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

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Background

- Ruminant livestock methane (CH_4) production accounts for 68% of Irish agricultural greenhouse gas (GHG) emissions.

- Manure storage generates CH_4 and nitrous oxide (N_2O) emissions (12% of Ireland's agricultural emissions).

Anaerobic digestion (AD)

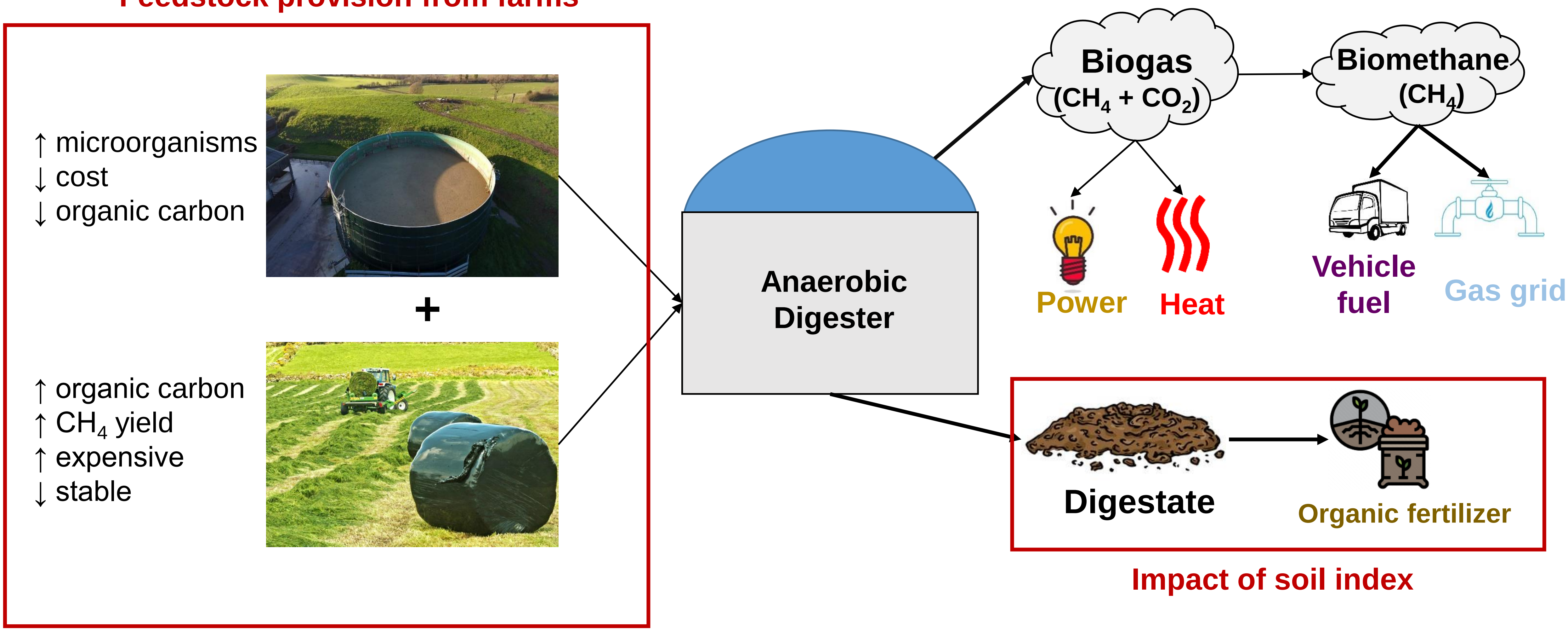
Microorganisms produce biogas and digestate from biodegradable material under anaerobic conditions.

Can reduce GHG emissions from slurry storage, produce a renewable energy source, recycle nutrients through digestate and mitigate odours.

Grassland: can be a major AD feedstock source in Ireland (90% of its agricultural land).

Background

Anaerobic digestion (AD)



Feedstock provision from farms

↑ microorganisms
↓ cost
↓ organic carbon

+

↑ organic carbon
↑ CH_4 yield
↑ expensive
↓ stable

Anaerobic Digester

Biogas ($CH_4 + CO_2$)

Biomethane (CH_4)

Power

Heat

Vehicle fuel

Gas grid

Digestate

Organic fertilizer

Impact of soil index

Objectives of this study

- Assess a farmland area dedicated to both beef production and providing grass silage for AD in terms of:

1. Slurry and AD silage provision into a full-scale AD plant
2. Greenhouse gas (GHG) emissions
3. Nutrient flow analysis between the livestock-pasture system and the AD plant
4. Impact of soil index on both nutrient flow and GHG emissions

- Incorporation of an AD submodel into an existing farm system model (the Grange Dairy Beef Systems Model; Kearney et al., 2022)

Methodology

Study framing – Model parameters

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

AD plant – 40 GWh (commercial scale) [b]	
Silage: slurry (VS basis)	0.8: 0.2
AD silage demand (t FM $year^{-1}$)	43,019
Slurry demand (m^3 $year^{-1}$)	50,042

[a] Incorporation of an AD submodel into an existing farm system model (Kearney et al., 2022).
[b] Himanshu et al. (2019).

