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Evaluating environmental impacts of pig slurry treatment technologies with a life-cycle perspective

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ABSTRACT

Pig husbandry has been developing rapidly during the past few decades, which has greatly increased the amounts of pig slurry as well as environmental impacts. How to appropriately treat the pig slurry has turned to a great challenge for sustainable pig husbandry, and this issue is especially critical to China, the biggest producer and consumer of pigs. This study tried to explore the effective ways of treating pig slurry, which could mitigate environmental impacts and increase resource utilization. The main method used in this study was life cycle assessment, which could evaluate the environmental impacts of four ways of treating pig slurry. Each kind of treatment technology consisted of three main processes - in-house handling, outdoor treatment and end disposal. This study used the CML2001 method to evaluate environmental impacts. Data sources for this study came from field investigations at pig farms, suppliers of relevant technologies, literature and the ecoinvent database. The results indicated that global warming potential (GWP), eutrophication potential (EP), and acidification potential (AP) were the three main impact categories. Meanwhile, all scenarios showed negative environmental impacts in ozone layer depletion potential (ODP), freshwater aquatic ecotoxicity potential (FAETP), abiotic depletion potential (ADP, element & fossil) and human toxicity potential (HTP) impact categories. It was also found that Deep-pit system and field application (DP-FA) scenario performed best in ADP (element & fossil). In-house separation and field application (S-FA) scenario had the lowest GWP and the second lowest EP, while having negative impacts in ODP, FAETP, HTP and ADP (element & fossil). Therefore, this study suggests using DP-FA scenario from the perspective of sustaining long-term resources and popularizing the S-FA scenario in the term of mitigating environmental impacts.

1. Introduction

As a result of enormous economic growth and great improvement of living conditions, China has rapidly developed its pig husbandry and become the leading pig breeding and consumption country in the world. The pig production in China accounted for 9% of the world's total in 1960, but the proportion increased to 34% in 2014 (FAOSTAT, 2017). The economic transformation that China has been witnessed greatly boosted intensive pig farms in China, the proportion of which increased from 23.2% in 1998 to 64.5% in 2010 due to increasing breeding costs and environmental protection stress (CAHVYB, 1998–2010). The environmental impacts associated with pig breeding, such as climate change, acidification and eutrophication, are mainly from inappropriate treatment of pig manure (Brockmann et al., 2014; Lopez-Ridaura et al., 2009; Prapaspongsa et al., 2010).

Pig manure treatment usually consists of three main phases: in-house handling, outdoor treatment and end disposal. As to in-housing handling, there are two major ways, traditional in-door separation and storage in deep pit. For the former one, which is used by 73.3% of pig farming (Su, 2012), solid manure is manually moved out of pigpen and the liquid part is washed out of the pigpen by water and flows directly into the outdoor treatment facility (Wang et al., 2017). The latter way is low labor-intensive and

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usually used at large and medium-scale pig farms (Zhu et al., 2011). In terms of the outdoor treatment, anaerobic digestion has been more and more popular, because it could effectively reduce greenhouse gas (GHG) emissions and increase renewable energy supply (Cherubini et al., 2015; Iordan et al., 2016). By the end of 2015, there had been more than 100,000 large-scale anaerobic digestion plants in China (NDRC, 2016). In addition, the Ministry of Agriculture has been actively promoting large-scale biogas projects using livestock manure as main inputs. As to the end disposal, the traditional way is to apply them to the cropland as a critical kind of fertilizer, which could improve the soil quality as well as the crop yield (Choudhary et al., 1996). With the higher manure transportation costs as well as strict application standards for organic fertilizer, some pig farmers are motivated to apply the biogas-digestate technology to treat manure.

In order to sustain the husbandry industry, the Central Government of China issued a regulation about recycling wastes of breeding systems in June 2017, which requires that 75% of wastes of breeding systems should be recycled and 95% of animal farmlands should have the manure treatment facilities in 2020. Under this situation, pig farmers need to find effective and environmentally friendly technologies for manure treatment, so it is critical to evaluate the environmental impacts of different manure treatment technologies.

