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Energy-water nexus of wastewater treatment system: conceptual model and framework

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Abstract

Energy and water are two interwoven elements of wastewater treatment system (WWTS). Energy is consumed to remove pollutants in wastewater, decrease negative influence on the natural water environment, water is used to generate energy for system input. With the rapid increasing on wastewater quantity, how to improve wastewater treatment efficiency and reduce energy costs has attracted many attentions. However, there is lack of synthesize understanding of the energy-water nexus in WWTS. In this study, a new energy-water nexus conceptual framework is developed, energy used for wastewater extraction, operation of the wastewater treatment process and the waste recycling were explored. Efficiency and redundancy of the WWTS were also examined in structural nexus analysis based on Network Environ Analysis (NEA). The conceptual framework would help to investigate the mechanism and properties of the energy-water nexus for WWTS.

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Keywords: Water-energy nexus; Structural nexus; Waste water treatment system (WWTS); Network Environ Analysis (NEA)

1. Introduction

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Water and energy are closely connected and both are significant for human development [1-2]. Waste water treatment system is central to water-energy interactions as it consumes electrical energy to decrease the pollutants in the wastewater, and water is required to generate electrical energy. Wastewater treatment requires various forms of energy [3-5], while almost every stage in the energy supply chain needs water [6-7].

Abbreviation

WWTS Waste water treatment system

NEA Network Environ Analysis

WF Water footprint

GWF Grey water footprint

GWFRE Grey water footprint reduction efficiency

Symbols

P_i Concentration of pollutants in the wastewater, which including Biochemical Oxygen Demand(BOD), Chemical Oxygen Demand(COD) and Total Nitrogen(TN) in discharge from the WWTS

P_{ti} Concentrations of pollutant in the waste water after treatment

V Wastewater volume treated by WWTS

E_i Total energy input during the wastewater treatment process (in kWh)

E_t Energy consumption of pumping waste water(Mtce)

θ Conversion coefficient of electricity to Joule(K_j/kW h),valued 3600

γ Specific weight of water value 9.8 K_n/m^3

$H^{'}$ Total dynamic head of the WWTS

Schnoor pointed out that probably the greatest water story of the 21st century is to treat wastewater through membranes and reverse osmosis for drinking water supplied with significant energy consumption [8]. Moreover, wastewater treatment accounts for about 3% of the electrical energy load in developed countries, and the high energy costs for treatment due to aeration requirement in developed countries cannot be borne by developing countries. Therefore, to balance the trade-off between energy consumption and wastewater cutting loads in the wastewater treatment system is highly needed.

As illustrated by Wiedmann and Minx(2008)[9], there are water footprint behind energy footprint input from a life cycle analysis perspective. According to the water footprint theory[10-13], Grey water footprint(GWF) is defined as the volume of freshwater that would be required to dilute the pollutants to meet given natural background concentrations or water quality standards[14]. In this work, GWF is utilized as a wastewater treatment indicator to measure the response relationship between energy consumption and pollutant removing quantity.

In this study, water-energy nexus conceptual framework in WWTS is constructed, energy consumption through the life cycle stage of the wastewater treatment is quantified. Grey water footprint, which includes removal quantity of BOD and COD are investigated. Moreover, Network Environ Analysis