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Cost Benefit Analysis of Centralized Wastewater Reuse Systems

Xiao Liang and Meine Pieter van Dijk

Abstract

The present paper carries out a cost benefit analysis of centralized wastewater reuse systems in Beijing. This study consists of two parts: financial analysis and economic analysis. The financial analysis is made from the point of view of plant manager, in which financial benefits and cost is calculated. The economic analysis is made from the point of view of society, in which the economic, environmental and social benefits and cost are determined. The results of financial analysis show that the financial benefits are larger than cost, which means the centralized wastewater reuse systems are financially feasible. It implies that the investment on centralized wastewater reuse systems is profitable. The results of economic analysis show that the ratio of benefit to cost is larger than 1, which means the centralized wastewater reuse systems are economically feasible. It implies that centralized wastewater reuse systems have positive effects on the society. From the point of view of plant manager, centralized wastewater reuse systems could operate in a long term, while from the point of view of government or society, the centralized wastewater reuse systems are worth to be promoted.

KEYWORDS: centralized, cost benefit analysis, economical analysis, financial analysis, wastewater reuse

1 Introduction

A rapidly growing urban population is one cause of the dramatic increase of water consumption in the world. Given limited water resources available, increasing water consumption increases demand in a way that has been called an urban water crisis. Meanwhile climate variability adds to the water crisis.

Wastewater reuse could effectively alleviate urban water scarcity. Wastewater reuse means reclaiming domestic wastewater and then reusing the reused water for industry, domestic use and agriculture. The use of reused water as an alternative water source can be a technical alternative for effective water management because fresh water is saved for other uses. The use of reused water may provide sufficient flexibility to allow a water agency to respond to short-term needs as well as to increase long-term water supply reliability in urban areas (Asano, 2001).

A centralized wastewater reuse system is used to describe a system which collects wastewater from households, small enterprises, industrial plants and institutions, and transports this ever-changing mixture to a wastewater treatment plant, and then distributes reused water from the wastewater treatment plant to all types of institutions. Centralized wastewater reuse system is relatively new in China. For example, the first centralized wastewater reuse system in Beijing called the Gaobeidian plant was completed in 2000.

Mostly, centralized wastewater reuse system research focuses on technological improvement (Wilderer and Schreff, 2000; Chu *et al.*, 2004; Asano, 2005) and cost calculations (Asano *et al.*, 1996; Jia *et al.*, 2005). It is rare that there is an extensive financial and economic analyses of centralized wastewater reuse systems. To reach a sustainable operation, a new system has to achieve both technological and economic feasibility (Braden and Van Ierland, 1999). Thus, it is important to carry out economic evaluation on a centralized wastewater reuse system. Through an economic evaluation, decision makers could make choices that are consistent with the long-term wellbeing of the community.

This study will carry out economic and financial analyses of centralized wastewater reuse systems through the method of benefit-cost analysis (BCA). BCA is a largely accepted economic method in water management research. The BCA method uses the principal of potential compensation by measuring the benefits and cost generated by a plant and calculating the difference between benefits and cost. The effects on the gainer are regarded as the benefits and the effects on the loser are regarded as the cost. According to modern welfare economic theory, if the benefits caused by a plant exceed the cost, the plant is regarded to lead to improved social welfare. This provides a benchmark for measuring the effects and performance of a plant (Mishan, 1988).

Research takes into account the fact that different decision makers with different points of view may have different judgments on the same event. One effect is regarded as beneficial by one decision maker, but it can imply higher costs to another. For example, taxes are treated as cost from a private perspective whereas from a public perspective they are not treated as cost. In this study, plant managers and the government, the two important stakeholders in water management, represent the private sector and public sector separately. The plant manager and the government should have different viewpoints on water management. It is necessary to encompass the full range of private and public sector concerns so as to make a valuable contribution to decision making (Campbell and Brown, 2005).

In this study, financial and economic analyses are carried out separately from private and public perspectives. The financial analysis takes the point of view of individual participants, in particular the plant manager, whereas the economic analysis takes the point of view of society, both of which are complementary in the study. The economic analysis determines the contribution of a proposed plant to the development of the total economy, whereas the financial analysis determines how much the individual participant could live with the plant (Gittinger, 1982). The framework for financial and economic analyses is presented in Section 2.

This paper studies the centralized wastewater reuse systems of Beijing, China. Beijing is a typical case of urban water scarcity, thus wastewater reuse is largely promoted by the Beijing government. Section 3 introduces the centralized wastewater reuse plants in Beijing. Section 4 explains how to implement the financial and economic analyses of centralized wastewater reuse systems. The results are shown in Section 5 and conclusions are drawn in Section 6.

2 Evaluation framework

The evaluation framework shown in Figure 1 is similar to the one used in Liang and van Dijk (2010). The research of Liang and van Dijk (2010) focuses on the decentralized wastewater reuse systems, whereas this paper studies the centralized wastewater reuse systems.

In the financial analysis, the financial cost and financial benefits are evaluated. From a private perspective, the net profit from an investment is important. Whether the plant makes money or not determines the incentive for a plant manager to operate the plant. Market values are used directly for the determination of the financial cost and financial benefits. The criterion in financial analysis is whether the plant is financially efficient or not, which could be determined by the difference between financial benefits and financial cost.

