# Grass as a C booster for manure-biogas in Estonia: a consequential LCA

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**ABSTRACT**

The aim of this study was to assess the environmental consequences of using grass (from both unused and cultivated boreal grasslands) as a co-substrate to dairy cow manure for biogas production. Environmental impact categories assessed were global warming, acidification and nutrient enrichment (distinguishing between N and P). Scenarios studied were: traditional management of dairy cow manure, mono-digestion of manure, manure co-digestion with reed canary grass and manure co-digestion with residual grass from semi-natural grasslands. The latter scenario showed the best environmental performance for the global warming category, for other categories it did not show clear benefits. Using reed canary grass specially produced for biogas purpose resulted in a climate change impact just as big as the reference manure management, mainly as a result of indirect land use changes. Increased impacts also occurred in the acidification and eutrophication (N) categories for the reed canary grass scenario, reflecting the impacts of the cultivation process. The main conclusion was that future strategies for manure-biogas production in Estonia should not rely upon land-dependent biomass, even if the availability of arable land in Estonia is, under current conditions, not considered to be an issue.

Keywords: anaerobic digestion, land use changes, dairy manure, reed canary grass, natural grass

## 1. Introduction

Biogas production from manure has a good potential to simultaneously produce a renewable and flexible energy carrier, while reducing the environmental impacts of manure management (mainly due to the reduced emissions from raw manure storage) and recycling biomass macronutrients (as well as the slowly degradable carbon) (Hamelin 2013). Although the energy produced from manure-biogas in the European Union (EU) is currently far below its full potential (Hamelin et al. 2014), a drastic increase of biogas production is nevertheless planned in the EU (Beurskens and Hekkenberg 2011), as well as in Estonia (Melts et al. 2013).

However, due to the too low carbon (C) and carbon-to-nitrogen (C/N) content of animal manure, it is usual practice to supplement manure with C-rich co-substrates for anaerobic digestion. Grass, especially reed canary grass, has been considered to have great potential for biogas production mainly due to its relatively high yield and the fact that arable land resource is available in Estonia (Ministry of Economic Affairs and Communications 2010; Värnik et al. 2011).

Two grass options were considered in this study: i) reed canary grass (this being one of the dedicated energy crops suggested to grow in Nordic countries) and ii) the residual grass from semi-natural grasslands, which is clearly underused currently but has a considerable biogas potential (Melts et al. 2013).

The goal of this consequential life cycle assessment (LCA) study was to quantify the environmental consequences of implementing, in Estonia, a manure-biogas strategy relying on grass as a co-substrate (options i) and ii), as opposed to managing manure conventionally and not harvesting the grass from semi-natural areas, nor producing energy grass. The focus is on dairy cow manure, this being presenting the highest share from all manure types in Estonia (Luostarinen 2013).

## 2. Methods

### 2.1. LCA approach

The life cycle impact assessment methodology used for this study was the EDIP2003 method described in Hauschild and Potting (2005) and the functional unit upon which all input and output flows were expressed was ”the management of 1 tonne of dairy cow manure ex-animal (i.e. the manure as freshly excreted by the animals)”. Four impact categories were considered: global warming, acidification and nutrient enrichment (distinguishing between N and P). Background data were based on Ecoinvent v.2.2 database (Frischknecht and Rebitzer 2005). Foreground data were mainly based on the Estonian situation, partly combined with Danish data.

The life cycle inventory and process flows are detailed in Pehme (2013), and the assessment was facilitated by the software SimaPro 7.3.2. The geographical scope was considered to be Estonia, i.e., inventory data for biomass composition, technologies and emissions were specific to the Estonian/Baltic conditions.

In this study, biogenic carbon flows (both removals from atmosphere by plants and also emissions) were fully accounted for each process.

### 2.2. System boundaries and description of scenarios

Four different scenarios are considered in this study: one reference scenario (conventional management of dairy cow manure) and three biogas alternatives (mono-digestion; co-digestion with energy grass; and co-digestion with grass from semi-natural areas).

In the reference scenario, dairy cow manure is handled as slurry after excretion, pumped towards outdoor storage at least once per day, stored outside in a concrete slurry tank covered by a naturally-forming crust layer and applied to fields when suitable. The life cycle inventory of the reference manure management is detailed in Hamelin et al. (2013), including details on the manure composition. The process flow diagram of this scenario is presented in Figure 1, reflecting the mass changes of manure due to emission losses and water addition in-house and at the outdoor storage through precipitation. The dry matter (DM) content of dairy manure ex-housing (i.e. as it leaves the housing unit) considered in this study is 11.5%, the volatile solids (VS) representing 82.0% of the DM (Hamelin et al., 2013).

