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DOI
10.1007/s11356-017-0895-0

Publication date
2018

Document Version
Final published version

Published in
Environmental Science and Pollution Research

Citation (APA)
Zhao, X., Yang, J., & Ma, F. (2018). Set organic pollution as an impact category to achieve more comprehensive evaluation of life cycle assessment in wastewater-related issues. *Environmental Science and Pollution Research*, *25*, 5960–5968. https://doi.org/10.1007/s11356-017-0895-0

Environmental Science and Pollution Research
https://doi.org/10.1007/s11356-017-0895-0

RESEARCH ARTICLE

Set organic pollution as an impact category to achieve more comprehensive evaluation of life cycle assessment in wastewater-related issues

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Received: 12 September 2017 / Accepted: 30 November 2017

Abstract

For wastewater-related issues (WRI), life cycle assessment (LCA) is often used to evaluate environmental impacts and derive optimization strategies. To promote the application of LCA for WRI, it is critical to incorporate local impact of water pollutants. Organic pollution, a main type of water pollution, has not been given much consideration in current LCA systems. This paper investigates the necessity of setting a regionalized impact category to reflect the local impact of organic pollution. A case study is conducted concerning an upgraded wastewater treatment plant (WWTP) in China, which is assumed to meet different sewage control strategies. Chemical oxygen demand (COD) is selected to represent the organic pollution and treated as an individual impact category. CML 2002 is used to quantify the environmental impacts of different strategies. Results show that abnormal LCA results are generated with the traditional eutrophication impact category, and after the introduction of COD, more reasonable LCA results are obtained, making the entire comparison of different control strategies more meaningful and compelling. Moreover, BEES, Ecovalue 08, and Chinese factors are adopted here as different weighting methods. Different weighting results exhibited various trade-offs for the increasingly strict control strategies; the results of BEES and Ecovalue08 underlined the potential environmental burden, but the results of Chinese factors only emphasized the local environmental improvement. It is concluded that setting regionalized impact category for organic pollution can make LCA results more reasonable in wastewater treatment, especially in evaluating Chinese cases because of the serious water pollution caused by large quantities of COD emission.

Keywords Life cycle assessment · Wastewater treatment · Chemical oxygen demand · Weighting method

Introduction

Life cycle assessment (LCA) is considered as a "cradle-to-grave" technique used to quantify the environmental impacts associated with all stages of a product, service, or process. For the wastewater-related issues (WRIs), this method can be used to evaluate or critique the changes that are taking place (Bai et al. 2017b; Corominas et al. 2013; Gabarrell et al. 2012; Hellweg and Canals 2014; Lassaux et al. 2007; Zhao et al. 2017). The related LCA studies include the improvement of the operation of municipal wastewater plant (Pasqualino et al. 2009), the comparison of alternative wastewater sludge treatment systems (Suh and Rousseaux 2002), and the development of technologies for wastewater recycling (Choe et al. 2015). When implementing LCA, an important purpose is to derive optimization strategies or recommendations to improve the environmental performance of WRI. Achieving this purpose requires LCA to fully reflect the environmental impacts of WRI and take into account the input and output as comprehensive as possible. One of the major environmental impacts of WRI is that the release of water pollutants can seriously influence the local aquatic environment. Therefore, if there were efforts to incorporate the local impact of water pollutants into LCA framework, it would promote the use of LCA in

Responsible editor: Philippe Garrigues

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evaluating WRI and facilitate a more reasonable balance between global influence and regional influence.

Eutrophication refers to oxygen depletion of river, lake, or sea water. Generally, there are two types of oxygen depletion: one is the primary oxygen consumption caused by the release of organic matter; another is the secondary oxygen consumption that resulted from the potential algae degradation (Karrman and Jonsson 2001). Existing manuals of LCA mainly consider the secondary oxygen consumption as the scientific background of eutrophication, stressing the potential contribution of phosphorus (P) or nitrogen (N) to biomass production (Guinee 2001; Hauschild et al. 2013; Seppala et al. 2004; Seppala et al. 2006), however, has not given much consideration to the primary oxygen consumption. With respect to WRI, especially various legislations or various policies, there would be great difference in emissions of organic matter, which will damage local aquatic environment directly and differently during the phase of primary oxygen consumption (Wang et al. 2015). To reflect the environmental impacts of WRI more comprehensively, it is necessary for LCA to consider the local influence of organic matters during the primary oxygen consumption.

