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ABSTRACT

In the context of climate change and non-renewable energy depletion, the transition toward increasing the contribution of renewable energy requires insight into environmental consequences of such energy production, such as anaerobic digestion (AD). In a pig farm producing crops used as ingredients for pig feed, biomass (fertilized with pig manure), crop residues and intercrops are highly valuable substrates for AD. Thus, the aim of this work was to assess the influence of on-farm digestion of pig slurry to produce bio-energy on environmental impacts of pig production from a life cycle perspective. This system allows maximum autonomy for the farmer, regardless of the availability of digester nutrients. It had lower negative impacts for most impact categories than a more energy-dependent system, even for hotspot impacts of climate change and cumulative energy demand. More accurate data about carbon mineralization of digestates are necessary to make conclusions about potential impacts on soil organic matter dynamics.

Keywords: anaerobic digestion, pig production, soil organic matter change

1. Introduction

In the context of climate change and non-renewable energy depletion, the demand for renewable energy is rising, and the European Union aims to obtain 20% of its energy from renewable sources by 2020 (EU 2009). This transition requires insight into environmental consequences, such as climate change (CC) and cumulative energy demand (CED), of renewable energy production. Change in soil organic matter (SOM) is also a hotspot indicator for soil quality (Garrigues et al. 2012) in the case of bio-energy produced from biomass by anaerobic digestion (AD) in the form of heat and electricity. The product that remains after AD is digestate, which can be recycled as organic fertilizer for crop cultivation. On a pig farm in which the main crops used as ingredients for pig feed are produced on the farm, biomass (fertilized with pig manure), crop residues and intercrops are highly valuable substrates for AD. Thus, the aim of this work was to assess the influence of on-farm co-digestion of pig slurry to produce bio-energy on environmental impacts of pig production from a life cycle assessment (LCA) perspective.

2. Methods

2.1. System definition

The agricultural system is assessed via its function of food production. System boundaries of the pig breeder/fattener system are from cradle to the farm gate. The system includes infrastructure, inputs, related resources and emissions for pig production and the crops used as ingredients in the pig feed. For crops used as pig-feed ingredients, the main crop rotation in its region of origin was assumed. For crops produced on the pig farm, crop rotations were considered in greater detail. Temporal system boundaries of crop rotations end with the harvest of the crop analyzed and begin after the harvest of the preceding crop. The functional unit is 1 kg of pig liveweight produced. Impact categories assessed were those of the CML-IA, plus CED and two soil-quality indicators: compaction and SOM change (Garrigues et al. 2012).

