Resources, Conservation & Recycling 131 (2018) 86–98

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

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

Full length article

Life cycle assessment of biological pig manure treatment versus direct land application − a trade-off story

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ARTICLE INFO

Keywords:
Pig manure
Biological treatment
Modelling
Life cycle assessment
Sustainability
ReCiPe

ABSTRACT

Excess manure can have two common fates: to be exported and applied to agricultural land, or to be treated, possibly with resource recovery (i.e. energy and/or nutrients). In this study, the environmental performance of a treatment system of pig manure (centrifugation and subsequent biological nitrogen removal from the liquid fraction and composting of the solid fraction) has been assessed using life cycle assessment (LCA) with the ReCiPe method to assess environmental impacts at midpoint and endpoint level. Such treatment system is typical for Flanders (Belgium), a region characterized by a manure excess.

The performance of this treatment-scenario has been compared to the direct field application of untreated manure (no-treatment-scenario) to gain insight in the environmental trade-offs between them. The hotspots dominating the environmental impact for manure treatment were the field application of compost and the effluent from the biological treatment, and the electricity needed to run the treatment facility. The substitution of synthetic fertilizers played an important role in both scenarios (mitigation of potential damaging impacts). The comparison between the two manure management scenarios showed that the treatment scenario scores better in some categories and vice versa. Manure treatment does prevent marine eutrophication and must be carried out in nitrate-vulnerable zones, such as the studied region of Flanders. Finally, the use of single score through normalization and weighting of midpoint impacts was evaluated. This underscores a policy direction towards manure treatment, but this message should be interpreted with care as the approach of normalization and aggregation can be questioned.

1. Introduction

The rapidly increasing world population and limited agricultural land have considerably driven an increase and intensification of the global livestock production since the 1960s (Prapaspongsa et al., 2010; Overloop et al., 2001). In 2014 Europe had an important contribution to the world meat production of chicken (17%), cattle (16%) and pig (24%), (FAOSTAT, 2017). This production is distributed across Europe with areas of higher production intensities. Traditionally, manure was applied as fertilizer to agricultural land and provided input of nutrients, which yielded crops and grass. Nowadays, there is a surplus of nutrients in areas with intensive livestock production and limited agricultural land as a result of excess manure production. This excess needs to be managed.

Excess manure production in a region is usually managed in three ways: i) exported and applied to agricultural land; ii) nutrient removal from the manure; iii) conversion of nutrients into mineral fertilizer. Flanders, Belgium, has regions that reach a total manure production equivalent to 340 kg N per ha (Jacobsen, 2015), and has been designated as a 100% Nitrate Vulnerable Zone according to the European Nitrate Directive (EC/91/676). That directive limits fertilisation from manure sources to 170 kg N per ha. In 2014, the manure production in Flanders reached 125 million kg N (VLM, 2015). That same year in Flanders, there was a manure management capacity (including exportation) of around 39.3 million kg N. Pig manure encompassed 44% of this total (VCM, 2014).

Life cycle assessment (LCA) allows one to assess the environmental sustainability of a product or service (e.g. manure management) over its

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https://doi.org/10.1016/j.resconrec.2017.12.010
Received 21 August 2017; Received in revised form 9 November 2017; Accepted 6 December 2017

complete life cycle (ISO, 2006a,b). In practice, the representation of the impact can be assessed at an early stage of the cause-effect chain, called the midpoint level, or as the final effect on areas of protection (AoP) at an endpoint level (De Meester, 2013). Indicators are used to express this damage, e.g. disability adjusted life years (DALY; i.e. loss in healthy life years) as endpoint indicator for damage to human health or kg CO_2 equivalents as midpoint indicator for the effect of greenhouse gas emissions on climate change. Ideally, without considering practical limitations, endpoint indicators should be preferred, as these cover the complete cause-effect chain up to the AoPs (Schaubroeck and Rugani, 2017). However, in practice, midpoint indicators are often considered or advised instead of endpoint indicators due to the higher reliability and availability of data and models (Hauschild et al., 2013).

