Energy Consumption and Greenhouse Gas Emission of Wastewater Treatment Plants in Northern China

Yinqiao Wang

ABSTRACT

Knowing the levels of energy consumption and Greenhouse Gas Emission of wastewater treatment plants is the essential first step to save energy and reduce unnecessary emissions for the plants in the future. However, there is limited information regarding energy consumption and Greenhouse Gas levels in wastewater treatment plants in Northern China, so I investigated the monthly electricity consumption levels of 2016 in two study sites: Fushun Secondary Wastewater Treatment Plant and Jinxi Wastewater Treatment Plant. I also examined the variations of energy consumption and Greenhouse Gas emission, each with respect to seasonality in Northern China in 2016. The relationships between the two data and seasonality showed that energy consumptions in both plants were higher in winter mainly due to heating and pre-heating procedures in low temperatures. During summer Greenhouse Gas emissions were higher because of more frequent agricultural activities and longer operation time. An understanding of how seasonality affects energy consumption and Greenhouse Gas emission in wastewater treatment plants will provide insightful operating strategies in saving energy and reducing pollution in the future.

KEYWORDS

chemical oxygen demand (COD), electricity consumption, seasonality, ammonia nitrogen

INTRODUCTION

Wastewater Treatment Plants (WWTPs) are one of the major sources of greenhouse gas emissions in the water industry around the world (US Environmental Protection Agency), since many municipal wastewater treatment plants practice in a non-sustainable way, employing treatment schemes that exert a high energy demand and have a large carbon footprint that contributes significantly to climate change (Mamais et al. 2015). Thus improving energy efficiency and reducing carbon emissions of WWTPs are becoming more important as part of global sustainability agendas.

Understanding the levels of energy consumption and Greenhouse Gas (GHG) emission of WWTPs is a critical first step for initiating political action around, and encouraging regulation of, these facilities. During the wastewater treatment processes, GHGs, particularly carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are produced (Doorn et al. 1997, Stocker et al. 2014). In the WWTPs in Beijing, China, the total GHG emissions are 404.93 gCO_2-eq/ m^3 wastewater and 864.98 gCO_2-eq/m^3 wastewater, respectively for two different treatment methods Anoxic/Oxic (A/O) and Sequencing Batch Reactors (SBR) in 2015(Bao et al. 2016). In 2016, the energy consumption of WWTPs in Shenzhen, China ranges from 0.12 to 0.38 kWh/t. The values are significantly less than those reported by WWTPs in developed countries like Japan, Norway, Netherlands and many countries in Europe (Yu et al. 2013, Panepinto et al. 2016).

However, there is limited information and research regarding energy consumption and GHG emission for WWTPs in Northern China. Most of the case studies were conducted in Beijing and more economically developed areas in Southern China. This is problematic because WWTPs in Northern China are developing at an accelerated rate due to the growing population there, as well as the pronounced economic development in the area. Thus, in order to further improve the green operation strategies for WWTPs in Northern China, this study seeks to determine current, baseline levels of energy efficiency and GHG emissions for these plants. In this research, I collected treatment and operations data from 2 WWTPs in Northern China in 2016 and calculated their energy consumptions during the year.

I sorted the data and constructed scatter plots to examine the relationships between energy consumption and GHG emissions, each with respect to seasonality for each tested WWTP. I hypothesized that during cold months, energy consumptions would be higher than during warm months because the extremely low temperature require more energy for heating and operation. GHG emissions would be higher in warm months because WWTPs operate longer during the warm seasons. Ultimately, study findings may inform valuable operational strategies for WWTPs in Northern China to save energy as well as to reduce GHG emissions.

METHODS

Study site

Fushun Secondary Wastewater Treatment Plant and Jinxi Wastewater Treatment Plant are the two study sites for my research. They are both located in Liaoning, China (41.9437° N, 122.5290° E). Liaoning province is in Northern China and famous for its drastic seasonal change and low temperatures in winter. The two WWTPs are 168 miles away from each other, so there is little climate difference between the two sites. They have similar operation capacities: on average, Fushun Secondary Wastewater Treatment Plant processes wastewater at the rate of 3730t/h and Jinxi Wastewater Treatment Plant processes about 3000t/h of wastewater (Z. Wang, *personal communication).*

Data collection

Through personal contact, I gathered monthly electricity consumptions in 2016 from both sites for energy consumption.