Considering that LCA is about product systems that are basically spanning the whole world, trade-offs of environmental impacts between the global scale and local scale would be needed when local influence of organic matters is considered in LCA evaluation of WRI. Accordingly, the use of weighting is needed to assign relative weights to different environmental impact categories. Currently, only a few studies adopted weighting as one step of LCA related to WRI (Corominas et al. 2013). Possible reason lies in that the design of weighting methods is believed to be subjective, and the use of weighting methods is thought to be a weakening to the objectivity of LCA results (Bengtsson and Steen 2000; Finnveden et al. 2006). However, this is a common misunderstanding about the nature of weighting. In fact, the use of weighting is a step that new information is embedded into the process of environmental impact assessment, and the information is based on certain social preference concerning the relative priorities of different environmental impact categories (Bengtsson and Steen 2000). By analyzing the final weighting results, it can contribute to illuminating the decision situations of stakeholders that have specific preference contexts. With respect to WRI, two groups of stakeholders are generally involved: one represents the LCA practitioners who could be more concerned about the global balance of all input and output, and another represents WRI stakeholders who could be more concerned about the local impact of WRI. Therefore, to achieve the trade-offs between global impact and local impact, it would be necessary to select the weighting methods that are embedded with global context or local context.

In this study, we first studied whether considering COD's local influence during the primary oxygen consumption into the eutrophication impact category would make LCA results more reasonable in wastewater treatment, and investigated the necessity of setting such a regionalized impact category. After that, we used different weighting methods to further evaluate this study and discussed the relationship between local preference and the associated better choice. In the end, we put forward a framework for future LCA studies related to regionalized waste control.

Experimental

Wastewater treatment plant

An upgraded wastewater treatment plant (WWTP), being operated in Heilongjiang Province in China, was selected for the case analysis. The WWTP was equipped with cyclic activated sludge technique and had a daily processing capacity of 10,000 m^3 sewage. The sewage discharge were assumed to meet three increasingly strict Chinese national control strategies, which were class 2 (scenario 2; Sc-2), class 1B (scenario 1B; Sc-1B), and class 1A (scenario 1A; Sc-1A), respectively (MEP 2002). In addition, scenario 3 (Sc-3) were defined as the situation that raw wastewater was discharged into the receiving water directly without any pretreatment. The class 2 strategy represents the secondary treatment in WWTPs, requiring a biological treatment plant to meet basic function of water pollutants removal without phosphorus removal and tertiary treatment. The class 1B strategy represents the high load secondary treatment and needs the ability to remove phosphorus. Based on class 1B, upgrading to the class 1A introduces a tertiary treatment stage, including coagulation, sedimentation, and filtration. More detailed information about the WWTP facilities and the control strategies were described in previous study (Wang et al. 2015).

Life cycle assessment

The environmental impacts of the three scenarios were evaluated using LCA. A widely used LCA approach, CML 2002, which was developed by Leiden University (Guinee 2001), was adopted here to quantify the environmental impacts of different scenarios. We took 10,000 m^3 sewage as function unit and mainly considered the operational phase of the WWTP. For the input of each scenario, we considered the electricity production, chemical consumption and transportation, and some other substance addition. Meanwhile, we considered the output of all emissions of water pollutants, harmful gases, and waste sludge. Detailed data about the input and output are shown in Table 1. In life cycle impact assessment (LCIA), impact categories involved in this study included: eutrophication (E), acidification (A), freshwater aquatic ecotoxicity (FAET), human toxicity (HT), ozone depletion

