The Role of Incentivising Biomethane in Ireland Using Anaerobic Digestion

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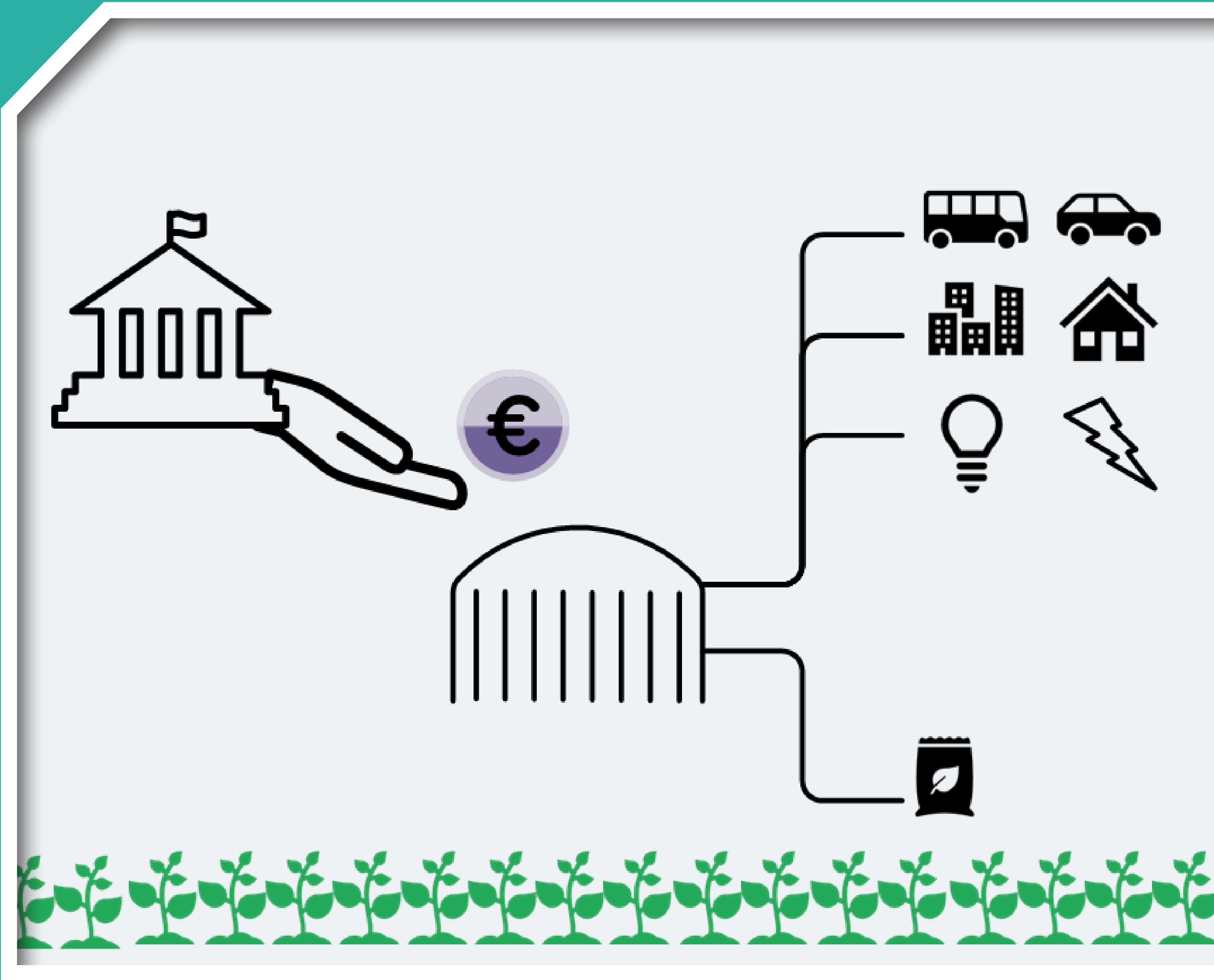
Authors: Karthik Rajendran, Brian Ó Gallachóir and Jerry D. Murphy



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EPA RESEARCH PROGRAMME 2014–2020

The Role of Incentivising Biomethane in Ireland Using Anaerobic Digestion

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Prepared for the Environmental Protection Agency

by

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DISCLAIMER

The EPA Research Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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Executive Summary

Ireland’s renewable energy targets for 2020 include 16% renewable energy; this can be broken down to 40% renewable electricity, 12% renewable heat and 10% renewable transport. Owing to the commercialisation of wind energy, the progression of carbon-free electricity generation is under way; however, this is not the case for heat and transport. Typically, electricity comprises only about 20% of final energy demand, with heat and transport making up approximately 40% each.

Biomethane (biogas upgraded through removal of CO_2) may be used as a direct substitute for natural gas and can be used to decarbonise electricity and more critically, heat and transport. The anaerobic digestion (AD) industry is not mature in Ireland and for this industry to prosper, as in other European Union (EU) Member States, national policy and financial incentives are required. This report analyses how biomethane in Ireland could be incentivised through assessment of technology, economics and policies.

The report describes a techno-economic assessment of biomethane feedstocks from urban, rural and coastal settings. Additionally, three upgrading technologies were investigated, namely commercialised water scrubbing, power-to-gas systems (advanced systems employing hydrogen to capture CO_2) and microalgae cultivation (advanced system utilising CO_2 in biogas). In total, nine scenarios were investigated (a combination of the three feedstock groups and the three upgrading technologies). The levelised cost of energy and the incentive required to allow financial sustainability were assessed.

For context, relevant policy and financial incentives associated with the implementation of successful renewable energy systems across the EU are described and assessed, with comparisons made on the basis of the cost to avoid a tCO_2.

The assessment showed that water scrubbing was the cheapest upgrading method. The optimum scenario was the combination of urban-based feedstock (food waste) with water scrubbing upgrading, costing €87/MWh, equivalent to €0.87/L of diesel. The incentive required was about €0.13/m^3 (or per L of diesel equivalent); however, if a power-to-gas system was used, an incentive of €0.40/m^3 was required. This was expected as food waste attracts a gate fee. Rural-based plants (using slurries and grasses) are expected to provide the majority of the resource; however, for this to become a reality, incentives in the range from €0.86/m^3 to €1.03/m^3 are required.

Various successful renewable energy policies were analysed across the EU, including photovoltaics and

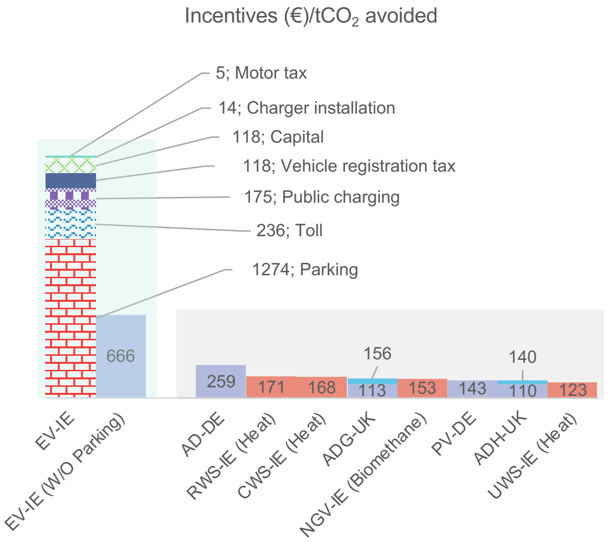

Figure ES.1. Incentives €/tCO_2 avoided for a range of renewable energy systems. The green bars show the incentives needed in an Irish context. The blue bars highlight the compared renewable technologies. The orange bars represent the upper-bound values of incentives provided. AD-DE, AD in Germany; ADG-UK, gas to grid in the UK; ADH-UK, biogas to heat in the UK; EV-IE, EVs in Ireland with parking; EV-IE W/O Parking, EVs in Ireland without parking; PV-DE, PVs in Germany. Reprinted from *Journal of Cleaner Production*, Vol. 219, Rajendran, K., O’Gallachoir, B. and Murphy, J.D., The combined role of policy and incentives in promoting cost efficient decarbonisation of energy: a case study for biomethane, pp. 278–290. Copyright 2019, with permission from Elsevier. https://www.sciencedirect.com/journal/renewable-energy

AD industries in Germany, gas-to-grid and biogas-to-heat systems in the UK, and electric vehicles (EVs) in Norway and Ireland. The schemes were compared with an incentive applied (or required) per tCO_2 avoided. For Ireland, this study predicts that biomethane needs a financial subsidy of less than €180/tCO_2 avoided, although most successful EU systems offer incentivisation levels of less than €260/tCO_2 avoided.

In terms of incentives per tCO_2 avoided (Figure ES.1) EVs stand out. When grants, incentives and avoided parking costs are included, EVs can receive a 16-fold-higher incentive than biomethane, based on tCO_2 emissions avoided. The rationale for this high incentive and supporting policy is based on the requirement to initiate a new infrastructure, which would not otherwise happen without the intervention of a government incentivising decarbonised transport and clean air.

Electric vehicles reduce the energy used per kilometre travelled; they tend to travel shorter distances and will predominately be used as a replacement for internal combustion engine-powered cars. As such, their impact on renewable energy targets is far lower than, for example, mandation of percentages of biofuels in liquid transport fuel. EVs are expensive and it may be argued that incentives for EVs transfer wealth to the richer strata of society. If heavy commercial vehicles (haulage and intercity buses) were incentivised for biomethane use the impact on renewable energy transport would be greater, with transport decarbonised for a large section of society. Biomethane as a transport fuel requires a very significant change in infrastructure, including the provision of compressed natural gas service stations and natural gas vehicles. Initially (as for other successful renewable energy systems), large incentives would be required to encourage the industry, but these subsidies can be reduced over time. Biomethane as a transport fuel offers similar rewards to EVs, namely decarbonised transport and clean air, as well as energy security, renewable energy, indigenous jobs and support for the greening of agriculture.

Recommendations

Recommendation 1: biomethane should be used for the thermal and transport sectors.

Recommendation 2: biomethane requires incentivisation levels similar to those for the EV industry.

1 Introduction

Primary energy consumption in Ireland was projected for 2017 to be 13 Mtoe (million tonnes of oil equivalent); oil is the major source, providing around 46% of energy (Dineen *et al*., 2016; Howley and Holland, 2016). Renewable energy constitutes 8% of this energy consumption, of which 45% comes from wind power and the remainder is derived from biomass, hydro, biogas and geothermal sources (Dineen *et al*., 2016; Howley and Holland, 2016).

By 2020, 16% of final energy production in Ireland needs to come from renewable sources, of which 10% should be energy related to transport (Scheer *et al*., 2016). There is a significant gap between present energy consumption and the looming target. By 2014, slightly more than half of the 10% renewable energy target in transport had been achieved, using 167 million litres of primarily imported biofuel. The transport sector is expected to consume *c*.3700 ktoe (kiloton of oil equivalent) by 2020.

For final energy production, the national targets for renewable electricity and renewable heat are 40% and 12%, respectively (Dineen *et al*., 2016; Scheer *et al*., 2016). Meeting the target for renewable electricity is an achievable goal, but the ability to satisfy the target for renewable heat by 2020 is uncertain (SEAI, 2017a).

Biogas from anaerobic digestion (AD) is a flexible vector for the supply of both renewable heat and renewable transport. In AD systems, organics, such as food waste and cattle slurry, are converted to biogas in the absence of oxygen. Biogas consists of methane, CO_2 and other trace gases, of which methane alone has an energy content between 50 and 55 MJ/kg (Rajendran *et al*., 2013; Sawatdeenarunat *et al*., 2016). Applications of biomethane, when upgraded by removing CO_2 through absorption or adsorption, include heat, electricity and transport fuel. According to the Sustainable Energy Authority of Ireland (SEAI), Ireland has a biogas potential of 0.95 Mtoe, but less than 2% of this is currently utilised (SEAI, 2016). Previous studies reported extensive biogas potential in Ireland from various resources, such as grass silage, slurry, food waste, seaweed and organic fractions of municipal solid waste (OFMSW) (Browne and Murphy, 2013; Browne *et al*., 2014; O'Shea *et al*., 2016, 2017); however, there is a lack of commercial operating plants in place because of uncertainties about the financial viability of such systems.

Most renewable energy technologies must compete with established fossil fuel sources and typically require government subsidies for financial sustainability. A common question raised when examining renewable transport fuel is whether or not biomethane can compete with diesel. However, this question is somewhat moot because of "Dieselgate" – whereby air quality associated with diesel vehicles was shown to be far worse than originally considered – and also because of climate change. Numerous cities (including Athens, Cologne, Mexico City and Paris) have proposed bans on diesel-powered vehicles within the next 10 years. Ireland plans to ban the sale of petrol and diesel cars by 2030. Currently, the government has suggested that no new purchases of diesel buses by Bus Éireann will be allowed after 2019.

