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Valorization of an untapped resource: Energy and greenhouse gas emissions benefits of converting manure to biogas through anaerobic digestion

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ABSTRACT

Livestock farming generates animal manure as a by-product. In comparison to in some countries, manure is hardly used for energy production in Switzerland. A growing awareness of renewable energy needs, resource depletion, and climate challenges make the huge untapped potential of livestock manure very attractive, particularly regarding biogas technology. Here, we assessed the energy and greenhouse gas (GHG) emissions benefits of using manure for biogas, considering its spatial distribution in Switzerland. First, laboratory measurements were conducted to compare the composition of fresh manure with values from literature. Then, detailed assessments of manure availability for biogas production were performed. Finally, the mitigation potential regarding GHG emissions was estimated for three scenarios. The new lab-scale values confirmed early storage as an important phase that is still not considered in practice. Under current farming practice, Swiss manure could produce 430 million m^3 biogas or 15 PJ gross biogas yearly, mostly from cattle. However, only 6% of this manure is currently being used for anaerobic digestion. The manure is widely spread across the country in relatively small farms. Considering the spatial distribution of manure and Swiss agricultural structures, there is considerable potential for small-scale individual installations, with a peak of approximately 250 GJ gross biogas yearly, as well as for joint-farm installations. If the currently exploitable amount of manure were used for energy, the emission of 159 kt of CO_2 equivalent could be prevented compared to emissions under current management practices. Thus, manure digestion could be promoted for its wide environmental and energetic benefits.

1. Introduction

Manure is an inevitable by-product generated from livestock farming, comprising animal excreta possibly mixed with water and/or straw. When poorly managed, animal manure can become a major source of air and water pollution. Nutrient leaching, ammonia evaporation and pathogen contamination are some of the major threats it poses (Holm-Nielsen et al., 2009). However, if appropriate practices are integrated into the management chain, manure can replace significant amounts of mineral fertilizers and boost soil fertility (Arthurson, 2009). In addition, methane (CH_4) and nitrous dioxide (N_2O), two major greenhouse gases, are emitted from decomposing manure under anaerobic conditions. On the one hand, CH_4 – the principal component of natural gas – is a valuable and versatile energy source (Capodaglio et al., 2016; Cornelissen et al., 2012). On the other hand, it is the second most prevalent greenhouse gas (GHG) emitted from human activities after CO_2 (IPCC, 2014b). It is estimated that livestock production is responsible for 15% of the global human-induced GHG emissions, with 5% of the emissions from this sector existing in the form of CH_4 resulting from manure storage (Gerber et al., 2013). In Switzerland, agriculture represents 12.7% of the country's total greenhouse gas emissions, of which 19% is due to manure management (FOEN, 2016). Anaerobic digestion is one of the most promising practices for mitigating CH_4 and N_2O emissions from manure storage while producing renewable bioenergy (Chadwick et al., 2011; Gerber et al., 2013; Moral et al., 2012). Although not part of our study, anaerobic digestion of animal manure offers additional benefits by improving fertilizer quality, reducing odors and limiting pathogens (Holm-Nielsen et al., 2009). For all these reasons, manure should be recognized not as a material to be discarded, but as a crucial resource that can be used for both soil fertilization and energy production, leading to reduced GHG emissions. Environmental benefits and risks of anaerobic digestion have been studied substantially through life-cycle assessments (LCA) (Bacenetti et al., 2016; Hijazi et al., 2016). A clear mitigation benefit has been found as long as no energy crops are used, which is the case in Switzerland. Reduction in GHG emissions through anaerobic digestion has been demonstrated in several studies using manure and agricultural residues (Hamelin et al., 2014; Styles et al., 2016; Tonini et al., 2016).

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Regarding other environmental aspects, anaerobic digestion of manure could lead to reductions in water depletion and acidification, as well as in aquatic eco-toxicity (Van Stappen et al., 2016). However, one study demonstrated that eutrophication could increase slightly with anaerobic digestion (Yasar et al., 2017). Anaerobic digestion additionally reduces the amount of organic carbon introduced into the soil in comparison to that from undigested feedstock, but long-term consequences of anaerobic digestate on the soil are not well known (Hamelin et al., 2011).

Switzerland has set the ambitious target of optimizing both material and energy use of its domestic biomass resources (SFOE, 2009; CORE, 2015). As major decisions are made at the national level, all resource assessments must cover the whole country. According to our previous study (Burg et al., 2018), the total theoretical potential of Swiss biomass is 209 PJ primary energy per year, of which about half stems from forest wood (108 PJ) and a quarter from manure (49 PJ). About half of this manure biomass could be used in a sustainable way (Steubing et al., 2010; Thees et al., 2017; Burg et al., 2018). Using this resource would be highly beneficial for implementing the energy transition. Indeed, biogas is a versatile energy source that can be converted into heat, electricity and fuel, both in developed and in developing countries (Surendra et al., 2015). Another point in favor of biogas is that it can compensate for fluctuations in other renewable power sources (e.g. sun, wind) and thereby perform an important function in the future energy supply (Wellinger et al., 2013). However, similar to in other countries, only 954 TJ biogas, which corresponds to less than 6% of the total estimated exploitable manure, is currently produced by approximately 100 agricultural biogas units in Switzerland (BFE, 2015b; Thees et al., 2017). Given this situation, manure represents a large, mostly untapped, locally available source of bioenergy whose sustainable use should be targeted. An integrated approach to bioenergy production is needed, where all important factors such as ecological impact, technological constraints and population acceptance are accounted for, and pros and cons of the bioenergy use are carefully estimated (Ruppert et al., 2013). Anaerobic digestion has multiple benefits as a waste management strategy and source of renewable energy, and it contributes to greenhouse gas emissions mitigation. Despite these benefits, such aspects have rarely been quantified simultaneously at a national scale to form a comprehensive knowledge base for political decisions.