Table 2. Model parameters implemented in the farm

Farm parameters	
Farm area (ha)	50
AD silage production (t FM ha^{-1}) [a]	44.3
Slurry production (m^3 ha^{-1}) [b]	9.1

[a] Red clover and perennial ryegrass sward. 25% DM. Clavin et al. (2017).
[b] Stocking rate = 2.4 LU ha^{-1}. 0.15 m^3 slurry produced $head^{-1}$ $week^{-1}$ (DAFM, 2018).

Methodology

Nutrient requirements and soil index

Table 3. Fertilizer requirement from each farm area according to soil index [a]

Soil index	Index 1	Index 2	Index 3	Index 4
Grazing area →	**Supplied by digestate and chemical fertilizers**			
kg N ha^{-1}	30	30	30	30
kg P ha^{-1}	33	23	13	0
kg K ha^{-1}	75	45	15	0
Livestock silage area →	**Supplied by digestate and chemical fertilizers**			
kg N ha^{-1}	225	225	225	225
kg P ha^{-1}	63	53	43	0
kg K ha^{-1}	340	310	280	0
AD silage area →	**Supplied by chemical fertilizers (Legume mix sward)**			
kg N ha^{-1}	0	0	0	0
kg P ha^{-1}	57	47	37	0
kg K ha^{-1}	315	285	255	0

[a] Calculated based on yields from Wall & Plunkett (2020).

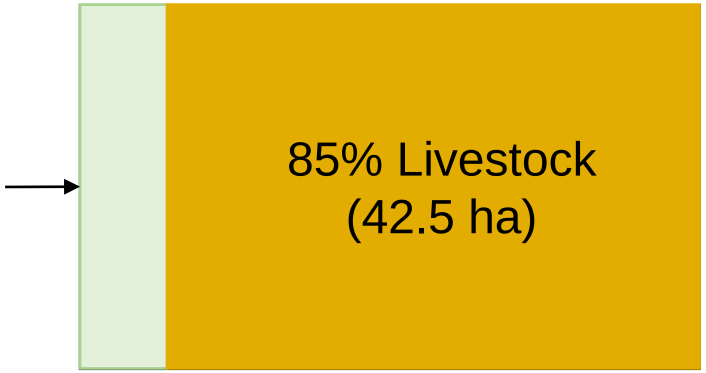
Results

Table 4. Supply chain and farm scale results to supply the annual demand of a 40 GWh biogas plant

AD and farm model results		
Supply chain scale		
Total livestock area (ha)	5,508	→ **85% of total**
Total AD silage area (ha)	970	→ **15% of total**
Net energy produced (MJ)	109,060,080	
Digestate volume (m^3)	83,754	
Nitrogen in digestate (kg N m^{-3})	2.9	
Phosphorus in digestate (kg P m^{-3})	0.6	
Potassium in digestate (kg K m^{-3})	4.1	

Farm scale

Total area = 50 ha



15% AD
(7.5 ha)

85% Livestock
(42.5 ha)

x 130 farms = Total annual demand of slurry and AD silage

Results

Table 5. Digestate application in livestock area and nutrients saved according to farms soil index

Soil index	Soil index 1	Soil index 2	Soil index 3 (Baseline)	Soil index 4
Total digestate applied [a]	48,773 (58%)	41,008 (49%)	60,041 (72%)	0 (0%)
Total N saved [b]	75%	75%	72%	0%
Total P saved [b]	17%	23%	33%	0%
Total K saved [b]	33%	42%	56%	0%
Digestate remaining [a, c]	0 (0%)	0 (0%)	3,604 (4%)	83,754 (100%)

