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An energy and greenhouse gas comparison of centralised biogas production with road haulage of pig slurry, and decentralised biogas production with biogas transportation in a low-pressure pipe network

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HIGHLIGHTS

- GHG emissions arising from biogas production were assessed in a variety of systems.
- Biogas transportation by pipe emitted less GHG than road haulage of slurry.
- Decentralised digestion with biogas pipelines reduced CO_2eq emissions by 19%.
- Reducing biogas network length by 34% increased CO_2eq emissions by 1%.

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ABSTRACT

For bioenergy installations producing heat, the minimum required GHG savings will be 85% from 2026. This is significant and a considerable challenge for biogas systems. This paper investigates use of biogas from pig farms at a nearby milk processing facility, a large energy user. The paper examines minimisation of greenhouse gas (GHG) associated with plant layout and in particular in transporting slurry by road to a large centralised anaerobic digestion (CAD) facility or transporting biogas by low pressure pipe from decentralised anaerobic digestion (DAD) at the pig farms.

In detail four scenarios were assessed: "CAD1" road transport of slurry to a CAD located at the biogas end user (milk processing facility); "CAD2" transport of biogas by pipeline from an optimally located CAD located a distance from the biogas end user; "DAD1" DAD with biogas transportation in a biogas pipe network; and "DAD2" DAD with biogas transportation via a biogas pipe network of minimum length to reduce cost.

Scenario CAD2 (transporting biogas by pipe from optimally located CAD) reduced CO_2eq emissions associated with the road haulage of pig slurry by 51% compared to CAD1 (transporting slurry by road to a CAD at the milk processing facility) and 7% overall. Scenario DAD1 (distributed biogas production in DAD and transportation of the biogas by pipe) was shown to be the best scenario with CO_2eq emissions reduction of 19% compared to Scenario CAD1 (road transport of slurry with CAD at the biogas user). Scenario DAD2 (distributed biogas production in DAD while minimising length of the biogas network) reduced CO_2eq emissions by 18% relative to scenario CAD1, reduced the network length by 34% compared to scenario DAD1 but increasing total CO_2eq emissions by 1% compared to Scenario DAD1.

1. Introduction

1.1. Background and state of the art

The goal of reducing greenhouse gas (GHG) emissions by 20% in the EU is envisaged to be achieved by a reduction in GHG emissions in sectors governed by the Emission Trading Scheme (ETS) of 21% by 2020 [1], and a reduction in emissions from non-ETS sectors of 10% by 2020 relative to 2005 levels [2]. The ETS covers large energy users (such as electricity and heat production with a thermal rating more than 20 MW). The non-ETS sectors include agriculture, residential energy consumption, and transportation. In addition to the GHG emission reduction targets, the EU also aims to ensure a renewable energy share of 20% by 2020 [3] and a minimum share of renewable energy in

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transport of 10% by 2020 [3].

A challenging aspect of meeting the non-ETS emission reduction targets in Ireland is the large role of agriculture in GHG production, accounting for 33.1% of total GHG emissions in 2015 [4], with 63% of agricultural emissions in the form of methane (CH_4) from enteric fermentation and manure management [5]. The Irish Environmental Protection Agency (EPA) predicts that Ireland will not meet the 20% reduction in non-ETS emissions; reductions in non-ETS emissions are estimated to be 4–6% relative to 2005 levels in 2020 [6]. This predicted shortfall is due to growth in emissions from agriculture (4–5% of 2015 levels) and transport (10–12% of 2015 levels) to 2020 [6].

For an energy source to count towards the renewable energy targets it must meet sustainability criteria, which specify the minimum required CO_2eq emissions saving compared to a standardised fossil fuel. These minimum required savings are set to increase from 50% for installations producing bioliquids and biofuels for use in transportation to 70% from 2021 [7]. For installations producing electricity, heating, and cooling, the minimum required GHG savings will be 80% from 2021, increasing to 85% in 2026 [7]. Meeting these emission savings criteria is critical in developing future renewable energy systems that can aid in meeting the GHG reduction targets.

To reduce GHG emissions in the non-ETS sector, reduce emissions in the ETS sector by offsetting fossil fuel use, and increase the share of renewable heat and transport (and the overall share of renewable energy) a promising technology pathway is the production of biogas via anaerobic digestion of livestock manure and slurry. Biogas and anaerobic digestion systems are a readily available commercial technology and are described in the literature [8–10]. The benefits of the anaerobic digestion of animal manures and slurries are taken into consideration in the proposed revision to the Renewable Energy Directive [7], with a proposed bonus CO_2eq saving of -46 gCO_2eq/MJ_{Manure} arising from improved manure management [11].

