Carbon emission assessment of the life cycle of a small town sewage treatment plant

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Abstract. The rise of greenhouse gas (GHG) concentration has caused global warming to become a consensus in human society. Carbon emissions from sewage treatment plants are one of the main sources of emissions. Among them, carbon emissions from small town sewage treatment plants cannot be ignored. Based on the life cycle (LCA) evaluation theory, the assessment scope of life cycle carbon emissions of small town sewage treatment plants is defined, and a corresponding evaluation system is constructed. According to the system, the carbon emissions of a small town sewage treatment plant in Jilin are evaluated. Based on the assessment results, the ways to reduce carbon emissions from small town sewage treatment plants were discussed to provide a reference for their emission reduction.

1 Foreword

The cause of global warming is generally believed to be excessive emissions of greenhouse gases such as CO₂, CH₄ and N₂O into the atmosphere during human activities, which has prompted international agreements and conferences on greenhouse gas reductions, including the Kyoto Protocol. Sewage treatment plant directly discharges CO₂ and CH₄ during operation. Greenhouse gases such as N₂O, energy and resource consumption also indirectly generate greenhouse gases. Therefore, sewage treatment plants are considered to be one of the main sources of carbon emissions [1].

The “12th Five-Year Plan for the Construction of Urban Sewage Treatment and Recycling Facilities” requires that the sewage treatment rate of the towns reached 30% by 2015, which has been basically completed. The “13th Five-Year Plan for Urban Sewage Treatment and Recycling Facilities Construction” proposes that by the end of 2020, urban sewage treatment facilities will be fully covered, and the towns will reach 70%. With the large-scale construction of small town sewage treatment plants, huge carbon emissions will be generated during construction, operation and demolition due to energy consumption, material consumption, direct discharge of operations and disposal of solid waste.

Compared with urban sewage treatment plants, small town sewage treatment plants have the following characteristics: small towns are small in size, low in population density, small in population, low in industrial development, small in sewage and water; residents are concentrated in water, early in the evening the water consumption is large, the water consumption is small at other times, and even the flow may occur at night. Therefore, the amount of sewage water and water quality

fluctuate greatly; the complex terrain, scattered residents and weak environmental awareness make the drainage network system imperfect, which increases the amount of sewage treatment water in small towns and the concentration of organic matter in sewage are reduced; the economy is underdeveloped, the funds for sewage treatment are insufficient, the operation management technology is weak, and the professional sewage treatment cannot be guaranteed to operate normally. These characteristics make it difficult to directly use the treatment process of large-scale sewage treatment plants in small town sewage treatment. Therefore, it is necessary to evaluate the carbon emissions of small town sewage treatment plants.

Based on the life cycle assessment theory, this paper analyzes the carbon emissions that may occur during the construction, operation and demolition of small town urban sewage treatment plants, in order to objectively understand the carbon emissions of small town sewage treatment plants and provide reference for the ways to reduce carbon emissions of small town sewage treatment plants.

2 Life cycle carbon emission assessment system for small town sewage treatment plants

2.1. Assessment range

Assessing the carbon emissions from the life cycle of a small town sewage treatment plant can consider the carbon emissions of the small town sewage treatment plant life cycle as a system to assess the total CO₂ equivalent of the system due to energy consumption, material consumption and treatment process to the

environment. The life cycle of a small town sewage treatment plant refers to the whole process from “cradle” to “grave”, including raw material mining, civil engineering materials, equipment processing and manufacturing, civil construction, equipment installation, operation and maintenance of sewage treatment plants and demolition. Evaluating plant-wide life cycle carbon emissions can assess carbon emissions in the construction, operation, and demolition phases, as shown in Figure 1.

During the construction phase, civil construction and equipment installation consume a lot of building materials, building materials in the production process due to energy consumption and various materials

produce a large amount of carbon emissions, construction process and equipment, manufacturing and manufacturing the process produces carbon emissions due to mechanical energy consumption. Carbon emissions during the operation phase are composed of direct emissions of greenhouse gases such as sewage, sludge treatment processes CO_2 , CH_4 and N_2O , as well as indirect emissions of energy and pharmaceutical consumption. It should be pointed out that this stage does not include the energy consumption and carbon emissions corresponding to tail water discharge or recovery, sludge transfer and disposal. Carbon emissions during the demolition phase should be deducted from the recycling of some building materials carbon emissions.

