Industrial symbiosis for biogas production, nutrient recirculation and reduced carbon footprint

F. Ometto[*,**], N. Svensson[***], A. Karlsson[*], X. Truong[*], C. Svedin[*], and J. Ejlertsson[*,**]

[*]Scandinavian Biogas Fuels AB, Research and Development Dept., Holländargatan 21A, SE-111 60, Stockholm, Sweden
E-mail: francesco.ometto@scandinavianbiogas.com; anna.karlsson@scandinavianbiogas.com; xubin.truong@scandinavianbiogas.com; christer.svedin@scandinavianbiogas.com; jorgen.ejlertsson@scandinavianbiogas.com;
[**]Linköping University, Dept. of Thematic Studies – Environmental Changes, SE-58 183, Linköping, Sweden
[***]Linköping University, Dept. of Management and Engineering, SE-58 183, Linköping, Sweden
E-mail: niclas.svensson@liu.se;

Abstract: Energy- and resource demanding industrial wastewater treatment plants (WWTP) are a reality for many large production units including pulp and paper mills. When considering WWTP with an activated sludge process (ASP), a way to reduce its carbon footprint is to change the view of waste activated sludge (WAS) as a problematic waste to dispose of and instead, optimize its production for anaerobic digestion (AD). This concept, denoted EffiSludge, would mean turning highly energy demanding wet-composting of valuable organic material towards the production of energy carrying bio-methane. Applying a life cycle assessment (LCA) to an industrial symbiosis reality in Skogn, Norway where EffiSludge condition are under implementation, reduced energy demand and nutrient recovery is expected to give carbon saving of up to 4600 tonnes CO_2-eq per year. Co-digestion of WAS and fish waste provides 125 GWh of liquid biogas and yearly savings in urea dosing at the WWTP for over 270 ton N.

Keywords: waste activated sludge, nutrient recirculation, life cycle assessment

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Introduction

Industrial wastewater treatment plants (WWTP) are often based on an activated sludge process (ASP) where extensive need for aeration is high energy demanding. This, together with external dosing of N and P to support microbial growth, result in high operational costs and carbon emissions. To improve the resource efficiency of traditional industrial WWTP that includes an ASP, a new concept, called EffiSludge, has been developed (Ejlertsson, 2018).

The main idea is to optimize the ASP for maximal production of waste activated sludge (WAS) with maintained COD reduction. Compared to today's conventional processes, that are often set-up to minimize WAS production by low COD loading and intensive aeration, this means that the ASP can be run at a higher load and with reduction of both hydraulic- and sludge retention times. Less air is thus needed per kg of COD treated thus reducing electricity consumption. At the same time the generated WAS under low sludge age condition is suitable as substrate for biogas production in anaerobic digestion (AD) systems (Ge et al., 2013; Magnusson et al., 2018). Furthermore, nutrient recirculation can be added to this basic concept thus creating an industrial symbiosis: if the WAS is co-digested with nutrient rich substrates, recirculation of the reject water from dewatering of the digestate into the wastewater treatment can provide nutrients for the ASP thus reducing the need for external dosing of N and P.

This industrial symbiosis concept is currently set-up at the pulp and paper mill in Skogn outside Trondheim (Norway). WAS from the wastewater treatment processing effluent from the mill, is co-digested at mesophilic condition with waste from Norwegian fish farming (Figure 1). The process, run in semi-CSTRs, is high loaded with ammonium nitrogen levels of around 4 g L^{-1} and it has a designed yearly production of 125 GWh of liquid biogas.

The effect of the changed regime of the WWTP under EffiSludge condition is here evaluated applying life cycle assessment (LCA) in term of CO_2-emissions. The impacts related to a reduced need of aeration and a reduced sludge retention time (from around 12 to 4-8 days), combined with the possibility to replace commercial urea and phosphoric acid with reject water from the CSTR-process, are considered.

Material and Methods

Data from the existing wastewater treatment (ca. 20 000 m^3 per day) at the Skogn mill has been used to estimate the greenhouse gas emissions as CO_2 equivalents per kg of COD going into the wastewater treatment at Skogn (Figure 1a) and compared to EffiSludge conditions based on expected changes in overall energy demand and nutrient dosing (Figure 1b).

For the base scenario the measured daily energy demand is 39MWh for the whole wastewater treatment (Figure 1). Within the ASP the sludge age is fixed to 12 days and sludge production is 0.2 kg SS kg^{-1} $COD_{degraded}$. The nutrient demand is equal to 750 kg N and 120 kg P per day provided by external dosing of urea and phosphoric acid. In the EffiSludge scenario we estimate that the need for electricity in the aeration will be reduced by half while 100% of externally added N and 50% of P can be replaced by recirculation of reject water from dewatering of the digestate from the CSTRs.

The effect of the reduction of the electrical consumption in the aeration on the greenhouse gas emissions was calculated using values both for "Norwegian electricity production" (NOR) and for an average "European electricity production" (EUR). Carbon emissions were calculate based on ECOINVENT carbon factors applied to electricity (0.03 and 0.48 $kgCO_2$-eq kWh-1 respectively), nitrogen (3.19 kg CO_2-eq kg^{-1} N) and phosphoric acid (0.97 kg CO_2 kg^{-1} H_3PO_4).