Prior works have assessed the potential energy resource associated with livestock slurries and manures in Ireland [12–14]. The resource identified was significant and ranged from 10.6 to 16.52 PJ per annum (PJ/a) [12,14] and could meet ca. 6–10% of natural gas demand in 2015/2016 [15]. Limitations on the distance over which livestock slurries can be hauled range from 10 to 30 km [16–17]. In prior work by the authors the distance over which livestock slurries were transported to anaerobic digestion plants, which upgraded biogas to biomethane for injection to the gas network was found to be 10–20 km [18–19]. The authors previously found that a significant portion of the livestock slurry resource was not utilised by anaerobic digestion plants producing biomethane for injection to the natural gas network owing to the resource being located at too far a distance from potential gas grid injection points [18–19].

A draw back associated with the use of animal slurries as a feedstock for anaerobic digestion is the high moisture content of slurry and low biogas yields per tonne of wet material. This increases the energy consumption associated with the road haulage of animal slurries to anaerobic digesters and results in a shorter feasible transportation distance to the biogas plant for slurries compared to feedstocks such as slaughterhouse wastes [20] and other agro-industrial processing wastes [21]. The transportation of feedstock to biogas plants can account for 30% of the total production costs [16] and can also be a limiting factor with respect to the sustainability of biogas production [22]. The use of centralised anaerobic digestion facilities also presents issues in relation to bio-aerosols, odours, and heavy vehicle traffic [23].

One method to alleviate this issue is to transport the slurry to large CAD facility by pipeline as is the case for example, in Maabjerg Biogas plant in Denmark [24]. An alternative solution would be the use of DAD facilities processing slurry close to the point of production, and transporting biogas to a central point using low pressure biogas pipelines. Low pressure biogas pipelines have already been constructed in The Netherlands [25–26], Sweden [27–28], Germany, and Austria [29] for the purpose of transporting biogas to a centralised upgrading facility or to a remote CHP unit.

Different configurations of biogas production and delivery to an end user result in a different total emission of GHG and result in biogas systems with differing GHG emissions savings. Comparison of differing configurations is required when planning a biogas production process to ensure that the biogas produced, or any energy derived therefrom, satisfies the GHG emission saving requirements.

Optimal configurations for feedstock transportation to centralised anaerobic digestion facilities have been proposed in literature [16,30–31], however the impact of these feedstock supply configurations on GHG emissions was not stressed.

The feasibility of using low pressure biogas pipelines to transport biogas to a centralised upgrading facility or biogas user has been assessed in prior literature [26–29]. Results show that distributed biogas production and transportation to a centralised user via low pressure pipelines can be financially viable depending on the specific case in question [32–35]. It was also found that while the transportation of biogas (derived from maize silage) via low pressure pipelines reduced energy consumption associated with biomass transport, overall energy consumption in the biogas production process was not significantly altered [34]. Modelling of different network configurations showed that reducing overall pipeline length reduced cost, but increased energy consumed for gas compression [35]. The use of decentralised biogas production could also mitigate issues relating to air pollution, noise, and traffic as well as increasing the likelihood of public acceptability [23]. Numerous works have assessed the optimal configuration of natural gas pipeline systems either from multiple sources to a single processing plant, or from a single processing plant to multiple users, in order to minimise total cost [36–38]. The impact of natural gas network configuration on GHG emissions was not assessed. No prior works have assessed the impact of biogas production configuration on a GHG basis to compare centralised facilities to decentralised facilities with biogas transportation in pipelines. Prior works comparing centralised and decentralised biogas production with the use of biogas pipelines focused mainly on the cost implications and not on the impact of differing configurations on GHG production.

1.2. Gap in state of the art

The main interest of prior works was the cost implication of differing biogas network configurations; the gap in the state of the art is the impact of network configuration on energy consumption and CO_2eq emissions in the production and delivery of biogas. The aim of this work is to assess the impact of different biogas production configurations on the energy consumption, GHG emissions, and biogas sustainability associated with biogas production from animal slurries in a region. This work is of importance owing to the need to ascertain methods in which the GHG savings associated with biogas production can be maximised to ensure that energy derived from the biogas is classified as being sustainable under the proposed increased GHG savings criteria of 85% from 2026 [7] .

1.3. Objectives

The aim of this work is to assess the impact of different biogas production configurations on the energy consumption and CO_2eq emissions associated with biogas production and delivery to an end user in a region. The implications of each configuration on the achievement of sustainability criteria will be assessed. This work will use a rural townland in the Republic of Ireland as an example, the region contains a large co-operative milk processing facility and several sources of pig slurry which could be used as feedstock for biogas production. A representation of the study region can be seen in Fig. 1. The four scenarios of biogas production configuration assessed in this work are outlined in Table 1.

The methodologies used within this work can be applied in any