Fig. 1 Assessment system boundary of life-cycle carbon emission for sewage treatment plants in small towns

2. 2 Evaluation indicators

The treatment scale, treatment water quality, treatment level and treatment process of small town sewage treatment plants are different, there is a large difference in material and mechanical usage and energy consumption during the construction process, the impact on carbon emissions during the operational phase is also significant. Eliminate the impact of scale of sewage treatment, select the carbon emissions corresponding to each cubic meter of sewage as the evaluation index, this is also the main selection evaluation index for the study of carbon emissions from urban sewage treatment in China. However, there are certain limitations in the treatment of carbon emissions per cubic metre of sewage as the sole evaluation criteria, large differences in water quality can also result in different carbon emissions from

sewage treated with the same amount of water [2]. In order to eliminate the impact of different sewage quality and treatment levels, the carbon emissions corresponding to the removal of BOD per kilogram were selected as evaluation indicators.

Therefore, in order to establish a horizontally comparable evaluation, the evaluation results is made consistent and comparable, this study selected two evaluation indicators: the carbon emissions per cubic metre of sewage are treated and the carbon emissions per kilogram of BOD are removed.

3 Small town sewage treatment plant carbon emission assessment method

For carbon emissions, it is generally measured in terms of the amount of CO_2 produced, other greenhouse gases

other than CO₂, such as CH₄, N₂O, etc, it can be converted to carbon equivalent based on global warming potential (GWP), the potential value of CO₂ is 1, and the potential values of CH₄ and N₂O are 23 and 296 [3], respectively, the carbon emissions of the small town sewage treatment plant life cycle are equal to the three stages of construction, operation and demolition of various greenhouse gas emissions, the sum of the amount of multiplication with its GWP.

3.1 Construction stage

Small town sewage treatment plants consume a large amount of various building materials and use various machinery during the construction process. But because of the variety of materials used, it is difficult to evaluate one by one, in this paper, all materials are sorted according to energy consumption and cost, materials with

a cumulative amount of more than 80% of the total materials are included in the evaluation, other carbon emissions that are not directly calculated are 5% of the calculated carbon emissions. The calculation formula for carbon emissions during the construction phase is as follows:

$$M_{CO_2-W} = 1.05 \sum W_i \times EF_{CO_2-W_i} \quad (1)$$

In formula (1): M_{CO_2-W} —CO₂ during construction emission quantity, unit: kg;

W_i —Construction material i consumption during construction, in: Kg;

$EF_{CO_2-W_i}$ — i materials emission factor, unit kgCO₂ / kg. According to existing research, the main CO₂ during the construction phase

The emission factors are shown in Table 1 [4 ~ 7].

Table. 1 CO₂ emission factors during construction stage (kgCO₂ /kg)

cement		Steel			Energy		plastic	
cement	Large steel	Small and medium steel	Hot rolled strip	Cold rolled strip	gasoline	diesel	PE	UPVC
0.716	2.800	2.320	2.430	2.940	2.031	2.171	0.603	4.700

Note: CO₂ of cement the emission factor is based on the cement clinker ratio of construction of 0.75.

3.2 operation stage

Carbon emissions from the operation phase of small town sewage treatment plants include direct emissions and indirect emissions. Sewage collection, sewage treatment and sludge treatment process directly discharge greenhouse gases such as CO₂, CH₄ and N₂O into the environment. In the United Nations Intergovernmental Panel on Climate Change (IPCC) Recommendation Methodology Guide, directly emitted CO₂ is bio-based and therefore not included in total carbon emissions [8], this article also does not consider, therefore, direct emissions are mainly derived from the emissions of biological treatment processes CH₄ and N₂O; indirect emissions include carbon emissions from power consumption and drug consumption in each process unit.

3.2.1 Direct emissions

The calculation of direct emissions refers to the 2005 China Greenhouse Gas Inventory Study and the 2006 National Greenhouse Gas Inventories Guide [8] published by the IPCC, the amount of CH₄ produced is calculated as follows:

$$M_{CH_4} = (TOW \times EF_{CH_4}) - R_0 \quad (2)$$

In formula (2): M_{CH_4} —CH₄ during biological treatment emission quantity, unit: kg;

TOW—calculate the organic matter content of the annual sewage, unit: kg;

EF_{CH_4} —CH₄ emission factors, refer to Cai Bofeng et al [9] study the methane emission factor of the aerobic during the operation of the sewage treatment plant, the treatment process.

R_0 —calculate the annual recovered CH₄ quantity, unit: kg, if dirty mud digestion facility is not running, R_0 take the default value of 0.

$$M_{N_2O} = TN \times EF_{N_2O} \quad (3)$$

M_{N_2O} in formula (3)—N₂O emissions during biological treatment quantity, unit: kg;

TN—calculate the total amount of nitrogen removed from the annual sewage, in units of kg;

EF_{N_2O} —N₂O emission factor, refer to Kimochi Y et al. [10] the N₂O emission factor of the intermittent aerated activated sludge process in the study.