Irish policy promotes electric vehicles (EVs) as a replacement for petrol and diesel cars. This drive includes financial subsidies to the user, such as charging point grants and reduced Vehicle Registration Tax, as well as financial incentives in the form of free tolls on motorways, free battery charging and free parking in cities. Although these policies appear generous, there has been limited success in terms of EVs purchased and CO_2 emissions avoided. EVs tend to underperform in renewable energy supply accounting because of their efficiency as a mode of transport; they use less energy per kilometre travelled and as such play a significant role in energy reduction.

It is also informative to compare and assess this EV policy against successful renewable energy policies across the European Union (EU). Incentivisation is usually necessary to kick-start an industry but the incentivisation mechanism and the level of incentivisation needs to be carefully selected. For example, could similar policies be implemented for biomethane as a transport fuel in natural gas vehicles (NGVs), particularly for heavy commercial vehicles for haulage and for buses?

Effective policies of this nature would allow the fledgling biomethane industry to mature and compete and would, ultimately, reduce costs. A pertinent example is the photovoltaic (PV) industry in Germany. Between 2010 and 2017, the cost of PV systems decreased by 70%, in part because of efficient incentivisation policies.

1.1 Aims and Objectives

This study uses technical, economic and environmental analyses to fully understand incentivisation requirements for successful implementation of a biomethane industry in Ireland. The analysis generates a production cost, a levelised cost of energy (LCOE) and the level of incentivisation needed for biomethane systems to prosper.

Based on these computed incentives, different successful renewable energy policies and associated incentivisation levels across the EU were assessed. In addition, different incentivisation mechanisms were considered, including carbon tax, the excess cost of renewable energy over fossil energy to avoid a tCO_2 and the level of incentives based on tCO_2 avoided.

The main aims of this study were as follows:

1. estimate the biomethane production cost using feedstocks from urban, rural and coastal environments;
2. calculate the amount of financial incentives required to reach a break-even point;
3. assess various renewable energy policies in the EU and compare them with suggested biomethane incentives.

2 What Level of Incentives Are Needed for Biomethane Commercialisation?

2.1 Introduction and Objectives

To estimate both the production cost and the level of incentives needed for biomethane commercialisation, it is essential to understand the investment cost and the operating cost of a biogas plant. A process model was developed using SuperPro Designer program (V10). The output of the model is synthesised in this report.

Urban, rural and coastal feedstocks were chosen for scenario modelling. Urban feedstocks were predominantly food wastes.

The average food waste production in Ireland is 180 kg/person/annum. It is assumed that segregated food waste will be employed such that after processing (including pasteurisation) the digestate may be applied on agricultural land. This circular economy ensures that nutrients used by crops for human consumption that end up as food waste can return to agriculture. The city of Dublin will be a suitable source of this feedstock because of its high population density and its potential to provide feedstock to a number of large-scale digesters, thereby taking advantage of economies of scale.

Rural scenarios included slurries and grass silage that may be surplus to feed requirements. It is envisaged that rural digesters would allow for co-operatives of farmers working together to avail of economies of scale. Ideally, these would be situated near an above-ground installation on the gas grid to allow for gas grid injection.

Coastal scenarios included food waste from restaurants, slurries and grass silage from agricultural land, and seaweed from coastal communities. These scenarios were derived from numerous coastal towns, such as Kinsale and Dingle, incorporating many restaurants, agricultural land and the facility to source cast seaweeds.

The produced biogas was modelled as being upgraded using three technologies. One system, water scrubbing, is readily available and is in use in hundreds of biomethane systems worldwide. The second system, power-to-gas, is available across Europe in several demonstration-scale plants and as such is a potential technology for the next decade. The third system, microalgae upgrading, is seen as part of a future biorefining process producing material such as microalgae, a product with more value than biogas. The combination of the three feedstocks with the three upgrading methods gives nine scenarios.

The objectives of this chapter are as follows:

1. develop simulations of renewable biomethane using feedstocks from urban, rural and coastal sources using “standard” AD plants, which are each supplemented by three different forms of upgrading: water scrubbing, microalgae upgrading and power-to-gas;
2. calculate the LCOE of biomethane over the lifetime of the plant for each of the nine scenarios;
3. assess the level of incentives required to stimulate the implementation of the scenarios investigated.

2.2 Methods

Three different feedstock systems were modelled from urban, rural and coastal areas. The upgrading methods were chosen based on the maturity of the technology. Water scrubbing is a widely applied upgrading mechanism in operation across the globe, whereas the power-to-gas system is in a proof-of-concept stage with a number of demonstration projects in place. Microalgae upgrading is still under laboratory assessment and has a low technology readiness level (TRL) (Figure 2.1). In the figures and tables throughout the report the scenarios are labelled as follows: “U” for urban feedstock, “R” for rural feedstock and “C” for coastal feedstock. Upgrading methods have the following acronyms: “WS” for water scrubbing, “P2G” for power-to-gas systems and “MA” for microalgae upgrading.

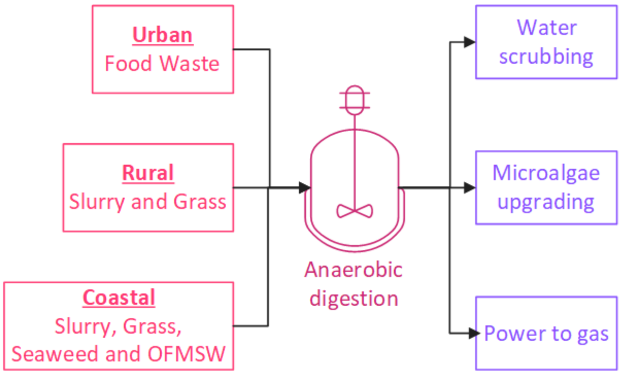

Figure 2.1. Schematics of the nine scenarios used in this study. Reprinted from *Renewable Energy,* Vol. 133, Rajendran, K., Browne, J.D. and Murphy, J.D., What is the level of incentivisation required for biomethane upgrading technologies with carbon capture and reuse?, pp. 951–963. Copyright 2019, with permission from Elsevier. https://www.sciencedirect.com/journal/renewable-energy

2.2.1 Substrate characteristics and methane yield

Urban

The modelled urban plant was envisaged to have a processing capacity of 100,000 t/annum of feedstock to avail of economies of scale in Dublin. Assuming 180 kg of food waste per person per year this equates to food waste from approximately 550,000 people. Table 2.1 shows the characteristics of the feedstocks, including total solids (TS), volatile solids (VS) and biomethane potential (BMP).

Landfilling of organic wastes is limited by the EU Landfill Directive (Council Directive 1999/31/EC of 26 April 1999). This limitation was effected in many EU countries, such as Ireland, by a landfill charge (in Ireland this is approximately €75/t). Organic waste may be composted; thus, in this report €50/t was assessed as a gate fee for food waste deliveries to the anaerobic digester. This gate fee is one of the main

Table 2.1. Feedstocks used in different scenarios and their characteristics, BMP and costs

Scenario	Composition	Capacity (t/annum)	TS (%)	VS (%)	BMP (L CH_4 / kgVS)	OLR (kg VS/ m^3/day)	HRT (days)	Cost (€/t)	References
Urban	Food waste	100,000	29.4	28	470	3.0	30	–50[a]	Browne and Murphy (2013); Browne *et al.* (2014); EPA (2014); Wall *et al.* (2016)
Rural	Grass silage	75,000	29.3	26.8	366	3.5	25	27	Caslin (2009); McEniry (2011); Wall *et al.* (2014)
	Slurry	65,000	9.6	7.5				4[b]	Wall *et al.* (2014); O'Shea *et al.* (2016)
Coastal	Grass silage	50,000	29.3	26.8	347	3.5	25	27	Caslin (2009); McEniry (2011); Wall *et al.* (2014)
	Slurry	45,000	9.6	7.5				4[b]	Wall *et al.* (2014); O'Shea *et al.* (2016)
	Food waste	2000	29.4	28				–50[a]	EPA (2014); O'Shea *et al.* (2016); Wall *et al.* (2016)
	Seaweed	5000	14.2	10.3				4[b]	Allen *et al.* (2015); Tabassum *et al.* (2017)

[a] The negative costs indicate the tipping fee to discard organic wastes without landfilling.

[b] Cost of the transport of slurry or seaweed from the production to the treatment facility.

HRT, hydraulic retention time; OLR, organic loading rate.

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sources of revenue for the food waste AD plant (Wall *et al.*, 2016). A basic assumption here is that the food waste is source segregated and collected using small bins to minimise grass cuttings and branches in the feedstock. This report is concerned with the upgrading process rather than the collection systems, but it is highly recommended by the authors that, particularly in urban areas, segregated collection of food waste in small containers with frequent collection is employed. It is further recommended to employ "pay by weight" rather than "pay by pick", as the latter can lead to decomposition and production of volatile fatty acids in the bin. Levels of contamination can be greatly reduced by such policies at local administration level.

Rural

In the rural facility 75,000 t/annum of grass silage and 65,000 t/annum of cattle slurry is assessed. This is based on a centralised AD system positioned near the gas grid. The ratio was based on the works of Wall *et al.* (2014), who reported an optimum ratio of 80 : 20 on a VS basis for grass silage to cattle slurry. Grass silage was purchased at €27/t, whereas no gate fee was applied to slurry acceptance. A transport cost of €4/t was assumed. The methane yield and operating conditions used for simulations are outlined in Table 2.1 (Kabir *et al.*, 2015).

Coastal

Coastal scenarios included diverse feedstocks such as food waste, slurry, grass silage and seaweed (Roesijadi *et al.*, 2010). The process considered 5000 t/annum of seaweed, 50,000 t/annum of silage, 45,000 t/annum of slurry and 2000 t/annum of food waste (Table 2.1). A transport cost of €4/t was modelled for beach-cast seaweed and slurry. In many coastal zones, such as Timoleague in West Cork, cast seaweed, such as *Ulva lactuca*, is a nuisance to users of the beach and requires removal. Co-digestion with slurries is a very positive use of such residues.

2.2.2 Model development

Biogas production

The AD model incorporates food waste screening prior to processing to remove metals, plastics and other foreign objects. The base-case scenarios assumed that 1% of waste was contaminated and was removed before further processing. To ensure a 1% contamination rate, food waste bins have to be collected frequently and source separation needs to be efficient (later in this report, a contamination rate of 3% is investigated). The storage for slurry is assumed to be slurry pits whereas all other wastes were assumed to be stored in a silo. After storage, solid wastes were conveyed to the shredder. The shredder consumes power at a rate of 0.09 kW/kg/hour (Kadhum *et al.*, 2017). Figure 2.2 shows the complete process flow from SuperPro Designer for the urban water scrubbing scenarios. In the model the process water from the digestate after AD was recycled back to the process to reduce water usage and enhance microbial consortium stability. Pasteurisation at 70°C for 1 hour was carried out to reduce pathogen content (DFAM, 2014a,b). The TS loading in the system varied between 12% and 15% to ensure that materials were pumpable (Rajendran *et al.*, 2014; Kabir *et al.*, 2015; Vo *et al.*, 2018). A heat exchanger was used to ensure that energy efficiency was maintained during pasteurisation. After pasteurisation, the contents were stored in two parallel storage tanks.

The digesters were operated under mesophilic conditions (37°C). The process data used in the simulation were based on previous experimental work carried out by this research group (see Table 2.1). The digestate after AD was modelled as being distributed to farmers at no cost. A decanter was used to concentrate the digestate; storage capacity of up to 90 days before discharge was provided. Biogas was conditioned (moisture and H_2S removal) before upgrading and injection to the grid.