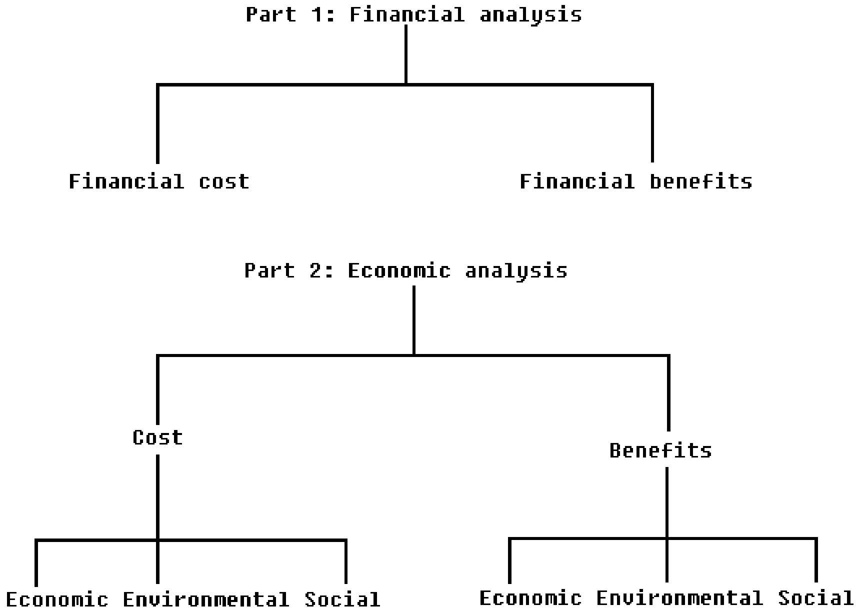

Figure 1 Financial analysis and economic analysis

In the economic analysis (shown in Figure 1), major economic, environmental and social effects are all identified and quantified. The traditional economic method of managing water resources ignores the environmental and social impact and only emphasizes minimizing prices and maintaining system reliability (Baumann *et al.*, 1998). Water plants can have an influence on the environment and society because they change the allocation of resources. Hence, it is important to take the environmental and social effects into consideration. All effects in the economic analysis are identified from a public perspective. The monetary values of cost and benefits of economic, environmental and social effects are required in the assessment and could be obtained through indirect valuation methods. Transfer payments such as subsidies are not considered in the economic analysis because they do not consume or create any new value for society (Dahmen, 2000). The criterion in economic analysis is that whether the plant is economically feasible or not, which is determined by the ratio of benefits to cost.

This evaluation framework provides a systematic and complete assessment on the centralized wastewater reuse systems, helping to effectively facilitate decision making. Different viewpoints on the wastewater reuse system are all taken into consideration. Additionally, environmental and social effects caused by a plant are identified and evaluated quantitatively.

3 The centralized wastewater reuse plants in Beijing

Currently, there are five centralized wastewater reuse plants in operation or still in construction in Beijing: the Gaobeidian wastewater reuse plant, the Jiuxianqiao wastewater reuse plant, the Fangzhuang plant, the Wujiacun plant and the Qinghe plant, of which the location is shown in Figure 2. Because only the Gaobeidian plant and the Jiuxianqiao plant have operated for several years, they are chosen for economic and financial analyses in this study.

Figure 2 Location of Beijing centralized wastewater reuse plants

3.1 The Gaobeidian plant

The Gaobeidian (Gao) plant is the largest wastewater reuse plant and the first centralized plant in Beijing, operating since 2000. The design capacity of the Gao plant is 470,000 m^3/day, but at present the amount of reused water of the Gao plant is only 300,000 m^3/day. The length of the pipes for water distribution in the Gao plant is around 24 km (BWA, 2004). The Beijing drainage group are in charge of operating the Gao plant.

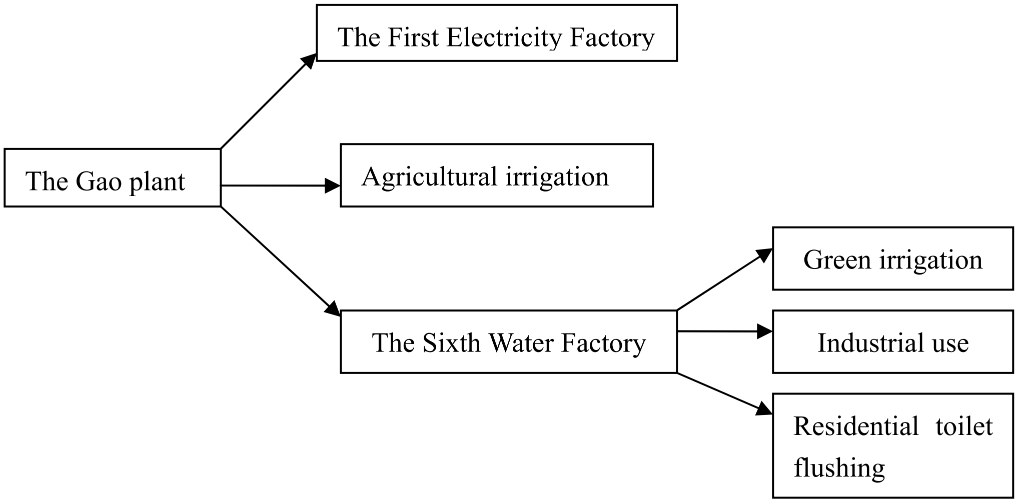

Figure 3 The distribution of the reused water of the Gao plant

Table 3 Use and level of treatment of water of the Gao plant

Use	Quantity (m^3/day)	Treatment degree
Cooling water for electricity factory	200,000	Advanced
Residential toilet flushing	20,000	Advanced
Green irrigation	30,000	Advanced
Industrial use	20,000	Advanced
Agricultural irrigation	30,000	Secondary
Total	300,000	

The reused water of the Gao project is used for industrial cooling water, agricultural irrigation, green lands irrigation and residential toilet flushing (shown in Figure 3). Table 3 presents the quantity distributed by the Gao plant. Firstly, the Gao plant implements the secondary degree of wastewater treatment. Around 200,000 m^3 effluent water is processed further and transferred to the first electricity factory to be used as cooling water; approximately 70,000 m^3 effluent water is delivered to the sixth water factory to be processed again for water quality improvement and then the water goes from the sixth water factory to residential green irrigation, industrial use and toilet flushing and approximately 30,000 m^3 of effluent water goes to a river to be treated further through a natural approach and then water is collected downstream for agricultural irrigation.

The level of treatment for different uses is also shown in Table 3 with the indicators based on ‘the quality requirement of reused water’, a bulletin issued by the Chinese Ministry of Construction. According to interviews with plant managers, reused water of the Gao plant satisfies these water quality requirements.

Because of the systematic promotion of wastewater reuse in Beijing, many hotels, factories, schools and residential buildings have been equipped with the dual pipes for water distribution: one pipe is connected to municipal water and the other is connected to reused water. According to interviews with the property company, pipe construction costs in 2002 in Beijing was around 25 Yuan/m^2 (1 Yuan = 0.16 USD$ = 0.12 euro).

