Do Environmental Protection Projects Necessarily Save Energy and Reduce Carbon Emissions? —Post-print of Carbon Emission Accounting for Shouchang Wastewater Treatment Plant in Jiande, Hangzhou

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Abstract

This study employs the Shouchang Wastewater Treatment Plant in Jiande City, Hangzhou as an empirical case to investigate the energy conservation and carbon reduction effects of county-level environmental protection projects. The paper commences with theoretical and methodological frameworks, introducing accounting methodologies for direct and indirect carbon emissions during wastewater treatment processes. Using the carbon accounting of Beijing' s Gaobeidian Wastewater Treatment Plant as a reference, the study conducts a detailed quantification of carbon emissions from the Shouchang facility. The research reveals that in 2023, the Shouchang Wastewater Treatment Plant removed approximately 15 tons of total nitrogen and 2 tons of total phosphorus annually. The total carbon emissions generated amounted to 1105.51 tons of CO equivalent, with a unit water treatment carbon intensity of 0.397 kg CO equivalent per ton of water. Electricity consumption constituted the primary emission source, while sludge drying and incineration technology effectively reduced carbon emissions. While wastewater treatment plants are essential for environmental remediation, they themselves generate carbon emissions. This study proposes converting the nitrogen and phosphorus removal effectiveness of water environmental protection projects into equivalent wastewater treatment plant units, which can serve as a benchmark for carbon emission calculation and comparison in water ecological projects, thereby providing scientific support for the carbon reduction evaluation of water environment purification-oriented ecological environmental protection projects.

Full Text

Preamble

Does Environmental Protection Engineering Necessarily Save Energy and Reduce Carbon Emissions? —Carbon Emission Accounting of Shouchang Wastewater Treatment Plant in Jiande City, Hangzhou

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Abstract

This study examines the energy-saving and carbon reduction effects of county-level environmental protection projects through an empirical case study of the Shouchang Wastewater Treatment Plant in Jiande City, Hangzhou. Beginning with theoretical and methodological frameworks, the paper introduces direct and indirect carbon emission accounting methods for wastewater treatment processes. Using the accounting results from Beijing' s Gaobeidian Wastewater Treatment Plant as a benchmark, it provides a detailed calculation of Shouchang Plant' s carbon emissions. The study finds that in 2023, Shouchang Wastewater Treatment Plant treated approximately 15 tons of total nitrogen and 2 tons of total phosphorus annually, generating total carbon emissions of 1105.51 tons CO equivalent with a carbon intensity of 0.397 kgCO equivalent per ton of water treated. Electricity consumption represents the primary emission source, while sludge drying and incineration technology effectively reduces carbon emissions. While environmental governance requires constructing and operating wastewater treatment plants, these facilities themselves generate carbon emissions. This research proposes converting the nitrogen and phosphorus reduction effects of water environment protection projects into equivalent wastewater treatment plant capacity, providing a methodology for carbon emission calculation and comparative benchmarking of water ecological projects, thereby offering scientific support for assessing carbon reduction in water environment purification initiatives.

Keywords: Wastewater Treatment Plant; Carbon Emission Accounting; Water Environment Protection; Energy Saving and Carbon Reduction; World Bank Loan Project
Classification Codes: X703; X196; TU991.2

Water purification treatment involves the transformation and removal of pollutants such as total nitrogen and total phosphorus from water bodies. However, does nitrogen removal in water bodies truly mean carbon reduction? While environmental protection engineering aims to save energy and reduce carbon emissions, it does not "necessarily" equate to 100% energy conservation and carbon reduction. Actual outcomes depend on multiple factors and may sometimes produce contradictory results. Why does environmental protection engineering "not necessarily" achieve 100% energy saving and carbon reduction, and may even increase energy consumption and carbon emissions? The most typical examples are wastewater treatment plants, waste incineration facilities, and air purification systems, as they are enormous energy consumers themselves. They require electricity to drive pumps, blowers, compressors, and other equipment. Although the treatment process reduces pollutant emissions (achieving environmental goals), operational energy consumption generates carbon emissions (unless powered by 100% renewable energy). This phenomenon is also known as the "rebound effect" or "Jevons Paradox."