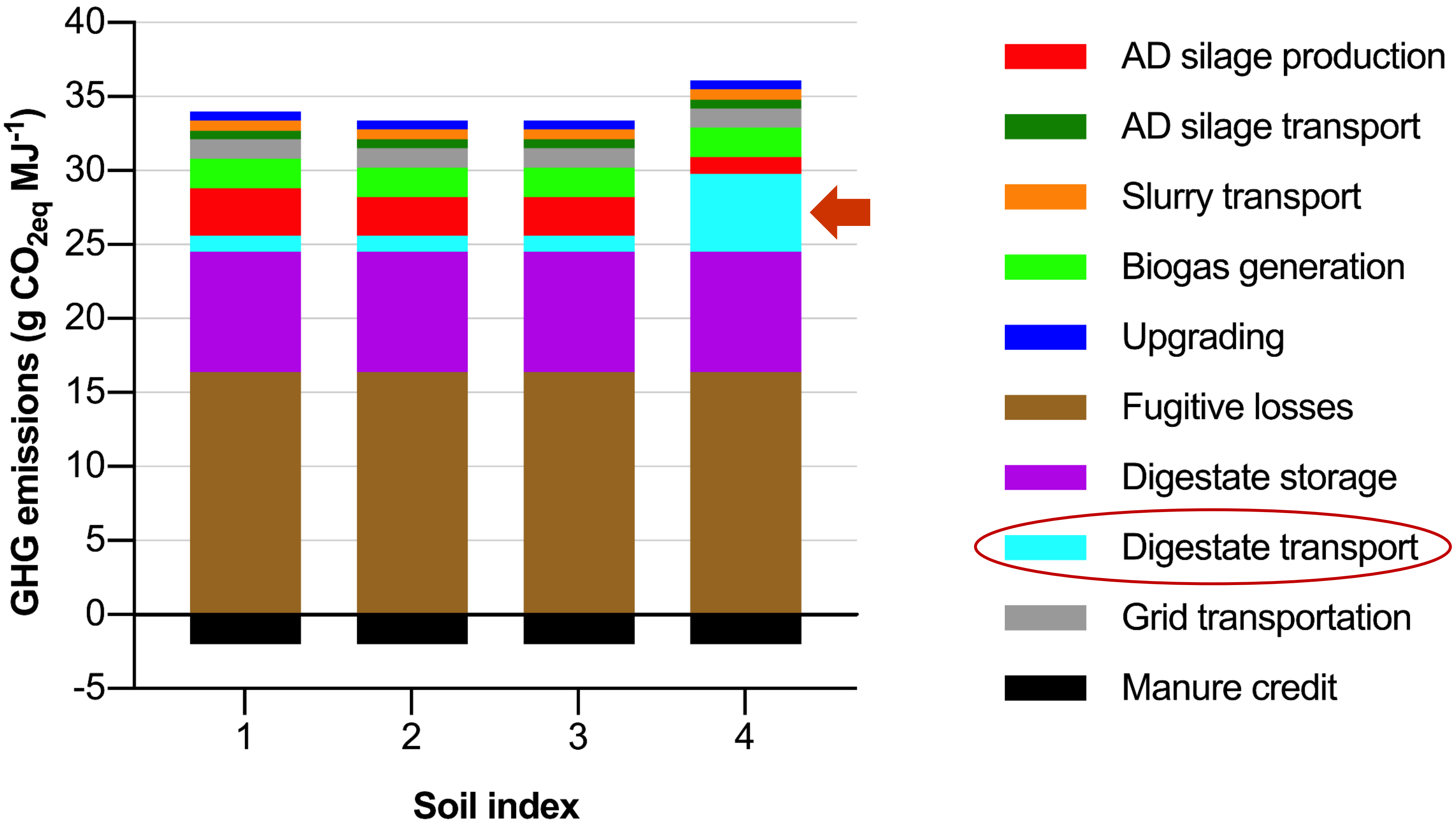
[a] Values in brackets indicate the percentage of total digestate.

[b] Values indicate the percentage of the total N, P and K needed by the total farmland area (AD silage and livestock).

[c] After application in livestock silage and grazing area.

Results

Fig. 2. Greenhouse gas (GHG) emissions per MJ of biomethane produced for the different soil indexes.