Table 1 Inputs and outputs of different scenarios

	Parameter	Unit	Sc-1A	Sc-1B	Sc-2	Sc-3
Inputs from the background system of different scenarios	Electricity	kWh	4380	3420	3120	480
	Inorganic chemicals	t	0.858	0.658	0.508	–
	Chemical transport	t km	1716	1316	1016	–
	PAM-acrylonitrile	kg	7.35	7.35	6.5	–
Outputs to the environment of different scenarios	Tertiary and phosphorus precipitation solid waste	t, water 60%	0.923	0.113	–	–
	Bio-sludge	t, water 80%	8.45	7.35	6.5	–
	CO2	t	1.76	1.76	1.41	–
	N2O	kg	1.02	0.68	0.18	0.22
	COD	kg	298	426	800	2592
	TN	kg	128	142	226	287
	TP	kg	5	7.8	22	34
	SST	kg	82	163	240	1874

(OD), photochemical oxidation (PO), global warming (GW), abiotic depletion of fossil fuels (ADF), and abiotic depletion of elements (ADE). For comparison between scenarios, characterization results of the impact categories were normalized based on the approach of previous study (Sleeswijk et al. 2008). All the normalized scores are shown in Table 2.

Local influence of organic matters

To characterize the local influence of organic matters, chemical oxygen demand (COD) was treated as an individual impact category in this study, and its characterization results and normalized scores were also calculated, with the coefficients of characterization and normalization being 1 (kg COD eq.) and 1.41×10^{10} (kg). All the coefficients of COD came from the e-Balance, a computer software used in LCA evaluation and developed by IKE Company (China, http://www.ike-global.com/). In order to investigate the influence of considering COD's direct impact on local receiving water, two kinds of eutrophication impact category were defined here. The first one was the traditionally defined eutrophication (named E1 here), in which organic matters had little effect on final LCA results. The second one was the new defined eutrophication (named E2 here), in which COD's direct impact was taken into account.

Table 2 LCA normalized scores of different scenarios

Impact category	Normalized scores (in 10^{-12} year)			
	Sc-1A	Sc-1B	Sc-2	Sc-3
ADE (kg antimony eq.)	160	120.8	78.2	4.3
ADF (MJ)	8131.8	5998.1	5323.9	615.8
GW (kg CO_2 eq.)	2472	1921	1654	124
OD (kg CFC-11 eq.)	131.1	98.7	57.4	1.5
HT (kg 1,4-DCB eq.)	1259.9	916.3	766.5	194.3
FAET (kg 1,4-DCB eq.)	354,892	253,731	215,588	122,553
PO (kg ethylene eq.)	150.4	111.1	98.9	9.7
A (kg SO_2 eq.)	2661	1915	1718	226
E_1 (kg PO_4 eq.)	57,834	61,880	112,455	167,790
E_2 (kg PO_4 eq.)	78,969	92,093	169,193	351,620

The normalized scores of COD has been integrated into the results of E_2, with the values of 21,135, 30,213, 56,738, and 183,830 being in Sc-1A, Sc-1B, Sc-2, and Sc-3, respectively

Weighting methods

We used three weighting methods here. BEES (Building for Environmental and Economic Sustainability), a panel-based weighting method, was developed for the US building sector (Suh and Lippiatt 2012). Ecovalue 08, a weighting method based on monetary values, was developed depending on the willingness-to-pay estimates for environmental quality (Ahlroth and Finnveden 2011). Chinese factors, the distance-to-target weighting method, were developed in the second conference of Chinese Life Cycle Management, and the weighting values came from the computer software e-Balance. Notably, BEES and Ecovalue 08 were used as global-scale weighting methods, and Chinese factors were used as regional-scale weighting method.

Data processing

Two situations were characterized here; the first one calculated the total environmental impact of different scenarios without considering organic matters' local influence (defined as Tot-1), and the second one included the COD's direct impact in the calculation of total environmental impact (defined as Tot-2). Impact categories of A, FAET, HT, OD, PO, GW, ADF, and ADE were included in both situations. The only difference existed in the eutrophication impact category. E1 was included in Tot-1 and E2 was included in Tot-2, which means that only results of Tot-2 can reflect the COD's direct influence in primary oxygen consumption. Single value was obtained for each scenario in both situations, with the same weighting method of BEES. Then, in order to explore the effect of different weighting methods, BEES, Ecovalue 08, and Chinese factors were used in Tot-2, respectively. Figure 1 shows the specific evaluation process in this study.

