The importance of resource recovery for environmental sustainability of an energy self-sufficient sewage treatment plant

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Abstract: We have applied a state-of-the-art env. sustainability assessment to an energy positive sewage treatment plant, its supply chain and resource recovery: electricity production out of biogas from sludge digestion and the associated stabilized digestate, applied as agricultural fertilizer, production. Prominent aspects of our study are: a holistic environmental impact assessment, measurement of greenhouse gas emissions (including N_2O), and accounting for infrastructure, toxicity of metals present in the digestate and replacement of conventional fertilizers and electricity. The impact of latter products is prevented. Overall, the system leads to a prevention of resource extraction from nature and a potential prevention of ecosystem diversity loss (though for some impact categories this cannot be quantified) but it also leads to a damaging effect on human health, mainly via climate change (dominated by N_2O) and heavy metal (mainly Zn) toxicity of digestate. Resource recovery plays a crucial role in the environmental sustainability though the assessment methodology needs improvement.

Keywords: life cycle assessment; environmental sustainability; anammox

Introduction

Although the main aim of the wastewater treatment plant (WWTP) is to decrease harmful emissions towards water bodies, recently more attention is paid to energy efficiency, resource recovery and even broader to overall environmental sustainability (Verstraete and Vlaeminck, 2011). The WWTP in Strass (Austria), studied in this work, has been put forward as energy self-sufficient and is one of the pioneer plants in this aspect (Nowak et al., 2011) (Figure 1.1).

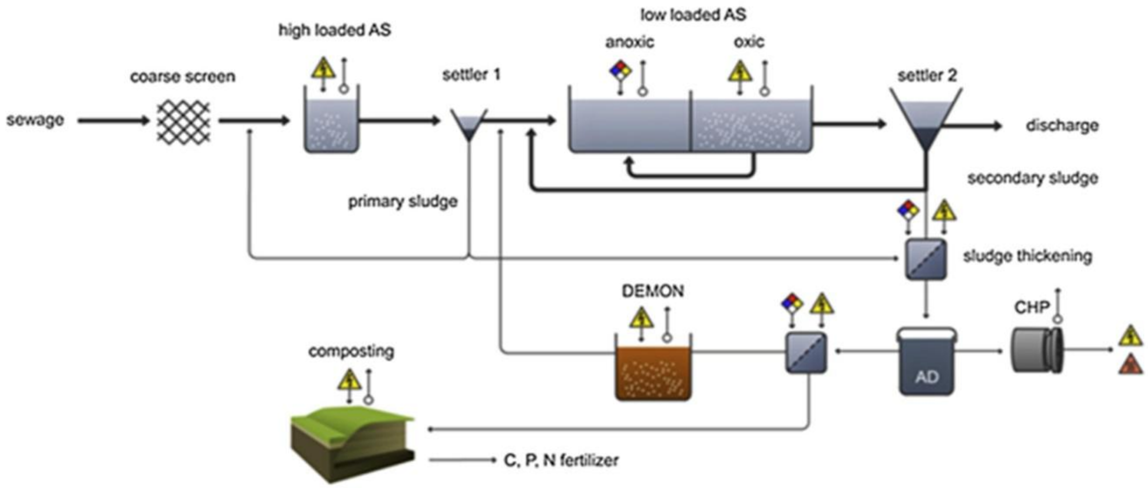

Figure 1.1 Schematic overview of the foreground system of the studied life cycle of the sewage treatment plant. AD: anaerobic digestion; CHP: combined heat and power; AS: activated sludge.

The latter WWTP is based on a two-stage activated sludge system (A/B system; (Wett et al., 2007)) as mainstream treatment and on sludge digestion. In the studied configuration, the energy-saving combination of partial nitritation and anammox (Kartal et al., 2010), DEMON /OLAND, is implemented to remove nitrogen out of the reject water of the digester and some co-substrate (kitchen waste and fat) is added to increase digester biogas production. The WWTP recovers following resources out of the wastewater and its co-substrate: electricity (the produced heat is not exported as a product) via burning of the biogas, and composted digestate that can be applied on land as a (C, N & P-)fertilizer. As a role model for other WWTP, the questions remain how environmentally sustainable this WWTP is overall (compared to direct disposal of the sewage) and what the benefits of resource recovery in this matter are. To address these questions, one should not only evaluate the WWTP on its own but also all the auxiliary processes needed to support it, such as production of chemicals added during the treatment, and further processing/application of its products, e.g. sludge disposal. To do so, life cycle assessment (LCA) is a fitting tool as it allows one to assess the environmental sustainability of a product or service (e.g. wastewater treatment) over its life cycle (ISO, 2006). LCA has been numerously applied to WWTPs (Corominas et al., 2013). However some main aspects should in general be dealt with (in a better manner) in LCA: (1) production and disposal of the infrastructure of the wastewater treatment plant (Corominas et al., 2013), (2) the effect of land application, especially heavy metal toxicity, of biosolids that optionally replace conventional fertilizers and (3) measurement of greenhouse gas emissions, with a focus on CH_4 and N_2O, at the plant. In our study all three matters were accounted for. Additionally, we have assessed resource consumption in a broader manner by applying a method which covers all types of resources, better highlighting resource recovery benefits.