Results

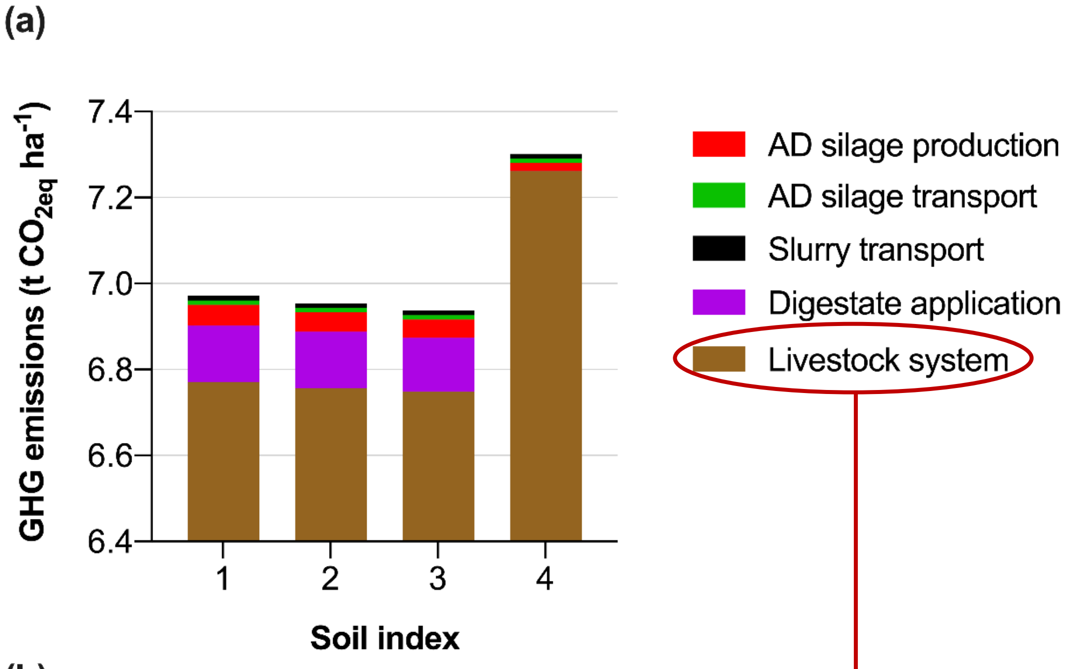


Fig. 3. (a) GHG emissions per process at a farm scale level for the different soil indexes.

