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# Using site-specific life cycle assessment methodology to evaluate Chinese wastewater treatment scenarios: A comparative study of site-generic and site-specific methods

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ABSTRACT

This study was conducted to investigate whether the environmental impact assessment of wastewater treatment plants (WWTPs) varies with different life cycle assessment (LCA) methods. A full-scale WWTP in China was investigated in this LCA analysis using a generic LCA method, CML, and a China-specific method, e-Balance. Specifically, environmental impact were examined and compared for four effluent treatment levels: no treatment, basic treatment, intermediate treatment and tertiary treatment. The results revealed great variation between the no treatment scenarios and between the tertiary treatment scenarios. The inclusion or exclusion of chemical oxygen demand (COD) as an independent impact category was identified as the main reason for the disparate results with respect to the no treatment scenarios. The absence of toxicity-based impact categories in the database associated with e-Balance method resulted in the lower environmental impact assessment for tertiary treatment scenario of e-Balance than CML method. We concluded that site-generic LCA methods might generate outcome bias when evaluating cases with obvious regional features, and that regionalized LCA methods are needed to deal with cases having an obvious impact on the regional environment.


## 1. Introduction

Sustainability is one of the primary concerns in many modern industries (Jiang et al., 2016; Zeng et al., 2016). For wastewater treatment plants (WWTPs), reducing the emission of water pollutants such as organic materials, nutrients and heavy metals can contribute to the recovery of contaminated aquatic environment and the sustainable development of the local economy and society. In China, the increasing emissions of water pollutants and decreasing environmental capacity of aquatic environment have necessitated higher levels of contaminant removal to protect receiving water bodies; therefore many WWTPs are required to expand and upgrade. However, increasing burden to WWTPs is controversial because additional fossil resource consumption, chemical substance addition and greenhouse gas emissions would cause negative environmental impact, which would surpass the positive environmental impact of reducing local aquatic pollution (Wang et al., 2015; Zeng and Chen, 2016).

Life cycle assessment (LCA), which is a useful technique to quantify the environmental impact assessment associated with all stages of products, services and processes, is a reasonable method for analyzing the weights associated with various contributors within a given environmental category. Researchers have developed many types of LCA methods, including the methodologies of CML 2002 (Guinée, 2001), EDIP (Hauschild and Potting, 2005), TRACI (Bare, 2011), Eco-indicator 99 (Goedkoop and Spriensma, 2001), EPS 2000 (Steen, 1999), Impact 2002 (Jolliet et al., 2003) and ReCiPe 2008 (Goedkoop et al., 2009). Comparative studies have been conducted to investigate whether the choice of LCA methods could influence LCA results through case analysis across various fields (Bovea and Gallardo, 2006; Bueno et al., 2016; Cavalett et al., 2013; Dreyer et al., 2003; Pant et al., 2004; Pizzol et al., 2011; Renou et al., 2008). Some of these studies generated similar LCA results showing no effect of LCA methods, whereas the results of other studies demonstrated choice of methodologies did influence LCA results significantly, especially for the characterization results

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within one or more major environmental impact categories. The divergence in inventory input and output coverage levels, the differentiation of characterization models, and differences in fate and exposure modeling have been identified as major reasons for variations in LCA results.

Although LCA has been widely used in the field of wastewater treatment (Cavalett et al., 2013; Ortiz et al., 2007; Renou et al., 2008), few studies have explained why specific methods were chosen, and little attention was given to investigate the influence of LCA methods selection. In a study conducted by Ortiz et al. (2007), three methods (CML 2000, Eco-Points 97, Eco-Indicator 99) were employed, but no comparative discussions concerning this topic were addressed. Renou et al. (2008) investigated the influence of method selection through a case study of a full-scale WWTP, and concluded that there was no obvious variation observed within impact categories representing global environmental impact, while great variation was generated by various LCA methodologies associated with toxic impact categories.

WWTPs can be seen as source point of pollutants that directly influence their receiving environment. Organic materials in the wastewater can encourage the growth of bacteria, which would exhaust the dissolved oxygen in receiving water. Additionally, nutrients in the wastewater such as nitrogen and phosphorous can stimulate the formation of eutrophication in receiving water via algal growth. Characterization of these regional impact within the LCA framework is necessary for accurate quantification of the influence of WWTP effluent, and can better help decision-makers and stakeholders make trade-offs between regional and global impacts. However, most commonly used LCA methodologies are unable to incorporate spatially differentiated characterization factors to calculate the regional impact of wastewater. For example, in wastewater treatment case studies that use LCA methodologies (Beavis and Lundie, 2003; Ortiz et al., 2007; Renou et al., 2008; Roeleveld et al., 1997; Vlasopoulos et al., 2006; Wang et al., 2015), the eutrophication characterization methods cannot deal with the level of eutrophication of a specific water stream, and the characterization factors available cannot fully represent the environmental impact in terms of the depletion of oxygen caused by wastewater.