In 1865, British economist William Stanley Jevons published *The Coal Question*, proposing a paradox—despite technological progress improving coal utilization efficiency, total consumption actually increased. He stated: "It is a confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption. The very contrary is the truth" [1][2]. In other words, when improving efficiency (saving energy) or reducing the environmental cost of an activity (such as cleaner transportation), the total volume of that activity may increase, ultimately offsetting or even exceeding the energy-saving and carbon-reduction benefits of efficiency gains. For example, more fuel-efficient cars may lead people to drive more or travel longer distances, and lower wastewater treatment costs may stimulate greater water usage.

Currently, against the backdrop of China's rapid development in the wastewater treatment sector, scientifically estimating carbon emissions from this expansion has become fundamental research for coordinating environmental governance needs with low-carbon development. Specifically, as China' s economy continues to grow, total wastewater discharge keeps rising, driving simultaneous expansion of urban wastewater treatment facilities. During wastewater treatment, anaerobic digestion releases methane (CH), and biological nitrogen removal produces nitrous oxide (N O). These two greenhouse gases have stable chemical properties and long atmospheric residence times, contributing to global warming. Their conversion relationships to CO are 25 and 298, respectively. This conversion relationship is also known as carbon dioxide equivalent or Global Warming Potential (GWP). A gas' s CO equivalent is calculated by multiplying its tonnage by its GWP—meaning reducing 1 ton of methane emissions is equivalent to reducing 25 tons of CO emissions. Note that according to the *Technical Guidelines for Coordinated Control of Greenhouse Gas Accounting for Pollutant Removal in Urban Wastewater Treatment Plants (Trial)* issued by the Ministry of Ecology and Environment in April 2018, 1 ton of methane from wastewater treatment plants is set at 21 tons CO equivalent rather than 25 tons. Similarly, GWP values may be adjusted in specific contexts. Additionally, note that CO emissions from wastewater treatment are biogenic and are not considered in the IPCC national greenhouse gas inventory guidelines, thus not included in national emission totals.

Domestic carbon emission calculations for wastewater treatment now basically follow the IPCC-recommended methodology. For instance, Wang Xixi et al. (2012) estimated carbon emissions from wastewater in China from 1998-2008, proposing a comprehensive accounting method that uses biochemical reaction process methods and electricity consumption conversion methods to calculate direct greenhouse gas emissions from biochemical reactions and indirect carbon emission equivalents from treatment system energy consumption. Ma Xin (2011) found significant differences between direct and indirect carbon emission characteristics. In absolute terms, indirect carbon emissions from provincial wastewater treatment plants generally exceed direct emissions by more than twofold. Meanwhile, indirect emissions show extremely strong correlation with total carbon emissions (correlation coefficient of 0.9), confirming that indirect emissions are the dominant source of greenhouse gases from wastewater treatment plants [3], though this conclusion was based on 2006-2009 data. The study further confirmed that direct greenhouse gas emissions in urban wastewater treatment mainly originate from the biochemical decomposition of organic matter represented by COD (Chemical Oxygen Demand). When treatment duration and total wastewater volume remain constant, improving COD removal rates significantly increases direct carbon emission intensity, while low-removal-rate processes correspond to lower emission levels. This phenomenon indicates a dilemma between improving COD removal efficiency and reducing direct greenhouse gas emissions. From a greenhouse gas reduction perspective, larger wastewater treatment plants have higher CO equivalent emission levels, which is unfavorable for mitigating greenhouse gases. Overall, developing medium-sized wastewater treatment plants can balance both objectives (COD removal rate and reduced direct greenhouse gas emissions) to some extent.