Water scrubbing

Water scrubbing was the first upgrading method that was evaluated in this work. However, unlike the other two scenarios, the water scrubbing scenarios did not entail CO_2 capture after biogas upgrading. The water scrubbing model was designed based on previous work (Sinnott and Towler, 2009; Masiren *et al.*, 2016; Rotunno *et al.*, 2017), in which the absorption column was operated at 7 bar (Figure 2.2). The methane content ranged between 96% and 98%. Biomethane was injected to the grid at 8 bar (Gas Networks Ireland, 2016). The water stream with dissolved CO_2 was sent to a stripper column to release the CO_2 and

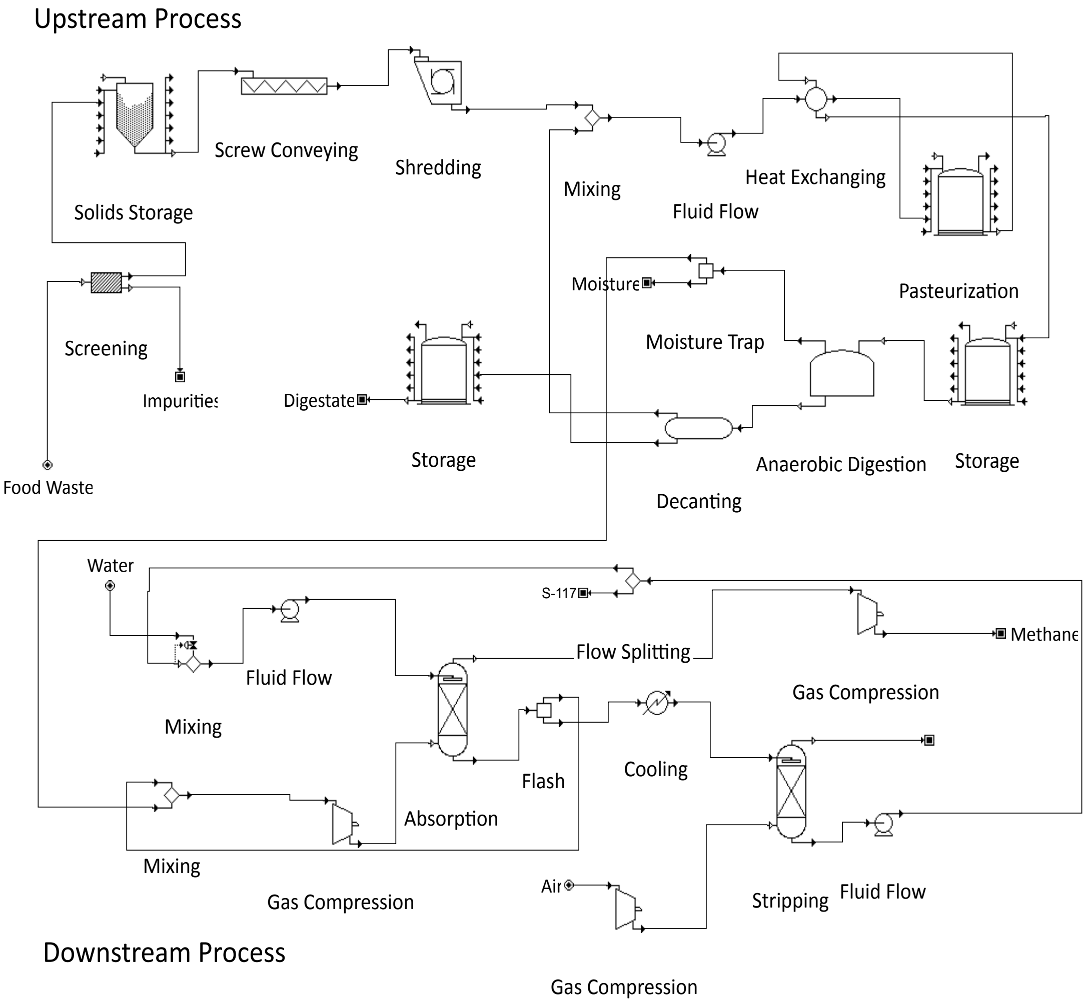

Figure 2.2. Schematic of the urban water scrubbing scenario. Top: biogas production or upstream processing; bottom: biogas upgrading or downstream processing.

recycle the water. About 5% of the regenerated water is considered unusable to avoid saturation.

Microalgae upgrading

Microalgae upgrading uses a carbonate–bicarbonate system to remove CO_2, thereafter using the absorbed CO_2 for the cultivation of microalgae (Chi *et al.*, 2011; Ho *et al.*, 2011; Pegallapati *et al.*, 2013; Xia *et al.*, 2015) (Figure 2.3). Microalgae upgrading involves two processes: (1) an absorption column, which works in a similar way to the water scrubbing system, and (2) algal cultivation, which converts the bicarbonate after the absorption column to carbonate. This carbonate solution is recycled back to the process. This process is set out in equations 2.1–2.4. Equation 2.1 occurs in the absorption column whereas equations 2.2–2.4 take place in the algal raceway pond. About 8 hectares of land space are required for microalgae cultivation from these urban feedstocks.

$$CO_2 + Na_2CO_3 + H_2O \rightarrow 2NaHCO_3 \tag{2.1}$$

$$NaHCO_3 \rightarrow CO_2 + NaOH \tag{2.2}$$

$$NaHCO_3 + NaOH \rightarrow Na_2CO_3 + H_2O \tag{2.3}$$

$$CO_2 + H_2O \rightarrow \text{algae} + O_2 \tag{2.4}$$

The microalgae concentration was modelled as 4.8 g/L, with a conversion efficiency of between 60% and 65% (Chi *et al.*, 2013). In the model the microalgae were sold as a precursor that could be used for biogas, biodiesel or edible applications (Mahapatra *et al.*, 2018). The carbonate losses ranged between 10% and 15%; the lost carbonate was then replaced with fresh carbonate.

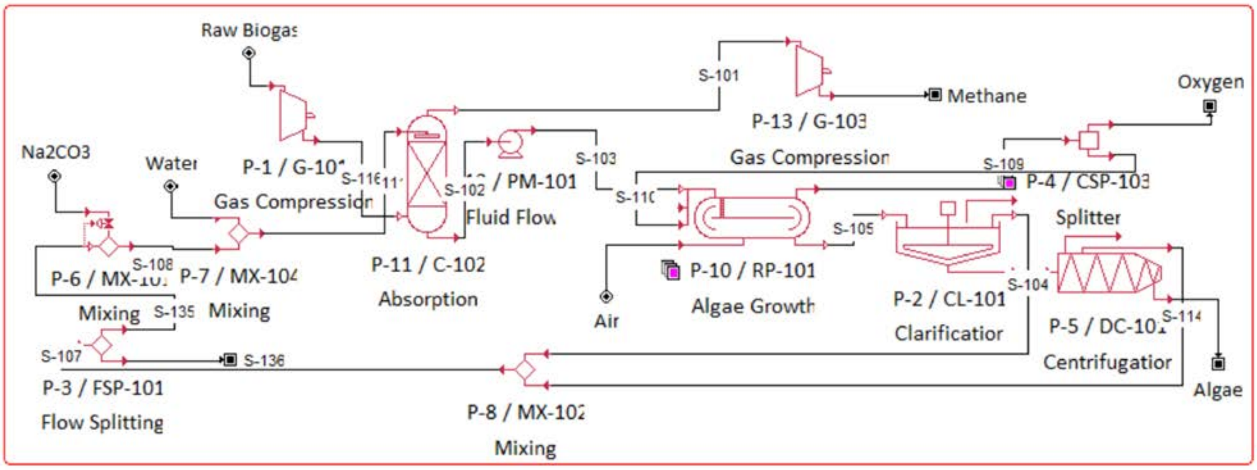

Figure 2.3. Schematic of microalgae upgrading utilising the carbonate–bicarbonate system.

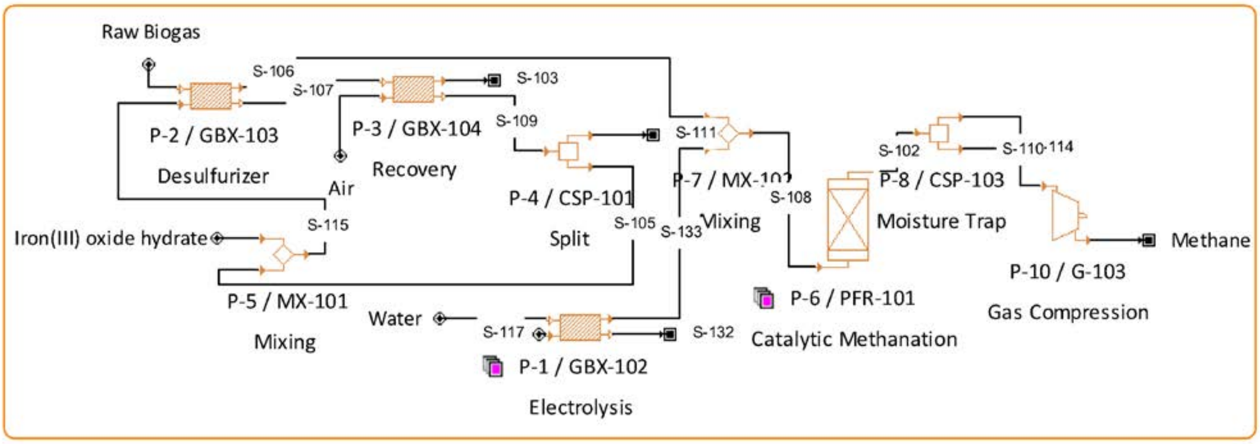

Figure 2.4. Schematic showing a power-to-gas upgrading system.

Power-to-gas

Power-to-gas technology converts electricity to hydrogen and subsequently to methane via electrolysis and methanation processes, respectively. Conditioning and cleaning the gas is necessary for it to be used in a methanation process; hence, a moisture trap and sulfate remover were modelled (Figure 2.4). Equations 2.5 and 2.6 show the principle of sulfate removal using iron (III) oxide (Horikawa *et al*., 2004; Petersson and Wellinger, 2009; Benjaminsson *et al*., 2013).

$$Fe_2O_3.H_2O + 3H_2S \rightarrow Fe_2S_3.H_2O + 3H_2O \qquad (2.5)$$

$$2Fe_2S_3.H_2O + 3O_2 \rightarrow 2Fe_2O_3.H_2O + 6S \qquad (2.6)$$

The model incorporated use of electricity to split water to form hydrogen (Götz *et al*., 2016) (equation 2.7).

$$2H_2O \rightarrow 2H_2 + O_2 \qquad (2.7)$$

The electrolyser was modelled with a 72% conversion efficiency (Schiebahn *et al*., 2015; Götz *et al*., 2016).

The hydrogen from the electrolyser and biogas is modelled as entering the catalytic methanation process, which operates at 200°C; this is where the methane is produced (Rönsch *et al*., 2016) (equation 2.8). The efficiency of the catalytic methanation process was modelled at 78%. This results in an overall efficiency combining the electrolyser and catalytic methanation of 56% (Benjaminsson *et al*., 2013; Schiebahn *et al*., 2015; Rönsch *et al*., 2016).

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \qquad (2.8)$$

Table 2.2. List of assumptions used in this study

Type	Assumption
Algae selling price	€10/t
Annual operating hours	7920
Construction period	18 months
Depreciation method	Straight line
Depreciation period	10 years
Digestate selling price	€0/t
Discount rate	7%
Corporation tax	12.5%
Inflation	4%
Insurance	1% on DFC
Lifetime of the plant	20 years
Methane selling price	€0.20/m^3 STP
Salvage value	5%
Start-up costs	5% on DFC
Start-up period	6 months
Working capital	1-month OPEX
Electricity cost	€35/MWh

DFC, direct fixed capital; OPEX, operating expense; STP, standard temperature and pressure.

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2.2.3 Economic analysis and assumptions

Each biogas plant was allocated a lifetime of 20 years, which includes a construction period of 18 months and a start-up period of 6 months. Other significant assumptions used in this study are highlighted in Table 2.2. For example, all food waste received was subject to a €50/t gate fee, a key source of revenue in the urban scenarios. The SuperPro Designer program was used to calculate the sizing and costing of different pieces of equipment whereas the digester costs were from taken from Krieg & Fischer Consultants (2010).

Electricity was one of the key requirements in the upgraded power-to-gas system. Wholesale electricity was procured through bid by wholesaler at an average cost of €35/MWh (Ahern *et al*., 2015). Any biomethane produced was sold without subsidy at a price of €0.20/m3 (SEAI, 2017b), the typical price of natural gas for large users.

2.2.4 Sensitivity analysis

The key factors affecting the calculation of the incentivisation needed to establish each biomethane plant were analysed in relation to the relevant technical and economical parameters.

Economic sensitivities

From the base case, scenarios that were deemed likely to be financially sustainable were assessed in a sensitivity analysis. The level chosen was an incentivisation of less than €0.5/m^3 of methane to allow financial sustainability and to meet the LCOE. The economic sensitivities assessed were methane price, electricity cost, feedstock cost and gate fee. Fluctuations of ±10% and ±20% were assessed for their effect on the financial viability of the proposed system.

