Is Low-carbon Together with Pollution Reduction?

——Calculation of CO_2 Emissions from Municipal Wastewater Treatment Plants

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Abstract—Municipal wastewater treatment plants (WWTP) are recognized as an important source of carbon emissions. Previous studies have calculated the CO_2 emissions in the operating process of WWTP in the sight of engineering technology and the CO_2 emission which is driven by the pulling effect of investment in WWTP are ignored. This paper calculates the CO_2 emissions of wastewater treatment plant from the macroscopic view based on the input-output method and the fixed log-liner model. The study discovers that Compared to the indirect CO_2 emissions from WWPT, the direct carbon dioxide emissions from WWPT are negligible. It calculates that in the year 2007, China's CO_2 emissions of WWTP in construction process amount to 98.23 million tons and the emissions in operating process is 11.24 million tons. The indirect emissions are 8.74 times the direct emissions; and the reduction of 1 ton of COD pollutants generates about 14.7 tons of carbon dioxide emissions.

Keywords- Environmental-Economic Input-output Model; Partially Closed Model; CO_2 Emission; Wastewater Treatment Plant

I. BACKGROUND

Wastewater treatment plants have become a chief means of reducing pollutant emissions. The construction of China's wastewater treatment plants has progressed relatively slowly until 2005, and after that, the number of wastewater treatment plants and their wastewater treatment capacity has skyrocketed. In 2009, the cumulative reduction of chemical oxygen demand in urban wastewater treatment plants amounted to more than 700 million tons. At present, the number of urban wastewater treatment projects under construction is up to 2360, with a total design capacity of about 64 million cubic meters per day; and the estimated total treatment capacity of the projects under construction and the existing projects is up to 160 million cubic meters / day. As predicted, China's population will reach a peak between 2020 and 2025, and the wastewater treatment capacity will also reach a peak in 2020, which means that China's wastewater treatment capacity will maintain rapid growth in the next decade.

As a major body of carbon dioxide emission, the construction of wastewater treatment plants will contribute significantly to the future increase of carbon dioxide emissions. Therefore, the quantitative research and analysis of the impact of such an engineering emission reduction measure on carbon dioxide emission not only provide the policy measures related to energy conservation and pollutant emission reduction with a scientific basis, but also improve the theoretical study related to the relationship between energy conservation and pollutant emission reduction.

Seen from the perspective of the research method of CO2 emissions from wastewater treatment plants, former studies calculated the carbon dioxide emissions through stages of wastewater treatment, and have tried to find the carbon dioxide emissions control methods in each stage [1~2].Some studies focus on the CH_4 and N_2O emissions in treatment process and the CO_2 emissions on electricity consumption and PAM consumption [3]. These studies lack the macroeconomic consideration and relevance in industries. In fact, the carbon dioxide emissions from wastewater treatment plants can be divided into two parts: one part is the carbon dioxide emissions caused by the consumption of cement, steel and other materials that are driven by the construction investment in wastewater treatment plants, including the emissions from the wastewater treatment plants themselves and the other sectors, the other part is the emissions from wastewater treatment plants during the operating process. This paper defines the carbon dioxide emissions generated by wastewater treatment plants as direct emissions, and the carbon dioxide emissions generated by the production and consumption of other sectors through the driving factor of wastewater treatment plant investment as indirect emissions.

II. METHODOLOGY

A. Research structure

The carbon dioxide emissions caused by the investment in WWTP and the operation of WWTP should be calculated respectively.

The carbon dioxide emissions caused by investment should be calculated by extended input-output model, and the specific calculation steps are as follows:

First, put the residents' consumption matrix into the part of intermediate flow to establish a partially closed input-output model.

Then separate the wastewater treatment activities from the traditional sectors.

After that, bring in the direct emission coefficient matrix of CO_2 on this basis for the purpose of the establishment of the pollution emission - environmental protection activities - economic input-output table.

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Finally, the CO_2 emissions can be calculated through operating the model.

The carbon dioxide emissions in the operation process are calculated by the fixed log-liner model and the specific calculation steps are as follows:

First, the national survey data for pollution sources in 2007 is used to build the electricity consumption of household wastewater treatment function by setting up the relationship between electricity consumption and wastewater treatment amount.

Then coefficient for the electricity consumption per wastewater treatment volume can be calculated.

After that, the total electricity consumption for wastewater treatment can be calculated according to the national wastewater treatment amount.

