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Life cycle assessment of two emerging sewage sludge-to-energy systems: Evaluating energy and greenhouse gas emissions implications

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HIGHLIGHTS

- ▶ Comparative life cycle assessment of two emerging sewage sludge-to-energy systems.
- ▶ One system uses anaerobic digestion (AD) followed by fast pyrolysis while the other excludes AD process.
- ▶ Both systems achieve net energy gain and greenhouse gas emission credits.
- ▶ The system involving AD process is preferable to the system excluding AD process.
- ▶ Detailed contribution and sensitivity analyses were also conducted for both systems.

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ABSTRACT

A "cradle-to-grave" life cycle assessment was conducted to examine the energy and greenhouse gas (GHG) emission footprints of two emerging sludge-to-energy systems. One system employs a combination of anaerobic digestion (AD) and fast pyrolysis for bioenergy conversion, while the other excludes AD. Each system was divided into five process phases: plant construction, sludge pretreatment, sludge-to-bioenergy conversion, bioenergy utilizations and biochar management. Both systems achieved energy and GHG emission benefits, and the AD-involving system performed better than the AD-excluding system (5.30 vs. 0.63 GJ/t sludge in net energy gain and 0.63 vs. 0.47 t CO_2eq/t sludge in emission credit for base case). Detailed contribution and sensitivity analyses were conducted to identify how and to what degree the different life-cycle phases are responsible for the energy and emission impacts. The energy and emission performances were significantly affected by variations in bioenergy production, energy requirement for sludge drying and end use of bioenergy.

1. Introduction

The sewage sludge-to-energy approach is a response to the increasing interest in exploiting and deploying renewable energy, and to the significant concern associated with conventional sludge disposal such as land application and landfilling. Landfill disposal generates undesired emissions (e.g. leachate and landfill gas) to water, air and soil, while land application represents an important pathway for soil input of contaminants including heavy metals (Zapusek and Lestan, 2009) and persistent organic pollutants (Dai et al., 2007).

Sewage sludge can serve as a renewable energy source since it is produced in large amounts and has considerable energy content. In Poland, for example, the current annual production of sewage sludge is estimated to exceed 620,000 dry tonnes, and the sludge generally has calorific values ranging from 11 to 17 MJ/kg (Werle and Wilk, 2010), indicating that at least 6.8 PJ of energy per year is available, an equivalence of burning about 443,000 tonnes of raw coal.

A number of technologies have been developed to convert sewage sludge to useable energy, with anaerobic digestion and incineration dominating in practical application (Metcalf and Eddy, 2003; Rulkens, 2008). Anaerobic digestion of sludge produces biogas that can be used as an alternative to fossil fuels to produce heat and electricity; however, the digestion process generally requires large amounts of heat energy for process operation (e.g. sludge heating and mixing), and cannot sufficiently transform the energy in sewage sludge into biogas as conventional digestion technologies convert only approximately 40–50% of the organic matter into biogas (European Commission, 2001). Incineration can reduce rapidly the sludge volume and emit energy that is recoverable in the form of heat and electricity, but sludge incineration is not broadly

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