Statistics show that China' s urban wastewater treatment plants consume an average of 0.292 kWh of electricity per cubic meter of wastewater treated [4][5]. Based on the greenhouse gas CO equivalent from power generation (i.e., emissions per kWh), electricity consumption is converted to carbon emissions using a conversion factor of 8.448×10 tons CO /kWh (this conversion factor comes from U.S. Department of Energy (EIA) data on China' s power emissions from 1999-2002; we will use values published by China' s Ministry of Ecology and Environment in subsequent calculations). The indirect carbon emissions for domestic wastewater treatment are then: conversion factor × total electricity consumption for wastewater treatment.

Currently, countries including the United States, Australia, Canada, the United Kingdom, and New Zealand regularly publish their national grid average emission factors. The European Environment Agency (EEA) has been collecting and updating electricity carbon emission intensity data for European countries and Europe as a whole annually since 1990. EEA' s calculation method is basically the same as China' s grid emission factor. This value has decreased from 0.524 tons CO /MWh at its initial release (1 MWh equals 1000 kWh) to approximately 0.289 tons CO /MWh in 2021. China has published its national grid emission factor three times so far: the first in December 2017 by the National Development and Reform Commission at 0.6101 tons CO /MWh; the second in March 2022 by the Ministry of Ecology and Environment adjusted to 0.5703 tons CO /MWh. The Ministry of Ecology and Environment also announced that if the annual national grid average emission factor is updated, it will be released at the end of each year.

2 Research Methods for Wastewater Treatment Plant Carbon Emission Accounting

For wastewater treatment plant carbon emission accounting, this paper adopts a stepwise accumulation method. Based on existing research, assuming the inverted AAO process conditions at Shouchang Plant, a complete wastewater treatment cycle requires COD removal, nitrogen and phosphorus separation, and final disposal of treated sludge. Therefore, the plant' s carbon emissions are divided into three components: "direct emissions" from nitrogen and phosphorus removal, "indirect emissions" from electricity consumption, and "solid waste treatment emissions" from waste disposal. Direct greenhouse gas emissions mainly come from: 1) CH emissions from CODCr removal, and 2) N O emissions from total nitrogen (TN) removal. The total carbon emission accounting for the wastewater treatment plant converts all emissions from these processes into corresponding CO emissions through appropriate factors and sums them

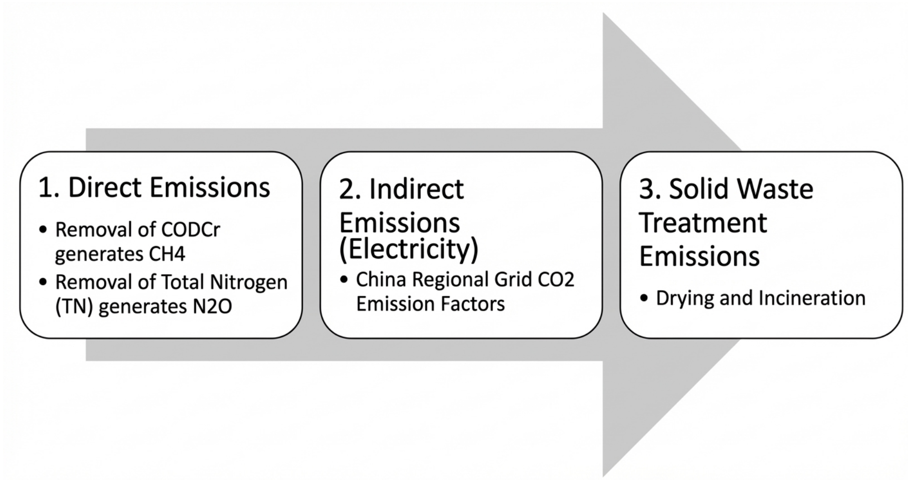

Figure 1: Figure 1

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Composition of Carbon Emissions from Wastewater Treatment Plants