The treatment units of the Gao project are shown in Figure 4. There are (1) and (2) directions connected to the chlorination contact tank. The (1) direction means that water is processed to be cooling water for the first electricity factory, and the (2) direction indicates water going to the sixth water factory. The reused water quality for the cooling water of the first electricity factory and the water quality of the effluent from the sixth water factory are presented in Table 4. As mentioned, the effluent from the sixth water factory is transferred to green land, industry and residential area. With regard to the reused water quality for agricultural irrigation of the Gao project, it satisfies 'the requirement of reused water quality for agricultural irrigation', which is issued by the State Environmental Protection Agency (Table 5).

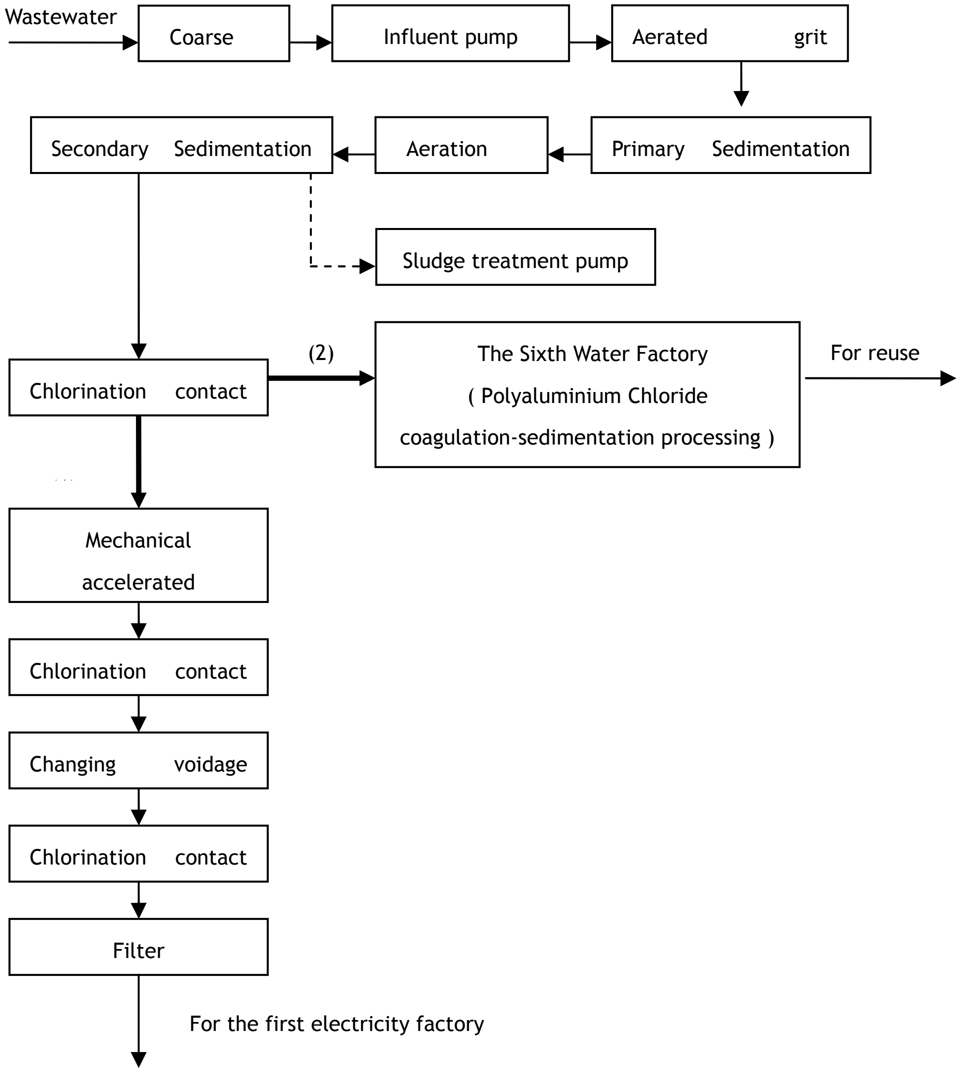

Figure 4 The treatment units of the Gao plant

Table 4 Reused water quality of the Gao plant

Parameter	For first electricity factory	Effluent from the sixth water factory
pH	6.88	7
SS (mg/l)	<2	<2
COD (mg/l)	19.78	24.12
BOD_5 (mg/l)	1.91	*N**
TP (mg/l)	*N**	0.48
NH_4-N (mg/l)	*N**	4
Turbidity (NTU)	0.18	2.32
Ammonia (mg/l)	0.52	*N**

*N** means data are not available (Source form BWA, 2004)

Table 5 The requirement of reused water quality for agricultural irrigation

Parameter	Values
pH	5.5–8.5
SS (mg/l)	100–200
COD (mg/l)	150–300
BOD_5 (mg/l)	80–150
TP (mg/l)	5–10

(Source form BWA, 2004)

3.2 The Jiuxianqiao (Jiu) plant

The Jiuxianqiao (Jiu) plant was completed in 2004. The amount of reused water of the Jiu plant is 60,000 m^3/day. The length of the pipes for water distribution in the Jiu plant is approximately 17 km (BWA, 2004). Similar to the Gao plant, the Jiu plant is also owned by the Beijing drainage group.

It is shown in Table 6 that 19,200 m^3 of reused water is for residential use and 30,000 m^3 of water is for lake or river water supplementation, 7,800 m^3 is for green irrigation and the remaining 3,000 is for agricultural irrigation. This illustrates that reused water of the Jiu plant is mostly used for residences and water supplementation. Compared with other uses, the amount of reused water for agricultural irrigation is much smaller. Meanwhile, the requirements to treatment degree for reused water uses are shown in Table 6. Similar to the Gao plant, reused water of the Jiu plant satisfies the water quality standards. Figure 5 shows the treatment units of the Jiu plant. The effluent of reused water quality is presented in Table 7.

