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Environmental Assessment of Sewage Sludge Management – Focusing on Sludge Treatment Reed Bed Systems

PhD Project by Larsen[1], Julie Dam. E-mail: judl@via.dk
Supervisors: Nielsen[2], Steen and Scheutz[3], Charlotte
Institutions hosting the project: Orbicon A/S, Technical University of Denmark (DTU)

Recent Affiliations: [1] Centre of Research and Development - Building, Energy, Water & Climate, VIA University College, Horsens, Denmark
[2] Orbicon A/S, DK 4000, Roskilde, Denmark
[3] Department of Environmental Engineering, Technical University of Denmark, Kgs. Lyngby, Denmark

The Project

In Denmark, the application of sludge on agricultural land as a substitute for commercial fertilisers is a common recycling strategy. Conventionally, sludge mend for this purpose is dewatered with mechanical devices; however, since the late 1980´s, sludge treatment reed bed (STRB) systems has gained ground in Denmark. Sludge treatment in STRB systems is often considered more environmentally friendly compared to mechanical sludge treatment technologies, albeit only a few life cycle assessments (LCAs) comparing the environmental performances of sludge treatment technologies include STRB systems. Furthermore, data on the STRB system technology suitable for LCAs are scarce.
To investigate the environmental performance of STRB systems, the project "Environmental Assessment of Sewage Sludge Management – Focusing on Sludge Treatment Reed Bed Systems" was conducted in 2013-2017, as a collaborative between the Danish environmental consultancy Orbicon A/S and the Technical University of Denmark (DTU). The project aimed at 1) generating data on the STRB system technology useable for LCA and 2) use these data to compare the environmental impacts caused by treatment of surplus activated sludge (SAS) in STRB systems with the impacts caused by mechanical treatment (centrifuging). Based on identified knowledge gaps, data generation focused on three areas; quantification of gas emissions directly related to treatment, substance flows through the treatment scenarios and the fate of carbon and nitrogen-based compounds in treated sludge when applied to the land. Field data were collected at three Danish, well-operated STRB systems. In addition, data representing the mechanical treatment technology were generated alongside data on the STRB system technology. When data had been generated, the environmental impacts caused by three different sludge management scenarios, two based on treatment in STRB systems and one based on mechanical treatment, were compared using the LCA principle. The results of the LCA can be used as a decision making tool in relation to choose the best sludge management strategy under given circumstances.

Management Scenarios

- The main goal of the project was to compare the environmental impacts caused by the treatment of surplus activated sludge (SAS) in 1) STRB systems and 2) by mechanical dewatering on centrifuge.
- Sludge subjected to treatment in STRB systems is systematically applied to the beds in the system. After several years (commonly 8 – 12), the beds are filled up with sludge residue and must be emptied. The sludge residue from an emptied bed can be transported directly to land application. In some situations, 1 – 6 months of post treatment/storage of the sludge residue on a Stock Pile Area (SPA) is added to the treatment process before the sludge residue is transfered to land application.
- Sludge subjected to mechanical dewatering must, after the dewatering process, be stored until it is time for land application. The span of the storage period can count from a few days to around one year.
- For the LCA analysis, three scenarios were defined (Figure 1):
  S - CEN: Mechanical dewatering → storage → transport to land application
  S - STRB: Treatment in STRB system → transport to land application
  S - SPA: Treatment in STRB system → post tretment on SPA → land application

