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

Authors: Shi Hao, Yu Guopei, Shi Hao

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Abstract

This study employs the Shouchang Wastewater Treatment Plant in Jiande City, Hangzhou as an empirical case study to investigate the energy conservation and carbon reduction effects of county-level environmental protection projects. The paper commences with a theoretical and methodological framework, introducing accounting methods for direct and indirect carbon emissions in wastewater treatment processes. Using the accounting results of Beijing Gaobeidian Wastewater Treatment Plant as a reference, it conducts detailed calculations of carbon emissions for the Shouchang Wastewater Treatment Plant. The study 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 CO2 equivalent, with a carbon intensity of 0.397 kg CO2 equivalent per ton of water treated. Electricity consumption constituted the primary emission source, while sludge drying and incineration technology effectively reduced carbon emissions. While environmental governance necessitates the construction and operation of wastewater treatment plants, the plants themselves also generate carbon emissions. This study proposes converting the nitrogen and phosphorus removal effects of water environmental protection projects into equivalent wastewater treatment plant numbers, which can serve as a benchmark for carbon emission accounting and comparison in aquatic ecological projects, thereby providing scientific support for carbon reduction assessment of water environment purification ecological protection projects.

Full Text

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

Shi Hao, Yu Guopei
E-commerce and New Consumption Research Institute, Zhejiang Financial College, Hangzhou 310018, Zhejiang

Abstract: This study employs the Shouchang Wastewater Treatment Plant in Jiande City, Hangzhou as an empirical case to investigate the energy-saving and carbon reduction effects of county-level environmental protection projects. 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 reference, it meticulously calculates the carbon emissions of the Shouchang facility. The research finds that in 2023, the Shouchang 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 study proposes converting the nitrogen and phosphorus reduction effects of water environment protection projects into equivalent numbers of wastewater treatment plants, providing a methodology for carbon emission calculation and comparative benchmarking of water ecological projects, thereby offering scientific support for carbon reduction assessment 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: 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 from water truly equate to carbon reduction? While environmental protection projects aim to save energy and reduce carbon emissions, they do not "necessarily" achieve 100% energy conservation and carbon reduction. Actual outcomes depend on multiple factors and may sometimes produce contradictory results. Why do environmental protection projects "not necessarily" achieve 100% energy saving and carbon reduction, and may even increase energy consumption and carbon emissions? The most typical examples include wastewater treatment plants, waste incineration facilities, and air purification equipment, as they are enormous energy consumers themselves. These facilities require electricity to drive pumps, blowers, compressors, and other equipment. Although the treatment process reduces pollutant emissions (fulfilling environmental goals), the operational energy consumption itself 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 his monograph *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 gained from efficiency improvements. For instance, more fuel-efficient cars may lead people to drive more or travel longer distances; reduced wastewater treatment costs may stimulate greater water consumption.

Currently, against the backdrop of rapid and sustained development in China’s wastewater treatment sector, scientifically estimating carbon emissions from this scale expansion has become fundamental research for coordinating environmental governance needs with low-carbon development. Specifically, as China’s economy continues to develop, total wastewater discharge keeps rising, driving simultaneous expansion of urban wastewater treatment facilities. During wastewater treatment, the anaerobic digestion process releases methane (CH), and biological nitrogen removal generates 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 (GWP values). This conversion relationship is also known as carbon dioxide equivalent or Global Warming Potential (GWP). A gas’s CO equivalent is calculated by multiplying the tons of that gas by its GWP value. Thus, reducing 1 ton of methane emissions is equivalent to reducing 25 tons of CO emissions, meaning 1 ton of methane has a CO equivalent of 25 tons. This method standardizes the effects of different greenhouse gases. Note that according to the “Technical Guidelines for Synergistic 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 CO equivalent of 1 ton of methane from wastewater treatment plants is set at 21 tons rather than 25 tons. Similarly, GWP values may be fine-tuned in different 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 currently basically follow the methods recommended by the IPCC. For example, Wang Xixi et al. (2012) estimated carbon emissions from wastewater in China from 1998-2008 and proposed a comprehensive accounting method using biochemical reaction process methods and electricity consumption conversion methods to account for direct greenhouse gas emissions from biochemical reactions during wastewater treatment and indirect carbon emissions 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 wastewater treatment plants in various provinces and cities generally exceed direct emissions by more than twofold. Meanwhile, indirect carbon 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 data from 2006-2009. The study further confirmed that direct greenhouse gas emissions during 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 processes with low removal rates 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 greenhouse gas emission reduction) to some extent.

