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Evaluating the environmental impacts of an urban wetland park based on emergy accounting and life cycle assessment: A case study in Beijing

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ABSTRACT

In this paper, emergy accounting (EA) and life cycle assessment (LCA) methods are employed to investigate a typical urban wetland park, the Green Lake Urban Wetland Park (GLUWP) of Beijing, in terms of its environmental and capital inputs, ecosystem services and organic matter yields, environmental support, and sustainability. The LCA method is also used to obtain a quantitative estimation of the environmental impact of discharges during the entire life cycle of the GLUWP. Various emergy-based indices, such as emergy yield ratio (EYR), environmental load ratio (ELR), emergy sustainability index (ESI), net economic benefit (Np), and environmental impacts of process-based LCA, including global warming potential (GWP), eutrophication (EU), nonrenewable resource depletion (RU), energy consumption (EN), acidification potential (AP), photochemical oxidant creation potential (POCP), particulate matter (PM) and wastes (W), are calculated. The results show that the GLUWP has higher proportions of renewable resource input, less pressure on the environment, more environmental support and better ecological and economic benefits, which can be considered as an environment-friendly and long-term sustainable ecological practice, compared with another constructed wetland in Beijing. Meanwhile, the dominant environmental impact is induced by POCP with the construction phase contributing the most on the entire life cycle. It is expected that increasing green area, extensively using environment-friendly materials, optimizing construction techniques and reducing power consumption can promote the sustainability of the GLUWP.

1. Introduction

With increasing pressure on the land, energy sources and eco-environment in the urban areas, wetland park, emerged as a new kind of constructed wetland, has played an important role in protecting the habitat of numerous species, environmental management, landscaping, eco-tourism, environmental education and providing recreational opportunities, and thereby enabled a balance of conservation and sustainable utilization of resources. Thus, to achieve the aim of sustainability, environmental impact assessment of urban wetland park related to harmonizing conservation and sustainable development of the entire urban ecosystem is of great importance, particularly in providing a theoretical basis of decision-making and policy guidance for urban ecosystem.

Given that urban wetland park is commonly considered as a viable alternative to conventional wastewater treatment, thus the benefit, sustainability and environmental impacts that can be gained from various phases of its life cycle must be illuminated or assessed, and methods on this have tended to be diverse. In the last 30 years, various models have been proposed to assess the economic, technical and environmental characteristics related to wastewater treatment and constructed wetlands, which have included, for instance, emergy accounting (EA), life cycle assessment (LCA), energy analysis, exergy analysis, environmental risk assessment, and cost-benefit analysis, etc. (Hellström, 1997; Ju and Chen, 2010; Ko et al., 2004; Ortiz et al., 2007; Palme et al., 2005; Russell, 1999; Zuo et al., 2004). These methods can be divided into two broad categories: one focuses on the amount of resources used per unit of the product, providing valuable insights into the hidden environmental costs and inherent sustainability, while the other is interested in a system's emissions and impact on the local ecosystem (Cherubini et al., 2008), with different goals, theoretical foundations, handling abilities, perspectives and scales (Geber and Björklund, 2002).

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With the framework of an ontological science (Ju and Chen, 2010), emergy, defined as the available solar energy used up directly or indirectly to create a service or product, can be used to assess natural inflows and services within a system (Odum, 1996; Ridolfi and Bastianoni, 2008). Emergy accounting is regarded as an environmental accounting methodology opposed to other methods depending on a populations' perceived value of nature's contribution (Tilley and Brown, 2006). A series of emergy indices for evaluating the eco-technological processes, such as emergy yield ratio (EYR), environment loading ratio (ELR), emergy investment ratio (EIR) and the emergy sustainability index (ESI) has already been proposed (Brown and Ulgiati, 1997). In the past decade, new emergy indices have been brought forward continuously to evaluate various ecosystems, such as renewable percentage (R%) (Brown and Ulgiati, 2002), base emergy change (Bec) and net profit (Np) (Zuo et al., 2004), emergy restoration ratio (ERR), ecological economic product (EEP), emergy benefit ratio (EBR), and the emergy benefit after exchange (EBE) (Lu et al., 2006). The integrated emergy indices including conservation value (CV), social self-sufficiency ratio (SSR), emergy conservation ratio (ECR) and emergy index of sustainable development (EISD) have also been developed and applied to evaluating the ecosystem from various aspects, e.g. the Yancheng Biosphere Reserve of China (Lu et al., 2007).