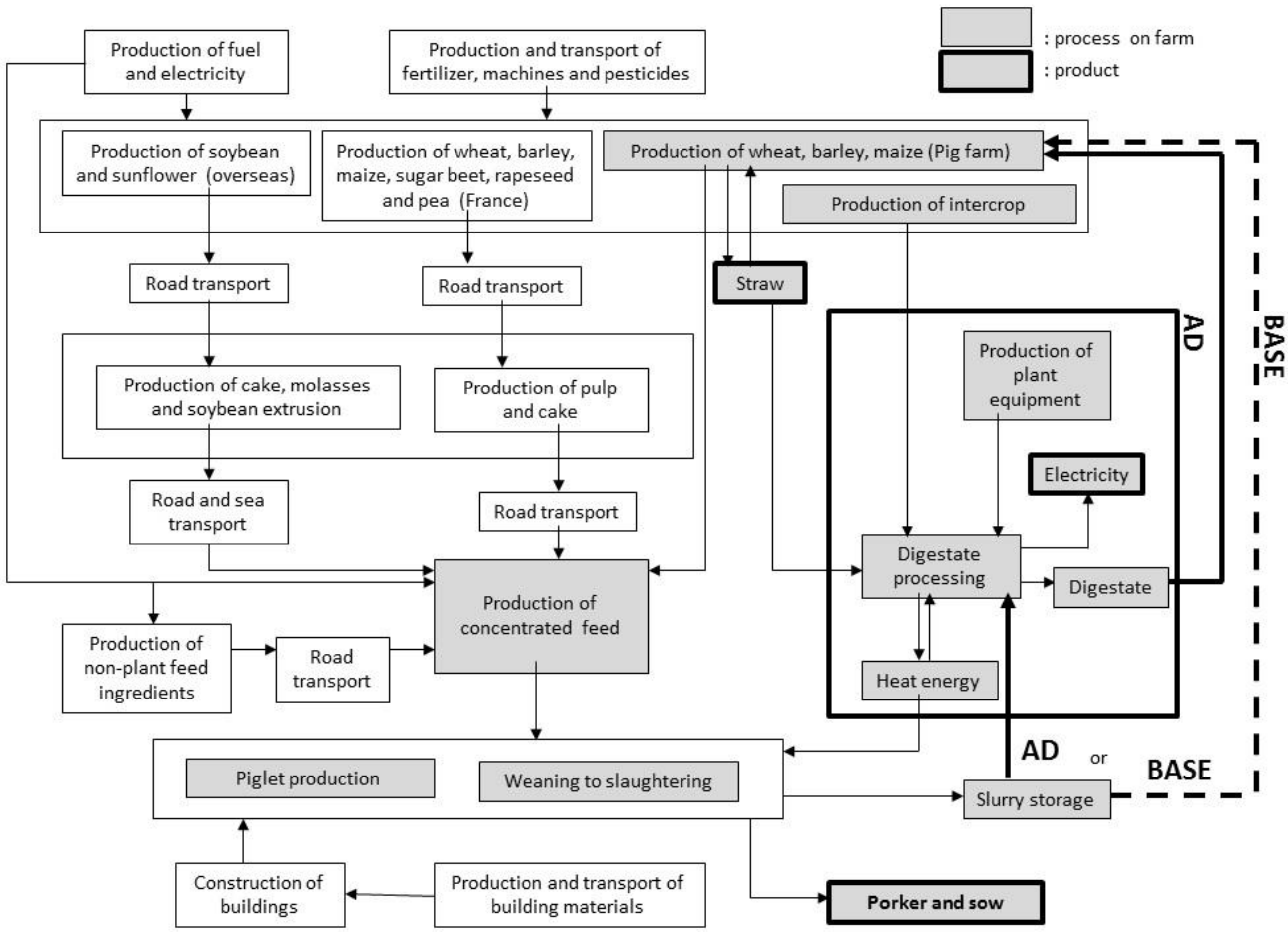

Figure 1. System boundaries for baseline (BASE) and anaerobic digestion (AD) scenarios

2.2. Definition of scenarios

We compared two scenarios (Fig. 1): (1) standard manure storage and spreading on a representative pig farm in Brittany, France (BASE scenario), and (2) the same pig farm with a 50 kW AD plant with digestate spreading on fields instead of slurry (AD scenario). The representative farm produces 4800 pigs per year with 225 permanent sows. Maize, wheat and barley are produced on 115 ha with phacelia as an intercrop. Four rotations are represented: wheat-maize and wheat-barley-maize on 48 ha each, wheat-maize-maize on 15 ha and maize monoculture on 4 ha. In the AD scenario, oats and triticale are also grown as intercrops with phacelia to feed the AD plant (Table 2). Fertilizer applications (mineral and organic) were calculated to maintain yield and to prevent pollution risk. Characteristics of the pig farm (e.g., volume of pig production, area, crops) were based on examples of existing pig farms in Brittany that remained economically viable after adding AD to the farm (Brittany Chamber of Agriculture, pers. comm.).

2.3. Life cycle inventory assumptions and model used for SOM change

2.3.1. Composition of pig feed in the two scenarios

Pig production in the breeder/fattener system uses seven different feeds, with compositions defined by the French Pork and Pig Institute (IFIP) according to the pig-production stage (Table 1). The farmer fabricates all feeds on the farm. All crop production is used to feed the sows, piglets and pigs and represents 88% of the maize, 82% of the barley and 70% of the wheat needed for the feeds. The rest of the ingredients are bought on national and international markets (Table 1).

Table 1. Ingredient composition (percentage by mass) and sources of representative pig feed produced in Brittany.