Table 6 Use and level of treatment of water of the Jiu plant

Use	Quantity (m^3/day)	Treatment degree
Residential use	19,200	Advanced
Lake or river water supplementation	30,000	Advanced
Green irrigation	7,800	Advanced
Agricultural irrigation	3,000	Secondary
Total	60,000	

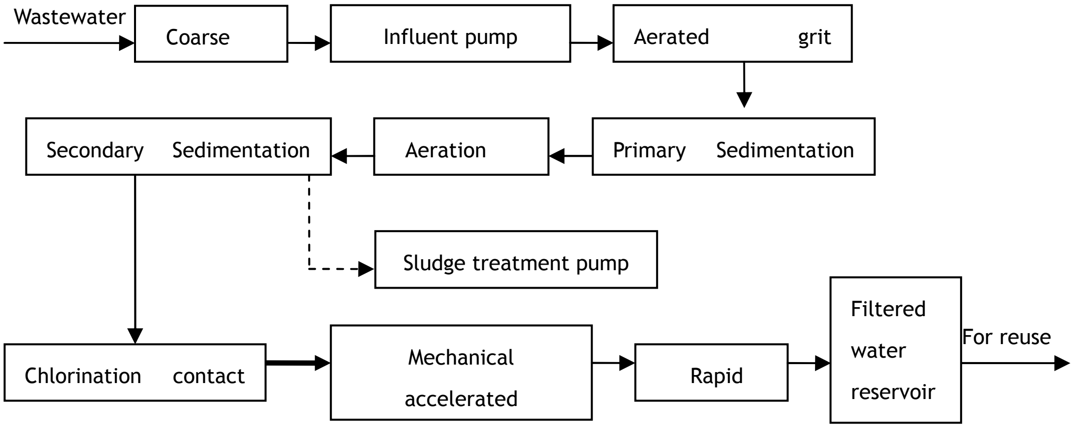

Figure 5 The treatment units of the Jiu plant

Table 7 Reused water quality of the Jiu project

Parameter	Values
SS (mg/l)	<5
COD (mg/l)	5–15
TP (mg/l)	<1
TN (mg/l)	<10
NH_4-N (mg/l)	2
Turbidity (NTU)	<5

(Source from Zhang *et al.*, 2007)

4 Financial and economic analysis of centralized wastewater reuse systems

4.1 Financial analysis

The financial analysis concerns the evaluation of the financial cost and benefits. The financial cost includes initial investment (defined as U_I), operation and maintenance (O&M) cost (defined as $U_{O\&M}$). All components contributing U_I and $U_{O\&M}$ are shown in Eqs. (1) and (2), respectively:

$$U_I = U_C + U_D + U_P + U_R + U_O \quad (1),$$

$$U_{O\&M} = \sum_{t=1}^{n} \frac{U_t}{(1+r)^t} \quad (2)$$

where U_C, U_D, U_P, U_R, and U_O are the initial costs of construction, demolition and relocation, preparation, interest and others, respectively. U_t is the O&M cost occurring in year t; r is the discounting rate; n is the evaluation period (number of years).

According to the publication “Chinese Economic Evaluation Parameters on Construction” (National Development Reform and Commission, 2006), the nominal discount rate (r) used for benefit cost studies in China is 8% which is determined by the social economic growth, the expected inflation rate and opportunity cost of capital. Inflation rates in China for the years 2007 and 2008 were 4.8% and 5.9% (China Statistical Yearbook, 2007, 2008). The evaluation period (n) is assumed to be 20 years. To avoid making risky estimates of future inflation rate and to simplify the analytical procedures, we use constant values rather than current values on cost and benefits, and assume that inflation will affect the values of all cost and benefits equally (Gittinger, 1982).

The financial benefits of a plant are represented by the income from the plant, including revenue from reused water charges and subsidies. In terms of its usage, the reused water is charged at different rates. Table 8 shows the latest reused water rates in Beijing, which is set by the government. According to the interviews with the officials of the Beijing Water Authority, the rate is determined in terms of the average wastewater reuse cost and municipal water rate. They hope that the rate for reused water should be higher than the unit cost of wastewater reuse so that the revenue can cover the cost. Meanwhile, the rate of reused water should be lower than the rate of municipal water so that reused water is an attractive option to users.

Based on the data of Tables 3, 6, and 8, the revenue of the Gao plant and the Jiu plant can be calculated. Subsidies are an important source of income for wastewater reuse plants. In this study, only the Gao plant obtained subsidies on the initial investments from the Beijing municipal government.

Table 8 The charge rates of reused water (Yuan/m^3)

Usage	Domestic	Landscape	Industrial	Power generating plant
Charge rates	1.2	0.8	1.5	0.9

The ratio of financial benefits to financial cost is the criterion to determine the financial feasibility of the plant. If the ratio is larger than 1, it means that the plant is financially feasible. Otherwise, the plant is not financially feasible. The financial cost, financial benefits and ratio are calculated by Eqs. (3) to (5), respectively:

$$fc_{pv} = U_I + U_{O\&M} \quad (3),$$

$$fb_{pv} = \sum_{t=1}^{n} \frac{fb_{r(t)}}{(1+r)^t} + fb_s \quad (4)$$

and

$$r_{fb/fc} = \frac{fb_{pv}}{fc_{pv}} \quad (5)$$

Where fc_{pv} is the present value of financial cost; fb_{pv} is the present value of financial benefits; $fb_{r(t)}$ is the revenue occurring in year t; fb_s is the subsidies for initial investment, $r_{fb/fc}$ is the ratio of financial benefits to financial cost.

4.2 Economic analysis

Table 9

Economic, social and environmental effects of centralized wastewater reuse

Items	All possible effects	Whether it is considered in the paper
Economic cost	Initial investment	Yes
	Operation and maintenance cost	Yes
Environmental cost	Carbon dioxide emission	Yes
	Noise pollution	No
	Air pollution	No
Social cost	Health risk	Yes
	Residential resettlement	Yes
Economic benefits	Cost saving on fertilizers	Yes
	Reuse of pollutants	No
	Reuse of methane gas	No
Environmental benefits	Increase of water availability	Yes
	Increase the water level of the rivers	No
	Avoidance of overexploitation of water-bearing resource	No
Social benefits	Raising social awareness	No
	Increase of jobs	Yes

As shown in the evaluation framework (Figure 1), economic, environmental and social effects are all taken into consideration in the economic analysis. In terms of the literature and interviews with the officials of the Beijing Water Authority, economic, social and environmental effects caused by centralized wastewater reuse systems are listed in Table 9 (BWA, 2002a; BWA, 2002b; Asano, 2005; Hernandez *et al.*, 2006). It is worth noting that not all the effects listed in Table 9 will be included in the economic analysis. Only the major economic, environmental and social effects are selected and quantified using monetary values. The reasons for selecting certain effects and how to determine their monetary values are explained below.