Finally, the CO_2 emissions can be calculated through CO_2 emission coefficient of electricity consumption.

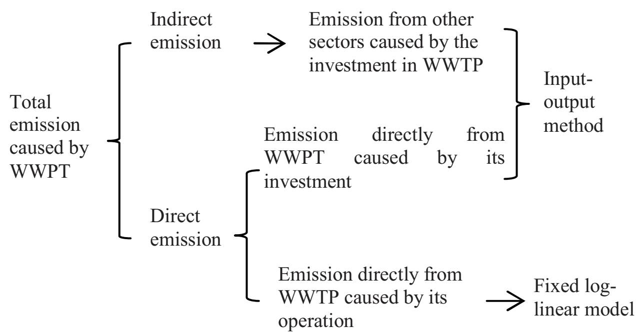

Figure 1. The Constitute of CO_2 Emission from WWTP

B. Input-outpu tmodel framework

Input–output analysis was developed by Leontief as a framework for the analysis of highly interconnected economic systems. In its most basic form, static input–output analysis is now an established technique by which nations account for economic activities and links of different industrial sectors [4~6]. Furthermore, there have been attempts to extend input–output analysis to account for environmental impacts [7~19].

The main piece of the model is the (I-A)-1matrix, or total requirements matrix, where each entry i,j is fraction of $1 spent on output from industry i to produce $1 of output for industry j. The driving equation is:

$$E_{investment} = R * (1 - A)^{-1} * F \quad (1)$$

Formula (1) is invest-driven total CO_2 emissions.

Where $E_{investment}$ is the total CO_2 emissions driven by increased final demand which is wastewater investment demand. F is a vector of increased final demand in dollar terms, R is a direct emission coefficient vector of CO_2 by sector and C is a direct emission vector of CO_2 by sector.

TABLE I. TABLEIFRAMEWORK OF ENVIRONMENT-ECONOMIC-INPUT-OUTPUT MATRIX ADDED BY CO_2 EMISSION MATRIC

		Intermediate output			**End use**	**Total output**
		Sector I	Sector II	**…**		
Intermediate use	Sector I					
	Sector II					
	…					
CO_2 emissions						
Initial investment						
Total investment						

1) The partially closed model

In the common input-output tables, the residents' consumption is put in the second quadrant as an exogenous variable. In residents' consumption, there also exists carbon dioxide emissions; therefore, it is necessary to put the mutual influence of the residents' consumption into the part of intermediate flow, so as establish a partially closed model. The specific methods for establishing the partially closed model is to establish the residents' sector and treat it as a production sector, the investment of the residents' sector in various sectors (rows) is the labor compensation paid by each sector and the residents' income gained through the profit distribution, i.e. the residents' total income gained from various sectors. The column in the residents' sector refers to the consumption of various consumption goods and services generated by the residents' sector. In the energy consumption announced by the National Bureau of Statistics, it doesn't differentiate between the residents' consumption and the government's consumption. Therefore, the part of governmental consumers is also treated as a production sector and is put into the part of intermediate flow together with the residents' sector; and the investment of government's sector in various sectors (rows) should be calculated through the net production taxes paid by each sector, i.e. the total revenue gained by the government from various sector. But in fact, due to the transfer payments conducted by the government, the revenue received by the government from various sectors and the governmental expenditure on various sectors are not on an equal footing. Therefore, actually there exists an assumption, i.e. the efforts of government sector on various sectors are equal to the revenue received by the government from various sectors. In addition, move the two columns of the residents' consumption and the government's consumption, as well as the two rows of the revenues and the production taxes into the part of intermediate flow, and then merge them into the input column and the output row. After that, you will find that the total number of the input column is different from that of the output row. It is because that the output row of the residents' and the government's revenues sectors including both of the purchase of fixed assets and the purchase of non-fixed assets, while the input column, namely the residents' and the government's consumption column, does not include the purchase of fixed assets. Therefore, the difference between the output row and the input column should be put into the row of depreciation on the fixed assets and the column of consumption as the input in the depreciation of fixed assets by residents and government.