Statistics show that the average electricity consumption for treating one cubic meter of wastewater in China's urban wastewater treatment plants is 0.292 kWh [4][5]. Subsequently, 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). Thus, indirect carbon emissions from domestic wastewater treatment are calculated as: 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 publication (1 MW equals 1000 kW) to approximately 0.289 tons CO /MWh in 2021. China has published its national grid emission factor three times to date: the first in December 2017 by the National

Development and Reform Commission with a value of 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 published at the end of each year.

2 Research Methods for Wastewater Treatment Plant Carbon Emission Accounting

For carbon emission accounting of wastewater treatment plants, this paper adopts a stepwise accumulation method. Based on existing research and assuming inverted AAO process conditions at the 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 emissions from the wastewater treatment plant are calculated by converting all emissions from these processes into corresponding CO emissions using appropriate factors and summing them up

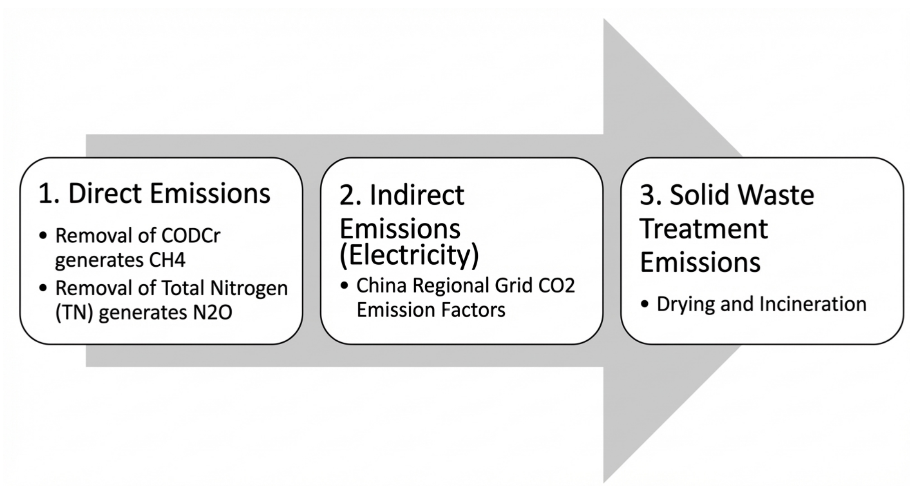

Figure 1: Figure 1

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Composition of carbon emissions from wastewater treatment plants

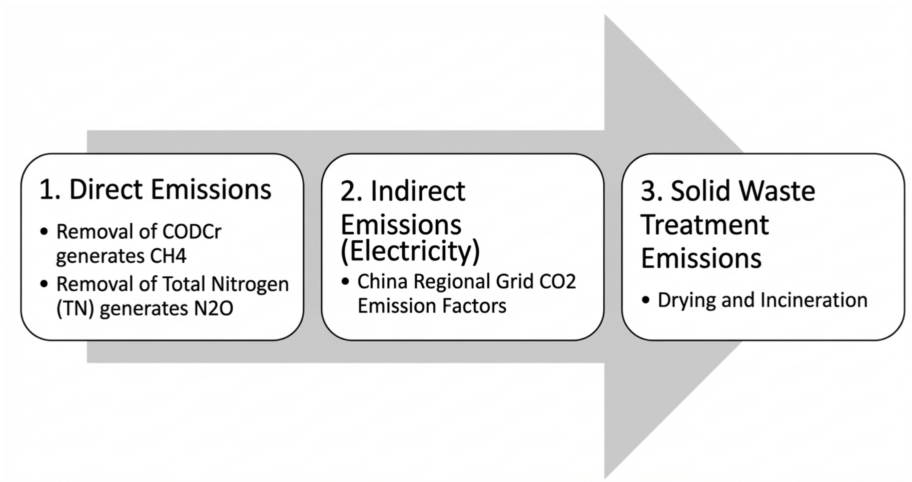

Figure 2: Figure 1

3 Case Study: Beijing Gaobeidian Plant as an Example

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

3.1 Direct Greenhouse Gas Emissions

The calculation formula is:
Emissions (direct) = $COD \times MCF \times B \times GWP(CH)$ ······Formula (1)