First of all, from a point of view of society, construction, operation and maintenance are seen as consumption of scarce resources, thus initial investment and O&M cost are included in the economic cost evaluation, which are the same components contributing to the financial cost.

Generally, we take the economic value of each category. However, as there are not many traded items in the initial investment and the operation and maintenance cost for urban wastewater reuse and there are not large distortions in market prices of wastewater treatment construction in Beijing, market prices could be used directly for the calculation of economic cost in the study. The economic cost (defined as c_f) can be obtained by adding the present values of initial investment (u_I) and O&M cost ($u_{O\&M}$), shown in Eq. (6).

$$c_f = u_I + u_{O\&M} \quad (6)$$

Second, large energy consumption of a centralized wastewater reuse plant could result in negative environmental influences. As centralized wastewater reuse systems generally have a large scale of wastewater treatment, the energy consumption for wastewater reuse is vast. There is a high carbon dioxide emission during the process of energy generation, and carbon dioxide emission becoming a greenhouse gas leads to a negative environmental impact. Moreover, it is listed in Table 9 that the environmental cost includes noise and air pollution. However, in this study, the noise and the stench generated by wastewater reuse cannot cause significant effects because centralized wastewater reuse plants are generally constructed in the suburban areas where there are few people living. The effects of noise and bad smell are hence not considered in the study. Therefore, only the environmental cost of carbon dioxide emission is considered in the analysis of environmental cost.

Although there are other emissions during the process of energy generation such as sulfur dioxide and nitrogen oxides, the amount of carbon dioxide emission accounts for around 60% of total emission from energy generation (Skeer and Wang, 2005). To simplify the study, only the effect of carbon dioxide is taken into consideration. The energy generation could be coal power, petroleum power, gas power and wind power. In China, 70% of energy consumption is from coal power and the majority of carbon dioxide emissions result from coal combustion (Dahowski *et al.*, 2009). Thus, we assume that 70% of the energy for wastewater reuse in centralized wastewater reuse systems in Beijing is from coal power. Owing to the small quantity, the effects caused by the remaining 30% of energy generation is neglected. Hence, only the carbon dioxide from coal power is calculated for environmental cost.

The primary environmental effect caused by carbon dioxide emission is climate change which is an issue at present. But the social impact of climate change is complex and difficult to evaluate because of the uncertainty of climate change. In the literature, indicators considered in various studies are different and even the values for the same parameters such as the discounting rate used for discounting the existence of carbon dioxide are very different (Skeer and Wang, 2005; Tol, 2005, 2008). The social impact of climate change could be regarded as the 'damage cost' of carbon dioxide. Tol (2005) found that the estimated results of the 'damage cost' of carbon dioxide in the existing studies ranged from $5/ton to $400/ton carbon dioxide. Tol calculated the mean value of marginal 'damage cost' in the peer-reviewed literature as $50/ton carbon dioxide (Tol, 2005). Thus, we take the mean value of marginal 'damage cost' $50/ton (350 Yuan/ton) carbon dioxide as unit environmental cost of carbon dioxide (defined as u_d) in this study. According to the literature, the unit carbon dioxide emission (defined as d) in a coal power plant is approximately 800 g/kWh (Skeer and Wang, 2005). Thus, the total amount of carbon dioxide emission due to energy consumption in centralized wastewater reuse systems could be obtained through multiplying 70% of the energy consumption (defined as g) and carbon dioxide emission (d). Hence, environmental cost (defined as c_e) can be obtained by multiplying the unit environmental cost per carbon dioxide emission (u_d) and the amount of carbon dioxide emission, and is mathematically expressed as:

$$c_e = u_d \times g \times d \quad (7)$$

Third, reused water may contain a certain quantity of pathogens. When water is used for green and agricultural irrigation, the pathogens in reused water can cause a negative effect on human health, directly or indirectly (Christova-Boal *et al.*, 1996; Ottoson and Stenström, 2003). Thus, wastewater reuse systems can lead to social cost of health risks.

Economists use different methods to value health effects, such as contingent valuation methodology and adjusted human capital methodology. Because of inherent limitations, these economic methods have to be applied to big samples with a large amount of data. We use an indirect valuation method to assess the health effects of wastewater reuse. The Disability Adjusted Life Year (DALY) index is taken as a measurement unit for the effect on human health. DALY is an index of health risk, developed by the World Health Organization (WHO) and World Bank. One DALY corresponds to one lost year of healthy life and the burden of diseases to the gap between current health status and an ideal situation where everyone lives with no diseases and disabilities (WHO, 2007). DALY is used in many studies for measuring health effects. For example, Aramaki *et al.* (2006) found that after building wastewater treatment units, the disease burden of a community changed from 60 DALYs per year to 5.7 DALYs per year (Aramaki *et al.*, 2006). In our study, DALY is a bridge to convert the monetary value of health effects from the national level to the scope of a small project. Moreover, diarrhea is assumed to be a negative health effect caused by wastewater reuse in this study. Diarrhea is the largest contributor to the burden of water-related illnesses (OECD, 2007).

