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Quantification and location of a renewable gas industry based on digestion of wastes in Ireland

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HIGHLIGHTS

- A spatial assessment of the biomethane resource in Ireland was undertaken.
- Biomethane from residues can supply 26.5% of industrial gas use in Ireland.
- Biomethane from residues can supply 7% of energy in transport in Ireland.
- The resource of biomethane from cattle slurry is 76% of the total resource.
- The resource is equivalent to woody energy crops from 17% of arable land in Ireland.

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ABSTRACT

Six EU gas grids have a target of 100% substitution of natural gas with renewable gas by 2050. This industry will start with biogas upgraded to biomethane. The biomethane resource and location of waste substrates (such as agricultural slurries, slaughterhouse waste, milk processing waste, and source separated household organic waste) were determined using the most recent spatially explicit data for Ireland. The total biomethane resource was estimated equivalent to: 7.6% of natural gas usage, 7% of energy in transport; 52% of the fuel usage in heavy goods vehicles in 2013. In terms of natural gas usage it corresponded to 26.5% of industrial gas use, and 52% of residential natural gas use. The resource as a source of thermal energy is equivalent to wood chips from 16.5% of arable land under short rotation coppice willow. Thematic maps illustrating the location of each resource were developed to highlight regions of significant biomethane production potential. The regions with the greatest resource of cattle slurry are located in the south and east of the country; sheep manure resources are concentrated on the western seaboard, while the largest biomethane resource from household organic waste is found in urban and city areas (63% of household organic waste biomethane resource).

1. Introduction

1.1. Energy consumption

Total primary energy requirement (TPER) is the total amount of energy used in a given year including energy used in the conversion of primary energy sources such as oil and gas into forms used by end customers, such as electricity. In 2013, the TPER for the Ireland (with a population of 4.4 million) was 558 PJ with oil and natural gas the main contributors (47% and 29%, respectively) [1]. Transport accounted for the largest share of TPER at 181 PJ, 32.7% of TPER [1]. Total final consumption (TFC) is defined as TPER minus losses in the conversion of primary energy sources (oil, gas and coal) into useable energy sources. In 2013, TFC amounted to 453 PJ with the largest shares attributed to oil (257 PJ), electricity (87 PJ), and natural gas (68 PJ) [1]. In 2013 transportation TFC was 179 PJ, the largest share of TFC (39.5%), 97.5% sourced from imported oil [1].

1.2. Renewable energy in transport

EU Directive 2008/28/EC mandates that 20% of the energy consumed by the EU in 2020 is sourced from renewables. In Ireland that target is 16% of the gross final consumption of energy by

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2020. Additionally 10% of the energy used in transportation must be renewable by 2020. Renewable energy supply in transport (RES-T) can be achieved through the use of biofuels, or renewable electricity used in electric vehicles (EVs). Limits have been set on the contribution of first generation biofuels (cereals, starch rich crops, sugar and oil crops) to 7% of TFC in transport by 2020 [2]. To promote the use of second generation biofuels, non-food related feedstock are allocated double their energy content towards RES-T calculation for 2020.

The Biofuels Obligation Scheme (BOS) requires that 6 out of every 100 L of road transport fuel is a biofuel. In 2014, a total of 167×10^6 L of liquid biofuel was used, of which only 25.3×10^6 L (15%) was sourced indigenously (all of which was biodiesel) [3]. As of 2010, two certificates are issued for each litre of transport biofuel produced from: biodegradable waste, residues, non-food cellulosic material, lingo-cellulosic material, or algae. A cubic metre of gaseous biofuel with a net calorific value in excess of 35 MJ/Nm^3 is eligible for 3 certificates [4]. As these certificates can be traded between parties a market for biomethane use as fuel in transport now exists.

1.3. Natural gas and renewable gas

Ireland has a substantial natural gas infrastructure. The natural gas network in the Ireland is 13,685 km in length and covers over 60% of the country [5]. The total gas system demand was 163 PJ from October 2013 to October 2014, comprising of 91 PJ by power generation, 47 PJ by industrial and commercial users, and 24 PJ by residential customers [6]. The use of natural gas as a vehicle fuel in Ireland is limited, however Gas Networks Ireland (GNI), the operator of the gas network, aim to provide 5% of the energy used in commercial transport, and 10% of the energy used in buses from compressed natural gas (CNG) or biomethane by 2024 [2]. This totals 2.2 PJ of gaseous fuel in transport by 2024 [5]. The total consumption of energy by heavy goods vehicles (HGVs) amounted to approximately 24 PJ in 2013 [7].

EU member states are required to provide CNG refuelling stations to enable public access to CNG and biomethane for use in transport, with a recommended average distance between refuelling points of 150 km [8]. A minimum of 5, refuelling stations are required in Ireland. CNG as a transport fuel has a low excise duty (0.11 €/$L_{\text{Diesel Equivalent}}$) as compared to that of petrol (0.59 €/L) and diesel (0.48 €/L) [9].