2) Environment-economic-input-output model

In accordance with the categories of industrial classification for national economic activities, the network operation of urban WWTP belongs to the industries of water conservancy, environment and public facility management, and the treatment of wastewater belongs to the industry of water production and supply. Due to the limited data, the operation of the wastewater network is ignored here, only the treatment activities within urban WWTP that belong to the industry of water production and supply are separated. (Table II)

According to the principles of input-output theory, the input column of wastewater treatment plants refers to the consumption of the products in various national economic industries caused by the wastewater treatment activities. For example, 500kg water consumed by WWTP is equivalent to 500 kg water product provided by the industry of water production and supply; therefore, this data should be put into the row of the industry of water production and supply, as well as the column of the wastewater treatment activities in the input-output table. The data in the column, which relate to the consumption of products in each national economic sector caused by urban wastewater treatment, can be obtained through the survey on each cost in WWTP (Table II). The rows refer to the intermediate products that are offered to all national economic sectors by the wastewater treatment industry.

TABLE II. INPUT-OUTPUT TABLE WITH SEPARATED WASTEWATER TREATMENT ACTIVITIES

The use of industrial products	**Domestic industrial production**		**Capital Formation**		**Net exports**	**Total use**
	Other sectors	WWTP activities	Other sectors	WWTP		
Other industries						
WWTP activities						
Added value						
Consumption of fixed capital						
Net production taxes						
Compensation of employees						
Net operating surplus						

C. The electricity consumption function

There are relatively great correlations among the electric power consumption of urban wastewater treatment plants, the wastewater treatment capacity and the degree of wastewater treatment (i.e. treatment class). Therefore, select the actual treatment capacity and the wastewater treatment class of urban wastewater treatment plants (among which, the treatment class should be set as a dummy variable) as independent variables, and establish the fitting model for the electric power consumption of urban WWTP and the wastewater treatment capacity and the wastewater treatment class. Actually, this model has been developed by Susmita Dasgupta as an instrument to the analysis of the relationship between the wastewater treatment investment or cost and water treatment capacity [20~21]. The equation is set as follows:

$$C = e^{\alpha_0 + f*\alpha_1} \bullet W^{\alpha_2} \quad (2)$$

$$E_{operation} = f * C \quad (3)$$

In this equation, the electricity consumption is a dependent variable, the actual wastewater treatment capacity and the treatment level are independent variables, and the treatment class should be set as a dummy variable, namely, 0-1 variable. C is: the electric power consumption during the operation of wastewater treatment, and its unit is: 10 thousand kWh; f is:0-1 variable, so it should be set as 1 for the primary class wastewater treatment plants, and it should be set as 0 for the secondary or tertiary class wastewater treatment plants. W_{tre} is: the wastewater treatment capacity of wastewater treatment plants, t; α_0, α_1, α_2 are parameters. $E_{operation}$ refers to the carbon dioxide emission that are generated during the running process of wastewater treatment plants, and f is the carbon dioxide emission factor.

III. DATA SOURCES

As Table 2 shows, the input column and the output row of wastewater treatment activities in the intermediate flow should be separated from the traditional sector of water production and supplying sector, and the data of the investment column of wastewater treatment activities in the end-consumption part should be attained.

As the operation part, the data in the electricity consumption function model comes from the first national general survey on pollution sources 2007.

A. The investment column of WWTP

In 2007, the investment of wastewater treatment industry in fixed assets was 142.95 million Yuan. The number of additional WWTP was about 320 in 2007. In accordance with the estimated construction investment of 150 million Yuan per wastewater treatment plant, the total construction investment in the wastewater treatment industry amounted to 48 billion Yuan in 2007, and the investment in equipment was 94.95 billion, including the investment in the manufacturing of special–purpose equipment, account for about 90% of the total investment in equipment, as well as the investment in instruments and meters, accounted for about 10%. The construction investment, the investment in special–purpose equipment and the investment in instruments and meters should be put respectively into the row of construction industry and the column of fixed investment in environmental protection, the row of equipment manufacturing industry and the column of investment in fixed assets of environmental protection, as well as the row of instruments and meters and the column of investment in fixed assets of environmental protection.

B. The input column of WWTP in the intermediate flow part

According to the data from general survey on pollution sources, the running cost of WWTP was 11.647 billion Yuan in 2007. Therefore, according to the table, the data of the input column of wastewater treatment industry can be obtained. For example, the electrical power consumption should correspond to the row of the industry of production and supply of electric power, which means the input in the wastewater treatment from the industry of production and supply of electric power; the water means the input in the wastewater treatment from the industry of water production and supply, the chemicals mean the input in wastewater treatment activities from the chemical industry, and the oil means the input in wastewater treatment activities from the industries of petroleum processing, coking and nuclear fuel processing.

