Life cycle assessment of sewage sludge treatment and its use on land

Sewage sludge is generated as an end-product of wastewater treatment processes, and its management holds importance in the operation of wastewater treatment plants from both an economic and an environmental point of view. At the same time, the management of sewage sludge is becoming increasingly multi-focused, as renewable energy and nutrient recovery have been added to the list beyond sanitation and stabilisation of sewage sludge. In order to organise and quantify environmental benefits and associated burdens, in order to facilitate an informed decision making process, life cycle assessments (LCAs) have been applied in the field of sewage sludge management for the past two decades. While providing a flexible platform for comparing a range of sewage sludge management options, a knowledge gap has been identified through the review of existing studies, including inconsistencies in pollutant coverage and quantification, the omission of unmetered gaseous emissions and a lack of long-term emission data regarding the land application of sewage sludge. An LCA depends heavily on existing emission and operational data, as generating such data could be prohibitively time- and resource-consuming. Emission and operational data are already collected by wastewater treatment plants for compliance with pollutant discharge requirements, but a part of this pollutant discharge is also reported to a web-based registry (European Pollutant Release and Transfer Registry (E-PRTR)) and is available to the public free of charge. While this data source provides a standardised data collection format, its viability has been questioned due to its limited pollutant coverage and the thresholds regarding reporting requirements. To address this issue, a targeted input data collection campaign was conducted at a municipal wastewater treatment plant. The substance flow analysis of a municipal wastewater treatment plant was conducted to identify the fate of 32 elements, and a reduction in toxicity potential was evaluated by applying USETox. The result was largely confirmative of previous studies, in that wastewater treatment is effective at removing pollutants from wastewater and concentrates them in sewage sludge. Efforts to collect site specific emission data were also expanded to gaseous emission measurements. The tracer dilution method was applied to measure a plant-integrated emission of N₂O and CH₄ from the wastewater treatment plant. Large variations in emissions were found within and between measurement campaigns, and almost ten times more emissions were found during periods of operational difficulty such as foaming or the malfunction of in-line control systems. The LCA was based on three input data collection schemes: a compulsory environmental information disclosure requirement, a pollutant discharge monitoring requirement and state-of-the-art on-site data collection. While adequately capturing impacts in relation to global warming and marine eutrophication, an LCA based on existing data sources might underestimate impacts associated with wastewater and sludge treatment processes. Finally, the effort to collect emission data was expanded to the use of sludge on agricultural land. The long-term consequences of sewage sludge application on land were evaluated by applying the DAISY dynamic agro-ecosystem model. The C and N mineralisation rates obtained from the 190-day laboratory-scale incubation test for sewage sludge were used to calibrate the DAISY model, and the fates of C and N in the agricultural field were simulated over a 100-year period. The outcome of the simulation was deduced further to emission factors per unit application of N fertiliser on land by fitting a linear mixed-effect model to the outcome of simulations with varying N application levels. It was evident that the effects of inorganic N fertiliser appear immediately after its application, while improvements in crop yield and emissions of reactive N from organic fertilisers persist over time. The window of emission is dependent on the degree of stabilisation: while the effect from treated sewage sludge ceases after 25 years, the effect from the application of more stable material such as composted municipal solid waste persists over 100 years. Large variations in emission factors, due to local conditions, were observed, especially in the case of the liquid application of sludge. When these emission factors were applied to an LCA comparing sewage sludge treatment alternatives, emissions of reactive N (NH₃, N₂O, NH₄⁺, NO₃⁻) into the environment were major contributors to almost all of the non-toxic impact categories. Hence, a depiction of the N balance through the target systems, beyond energy and C balance, often included in environmental assessments is vital for accurately evaluating the environmental performance of sewage sludge management options.