Within Europe, 7 gas transmission operators have already signed a joint declaration to supply 100% CO_2 neutral gas by 2050 [10]. GNI have announced a target of 20% renewable gas in the Irish gas network by 2030 with an interim goal of 21.5 PJ (12%) by 2024 [5]. A key route to achieving this is the utilisation of biomethane produced through anaerobic digestion (AD) of biodegradable materials including wastes, energy crops, and algae. Renewable gas can also be generated in the production of synthetic natural gas via thermal gasification of biomass, and through the conversion of excess renewable electricity from intermittent sources (wind turbines) to methane in power to gas systems.

1.4. AD for the production of renewable gas

Renewable gas can be sourced from biogas. Following removal of carbon dioxide and other impurities, biomethane (>97% methane) can be compressed, injected into gas cylinders or the natural gas network. Renewable methane from biodegradable waste streams can be utilised in heat production, electricity generation, and transportation. The biodegradable materials assessed in this work are; cattle slurry, sheep manure, chicken manure, pig slurry, slaughterhouse waste, milk processing waste, and source separated household organic waste. These waste streams are thought of as the "low hanging fruit", feedstock with no major sources of competition, and which are double counted in the contribution to RES-T.

1.5. Overview of biomethane resource assessments

The overall national resource of biomethane from various feedstocks has been assessed for a number of countries worldwide [11–18]. These works typically use high level national figures for livestock population and waste generation and result in an overall national or high level regional resource. Data on the biomethane resource of a country on a refined regional level, detailed enough to inform the development of a biomethane industry, is limited.

The biomethane potential of three regions in southern Finland was assessed using GIS developed by Hohn et al. [19], quantities of wastes generated were determined from a combination of reports, studies, and interviews. The overall national resource was not assessed. A similar GIS based methodology to estimate the biogas resource of two regions in Italy was carried out by Chinese et al. [20]. This study assessed the resource of livestock manure and maize silage with data on livestock numbers and land use areas obtained from census results in the two regions. Again, the overall national resource was not determined. The regional potential biomethane resource of grass silage and cattle slurry in Ireland was assessed using a GIS by Smyth et al. [21] using information on land use, crop yields, livestock populations, and the presence of natural gas infrastructure in sub-regions. The work did not assess the biomethane resource on a finer geographical scale than these sub-regions. Within Ireland, significant work has been carried out assessing the potential biomethane resource of numerous waste streams, these are summarised below.

1.6. Prior assessments of the biomethane potential of wastes in Ireland

1.6.1. Cattle slurry

Use of cattle slurry as a feedstock for biogas production is permitted following treatment at 70 °C for 60 min, or 60 °C for 48 h, twice, if quantities in excess of 5000 t_{wwt}/a are used [22]. Singh et al. estimated that 30 Mt_{wwt} of cattle slurry was produced in 2010 in Ireland, with an energy resource of 13.7 PJ [15]. Wall et al. calculated the production of slurry from dairy cows to be 7 Mt_{wwt} [23]. Using a dry solids (DS) content of 87.5 g/kg_{wwt}, a volatile solids content (VS) of 66.9 g/kg_{wwt} and a methane yield of 239 LCH_4/kgVS for dairy slurry [23], 7 Mt_{wwt} of dairy slurry equates to 4.06 PJ of energy (35.9 MJ/Nm^3CH_4). The resource of cattle slurry available out to 2020 was estimated by Clancy et al. as 0.356 PJ in 2011 [24] assuming only 10% of dairy cow slurry and 5% of "non-dairy cattle" slurry could be used.

1.6.2. Sheep manure, pig slurry and chicken manure

Sheep manure and pig slurry can be used with prior treatment conditions as specified for cattle slurry. Singh et al. estimated the quantity of sheep manure available in 2010 to be 170,000 t_{wwt}, with a potential energy resource of 0.19 PJ [15].

Singh et al. estimated a pig slurry resource of 2.32 Mt_{wwt} in 2010, with an associated energy potential of 1.06 PJ [15]. Xie et al. estimated a total annual pig slurry generation of 3.2 Mt_{wwt} in 2011. Applying a VS content of 9.3%$_{wwt}$, and a methane yield of 280 LCH_4/kgVS [25] yields an energy resource of 3.15 PJ (37.78 MJ/Nm^3CH_4) assuming that all pig slurry can be utilised. Clancy et al. estimated an energy potential of 1.64 PJ in 2010, assuming 75% of available pig slurry was accessible [24]. The use of pig slurry in large AD facilities was modelled by Murphy et al. in which 73,000 t_{wwt}/a of pig slurry was co-digested with 14,000 t_{wwt}/a of the organic fraction of municipal solid waste (OFSMW) for the production of 1.1–1.5 Mm^3CH_4/a (55.5 GJ/a) [26].