Results and discussion

COD as an individual impact category to obtain more reasonable LCA results

Without organic matters' direct impact considered, Sc-3 had the lowest score in Fig. 2a, which meant that the scenario 3, representing the direct emissions of wastewater without any disposal, was the most environment-friendly scenario, compared with other scenarios with more or less degree of pretreatment. Such result might be reasonable in certain situation. For example, some kinds of the receiving water with strong self-cleaning capacity may have the ability to contain large quantities of wastewater (Sondi et al. 1994). In this situation, wastewater could be directly released into the receiving water with no extra energy consumption and chemicals utilization for pretreatment. However, there were many limiting conditions to achieve this situation. Firstly, the receiving water should have adequate self-cleaning capacity to convert most of the waste substances into the harmless substances. Secondly, it depends on the city scale and population density because large cities with high population density would generate large quantity of wastewater, which would exceed the limit of receiving water easily and would damage the local aquatic environment seriously. Thirdly, the function of receiving water is also worth considering. When shipping is the only function of receiving water, wastewater may not need excess pretreatment before being released. But when the receiving water holds the important function of irrigation, wastewater should be disposed effectively to protect public health.

In this study, however, the evaluated WWTP case locates in China, and China is facing serious water pollution, with limited environmental capacity in many rivers and lakes (MEP 2002). The COD emission of Sc-3 was 2592 kg/day, almost three times higher than Sc-2 and six times higher than Sc-1B. If Sc-3 happened in the real situation of China, serious water pollution would occur due to the primary oxygen consumption. So, the direct release of wastewater is prohibited and the wastewater should be treated in order to protect the local aquatic environment.

The initial purpose of performing LCA aimed to identify the best control strategy which could protect the local receiving water and would not cause the problem shifting simultaneously (Reap et al. 2008). The decision making needed to rely on the reasonable LCA results. But if we used the results in Fig. 2a, there would be an obvious contradiction between the LCA result of Sc-3 and the real situation of this WWTP case. The lowest LCA result of Sc-3 indicated that the direct release of wastewater had the lowest negative environmental impact, and it was not necessary to dispose the wastewater before being emitted, but the real situation of this WWTP case showed that the wastewater would seriously damage the local receiving water and should be treated effectively before being released. In other words, the primary oxygen consumption was not covered in the eutrophication impact category, making the result of Sc-3 could not completely reflect the seriousness caused by the direct release of wastewater which