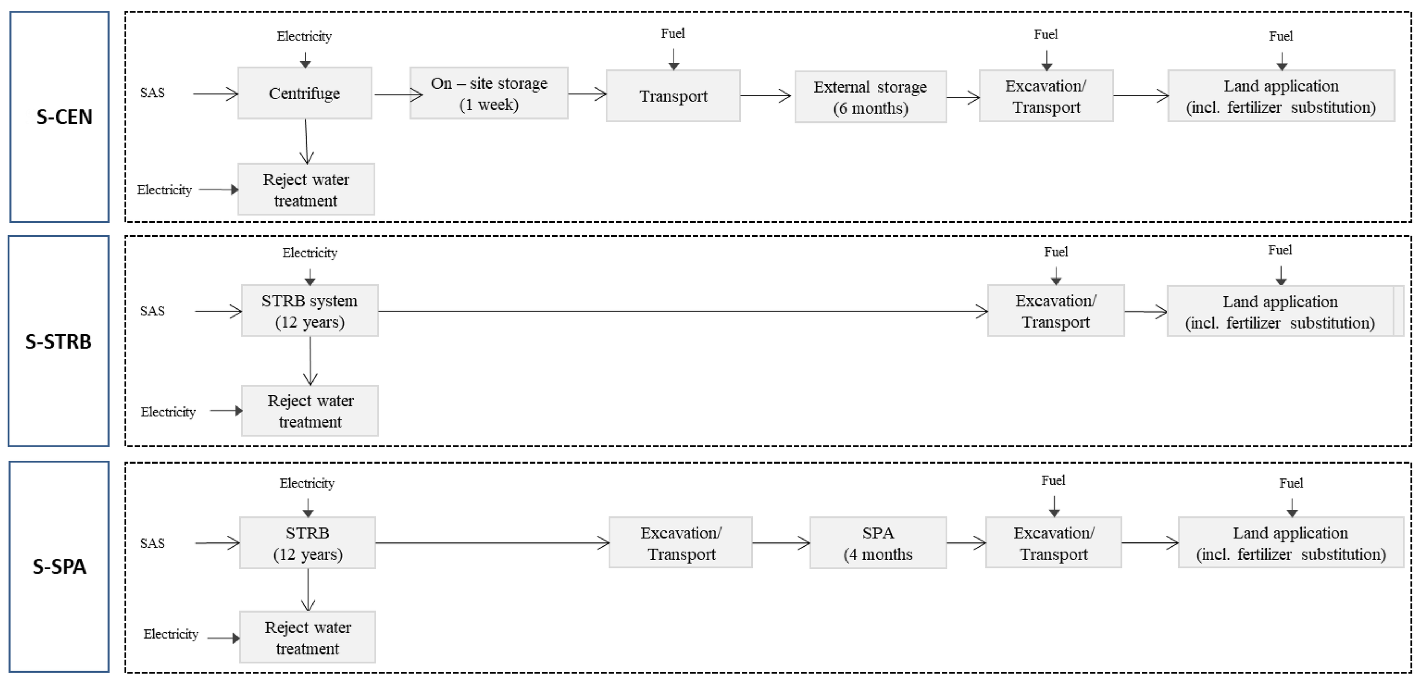

Figure 1: Schematic overview of the three LCA scenarios.

Data Generation

- To be able to calculate the environmental impacts caused by each step of the different LCA scenarios (Figure 1), data on three different research areas were collected:
  RA 1: Quantification of biological gas emissions from sludge treatment and storage
  RA 2: Substance flow analysis of sludge treatment scenarios
  RA 3: Emissions from treated sludge when applied to the land
- Field data was collected at three STRB systems, located at three different, Danish wastewater treatment plants (WWTP): One of these WWTPs (located in Helsinge) also housed a centrifuge: From this plant, data needed for the scenario representing mechanical dewatering (S-CEN, Figure 1) was collected.
- From the WWTP located in Helsinge, data on electricity and fuel consumption related to the three treatment scenarios was also collected.
- Figure 2 shows a schematic overview of the data generation process:

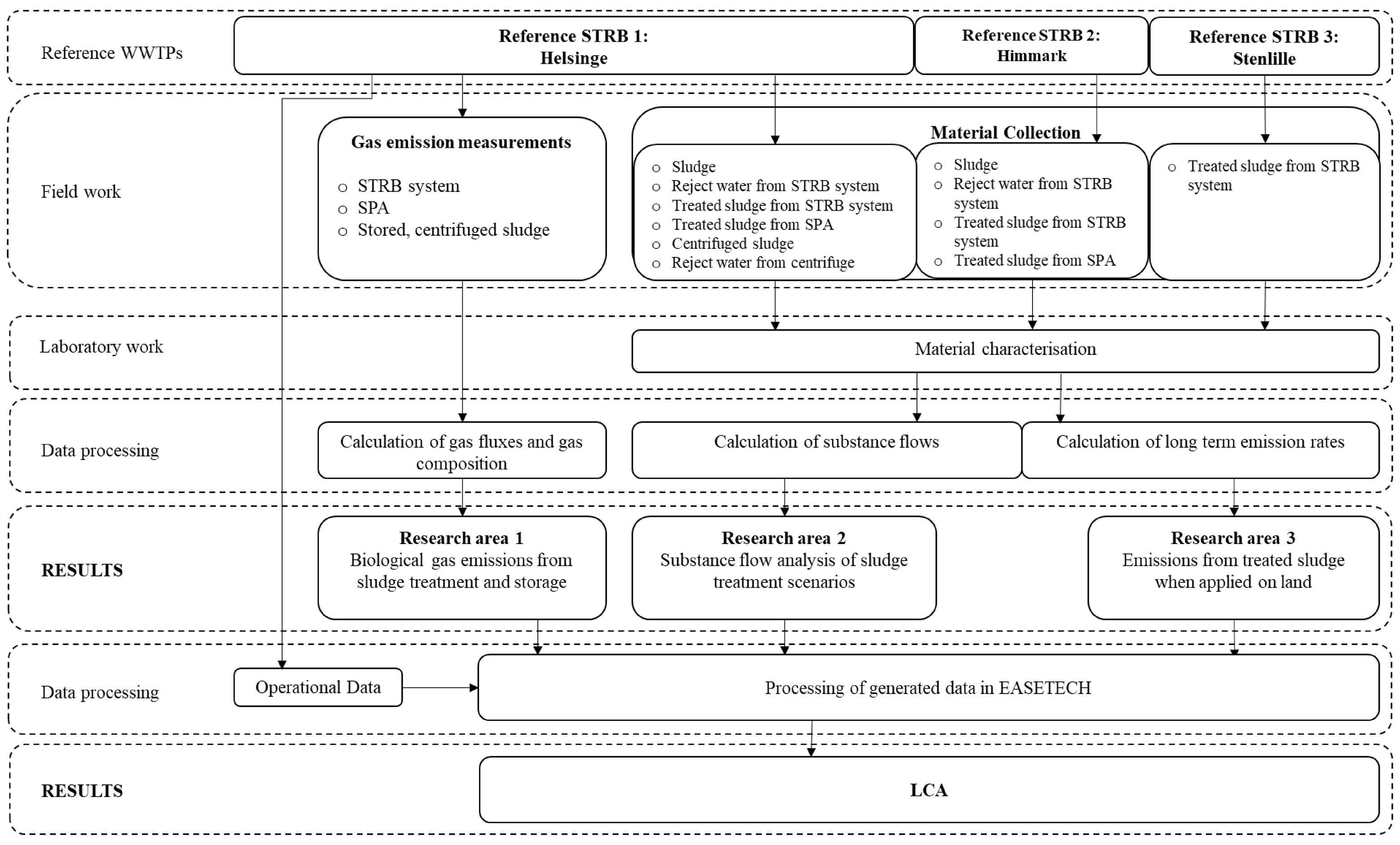

Figure 2: Schematic overview of the data generation process.

The LCA – Results and Conclusions

The collected data was processed into a form suitable for LCA analysis. The LCA comparing the three scenarios was conducted according to the ISO standards 14040 and 14044. Calculation of 14 chosen environmental impact categories for the scenarios were done using the software EASETECH, developed by the Technical University of Denmark (Clavereul et al., 2014).
Here, the calculated impacts for five chosen categories are shown in Figure 3. The calculated impacts of the different categories are based on the treatment of 1000 kg wet weight of SAS during a time span of 100 years.To make the environmental impact categories comparable, the impacts were normalised into people equivalents (PE), thereby representing the annual impact of an average person in relation to the various impact categories.

Main results of the LCA analysis included:

- For all three scenarios, the main activities affecting the impact category "Climate Change" (Figure 3) was emissions of N_2O and CH_4 related to biological mineralisation of sludge residue (S-STRB and S-SPA) or stored, dewatered sludge (S-CEN) and gaseous emissions related to the final land application.
- The relative amount of N converted into climate neutral $N_{2,}$ due to biological mineralisation of sludge residue or stored, dewatered sludge, was higher for the scenarios based on the STRB system technology (S-STRB and S-SPA) compared to the scenario based on mechanical dewatering (S-CEN). This indirectly affected the impact category "Marine Eutrophication": The sludge residue apllied to land in the scenarios S-STRB and S-SPA caused less nitrate run-off compared to S-CEN, resulting in a much lower impact on Marine Eutrophication (Figure 3).
- Compared to the size of the country, Denmark has a large costal area; therefore, Marine Eutrophication has great relevance in Denmark. All three scenarios performed equal in relation to Climate Change, but in terms of Marine Eutrophication the scenarios based on the STRB system technology performed considerably better in a Danish context.
- The impacts on the impact categories "Human Toxicity – Non carcenogenic" and "Ecotoxicity" (Figure 3) were mainly affected by zink and cobber originating from the wastewater. As either the STRB system technology or mechanical dewatering actively removes metals from the sludge prior to land application, the impacts for these categories were the same for all three scenarios.
- Adding post treatment on a SPA to the STRB system technology (S-STRB vs. S-SPA) did not affect the environmental performance of the treatment process noticeably. However, there are practical advantages from adding post-treatment on a SPA which is not evaluated in an LCA analysis.