Based on the above formula, substituting parameter values as follows:
Emissions (direct) = $79324.7 \times 0.8 \times 0.25 \times 21 = 333163.74$

In 2007, the 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 as 0.25 kg CH /kg COD. Based on greenhouse gas accounting for the wastewater treatment process, CH emissions for that year were calculated as $79{,}324.7 \times 0.8 \times 0.25 = 15{,}864.94$ tons. This value must be multiplied by methane' s Global Warming Potential (GWP) of 21 to assess climate impact. Therefore, the CO equivalent emissions from the Beijing Gaobeidian Wastewater Treatment Plant' s treatment process in 2007 are $15{,}864.94 \times 21 = 333{,}163.74$ tons.

The 2007 Gaobeidian Wastewater Treatment Plant case is cited from the literature "Ma Xin. Study 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 Synergistic 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 the CO equivalent of 1 ton of methane from wastewater treatment plants at 21 tons.

3.2 Indirect Greenhouse Gas Emissions

The calculation formula is:
CO emissions = Annual electricity consumption (MWh) × Electricity margin emission factor (tCO /MWh) ······Formula (2)

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

Thus, the total CO emissions for the Gaobeidian Wastewater Treatment Plant (Beijing) in 2007 are calculated as 33,884.6 tons, representing 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 the sludge treatment process were not included in this calculation.

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

The accounting method employed in this study is based on 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 "Guidelines for Provincial Greenhouse Gas Inventory Compilation (Trial)," and the "Technical Guidelines for Synergistic 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

[6][7].

Relevant provisions in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories

Where EF is calculated as EF = B × MCF, with B representing the maximum CH production capacity (default values of 0.6 or 0.25 kg CH /kg COD) and MCF representing the CH correction factor. The IPCC Guidelines provide Table 1 -3 (please refer to

) to support countries in generating comparable greenhouse gas emission inventories. When no country-specific emission factor data is available, the preset