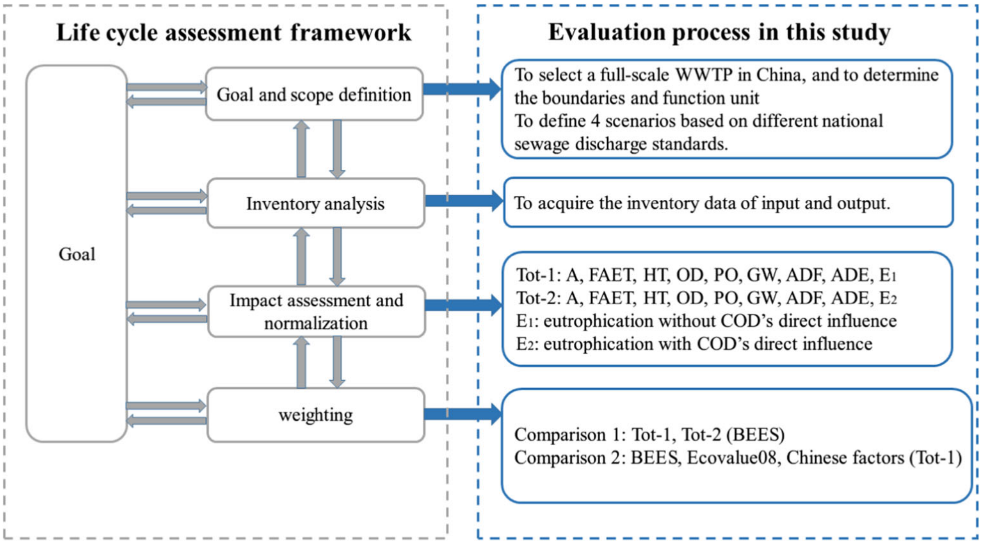

Fig. 1 LCA framework and evaluation process in this study

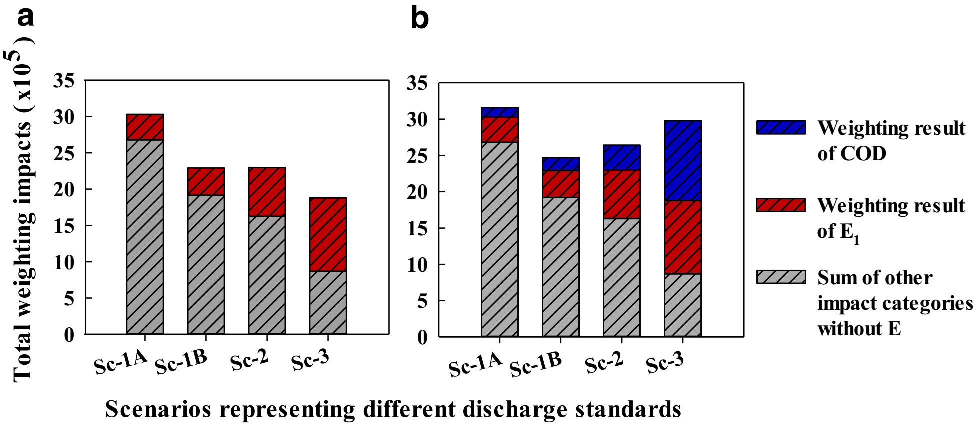

Fig. 2 Final LCA results of Tot-1 and Tot-2 with the same weighting method of BEES. **a** Tot-1; E_1 represents the eutrophication impact category without COD's direct influence. **b** Tot-2; E_2 represents the eutrophication impact category with the COD's direct influence, and the weighting results of E_2 was the sum of E_1 and COD

contained large quantities of COD, and making the entire LCA results of Tot-1, therefore, seem unreasonable and ineffective in this Chinese WWTP case.

When we integrated the COD's direct influence on receiving water into the eutrophication impact category, more reasonable LCA results are obtained in Fig. 2b, with the value of Sc-3 being higher than the value of Sc-2 and the value of Sc-1B. In this circumstance, it all made sense to compare the different control strategies (the other three scenarios) because the result of Sc-3 suggested that the direct release of wastewater would harm the environment and the wastewater should be treated before being emitted.

In the eutrophication impact category of LCA, whether considering COD's direct influence in the primary oxygen consumption needs to be discussed from two perspectives: (1) the nature of the evaluated object and (2) the environmental characteristics that this object located in. In this WWTP case, the evaluated objects are the sewage control strategies with increasingly stringent levels. One of the main purposes of using LCA herein is to understand the possible environmental implications of tightening the standard levels. When choosing LCIA methods, it is important to note that results of each impact category should fully reflect the possible environmental impact. In this study, the negative impact can be comprehensively captured through the impact categories of A, FAET, HT, OD, PO, GW, ADF, and ADE. But for the environmental benefit, the results of E1 can only provide an evaluation on total environmental benefit. As we know, the main function of setting strict strategies for WWTPs are to reduce the local water pollution and to improve the environmental capacity of local receiving water (Wang et al. 2015). If we want to fully quantify the environmental implication of certain control strategy, its impact on local aquatic environment needs to be considered.

When considering whether to cover the COD's direct influence, another important thing is to have a whole understanding of local environmental situation. In this study, we took a Chinese WWTP as the example. Although it is difficult to know the specific characteristics of receiving river due to the lack of data, investigation of the current pollution state of Chinese freshwater environment will be more helpful. For the recent decades, the extensive modes of local economic development in China have made the local environment suffered serious pollution. Over time, the rapid urbanizations and the associated high population density are increasing the quantities of wastewater emission. All these factors add up to make China suffering great pressure of water pollution in many local areas, and this has become an urgent problem that needs immediate attention and stronger treatment. According to China Environmental Status Bulletin (MEP 2014), the annual emissions of COD have a value of 22.94 million tons, which is much greater than the total water environmental capacity, with a value of 7.4 million tons. For the seven main watershed in China, more than 13% sections are seriously polluted (labeled as grade V and worse than grade V). And in Chinese national policies, such as the government's 11th Five-Year plan (2006–2010) and the 12th Five-Year plan (2011–2015), COD is regarded as the main emission reduction target. Moreover, water pollution accidents happened frequently in China, and the emissions were found to contain COD at up to 3–8 times the level allowed in national standard. All this suggests that COD remains one of the most prevalent contaminants in Chinese water pollution and is a serious threat to local aquatic environment. Therefore, in this Chinese WWTP case COD's direct influence on local aquatic environment in the primary oxygen consumption should be included into eutrophication impact category, and in this way, the final LCA results will become more reasonable and more compelling.

