse osmosis technology has the advantages of lower project investment, shorter construction period, smaller footprint, easier operation and maintenance, lower energy consumption and lower cost than other methods [19]. Furthermore, RO is more suitable for small- and medium-scaled plants, which are the most common in China. MSF, which is more suitable for large-scale plants, is an important method,

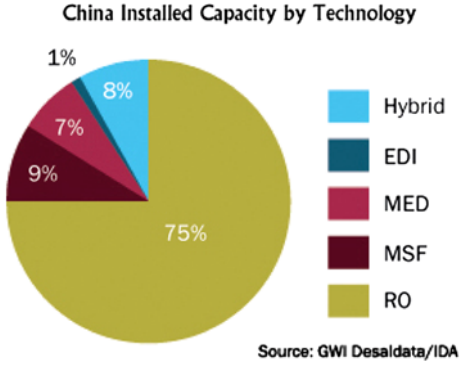

Fig. 3. China installed capacity by technology [9–12].

second only to RO in the world with about 30% of installed capacity globally, while a modest 9% in China. Besides the scale, energy is another reason for that RO is much more applied than MSF in China since China is also an energy shortage country. For some cases, MSF even has higher cost than RO in China, since it consumes more energy. However, for thermal electric power plants, petrochemical and other enterprises, which require boiler feed water and process water, and produces low-grade steam or heat, MSF has a certain competitive advantage, while RO has large edge for municipal water supply.

From technology perspective, another problem is China is a lack of independent intellectual property rights of core technology and key equipments. About 80% of installed capacity use introduced technology from foreign countries, and key equipments, such as RO membrane and energy recovery equipment, are mainly dependent on imports, which is one main reason for elevated investment costs. Information from CDA shows that 50% of the thermal material and 90% of the membranes (mainly RO) are imported, which increase the investment costs [20]. In addition, the quality of any domestic equipment, such as RO membranes, is an issue. Domestic desalination industry in China performs worse than international industry in terms of retention, energy efficiency and expected lifetimes of the plants. This is the main reason why Chinese enterprises have a small proportion in the market in spite of lower prices. In the 16 completed desalination projects over 10,000 m^3/d, only 25% are self-constructed, and less than 13% if calculated in capacity [8]. For China, independent research and development of technology and domestic equipment with higher performance is a major way to reduce the cost and promote development of desalination and related industry. In 'Membranes industry "12th

Five-Year Development Plan" by China Membrane Industry Association, the market share of domestic RO membrane should increase to 25–30% in the coming five years. The reform and innovation of technology with own intellectual property right is regarded to be the basis for future development of Chinese desalination market. The Chinese Membrane Industry urges the government to increase the investments in relevant research and to formulate the detailed methods and steps for how to support and promote the industry, not only through general planning.

Energy consumption is the one of the main technical and economic indicators for desalination and has important impact on technology selection and cost. It has special relevance for China, which is an energy shortage country. In 1997, "500 m^3/d reverse osmosis desalination demonstration project" used a turbine-type energy recovery device for the first time, which made desalination energy consumption of fresh water decrease to below 5.5 kW h/m^3; In 2000, a 1000 m^3/d reverse osmosis desalination demonstration project built two plant in Changdao of Shandong Province and in Shengsi of Zhejiang Province, using a pressure switching energy recovery device, which made desalination energy need to decrease to below 4.0 kW h/m^3 for produced freshwater [19]. In China, desalination energy consumption indicators have decreased by about 90% for the best-performing plants (from 26.4 to 2.9 kW h/m^3) in 40 years [21]. The utilization of energy recovery and frequency conversion control technology significantly reduces energy consumption of desalination project, accordingly leading to a reduction in the operational cost. From data above, we can see that China has a certain progress on energy recovery device, but as same as other equipment, energy recovery technology with Chinese independent intellectual property rights is still in the research or initial development stage, and it has not been a mature industry. Furthermore, in China as globally, most desalination plants use conventional sources of energy (gas, oil and electricity), which is cheaper at present but has negative impact on environment. Desalination powered by alternative energy sources, which includes nuclear energy and renewable energy (wind, solar, geothermal energy, etc.), as opposed to conventional energy sources, should be an attractive solution in terms of induced environment impact due to lower conventional energy consumption and lower gas emissions. Since conventional energy sources are limited and has a significant environmental impact, renewable energy sources for desalination will have a great potential market also in China.