In the biogas scenarios, manure is instead collected from the animal houses and used in biogas plants, digested in a mesophilic 2-steps digestion process. The biogas was considered to be used for combined heat and power production (CHP). The marginal energy sources displaced by the biogas were natural gas for the heat and oil shale for the electricity. The digestate was assumed to be stored and used as a fertilizer, displacing the marginal mineral nitrogen, phosphorus and potassium fertilizers for Europe (respectively taken as calcium ammonium nitrate, diammonium phosphate and potassium chloride; Hamelin 2013). The rationale behind this fertilizer substitution is, based on the Estonian context, that if the farmer would not have had the manure or digestate, the farmer would have applied mineral fertilizers up to the crop needs and national regulations. Yet, this does not mean that 100% of the N, P and K applied with the raw manure (reference scenario) and digestate (biogas scenarios) correspond to avoided mineral fertilizer; only the portion available to plants was considered to avoid the production and use of mineral N, P and K. The full calculation of avoided fertilizers is detailed in Pehme (2013).

For the 2 scenarios involving co-substrates, it was considered, based on Hamelin et al. (2011), that these were added to manure in order to get an input mixture with a DM content of 10% after the first digestion step. Fugitive $CH_4$ losses from the anaerobic digestion process were taken as 1% of the overall $CH_4$ produced, based on Hamelin et al. (2014) and assuming the implementation of state-of-the-art biogas technologies. Further life cycle inventory data, details and mass balances for all biogas scenarios are detailed in Pehme (2013).

The co-digestion with energy grass scenario, here referred to as the “Reed canary grass (RCG) scenario”, is based on co-digestion of dairy cow slurry and reed canary grass silage. RCG is here produced specially for biogas purpose, fertilized and harvested twice per year. The average grass yield for a 15 years plantation is considered as 8.23 t DM/year. RCG production data were based on Värnik et al. (2011). The production of RCG is considered to displace the use of land for cultivating barley, thus this barley cannot be produced on the same land and has to be produced somewhere else, thus involving land use changes emissions (expansion and intensification). Different life cycle assessments have identified spring barley as the marginal crop displaced by an increased demand for other crops (e.g. Hamelin et al. 2012; De Vries et al. 2012). Barley is mostly produced in areas with lower soil quality and its gross-margin value is lower compared to other crops. Thus, production of energy grass instead of barley has been presented as an attractive choice for Estonian farmers from the economic and agronomic point of view (Värnik et al. 2011). In this study, indirect land use changes (ILUC) emissions of 357 t $CO_2$ eq. per ha of barley displaced were considered on the basis of (Hamelin et al. 2014), which corresponds to 18 t $CO_2$ eq. ha per year (20 years annualization). Hamelin et al. (2014) derived that estimate from the results of Kløverpris (2008) for a marginal increase in wheat consumption in Denmark. Process flows for the RCG scenario are illustrated in Figure 2.

The co-digestion scenario involving natural grass (NG) is based on co-digestion of dairy cow slurry and natural grass silage. Grass is collected once per year from semi-natural grassland (alluvial meadows) where no soil cultivation is practiced and no agrochemical inputs are used. The grass yield is assumed to be 5.5 t DM/ha according to Melts et al. (2013). Currently there is no use for most of the biomass from those areas, so harvesting the grass prevents it to decompose and cause $CO_2$ emissions to the atmosphere. This (avoided) decay process was modeled following a first order ($C_t=C_oe^{-kt}$) decay, assuming that 100% of the above-ground biomass is transferred to the soil, and using the decay rates of Freschet et al. (2013). On the basis of this, it was considered that 100% of the C in the above-ground grass biomass would have been emitted as $CO_2$, if the grass would not have been harvested. In this system, this translates to avoided $CO_2$ emissions of 9.5 t $CO_2$ eq. ha per year (20 years annualization), considering a C content in the grass biomass of 0.47 kg C $kg^{-1}$ DM. Of course, as the grass C ends up to be emitted through the biogas scenario (among others in the biogas and through the application of the digestate), this credit is, at the end, essentially counterbalanced. Production, cutting, chopping and transport of grass are accounted in the analyses for both grass co-digestion scenarios.