LCA has been used to assess different pig manure management scenarios in different geographical locations. Prapaspongsa et al. (2010) identified environmental impacts from twelve different scenarios in Denmark, changing the type of treatment, storage and land application systems. De Vries et al. (2012) assessed the consequences of a manure processing technology that separates the manure into a solid and liquid fraction and de-waters the liquid fraction using reverse osmosis (in the Netherlands). Lopez-Ridaura et al. (2009) compared the environmental performance of the biological treatment of manure to its direct transportation and injection into crop land (in Bretagne, France). These studies calculated the environmental impacts at midpoint and used up to five impact categories to make their analyses. Brockmann et al. (2014) also compared the environmental performance of the biological treatment of manure to its direct application to the field, and took into account 18 midpoint impact categories in their discussion (in Bretagne, France). Endpoint impact was also calculated, but not discussed in the article. De Vries et al. (2015) assessed the trade-offs between the North West European practice, the Dutch current situation of progressive manure management and the application of a new integrated manure management practice applied to the European one. They paid particular attention to avoid pollution swapping within the manure management system. An overview of these works is shown in Table 1. Furthermore, a thorough chronological review of LCA studies of pig production was carried out by McAuliffe et al. (2016). In their study, LCA evaluations of pig production were studied that covered three life cycle stages: feed production, entire-system livestock rearing, and waste management.

This study is looking into the environmental performance and trade-offs between two manure management scenarios within the context of Flanders, Belgium, a nitrate vulnerable zone. The *treatment-scenario* comprises centrifugation and subsequent biological nitrogen removal from the liquid fraction, which is the most applied manure processing technique in Flanders, Belgium —80 out of 120 installations in 2015 (VLM, 2015). The *no-treatment-scenario* comprises the transportation and field application of untreated manure. This comparison will be done through the analysis of 18 midpoint categories, pinpointing of hotspots through endpoint impact assessment, assessing the sensitivity to the selection of background processes and discussing the validity of single-score impact assessment.

2. Materials and methods

2.1. LCA goal and scope

The goal of this study was to construct an inventory and evaluate the potential environmental impacts of a nitrification/denitrification biological pig manure treatment plant in a nitrate-vulnerable zone − Flanders, Belgium. The environmental impact evaluation was carried out using the LCA framework according to the ISO 14040/14044 guidelines (ISO, 2006a,b). The environmental impacts from this manure management option (treatment scenario) were then compared to the ones of the direct field application of untreated manure (no-treatment scenario). The comparison provides transparent information for different stakeholders regarding the environmental trade-offs between those two scenarios for managing the excess nitrogen from pig manure. An overview of the scenarios inputs, outputs, foreground system and background system is presented in Fig. 1.

As foreground system for the treatment-scenario, the manure management system considered is described. When arriving to the treatment facility, raw manure is pumped into an underground storage as soon as it arrives. Then, the raw manure undergoes centrifugation. The thin fraction is sent to the biological treatment, while the thick fraction is transported to a composting facility. Finally, the biological effluent and the compost are transported and applied to agricultural fields. In the no-treatment scenario, the foreground system describes raw manure storage, and transport and spreading to agricultural land. In the background systems of both scenarios (see Section 2.2.4), impacts outside the manure management systems considered have been accounted for — e.g. electricity production, manure transport to the treatment facility, chemical production (Fig. 1). The main input to the system is raw manure. Emissions to air and soil are the main outputs.

The Functional Unit (FU) used was “1 m^3 of raw manure” since the final output generated in each scenario is different and volume is the most commonly used FU for wastewater treatment plant (WWTP) analysis (Corominas et al., 2013).

2.2. Life cycle inventory and assumptions

The life cycle inventory (LCI) for both the treatment and the no-treatment scenarios per 1 m^3 of raw manure is displayed in Appendix A in Supplementary material. The life cycle inventory (LCI) data for the foreground system were compiled from the mathematical modelling of the biological treatment process, expertise-based estimations and

Table 1
Overview of considered LCA studies that compare the environmental performance between pig manure treatment and no treatment.

Reference	Region	Background databases	Software	Environmental Impact
De Vries et al. (2012)	the Netherlands	ecoinvent v2.0	SimaPro v.7.2	ReCiPe midpoint v.1.04
Prapaspongsa et al. (2010)	Denmark; European practices	ecoinvent v2.0 (Frischknecht et al., 2005)	SimaPro	STEPWISE2006
Lopez-Ridaura et al. (2009)	Bretagne, France	BUWAL 250 (BUWAL, 1996) ETH-ESU (Frischknecht and Jungbluth, 2004) IDEMAT (TUDelft, 2001)	SimaPro 6 (PRé Consultants, 2001)	(Eutrophication, Acidification, Climate change, Non-renewable energy use)
Brockmann et al. (2014)	Bretagne, France	ecoinvent v2.2 (Frischknecht et al., 2005)	SimaPro 7.3.3	ReCiPe v1.07 Hierarchist Midpoint and Endpoint
De Vries et al. (2015)	the Netherlands	ecoinvent v2.0	–	ReCiPe v1.04
This study	Flanders, Belgium	ecoinvent v3.2, “cut off” variant (Wernet et al., 2016)	SimaPro 8.2 (PRé Consultants, 2016)	ReCiPe v1.12 Hierarchist Midpoint and Endpoint