China has some research on solar energy device for desalination. For example, the solar power device for distillation desalination named HM/HD, which is developed by Huangming Solar Energy Group, reduces the amount of heat losses and saves energy and cost. The cost is less than 20 Yuan RMB/m^3, and the energy consumption is less than 3 kW h/m^3 [22]. There are also some small capacity projects using solar, mainly concentrated in islands which lack other energy sources. Nevertheless, the solar power has still not been able to compete with conventional energy sources due to technology problems, such as low water production and high costs. Similar with solar power, other renewable energy sources only take up small proportions of the production, mainly because of the higher operational costs. According to the study by Tian (2001), nuclear energy, which causes less greenhouse gas emissions, has economic competitiveness compared with fossil energy when it is applied in RO, MSF and MED [23]. The stability and sustainability are regarded as superiority to some renewable energy sources depending on the weather conditions. The issue of this kind of energy is the safety of nuclear reactor and how to control the nuclear waste. Another potential energy is biological energy, which can stimulate a recycling economy. Bio-energy can supply energy and reduce waste pollution. It should be more suitable for China, since solid waste management is also a problem in China. The alternative energy is an important direction for research and development, since the conventional energy is more and more limited and the safe energy supply will be critical and a bottleneck for sustainability of desalination development. The implement of "Renewable Energy Law" [24] clarified the status and importance of renewable energy, and it will bring broad prospects for development and investment.

3.2. Feed water

The data show that higher salinity in the feed water means higher operational costs. The selection of feed water depends on local condition and water

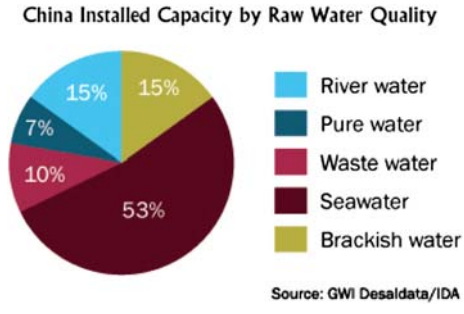

Fig. 4. China installed capacity by raw water quality [9–12].

availability. In Fig. 4, the installed capacity by raw water quality is presented. The main water source for desalination in China is seawater, accounting for 53%. The brackish proportion in China is lower than the mean value worldwide (19% in 2009 [12]). Wastewater as feed water is used modestly but is expected to gradually grow in importance as it is a stable water source with significant amounts of water with low salinity and thus a lower operational cost than seawater desalination. Wastewater has generally higher concentrations of pollutants and may even contain toxic and hazardous substances. Thus, the health risk is a potential problem and constrain for wastewater desalination. Rivers and pure water have lower salinity and operational costs compared with other raw water types, but desalination of these waters is more expensive compared with regular water treatment processes. That is the reason why these two kinds of feed water are used less even if they are cheaper. Thus, the desalted water from rivers and pure water could be only used in some special industries, which require better water quality. Increasing the proportion of feed water with less salinity, through for instance mixing seawater with wastewater, is another way to decrease the operational cost of a desalination plant.

