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Carbon neutrality analysis of sewage treatment plant in China

Delin Fang[1*], Wenjie Zhang[1], Zhihan Zheng[1], Qingnan Cai[1], Bin Chen[2*]

1 Center for Geodata and Analysis, Faculty of Geographical Science, Beijing Normal University, Beijing 100875, China

2 School of Environment, Beijing Normal University, Beijing 100875, China

ABSTRACT

In order to achieve the carbon peak by 2030 and achieve the comprehensive goal of carbon neutrality by 2060, the research investigate the carbon emission performance of wastewater treatment plants (WWTPs) in China, and proposes suitable low-carbon strategies for WWTPs. The study utilized the operating data of 4346 WWTPs in China from 2014 to 2018, and calculated the carbon dioxide emissions and emission reductions. The carbon emissions include direct emissions (CH_4 and N_2O) during the treatment processes, and indirect carbon emissions embodied energy consumption. The carbon sinks comprise energy self-sufficient, energy saving by water reuse, and carbon emissions reduced by sludge composting. Research further simulated provincial carbon neutrality situation by meticulously giving each province a series of index determined by their per capita GDP, sunlight hours, per capita water sources, energy consumption of process design and agricultural land area. The results show that from 2014 to 2018, WWTPs in all provinces were still unable to achieve the target of carbon neutrality. Since the growth rate of carbon emissions is generally higher than that of carbon sequestration, the carbon neutrality efficiency has declined in the past five years. The direct carbon emissions of CH_4 generally account for a relatively high proportion of all carbon emissions, and provinces with higher carbon neutrality level, such as Sichuan, Hubei and Shandong, also have a relatively low proportion of CH_4 emissions. According to the simulating, we came up with the following results: nationwide, the net carbon emissions of WWTPs will reach its peak in 2027 and achieve carbon neutrality in 2052; provincially, the emissions of WWTPs will reach carbon neutrality in the time period between 2030-2060, and the timing of carbon neutrality is roughly the same as that of carbon peak; Except for Tibet with low carbon peak of WWTPs, carbon neutrality in other provinces can be achieved about 24 years after they reaching the peak of carbon emission respectively. Therefore, the study implicates more advanced emission reduction facilities of WWTPs are encouraged, such as the photovoltaic power generation devices, and suggest to increase the proportion of water reuse, and improve sludge utilization, in order to achieve the carbon neutrality goals.

Keywords: Carbon emission, carbon sequestration, carbon neutrality, wastewater treatment plants

NONMENCLATURE

Abbreviations	
APEN	Applied Energy
WWTP	Wastewater Treatment Plant
PV	Photovoltaic
LCA	Life Cycle Assessment
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
AD	Anaerobic Digestion
GWP	Global Warming Potential
WSHP	Water Source Heat Pump
EF	Emission Factor

1. INTRODUCTION

Wastewater Treatment Plants (WWTPs) are the fundamental infrastructures for socio-economic activities and protect the water ecosystem as well. However, doubled in the past 10 years, WWTPs discharges tens of millions of tons CO_2 emissions directly and indirectly in whole process [1], which deserves abundant concerns under the background of the 2060 carbon neutrality goal.

Compare narrow and generalized definitions of carbon neutrality, narrow definitions of carbon neutrality mainly focus on the energy sufficiency while the latter focus on both direct and indirect emission and the sequestrations along with the emission [2]. The actual operation case shows that achieving energy neutralization of WWTP does not mean that carbon neutralization can be achieved at the same time, but if carbon neutralization is achieved, it can be considered that energy neutralization can also be achieved at the same time [3]. Previous studies mainly focused on the energy sufficiency (narrow definition) and carbon emissions of the WWTPs [2,4,5], while the calculation of generalized definition is not sufficient. Moreover, the neutrality analysis boundary of the previous studies only included the treating process of the WWTPs [6,7], while we considered the carbon sequestrations of the outputs of the WWTPs. Further, carbon neutralization strategy of WWTPs suitable for each province depends on the meticulous index settings considering emissions as well as sequestrations, compared to the undistinctive simulating index of the previous studies [8].

In the near future, a more stringent wastewater treatment standard [9,10] and the increasing amount of WWTPs will lead to a more serious environmental problem without an adjustment. On the other hand, as long as the superiorities of potentials have been brought into full play, the high emitting WWTPs can transferred into a carbon surplus industry, which contribute a lot to the reduction of carbon emission of the whole society and further promote the realization of the carbon neutrality promise [11].

2. MATERIAL AND METHODS

2.1 Basic data and coefficients

A total of 4346 WWTPs were inventoried in this case study. A large sample of WWTPs, and Data of per capita GDP, sunlight hours, per capita water sources and agricultural land area in provincial level from China Statistical Yearbook from 2014-2018 allow us to offer a panorama of present and future carbon neutrality situation.