Technical sensitivities

Technical sensitivities included pasteurisation type and the level of contamination in the waste before it was processed. The sensitivity analysis was carried out on urban feedstocks as they are dominated by food waste. The base case used pasteurisation before the AD process, whereas the sensitivity analysis looked at pasteurisation after AD. Similarly, food waste loss of 1% in the base case was altered to 2% and 3% in the sensitivity analysis. The changes in biomethane produced and production costs were calculated as outputs.

2.3 Results and Discussions

2.3.1 Technical analysis

The parasitic energy demand for water scrubbing as an upgrading option, as modelled, varied between 12% and 14% depending on the feedstock used. The power-to-gas system had a 17% parasitic energy demand for all feedstocks (Figure 2.5a). Water scrubbing had a parasitic energy demand of 0.13–0.15 kWh/m^3 of renewable methane, whereas microalgae cultivation had a parasitic energy demand of 0.25–0.28 kWh/m^3 of renewable methane and the power-to-gas system had a parasitic energy demand of 1.02–1.05 kWh/m^3 of renewable methane (Figure 2.5b).

The overall mass balance for each of the nine scenarios evaluated in this study is highlighted in Figure 2.6. Methane composition varied between 55% and 61% depending on the feedstock used. Urban scenarios produced methane of between 11.6 and 20.1 million m^3/annum depending on the upgrading method. The power-to-gas system as an upgrading option produced 75 ± 3% additional methane in comparison with water scrubbing as an upgrading option.

Table 2.3 shows the total costs for the equipment used in the various scenarios. Water scrubbing as an upgrading method had the lowest equipment costs, whereas the power-to-gas system had the highest equipment costs. Urban scenarios were also subject to higher equipment costs.

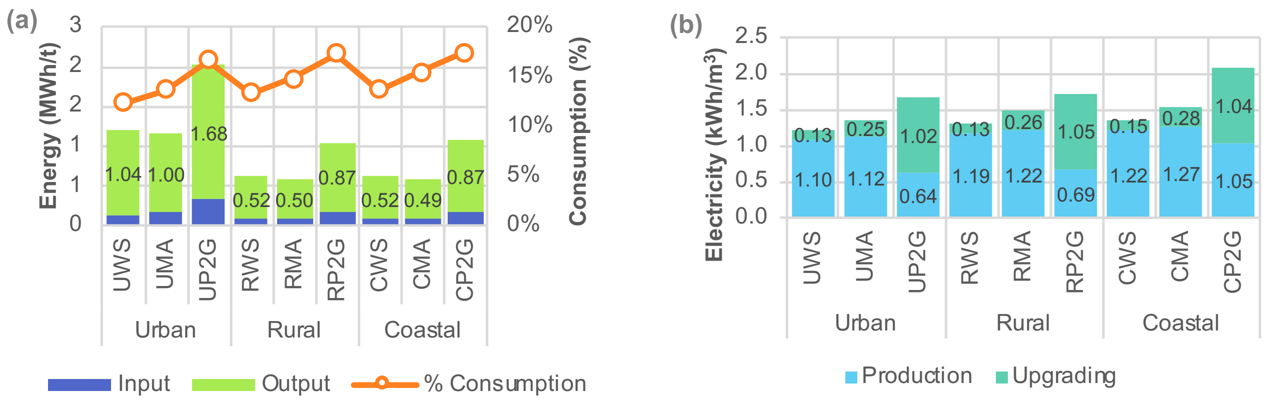


Figure 2.5. Energy production and consumption patterns in different scenarios. (a) Energy input, energy output and consumption rate based on input and output. (b) Share of electricity consumption for biogas production and biomethane upgrading. Reprinted from *Renewable Energy,* Vol. 133, Rajendran, K., Browne, J.D. and Murphy, J.D., What is the level of incentivisation required for biomethane upgrading technologies with carbon capture and reuse?, pp. 951–963. Copyright 2019, with permission from Elsevier. https://www.sciencedirect.com/journal/renewable-energy

Table 2.3. Total equipment costs used in different scenarios

Scenario	Cost (€)	Scenario	Cost (€)	Scenario	Cost (€)
UWS	5,104,000	RWS	4,140,000	CWS	2,741,000
UMA	5,653,000	RMA	4,589,000	CMA	3,119,000
UP2G	7,734,000	RP2G	6,451,000	CP2G	3,979,000

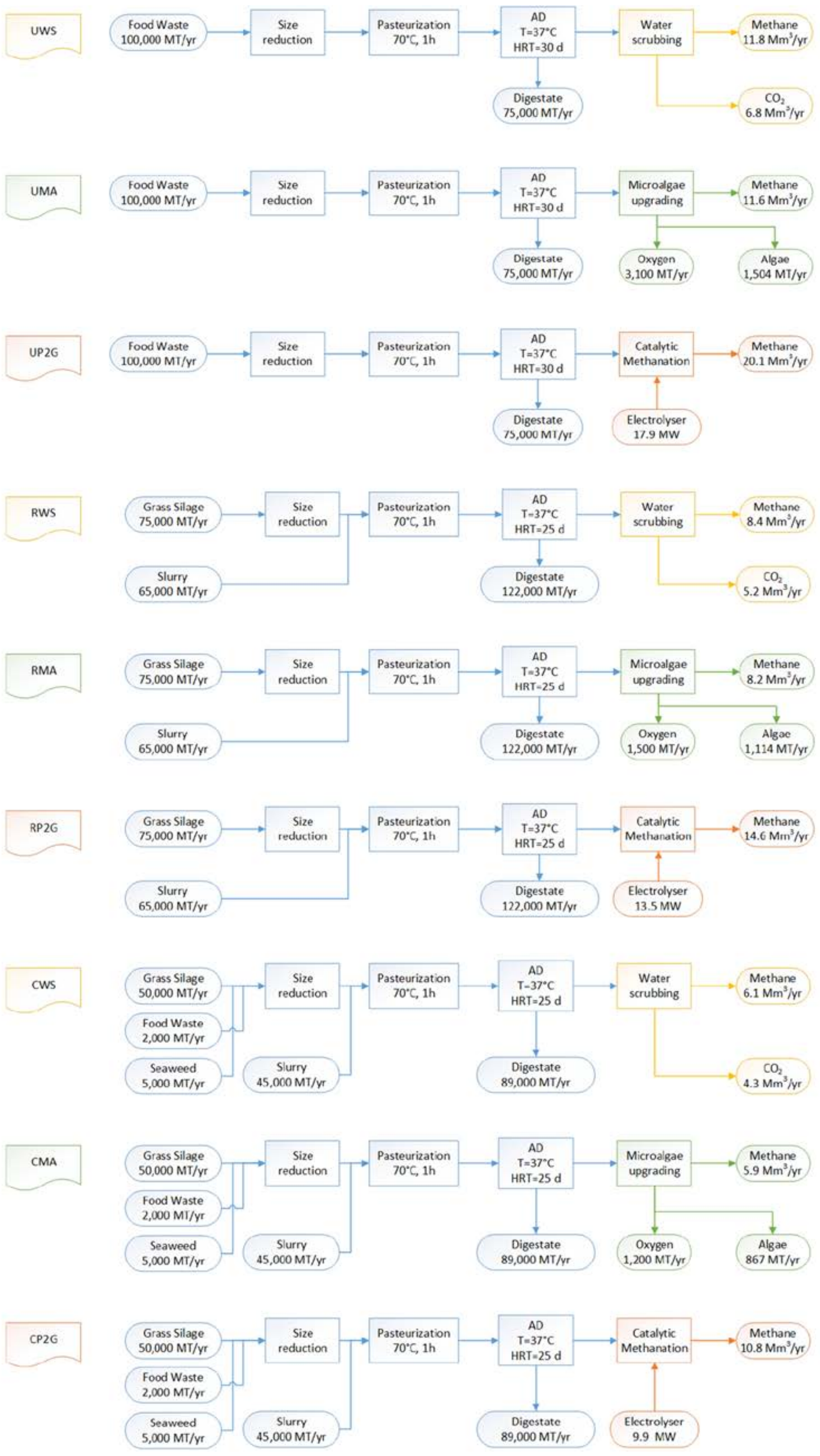


Figure 2.6. The overall mass balance of different biomethane systems with and without carbon capture and reuse. HRT, hydraulic retention time. Reprinted from *Renewable Energy,* Vol. 133, Rajendran, K., Browne, J.D. and Murphy, J.D., What is the level of incentivisation required for biomethane upgrading technologies with carbon capture and reuse?, pp. 951–963. Copyright 2019, with permission from Elsevier. https://www.sciencedirect.com/journal/renewable-energy

2.3.2 Economic analysis

Both capital costs and operational costs were evaluated as part of the economic analysis, as well as other essential parameters that benchmark profitability.

Capital expenditure (CAPEX), the total investment required to build a biogas plant, was highest for the urban scenarios (€318–495/t/annum), followed by the rural (€183–294/t/annum) and coastal (€169–251/t/annum) scenarios (Figure 2.7a). The large volumes of slurry reduced the CAPEX/t/annum of feedstock in the rural scenarios. The urban plant treating 100,000 t/annum had a CAPEX of between €32M and €50M, depending on the upgrading method used.

The power-to-gas system was the most expensive upgrading method (modelled costing was between 44% and 46% of the CAPEX), followed by microalgae cultivation and water scrubbing. Power-to-gas and microalgae cultivation have lower TRLs, which results in higher costs, but these could be reduced through technical advancements in the future (Schiebahn *et al*., 2015; Götz *et al*., 2016).

The operational expenditure (OPEX) for water scrubbing, as modelled, varied between €62/t and €87/t depending on the feedstock used, whereas for microalgae cultivation it varied between €70/t and €110/t and for power-to-gas it varied between €106/t and €166/t (Figure 2.7b). The high electricity consumption in power-to-gas scenarios increased the OPEX when compared with other upgrading methods.

Revenues followed a similar trend as for CAPEX and OPEX. Revenues were highest for urban scenarios (€84–108/t/annum), followed by the rural scenarios and coastal scenarios, which had very similar values (€18–31/t/annum) (Figure 2.7c). This was the result of the credit accrued for the gate fee for the incoming food waste.

The urban scenarios had the lowest production cost (€0.73–0.94/m^3 of renewable methane) (Figure 2.8a), followed by the rural scenarios and the coastal scenarios, with values in the range €1.04–€1.37/m^3. The lower production costs were attributed to the higher methane yield of the food waste. As water scrubbing is a widely used commercially mature technology, it was the cheapest upgrading method, costing between €0.12/m^3 and €0.21/m^3 of renewable methane.

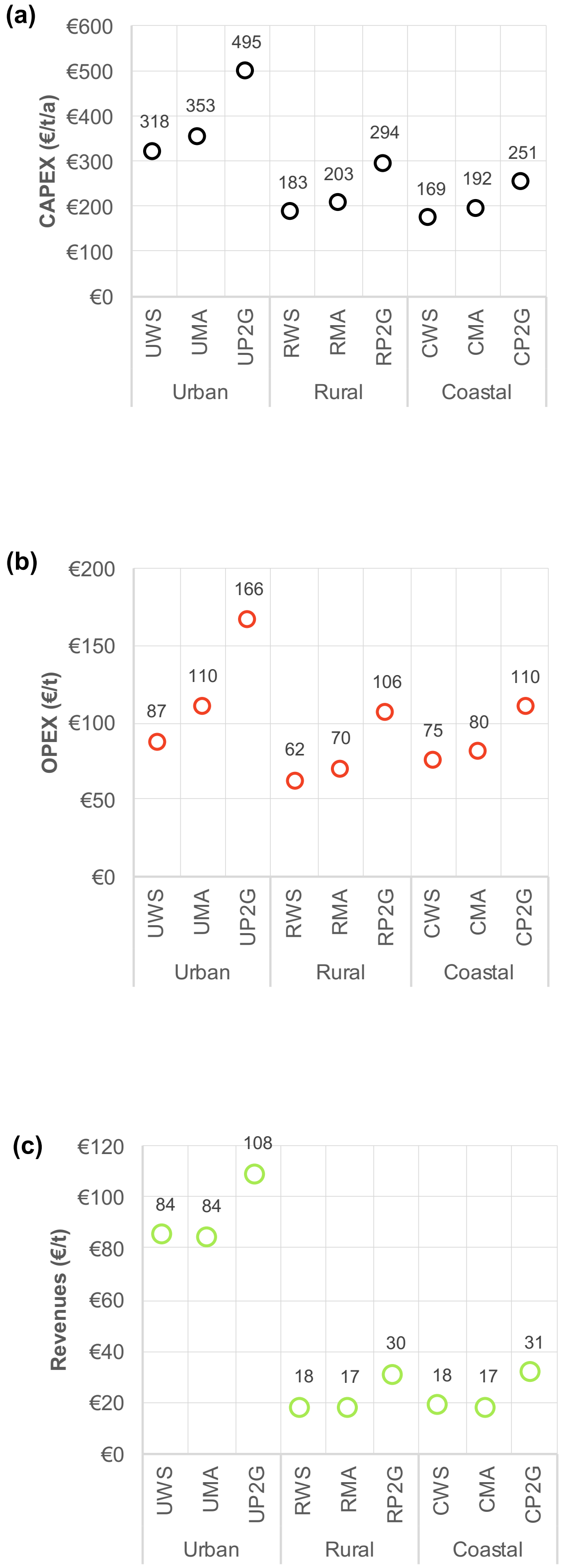


Figure 2.7. Different economic metrics. (a) CAPEX (€/t/annum of feedstock processed). (b) OPEX (€/t of feedstock processed). (c) Revenues (such as gate fees and methane sales) expressed in €/t of substrate.