The objective of this study was to assess within the same study the resources, as well as the energy and GHG emissions benefits, of converting manure to biogas in Switzerland, taking into consideration the spatial distribution of manure throughout the country. Indeed, spatial distribution and local biomass supply security are known to be critical issues for investors in bioenergy facilities (Richard, 2010) but are rarely investigated. Feeding practices and the animal production system can both influence manure composition and its potential methane production, so lab-scale measurements were conducted as part of this study to update and complement existing literature values for Switzerland. In addition, the availability of Swiss manure for biogas production was estimated, considering various explicit restrictions. The spatial distribution of stored manure was analyzed using Geographic Information Systems (GIS), which facilitated in-depth estimations of possible exploitation limitations and opportunities for using manure. Finally, changes in GHG emissions were compared among different scenarios regarding the treatment of livestock manure in Switzerland: (i) Scenario A represents business as usual; (ii) Scenario B assumes treatment of the total amount of livestock manure in anaerobic digesters; and (iii) Scenario C represents a feasible situation in which only 65% of the total manure quantity is digested.

2. Material and methods

2.1. Composition and potential biomethane yield: lab-scale measurements

The composition and effectiveness of manure as a source of biomethane depends on several factors including the type of ration fed, housing system, method of manure collection, storage and handling (Coppolecchia et al., 2015).Further, these factors may differ considerably from farm to farm and country to country, or may change over time due to changes in animal husbandry. In addition, early decomposition during storage represents a major cause of biogas loss, leading to higher GHG emissions and lower energy recovery. Indeed, freshness is a key factor, as biodegradation occurs even before manure is added to the digestion unit. Therefore, the longer the interval between manure excretion and the beginning of enclosed anaerobic digestion, the more non-collected biogas created (Møller et al., 2004a; Gopalan et al., 2013). In a previous study, the biogas potential was found to decrease as a function of the pre-digestion storage time (Moset et al., 2012). To take these factors into account, a series of lab-scale measurements were performed in this study to evaluate the characteristics of animal manure in Switzerland.

Considering the agricultural situation in Switzerland, focus was set on manure from cattle and especially dairy cows (Thees et al., 2017; Burg et al., 2018), but manure from pigs, horses and poultry was also analyzed. Whenever possible, animal categories were further divided into animal use (dairy, meat, breeding) and stalling system (Table 1). Fresh manure was collected from the stables in 48 farms located across Switzerland, from August to September 2015. In total, 79 samples were taken and 40 were deemed suitable for analysis (dw and odw, Table 1). Regarding methane yield, manure from one farm per animal category was analyzed. Up to four samples (1.5 L each) per location were taken, and then the samples from each farm were mixed together to obtain a single 0.5 to 1 L sample per location for the analyses. The samples were transported immediately to the laboratory without outside storage and stored at 4 °C prior to analysis (thus preventing most biological processes). Manure characteristics can vary among seasons and even the day, more or less strongly depending on local conditions such as

Table 1
Solids and elemental contents (dw, odw, methane yield; sample means with their standard errors) of manure from our analyses in Switzerland and according to literature data (dw, odw: Flisch et al., 2009; methane yield: Kuratorium für Technik und Bauwesen in der Landwirtschaft (KTBL, 2013).

Categories	Lab-scale measurement (fresh from the stable)				Literature values		
	Dry weight dw %	Organic fraction of the dry weight odw (%)	Number of farms sampled	Methane yield (NL/kg odw)	Dry weight dw (%)	Organic fraction of the dry weight odw (%)	Methane yield (NL/kg odw)
Dairy cow, liquid	8 (± 3)	70 (± 17)	5	364 (± 14)	9	78	150
Dairy cow, solid	20 (± 4)	80 (± 7)	4	359 (± 14)	21	84	250
Fattening cattle, liquid	8 (± 3)	78 (± 10)	6	326 (± 2)	9	72	150
Fattening cattle, solid	17 (± 6)	80 (± 9)	5	355 (± 3)	21	74	250
Pig, liquid	6 (± 1)	74 (± 2)	14	411 (± 3)	5	72	250
Horse, solid	29 (± 4)	88 (± 3)	3	298 (± 11)	35	86	255
Hen	53 (± 3)	78 (± 10)	3	259 (± 9)	50	71	290