Material and Methods

In this research, an LCA of the Strass WWTP (Figure 1.1) was performed. Added sodium aluminate, wastewater and co-substrate were waste flows and hence no environmental impacts were attributed to them. The impact of displaced products (electricity and fertilizers) were subtracted from the total impact of the life cycle. Impact on human health and ecosystems was assessed and expressed as loss in healthy human life years (disability adjusted life years; DALY) and biodiversity loss (species*yr), respectively. For some impact categories that cover diversity loss, no quantitative modeling of diversity loss is available and the impact at midpoint of the cause-effect chain is presented. Resource consumption was assessed in MJ_{ex} as the cumulative exergy (usable share of energy) extracted from the natural environment. For more information, read the work of Schaubroeck et al. (2015).

Results and Conclusions

Results are shown in Figure 1.2. A full elaboration is given by Schaubroeck et al. (2015). The complete system prevented the net-extraction of 2.5 MJ_{ex} m^{-3} treated wastewater, i.e. this amount of natural resources was saved. If sodium aluminate had to be obtained from the regular market, this amount would drop to 0.6 MJ_{ex}. More greenhouse gases were prevented from being emitted than there were emitted; the global warming potential is negative at -0.002 kg CO_2 equivalents. However, the heavy metals (mainly Zn) in the stabilized digestate were estimated to have led to considerable loss in human health. Using another method for heavy metal toxicity estimated the human health damage a factor 10-100 higher. Hence, we need to find and use means to lower the metal, especially Zn, content of the stabilized digestate.

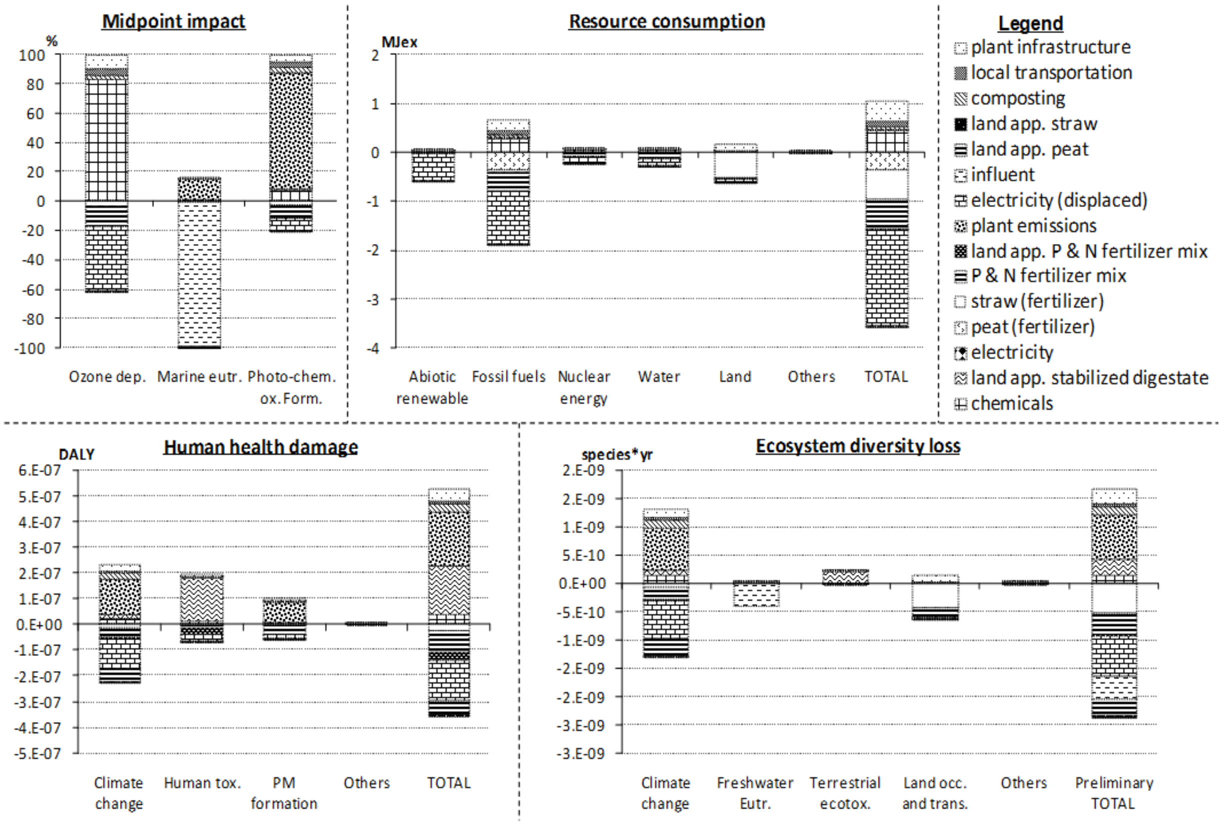

Figure 1.2 Environmental impact of the treatment of 1 m^3 sewage comprising the Strass wastewater treatment plant, its supply chain and valorization of the byproducts. A positive value represents damage caused, a negative value damage prevention, via displacement of products and water purification. For some impact categories no final damage to natural systems expressed as diversity loss cannot be quantified, hence the respective normalized midpoint impacts are presented. 100% corresponds to 0.0477 kg N equivalents for marine eutrophication, 1.85E-08 kg trichlorofluoromethane equivalents for ozone depletion and 0.00187 kg non-methane volatile organic compounds equivalents for photochemical oxidant formation. DALY: disability adjusted life years.

Regarding ecosystem damage, there is most probably a prevention of damage. Overall, production of electricity and stabilized digestate were both of equal and high relevance. Resource recovery is thus estimated to play a crucial role in obtaining an environmentally sustainable WWTP in this case. Keep though in mind that the LCA tool needs improvement.

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