More straightforward, the mono-digestion scenario is based on the anaerobic digestion of dairy cow slurry ex-housing, this being the only substrate. The digestate then undergoes the same processes as for the other biogas scenarios.

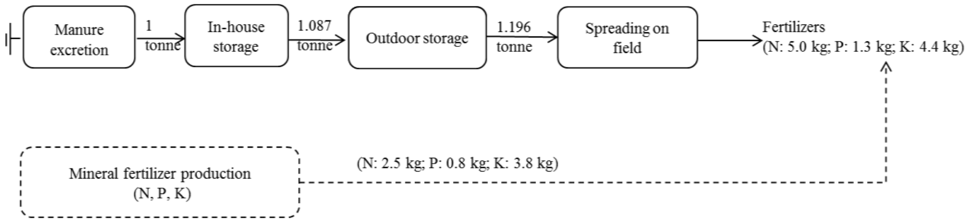

Figure 1. Process flow diagram for the reference manure management scenario per 1 tonne of manure ex-animal

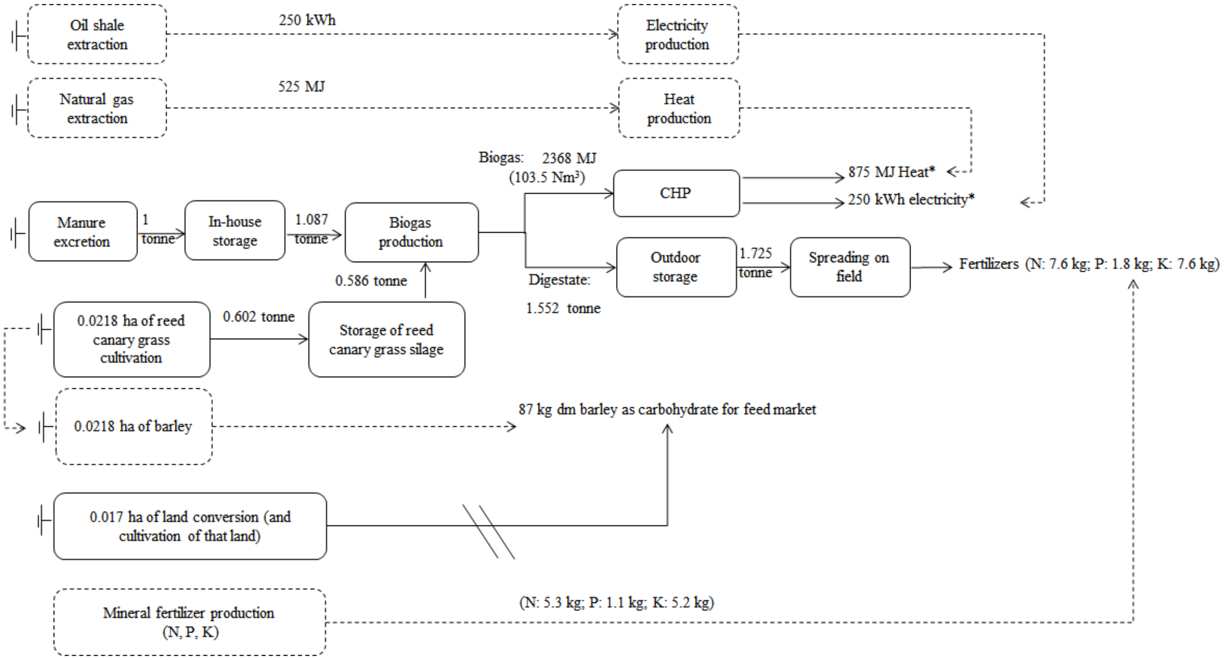

Figure 2. Process flow diagram for the reed canary grass scenario per 1 tonne of manure ex-animal

## 3. Results

The natural grass scenario had the best reduction potential for the global warming impact category (Table 1). The reed canary grass scenario showed equal result compared to reference scenario; the main reason for this was indirect land use changes. Mono-digestion displayed a good potential to reduce the global warming impact, but its energy production is significantly lower.

Most of the induced greenhouse gas (GHG) emissions originated from field application of manure and digestates, and from the burning of the biogas in the biogas engine prior to CHP. For all scenarios, the main reduction of GHG emissions was caused by the avoided oil shale-based electricity.