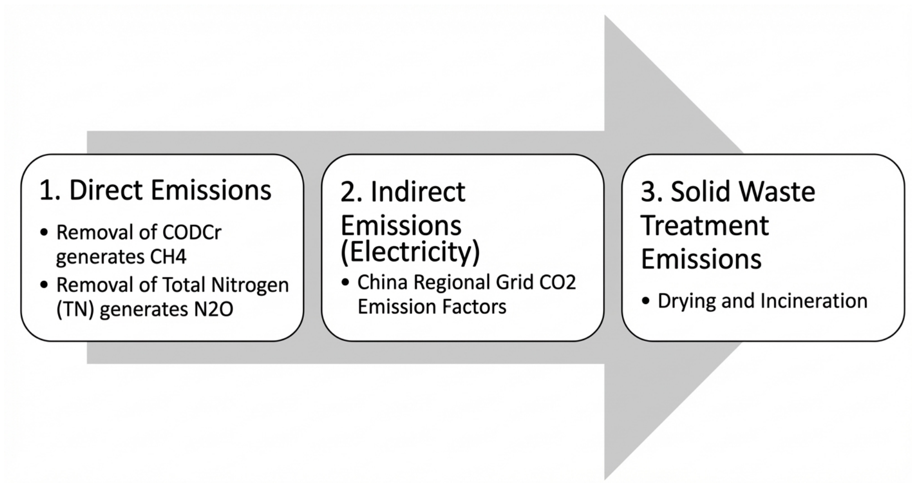

Figure 3: Figure 1

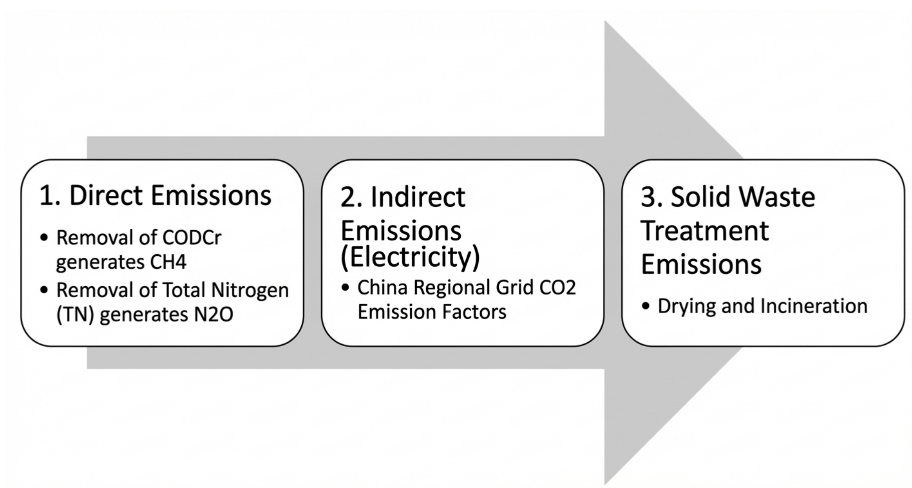

Figure 4: Figure 1

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 5: Figure 2

default values in this table are recommended for accounting CH emissions from wastewater treatment.

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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 6: Figure 2

Default MCF values from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories

Following the IPCC Guidelines and using the calculation steps for the Hebei Gaobeidian Wastewater Treatment Plant as a template, we estimate the carbon emissions of the Jiande Shouchang Wastewater Treatment Plant using a similar method.

4.1 Direct Greenhouse Gas Emissions

Direct carbon emissions include CH and N O emissions (according to the IPCC Guidelines, CO from biological decomposition is considered biogenic carbon, while biogas and sludge are classified as biofuels or renewable energy, and thus neither is included in carbon emission inventory accounting). Greenhouse gas emissions are associated with pollutant removal activities—under anaerobic conditions, CODCr removal produces CH through biochemical conversion, and anaerobic microbial degradation of sludge organic matter also generates significant CH ; simultaneously, in the biochemical nitrogen removal pathway (nitrification→denitrification), TN reduction brings N O emissions.

4.1.1 CH Emissions from CODCr Removal Based on Formula (1), substituting data as follows:
Emissions (direct) = 78.58 × 0.3 × 0.25 × 21 = 123.76

According to survey data from the Jiande Shouchang Wastewater Treatment Plant, in 2023 the plant adopted an inverted AAO process [8][9], with annual COD removal of 78.58 tons. Based on this inverted AAO process, MCF can be taken as 0.3 and B as 0.25 kg CH /kg COD. Accounting shows CH emissions from the wastewater treatment process that year were 78.58 × 0.3 × 0.25 = 5.8935 tons. Multiplying by methane' s Global Warming Potential coefficient of 21 yields total CO equivalent emissions of 5.8935 × 21 = 123.76 tons CO e for this process at the Jiande Shouchang plant in 2023.

4.1.2 N O Emissions from Total Nitrogen (TN) Removal Given that excessive nitrogen and phosphorus discharge causes water eutrophication, China lists ammonia nitrogen and total phosphorus as key indicators for evaluating wastewater treatment plant performance. Current wastewater treatment processes primarily rely on biological nitrogen removal, which converts nitrogen in wastewater to nitrogen gas through nitrification under aerobic conditions and denitrification under anoxic conditions.

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 7: Figure 3

N O emissions from TN removal
Data source: "Technical Guidelines for Synergistic Control of Greenhouse Gas Accounting for Pollutant Removal in Urban Wastewater Treatment Plants (Trial)," Ministry of Ecology and Environment, April 2018 [10]

According to the formula in

, substituting data as follows:
N O emissions = 14.89 × 0.016 × 28 × 310 = 116.06

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 8: Figure 3

In 2023, the Jiande Shouchang Wastewater Treatment Plant treated 14.89 tons of total nitrogen TN annually using biological nitrogen removal. According to Section 6.2.4 of the "Technical Guidelines for Synergistic Control of Greenhouse Gas Accounting for Pollutant Removal in Urban Wastewater Treatment Plants (Trial)" (please refer to

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 9: Figure 3

), and using the IPCC-recommended default emission factor of 0.016 t N O-N/t N [11][12], the equivalent CO emissions from TN removal are calculated as 14.89 $\times$ 0.016 $\times$ 28 $\times$ 310 = 116.06 tons.