Ingredient	Maize	Wheat	Wheat middlings	Barley	Rape-seed oil	Rapeseed cake	Soya cake	Sunflower cake	Sugarbeet pulp
Origin	France (Brittany)	France (Brittany)		France (Brittany)	France (Brittany)		Brazil (Santa Catarina)	Argentina (Balcarce)	France (Picardy)
Source crop	Maize	Winter wheat		Barley	Rapeseed		Soya	Sunflower	Sugarbeet
Economic allocation[a] (%)	100.0	100.0	14.0	100.0	75.6	24.4	66.0	37.6	15.6
Pregnant sow feed (%)	6.8	40.0	3.2	30.0	0	6.7	0	5.0	5.0
Lactating sow feed (%)	12.7	30.0	0	32.0	0	5.7	13.0	2.0	1.0
Piglet prestarter feed (%)	0	61.9	0	0	4.6	0	27.6	0	0
Piglet starter feed (%)	0	42.0	0	32.0	0	0	20.0	0	0
Post-weaning feed (%)	0	58.0	0	20.0	0	0	19.0	0	0
Growing pig feed (%)	20.0	43.0	0	15.0	0	0	19.0	0	0
Finishing pig feed (%)	50.1	28.0	0	0	0	0	17.0	0	0

[a] Economic allocation based on Olympic mean price from 2006-2010 (ISTA 2009 & 2011).

2.3.2. AD scenario

In seeking maximum autonomy for the farmer, dimensions of the AD plant (energy produced and substrate quantities needed) aim for economic viability of the pig farm: no need to import substrates for AD other than those produced on the farm and spreading of all digestate produced on farm crops as fertilizer.

The AD is operated at a mesophilic temperature (around 35°C) with a hydraulic retention time of 66 days. CH_4 production from the AD is 110,832 m^3/year, with an electricity-production capacity of 50 kW and energy efficiency of 36%. Operating the AD requires 3% of the electricity produced and consumes 36% of the heat produced. The heat produced covers all heating needs of pig buildings and provides a surplus in summer. This scenario reflects simple biogas installations, which produce less electricity but also cost less to install.

Table 2. Substrates of the anaerobic digestion (AD) plant and their organic matter (OM) before and after AD

Substrates	% of substrate produced on-farm used for digestion	t/year	OM before digestion (t)	OM after digestion and storage (t)
Pig slurry	100	207	147	100
Wheat chaff	100	71	65	31
Barley chaff	100	17	15	7
Grass silage	100	12	11	4
Oats (intercrop)	100	56	53	9
Triticale (intercrop)	100	60	56	13
Barley straw	50	28	26	15
Maize stalks	33	64	59	34

To obtain a liquid rather than solid digestate, not all of the available straw and maize stalks are placed into the digester. The digestate is liquid enough (5.8% DM) to be spread as fertilizer, in the same way that slurry is spread in the BASE scenario. In the AD scenario, slurry and digestate are stored separately in covered concrete tanks, and the remaining 50% of the wheat straw is sold. CH_4 and N_2O emissions of the AD plant (storage and digestion) were calculated with the DIGES tool (Gac et al. 2006). Since emission factors for digestate applied to fields were not available, we assumed them to be the same as those for pig slurry. In the BASE scenario, slurry is stored in and open concrete tank, and 100% of the wheat straw is sold. During storage, nutrient leaching from the slurry or digestate is assumed to be negligible in both scenarios.

2.3.3. Soil carbon change modeling

RothC (version 26.3) simulates dynamics of organic carbon (C) in soil (Coleman *et al.* 1997; Coleman and Jenkinson 2008). The effects of soil type, temperature, moisture content and plant cover are considered in the turnover process. Soil organic C is split into four active compartments and a small amount of inert organic matter (IOM). The four active compartments are decomposable plant material (DPM), resistant plant material (RPM), microbial biomass (BIO) and humified organic matter (HUM). When exogenous organic matter is added to the soil, it is split between the DPM, RPM and possibly HUM pools according to partition coefficients, such as DPM/RPM. For crop residues, we used a DPM/RPM ratio of 1.44, i.e. DPM of 59% and RPM of 41%. For slurry and digestate, DPM and RPM was calculated from their Van Soest biochemical fractions via an indicator of remaining organic C (I_{ROC}) (Lashermes et al. 2009) based on equations developed by Peltre et al. (2012):

$$DPM = -1.254 \times I_{ROC} + 115.922 \quad \text{Eq. 1}$$

$$RPM = 0.979 \times I_{ROC} - 8.928 \quad \text{Eq. 2}$$

We used DPM of 63.9% and RPM of 31.7% for slurry and DPM of 29.5% and RPM of 58.5% for digestate.