TABLE III. COSTS ON ECONOMIC OPERATION OF WASTEWATER TREATMENT PLANTS

No.	The name of the paid fees	Proportion%	No.	The name of the paid fees	Proportion%
I	Energy consumption	40~55	III	Depreciation of fixed assets	15~25
1	Electric power	25~40	IV	Funds held in escrow for overhaul	10~25
2	Water	0.5~1.5	V	Wages and benefits	2~5
3	Chemical	8~20	VI	Management Training	5~10
4	Oil	1.5~3	1	Vehicle management	0.5~1
II	Routine maintenance and repair	5~15	2	Taxes	5~10
1	Ancillary facilities	2~5	3	Training fees	
2	Materials and equipment	5~12	4	Administrative expenses	

C. *The output row of urban wastewater treatment industry*

The output of urban wastewater treatment industry refers to the product supply from the wastewater treatment industry; therefore, the first step is to clearly identify the product of the wastewater treatment industry. The product of wastewater treatment industry should include two contents: namely, the wastewater treatment services for the users and the supply of reclaimed water. Due to the relatively small market share of reclaimed water, which is mainly used in the urban scenery areas at present, the product of wastewater treatment industry here mainly refers to the wastewater treatment services.

The total input is equivalent to the total output, and in accordance with this principle, the total output of the wastewater treatment industry is equal to the running costs of the wastewater treatment industry, and the costs for wastewater treatment services should primarily be assumed by the wastewater treatment fees paid by each industry. Therefore, each column that corresponds to the row of urban wastewater treatment activities is the fees paid by each industry for the urban wastewater treatment.

But at present, there is no fee paid by any industry for the urban wastewater treatment, and the major target clients of the urban wastewater treatment are the residents. So assuming that the residents pay all the costs of wastewater treatment, the running costs of wastewater treatment can be put into the column of residents' consumption and the row of urban wastewater treatment.

IV. THE RESULTSOF CALCULATION

A . *The carbon dioxide emissions caused by investment*

APPENDIX I refers to the increase in total output and the carbon dioxide emissions driven by investment in wastewater treatment plants. The investment drives greater carbon dioxide emissions in the consumption, the general, special equipment manufacturing industry, as well as the metal smelting and rolling processing industry. The sectors with the largest carbon dioxide emissions are the electricity supply, the metal smelting and rolling processing industry, the chemical industry, and the petroleum processing industry, and their respective contribution rates to carbon dioxide emissions are 31.9%, 19.59%, 14.87% and 6.45%. And the investment drives less carbon dioxide emissions in wastewater treatment plants, which is only up to 112,000 tons, with a contribution rate of 0.102% to the total CO_2 emissions driven by investment.

The total carbon dioxide emissions driven by investment amounted to 98.34 million tons in 2007. And the indirect emissions of other sectors driven by investment amounted to 98.23 million tons.

B. *Carbon dioxide emissionscausedby the operation of wastewater treatment plant*

Through calculation, for a WWTP with a treatment capacity of 10 thousand tons per day, the power consumption of the primary class ones for the treatment of unit volume of wastewater is 0.154 kWh, and the power consumption of the secondary or tertiary class ones for the treatment of unit volume of wastewater is 0.225 kWh. In 2007, the proportion of total treating capacity represented by the primary class WWTP was 6.8%, and the proportion of total treating capacity represented by the secondary or tertiary class wastewater treatment plants was 93.2%. The corresponding electricity consumption for wastewater treatment in the primary class WWTP was 204.8 million kWh, and the corresponding CO_2 emissions was 127 thousand tons. And the corresponding electricity consumption in the secondary or tertiary class WWTP was 17.745 billion kWh and the corresponding CO_2 emissions was 11 002 thousand tons.

The total carbon dioxide emissions driven by operation are amount to11.12 million tons.