For GHG emission, the data I gathered were: wastewater influent flow rate (m^3/hr), oxygen demand of influent wastewater to the biological treatment unit determined as COD ($mg/L = g/m^3$) and biomass yield (g C converted to biomass/g C consumed in the wastewater treatment process).

To see how energy consumptions and GHG emissions vary with seasonality, I also gathered average monthly temperatures in Liaoning in 2016 from the work book that Fushun Secondary Wastewater Treatment Plant provided and average monthly Ammonia Nitrogen (NH_3-N) in Influent sewage from both sites.

Data analysis

Because the data of monthly energy consumption of 2016 was straightforward, I did not sort the data.

For GHG emission, I used the following equations to show the trends of GHG emission variations in 2016 for both WWTPs (RTI 2010).

$$CO_2 = 10^{-6} \times Q_{WW} \times OD \times Eff_{OD} \times CF_{CO_2} \times [(1 - MCF_{WW} \times BG_{CH_4})(1 - \lambda)]$$

$$CH_4 = 10^{-6} \times Q_{WW} \times OD \times Eff_{OD} \times CF_{CH_4} \times [(MCF_{WW} \times BG_{CH_4})(1 - \lambda)]$$

where

CO_2: CO_2 emission rate (Mg CO_2/hr)

CH_4: CH_4 emission rate (Mg CH_4/hr)

10^{-6} : Units conversion factor (Mg/g)

Q_{WW}: Wastewater influent flow rate (m^3/hr)

OD: Oxygen demand of influent wastewater to the biological treatment unit determined as either BOD5 or COD (mg/L = g/m^3)

Eff_{OD} *:* Oxygen demand removal efficiency of the biological treatment unit

CF_{CO_2} *:* Conversion factor for maximum CO_2 generation per unit of oxygen demand 44/32 = 1.375 g CO_2/ g oxygen demand

CF_{CH_4} *:* Conversion factor for maximum CH_4 generation per unit of oxygen demand 16/32 = 0.5 g CH_4/ g oxygen demand

MCF_{WW} *:* Methane correction factor for wastewater treatment unit, indicating the fraction of the influent oxygen demand that is converted anaerobically in the wastewater treatment unit

BG_{CH_4} : Fraction of carbon as CH_4 in generated biogas (default is 0.65)

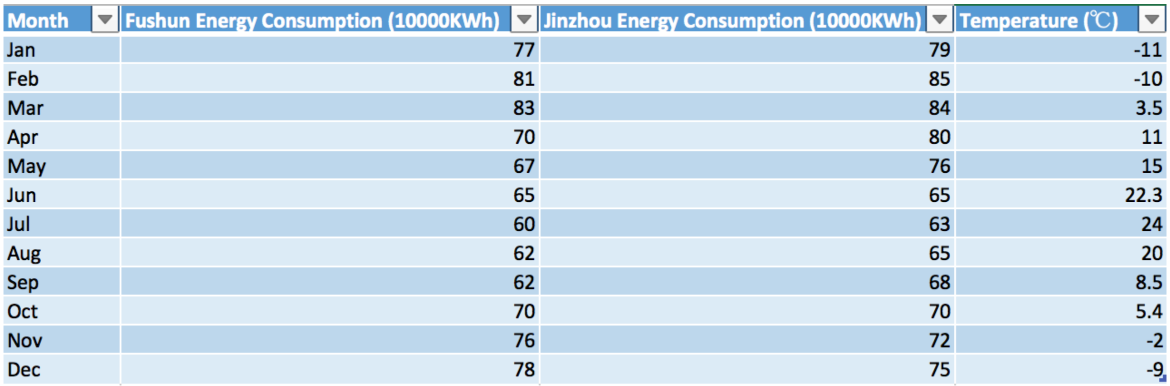
λ: Biomass yield (g C converted to biomass/g C consumed in the wastewater treatment process).