2.2 Evaluation of carbon emission and carbon sequestration

The evaluation boundary of WWTPs is shown in Fig. 1.

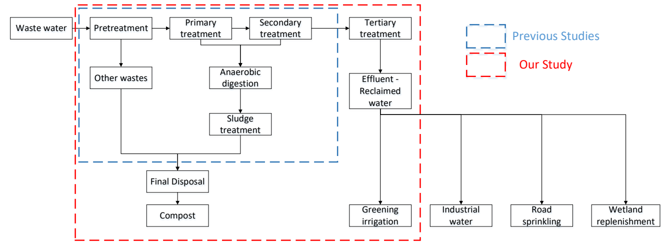

Fig. 1. Research Boundary

7 categories have been divided, subordinating to 2 aspects of emissions and 3 aspects of sequestrations (Fig.2.).

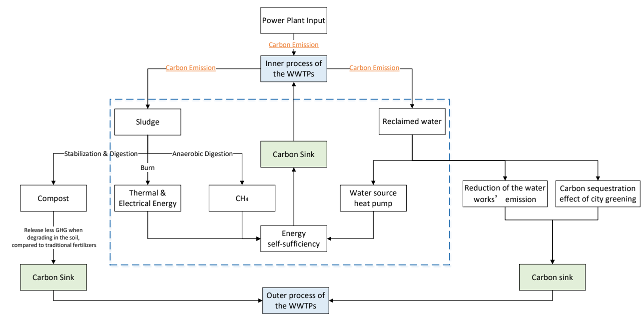

Fig. 2. Calculation flow chart

Main formulas are as followed:

- Direct emission of CH_4:

$$M_{CH_4}=V\times(BOD_0-BOD_e)\times EF_{CH_4}\times10^{-3}\times GWP_{CH_4} \quad (1)$$

where $\boldsymbol{M_{CH_4}}$ is CH_4 emission ($kgCO_2e$), ***V*** is volume of sewage, $\boldsymbol{BOD_0}$ is BOD influent(mg/L), $\boldsymbol{BOD_e}$ is BOD effluent(mg/L).

- Direct emission of N_2O:

$$M_{N_2O}=V\times(TN_0-TN_e)\ EF_{N_2O}\times10^{-3}\times GWP_{N_2O} \quad (2)$$

where $\boldsymbol{M_{N_2O}}$ is N_2O emission ($kgCO_2e$), $\boldsymbol{TN_0}$ is total nitrogen influent (mg/L), $\boldsymbol{TN_e}$ is total nitrogen effluent (mg/L).

- Indirect emission of electricity use:

$$M_{CO_2\bullet E}=EF_{CO_2}\times E\times GWP_{CO_2} \quad (3)$$

where $\boldsymbol{M_{CO_2\cdot E}}$ is CO_2 emission (kg), ***E*** is Electricity consumption.

- Organic & thermal energy in the sewage:

$$\Delta E_1=E_{AD}\times+E_{Burn}+E_{WSHP}$$

$$E_{AD}=E_{CODtrans}\times M_{COD}\times\Delta H_f$$

$$E_{Burn}=\frac{3}{7}\times D_{sludge}\times H_f(sludge)$$

$$E_{WSHP}=\frac{V\times\rho_{water}\times\Delta T\times C_{water}\times F}{F+1} \quad (3)$$

where $E_{CODtrans}$ is the proportion of sludge for AD in total. ΔT is differential value between waste water and environment.

- Carbon sequestration effect of city greening:

$$\Delta E_2 = \frac{V \times EF_{reuserate}}{EF_{irrigationamount}} \times EF_{carbonsequestration} \quad (4)$$

where $EF_{reuserate}$ is reuse rate of reclaimed water. $EF_{irrigationamont}$ is urban irrigation water demand of green spaces. $EF_{carbonsequestration}$ is carbon sequestration of urban green space.

- Reduction of the water works' emission:

$$\Delta E_3 = V \times EF_{reuserate} \times EF_{waterworkemi} \quad (5)$$

where $EF_{reuserate}$ is reuse rate of reclaimed water, $EF_{waterworkemi}$ is emission of the water works.

- Reduction of the land carbon emission:

$$\Delta E_4 = \frac{S \cdot D_{sludge}}{M_{fertiliazation}} \times EF_{sludge} (6)$$

where S is provincial agricultural land area. D_{sludge} is the amount of sludge for compost. $M_{Fertilization}$ is the provincial amount of compound fertilizer used.