The social cost of health risk (defined as c_{s1}) can be calculated by Eq. (8). The origin of such a calculation method for social cost is explained as follows. Through the contingent valuation methodology, the World Bank values the total health cost (defined as C_M) caused by water pollution in China, which is approximately 14.22 billion Yuan each year (World Bank, 2007). In terms of the figure of the WHO report (2004), the total estimated DALYs (defined as M) caused by diarrhea is 5,055,000 DALYs each year. The DALY cost rate (C_M/M) is calculated to be 2813 Yuan per DALY per year. The product of DALYs rate (defined as R) and population number (defined as K) gives the total DALYs of Beijing. As a result of missing data, the DALYs rate of Beijing (R) is determined by the DALYs rate of China, which is 389×10^{-5} DALYs per person (WHO, 2004). The registered permanent population living in Beijing central district is 2.25 million. It is supposed that the DALYs of Beijing resulting in diarrhea is caused by total reused wastewater. As mentioned, using reused water for green land irrigation and for agricultural irrigation may cause a health risk. Accordingly, the probability of DALYs due to the wastewater reuse plant (P) could be represented by the ratio of the reused water amount for green and agricultural irrigation to the total amount of reused water in Beijing.

$$c_{s1} = C_M/M \times R \times K \times P \quad (8)$$

Pipe construction is an important and difficult part of the construction of a centralized wastewater reuse plant. In addition to a high expenditure on pipe construction, there are serious social influences caused by pipe construction. According to interviews with the officials of the Beijing Water Authority, 60% of the distribution pipes of centralized wastewater reuse systems are constructed through demolition and relocation and 40% of pipes are constructed following rivers. There are severe effects on society when pipes are constructed through demolition and relocation, whereas the effects are limited when pipes are constructed following rivers. Thus, centralized wastewater reuse plants cause negative social effects of demolition and relocation.

Demolition and relocation can lead to changes in the road net, the destruction of existing city buildings and residential resettlement (Camagni *et al.*, 2002). Because of the extreme difficulty of quantifying social cost, it is rare in the literature that the total social costs caused by demolition and relocation in pipe construction are evaluated. Most research focuses on financial costs such as the compensation to people resettled in other living places (Mao, 1966; Malpezzi, 1999; Osman *et al.*, 2008). It is worth noting that this study only evaluates the main social costs resulting from the major effects. This could help to simplify the economic determination of social cost of demolition and relocation due to pipe construction.

Among the effects caused by demolition and relocation, the effect on residential resettlement is the most important one, because residential resettlement can lead to people becoming unemployed or increased cost in education, healthcare and transportation (Luo, 2007). The effect of residential resettlement is the most important effect considered in this study. Residential resettlement means residents living along the line of pipe construction must move to accommodate construction. As mentioned previously, residential resettlement can result in various negative influences on people's life, such as unemployment and increasing living costs. It seems to be very difficult to evaluate all the negative influences from residential resettlement. In the literature, the increased transportation cost due to residential resettlement is an essential and real effect on people's lives (Camagni *et al.*, 2002; Luo, 2007). Thus, only increased cost of transportation due to residential resettlement is regarded as a social cost of demolition and relocation, and determined in this study.

Eq. (9) shows how the increased cost of transportation due to residential resettlement, namely the social cost of demolition and relocation (defined as c_{s2}), is determined. The origin of such a calculation is as follows. The increased cost of transportation can be calculated by multiplying the average increased public transport cost for one person (defined as μ) and the affected number of people. As public transportation is the main travel method for Beijing residents, after moving to a new place, it is assumed that all affected residents will make one additional transfer each day via public transportation. The transportation fees due to travel transfer could be regarded as an increased transport cost. The average public transportation (including metro and bus) cost in Beijing is around 4 Yuan per person for a round trip. We can regard 4 Yuan per person as the value of the average increased public transport cost for one person (μ). The population density (defined as p) and the size of area determine the population affected by the resettlement. The area can be obtained by multiplying the length of pipe construction (defined as l) and the width, which is supposed to be 1 meter. Hence, the product of the population density (defined as α) and the length of pipe construction (defined as l) can be regarded as the number of people affected by resettlement. In the Beijing Statistic Yearbook (2009), the population density of urban areas of Beijing is 20,000 persons per square meter.

$$c_{s2} = \mu \times \alpha \times l \quad (9)$$

Therefore, the total social cost (defined as c_s) is the sum of the social cost of health risk (c_{s1}) and the cost of demolition and relocation (c_{s2}).

$$c_s = c_{s1} + c_{s2} \qquad (10)$$

Fourth, part of the reused water produced by centralized wastewater reuse systems is reused for agricultural irrigation. The reused water contains nitrogen and phosphorus which are important fertilizers for agricultural production (Wang, 2007). Taking reused water for agricultural irrigation limits the use of fertilizers in agricultural production. The cost-saving on fertilizers could be regarded as the economic benefits of centralized wastewater reuse. Moreover, normally methane gas of anaerobic digestion and pollutants of wastewater reuse systems in Beijing are not reused, the benefits of reuse of methane gas and pollutants are not considered in the study. The economic benefit of cost-saving on fertilizers (defined as b_f) could be determined through multiplying the unit cost of saving on fertilizers (defined as u_f) and the amount of reused water for agricultural irrigation (defined as f), shown in Eq. (11). As mentioned, reused water of the Gao and Jiu plants has reached the standard of reused water quality for agricultural irrigation (shown in Table 5). Thus, the value of the unit cost-saving on fertilizers is determined based on the standard quality of reused water. The Beijing Water Authority has calculated the unit cost-saving on fertilizers as a result of using reused water through dividing the increase of agricultural production by the quantity of reused water for irrigation, and they found the value (u_f) to be approximately 0.0225 Yuan/m^3 (BWA, 2002b).

$$b_f = u_f \times f \quad (11)$$

Fifth, it is listed in Table 9 that the environmental benefits include the increase of water availability, the increase in the water level of rivers and the avoidance of overexploitation of water-bearing resources. As large quantities of "new water" is created by reclaiming wastewater and is reused, "increase of water availability" is an important environmental benefit. However, there are no significant effects of "increase the water level of the rivers" and "avoidance of overexploitation of water-bearing resources" caused by centralized wastewater reuse systems. Although approximately half of the reused water produced by the Jiu plant is used to supplement lakes or rivers, the quantity is too small to take into consideration. Therefore, only "increase of water availability" makes major contributions to environmental benefits. The environmental benefit of "increase of water availability" is calculated by Eq. (12).

$$b_e = u_e \times e \quad (12)$$

where b_e is the environmental benefit, u_e is the monetary value of water, e is the amount of reused water. The monetary value of water resources (u_e) is estimated to be approximately 3 Yuan/m^3 in Beijing by Liu and Chen (2003). Liu and Chen (2003) combine the input-output analysis method with the linear programming model to evaluate the shadow price of water resource. Many studies use a small range of data for the estimation of water shadow price in China, leading to a nonrigorous value (Wang *et al.*, 1999; Yuan *et al.*, 2002). However, Liu and Chen (2003) did take extensive data for their estimation, including data from the nine major Chinese river basins and data from agriculture, industry, commerce and service. Thus, the estimated water shadow price of 3 Yuan/m^3 by Liu and Chen (2003) is taken into the calculation.