Originally I planned to estimate the numerical levels of CO_2 *and* CH_4, assuming all organic carbon removed from the wastewater is converted to either CO_2 *and* CH_4 (RTI 2010). However, Eff_{OD} was not recorded in neither WWTP, so instead I used COD (expressed as OD in the equation) to show the trends of GHG emission, since holding everything else constant, higher COD indicates higher CO_2 *and* CH_4.

RESULTS

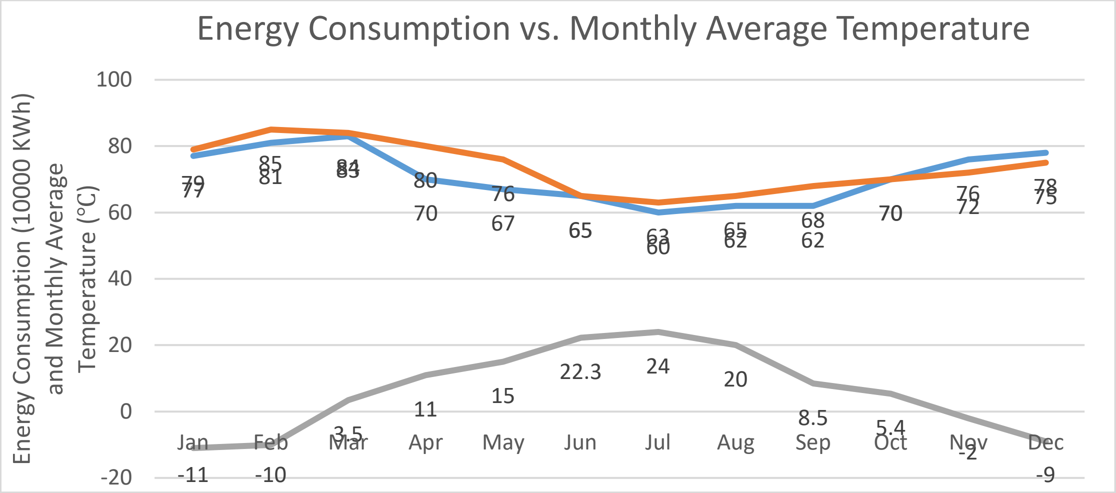
In table 1, I sorted and displayed the monthly energy consumption data of the two WWTPs with the average monthly temperature in Liaoning. I also constructed a figure to show how energy consumptions varied with monthly average temperatures.

Table 1. Monthly energy consumption and average monthly temperature of the study sites



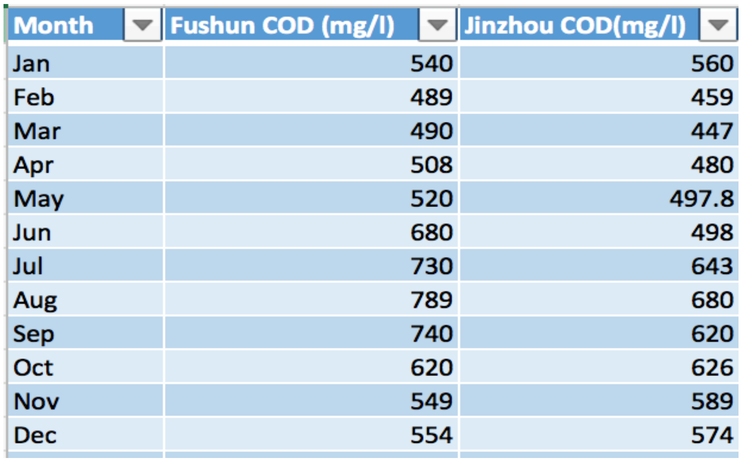
Month	Fushun Energy Consumption (10000KWh)	Jinzhou Energy Consumption (10000KWh)	Temperature (℃)
Jan	77	79	-11
Feb	81	85	-10
Mar	83	84	3.5
Apr	70	80	11
May	67	76	15
Jun	65	65	22.3
Jul	60	63	24
Aug	62	65	20
Sep	62	68	8.5
Oct	70	70	5.4
Nov	76	72	-2
Dec	78	75	-9

