Integration of anaerobic co-digestion into a sustainable livestock farming system

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Introduction

Beef production contributes substantially both to economic activity and global food production. With an increasing population and a current concern towards climate change, attention must be paid to decarbonizing food systems. Livestock farming generates a large amount of animal slurry, which gives rise to emissions of greenhouse gases (GHG), predominantly in the form of methane (CH_4) and nitrous oxide (N_2O). Anaerobic digestion of slurry is an effective approach to generate valuable products such as energy and organic fertilizer, through biomethane and digestate, respectively, while reducing GHG emissions from slurry management. However, due to the low biogas yields of slurry mono-digestion, co-digestion with other organic substrates improves gas yields and process performance. In Ireland, grass silage is the main organic substrate available for AD after slurry. Pasture-based beef systems offer the possibility to provide grass in the form of grass silage to be used for AD. In this regard, there is a need to analyze how anaerobic co-digestion of grass silage and cattle slurry could be sustainably integrated into a beef farm system.

The objective of this study is to augment an existing dairy-beef bioeconomic systems model (the Grange Dairy Beef Systems Model; Kearney *et al*., 2022) with an AD sub-model to compare different farmland area proportions dedicated to growing grass for biomethane in terms of feedstock provision, sustainability and economic performance. A special focus will be given to analyzing the nutrient flows between the livestock-pasture system and the AD plant.

Materials and methods

Grange Dairy Beef System Model (GDBSM)

The model implemented in this study is the GDBSM model which includes biophysical, economic and GHG emissions submodels (Kearney *et al*., 2022). The GDBSM consists of an overall farm simulation model that permits the economic and technical assessment of pasture-based dairy-beef production systems. The model functions on a monthly time step and assumes a single-year static approach. The GHG emissions submodel incorporates a cradle-to-farm gate life cycle assessment (LCA) modelling approach, which allows for a comparison of the economic and GHG emissions performance of alternative farm systems.

Anaerobic digestion incorporation into the GDBSM

Economic and LCA parameters for AD will be included in the whole GDBSM model to evaluate the incorporation of an AD system into the livestock farm. A 40 GWh biogas plant is assumed as the plant model, as it represents the commercial scale in Ireland. Biogas is assumed to be upgraded to biomethane. Four main grass silage (GS) to cattle slurry (CS) ratios will be investigated (Table 1). Emissions and costs of each feedstock mix will be calculated per MJ of biomethane produced to evaluate the optimal combination.

Table 1. Anaerobic digestion parameters for the Grange Dairy Beef System Model [a]

AD plant – 20 GWh (commercial scale)				
GS: CS (VS basis)	0.2: 0.8	0.4: 0.6	0.6: 0.4	0.8:0.2
Silage demand (t FM $year^{-1}$) [b]	6,588	15,000	25,000	40,875
Slurry demand (m^3 $year^{-1}$) [b]	81,688	69,362	51,379	31,502

Notes: [a] Grass silage (GS), cattle slurry (CS), volatile solids (VS), tonnes of fresh matter (t FM).
[b] Himanshu *et al*. (2019).

Farm scenarios

A single livestock farm system will be considered for all the scenarios. A total land area of 50 ha will be assumed (Kearney *et al*., 2022). Consequently, three main scenarios with different land assignments for growing grass for biomethane will be compared: 0% (0 ha, livestock only), 50% (25 ha) and 100% (50 ha, AD only) (Figure 1). Furthermore, red clover and perennial ryegrass (RC/PRG) and multi-species swards (MSS) will be considered as possible swards for AD since Beausang *et al*. (2023) have identified these swards minimize GHG emissions associated with feedstock provision. Emission factors per process will also be taken from Beausang *et al*. (2023).

Results and Discussion

Preliminary findings indicate that slurry greatly influences total emissions due to the high volumes needed to transport into the plant (Table 1). On the other hand, at a farm level, emissions per ha increased as the proportion of grass biomethane increased (Table 2). In this regard, there is a need to integrate both farm and biomethane production emissions to determine the optimal feedstock mix and proportion of feedstock produced on each farm.