3.3. Investment, cost and price system

At present, the investment for desalination mainly comes from two sources: Corporate (desalinated water needed) self-financing or public investments. The former is still the main case. The investment ways are still impacted by habits and customs from the former planned economic system. There are exemptions such as a 100,000 m^3/day RO-project in Dagang district in Tianjin, where the BOO model is tested for the Chinese desalination market, yet this kind of investment model is still applied for few cases. The investment institution based on market-oriented operation has not been formed. Furthermore, the government only provides subsidies to the desalination plants owned by government. For the plants invested by company, no incentives or subsidies are granted from government. Because of the higher cost than regular water sources, the investors cannot get benefit from desalination, which decrease their investment interests. Larger desalination projects need substantial investments, which cannot be provided for by local government or small corporate. That is one important reason for the mostly small and middle capacity desalination projects that launched in China. There are still not enough investment funds for large-scale projects. At the same time, China has no lack of investment capital. Private and international funds can be used for investment in desalination. Thus, for long-term development of the desalination structure in China, it is necessary to establish a market-oriented operation institution and relevant policies, which can attract private capital and foreign investment under the premise that the plants are owned or controlled by government. The enterprises, which get the franchise authorized from government, raise funds for the investment of plant construction and collects charges as a return on investment to realize the rolling investment. The government should keep the responsibility for investments of the construction of facilities, such as public distribution networks, and provide subsidy or preferentials to the enterprises, such as price subsidy and preferential of electricity price, so that it has enough benefit to maintain normal operation.

On the other hand, only there is demand, there will be market. The price is the one of most important factors to stimulate the demands. Despite of investment institution based on market-oriented operation, a rational price system is another important way to promote desalination market. Due to multifactors impact, such as technology, device, scale and pollution in water source, the average Chinese seawater desalination cost, which is 5–7 Yuan RMB/m^3, is higher than the average in the world (0.5 US$/$m^3$) [21], [25]. Together with distribution fee, tax and benefit for enterprise, the price is higher than tap water for resident and industry in most regions. That is the main reason that most desalination capacity is used for islands with fresh water shortage and industry with limited water supplies and higher cost than desalination if tap water is used to make process water. Up to now, independent desalination supply for residents and supporting tap water supply through blending in desalinated water has only taken place in Tianjin and Qingdao. Despite the reason of water quality, price is another key factor for the situation. For example, Tianjin, as a coastal city with serious freshwater shortage, has mixed the desalinated water into municipal water supply pipelines in Hangu district. According to the news report by Xinjing Newspaper in 2011 [30], the price for residents is 4.6 Yuan RMB/m^3, as same as tap water before mixture. But the actual cost is about 7.5 Yuan RMB/m^3, and the price for the water supply company is 8.15 Yuan RMB/m^3, which means there is a 3.55 Yuan RMB deficit per cubic meter of water supplied from the company. For industry supply, the desalination price is decided by users and producer. In Tianjin, the tap water price for industry is 6.6 Yuan RMB/m^3, which is lower than the desalination cost. Thus, the producer always have deficit when they sell water. Who should

pay for the price difference? In Tianjin, the view is that the deficit should be covered through governmental funds, before the pricing system has evolved so far that the water prize covers the actual costs. Before this has been reached, the financial support from the government is important to allow for new investments in desalination. In the beginning of a development process, deficits should and can only be paid by government before a system for sustainable development has been established.

Under the background of market economy, benefit is the most important driving force for both investors and users. For investors, they want to reduce the cost, which is mostly depending on the technology innovation as mentioned previously. For users, under the premise of safe water quality and supply, the price is the most impact factor for selection in multi-water sources. To promote desalination and make it more accepted by users, desalination must have price superiority. However, due to the implementation of the planned economy in the past, the price of tap water was on the low side in long term with the average price is 1–1.5 Yuan RMB/m^3. The low price make users lack of awareness of water resources shortage and water saving. Furthermore, the low prize on tap water means that the users who use the desalinated water cannot get more benefit, which hinders the widespread use of desalination. After 2000, with the reform of water price and rise in water tariff, the situation is gradually improving. The reform also brings opportunity of the development for irregular water sources, such as desalination and wastewater reuse.

Different from cost, price system can be more controlled by policy. Thus, in the case that the desalination cost cannot greatly decrease in short time, the development of rational price system, which should play a regulation role between investors and users, is particular important to promote the market. At present, similar to investment institution, the rational price system still has not been established in most areas. For the development in long term, the followed price proposal can be tried.

