Bioresource Technology 125 (2012) 239–248

Contents lists available at SciVerse ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Comparing environmental consequences of anaerobic mono- and co-digestion of pig manure to produce bio-energy – A life cycle perspective

J.W. De Vries [a,*], T.M.W.J. Vinken [a], L. Hamelin [b], I.J.M. De Boer [c]

[a] Wageningen UR Livestock Research, Wageningen Universtity and Research Centre, P.O. Box 135, 6700 AC Wageningen, The Netherlands
[b] Institute of Chemical Engineering, Biotechnology and Environmental Technology (KBM), University of Southern Denmark, Campusvej 55, 5230 Odense M., Denmark
[c] Animal Production Systems Group, Wageningen University, P.O. Box 338, 6700 AH Wageningen, The Netherlands

HIGHLIGHTS

- Production of substitutes required for initial use of co-substrates was included.
- Land use change emissions from maize, barley, and soybean production were included.
- Mono-digestion had good environmental performance, but low bio-energy production.
- Co-digestion with animal feed increased bio-energy, but also environmental impact.
- Co-digestion with roadside grass showed best environmental performance.

ARTICLE INFO

Article history:
Received 4 July 2012
Received in revised form 27 August 2012
Accepted 27 August 2012
Available online 4 September 2012

Keywords:
Consequential LCA
Pig slurry
Renewable energy
Indirect land use change
Greenhouse gases

ABSTRACT

The aim of this work was to assess the environmental consequences of anaerobic mono- and co-digestion of pig manure to produce bio-energy, from a life cycle perspective. This included assessing environmental impacts and land use change emissions (LUC) required to replace used co-substrates for anaerobic digestion. Environmental impact categories considered were climate change, terrestrial acidification, marine and freshwater eutrophication, particulate matter formation, land use, and fossil fuel depletion. Six scenarios were evaluated: mono-digestion of manure, co-digestion with: maize silage, maize silage and glycerin, beet tails, wheat yeast concentrate (WYC), and roadside grass. Mono-digestion reduced most impacts, but represented a limited source for bio-energy. Co-digestion with maize silage, beet tails, and WYC (competing with animal feed), and glycerin increased bio-energy production (up to 568%), but at expense of increasing climate change (through LUC), marine eutrophication, and land use. Co-digestion with wastes or residues like roadside grass gave the best environmental performance.

1. Introduction

The demand for renewable energy is rising because of increasing social awareness of consequences related to non-renewable energy use, e.g. fossil fuel depletion, energy security, and climate change (CC). Renewable energy production in the European Union, for example, is targeted to reach 20% of total energy production by 2020 (EU, 2009). This transition requires insight into environmental consequences of producing renewable energy, including CC, fossil fuel depletion, and land use changes. Life cycle assessment (LCA) is an internationally accepted method to gain insight into the environmental consequences of a product or system (ISO-14040, 2006).

Bio-energy is a form of renewable energy and is produced from biomass. Biomass can be converted by anaerobic digestion (AD) into biogas, composed of methane (CH_4), carbon dioxide (CO_2) and some trace gases (e.g., hydrogen gas), which can then be used to produce bio-energy in the form of electricity, heat, or transport fuel (De Vries et al., 2012; Hamelin et al., 2011). The remaining product after AD, i.e. digestate, can be recycled as organic fertilizer for crop cultivation to substitute mineral fertilizer (Börjesson and Berglund, 2007). Main substrates for AD include agricultural biomass in the form of animal manures and energy crops (e.g. maize), organic residues from the processing industry (e.g. glycerin, beet tails, and gut and intestines from slaughtering houses), and other residues such as, roadside grass or forest residues (Cherubini and Strømman, 2011).

Environmental LCA studies of AD of pig and cattle manure (raw or separated fraction) and energy crops, such as maize and rye grass focused on bio-energy production, greenhouse gas (GHG) emission reduction potentials, and various biogas end applications (Börjesson and Berglund, 2007; De Vries et al., 2012; Hamelin et al.,

* Corresponding author. Tel.: +31 (0)320 238044; fax: +31 (0)320 238094.
E-mail address: jerke.devries@wur.nl (J.W. De Vries).

0960-8524/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.biortech.2012.08.124

2011; Thyø and Wenzel, 2007). These studies highlighted that AD of solely, or fractions of, animal manure (mono-digestion) reduced GHG emissions and fossil fuel depletion due to bio-energy production compared to a reference without digestion. To boost bio-energy production and economic profitability of mono-digestion, co-substrates are added, including energy crops and wastes (co-digestion) (Hamelin et al., 2011; Thyø and Wenzel, 2007). This use of co-substrates competes with other applications, such as animal feed or the production of heat or compost and, therefore, will induce the need of a substitute for their initial use. The environmental impact of producing these substitutes, however, has so far not been considered in LCAs of AD. To further improve the insight into the consequences of such a change, LCAs of bio-energy should include other environmental impacts, such as acidification and eutrophication (Cherubini and Strømman, 2011). Additionally, LCAs of bio-energy production should account for the impact of land use change (LUC) and its related carbon (C) emissions from using various substrates. Generally direct (DLUC) and indirect land use change (ILUC) are distinguished, both included in LUC. While DLUC represents the land use changes in a given country or region associated with the expansion of a specific crop in that area, ILUC refers to global market reactions to feedstock displacement and the resultant land use changes. Accounting for LUC is important as it has the potential to undermine reductions in GHG emissions obtained by bio-energy production (Plevin et al., 2010). However, LUC is most often not addressed in LCAs of AD.