This study was conducted to investigate how, and to what extent, the LCA results could be influenced by the adoption of various LCA methodologies, via a case study of a representative WWTP in China. Two LCA methods were used in this comparative study: CML and e-Balance. CML has been widely employed in environmental assessments of wastewater treatment scenarios across different regions of the world. By providing a list of obligatory impact indicators, CML has the advantage of covering more comprehensive categories for LCA analysis. With CML, it is possible to present a general reference for LCA application in a certain area. In other comparative analyses utilizing different LCA methods, CML is also the most common approach used for comparison with other methods. Therefore, CML can be seen as a valuable site-generic LCA method. The e-Balance method was designed specifically for China and is thereby considered site-specific. Connected with the Chinese Life Cycle Database (CLCD), e-Balance was developed using input parameters consistent with Chinese locations. Additionally, this study compared the results of environmental impact assessments obtained at four effluent disposal levels by each LCA method, and identified the major reasons for observed variations.

## 2. Methodology

### 2.1. Goal and scope definition

The operational stage of a domestic WWTP in China was selected for evaluation by the CML method and the e-Balance method. The original effluent level was basic treatment, after which nutrient removal technology was applied. The WWTP is currently in the process of being transformed into a tertiary treatment system. The basic treatment is designed to remove organic materials from wastewater. Escalation from basic treatment to intermediate treatment requires that the WWTP enhance the capacity for nutrients removal. If the effluent must be reused or discharged to a recreational water body, tertiary treatment will be used to further remove the water pollutants. Four scenarios were defined in this study: effluent quality meeting tertiary treatment (scenario-1), intermediate treatment (scenario-2), basic treatment (scenario-3) and no treatment (scenario-4). More information concerning the scenarios and effluent levels are presented in Table 1.

### 2.2. Functional unit and system boundary

The function unit for comparison of four scenarios selected was 10,000 $m^3$ of wastewater produced by the WWTP. The operational stage of the WWTP was considered during the impact assessment. The constraction and demolition phases were ignored in this study because their environmental impact could be considered negligible relative to the operational phase (Pasqualino et al., 2009). The system took into account the treatment of sewage, as well as the electricity production, the manufacture and transportation of chemicals, and waste activated sludge processing.

### 2.3. Life cycle inventory

For each scenario, input flows of the WWTP included elements of electricity, inorganic chemicals, and PAM- acrylonitrile (Table 2). The output flows included emissions associated with the liquid phase, solid phase and air phase. Chemical oxygen demand (COD), total nitrogen (TN), and total phosphorus (TP) were regarded as the main water pollutants to the local aquatic environment. Other substances such as carbon dioxide, nitrous oxide, bio-sludge, tertiary precipitation, phosphorus precipitation and pre-treatment solid waste accounted for the main contributors to the solid phase and air phase. The Ecoinvent database V2.1 was used as an inventory data source to support the CML method. The data needed to conduct e-Balance were obtained from the Chinese Life Cycle Database (CLCD). More than 600 datasets are included in the CLCD, and this database is still expanding. The CLCD data were obtained from chemical equilibrium calculations, cooperative factories, industry statistics, technical literature, and the China Pollution Source Census.

### 2.4. Life cycle impact assessment

The impact categories obtained from CML were: eutrophication (E, kg $PO_4$ eq.), acidification (A, kg $SO_2$ eq.), freshwater aquatic ecotoxicity (FAET, kg 1,4-DCB eq.), human toxicity (HT, kg 1,4-DCB eq.), ozone depletion (OD, kg CFC-11 eq.), photochemical oxidation (PO, kg ethylene eq.), global warming (GW, kg $CO_2$ eq.), abiotic depletion of fossil fuels (ADF, MJ), and abiotic depletion of elements (ADE, kg antimony eq.). Without indicators of OD, HT, FAET and PO, the major impact categories of e-Balance were COD, E, GW, A and ADF. In the eutrophication impact category, the two LCA methods agreed on characterization models and scientific background. Phosphorus (P), nitrogen (N), and organic matter (C) were considered the main contributors to eutrophication. The potential environmental impact of eutrophication was calculated by aggregating the potential contribution of P, N and C to biomass production, with P being regarded the limiting factor (Guinée, 2001). COD was treated as an individual impact category in the characterization