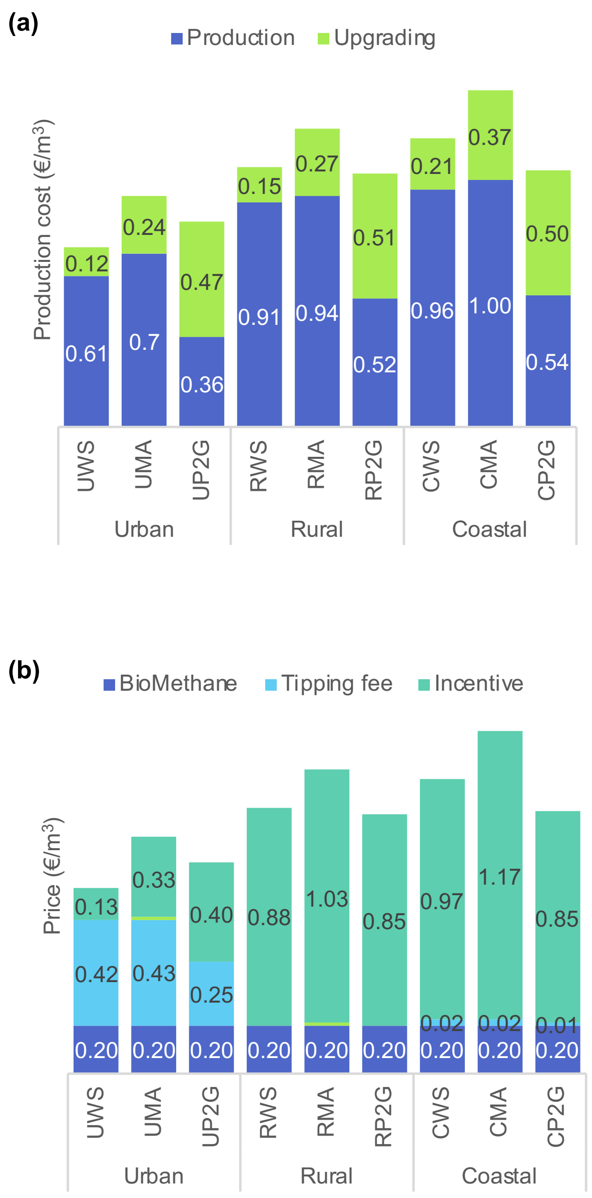


Figure 2.8. Different profitability indices. (a) Production costs for the production and upgrading. (b) Split of revenues and incentives required to meet the LCOE in each scenario. Reprinted from *Renewable Energy,* Vol. 133, Rajendran, K., Browne, J.D. and Murphy, J.D., What is the level of incentivisation required for biomethane upgrading technologies with carbon capture and reuse?, pp. 951–963. Copyright 2019, with permission from Elsevier. https://www.sciencedirect.com/journal/renewable-energy

Economies of scale reduced the cost of biomethane production because of the change in the overall rate of methane yield. Urban water scrubbing upgraded 2300 m³ of biogas at standard temperature and pressure (STP)/hour, whereas rural water scrubbing upgraded 1700 m³ STP/hour and coastal water scrubbing 1300 m³ STP/hour. Urban water scrubbing cost €0.12/m³ whereas coastal water scrubbing cost €0.21/m³.

The production cost in the urban water scrubbing scenarios was modelled at €0.73/m³. From the gate fee and sale of methane generated, an income of €0.62/m³ was modelled. The incentive was evaluated by varying the sale price of biomethane until a net present value (NPV) of zero was obtained at a 7% internal rate of return; for urban water scrubbing this value was €0.33/m³, thus necessitating a €0.13/m³ incentive (Figure 2.8b).

The amount of incentives needed varied depending on the feedstock and upgrading method used. The urban scenarios required an incentive between €0.13/m³ and €0.40/m³, whereas rural feedstocks needed an incentive between €0.85/m³ and €1.03/m³. A cut-off of €0.5/m³ was considered for application of sensitivity analysis; hence, rural and coastal feedstocks were not considered for sensitivity analysis and Monte Carlo simulation.

2.3.3 *Sensitivity analysis*

Economic sensitivities

Key factors that affected the profitability and the required subsidy levels were assessed as part of the sensitivity analysis. The factors included plant capacity, biomethane selling price, electricity costs and gate fee. A ±10% variation and a ±20% variation in these factors were considered as fluctuations from the base case.

Electricity consumption in the water scrubbing and microalgae cultivation upgrading scenarios was negligible in comparison with the power-to-gas upgrading scenarios. Hence, the required subsidy level did not change significantly in the sensitivity analysis for water scrubbing and microalgae cultivation upgrading (Figure 2.9a and b). In contrast, for power-to-gas upgrading, any fluctuation in electricity prices had the second biggest effect on subsidy levels after variation in capacity.

Variations in gate fee had a very significant impact on the urban water scrubbing and urban microalgae cultivation scenarios. The effect was far less pronounced for urban power-to-gas upgrading, as a significant portion of the methane was sourced from electricity rather than from organic feedstock. The gate fee was more important than the sale price of biomethane. This is because of the higher income generated by the gate fee (€0.25/m^3 and €0.43/m^3) than from the biomethane (€0.2/m^3) as highlighted in Figure 2.8. Increasing capacity had a positive effect on the incentives needed because of economies of scale, whereas decreasing capacity had a negative effect.

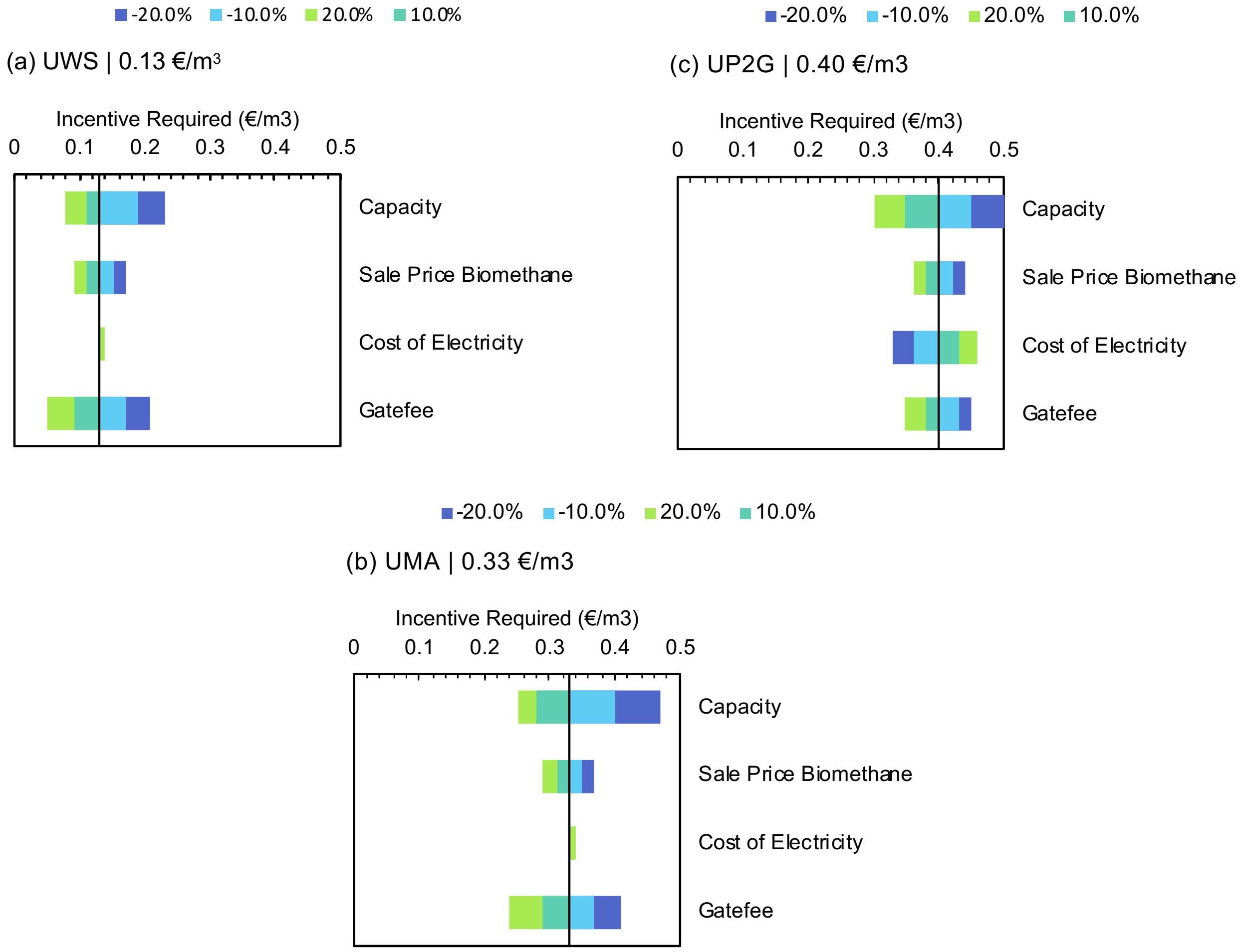
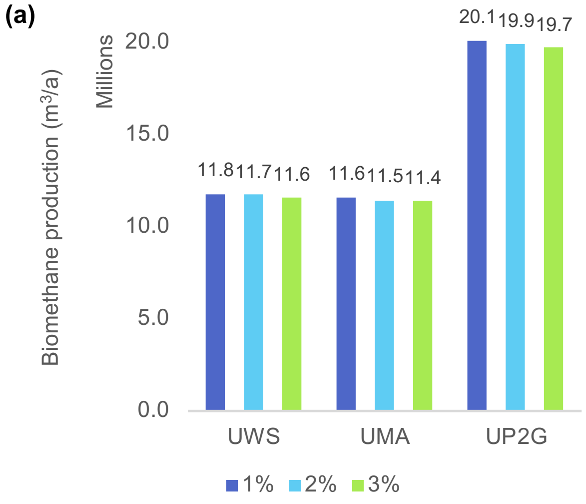


Figure 2.9. Sensitivity analysis in the urban scenarios of factors that affect their incentives. (a) Water scrubbing, (b) microalgae upgrading and (c) power-to-gas upgrading. The vertical bar in the graphs shows the incentive required in the base case. The fluctuations in the level of incentives required from the base case are highlighted. Reprinted from *Renewable Energy,* Vol. 133, Rajendran, K., Browne, J.D. and Murphy, J.D., What is the level of incentivisation required for biomethane upgrading technologies with carbon capture and reuse?, pp. 951–963. Copyright 2019, with permission from Elsevier. https://www.sciencedirect.com/journal/renewable-energy

Technical sensitivities

Technical sensitivities included the amount of food waste rejected as impurities before further processing. In the base case, a 1% impurity level was assumed; this was increased to 2% and 3% in the sensitivity analysis. Annual biomethane production decreased by 0.8% for every 1% increase in impurity of the food waste in the urban scenarios (Figure 2.10a). Similarly, the production cost increased when contamination levels increased. The production cost increased by €0.01/m³ when the impurity level increased from 1% to 2% (Figure 2.10b). Pre-pasteurisation or post-pasteurisation of feedstock did not result in any change in methane yield or production cost.