We simulated 20 years of the same management practice and divided the total change in soil organic C by 20 to provide the mean rate over one year. When analyzing crop rotations, temporal system boundaries differed from those of individual crops, for which the C brought to the soil by crop residues was considered from just after the harvest of the crop of interest (when residues are left in the soil) to the harvest of the following crop. We thus followed back-effects of the C supplied. The change in soil C could be positive or negative, indicating soil C storage or loss, respectively.

3. Results

Table 3. Potential impacts of the (BASE)line and anerobic digestion (AD) scenarios per kg of pig liveweight according to the CML-IA method.

Impact category	Unit	BASE	AD	AD vs. BASE (%)
Abiotic depletion	kg Sb eq	3.96E-03	3.66E-03	-7.6
Acidification	kg SO_2 eq	5.45E-02	5.57E-02	+2.1
Eutrophication	kg PO_4^{---} eq	1.53E-02	1.57E-02	+2.5
Climate change (GWP100)	kg CO_2 eq	1.90E+00	1.86E+00	-1.9
Ozone layer depletion	kg CFC-11 eq	9.07E-08	8.66E-08	-4.5
Human toxicity	kg 1.4-DB eq	9.36E-01	9.21E-01	-1.6
Fresh water aquatic ecotoxicity	kg 1.4-DB eq	9.33E-01	9.22E-01	-1.2
Marine aquatic ecotoxicity	kg 1.4-DB eq	3.65E+02	3.58E+02	-2.0
Terrestrial ecotoxicity	kg 1.4-DB eq	1.52E-01	1.50E-01	-1.1
Photochemical oxidation	kg C_2H_4	8.81E-04	8.79E-04	-0.3
Land occupation	m^2y	3.93E+00	3.94E+00	+0.2
Total cumulative energy demand	MJ	1.18E+01	1.09E+01	-8.1
Soil organic matter change	kg C	1.35E+01	1.12E+01	-17.5
Compaction	m^3	1.21E+01	1.90E+01	+36.4

LCA of the two scenarios showed lower environmental impacts per kg of pig liveweight of the farm with AD (Table 3). Installation of an AD plant reduced CC by 1.9% (BASE: 1.90 kg CO_2-eq/kg; AD: 1.86 kg CO_2-eq/kg) and CED by 8.1% (BASE: 11.84 MJ/kg; AD: 10.88 MJ/kg). SOM was sequestered in both scenarios (positive impacts) despite less soil C storage when straw was exported compared to a scenario (results not shown here) in which straw was left on the soil. The BASE scenario sequestered a mean of 13.5 kg C/kg and the AD scenario 11.2 kg C/kg. The AD scenario had higher acidification and eutrophication impacts than the BASE scenario (by 2.1 and 2.5% respectively). The greatest increase in impact due to the installation of an AD plant was for soil compaction, which increased by 36.4%. The AD scenario had lower impacts than the BASE scenario for the other categories.

4. Discussion

Introducing biogas technology in a pig farm in Brittany reduced greenhouse gas emissions, mainly by replacing natural gas for heating piglet nurseries. In France, where most electricity is produced by nuclear energy, CC impacts from electricity production were similar for both scenarios. Even though the AD plant studied was small, CED decreased due to direct production and use of heat and electricity.

The increase in SOM was lower in the AD scenario than the BASE scenario. AD's digestate has a lower C content than the substrates used to create it because of the loss of C via CH_4, but it has greater stability, which decreases long-term loss of SOM. In a Danish study (Thomsen et al. 2013), a three-pool model used to simulate

C mineralization predicted similar long-term C sequestration in soil for initial turnover of plant biomass in the soil, ruminant digestive tracts, an AD plant or a combination of the latter two. In that study, C pools in the model were calibrated with laboratory incubations. In our study, the RothC model was initialized with pedotransfer functions. Although both scenarios sequester C, the lower C sequestration due to spreading digestate instead of slurry can be compensated by changing straw management: C sequestration was 19.5 kg C/kg (74% higher) if all straw was returned to the soil in the AD scenario.