Different weighting results

By using different weighting methods, different final results were generated as shown in Fig. 3, especially for Sc-1A, which obtained the lowest score in Chinese factors (regional-scale weighting method) but the highest scores in both BEES and Ecovalue 08 (global-scale weighting method).

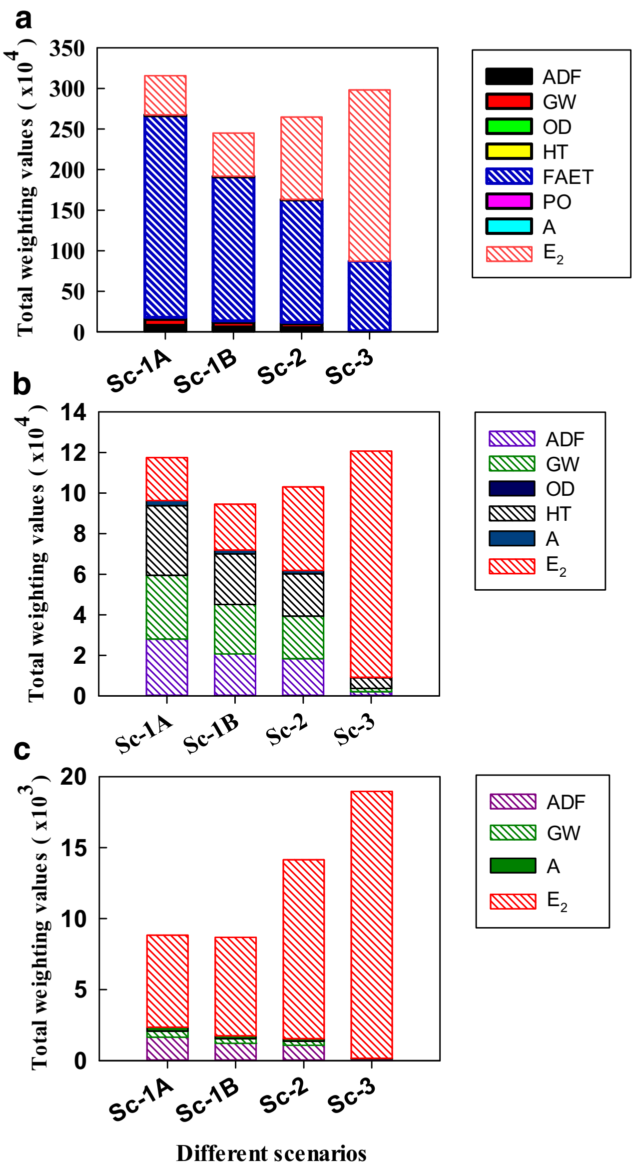

Fig. 3 Final LCA results with different weighting methods in the same situation of Tot-2. **a** BEES. **b** Ecovalue 08. **c** Chinese factors

Facing the totally opposite results, it is hard for decision makers to determine whether class 1A should be used to replace other control strategies. But through the analysis of the different weighting results, it can provide us more information and multiple perspectives to better understand the possible trade-offs involved in the decision making.

In this case, weighting results were obtained by balancing the environmental benefit and the environmental cost. For the increasingly strict control strategies, environmental benefit is characterized by the reduction of water pollution, with the decreased weighting values of eutrophication impact category. This environmental benefit can be regarded as the local environmental improvement. There are many types of environmental cost, including fossil resource depletion or carbon dioxide emissions, which can be reflected in the increased weighting values of the associated LCA impact categories, such as ADF or GW (Heijungs et al. 2013; Zhao et al. 2017). These environmental costs can be treated as the potential environmental hazard. So, the weighting results in this case can also be regarded as the trade-offs between the local environmental improvement and the potential environmental hazard.