From the perspective of integrated utilization of all water resources, including surface water, groundwater, remote water diversion, desalination and wastewater reuse, the management sectors should make integrated prices for different water sources. Desalinated water, as a kind of water resource, should be a part of the whole system, not be considered separately.

For the regulation of balance between supply and demand for different water sources, the price gradient should be formed with the comprehensive consideration of the scarcity of different types of water source, cost, demand, quality, acceptance by users, policy guidance and supports. At the premise of safe supply and water quality, the principle can be the higher consumption, the higher prices for different types of water sources. Scarce water resources, such as groundwater, could be priced higher.

Deepen the reform of tap water price and gradually improve the present situation when the water price is much lower than the supply cost, to make the price more close to value. The increase in tap water price is an inevitable trend. Since water is a necessity of life, the adjustment of water price will influence on the daily life. For municipal water supply, the government should increase the investment to pay for price difference between desalinated water and tap water and guarantee the residents' life quality not to be decreased due to use of desalinated water at higher price. For industries and special high water consumption industry, an increase in tap water price to allow for investments in desalination should have the priority. The profit from water source with higher price but lower cost, such as tap water for industry and special high water consumption industry and from industry with special requirements for water quality, can be subsidies to desalination. Here, pilot areas to test whether the water price system can be accepted by both users and supplier could be established.

Encourage the development of by-products' industries of desalination, such as salt production, or the direct use of seawater and use the profit to subsidize desalination.

Make overall planning for all types of water supply in individual regions to see whether desalination can replace some higher cost water supply ways, such as remote water diversion in some areas. And use the saving money to subsidize desalination.

Since the water resource situations in different regions are quite different, the price systems should also be diversification according to actual water, social and economic situation.

3.4. Management systems and policy

The management system includes soft parts, such as laws, guidelines, planning, regulation and management sectors, which execute the related provision. At present, except planning, there is almost blank in the other aspects of government management for desalination. In the "Special planning for seawater desalination" jointly issued by National Development and Reform Commission, the State Oceanic Administration and the Ministry of Finance in 2005, the programmatic objective during "11th Five-year" (2006–2010) was that the overall capacity should reach 800,000–1,000,000 m^3/day to 2010, which however was not reached. This is

unusual, since normally, and the objectives are always reached on schedule or even in advance in China [26]. The reason is mainly that there is no enough supporting policy and detailed implementing measures to achieve goals. The bottlenecks in the development, such as technology, device, investment and price, have not been fundamentally solved due to lack of supporting policy. Most desalination projects are individual schemes and the desalination industry has not formed the properly functioning system, since there are no laws or detailed executable guidelines to follow. And there are no clear provisions for which sectors should be responsible for desalination, which means that the projects invested by enterprise cannot get enough support from government, if any.

The lack of effective management system and policy fundamentally hinders the desalination development. For avoiding the "11th Five-year plan for desalination" same unsuccessful road, the development of relevant policy and forming management system are the most imperative. The proposals are as following:

One of the reasons for lack of management and policy is the lack of sufficient attention to the importance of desalination. The legal protection is the first and most important way to increase the attention in China. Desalination should be acknowledged as a safe water supply method in the national "Water Law", and further on laws to provide legal basis for management and policy should be developed.

Guidelines for safe water quality and supply must be established, since the qualified and safe water is the basis for social and economic growth. The water quality of desalinated water is rather good, but it does not mean there is no any problem for safe use. Especially for municipal water supply, although desalinated water is purer compared with tap water, it is not better for health due to lack of some substance necessary for human. And when the desalinated water is mixed into tap water and distributed in municipal mains, it may cause some problems, such as rust formation and bacteria growth if not the total water quality is taken care of properly. This may in worst-case lead to unsafe water quality and health risk of users. Thus, the guidelines not only include the requirements for water quality, but also for the pipelines and indicate the precautions on how to guarantee the safe supply and use of water. The guidelines should have details and executable, not only on the principal level.