3.2.2 Indirect emissions

lifting pump unit, the aeration blast unit, the drug convey unit, and the sludge unit will consume a lot of energy, the production of these energy sources will have carbon emissions, the calculation formula is as follows:

$$M_{CO_2-E} = E \times EF_{CO_2-E} \quad (4)$$

M_{CO_2-E} —energy consumption in the formula (4) indirectly emits CO₂ the amount, unit: kg;

E —power consumption, unit: kW·h;

EF_{CO_2-E} —CO₂ for power consumption emission factor, unit: Kg CO₂ / kW·h, according to the 2015 China Regional Grid Reference Line Emission Factor are

determined.

treatment will use a large amount of chemicals, such as stone. Ash, methanol, coagulant and disinfectant for better sludge pressure reduce the effect, use a large amount of flocculant, coagulant and so on. Drug consumption carbon row put the calculation formula as follows:

$$M_{CO_2,Y} = \sum Y_i \times EF_{CO_2,Y_i} \quad (5)$$

$M_{CO_2,Y}$ in the formula (5) —indirect CO_2 emissions, single bit: kg;

Y_i —pharmaceutical i consumption, unit: kg;

EF_{CO_2,Y_i} — i CO_2 consumed by the agent emission factor,unit:Kg CO_2 /kg, according to statistics, $EF_{CO_2,coagulant}$ is 25 kg CO_2 /kg coagulant.

3. 3 Demolition phase

The carbon emissions during the demolition phase mainly include the carbon emissions generated by the demolition process and waste transportation and waste disposal, however, some materials are recycled to reduce raw material production, therefore, the carbon emissions in the demolition phase should be deducted from the carbon emissions corresponding to the recycled materials. Among them, the carbon emissions from the demolition process and waste transportation can be assessed by the

In order to meet the standard discharge, sewage energy consumed during the dismantling and transportation of the waste.

4 case study

4.1 Overview of small town sewage treatment plants

According to the characteristics of the small town sewage treatment plant, when selecting a process suitable for treating sewage in small towns, CASS process has a high degree of applicability [11 — 12] .This paper takes a small town sewage treatment plant with a treatment scale of 2 000 m³/d in Jilin as an example, the treatment process is “pretreatment + CASS + coagulation and phosphorus removal + filtration disinfection”, after treatment, the effluent water quality meets the Grade A standard of the Pollutant Discharge Standard for Urban Sewage Treatment Plants (GB18918 - 2002),the process flow is shown in figure 2.The small town sewage treatment plant has a structural design period of 50 years.

Fig. 2 The process flow diagram of a typical small town sewage treatment plant

Due to the lack of basic data for the demolition phase, this case only calculates the carbon emissions during the construction phase and the operational phase. (1) The data for the construction phase comes from the

construction plan, the bill of quantities and the construction budget. The main materials are shown in Table 2.

Table. 2 Materials quantity and energy consumption in construction stage

(t)

Construction materials	cement	Reinforce ment	Steel plate, Section steel	Steel Pipe	Other steel	PE tube	UPVC pipe	gasoline	Diesel
consumption	668.131	169.709	20.556	54.149	0.418	9.504	0.323	3.352	21.842

(2) This study collected basic data such as water quality, sewage treatment capacity, electricity consumption, and chemical use of the sewage treatment plant in 2016. In 2016, the total amount of treated sewage

was about 763 200 tons, and the water quality of the inlet and outlet was taken as the 2016 average. See Table 3 for details.

Table. 3 Water quality of the small town sewage treatment plant

index	Treatment volume (t /a)	BOD ₅ (mg /L)	COD _{Cr} (mg /L)	TN (mg /L)
Influent water quality	763 200	121	253	34
Effluent water quality		8	42	13

The annual electricity consumption of the small town sewage treatment plant is 195 379.2kW•h, the power consumption per sewage is 0.256 kW•h, the main agents are PAM, PAC coagulant. The annual usage is 0.23 t and 10.62 t.

According to 3.1, the carbon emissions of the sewage treatment plant during the construction phase and the operation phase are calculated separately. The results are shown in Table 4.

4. 2 Carbon emission assessment and analysis

Table 4. Life – cycle carbon emission of the small town sewage treatment plant

	Construction phase	Operational stage			total
		Direct emissions	Indirect emissions	total	
Carbon emission	1228. 47t	16. 95 t /a	457. 15 t /a	474. 1 t /a	
Evaluation index (kg /m³)	0.03	0.02	0.60	0.62	0.65
Evaluation index (kg / kg BOD)	0.28	0.20	5.30	5.5	5.78

As can be seen from Table 4, the small town sewage treatment plant has a large carbon emission during the construction phase, reaching 1 228. 47t, however, the sewage treatment plant has a structural life of 50 years, amortize carbon emissions from its construction phase to less per cubic metre of sewage or remove carbon emissions per kilogram of BOD, only 0.03 kg/m³, 0.28 kg/kg BOD. The sewage treatment plant's carbon emissions during the life cycle is as high as 46 272.97t, carbon emissions during the construction phase account for approximately 5% of total life cycle carbon emissions, less contribution to total carbon emissions from the life cycle of small town sewage treatment plants.