4.2 Indirect Emissions

The grid CO emission factor is an important basis for carbon emission accounting and verification. In October 2023, the Environmental Planning Institute of the Ministry of Ecology and Environment officially released the "Study on CO Emission Factors of China's Regional Power Grids (2023)" report [13], which calculates CO emission factors by province. For Zhejiang Province in 2020, the factor was 0.532 kg CO /kWh (please refer to

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 10: Figure 4

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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;

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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 11: Figure 4

CO emission factors of China' s regional power grids
Data source: "Study on CO Emission Factors of China' s Regional Power Grids (2023)" (Environmental Planning Institute, Ministry of Ecology and Environment)

According to Formula (2), substituting data as follows:
CO emissions = 1,456.770 MWh × 0.532 kg CO /kWh = 775 tons

In 2023, the Jiande Shouchang Wastewater Treatment Plant consumed 1,456.770 MWh of electricity. Using Zhejiang Province' s CO emission factor of 0.532 kg CO /kWh, CO emissions are calculated as 775 tons.

4.3.1 Wet Sludge Incineration

Waste disposal generally employs incineration. Due to high organic content and calorific value in sludge, incineration utilizes these characteristics for disposal. Compared with other sludge disposal methods such as composting and landfilling, incineration offers significant advantages: its product is sterile, odorless inorganic residue, achieving harmless and reduced-volume treatment goals.

However, incineration technology is difficult to popularize in developing countries. On one hand, it requires specific equipment and energy with high operating costs; on the other hand, sludge incineration produces smoke pollution, and the post-incineration ash is difficult to handle properly, limiting widespread application.

Notably, CO emissions from sewage sludge incineration are biogenic and, according to the IPCC Guidelines, are not included in total emissions. Therefore, this study only calculates CH and N O emissions. Assuming wet sludge incineration, and given that fluidized bed incineration is currently the main technology in China, the IPCC-recommended CH emission factor of 188 kg CH /t wet weight is adopted (Ma Xin, 2011) [3].

Using China' s specific emission factor values and setting methane recovery to zero, the calculation shows:
Wet sludge emissions = 188 kg CH /t × 25 kg CO e/kg CH = 4.7 tons CO equivalent per ton of wet sludge.
Thus, incinerating 1 ton of wet sludge produces 188 kg of CH , which converts to 188 × 25 = 4,700 kg CO = 4.7 tons CO equivalent.

According to Ma Xin's (2011) statistical survey of sludge generation in literature [3], as shown in

, the sludge generation coefficient for the inverted AAO process is 6.64 tons/ton COD (please refer to the last column of the second row in

). Since the plant' s annual COD removal is 78.58 tons, estimated sludge generation is 78.58 × 6.64 = 521.7712 tons. Incineration would thus produce 521.77 × 4.7 = 2,452 tons CO . This wet sludge approach is extremely undesirable and would generate massive carbon emissions.

Average sludge quantity statistics from Ma Xin (2011) literature

4.3.2 Drying and Incineration

The Jiande Shouchang Wastewater Treatment Plant adopts drying and incineration for waste disposal. Sludge incineration emits N O; if combustion is incomplete, CH is also produced, both constituting direct carbon emissions. However, in sludge drying and incineration projects, due to high incineration temperatures, strong turbulence, and long flue gas residence time, CH generation is typically avoided. Therefore, only N O emissions need consideration in drying and incineration. According to Jin Zechen et al. (2022) [14], the average CO equivalent carbon emission from N O produced per ton of dry sludge during incineration is 371 kg/t. Through actual investigation, the Shouchang plant generated 244.45 tons of dry sludge in 2023, thus producing 244.45 × 0.371 = 90.69 tons CO emissions.

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 12: Figure 5

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 13: Figure 5

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
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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 14: Figure 5

4.4 Total Emissions

In 2023, the total CO emissions of the Jiande City Shouchang Wastewater Treatment Plant include direct emissions, indirect emissions, and greenhouse gas emissions from sludge incineration treatment. The specific calculation is: 123.76 (CH direct emissions) + 116.06 (N O direct emissions) + 775 (electricity indirect emissions) + 90.69 (post-incineration emissions) = 1,105.51 tons CO equivalent.

Based on the Shouchang plant' s annual wastewater treatment volume of 2.783 million tons in 2023, the average carbon emission intensity is 0.397 kg CO equivalent per ton of water. This emission level closely matches 2023 wastewater plant emission levels in other regions of China. According to Hu Xiang, Meng Lingxin et al. (2023) [15], greenhouse gas emissions per unit of wastewater treated at a plant in the Chaohu Lake basin decreased from 0.3574 to 0.3009 kg [CO eq]/m^3, consistent with our accounting in magnitude. Electricity remains the primary greenhouse gas emission source, a conclusion that aligns with mainstream research literature (Zhang Zhiyong, 2023) [16].