Establish special management sectors for desalination in all levels of water management institution. This would address the responsibilities of various departments for safe implementation of desalination in the water supply sector. It is very important to pick out special departments that are responsible for co-operation and coordination between internal sectors as well as other departments related to desalination. And it is better to have a competent department to integrate the management of all the aspects related to desalination to avoid the contradictions and conflicts or blank and overlapping management in parallel sectors with different or no responsibility.

Based on national laws and policy, the local governments should develop their own management guidelines and detailed policies according to local conditions, which naturally vary a lot in different areas of China. And the management of desalination should be combined with other water sources or supply methods, not be separated from the whole-water management system. That requires a strong cooperation with other departments and overall coordination and optimized planning for different water sources to get the optimal programme for utilization and to avoid wasting of resources and funds.

Develop and improve the supporting policy as indicated above, such as investment institution, price system, subsidy and preferential policy and so on. The policy should take all stakeholders, such as investor, supplier, users and manager, into account. At the same time of enabling investors the right to get some profit from the work, it is also central to allow the users obtain to get benefits from desalination. This will be accomplished if there is a gradual change of the view on desalination from political will or government imperative to a method among others for unified planning and management of water supply, multiple financing channels used for investment and market-oriented operation at the premise of the plants owned by government should be utilized.

Based on relevant policies, publicity and communication both to investors and users must be intensified, to attract more capital investments and increase the acceptance of the users for desalination as a water supply technology. People always do not want to use or invest something new which they do not know well. As desalinated water is regarded as an unconventional water resource, administrate departments should intensify information and education for the public. Modern media and channels, such as internet and TV, should be used fully to popularize and promote desalination knowledge. And education centres can be established for introducing the details about desalination to the public.

Develop clear incentive regulations to guarantee that the guidelines or policies can be executed strictly and effectively. At the same time, strengthen supervision and inspection efforts to make the regulation not only on the paper. And it is better to select the third

party unrelated to the interests to supervise and inspect the sensitive parts, such as water quality and the use of the funds to make the management more fair, open and transparent. And it is also important to establish the platforms for public supervision.

At the same time of developing desalination, the government should pay attention to the impacts of desalination on marine environment and biological life. Lots of research shows that the concentrated water discharged directly to the ocean will change some characteristic of offshore, such as temperature, pH and salinity, and adversely impact on marine life [27–29]. At present, there are not much research about this topic in China, since desalination itself has not been attached enough importance to, and the research mainly focus on how to reduce cost and develop markets. Thus, when government develops the laws and regulations, guidelines and policy, environmental impact analysis should be considered to avoid marine pollution by desalination projects. There should be clear provisions for how to treat concentrated water and clear punitive regulations. The way of 'treatment after pollution', like other industry development process, should not be repeated for desalination development. The principles of clear production should be implemented at the beginning of development even if it may increase the cost sometimes, since we cannot afford the cost of the ocean contaminate. Several methods, such as salt making by concentrated water and dilution by reclaimed water, can be selected or combined used by producer, according to different local conditions.

4. Compare and integrated use of desalination and wastewater reuse in China

At the situation of scarcity of conventional water source, the unconventional water use should be developed a lot. Besides desalination, reclaimed water, which is widely used in water shortage countries, is another important unconventional water source. When facing many options, the critical point is how to optimal allocate and integrated use multiwater sources to make the maximum benefit both for society and environment.

From water quality perspective, desalinated water has much higher quality than reclaimed water. For reclaimed water, since the source is wastewater, which contains much pollution, the water quality, especially indicators of microorganism and toxic and hazardous substance, must be monitored to allow for safe use. The guidelines for use of reclaimed water for different application must be followed and preferably developed further, particularly on the aspects of microbial contamination. Compared with reclaimed water, the quality of desalinated water itself is not of a high risk. The problem happens when it is mixed into municipal pipelines as mentioned earlier above. Thus, for developing the guidelines for desalinated water, the focus should be on how to maintain the high safety and quality during distribution in the mains.

