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Life cycle environmental impacts of substituting food wastes for traditional anaerobic digestion feedstocks

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ABSTRACT

In this study, life cycle assessment has been used to evaluate life cycle environmental impacts of substituting traditional anaerobic digestion (AD) feedstocks with food wastes. The results have demonstrated the avoided GHG emissions from substituting traditional AD feedstocks with food waste (avoided GHG-eq emissions of 163.33 CO_2-eq). Additionally, the analysis has included environmental benefits of avoided landfilling of food wastes and digestate use as a substitute for synthetic fertilisers. The analysis of the GHG mitigation benefits of resource management/circular economy policies, namely, the mandating of a ban on the landfilling of food wastes, has demonstrated the very substantial GHG emission reduction that can be achieved by these policy options – 2151.04 kg CO_2 eq per MWh relative to UK Grid. In addition to the reduction in GHG emission, the utilization of food waste for AD instead of landfilling can manage the leakage of nutrients to water resources and eliminate eutrophication impacts which occur, typically as the result of field application. The results emphasise the benefits of using life-cycle thinking to underpin policy development and the implications for this are discussed with a particular focus on the analysis of policy development across the climate, renewable energy, resource management and bioeconomy nexus and recommendations made for future research priorities.

Keynotes

- LCA of feedstock substitution for biogas production from anaerobic digestion utilising operational data.
- Environmental advantages of biowaste AD vs landfilling.
- Sensitivity analysis of key parameters:
  (1) Biogas yield of the food waste.
  (2) Utilisation of different rates of synthetic fertilisers and digestate produced in the plant.
  (3) Distances considered in the food waste model.
- LCA study on biogas production with a focus on informing resource management, bioeconomy and renewable energy policies.

1. Introduction

The need to rapidly reduce greenhouse gas (GHG) emissions, increase renewable energy production and improve resource efficiency has seen the introduction of a range of policies at European, National and Regional levels. With the entry into force of the Paris Climate Agreement in October 2016, the EU has reinforced its 20:20:20 targets of 20% cut in GHG emissions (from 1990 levels), 20% of EU energy from renewables and 20% improvement in energy efficiency (Commission, 2010). In addition, the European Commission has adopted the Communication "Towards a circular economy: a zero waste programme for Europe", which include actions to phase out landfilling of bio-waste by 2015 and show how industrial symbiosis can move us towards zero-waste (Commission, 2014). In Northern Ireland, policies on renewable energy, waste and resource management and climate are driving the development of anaerobic digestion (AD).

1.1. Legislative and policy drivers for AD in Northern Ireland

1.1.1. Renewable energy policy

The Northern Ireland Renewables Obligation (NIRO) is the main policy instrument for incentivising renewable electricity generation in Northern Ireland. When a business generates renewable energy, they are issued with Renewables Obligation Certificates (ROCs) based on the technology they are using and the amount

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of energy they produce (Economy, 2016). This is summarised in Table 1.

1.1.2. Resource management and circular economy policy

While the key driver to date in the growth of the AD sector has been the policy support for renewable energy, in Northern Ireland (NI) a further driver exists in the form of waste and resource management policy. In 2013 the NI Assembly introduced Food Waste Regulations, which places a duty on food businesses (e.g. businesses involved in food preparation or the sale of food) to present food waste for separate collection from April 2016, bans the landfilling of source separated food wastes and additionally places an obligation on councils to provide receptacles for the separate collection of food waste from households by 1 April 2017 (Ireland, 2015). This has created a strong driver for projects that support the development of circular/bioeconomy policies and research. One example of this, in which the Northern Ireland region was a partner, is the ReNEW project which has demonstrated that more than 13,000 jobs could be created if NI moved to a circular economy, identifying particular opportunities in food and drink, biorefining and the bioeconomy (Mitchell and Doherty, 2015).

1.1.3. Climate change policy

The NI Executive has published a GHG Reduction Action Plan (Executive, 2011) which has identified actions to reduce GHG emissions. The agri-food sector in NI accounts for a higher proportion of the economy than the UK average, as it is the region's largest employer and accounts for a much higher proportion of the regions total GHG emissions (29% as opposed to 9% in the rest of the UK) (Committee on Climate Change, 2011). In addition, the sector has set ambitious growth targets to 2020 (grow sales by 60% to £7bn and sales outside NI by 75%), which will result in a commensurate growth in wastes and GHG's from this sector. The Agri-food sectors Strategic Vision for 2020 includes both the production of low carbon food and the promotion of renewable energy (Board, 2013)

In this context, the production of biogas from AD is receiving increasing attention as a contributor to renewable energy policy and renewable energy (Curry and Pillay, 2012), waste and resource management (Davidsson et al., 2007) and mitigating emissions of GHG's from agriculture and food production (Kaparaju and Rintala, 2011; Bacenetti et al., 2015, 2016).