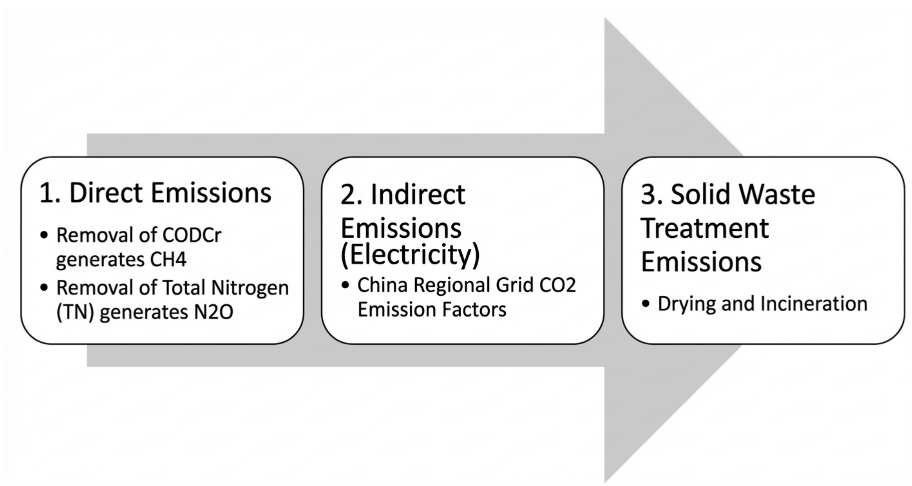

Figure 2: Figure 1

3 Case Study–Beijing Gaobeidian Plant as an Example

Following Ma Xin (2011) in the literature *Research on Greenhouse Gas Emissions from Urban Domestic Wastewater Treatment Plants in China* [3], we calculate the carbon emission effects using Hebei Gaobeidian Wastewater Treatment Plant as an example:

3.1 Direct Greenhouse Gas Emissions

The calculation formula is:

$$\text{Emissions (direct)} = \text{COD}_{\text{removed}} \times \text{MCF} \times B_0 \times \text{GWP}$$

······Formula (1)

Based on the above formula, substituting parameter values:

$$\text{Emissions (direct)} = 79324.7 \times 0.8 \times 0.25 \times 21 = 333163.74$$

Where in 2007, Gaobeidian Wastewater Treatment Plant achieved a chemical oxygen demand (COD) removal of 79,324.7 tons. According to its treatment process, MCF can be taken as 0.8, and B uses 0.25 kg CH /kg COD. Based on greenhouse gas accounting for the wastewater treatment process, the CH emissions for that year are calculated as 79,324.7 × 0.8 × 0.25 = 15,864.94 tons, which must be multiplied by methane' s Global Warming Potential (GWP) of 21 to assess climate impact. Therefore, the CO equivalent emissions from

Beijing Gaobeidian Wastewater Treatment Plant in 2007 are 15,864.94 × 21 = 333,163.74 tons.

The 2007 Gaobeidian Wastewater Treatment Plant case is cited from the literature "Ma Xin. Research on Greenhouse Gas Emissions from Urban Domestic Wastewater Treatment Plants in China [D]. Beijing Forestry University, 2011." Here, the CH GWP value of 21 is taken from Section 6.2.2 on page 4 of the *Technical Guidelines for Coordinated Control of Greenhouse Gas Accounting for Pollutant Removal in Urban Wastewater Treatment Plants (Trial)* issued by the Ministry of Ecology and Environment in April 2018, which sets 1 ton of methane from wastewater treatment plants at 21 tons CO equivalent.

3.2 Indirect Greenhouse Gas Emissions

The calculation formula is:

CO_2 indirect emissions = Annual electricity consumption (MWh)×OM emission factor (tCO_2/MWh)

······Formula (2)

Substituting Gaobeidian Wastewater Treatment Plant' s 2007 annual electricity consumption of 5,644 MWh, and since the plant is located in Beijing under the North China regional grid coverage, the Operating Margin (OM) emission factor of 1.0069 tCO /MWh is used as the calculation basis, yielding CO indirect emissions of 5,682.9 tons.