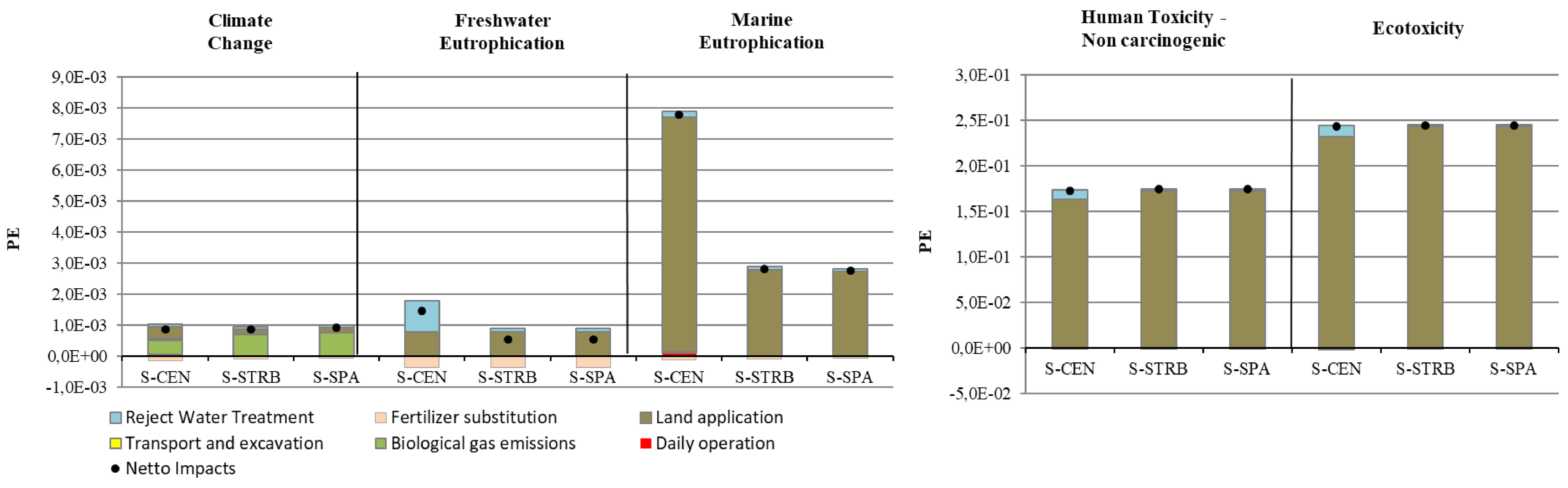

Figure 3: The environmental impacts caused by treatment of 1000 kg of sludge (wet weight) for the treatment scenarios S-CEN, S-STRB and S-SPA. The impacts of the different impact categories were converted into people eqvivalents (PE).

Scientific Papers

Based on the work and results related to the project, six scientific papers have been published:

J. D., Larsen, Hoeve, M. t., Nielsen, S., Scheutz, C., 2018: Life cycle assessment the treatment of surplus activated sludge in a sludge treatment reed bed system with mechanical treatment on centrifuge. *Journal of Cleaner Production,* **185**, pp. 148 – 156
Gómez-Muñoz, B., Larsen, J. D., Bekiaris, G., Scheutz, C., Bruun, S., Nielsen, S., Jensen, L.S., 2017: Nitrogen mineralisation and greenhouse gas emission from the soil application of sludge from reed bed mineralisation systems. *Journal of Environmental Management*, **203**, pp59-67
J. D., Larsen, Nielsen, S., Scheutz, C., 2017: Assessment of a Danish sludge treatment reed bed system and a stockpile area, using substance flow ananlysis. *Water Science & Technology*, **76**, pp. 2291-2303
J. D., Larsen, Nielsen, S., Scheutz, C., 2017: Gas composition of sludge residue profiles in a sludge treatment reed bed between loadings. *Water Science & Technology*, **76**, pp. 2304-12
J. D., Larsen, Nielsen, S., Scheutz, C., 2017: Greenhouse gas emissions from the mineralisation process of in a Sludge Treatment Reed Bed system: Seasonal variation and environmental impact. *Ecological Engineering,* **106**, 279-286
Nielsen, S., Larsen, J. D., 2016: Operational technology, economic and environmental performance of Sludge Treatment Reed Bed systems–based on 28 years of experience. *Water Science and Technology*, **74**, pp. 1793 -99

References: Clavreul J., Baumeister H., Christensen T. H. and Damgaard A. (2014). An environmental assessment system for environmental technologies. *Environ. Model. Softw.* **60**, 18 - 30.