Life cycle assessment (LCA) is an effective tool to quantify environmental impacts of a product or system. It has been applied to assess the environmental impacts of several manure treatment methods, such as in-house acidification (ten Hoeve et al., 2016b), anaerobic digestion (Cherubini et al., 2015; Croxatto Vega et al., 2014; Hamelin et al., 2011), separation (De Vries et al., 2012; ten Hoeve et al., 2014), incineration (Prapaspongsa et al., 2010), field application optimization (Langevin et al., 2010; Sandars et al., 2003). However, few studies concern the in-house separation, which is widely used in China. De Vries assessed the life cycle environmental consequences of segregating pig urine and feces with a V-belt system (De Vries et al., 2013). However, this separation technology is different from traditional Chinese in-house separation. Luo examined Chinese in-house separation but did not compare it with other in-house treatment methods (Luo et al., 2014). In addition, LCA is seldom used to assess the integrated wastewater treatment facilities, though it has been applied for wastewater treatment facilities in industrial parks (Tong et al., 2013).

Therefore, this study used LCA to assess the environmental impacts of four main treatment technologies to identify the most appropriate one as well as environmental hotspots which could be potentially be improved.

2. Materials & methods

2.1. LCA approach

This study followed the principles of the ISO 14040 series of standards for life cycle assessment (ISO14040, 2006; ISO14044, 2006) and used Gabi 6.0 software to run LCA model. The functional unit (FU) of all scenarios was 1 ton pig slurry excreted by fattening pigs under general conditions in China.

2.2. Goal and scope

With the goal of alleviating the environmental pressures caused by pig manure treatments, this study tried to 1) evaluate the environmental impacts of 1 ton pig slurry under each treatment technology, 2) identify environmental hotspots of each technology, and 3) propose strategies to promote appropriate treatment methods. The prevailing technologies of biogas and wastewater treatment in China were used as the technological scope in this study.

2.3. System boundaries and scenarios

2.3.1. System boundaries

The LCA covered the resource use and environmental impacts of the following processes: in-house handling of pig slurry, outdoor storage, transportation, application of final products in the farmlands, anaerobic digestion of pig slurry (all feces and urine) and liquid manure (30% feces and 100% urine), biogas use, treatment of liquid digestate, and avoided production and use of energy and mineral fertilizer. This study counted pig breeding out of the system, as different ways of pig slurry treatment had no influence on pig production (ten Hoeve et al., 2016a). This study excluded all the facilities from the system due to the shortage of first-hand data. In addition, biogenic CO_2 emissions in the storage and field application processes were not calculated (De Vries et al., 2012; ten Hoeve et al., 2016b).

2.3.2. Scenarios

This study set up four scenarios for comparison, by combining two in-house treatment methods, one outdoor treatment method and two end disposal methods (Fig. 1). The four scenarios were briefly introduced as follows.

(1) In-house separation and field application (S-FA) scenario. It consisted of two main processes, separating pig slurry in house and applying end disposal to the field. The pig slurry was separated into solid and liquid manure in house. The solid manure was temporally piled in house, then stored outside, and finally used in the nearby farmlands as organic fertilizers. The liquid manure was washed out into the biogas digester and turned to be digestate, and then went to farmland as well.
(2) In-house separation and wastewater treatment(S-WT) scenario. It was largely the same with S-FA above, except its further separation of digestate from liquid manure into liquid and solid digestate. Solid digestate was stored outside first and then used in nearby farmland as organic fertilizer. While the liquid digestate went into wastewater treatment facilities.
(3) Deep-pit system and field application (DP-FA) scenario. It used deep-pit storage instead of in-house separation as the first step. Then the products went to biogas digester and turned to biogas and digestate. The digestate was stored outside and finally used in nearby farmlands as organic fertilizers.
(4) Deep-pit system and wastewater treatment (DP-WT) scenario. It was generally the same with DP-FA, except its further separation of digestate produced in biogas digester into liquid and solid ones. The liquid digestate went into wastewater treatment facilities and the solid one was used in nearby farmland as organic fertilizer.

2.4. Life cycle data inventory and assumptions

The data used in this study came from fieldwork at pig farms, related literature as well as technology providers. Background data such as those about the transportation and the avoided productions of energy and fertilizers were from ecoinvent database in GaBi software.