Thus, Gaobeidian Wastewater Treatment Plant (Beijing) total CO emissions for 2007 are calculated as 33,884.6 tons, the sum of direct and indirect emissions, with an emission intensity of 0.34 tons CO equivalent per ton of water. Note that greenhouse gas emissions from sludge treatment processes were not included in this calculation.

4 Empirical Analysis of Carbon Emission Accounting for Shouchang Wastewater Treatment Plant in Jiande City, Hangzhou

The accounting methodology employed in this study follows multiple officially published guidelines and standards, including the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (currently used by World Bank China projects for carbon reduction accounting), the emission factor method in the *Provincial Greenhouse Gas Inventory Compilation Guidelines (Trial)*, and the *Technical Guidelines for Coordinated Control of Greenhouse Gas Accounting for Pollutant Removal in Urban Wastewater Treatment Plants (Trial)* issued by the Ministry of Ecology and Environment in April 2018. The carbon emission calculation formulas for methane (CH) and nitrous oxide (N O) follow the IPCC Guidelines as shown in [FIGURE:

Figures

① The carbon emissions for CH_4 carbon emmission is is shown in equation (1).

$$M_{CH4}= \Delta COD \times V \times EF_{CH4} \times 10^{-6} \times GWP_{CH4} \qquad (1)$$

Where:

M_{CH4}——CH_4 castawater mt during carbon immissions, $kgCO_2$;

ΔCOD——COD concecration reduction, mg/L;

V——Wastewater treatment volume, L;

EF_{CH4}——CH_4 emission factor, $kgCH_4/kgCOD$;

GWP_{CH4}——Global Warming Potential, GWP of CH_4 is 25.0.

Figure 3: Figure 2

Table 1-3 The MCF defaults of domestic sewage recommended by IPCC [a]

Treatment and discharge pathway / System type	Remarks	MCF	Range
	Treated systems		
Centralized aerobic treatment plant	Must be well managed, some CH_4 will be emitted from settling ponds and sludge bags	0	0-0.1
Centralized aerobic treatment plant	Poorly managed, overloaded	0.3	0.2-0.4
Anaerobic digester for sludge	CH_4 recovery is not considered here	0.8	0.8-1.0
Anaerobic reactor	CH_4 recovery is not considered here	0.8	0.8-1.0
Shallow anaerobic pond	Depth is less than 2 meters, based on expert judgment	0.2	0-0.3
Deep anaerobic pond	Depth exceeds 2 meters	0.8	0.8-1.0
Septic system	Half of the BOD settles into the anaerobic pond	0.5	0.5

Note a: Translated from the IPCC report

Figure 4: Figure 3

Source: ChinaXiv —Machine translation. Verify with original.

6.2.4 N_2O Emissions from TN Removal

$$E_4 = R_{TN} \times EF_{N2O} \times C_{N2O/2N} \times GWP_{N2O}$$

Where: E_4 — Annur sewage treatment from total TN removal N_2O emissions converted to carben dioxide equivalent, t CO_{2eq}/a;

R_{TN} — Anrual sewage treatment planual TN removal amount, t N/a;

EF_{N2O} — Amount of nitrogen in sitrogen pews can be convverted to nitrous oxide nitrogen. The value for the aerobic section is 0, ar, the anolcic value is 0.005 t N_2O-N/t N;

C_{N2O/N_2} — l Ratio of molecular weights of N_2O to N_2, 44/28;

GWP_{N2O} — N_2O Global Warming Potential value, taken as 310.