2.2.2 Scenario simulation

We simulated the emission and sequestration from 2019 to 2060. To achieve a more reasonable simulation in province level, we ranked and graded the per capita GDP, sunlight hours, per capita water sources, energy consumption of process design and agricultural land area of each province, based on which give the graded scenario index parameters. The index connotation is shown in the chart below (table.2.):

Table. 1. the impact on scenario setting of each factor

Influencing factor	Effects
Per capita GDP	To achieve the effect of emission reduction and energy self-sufficiency, by endowing fund in the WWTPs facilities upgrading.
Sunlight hours	Achieve the energy self-sufficient by PVs.
Per capita water sources	To reduce the emission of the water works and to achieve the carbon sequestration effect by reusing reclaimed water.
Energy consumption of process design	To achieve energy self-sufficiency by adopting process design with lower energy consumption and carbon emission
Agricultural land area	To achieve less GHG emission by replacing fertilizers with treated sludge.

Energy consumption of process design is measured by the approach below:

$$S = \sum_{i=1}^{n} p_i \times C_i \quad (7)$$

where S is the scores of energy consumption of process design, i represents the number and categories of the top 70% ranking process design in the using proportion, p_i is the using proportion of process design i, C_i is the corresponding energy cost marks to the process design i given by energy consumption ranks from previous studies.

Besides, Exponential smoothing method has been used to complete the simulation.

$$Y_t + 1 = \alpha X_t + (1 - \alpha) \times Y_t \quad (7)$$

where:

Yt+1: predictive value of season t + 1, namely the smoothed values of current season(t)

Xt: actual value of current season(t)

α: smoothing coefficient

***1 – α* = β**: damping coefficient.

3. Results

3.1 Current situation

As for current emissions, WWTPs in no province has achieved carbon neutrality from 2014 to 2018.

Different characteristic has been found in the study. For CH_4, emissions contributed around 35% of total GHG emissions, and decreases by year. Indirect carbon emissions of WWTPs due to electricity consumption accounted for the second largest share in GHG emissions, and increased, while N_2O emissions contributed the least in GHG emissions (Fig.3.).

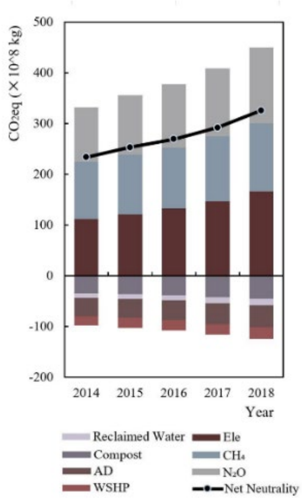

Fig. 3. Carbon emission and sequestration of WWTPs in China

As for parts of carbon sinks, the treated sludge replacing compound fertilizer reduced 9.9% of the total emissions. Reclaimed water used for greening irrigation reduced 3.0% of the total emissions.

The proportion of carbon neutrality is generally low, and the carbon neutrality level went down in most provinces due to the higher growth rate of carbon emissions. Thus, provinces like Anhui, Shandong and Hubei out stands in the whole China with their carbon neutrality level growing gradually and value higher than 30%.

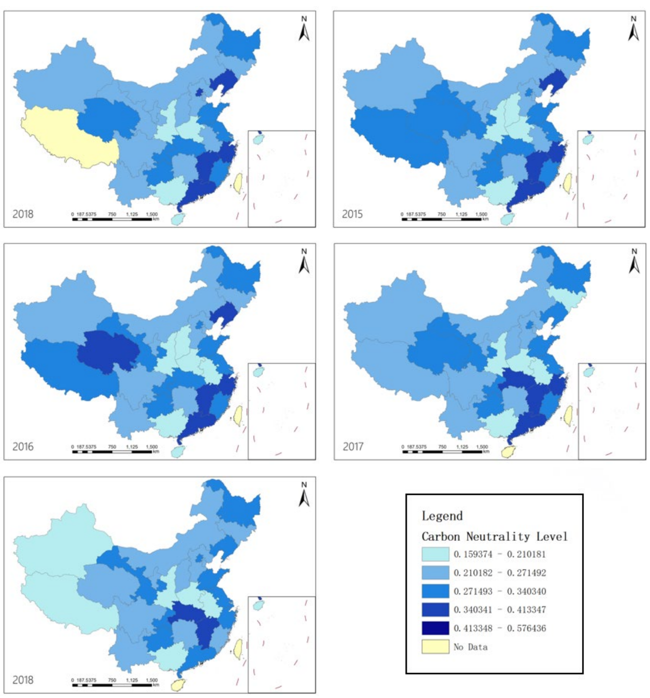

Fig. 4. Carbon neutrality level in province level

Besides, CH_4 emission has a remarkable negative correlation with carbon neutrality level in most provinces. It worth noting that the installation of WSHP has a great promotion on carbon neutrality efficiency.