Figure 1. Monthly energy consumption and average monthly temperature of the study sites



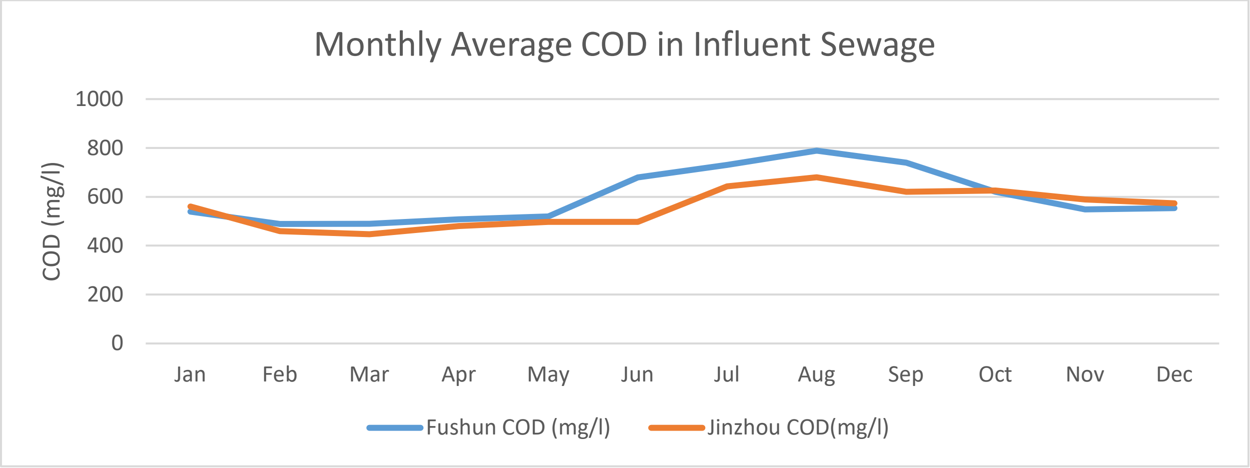
In table 2 and Figure 2, I displayed two sites' monthly average COD in influent sewage with respect to 12 months in 2016.

Table 2. Monthly average COD in influent wastewater of two study sites



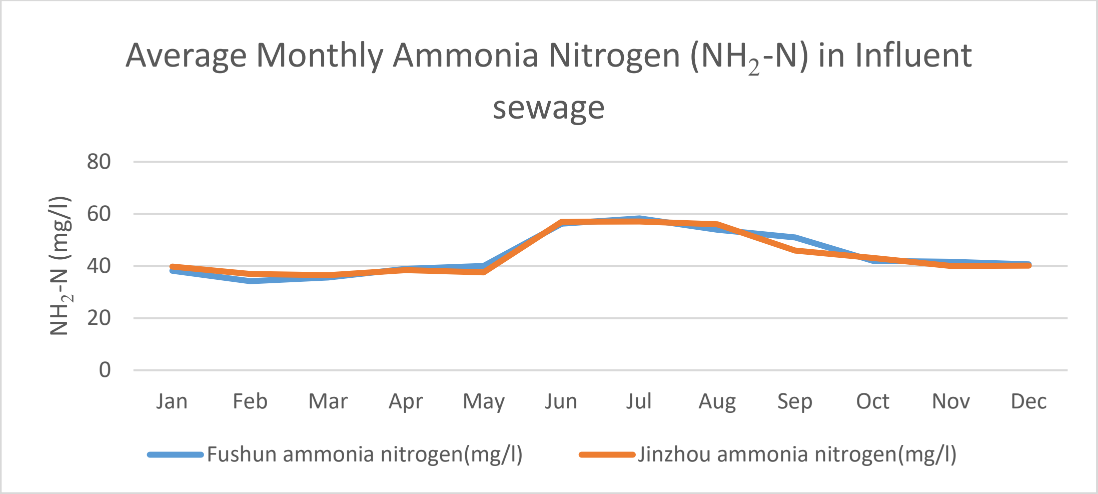
Month	Fushun COD (mg/l)	Jinzhou COD(mg/l)
Jan	540	560
Feb	489	459
Mar	490	447
Apr	508	480
May	520	497.8
Jun	680	498
Jul	730	643
Aug	789	680
Sep	740	620
Oct	620	626
Nov	549	589
Dec	554	574

Figure 2. Monthly average COD in influent wastewater of two study sites



I sorted data for average monthly ammonia nitrogen (NH_3-N) in influent wastewater with respect to 12 months in Figure 3.