Adopting AD technology on a pig farm appears to increase compaction due to the greater number of field operations required for the new intercrops grown to feed the AD plant. Since the compaction indicator only considers neutral (plowing) or negative impacts of field passes, the more field operations, the higher the predicted compaction (Garrigues et al. 2013). Furthermore, the new operations occurred when soil water content was high (spring and autumn), thereby increasing compaction risk. The compaction indicator represents the potential impact well if these practices are performed every year. Indirect implications of soil compaction, such as lower future yields, should not be neglected, but crop rotations should decrease this risk. Despite this, AD of slurry, straw and intercrops is well accepted in France. Replacing the intercrops with crops to feed the digester would probably decrease compaction and increase efficiency of the AD, but this practice is not currently accepted in France. A sensitivity analysis is planned to assess the relative influence of farm and AD plant characteristics.

5. Conclusion

Installation of a small AD plant on a pig farm producing most of the ingredients in its animal feed provides maximum autonomy for the farmer, who does not have to depend on the availability of plant substrates for AD. The AD system tended to have lower environmental impacts than a more energy-dependent system, even for the hotspot impacts of climate change and cumulative energy demand. Careful attention must be paid to SOM management through C amendment with digestate and straw. Digestates are quite new types of exogenous organic matter with a wide diversity of C mineralization characteristics depending on the plant substrate. More accurate data about carbon mineralization of digestates are necessary to make conclusions about potential impacts on SOM dynamics.

6. References

Coleman K, Jenkinson DS (2008) ROTHC-26.3 A model for the turnover of carbon in soil. Model description and windows users guide. Harpenden, Herts, UK, 47 p.

Coleman K, Jenkinson DS, Crocker GJ, Grace PR, Klír J, Körschens M, Poulton PR, Richter DD (1997) Simulating trends in soil organic carbon in long-term experiments using RothC-26.3. Geoderma 81:29-44.

EU, 2009. Directives on the promotion of the use of energy from renewable sources. Directives 2009/28/EC, European Parliament, Brussels, Belgium. Available at: http://europa.eu/legislation_summaries/energy/renewable_energy/en0009_en.htm (accessed 6 Feb. 2014).

Gac, A, Beline F, and Bioteau T (2006) DIGES - DIgestion anaérobie et Gaz à Effet de Serre Cemagref, ADEME. 45 pages.

Garrigues E, Corson MS, Walter C, Angers DA, van der Werf HMG (2012) Soil quality in life cycle assessment: towards development of an indicator. Ecol Indic 18:434-442.

Garrigues E, Corson MS, Walter C, Angers DA, van der Werf HMG, (2012) Developing new methodology to assess direct and indirect impacts of agricultural activities on soil quality. Proceedings of the 8th International Conference on LCA in the Agri-Food Sector, Saint-Malo, France, October 2-4, 2012. p 343-348.

Garrigues E, Corson MS, Walter C, Angers DA, van der Werf HMG (2013) Development of a soil compaction indicator in life cycle assessment. Int J Life Cycle Assess 18: 1316-1324.

ISTA (Information Science, Technology and Applications) (2009) Oil world annual 2009, vol. 1 ISTA Mielke GmbH, Hamburg, Germany

ISTA (Information Science, Technology and Applications) (2011) Oil world annual 2011, vol. 1 ISTA Mielke GmbH, Hamburg, Germany

Lashermes G, Nicolardot B, Parnaudeau V, Thuriès L, Chaussod R, Guillotin M.L, Linères M, Mary B, Metzger L, Morvan T, Tricaud A, Villette C, Houot S (2009) Indicator of potential residual carbon in soils after exogenous organic matter application. Europ J Soil Sci 60: 297-310.

Peltre C, Christensen BT, Dragon S, Icard C, Katterer T, Houot S (2012) RothC simulation of carbon accumulation in soil after repeated application of widely different organic amendments. Soil Biol Bioch 52: 49-60.
Thomsen, IK, Olesen, JE, Moller, HB, Sorensen, P, Christensen, BT (2013) Carbon dynamics and retention in soil after anaerobic digestion of dairy cattle feed and faeces. Soil Biol Bioch 58: 82-87.