3.2 Scenario simulation

By simulating the influence of various factors, we reach the results as followed.

Nationwide, the net carbon emissions of WWTPs will reach its peak in 2027 and achieve carbon neutrality in 2052 (Fig.6.).

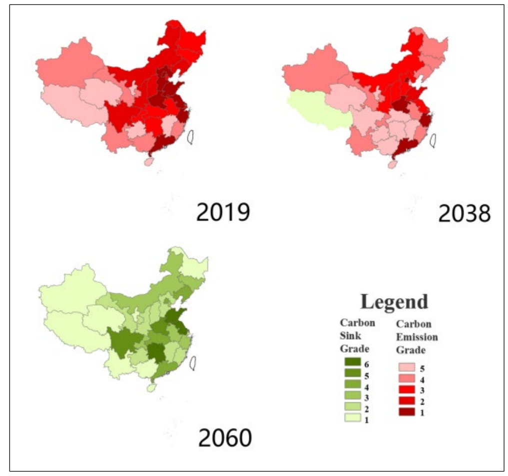

Fig. 5. The starting year (2019), ending year (2060) and the year for the first province to be carbon neutralized (2038)

Provincially, the emissions of WWTPs will reach carbon neutrality in the time period between 2030-2060. The timing of carbon neutrality is roughly the same as that of reaching peak.

Except for the provinces with low carbon peak of WWTPs (such as Tibet), carbon neutrality in other provinces can be achieved about 24 years after they reaching the peak of carbon emission (Fig.7.).

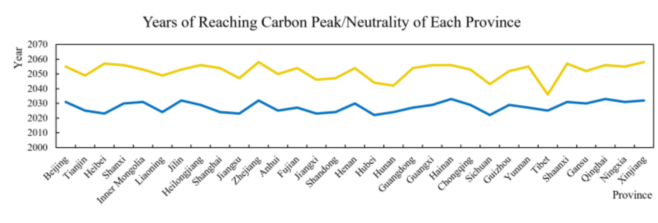

Fig. 6. Years of reaching carbon peak/neutrality of each province

Specially, Province that discharges less, has relatively shorter time to reach the peak, such as Tibet, and provinces whose emission reduction potential of all aspects is relatively balanced, such as Sichuan, Hubei, Shandong can be the pioneer of carbon neutrality (Fig.8.).

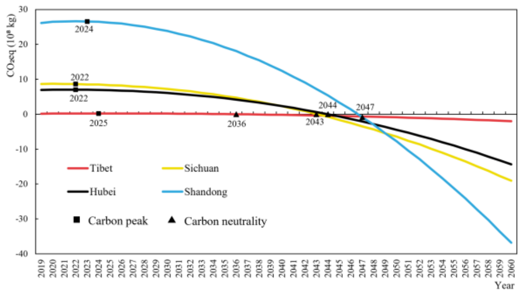

Fig. 7. Years of reaching carbon peak/neutrality of Tibet, Sichuan, Hubei and Shandong

Provinces with larger carbon peaks, such as Xinjiang, and those who have relatively poor potentials of emission reduction, such as Heilongjiang, and Shaanxi will reach carbon neutrality later than others (Fig.9.).

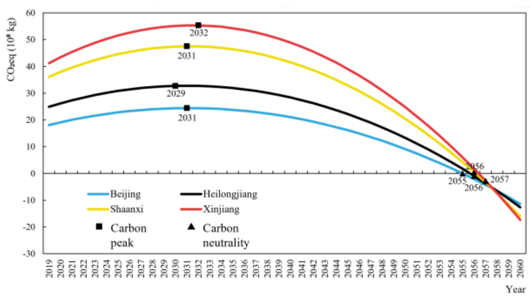

Fig. 8. Years of reaching carbon peak/neutrality of Beijing, Heilongjiang, Shaanxi and Xinjiang

4. Conclusion

All the five aspects, including recycling water resource, sludge compost, wastewater source heat pump, anaerobic digestion and photovoltaics, can surely be completed and will have great promotion on the realization of carbon neutrality. As long as every province continues to carry forward its strengths with some feasible inputs, carbon neutrality can be reached.

Through our analysis, carbon neutrality has a great relationship with its natural endowment. Correlation has been found between per capita GDP and the speed of neutrality. Moreover, contain recyclable resources, including chemical energy, heat and water in the products of WWTPs should be utilized.

More environmentally friendly facilities should be encouraged to use. The utilization of contained recyclable resource and high energy efficient treatment process should also be encouraged. Transformation of facilities and innovation of facilities of better efficiency on emission reduction, should be supported.

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