Figure 3. Average monthly ammonia nitrogen (NH_3-N) in influent wastewater



DISCUSSION

Seasonality and energy consumption

After sorting and analyzing data, I found that seasonality could be an important factor in the variations of energy consumption and GHG emissions. During winter time, energy consumptions in both WWTPs were higher than other months, while during summer time, GHG emissions as well as ammonia nitrogen were higher. This was mainly due to greater energy demand for heating equipment in winter and more frequent agricultural activities during summer.

The big temperature difference between seasons in Northern China correlates with variation of WWTPs' energy consumptions (see Figure 1). The variations of average temperatures in Northern China between winter (-20 °C in Jan) and summer (24 °C in Jul) reached 48 °C. The average electricity consumptions of WWTPs during those months also varied greatly in my sample plants. I observed that during winter, the average energy consumption of the WWTPs was significantly higher than that reported in summer. This variation could be explained by the heating procedure prior to the treatment during winter. After consulting with workers in the WWTPs, I understood that under low temperatures, some of the machines and equipment in WWTPs (especially those operated in outdoor open areas) cannot function properly. Thus, WWTP operators usually conduct the pre-heating procedure by turning on the machine and operating it without any wastewater treated. After the equipment has reached a certain temperature, they can function properly and the treatment process officially begins. Additionally, outdated equipment in WWTPs consumes more energy to pre-heat and operate in winter (Z. Wang, *personal communication*). Also, WWTPs extend aeration time in winter for chemical reaction, so longer operation time causes more energy use. Therefore, the electricity consumption in winter is likely much higher than other seasons in Northern China WWTPs.

Seasonality and GHG emission

Seasonality influenced WWTPs' GHG emissions for my study sample. During summer months the monthly average CODs in influent wastewater were higher than those in summer (see Figure 2). Because during spring and summer, people conduct more agricultural activities than winter, and more organic and chemical wastes such as fertilizers are produced. Thus, ammonia nitrogen, usually found in water-soluble fertilizers to lower PH of soil and provide necessary nutrients (Argo et al. 2008), was high in influent wastewater in both WWTPs (Figure 3). Higher ammonia nitrogen level indicates higher COD in influent wastewater since more oxygen is needed to oxidize ammonia nitrogen (Z. Wang, *personal communication*). Consequently, GHG emission is higher in summer. In addition, WWTPs operate longer and process more wastewater during summer since the energy costs in summer are relatively lower than winter. Thus, more oxygen is demanded in summer (higher COD) and more GHG is emitted.

Implications

Low temperatures in winter of Northern China affect WWTPs operations in many ways. Due to low temperatures in winter, heating and pre-heating procedures, as well as longer reaction time are necessary in WWTPs, consuming more energy. Also, because little agricultural activities can be conducted in winter due to the coldness, people conduct more agricultural activities and WWTPs operate longer in summer. Thus COD is higher in summer, indicating more GHG emissions.

In order to save energy consumption, I suggest that WWTPs should improve their heating systems. For example, WWTPs should use energy-saving air conditioners and heating tubes, and cut unnecessary electricity use. In addition, since outdated equipment requires more energy to pre-heat and operate, I suggest that WWTPs should update their equipment and offer maintenance more frequently.

Last but not least, I suggest that WWTPs in Northern China could record and analyze their working data more precisely and frequently since I have noticed that some data is missing. Complete and accurate data set is needed to find out the precise numerical levels of energy consumption and GHG emissions of WWTPs in Northern China.

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