The aim here was to assess and compare environmental consequences of anaerobic mono-digestion and co-digestion of pig manure to produce bio-energy. Environmental impacts of producing a substitute for the initial use of the substrates, including the induced LUC, were accounted for. For co-digestion, five co-substrates were evaluated: ensiled whole crop maize, glycerin, beet tails, wheat yeast concentrate (WYC) and roadside grass. These co-substrates represent various product groups that are, or will be, used in agricultural digesters, i.e. energy crops, by-products from food or feed industry, animal feed products, and residual or waste products.

2. Methods

2.1. LCA approach and functional unit

The ISO-14040 standard provides the general framework for LCA, which was followed in this study (ISO-14040, 2006). A consequential approach to LCA was used to compare the environmental consequences of mono-digestion with co-digestion using alternative substrates. This implied that all processes affected by the mono- or co-digestion systems studied were included in the model (i.e. system expansion). For the affected processes the marginal suppliers were included (e.g. for electricity, heat, and mineral fertilizers) (Weidema, 2003).

To enable a comparison of scenarios, environmental impacts were related to a functional unit (FU), i.e. the main function of the system expressed in quantitative terms. As the study is focused on the use of various substrates and the substitution of their initial use, an input-related FU of 1 ton substrate (fresh matter) added to the digester was used. This was either pig manure or a mixture of pig manure and co-substrate(s). Studies addressing different applications of substrates, in this case bio-energy production, are recommended to use input-related FUs (Cherubini and Strømman, 2011).

2.2. System boundaries and definition of scenarios

2.2.1. System boundaries common to all scenarios

The general scope of this research was North-Western Europe. The context of The Netherlands was used to identify the involved marginal suppliers for electricity, heat, and mineral fertilizer, when establishing the composition of manure and co-substrates, and when legislation had to be taken into account (e.g. for co-digestion).

The system, the included processes, and the system boundary are illustrated in Fig. 1. It was considered that digesting manure avoided the conventional management of raw manure without further processing, i.e. outside storage in a concrete-covered tank, transport, and field application. Hence, manure was stored solely

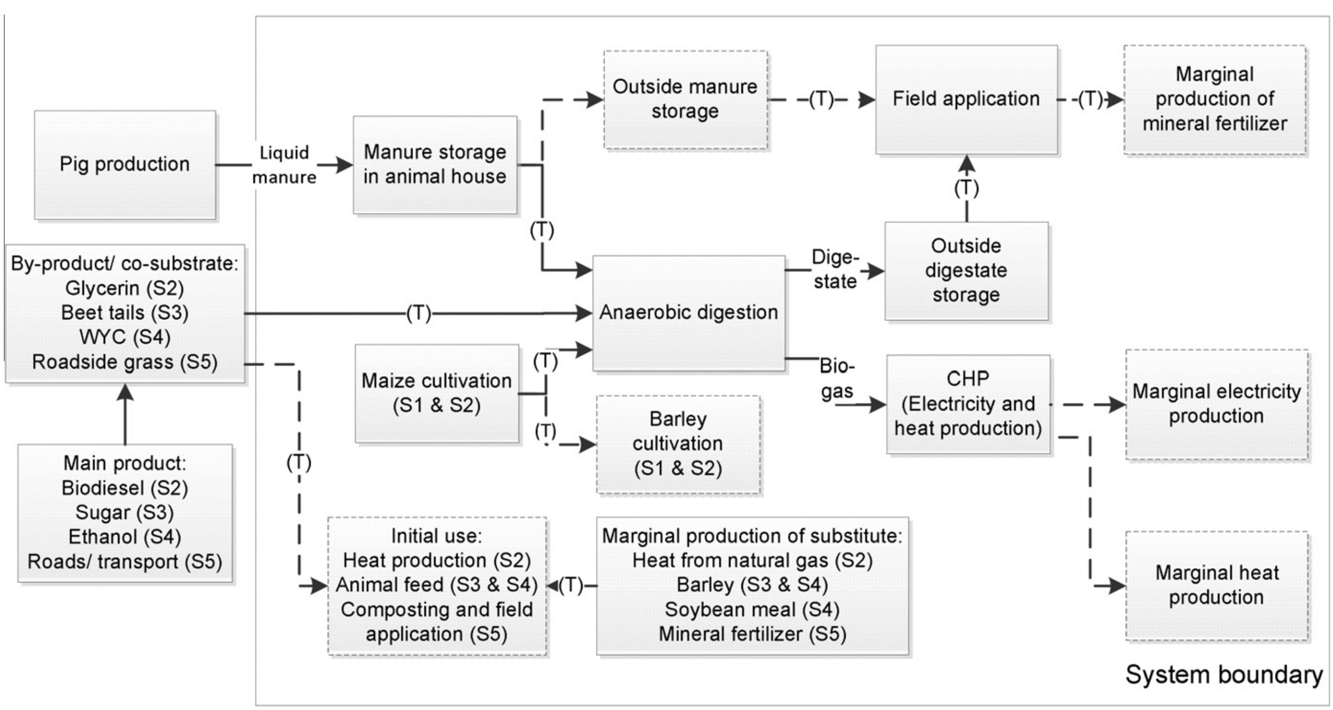

Fig. 1. Processes considered within the system boundary. Dashed boxes represent avoided processes. Black arrows indicate induced flows whereas dashed arrows indicate avoided flows. (T) represents transportation. S1–S5 are the considered scenarios.