V. CONCLUSIONS

a) The indirect carbon dioxide emissions from WWTP are far greater than the direct carbon dioxide emissions from WWPT. From the above analysis, we can conclude that the total emission from WWTP amount to 109 million tons with the direct emissions from WWTP of 11.24 million tons, and the indirect emissions of 98.23 million tons. Therefore, the indirect emissions are 8.74 times the direct emissions. In 2007, the COD reduction in WWTP in China was 7.432 million tons, which means that 1 ton of COD reduction generates 14.7 tons of carbon dioxide emissions.

b) Former calculations are all concentrated on the running process of wastewater treatment plant. This paper expands the carbon emission calculation area of wastewater treatment plants by covering emissions both on running process and construction process, and estimates the emissions on wastewater treatment plant's lifecycle which reflects its carbon consumption more comprehensively.

c) The construction and running of WWTP has caused the increase of CO_2 and formed a new carbon source. From the year of 2005 to 2008, the COD emission reduction from WWTP was 22.58 million tons (estimated by the author based on population form China's Statistics Year Book 2006-2008 and COD emission from China's Environmental Statistics Year Book), and the total CO_2 emission caused by WWTP is 331.87 million tons. This shows that the large-scale construction of WWTP in China did have played a great effect on environment governance, but not conductive to low-carbon.

d) The CO_2 emission reduction of wastewater treatment plant is of necessity. According to the China's total energy consumption in 2007 (China Energy Statistical Yearbook 2007) and CO_2 emission coefficient (issued by IPCC）, the total CO_2 emissions in China in 2007 is 9495.92 million ton. This means the CO_2 emissions of wastewater treatment account for 1.15% of the national emissions and list as the 5th large CO_2 emissions source. And in the rapid growth of wastewater treatment plants, the proportion of CO_2 emission of wastewater treatment in total emission will probably increase. In this situation, the CO_2 emission reduction in WWTP is of great necessity.

e) Develop suitable WWTP plans and increase its energy efficiency. According to the above calculation, the CO_2 emission of wastewater treatment plant is concentrated in the material consumption of its construction process. And recently in some cities of China the treating capacity of wastewater treatment plant is higher than its actual treating amount. This is a waste of construction cost in some extent and cause the increase of CO_2 emission per COD reduction. Thus, the decision makers should make careful plan of the wastewater treatment plants' construction and design its capacity according to the local wastewater treating needs. In long-term plan, the construction could be developed in stages based on the treating needs prognosis.

f) The best solution to emission reduction is to reduce pollution at source. The end-of-pipe pollution control measures can result in a waste of energy and greenhouse gas emissions. In this way, reducing pollution at source should be emphasized in emission reduction, so as to achieve the win-win relationship between energy conservation and environmental protection.

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APPENDIX I THETOTAL OUTPUT OF ALL SECTORS DRIVEN BY INVESTMENT AND THE CARBON DIOXIDE EMISSIONS GENERATED BYALL SECTORS

Industry	Agriculture, Forestry, Animal Husbandry, Fishery and Water Conservancy	Mining and Washin g of Coal	Extraction of Petroleum and Natural Gas	Mining and Processing of Ferrous Metal Ores	Mining and Processing of Non-metal Ores	Processin g of Food from Agricultur al Products	Textile	Textile, Garment, Leather and Feather, and Products Processed from them	Wood Processing and Furniture Manufacturing Industries	Paper, Printing and the Manufacturing of Products for Education and Sports
Increase in total output (10 thousand yuan)	384	113	174	142	38	357	99	106	63	125
Carbon dioxide emissions (thousand tons)	1,279	4,030	1,394	943	235	862	472	120	113	868
Industry	Petroleum processing, coking and nuclear fuel processing	Chemic al Industry	The industry of non-metallic mineral products	Metal smelting and rolling processing industry	Fabricated metal products	General, special equipment manufactu ring industry	Equipment manufacturi ng for traffic and transportati on	Electrical Machinery and equipment manufacturin g	Communicatio ns equipment, computers and other electronic equipment manufacturing	Instruments and meters, and office machinery manufacturing
Increase in total output (10 thousand yuan)	244	618	199	833	173	1295	169	229	289	155
Carbon dioxide emissions (thousand tons)	16,273	7,064	4,217	21,452	517	2,644	247	230	256	150
Industry	Artwork and other manufacturing industry	Wastepr oducts and waste material s	Production and supply of electricity, and heat	Gas production and supply	Water production and supply	Constructi on industry	Traffic and transport, storage and postal industry	Wholesaleand retail \ accommodati on and catering services	Other industries	Consumption
Increase in total output (10 thousand yuan)	44	77	386	12	12	508	379	376	1,019	1491
Carbon dioxide emissions (thousand tons)	194	17	34914	360	41	384	3300	901	1642	4242