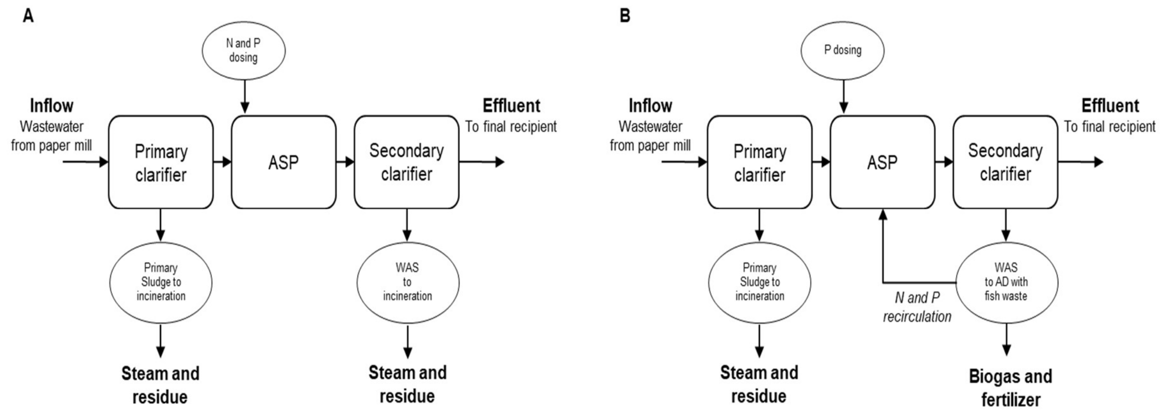

Figure 1. Base scenario (A) representing conventional WWT at pulp and paper mills, and case scenario (B) considering EffiSludge alternative approach where WAS is co-digested with fish waste.

Results and Conclusion

The calculated carbon emission, given as CO_2 equivalents per kg of COD, is in the base scenario equal to 0.05 and 0.24 depending on the carbon factors used (NOR and EUR respectively). When the carbon factor for NOR is used the main contributor to the carbon emissions are the nutrients dosed in the ASP (corresponding to 0.03 kg CO_2-eq for N and 0.005 kg CO_2-eq for P). Conversely, if the factor for EUR is used the main contributor is the electricity consumed in the aeration of the wastewater treatment process (corresponding to 0.02 kg CO_2-eq).

At EffiSludge conditions the carbon emissions from the wastewater treatment is estimated to be reduced to 0.01 kg CO_2-eq with NOR and 0.10 kg CO_2-eq with EUR. If recalculated to annual CO_2-emissions from the wastewater treatment the emission savings by the introduction of the EffiSludge concept would be 1400 tonnes (83% savings) with NOR and 4600 tonnes (57% savings) with EUR. This roughly corresponds to driving a fully loaded (32 tonnes) EURO5 truck 12 and 40 times around the world, respectively. The biogas produced in the semi-CSTRs (corresponding to ~100 GWh) will replace fossil fuel in busses in the city of Trondheim and in trucks and will mean a reduction in CO_2-emissons of roughly 34000 tonnes.

Overall, the considered concept appears to be an effective solution for carbon saving within industrial wastewater treatments. The specific impact of EffiSludge depends on the carbon factors applied but also highly on the possibility to run the extended industrial symbiosis concept where external addition of N and P to the ASP is replaced with internally recirculated nutrients.

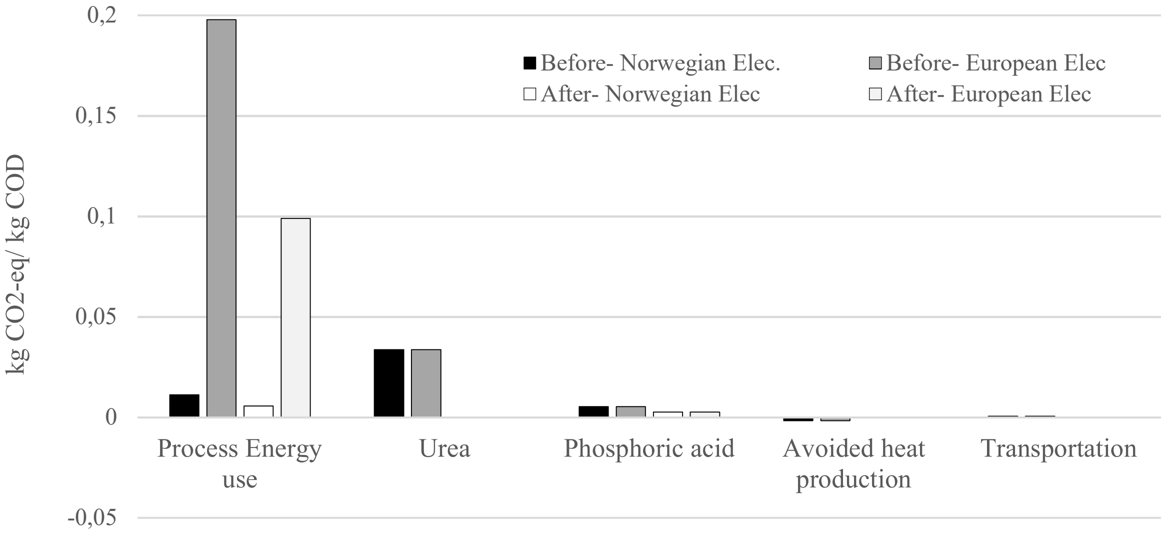

Figure 2. Climate change emissions (GWP_{100}) expressed in CO_2-eq for the waste water treatment of the Skogn paper mill. Results for different electricity production systems before and after the EffiSludge process implementation.

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