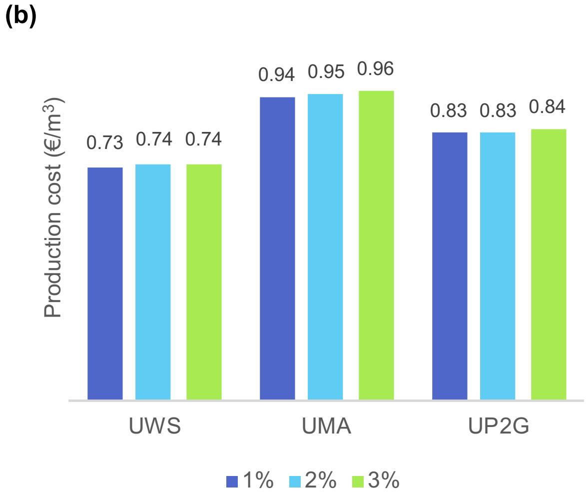


Figure 2.10. Sensitivity analysis based on the level of impurities in the food waste in urban scenarios. (a) Biomethane production and (b) production cost.

2.4 Key Findings

1. As of 2018, urban food waste is the most cost-efficient source of biomethane, as modelled, requiring a subsidy of €0.13/m³ of biomethane. This is equivalent to €0.13/L of diesel equivalent.
2. The key factors that affected the profitability of the urban scenarios included the gate fee for the food waste, the scale or capacity of the system and the methane sale price.
3. When using power-to-gas as an upgrading method, the cost of electricity, which is the source of almost half of the methane, becomes a very significant parameter.
4. The urban-based AD plant, as modelled, needs an incentive of €33/MWh for microalgae upgrading and €40/MWh for power-to-gas upgrading.
5. The energy consumption for different upgrading technologies was as follows: water scrubbing, 0.13–0.15 kWh/m³; power-to-gas, 1.02–1.05 kWh/m³; and microalgae cultivation, 0.25–0.28 kWh/m³.
6. The incentives required for a plant in a rural setting are significantly higher than those required for urban food waste systems. There is no gate fee for slurry and grass silage must be purchased. Incentivisation levels of between €85/MWh and €103/MWh are required; lower incentive levels are required for power-to-gas upgrading and higher levels are required for microalgae upgrading.
7. Collection systems must minimise levels of contamination. Contamination of food waste increases the production cost by about €0.01/m³ for each extra 1% of contamination at low levels of contamination. Further work is required to establish and collate the level of food waste contamination in Ireland over time in order to verify the projections and findings of this study.

3 How Policy Should Be Effected to Facilitate the Green Gas Industry

3.1 Introduction and Objectives

The production of energy from renewable sources is relatively new; by contrast, fossil fuel-based energy systems have been optimised for many years, for example through improvements in internal combustion engines. Renewable energy systems have some way to go on the technology optimisation curve.

Renewable energy systems therefore need additional time to mature and, in the short term, cannot compete with fossil fuel energy systems on a cost basis. This is where policy intervention plays a crucial role. A pertinent example, which is often quoted, is the governmental support for the PV industry in Germany. At present, green gas also needs to be incentivised; inevitably, potential first entrants to a new market of this nature will need some form of financial support.

Worldwide, a variety of different incentivisation mechanisms are available and some of these will be summarised in this chapter, alongside a comparison of successful renewable energy policies across the EU. Figure 3.1 highlights the approaches used in this work. A number of successful implementation schemes for renewable energy systems will be discussed in terms of policy evaluation and incentives, expressed per tCO_2 avoided. These will be compared with

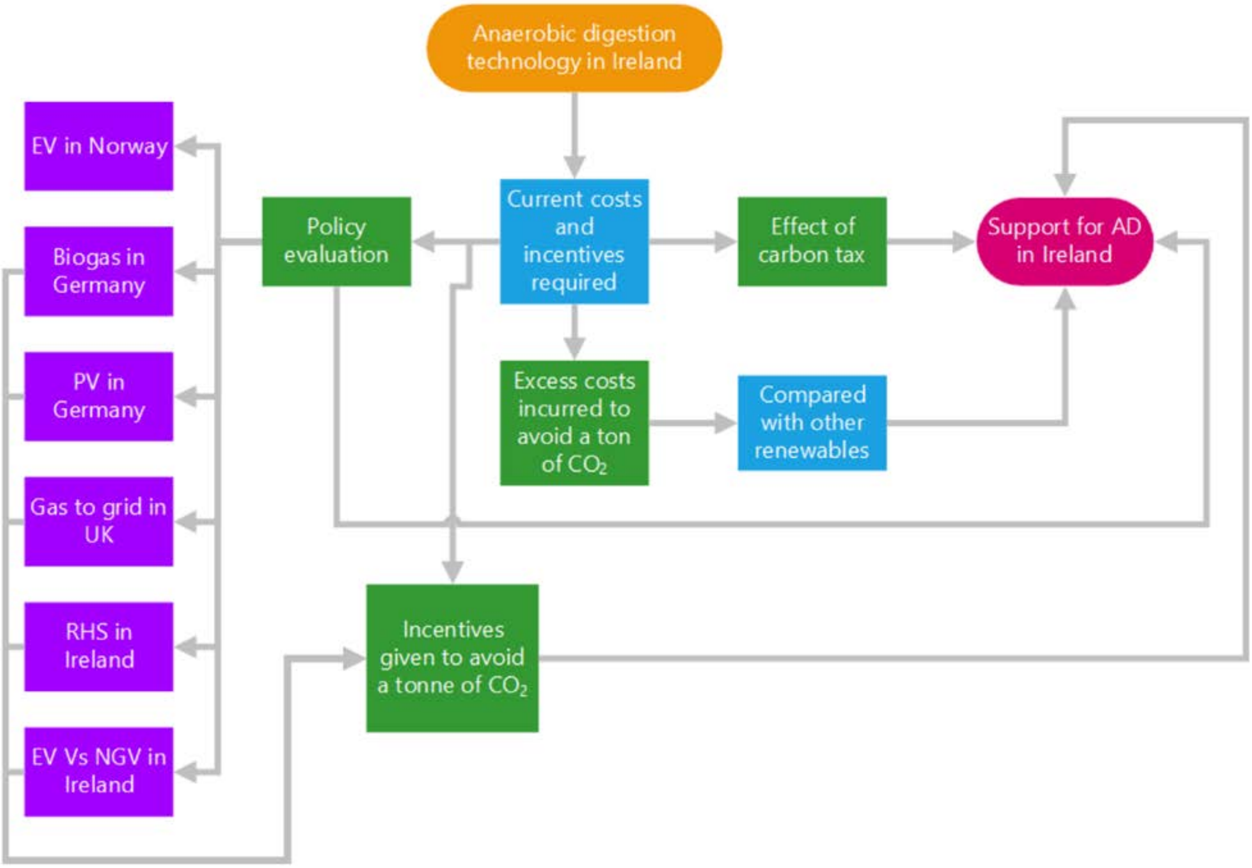


Figure 3.1. Methodologies used in this chapter to evaluate the support of AD technology in Ireland. RHS, Renewable Heat Support. Reprinted from *Journal of Cleaner Production,* Vol. 219, Rajendran, K., O'Gallachoir, B. and Murphy, J.D., The combined role of policy and incentives in promoting cost efficient decarbonisation of energy: a case study for biomethane, pp. 278–290. Copyright 2019, with permission from Elsevier. https://www.sciencedirect.com/journal/renewable-energy

required incentives calculated for biomethane. Carbon taxes allowing for financial sustainability will also be assessed.

Having identified a range of different national policy supports, the objectives of this chapter were as follows:

1. calculate the additional costs of renewable energy over fossil fuel energy to avoid the production of a tonne of CO_2;
2. assess the effect of a carbon tax at various prices as a credit mechanism to support a range of biomethane systems;
3. compare successful renewable energy policies in the EU for various technologies that might be adapted to support a major national initiative on biomethane;
4. determine the incentives allocated to different renewable energy systems in the EU based on tCO_2 avoided and compare these with that required for biomethane.

3.2 The Cost of Avoiding CO_2 Emissions through Use of Renewables

At present, the replacement of fossil fuel-based energy with renewables has an additional financial cost. However, this needs to be seen in the context of climate change mitigation and improved air quality.

As part of this study, the excess cost to avoid 1 tCO_2 for the different types of AD technologies described earlier was calculated. These costs were then compared against those associated with other forms of renewable energy. Box 3.1 shows the calculation methodology used to evaluate the excess cost associated with avoiding 1 tCO_2 for biomethane used as a source of thermal energy. The process involves assessing the additional cost of the renewable energy system as opposed to the fossil fuel system, assuming that the renewable energy system is CO_2 neutral and dividing the additional cost by the CO_2 saved. For thermal energy, this is assessed as €215/tCO_2 avoided. A similar calculation yields a value of €115/tCO_2 avoided for biomethane as a transport fuel displacing diesel.

Box 3.1. The calculation for excess costs incurred to avoid a tonne of CO_2 for renewable heat

Fossil Fuel Comparator (European Commission, 2017)

FFC for heat = 80 gCO_2/MJ (or 80/0.2777 =) 288 $kgCO_2$/MWh;

FFC for transport = 94 gCO_2/MJ (or 94/0.2777 =) 338 $kgCO_2$/MWh;

FFC for electricity = 183 gCO_2/MJ (or 182/0.2777 =) 656 $kgCO_2$/MWh;

LCOE of FFC = 25 €/MWh for natural gas; 48 €/MWh for diesel in transport; 40 €/MWh for combined cycle gas turbine (electricity) (OpenEI, 2013).

LCOE of Renewable methane (Rajendran et al.*, 2019).*

LCOE Urban (UWS)– 87 €/MWh; Rural (RWS)– 121 €/MWh; Coastal (CWS)– 131 €/MWh

Cost of GHG savings of renewable gaseous methane for scenario UWS for renewable heat.

GHG savings = 288 $kgCO_2$/MWh

Excess cost occurred = LCOE of Urban − LCOE of FFC = 87 − 25 = 62 €/MWh

Excess cost/tonne CO_2 avoided = 62 €/MWh/0.288 tCO_2/MWh = 215 €/tCO_2 avoided

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This process was carried out for a number of renewable energy systems to enable a comparison between the different scenarios in this study and other renewables (Figure 3.2).

Overall, this analysis shows that the marginal cost to avoid a tCO_2 for urban water scrubbing was €215/tCO_2 avoided for renewable heat (see Box 3.1). For rural water scrubbing and coastal water scrubbing the equivalent figures increase to €330/tCO_2 avoided and €368/tCO_2 avoided, respectively, for renewable heat.

When these figures are compared with those for other forms of renewable energy generation, non-AD systems might appear to be more effective. However, this needs to be set against the inherent advantages of biomethane systems, such as having dispatchable energy and the ability to support intermittent renewable energy (such as wind energy or PV), by “turning on” when the wind is not blowing or the sun is not shining. In terms of transport, the relevant comparator may be advanced transport biofuels such as Fischer–Tropsch biodiesel, which is at a lower TRL and requires a higher cost to replace CO_2 than biomethane. It is cheaper for biomethane to displace CO_2 in transport than in thermal energy (€115/tCO_2 vs €215/tCO_2 for urban water scrubbing).

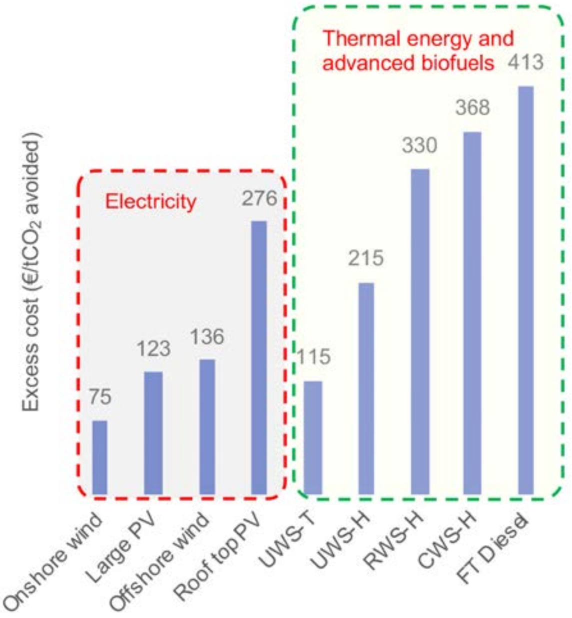

Figure 3.2. Excess cost to avoid a tCO_2 for different renewable energy technologies. FT, Fischer–Tropsch; H, heat; T, transport. Reprinted from *Journal of Cleaner Production,* Vol. 219, Rajendran, K., O’Gallachoir, B. and Murphy, J.D., The combined role of policy and incentives in promoting cost efficient decarbonisation of energy: a case study for biomethane, pp. 278–290. Copyright 2019, with permission from Elsevier. https://www.sciencedirect.com/journal/renewable-energy

3.3 Carbon Tax Calculations

Carbon credits are used to penalise fossil fuels and to aid the financial transition from fossil fuels to renewable energy. As such, they can act as an incentive mechanism for biomethane systems. At present, the carbon tax in Ireland is €20/tCO_2 released (EPA, 2015). In this section, carbon tax rates between €0/tCO_2 and €350/tCO_2 were assessed.