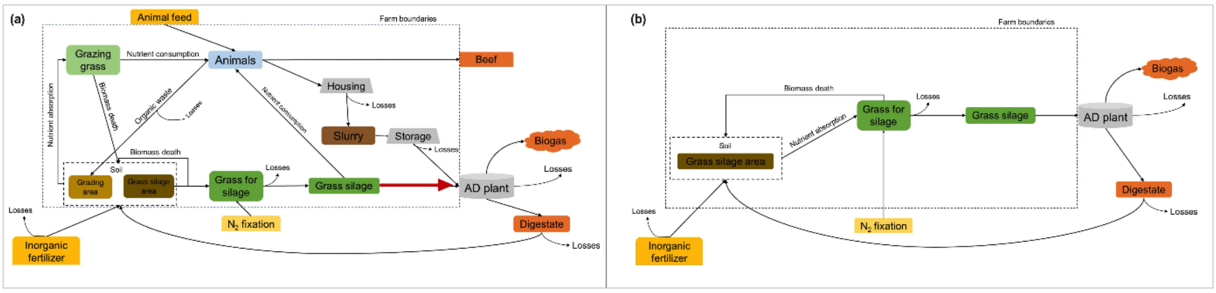

Figure 1. Schematic diagram of the different farm scenarios. (a) Absence of red arrow indicates 100% livestock farming scenario (0% grass biomethane), whereas the presence of red arrow indicates 50% grass biomethane scenario (b) 100% grass biomethane scenario.

Table 2. Emissions per MJ of biomethane produced [a].

Emissions per process	g $CO_{2\,eq}$ MJ^{-1} / % of total emissions							
	0.2: 0.8 [b]		0.4: 0.6 [b]		0.6: 0.4 [b]		0.8: 0.2 [b]	
Silage production for AD [c]	0.80	3%	1.22	5%	1.48	7%	1.65	9%
Silage transport	0.59	2%	0.90	4%	1.08	6%	1.21	7%
Slurry transport	7.33	27%	4.15	19%	2.23	11%	0.93	5%
Biogas generation	5.93	22%	3.85	17%	2.60	13%	1.75	10%
Upgrading	0.62	2%	0.62	3%	0.62	3%	0.62	3%
Methane losses	11.68	43%	11.68	52%	11.68	59%	11.68	65%
Total	27	100%	22	100%	20	100%	18	100%

Notes: [a] Sward corresponds to red clover and perennial ryegrass mixture (RC/PRG).
[b] Corresponds to grass silage: cattle slurry ratio (in volatile solids basis).
[c] Silage produced for anaerobic digestion (AD).

Table 3. Emissions per ha of feedstock mix produced [a].

Emissions per process	g $CO_{2\,eq}$ ha^{-1} $year^{-1}$ / % of total emissions					
	100% Livestock [b]		50 % AD [c]		100% AD [d]	
Silage production for AD [e]	0	0%	183,355.7	12%	183,355.7	10%
Silage transport	0	0%	134,820	9%	134,820	8%
Slurry transport	146,799	32%	73,399	5%	0	0%
Biogas generation	108,346 [f]	24%	152,982.6	10%	126,944	7%
Upgrading	9,862	2%	51,706.6	3%	65,914	4%
Methane losses	187,235	41%	981,679.7	62%	1,251,420	71%
Total	452,242	100%	1,577,944	100%	1,762,454	100%

Note: [a] Sward corresponds to red clover and perennial ryegrass mixture (RC/PRG).
[b, c, d] Corresponds to 0%, 50% and 100% grass biomethane scenarios, respectively.
[e] Silage produced for anaerobic digestion (AD).
[f] Assumed slurry produced is used for anaerobic digestion (AD)

Conclusions

This study will provide practical data regarding the provision of grass silage and cattle slurry to a commercial-scale biogas plant in Ireland, indicating the limitations of slurry availability. Further details, including results of the economic and environmental assessment, will be included in the full paper submission. These outcomes will enhance our understanding of agricultural feedstock provision from a farm system into a full-scale biogas plant and could guide farmers and decision-makers to implement the proper management and policies.

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