For the rest of the impact categories, natural grass did not show clear environmental benefits in comparison to the reference scenario (conventional manure management without biogas) (Table 1).

Table 1. LCA results, per 1 tonne of dairy cow manure ex-animal.

| **Impact category** | **Reference manure** | **Mono-digestion** | **Co-digestion with RCG** | **Co-digestion with NG** |
|---|---|---|---|---|
| Global warming, kg $CO_2$ eq. | 314 | 155 | 314 | -207 |
| Acidification, $m^2$ "unprotected ecosystems eq." (UES) | 43 | 37 | 60 | 48 |
| Aquatic Eutrophication, N eq. | 0.40 | 0.28 | 0.89 | 0.38 |
| Aquatic Eutrophication, P eq. | -0.02 | -0.02 | 0.01 | 0.04 |
| Grass input to digester per FU, tonne | - | - | 0.586 | 0.407 |
| Energy produced per FU, MJ | - | 860 | 2368 | 1916 |

The highest contributions to the acidification category were caused by the field application and outdoor storage for all scenarios, reflecting essentially the losses of nitrogen as ammonia. For the RCG scenario, additional emissions were caused by the grass cultivation process. For the N and P eutrophication, the main contributions came from field application and the main emission reductions originated from the avoided mineral fertilizers production and application.

## 4. Discussion

The results of this study highlighted the important potential environmental impacts related to the use of land-dependent biomass, when implementing a national renewable energy strategy (in this case based on manure-biogas). In this study, co-digesting dairy cow manure with dedicated RCG resulted in an overall worse environmental performance than not producing biogas at all (i.e. the reference scenario where heat and power are based on fossil fuels and manure is managed conventionally). Similar conclusions are presented in some studies (De Vries et al. 2012; Hamelin et al. 2014), but very often bioenergy studies exclude the land use change impacts. In the Estonian context, in can indeed be debated whether it is reasonable to consider that cultivating RCG would lead to the displacement of barley, given the great availability of uncultivated land. However, if the Estonian stakeholders are really serious about a manure-biogas strategy relying upon the supply of dedicated energy grass, it seems reasonable to assume that the frontier between the availability of arable land (supply) and the demand for it will be reached. This situation is exactly what this LCA endeavored to model, in the aim of preventing eventual misleading decisions.

Residual biomass from nature conservation areas as it is illustrated by the natural grass scenario results of this study should be preferred to cultural grass to achieve the target for increased biogas production reflected in the National Renewable Energy Action Plan of Estonia 2020 (Ministry of Economic Affairs and Communications 2010). Natural grass shows great reduction potential especially in global warming category, but there are technological issues to solve connected to the access to harvesting mainly due to the seasonal flooding (Heinsoo et al. 2010). Managing natural areas has also other benefit not reflected in the LCA results– it would ensure to maintain their high biodiversity value. Grass yield from floodplain meadows in Estonia have been estimated to

113,349 tonne of DM (Heinsoo et al. 2010). If half of the biomass is considered to stay unused currently and would be used for anaerobic digestion in mixture with manure as presented in this study, it would result in a biogas amount of 11.4 x $10^{-6}$ $Nm^3$, which would correspond to a greenhouse gas emissions reduction of approximately 28,000 t $CO_2$ eq.

However, this study did not reflect the practical aspects of using grass for anaerobic digestion. Economic aspects of grass collection, feasibility of harvesting, possible impacts on the digestion process (e.g. corrosion) need further investigation.

It can also be debated whether the alternative use of the natural grass would, on a long-term perspective, be to be left on land. If, for example, this grass has a high protein value and could become competitive enough to be used for animal feed, then a protein feedstuff is displaced. In such case, it is likely that no environmental benefits would be obtained from using the grass as a co-substrate to manure-biogas, as e.g. shown in De Vries et al. (2012) for agro-industrial residues with high protein value.

## 5. Conclusion

Manure-biogas does, for the Estonian context, lead to significant benefits. In this study, manure-biogas strategies were shown to yield overall environmental benefits if based on grass co-substrates from natural areas, or if simply based on mono-digestion. Yet, a strategy relying on the use of dedicated reed canary grass was shown to lead to an overall worse environmental performance than not producing biogas at all. This was essentially due to the impacts of the cultivation process itself, as well as to the cascading effects involved when considering the use that the land would have otherwise had, if not used for dedicated energy grass cultivation.

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