Different weighting results exhibited various trade-offs for the increasingly strict control strategies (Bai et al. 2017a). Similar final results were generated with the method of BEES and Ecovalue 08 (Fig. 3a, b), but the trade-off of BEES results showed that FAET contributed most to the potential environmental hazard, while HT, GW, and ADF were the main contributors of potential environmental hazard in the trade-offs of Ecovalue 08 results. Chinese factors, however, showed different final results from those two methods. Eutrophication was the only decisive factor in the final results, and other impact categories contributed little. It indicated that performing stricter control strategies had almost no extra potential environmental hazard under this method, and the only important thing was to improve the local aquatic environment.

There is no right or wrong on the choice of weighting methods, and there is no one criteria to judge which set of weighting results should be better (Schmidt and Sullivan 2002). More important thing is that the choice of weighting methods need to be consistent with the environmental values of the stakeholders who will make decisions based on the LCA results. If the stakeholders emphasize the reduction of potential threat on total environment, they may be more likely to take the results of BEES or Ecovalue 08 as reference, in which the weighting values of the impact categories representing potential environmental hazard account for a large part in the entire weighting results. To be more specific, if one area that the evaluated WWTP locates in is under severe condition of limited fossil resources, it would be unlikely for them to pay more fossil resources to achieve extra improvement of local aquatic environment. In this situation, the weighting results of Ecovalue 08 provide such an evidence that the overly strict control strategy could increase the burden of fossil resource scarcity. As the results shown in Fig. 3b, the scenario with the highest final score and the lowest net environmental benefit was Sc-1, in which the ADF was one kind of major potential environmental hazards.

If the improvement of local aquatic environment is valued more by stakeholders, they may tend to take the results of Chinese factors as reference, and the results could provide necessary support for the establishment of stricter control strategies. But it also needs to be noticed that the improvement of local aquatic environment would not be obvious when the control strategy is tightened to some point. As shown in Fig. 3c, although the general downward from the final weighting scores of the increasingly strict control strategies reflect the necessity of improving the local aquatic environment, the effect of improvement is not obvious when the Sc-1B is tightened to Sc-1A. Moreover, the emphasis on local environmental improvement does not mean that the potential environmental hazard is not important. At least, the weighting results of BEES and Ecovalue 08 can remind the stakeholders that the improvement of local environment often comes at a price. At one time, it seems necessary and urgent to achieve the improvement of local environment at the cost of more energy consumption and other increased environmental hazard such as global warming. But whether it is also worthy in the long run needs to be considered more carefully and more comprehensively. Accordingly, the results of BEES and Ecovalue 08 can also remind us to develop some more efficient wastewater treatment technologies, which can achieve the effective wastewater sanitation and decrease the consumption of resources simultaneously.

Implication of this study

Herein, we used a simple method to integrate COD's direct influence in primary oxygen consumption into the eutrophication impact category. We treated COD and eutrophication as two independent impact categories in characterization and normalization first, and then regarded them as one impact category in the weighting phase. The main goal was to propose the necessity of considering COD's direct influence in primary oxygen consumption when dealing with the WWTPs case in LCA. We did not develop a new characterization model to estimate the combined effect of primary oxygen consumption and secondary oxygen consumption because of their different mechanisms. Primary oxygen consumption is caused by the release of organic matter, which can trigger an increasing population of aerobic bacteria in receiving water to consume large quantities of dissolved oxygen. Secondary oxygen consumption is caused by the excessive release of nutrients. The enrichment of nutrients can contribute to the formation of algae or biomass, and the decomposition of these algae or biomass needs the consumption of dissolved oxygen. Although both of the two mechanisms can reduce the dissolved oxygen levels of the receiving water, their effects vary with different time, places, water quantities, water quality, local environmental characteristic, total environmental characteristic, and etc. Including all the factors into one characterization model means more effort and time, and it would be inconvenient to build and operate such a model, and might bring the risk of being less transparent and more uncertainty.