Box 3.2 shows the calculation methodology used to determine what level of incentive is needed for the AD systems used for renewable thermal energy described earlier to reach financial sustainability. Box 3.2 shows that increasing the carbon tax level decreased the level of subsidy needed. In the base case, urban water scrubbing needed €13/MWh as a direct subsidy; however, the current carbon tax of €20/tCO_2 already decreases this to €5.76/MWh. No subsidy is needed for urban water scrubbing if the carbon tax is increased to €50/tCO_2. This process is illustrated graphically in Figure 3.3.

Similarly, the rural and coastal water scrubbing options need a carbon tax of at least €350/tCO_2 to negate the need for any subsidy.

3.4 Resource Analysis and Avoided Emissions

It is important to determine the level of CO_2 emissions that can be avoided from the resources available in an Irish context. These issues are illustrated in Table 3.1 (O’Shea *et al*., 2016). With a national food waste production level of 6.4 Mt/annum (EPA, 2014), there is the potential for the urban scenario to avoid the generation of 2.19 $MtCO_2$/annum. Similarly, AD derived from grass and slurry feedstocks in rural and coastal settings could lead to a further avoidance of 10.4 $MtCO_2$/annum. Grass resources, after livestock usage, were calculated. Together, use of food waste, grass and slurry resources could have reduced the overall emissions produced in 2016 by 13%.

Box 3.2. Carbon tax calculation for UWS scenario used in thermal energy

FFC emission = 80 gCO_2/MJ or = 0.288 tCO_2/kWh (Heat) (European Commission, 2017)

Current carbon tax in Ireland for FFC = 20 €/tonne CO_2 released (EPA Ireland, 2015)

Upper bound value of carbon tax used in this study = 350 €/tonne CO_2 released

Capacity of energy produced from UWS = 118,323 MWh/a (Figure 2.6)

Comparative amount of CO_2 avoided from FFC = Capacity of energy × (FFC emission) = 118,323 MWh/a × (0.288) tCO_2/MWh = 34,077 tonne CO_2/a

Carbon tax per MWh at 20 €/tonne CO_2 = Tonne CO_2 avoided × carbon tax/capacity = 34,077 × 20/118,323 = 5.76 €/MWh

Incentives needed for UWS in the base case = 13 €/MWh

Incentives needed after carbon tax = Initial incentives – carbon tax credit = 13 – 5.76 = 7.24 €/MWh

Incentives needed after upper bound carbon tax (350 V/tonne CO_2) 13 – 100.8 = –87.8 €/MWh

Note: The negative value infers that the carbon tax credit from FFC will add a positive cash flow to the renewable methane.

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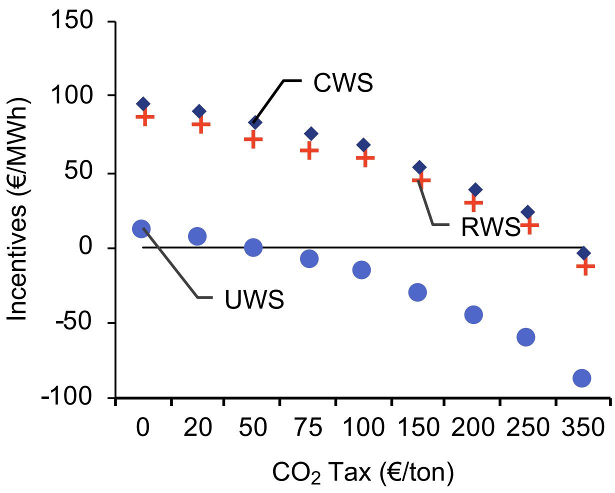

Figure 3.3. Effect of carbon tax on the incentives needed to meet a break-even point for use of biomethane in thermal energy. Reprinted from *Journal of Cleaner Production,* Vol. 219, Rajendran, K., O'Gallachoir, B. and Murphy, J.D., The combined role of policy and incentives in promoting cost efficient decarbonisation of energy: a case study for biomethane, pp. 278–290. Copyright 2019, with permission from Elsevier. https://www.sciencedirect.com/journal/renewable-energy

3.5 Review of International Policy

Using six different examples from across the EU, the third key element of this study was to analyse the key factors in successful renewable energy policy. The main focus was on subsidies and other incentives, each of which was benchmarked on the basis of €/tCO_2 avoided.

3.5.1 Electric vehicles in Norway

The key elements of Norwegian EV policy include:

1. exemptions from import taxes since before 2005;
2. EV access to bus lanes, an infrastructure development programme and free access to ferries;
3. financial incentives and exemption from value-added tax (VAT).

The result of these initiatives was that EV sales in Norway increased 21-fold in the 6 years between 2010 and 2015 (Statista, 2015) (Figure 3.4a).

In addition, technology improved during this period, which also decreased the financial cost of EVs.

Table 3.1. Energy generation and avoided emissions from different resources for renewable thermal energy production

		Unit	Food waste	Grass silage	Slurry
This study	Capacity	t/annum	100,000	75,000	65,000
	Avoided emissions	tCO_2/annum	34,077	24,392	
	Energy	MWh/annum	118,323	84,694	
Functional unit	Avoided emissions	tCO_2/annum	0.34	0.17	
	Energy	MWh/t	1.18	0.60	
Resource estimation	Resource	t/annum	6,428,000	31,300,000	28,500,000
	Energy	MWh/annum	7,605,802	36,176,437	
	Avoided emissions	tCO_2/annum	2,190,463	10,418,823	

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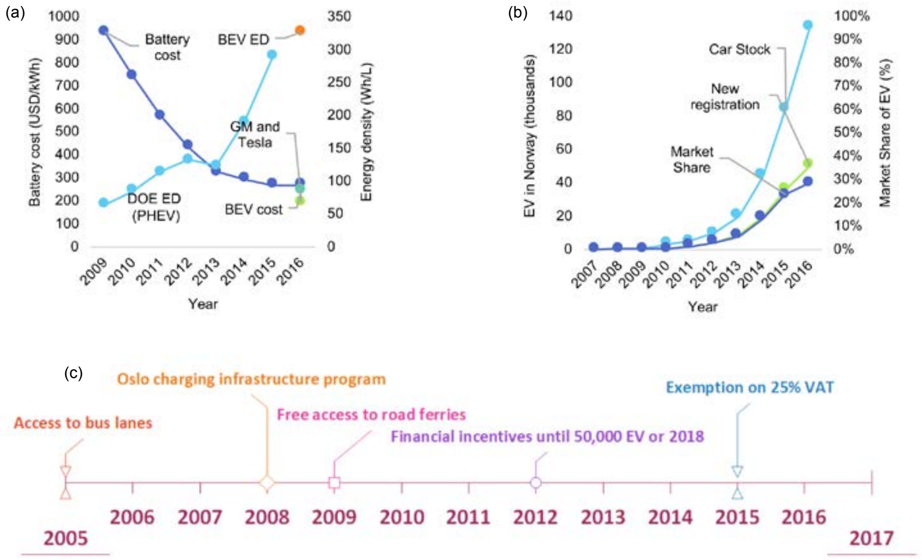

Figure 3.4. A detailed case study of an incentive programme that boosted use of EVs in Norway. (a) Change in battery cost and energy density of EVs since 2009; (b) EV sales and market share in Norway from 2007 to 2016; and (c) policy drivers influencing EV use in Norway from 2005 to 2017. BEV, battery electric vehicle; DOE, Department of Energy; ED, energy density; GM, General Motors; PHEV, plug-in hybrid electric vehicle. Reprinted from *Journal of Cleaner Production,* Vol. 219, Rajendran, K., O'Gallachoir, B. and Murphy, J.D., The combined role of policy and incentives in promoting cost efficient decarbonisation of energy: a case study for biomethane, pp. 278–290. Copyright 2019, with permission from Elsevier. https://www.sciencedirect.com/journal/renewable-energy

In particular, there was a significant increase in battery efficiency and a decrease in battery costs (Figure 3.4b).

3.5.2 Photovoltaics in Germany

Germany has become one of the world leaders in PV technology. The proportion of electricity obtained from PVs has increased from 0.25% in 2005 to 7.4% in 2016 (Figure 3.5a) (Wirth, 2018), whereas the cost has decreased by 70% since 2010 (Mayer *et al*., 2015; Wirth, 2018).

Photovoltaic integration in Germany has been achieved through effective policy intervention and technical innovation. Policy intervention includes favourable feed-in tariff (FiT) schemes and easy loan mechanisms, with tariffs decreased or increased

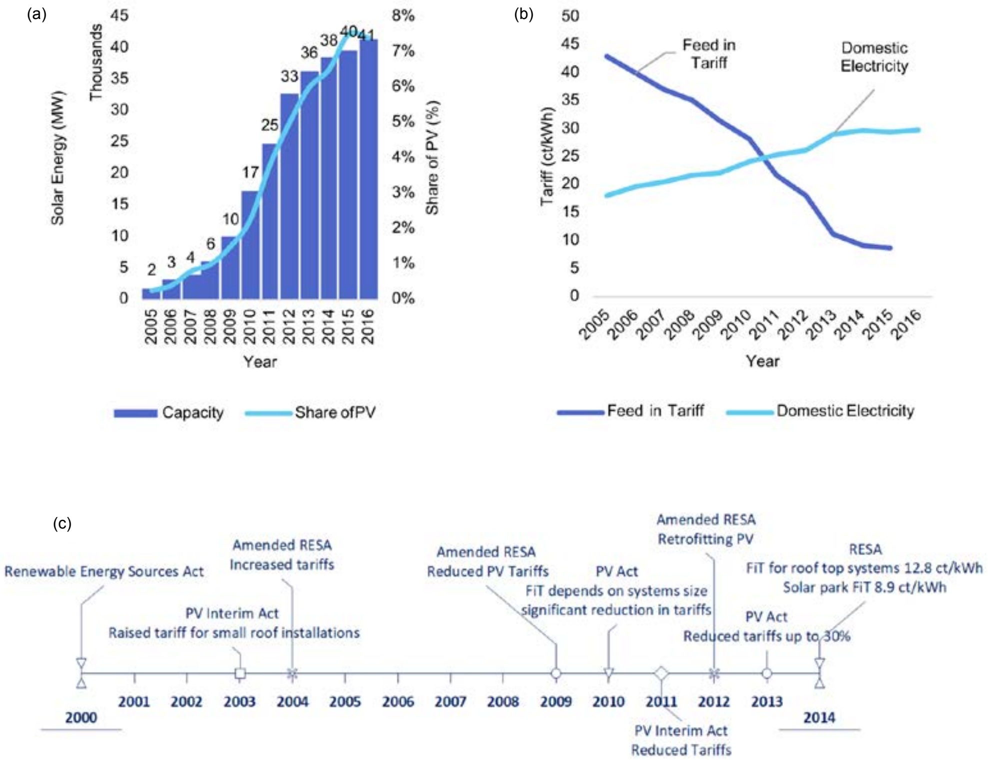

Figure 3.5. Solar energy in Germany. (a) Installed solar energy capacity and share of PV electricity in Germany from 2005 to 2016; (b) historical FiTs for PVs and domestic electricity prices in Germany from 2005 to 2016; and (c) policies implemented and amended in relation to PVs since 2000. RESA, Renewable Energy Sources Act. Reprinted from *Journal of Cleaner Production,* Vol. 219, Rajendran, K., O'Gallachoir, B. and Murphy, J.D., The combined role of policy and incentives in promoting cost efficient decarbonisation of energy: a case study for biomethane, pp. 278–290. Copyright 2019, with permission from Elsevier. https://www.sciencedirect.com/journal/renewable-energy

depending on demand and market situation. This approach allowed national and state governments to effectively regulate price supports while PV technology matured over that period. Initially, a high tariff supported the fledgling PV industry but, as the technology matured, the level of FiT decreased and return on investment was made through an increase in electricity prices (Figure 3.5b). The policies implemented between 2000 and 2014 are indicated in Figure 3.5c.

3.5.3 Biogas in Germany

Germany is also one of the world leaders in biogas production. Between 2001 and 2017, the number of biogas facilities in Germany increased from 1300 to 9346, with a corresponding 25-fold increase in electrical capacity to over 4500 MWe (Clean Energy Wire, 2016; Fachverband Biogas, 2017) (Figure 3.6a). This was achieved through incentives relating to FiT, which stimulated:

1. the use of slurry or energy crops;
2. the deployment of innovative technologies, including reduced water usage/emissions;
3. the categorisation of biogas plants into four bands (< 150 kW or 500 kW or 5000 kW or 20,000 kW), with smaller plants receiving additional tariff support (Figure 3.6b).