AD is an established technology in which organic materials are degraded and stabilised under an oxygen free environment. It is aided by microbial organisms to produce biogas, a mixture of methane and carbon dioxide at a ratio of 50–75% and 50–25% respectively, along with trace gases (AEBIOM, 2010). Digestate is also produced in the AD and it is where the most of nutrients remain after the process thus being composed of a mixture of microbial biomass from the digester with multiple applications (Chen et al., 2008).

Table 1
Renewables Obligation Northern Ireland – current banding levels (2016).

Technology		Banding Level
Solar PV	<50 kW	4 ROCs
	50 kW–5 MW	2 ROCs
Wind	<250 kW	4 ROCs
	250 kW–5 MW	1 ROC
Hydro	<20 kW	4 ROCs
	20 kW–250 kW	3 ROCs
	250 kW–1 MW	2 ROCs
	1 MW–5 MW	1 ROC
Biomass	<50 kW	2 ROCs
	50 kW–5 MW	1.5 ROCs
Anaerobic Digestion	<50 kW	4 ROCs
	50 kW–500 kW	4 ROCs
	500 kW–5 MW	3 ROCs

Reproduced from http://greenbusinesswatch.co.uk/feed-in-tariff-in-northern-ireland-niro.

The most common utilisation option for the biogas is its combustion in a biogas engine to produce electricity and/or heat (Holm-Nielsen et al., 2009). However, the biogas can also be upgraded for other utilisation options such as biomethane or biodiesel as part of a wider bioenergy system (Murphy et al., 2014), or utilised for producing energy and chemicals within the biorefinery concept (Cherubini, 2010).

However, although AD to biogas has a demonstrated potential to reduce GHG emissions by substituting for fossil fuels, the GHG emission reductions achieved can vary greatly depending on a range of factors such as regional land-use management practises (Dressler et al., 2012), feedstock/s and biogas yields (Alkanok et al., 2014; Nizami et al., 2012; Pitk et al., 2013), plant management and efficiency (pre and post-treatment, methane slip (Carrere et al., 2016; Kondusamy and Kalamdhad, 2014), and biogas and digestate end uses (Whiting and Azapagic, 2014; Evangelisti et al., 2014; Vázquez-Rowe et al., 2015). On the other hand, other methods of valorisation for manure, like for instance superheated steam drying, have shown lower GHG emissions than AD (Hanifzadeh et al., 2017) which also depends on the local conditions and management possibilities.

This emphasises the need for policies which seek to promote renewable sources of energy, particularly from biogas to be underpinned by evidence based on life-cycle thinking and analysis, to ensure the assumptions underlying the policies are robust (Fiorentino et al., 2015).

1.2. Earlier studies

There have been a range of studies carried out on the life-cycle impacts of biogas production and use systems. Examples include comparison of the environmental impacts of AD with energy and organic fertiliser production with incineration, with energy production and landfill with electricity production (Evangelisti et al., 2014; Astrup et al., 2015), using life cycle assessment to compare the relative greenhouse gas reduction merits of different biomass/bioenergy systems (Thornley et al., 2015), the role of AD in mitigating GHG emissions from the agri-food sector in Italy (Bacenetti et al., 2015), to assess the environmental performance of two different crop systems in terms of biomethane potential production (Bacenetti et al., 2014), to compare the environmental performance of two alternative bioenergy systems (González-García et al., 2012) and the impacts of regional farming practices on biogas production from maize and the conversion of biogas into electricity (Dressler et al., 2012).

1.3. Aims of the study

The overall aim of this study was to evaluate the life cycle environmental impacts of substituting food wastes for traditional anaerobic digestion feedstocks (traditional – maize and grass silage and cattle slurry; and alternative – food wastes). The following underlying objectives underpinned this aim:

- To carry out an integrated analysis of implications for policy development across the climate, renewable energy, resource management and bioeconomy nexus; and
- To gain an understanding of the usefulness of life cycle analysis in evaluating bioenergy and bioeconomy systems and make recommendations for future research priorities.

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