The decision-making in real world is a complex process, involving different factors from different dimensions. Due to the uncertainties in LCA results and the limitations in LCA methodology, it might not be possible to decide that one choice is better than others (Curran 2013; Hellweg and Canals 2014). But it does not mean that LCA is not a useful method. LCA remains a viable tool because it can not only quantify the environmental impact of certain objects, but also gather the scattered information, put them together to balance, and improve understanding of the cost and benefit associated with each choice.

Through the analysis of this study, we propose the necessity of setting regionalized impact category and weighting factors to achieve more reasonable LCA results in the field of wastewater treatment. If the analysis could be extended to other areas concerning waste control, we put forward a framework of regionalized LCA evaluation here as a reference for future related study.

1. Describing the main function of evaluated scenarios. In the description of the goal and scope, the main function of the related scenarios in waste control should be stated clearly. What is the main control target of the scenarios? How would the control target and the scenario influence local environment?
2. Evaluating the scenarios with general LCA. The scenarios could be evaluated with the general LCA methodologies such as CML 2002 used in this study, and the general results (Re-1) should be analyzed and interpreted to investigate the possible trade-offs involved in the comparison between different scenarios. Then, it is necessary to decide whether Re-1 is reasonable enough to reflect the main function of the scenarios, especially the effect on local environment. If not reasonable, it means that some factors in LCA need to be modified toward regionalization to include the local effect of those scenarios in LCA results.
3. Setting regionalized impact category and weighting factors. In LCIA, the control target could be regarded as an individual impact category, named CT here. The CT is independent of other traditional impact categories such A, PO, E, or GW. Then, the coefficients of characterization and normalization should be calculated according to the standard way or based on the actual scientific background in local environmental pollution. For example, COD in this study was treated as an individual impact category. The coefficient of characterization was 1 (kg COD eq.) that was based on the actual background in Chinese water pollution, and the coefficient of normalization was 1.41×10^{10} (kg) that was calculated according to the approach of previous study (Sleeswijk et al. 2008). Moreover, it needs to be careful not to double-count, if the control target belongs to certain traditional impact category. The traditional impact category needs to be modified to remove the effect of this control target, when it is regarded as an individual impact category. In this study, we avoided the problem of double-count. The COD impact category emphasized its direct influence in the primary oxygen consumption, while the traditional

eutrophication impact category emphasized the secondary oxygen consumption caused by nitrogen or phosphorus where COD has little influence. After the characterization and normalization, weighting could be chosen to obtain single values for comparison. Because of the introduction of new impact category, the usual weighting methods may not be suitable. It needs to build up a set of new weighting factors, in which the valuation of each impact category should be tightly based on the local characteristics.

4. Re-evaluating the scenarios with new LCA. The scenarios could be re-evaluated with the modified LCA, and the final results (Re-2) could be obtained. The two sets of results should be presented to decision makers in order to improve the understanding of the trade-offs involved in the related scenarios.
5. Informing the decision makers. It is important to note that the settings of regionalized impact category and weighting factors are not the usual step in general LCA methodology. The new settings can be regarded as the new information being introduced into the general LCA methodology. It is the new information that leads to the difference between Re-1 and Re-2, which might further cause different policy implication. Therefore, when presenting these results to the decision makers to decide which scenario should be implemented, it is necessary to inform the decision makers that what the new information is and how the new information affects the final results.

Conclusion

In this study, we introduced the organic matters' direct influence during the primary oxygen consumption into the LCA framework and investigated its effect on final LCA results. By setting an independent impact category, it could make the LCA results more reasonable for the comparison of different control strategies in wastewater-related issues. Moreover, we investigated the relationship between different social preferences and different weighting results and indicated that the choice of weighting methods need to be consistent with the environmental values of the stakeholders who will make decisions based on LCA results. Finally, we put forward a framework for future related study concerning the incorporation of local issues into LCA evaluation.

Acknowledgements The authors would like to express their gratitude for the PhD Fellowship Awards provided by China Scholarship Council to Xinyue Zhao (No. 201606120194).

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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