Recently, emergy has been widely used to assess the sustainability of various constructed wetlands and plants treating wastewater, such as the vertical subsurface-flow constructed wetland (Chen et al., 2008), traditional wastewater treatment plant coupled with a surface-flow constructed wetland (La Rosa and Siracusa, 2006), conventional wastewater treatment plants (Björklund et al., 2001), constructed wetland and conventional wastewater treatments (Zhou et al., 2009), original and constructed wetlands (Zuo et al., 2004) and natural wetland park as well (Ren et al., 2009).

Meanwhile, the systematic LCA method is often employed to assess the potential environmental impact of a product or system over its entire life cycle, which includes resource extraction, transportation, manufacture, utilization, consumption, recycling and waste management (Dixon et al., 2003). The LCA method has been found to be a useful methodological tool in undertaking a quantitative environmental analysis of the entire process. However, it only focuses on the environmental impact of emissions while ignoring the contributions of ecological products and services. The main limitation of LCA is that the rankings and indicators are mixed units, making it difficult to conduct a comparative analysis between products or services (Brown and Buranakarn, 2003). Until now, LCA has been broadly applied in practice, such as in technical comparison or alternatives (Cherubini et al., 2008; Houillon and Jilliet, 2005; Ortiz et al., 2007); production development and improvement (Papong and Malakul, 2010); strategic planning and public policy making among others (Finnveden and Ekvall, 1998).

Thus, these two different methods, i.e., EA and LCA, could be combined to properly estimate the tradeoff between human demand and natural service, as well as to appraise current utilization methods of natural resource and environmental emission levels. Few studies have combined these two scientific tools to measure human impact on nature and the sustainability of a system, as exemplified by a study on two wine farms in Italy (Pizzigallo et al., 2008) and urban residential area (Li and Wang, 2009). In this paper, we intend to employ them as good alternatives in evaluating the sustainability and environmental impacts of urban wetland park, of which LCA is used to evaluate the environmental impact from materials extraction to dismantlement of the concerned system, and EA is integrated with a physical evaluation of the resource, ecological service and the sustainability. In the following sections, the calculation procedure is described, and various indices and ratios are used to evaluate the environmental impacts of emissions and the sustainability of the entire process. Finally, reasonable strategies for reducing emissions and promoting sustainability of the wetland park are presented in Section 4.

2. Materials and methods

2.1. Study site

The Green Lake Urban Wetland Park (GLUWP), with a total area of 157.62 ha, is located in the town of Shangzhuang, northwest of Haidian District, in Beijing, China. It is 36 km from Tiananmen Square, just around the corner of the Zhongguancun Technical Garden, which is described as the back garden and "water country" of Beijing. The phase-I project has been completed with an area of 53.3 ha, among which 30 ha water areas are used to treat 1000 m^3 household wastewater of the upper branch villages per day. More than 250 species of wetland plants and animals have been introduced to the park, forming a specific wetland landscape. Lotus ponds, reed marshes, swan lakes, exhibition areas for wild wetland plants, waterfowl protection areas, central park and science gallery are all important components of the GLUWP, which has become a preferred habitat and transit station for migrating birds in winter. Wastewater treatment facilities normally require transformation or updating after 15–20 years of operating, thus, 20 years will be considered as a lifetime of GLUWP. The scenery of GLUWP is presented in Fig. 1.

2.2. Methodology

2.2.1. Emergy accounting

As an ecological evaluation approach, EA incorporates environmental services into an entire-system analysis (Vassallo et al., 2009), in which, each form of energy (i.e., environmental and economic inputs in the system) is multiplied by suitable conversion factors, i.e., transformity (expressed in sej/J) or specific emergy (expressed in sej/g or other units), and then translated into its solar energy equivalent or solar emergy (Chen et al., 2006; Pizzigallo et al., 2008). The renewable energy and resources including sunlight, wind, rain and tides used to be regarded as free and considered externalities of the production process that are calculated as environmental support (Chen et al., 2009). The free environmental support and purchased inputs account for the direct and indirect contributions of human activities. Emergy evaluation is particularly useful for the assessment of wetlands, since it has a strong capacity to account for all the work done by nature and human-economy in the production of resources used by the economy (Siche et al., 2009). In addition, the global emergy baseline used here is 15.83E+24 sej/year, and the transformites are obtained from the recent studies.

Fig. 1. The landscape of the GLUWP.