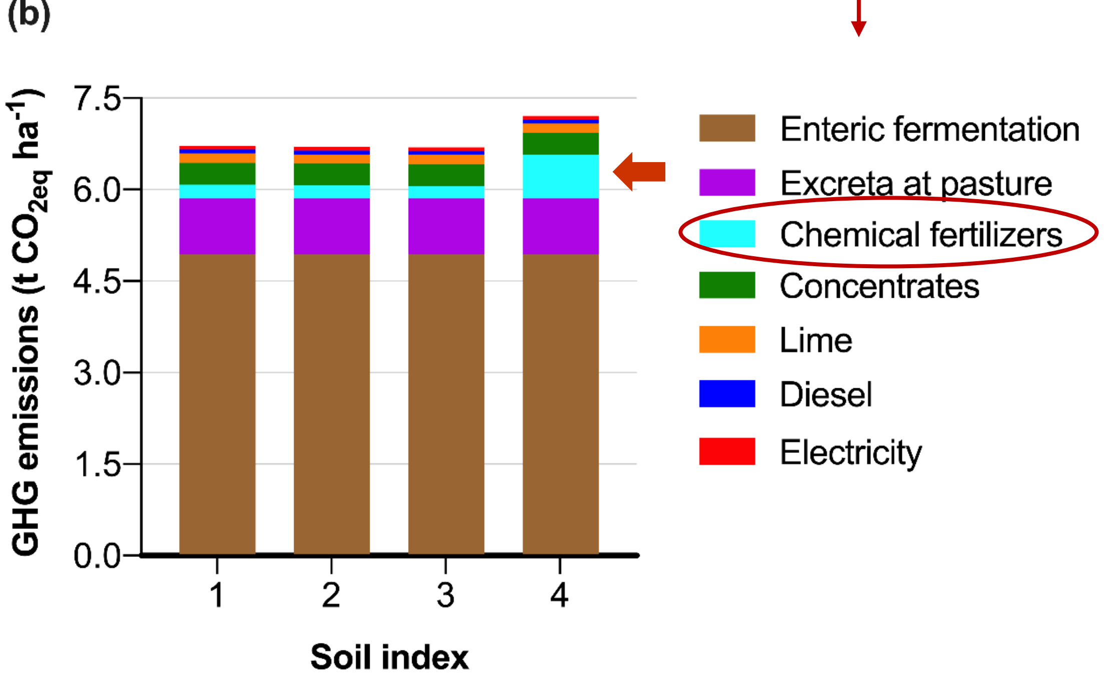
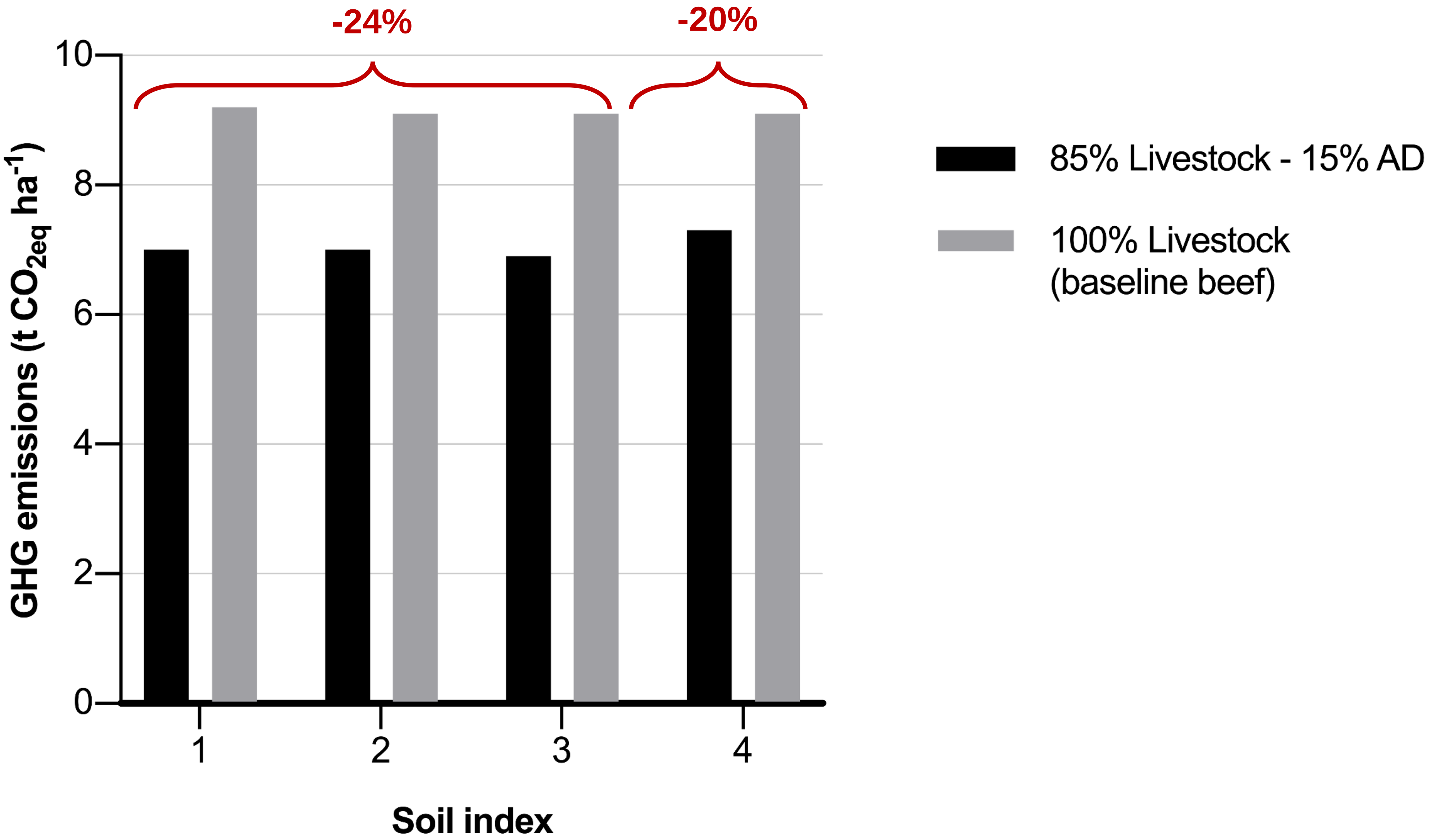


Fig. 3. (b) GHG emissions per process from the livestock system of the farms analyzed in this study.

Results

Fig. 4. Comparison of the farm system during this study (85% Livestock – 15% AD) with a conventional beef farm (100% Livestock).



Conclusions

- **Digestate** application led to **N**, **P** and **K** fertilizer **savings** of up to **72%**, **33%** and **56%** of the total required by the farms.
- **GHG emissions** at a farm level could be **reduced** by up to **24%** if **slurry** is used for the **co-digestion** and **grass silage** is **grown** for the **AD** plant.
- An economic assessment is further needed to determine the costs of producing biomethane from feedstocks.
- These outcomes enhance our understanding of agricultural feedstocks provision from a farm system into a full-scale biogas plant.

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Ollscoil na Gaillimhe
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Thank you for your attention