Among them, the carbon emission of steel is 630.12t, accounted for 51.29% of the total carbon emissions during the construction phase, it can be seen that reducing the carbon emissions of steel is an important way to achieve low carbonization during the construction phase. Steel is a high carbon emission building material, but its recovery rate is also high. Considering that it is difficult to fully recycle steel in reinforced concrete, the recovery rate is 40%, section steel, steel pipe and other steels have higher recovery rates, up to 90%, the carbon emissions of recycled steel are based on 35% of the original steel carbon emissions. Consider recycling, the carbon emission of the sewage treatment plant is 395.53t, the total carbon emissions during the construction phase were reduced to 993.88t, nearly 20% of total carbon emissions during the

construction phase have been reduced.

Carbon emissions during the operational phase are concentrated on indirect emissions, the direct conversion of CH₄ and N₂O emissions is only 14.82t/a and 2.13t/a respectively, the carbon emissions from energy consumption are 185.90t/a, the drug consumption carbon emission is 271.25t/a, indirect emissions account for approximately 95% of total carbon emissions during the operational phase. The treatment of small town sewage treatment plants is relatively small, the energy consumption per unit of water is greater than that of urban sewage treatment plants. This study uses a chemical phosphorus removal process, adding a large amount of PAC during operation to achieve phosphorus removal, increasing the carbon consumption of the drug, the sewage treatment plant has a relatively large amount of drug consumption, it accounted for 57.21% of the total carbon emissions during the operation phase. Taking the carbon emissions corresponding to each cubic meter of sewage as an evaluation index, the carbon emission of the sewage treatment plant during the operation phase is 0.65kg/m³, slightly lower than the carbon emissions of domestic urban sewage treatment plants [2]; taking the carbon emissions corresponding to the removal of BOD per kg as an evaluation index, the carbon emission of the sewage treatment plant during the operation phase is 5.78kg/kg BOD, higher than the similar study of urban sewage treatment plants [2], this is caused by the low BOD of the water entering the small town sewage treatment plant.

To achieve the emission reduction targets of small carbon emissions during the construction phase and operation phase, it is especially important to reduce the carbon emissions during the operational phase. The ways to reduce carbon emissions during the construction phase are: ① clean production and reduce carbon emissions during building materials production; ② sewage treatment plants reduce the use of building materials with more carbon emissions in the production process; ③ improve the efficiency of mechanical use and reduce energy consumption such as diesel; ④ recycling resources to recover building materials as much as possible to reduce carbon emissions. The ways to reduce carbon emissions during the operational phase are: ① biogas recovery. If CH_4 is burned, it can be converted into CO_2 with low global warming potential, at the same time, the energy produced by combustion can be used as an energy supply; ② optimize equipment such as lifting pumps and blowers, reduce energy consumption; ③ do a good job of saving water at the source, sewage reuse to reduce the treatment load of the sewage treatment plant, indirectly reduce carbon emissions; ④ reasonable allocation of drug consumption, etc., enable sewage treatment plants to operate at low carbon.

5 Conclusion

According to the principle of life cycle assessment, defining the scope of assessment of life cycle carbon emissions from small town sewage treatment plants, the carbon emissions of the construction, operation and demolition phases of the small town sewage treatment plant were analyzed, established a life cycle carbon emission assessment system for small town sewage treatment plants, and carried out a case study.

The case study shows that, large carbon emissions during the construction phase, but measured by the life cycle, its carbon emissions account for only 5% of total carbon emissions. Among them, the carbon emissions of steel accounted for 51.29% of the total carbon emissions during the construction phase, through recycling, carbon emissions can be reduced by 20% during the construction phase, significantly reduce carbon emissions at this stage. Reducing carbon emissions during the construction phase can also be achieved through cleaner production, reduced use of high carbon emissions building materials and improved mechanical performance. Carbon emissions in the operational phase are the main part of the total carbon emissions of the

town sewage treatment plants, it is necessary to reduce plant, its carbon emissions are concentrated in indirect carbon emissions, indirect emissions, energy consumption and drug consumption accounted for 39.21% and 57.21% of the carbon emissions in the operational phase, reduce energy consumption by optimizing mechanical equipment, reasonable allocation of drug consumption and other aspects of indirect carbon emissions with less operating phase. This study calculate carbon emissions at various stages of the life cycle of a small town sewage treatment plant, master the main factors of carbon emissions, find reasonable low-carbon measures, provide a scientific basis for its emission reduction.

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