Figure 5: Figure 4

China's Provincial Grid Emission Factors for 2010, 2012, 2018, and 2020 ($kgCO_2/kWh$)

Province	2010	2012	2018	2020
Liaoning	0.836	0.775	0.722	0.91
Jilin	0.679	0.721	0.615	0.839
Heilongjiang	0.816	0.797	0.663	0.814
Beijing	0.829	0.776	0.617	0.615
Tianjin	0.873	0.892	0.812	0.841
Hebei	0.915	0.898	0.903	1.092
Shanxi	0.88	0.849	0.74	0.841
Inner Mongolia	0.85	0.929	0.753	1.000
Shandong	0.924	0.888	0.861	0.742
Shanghai	0.793	0.624	0.564	0.548
Jiangsu	0.736	0.75	0.683	0.695
Zhejiang	0.682	0.665	0.525	0.532
Anhui	0.791	0.809	0.776	0.763
Fujian	0.544	0.551	0.391	0.489
Jiangxi	0.764	0.634	0.634	0.616
Henan	0.844	0.806	0.791	0.738
Hubei	0.372	0.353	0.357	0.316
Hunan	0.552	0.517	0.499	0.487
Chongqing	0.629	0.574	0.441	0.482
Sichuan	0.289	0.248	0.103	0.117
Guangdong	0.638	0.591	0.451	0.445
Guangxi	0.482	0.495	0.394	0.526
Hainan	0.646	0.496	0.515	0.459
Guizhou	0.656	0.495	0.428	0.42
Yunnan	0.415	0.306	0.092	0.146
Shaanxi	0.87	0.769	0.767	0.641
Gansu	0.612	0.573	0.491	0.46
Qinghai	0.226	0.232	0.26	0.095
Ningxia	0.818	0.779	0.62	0.872
Xinjiang	0.764	0.79	0.622	0.749

Note: The data for 2010 in the table comes from the National Development and Reform Commission's "Average Emission Factors of China's Regional and Provincial Grids in 2010"; the data for 2012 comes from the National Development and Reform Commission's "Average CO_2 Emission Factors of Provincial Grids in 2012"; the data for 2018 comes from the "Letter regarding the request for submission of the 2018 provincial government's self-assessment report on the implementation of greenhouse gas emission control targets"; the data for 2020 are calculated by this study.

Figure 6: Figure 5

Table 3-2 Comparison of Sludge Generation in Four Treatment Processes

Tab.3-2 The comparation of four kinds of processes on sludge generation

Treatment Method	Statistics (Plants)	Actual Annual Water Treated (10^4 tons)	Sludge Production (10^4 tons)	COD Removed (10^4 tons)	Average Sludge (tons/10^4 tons water)	Average Sludge (tons/ton COD)
Activated Sludge	95	144685	126.09	45.62	8.71	2.76
A^2/O	83	105137	218.79	32.97	20.81	6.64
SBR	111	61698	110.18	14.24	17.86	7.74
Oxidation Ditch	129	76715	52.82	17.53	6.88	3.01

Figure 7: Figure 6

Wastewater Treatment Plant	Total Annual Wastewater Treatment Volume (T/Day × 365 Days)	Annual CO_2 Equivalent Discharge (KgCO2-Eq/Annual)	Carbon Emission Intendity (KgCO2-Eq/T)
Hangzhou Jiande Shouchang Wastewater Treatment Plant	0.76247 Thond Tons/Day × 365 Days = 278.3 Thond Tons/Year	1105.51×10^3	0.397
Germany Bochum-Ölbachtal Wastewater Plant	4.3 Thond Tons/Day × 365 Days = 1569.5 Thond Tons/Year	5640×10^3	0.359
Germany Köhlbrandhöft/Dradenau Wastewater Treatment Plant	38.2 Thond Tons/Day × 365 Days = 13943 Thond Tons/Year	176703×10^3	1.267
Greece Chania Wastewater Treatment Plant	1.94 Thond Tons/Day × 365 Days = 708.1 Thond Tons/Year	3023×10^3	0.427

Source: Hao Xiaodi, Zhang Yining, Li Ji, et al. Case Analysis of Energy Neutrality and Carbon Neutrality in Wastewater Treatment.

Figure 8: Figure 7