Assessing Ecosystem Services with Life Cycle Assessment: A Nature-Based Solution for Wastewater Treatment in Lesvos, Greece

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Introduction

Nature-based solutions (NBS) harness the resilience of healthy ecosystems to safeguard communities, optimize infrastructure, and promote biodiversity. Recent literature underscores the cost-effectiveness and local adaptability of NBS, offering a range of environmental, social, and economic benefits (Langergraber et al., 2020; Nika et al., 2020; O'Hogain and McCarton, 2018). Environmental Life Cycle Assessment (LCA) serves as a cornerstone for assessing product sustainability, accounting for inputs and outputs to evaluate environmental impacts (International Organization for Standardization, 2006). Various LCIA methods approach environmental impact assessment differently, with Environmental Priority Strategies 2015dx (EPS) (Rydberg and Steen, 2023) focusing specifically on "Ecosystem services." Ecosystem services, categorized by CICES, encompass provisioning, regulating, and cultural services (Haines-Young and Potschin, 2017). Despite traditionally focusing on environmental burdens, LCA struggles to quantify ecosystem benefits, prompting recent integration efforts to bridge this gap (De Luca Peña et al., 2022). These integration strategies involve incorporating ecosystem services into LC Impact Assessment or expanding system boundaries to account for ecosystem supply and demand (Boone et al., 2019; Liu et al., 2020). This study applies EPS and ReCiPe impact methods to evaluate the environmental benefits of an NBS for urban wastewater treatment, comparing it with existing infrastructure and assessing EPS and ReCiPe capacity to quantify ecosystem services.

Material and methods

The hydrogeological system of Lesvos Island faces natural and human-induced pressures, lacking resilience (Simha et al., 2017). The original system, designed to replace the Antissa WWTP, aims to treat urban wastewater, generate clean water for agriculture, and foster a resilient ecosystem, producing approx. 10 tons/y of fruits and vegetables and 90 kWh/d of biogas energy. This study compares the original system with a reference system that provides the same functions. The functional unit (FU) is one year of operation, focusing on treating 23,780 m^3 of wastewater, producing 35,644 MJ of heat, and yielding 9,864 kg of crops. The EPS (Rydberg and Steen, 2023) and ReCiPe (Huijbregts et al., 2017) impact methods were applied.

Results and Discussion

Figure 1 illustrates the normalized assessment results of the original and reference systems using both impact methods. Normalization was necessary due to the different units used by EPS and ReCiPe. In addition, EPS focuses on fewer impact categories compared to ReCiPe. Results from both methods indicated environmental benefits of 63% for EPS and 90% for ReCiPe compared to the reference system. The primary source of benefits identified was the reduction in oil-based electricity consumption. While both original and reference systems capture atmospheric CO_2, the reference system falls short of surpassing the original system due to insufficient CO_2 sequestration. Key contributors to damage in the original system for EPS include 'Crop growth capacity' and 'Fish and meat production capacity', while for ReCiPe, 'Global warming, Terrestrial ecosystems' is significant, emphasizing terrestrial ecosystem damage in both methodologies.

LCA lacks explicit consideration of ecosystem service benefits, but in the inventory analysis, practitioners conduct mass balances to ensure data accuracy and completeness, potentially capturing benefits like improved water and soil quality and increased crop yield. Quality indicators such as water pollutants and phosphorus content can be used to quantify these benefits. EPS evaluates limited ecosystem services, focusing on crop and wood growth capacities, quantifying environmental emissions' damage. ReCiPe assesses ecosystem damage based on global species extinction but doesn't directly assess ecosystem services.

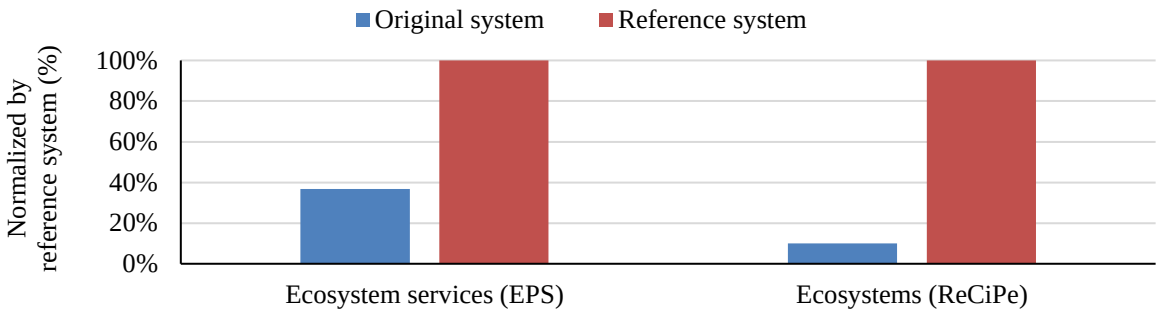

Figure 1. Normalized endpoint results of original and reference systems with environmental priority strategies (EPS) and ReCiPe methods

Conclusions

This study evaluates the impact of an NBS for urban wastewater treatment and food production using EPS and ReCiPe methods, focusing on ecosystem services. Results suggest significant benefits, mainly due to biogas-derived electricity replacing oil-based power. While both methods fail to assess ecosystem service benefits, EPS quantifies damage to crop and wood production capacities, while ReCiPe considers land transformation and biodiversity. Therefore, these methods only complement ecosystem service studies, with ongoing research aiming for further integration into environmental impact assessments. Standardization of ecosystem service assessment remains a challenge, suggesting that using technical data in the inventory phase may reduce uncertainty compared to directly integrating ecosystem services into LCA.

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