Different water quality can be used for different applications. In China, reclaimed water are mostly applied in fields with requirements for water qualities lower than tap water, such as agriculture, landscape water, industry and urban non-potable miscellaneous water. The indirect application, such as groundwater recharge, is very limited, since it requires higher water quality which means advanced technology and more cost. Desalinated water is mostly used for fresh water supply to islands or industry that needs water purer than tap water for special process requirements. If in an area, it is possible to use both desalination and wastewater reuse, stakeholders and the government should not only consider the cost but also efficient water supply by different water quality requirements and avoid waste caused by high-quality water used in low-requirement fields or unsafe due to use water unqualified.

Mainly because of different technologies, the cost and price of desalinated water is higher than for reclaimed water, which is one of the main reasons for why wastewater reuse is more widely applied in China. Even if using membrane technology, reclaimed water which has less salinity than seawater and lower requirement for water quality, have lower cost and price than seawater desalinated water. Thus, as mentioned previously, the profit from reclaimed water could be used to subsidised desalination projects. At the same time, reclaimed water can be used for dilution of retentate (brine) from desalination plants. For example, in Tianjin, the seawater of Bohai Bay has poor mobility, which means that the discharge of retentate directly into the sea will have a negative impact on sea ecology. Desalination is generally used in regions with freshwater shortage, where there is not enough freshwater for dilution. Using reclaimed water for dilution not only can solve the problem of brine discharge but may also save tap water and lower the cost. The only problem to be observed is the safe water quality of reclaimed water, to avoid bringing more chemical or microbial pollution to the sea. Thus, the requirements for dilution water should be set up.

From management and policy perspective, wastewater reuse has developed ahead of desalination in China. There have been management sectors, laws,

regulations, guidelines and policy on both national and local level for wastewater reuse, although they are far from complete have various flaws. The development for management system and policy of desalination can learn the experience from wastewater reuse, such as investment institution and water quality guidelines. At the same time, it should be possible to learn the lesson to avoid the same mistake. Furthermore, to develop the policy and detailed incentive regulations to encourage integrated use of desalination and reclaimed water to avoid fragmented work should be possible. And to establish unified management systems for better overall planning, such as quantity, quality and pipe network contribution.

From the public acceptance perspective, desalination is easier accepted for its higher quality, while reclaimed water is accepted by its lower cost. But the benefits of them need to be communicated clearly and pedagogically, since they are both unconventional water resources. The information can be done together and form fixed publicity system in multifaceted and long-term campaigns.

5. Summary

In China, there is feasibility and necessity to develop desalination, especially in the eastern coastal regions. Whether from water shortage status or the situation of different types of water resources perspective, desalination should be an important water supply method and have broader market and potential for development. At present, from the perspective of market demands and desalination capacity, China is still at the primary stage. Multifactors lead to the slower development of desalination market than it expected is. For long-term development, proposals are summarized as following:

- Take effective methods to reduce the cost, especially accelerate the development of key technology and equipment with independent intellectual property rights.
- Government should increase the attention and investment.
- Develop rational investment institution and price system to promote market-oriented operations. Broaden the investment channels and comprehensive consider the pricing of different water sources.
- Management systems such as laws and regulations, guidelines, regulations and management sectors should be established or improved, not only programmatic objectives without any detailed procedure and action.
- Relevant supporting policy should be developed, which can learn from the policy for wastewater reuse, and there should be regulations to guarantee the enforcement.
- According to local conditions, optimal allocation and rational overall planning of different water sources, both quantity and quality, to make benefit for both society and environment.
- Intensify the integrated use of desalinated water with other water sources, especially reclaimed water.
- Pay more attention to the impact of desalination projects on ecological environment and make clear regulations for minimize the impact.
- Use of various means of media to increase the publicity of unconventional water sources. Make the public know more about the knowledge, such as pros and cons, why and how to use it, which can make unconventional water sources more accepted by public.

From '12th Five-year plan for desalination', we can see the government attitude and opportunity for development of desalination. But if there is no actual action, the objective will miss again like the plan during 11th five-year. And the development should learn the experience and lesson from wastewater reuse to avoid detours.

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