5.1 Analysis of Shouchang Wastewater Treatment Plant Carbon Emission Assessment Results

The 2023 carbon emission accounting results for the Shouchang Wastewater Treatment Plant in Jiande City, Hangzhou show total annual carbon emissions of 1,105.51 tons CO equivalent, with a carbon intensity of 0.397 kg CO equivalent per ton of water treated. For domestic comparison, Wang Hongchen (2017) [17] found that in 2015, China' s carbon emission intensity per unit of water treated was 0.78 kg/m^3. For neighboring provinces, Zhang Xing (2018) [18] reported that Jiangsu Province' s wastewater treatment plant carbon emission intensity was 0.4960 kg CO equivalent per ton of water in 2015. For international comparison, using data from Hao Xiaodi, Zhang Yining et al. (2021) [19], we calculated carbon emission intensities for European wastewater treatment plants of different scales . These comparisons show that the estimated carbon emissions for the Jiande Shouchang plant fall within a reasonable and appropriate range.

Comparison of carbon emissions between Shouchang Wastewater Treatment Plant and typical European wastewater treatment plants

The empirical study of the Shouchang Wastewater Treatment Plant demonstrates that county-level environmental protection projects exhibit significant complexity in their carbon emission characteristics while achieving water quality purification. The plant's total annual carbon emissions are at a medium level, with carbon intensity per unit of water treated below the national average. This result primarily benefits from three factors: adopting advanced processes with low methane generation potential, innovative sludge drying and incineration technology, and moderate treatment scale balancing energy consumption and efficiency. Notably, electricity consumption remains the main source of carbon emissions, highlighting the urgency of optimizing energy structure, while scientific selection of sludge disposal methods can yield significant emission reduction benefits.

5.2 Implications for Carbon Emission Reduction in Ecological Environmental Protection Projects

Through carbon emission accounting for the Shouchang Wastewater Treatment Plant in Jiande City, Hangzhou, this research holds multidimensional significance for study and practice in energy saving and carbon reduction within the wastewater treatment sector. First, the study clarifies the order of magnitude of carbon emissions from wastewater treatment plants, providing industry and relevant departments with a clear understanding of the carbon footprint scale of wastewater treatment processes. This establishes a foundation for formulating targeted carbon reduction policies and planning energy-saving and emission-reduction pathways.

Second, the study reveals significant variations in carbon emission performance among wastewater treatment plants in different regions due to process and scale differences. The carbon emission accounting method used in this study demonstrates strong universality and flexibility, allowing adjustment and application according to different regions' climate conditions, energy structures, and wastewater characteristics. By extending this method to wastewater treatment plants in various regions, carbon emissions from wastewater treatment processes can be more accurately assessed, enabling scientifically sound and rational emission reduction strategies tailored to local conditions.

Furthermore, to improve environmental quality and water quality, at least two options exist: implementing "water environment protection projects" or constructing and operating wastewater treatment plants—both approaches achieve nitrogen and phosphorus reduction effects through different paths. For instance, the Shouchang plant treated approximately 15 tons of total nitrogen and 2 tons of total phosphorus in 2023. Unlike environmental protection projects, however, wastewater treatment plants inevitably generate carbon emissions. Therefore, by converting the nitrogen and phosphorus reduction effects of "water environment protection projects" into equivalent numbers of wastewater treatment plants, the carbon emission reductions achieved by these projects can be calculated. The measurement method developed in this study provides a unified calculation and comparison benchmark for water environment purification ecological protection projects. Previously, such water environmental projects lacked systematic carbon emission monitoring and evaluation systems, making objective assessment of their carbon reduction benefits difficult. The accounting method and evaluation standards established in this study can quantify the carbon reduction effectiveness of "water environment protection" type projects, facilitate horizontal comparison among water ecological projects, and promote the development of the entire environmental protection industry toward low-carbon and green transformation, providing important support for achieving ecological environmental protection and sustainable development goals.

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Figures

Source: ChinaXiv –Machine translation. Verify with original.

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 15: 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 16: Figure 7