Finally, raising social awareness is not considered in the determination of social benefits in this study. Using reused water could help to improve public awareness concerning the importance of water saving. However, in centralized systems, it is not immediately clear to the user whether the water is tap water or reused water. Reused water could be obtained easily through direct distribution, which is similar to the way of accessing tap water. Hence, people may not realize that they are using reused water and public awareness about the benefits of using reused water is not influenced.

Turning to social benefits, the operation of a centralized wastewater reuse system generally requires many workers so that many new jobs are created, improving employment of the region. It is not easy to estimate the monetary value of improved employment. Hence, an indirect valuation method is employed. The employment elasticity (β), being the ratio of employment growth to economic growth, is used to determine the benefit of created employment. If the employment elasticity is 0.1, that means an economic growth of 1% increases employment by 0.1% (Rawski, 1979; Li, 2003). Given the data, we assume that the amount of 1% of economic growth is the social benefit value due to 0.1% of employment growth. In terms of the literature, the employment elasticity of China is estimated to be 0.3 (Li, 2003). Because of data limitation, we assume that the employment elasticity of China also applies for Beijing. Given that we know β to be 0.3, Eq. (13) allows us to calculate the monetary value (b_s) of creating new jobs through the wastewater reuse plants. In Eq. (13), w is the number of increasing jobs in the plant, W is the total employment of Beijing and Y is the Beijing's GDP (Gross Domestic Product).

$$b_s = \frac{\frac{w}{W}}{\beta} \times Y \qquad (13)$$

The ratio of benefits to cost (defined as $r_{b/c}$) is used as the criterion for economic feasibility. If $r_{b/c} > 1$, it means that the plant is economically feasible. If $r_{b/c} < 1$, it means the plant is not economically feasible. The present values of the cost (c_{pv}) and benefits (b_{pv}) and the ratio of benefits to cost ($r_{b/c}$) are calculated by Eqs. (14), (15) and (16), respectively.

$$c_{pv} = c_f + \sum_{t=1}^{n} \frac{c_e}{(1+r)^t} + \sum_{t=1}^{n} \frac{c_s}{(1+r)^t} \qquad (14),$$

$$b_{pv} = \sum_{t=1}^{n} \frac{b_f}{(1+r)^t} + \sum_{t=1}^{n} \frac{b_e}{(1+r)^t} + b_s \qquad (15),$$

and

$$r_{b/c} = \frac{b_{pv}}{c_{pv}} \quad (16).$$

Table 10 Summary of the parameters on determination of cost and benefits

	Definition	Values (Gao/Jiu)	Reference/source
u_I	Initial investment (million Yuan)	324/77	BWA, 2002b
$u_{O\&M}$	Operation and maintenance cost (Yuan)	102/36	BWA, 2002b
c_f	Economic cost (Yuan)		
u_d	Unit environmental cost of carbon dioxide emission (Yuan/ton)	350	Tol, 2005
d	Unit carbon dioxide emission of energy consumption (g/kWh)	800	Skeer and Wang, 2005
g	Energy consumption (million kWh/year)	7/1.4	BWA, 2002a
c_e	Environmental cost (Yuan/year)		
C_M	Total health cost (billion Yuan/year)	14.22	World Bank, 2007
M	Total DALYs caused by water (million DALYs/year)	5.055	WHO, 2004
R	DALYs rate (DALYs per person per year)	389×10^5	WHO, 2004
K	Population of Beijing (million persons)	2.25	China Statistical Yearbook, 2010
P	Probability of DALYs due to the wastewater reuse plant (%)	0.03/0.006	Interview, Calculate
c_{s1}	Social cost of health risk (Yuan/year)		
u	Average increased public transport cost (Yuan/person year)	1460	Interview, Calculate
a	Population density (persons/km^2)	20,000	China Statistical Yearbook, 2010
l	Length of pipe construction (km)	25/17	BWA, 2002a
c_{s2}	Social cost of residential resettlement (Yuan/year)		
c_s	Social cost (Yuan/year)		
u_f	Unit cost saving on fertilizers (Yuan/m^3)	0.0225	BWA, 2002b
f	Amount of reused water for agricultural irrigation (m^3/year)	30,000/3000	BWA, 2002a
b_f	Economic benefit (Yuan/year)		
u_e	The monetary value of water (Yuan/m^3)	3	Liu and Chen, 2003
e	Amount of reused water (million m^3/year)	109.5/21.9	BWA, 2002a
b_e	Environmental benefit (Yuan/year)		
w	Number of workers of the plant (persons)	30/20	Interview
W	Total employment number of the region (million persons)	6.29/8.78	China Statistical Yearbook, 2010
Y	GDP of the region (billion Yuan)	371/689	China Statistical Yearbook, 2010
β	Employment elasticity	0.3	Li, 2003
b_s	Social benefit (Yuan)		

All the parameters used to determine the monetary value of economic, environmental and social effects are summarized in Table 10. As mentioned previously, subsidies are not considered in the economic analysis. The values and reference sources of the parameters are also listed in Table 10. Because the values of the Gao plant and the Jiu plant are different, certain parameters in Table 10 have two values.

5 Results

5.1 Results of financial and economic analysis

Table 11 presents the results of the financial analysis of the Gao and the Jiu centralized wastewater reuse plants. It is shown in Table 11 that the initial investment of the Gao plant was 323.52 million Yuan and that of the Jiu plant was 76.96 million Yuan. As mentioned, the treatment capacity of the Gao plant is 300,000 m^3/day and the capacity of the Jiu plant is 60,000 m^3/day. This means that the scale of the Gao plant is five times the scale of the Jiu plant. Accordingly, the initial investment of the Gao plant is four times the investment of the Jiu plant.

It is shown in Table 11 that the construction cost and the demolition and relocation cost separately accounts for around 50% and 35% of total initial investments. The cost of construction and demolition and relocation are the main part of the initial investment of a centralized wastewater reuse system. Because a substantial investment is required for the construction of a centralized wastewater reuse system, part of the finance may need to be borrowed so that there is an additional cost of paying interest. In this case, the Gao plant needs to pay interest of 11.7 million Yuan (Table 11) because it has a bank loan of 200 million Yuan (BWA, 2002a; BWA, 2002b).

Among the O&M cost, energy cost is the highest cost, accounting for approximately 40% (shown in Table 11). As centralized wastewater reuse systems require vast energy, the price of electricity in China will have a significant influence on the O&M cost. In addition to energy cost, maintenance cost is a large part of the O&M cost. For instance, the maintenance cost of the Gao plant is 3.48 million Yuan which is 35% of the O&M cost (shown in Table 11).

Table 11 Financial analysis of centralized wastewater reuse systems

	Gao plant	Jiu plant
Financial cost		
Initial investment (million Yuan)		
Construction cost	166.31	38.33
Demolition and relocation cost	108.37	29.21
Preparation cost	11.77	5.68
Interest rate	11.70	0
Others	25.37	3.74
Subtotal	323.52	76.96
O&M cost (million Yuan/year)		
Energy cost	4.39	1.45
Chemical	1.8	0.44
Maintenance	3.48	1.29
Personnel	0.72	0.48
Subtotal	10.39	3.66
Financial benefits		
Revenue (million Yuan/year)	576.96	20.3
Subsidies (million Yuan)	123.52	0

The present value of all effects in the economic analysis is calculated and shown in Table 12. Because of the large treatment capacity of centralized wastewater reuse systems, a large quantity of reused water is generated and reused, leading to the large amount of environmental benefits of increased water availability. The environmental cost of the Gao plant is 19.24 million Yuan, whereas the environmental benefit of the Gao plant is 3225.26 million Yuan. The environmental benefits are much higher than the environmental cost, which is also the case in the Jiu plant. The result of environmental benefits being larger than environmental cost implies that centralized wastewater reuse systems are environmentally friendly, although they cause serious environmental cost due to carbon dioxide emission.

With regard to the social effects in the economic analysis, the economic value of the cost is the same as the value of benefits. The social cost is caused by resettlements due to pipe construction, and the social benefit is represented by the improvement of employment. For both the Gao plant and the Jiu plant, there is no big difference between the values of social benefits and social cost.

Table 12

Economic analysis of centralized wastewater reuse systems(million Yuan)

	Gao plant	Jiu plant
Cost		
Economic cost	425.53	112.89
Environmental cost	19.24	0.38
Social cost	15.28	6.4
Total	460.05	119.7
Benefits		
Economic benefits	2.4	0.24
Environmental benefits	3225.26	645.05
Social benefits	5.9	5
Total	3233.6	650

Table 13 shows the results of the ratios of benefits to cost in the economic and financial analyses. In the financial analysis, the ratios of financial benefits to cost of the Gao plant and the Jiu plant are 1.6 and 1.7, respectively, which are larger than 1. It means that the two plants are financially feasible. Given this situation, the plant managers have an incentive to operate the wastewater reuse plant. Although the construction cost and energy cost of a centralized wastewater reuse plant is very high, its revenue is high enough to cover these costs. From the point of view of plant managers, centralized wastewater reuse systems can be operational in the long term.

Table 13 The results of financial and economic feasibility of centralized systems

	Gao plant	Jiu plant
Financial analysis (ratio of financial benefits to financial cost: $r_{fb/fc}$)	1.6	1.7
Economic analysis (ratio of benefits to cost: $r_{b/c}$)	7	5.4

In the economic analysis, the ratio of benefits to cost of the Gao plant is 7.2 which is larger than 1. Similarly, the ratio of benefits to cost of the Jiu plant is larger than 1. This means that both the Gao plant and the Jiu plant are economically feasible. It implies that centralized wastewater water reuse systems have a positive influence on the welfare of society. Centralized wastewater reuse systems produce a large quantity of new water and are environmentally friendly. From a government point of view, centralized wastewater reuse systems deserve to be promoted.

5.2 Sensitivity analysis

Given the uncertainty concerning the discounting rate, a sensitivity analysis is carried out through recalculating at different discounting rates: 12% and 15%. The results in Table 14 show that the ratio of benefit to cost becomes smaller when discounting rate increases, but the ratio is still larger than 1. The Gao plant and the Jiu plant are both financially and economically feasible when the discounting rate increases from 8% to 12% and 15%.

Table 14 Sensitivity analysis based on various discounting rates

		8%	12%	15%
Financial analysis	Gao plant	1.6	1.4	1.2
	Jiu plant	1.7	1.4	1.2
Economic analysis	Gao plant	7	5.7	5
	Jiu plant	5.4	4.7	4.1

6 Conclusions

The present paper carries out a benefit-cost analysis of centralized wastewater reuse systems in Beijing. The framework of this study includes two parts: the financial and the economic analyses. The financial analysis is carried out from the point of view of the plant manager, whereas the economic analysis is done from the point of view of society. The major economic, environmental and social effects of the projects are all considered in the economic analysis.

The results of the financial analysis show that the centralized wastewater reuse systems are financially feasible. This means the investment in centralized wastewater reuse systems is profitable, which could raise the incentive of plant managers to operate the plant long term.

The results of the economic analysis show that the economic, social and environmental benefits caused by centralized wastewater reuse plants are larger than the cost. Thus, the centralized wastewater reuse systems are also economically feasible. This means centralized wastewater reuse systems have positive effects on society. From a government or society point of view, the centralized wastewater reuse systems are worth being promoted. Moreover, the results show that centralized wastewater reuse systems make a large positive contribution to the environment despite the fact that they consume substantial resources for construction and may increase carbon dioxide emissions.

From a technological point of view, centralized waste water reuse systems producing a large quantity of "new water" could effectively relieve the pressure of urban water scarcity (Asano, 2001). This study illustrates that from an economic point of view a centralized wastewater reuse system is a profitable investment and has a positive influence on the welfare of society.

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