As the level of FiT was guaranteed, this led to bankability and ready access to finance. However, as biogas technology matured, financial incentives were dropped in respect of the larger scale plants. The Renewable Energy Sources Act, through its granular incentivisation scheme (Figure 3.6c), ensured that more innovative and sustainable technologies were better funded. This in turn reduced the overall financial costs of biogas technology.

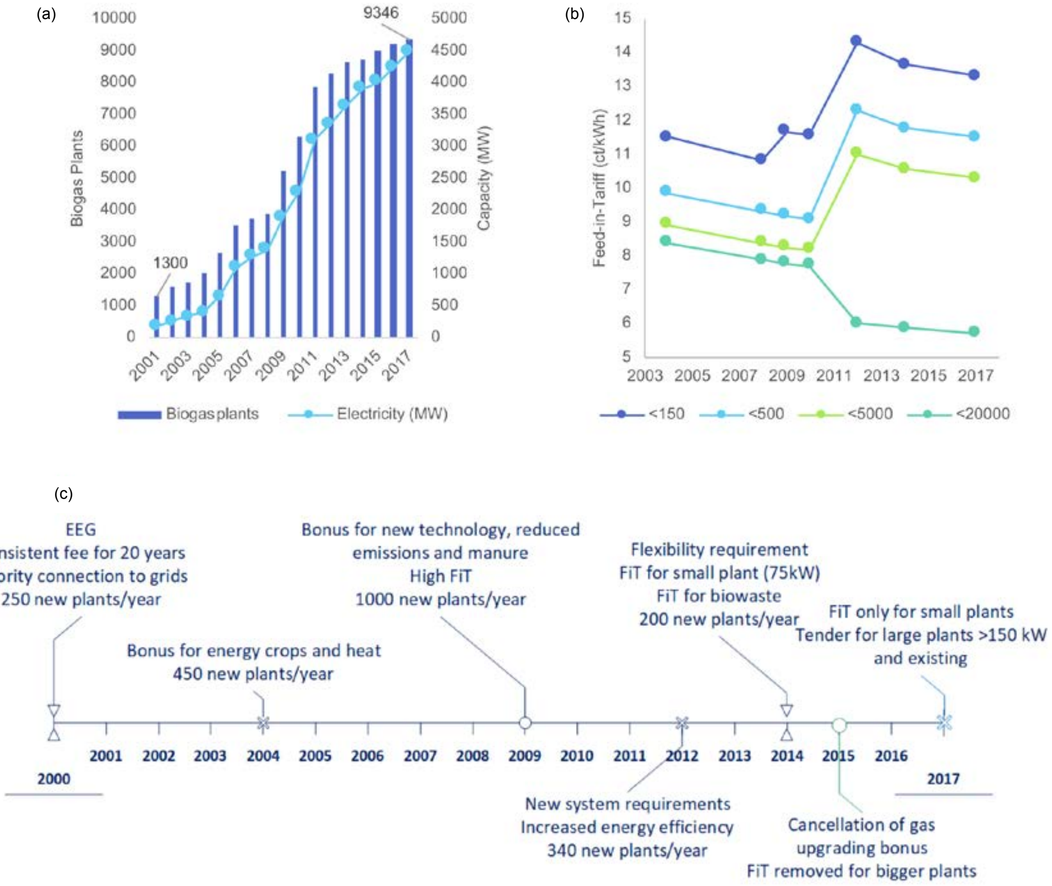

Figure 3.6. Biogas in Germany. (a) Number of biogas plants installed and the electricity production capacity from the plant from 2001 to 2017; (b) changes in the FiT for biogas plant of different capacities from 2003 to 2017; and (c) policies implemented and amended in relation to biogas in Germany since 2000. EEG, Renewable Energy Sources Act. Reprinted from *Journal of Cleaner Production,* Vol. 219, Rajendran, K., O'Gallachoir, B. and Murphy, J.D., The combined role of policy and incentives in promoting cost efficient decarbonisation of energy: a case study for biomethane, pp. 278–290. Copyright 2019, with permission from Elsevier. https://www.sciencedirect.com/journal/renewable-energy

3.5.4 Gas to grid in the UK

The UK shares a similar socio-cultural make-up to Ireland and thus it is relevant to compare each state's policies. Figure 3.7 shows the present renewable heat mechanism in the UK for biogas heat and grid injection. Gas-to-grid injection in 2013 received 9.21 ¢/kWh, but, as the industry evolved, this was reduced to between 3.58 ¢/kWh and 2.61 ¢/kWh depending on capacity (Ofgem, 2017).

3.5.5 Support scheme for renewable heat in Ireland

Ireland recently announced the Support Scheme for Renewable Heat (SSRH), a high-level support scheme to meet renewable heat targets. The SSRH includes FiT; however, for AD systems, no incentives

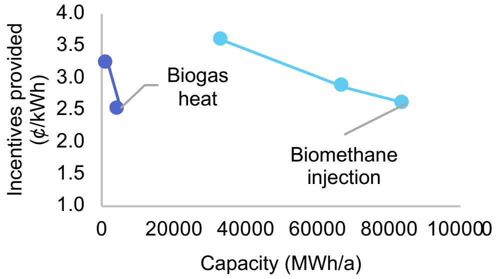

Figure 3.7. Renewable heat incentive scheme in the UK. Reprinted from *Journal of Cleaner Production,* Vol. 219, Rajendran, K., O'Gallachoir, B. and Murphy, J.D., The combined role of policy and incentives in promoting cost efficient decarbonisation of energy: a case study for biomethane, pp. 278–290. Copyright 2019, with permission from Elsevier. https://www.sciencedirect.com/journal/renewable-energy

were given for plants producing more than 2400 MWh/annum. Incentives for AD systems in Ireland now vary between 2.95 ¢/kWh and 0.5 ¢/kWh (Figure 3.8) (DCCAE, 2017).

3.5.6 *Electric vehicles versus biomethane as a transport fuel in Ireland*

Biomethane may also be used as a transport fuel and, as this sector is particularly difficult to decarbonise, this option is potentially significant. At present, there is no state roadmap or incentive for this. However, there is significant incentivisation for EVs in Ireland. This section examines Irish EV policy and assesses its relevance to future incentives for biomethane. EVs receive financial support for capital costs, motor tax, parking, installation of fuelling points and free electricity in public fuelling points. Box 3.3 highlights the financial supports available for EVs in Ireland. The main incentives include a capital grant of €5000 (SEAI, 2018), vehicle registration tax relief of a further €5000 (VRT Ireland, 2018) and charging system installation subsidies of €600. EVs are also eligible for free parking and free tolls on motorways. Totalling all of these incentives generates a benefit to an EV over its lifetime of between €3924/annum and €4112/annum, at a cost of between €1851/tCO_2 avoided and €1940/tCO_2 avoided. If we exclude parking, as all may not avail of this, the incentive approximates €666/tCO_2 avoided.

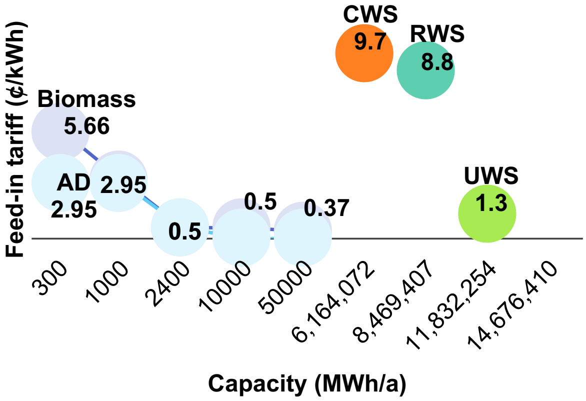

Figure 3.8. Proposed FiT for renewable heat in Ireland compared with the incentives needed for conventional upgrading methods. Reprinted from *Journal of Cleaner Production,* Vol. 219, Rajendran, K., O'Gallachoir, B. and Murphy, J.D., The combined role of policy and incentives in promoting cost efficient decarbonisation of energy: a case study for biomethane, pp. 278–290. Copyright 2019, with permission from Elsevier. https://www.sciencedirect.com/journal/renewable-energy

Biomethane use in an NGV has no policy support in Ireland. Box 3.4 highlights the cost if the highest incentive in the SSRH for biomethane were applied as an incentive for a biomethane-fuelled NGV (2.95 ¢/kWh) (DCCAE, 2017). This would be approximately €260/annum/car, which equates to €123/tCO_2 avoided. This is significantly less than the incentivisation level for EVs.

3.6 Conclusions

When expressed in euros per unit of CO_2 avoided, instructive comparison can be made between different levels of incentives across renewable energy systems (Figure 3.9).

The policies discussed in this chapter were assessed based on emissions avoided. In an Irish context, the use of biogas for heating received incentives of between €123/tCO_2 avoided and €171/tCO_2 avoided (Figure 3.9). Similarly, the use of biogas for heating in the UK received incentives of up to €140/tCO_2 avoided, whereas the use of biogas in the grid received incentives of up to €156/tCO_2 avoided. Most EU policies provided incentives of between €140/tCO_2 avoided and €259/tCO_2 avoided. The exception to this is incentives for EVs. The overarching incentive and policy support for EVs can be viewed as a 16-times higher incentive than for biomethane-fuelled NGVs.

Electrification of private transport is essential and should be incentivised to effect a transition away from diesel- and petrol-fuelled cars. Experience has shown that higher initial incentives encourage the difficult transition from a fossil fuel energy system to a decarbonised system. Biomethane is an attractive option to decarbonise heavy commercial vehicles and buses but it is not incentivised. To be able to convert transport fleets to NGVs and construct compressed natural gas service stations, the same level of incentives that are available for EVs are needed.

Box 3.3. Incentives calculations for PHEVs

Assumptions:

Annual distance travelled	**20,000 km**
Lifetime of EV	20 years
Parking hours	150 h/month
Public charging time	1 h/day
Charging speed (7 kW)	40 km/h or 6kWh/h
Energy needed by EV	0.124 kWh/km/

Capital incentives = 5000 €; Annualized incentives (1) = 5000/20 = 250 €/a (SEAI, 2018)

Charger installation incentives = 600 € (SEAI, 2018); Annualized incentives (2) = 600/20 = 30 €/a

Vehicle registration incentives = 5000 €; Annualized incentives (3) = 5000/20 = 250 €/a (VRT Ireland, 2018)

Parking incentives (4) = 1.5 (€/h) × 150 (h/month) × 12 = 2700 €/a (IPA, 2010)

Motor tax for PHEV = 170 €/a; Motor tax for NGV = 180 €/a (Environment Community and Local Government, 2016)

Motor tax incentives (5) = 180 – 170 = 10 €/a

Night-time electricity rate = 8.4 ¢/kWh; Daytime electricity rate = 17 ¢/kWh

Night time charging incentives (6) = 6 (kWh/h) × 8.4 (¢/kWh) × 1 (h/day) × 365 days = 184 €/a

Daytime charging incentives (7) = 6 (kWh/h) × 17 (¢/kWh) × 1 (h/day) × 365 days = 372 €/a

Toll incentives (8) = € 500/a (DTTAS, 2018)

Total annual incentives (1 + 2 + 3 + 4 + 5 + 6 or 7 + 8) = 3924 – 4112 €/a

CO_2 emissions of a VW Golf diesel car = 106 gCO_2/km; Fuel efficiency = 4.1 L/100 km

Diesel car emission for 20,000 km = 106 gCO_2/km × 20000 km = 2.12 tCO_2/a

Avoided emissions = Diesel car emissions = 2.12tCO_2/a

Incentives based on emissions avoided (Min) = Total incentives/avoided emissions = 3924/2.12 = 1851 €/$tCO_{2avoided}$

Incentives based on emissions avoided (Max) = 4112/2.12 = 1940 €/$tCO_{2avoided}$

PHEV, plug-in hybrid electric vehicle.

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3.7 Key Findings

1. To be effective, incentivisation must include financial subsidies and financial savings coupled with effective policy that caters for complexity and granulation to a level that encourages and promotes innovative and sustainable systems.
2. Experience dictates that the transition from a fossil fuel system to a sustainable decarbonised system requires higher initial incentives to effect the initial change. As the industry matures, the level of incentivisation may be reduced.

Box 3.4. Incentive calculations for NGVs operating on biomethane

Fuel Efficiency of NGV = 3.5 kg/100 km; Density of NG = 0.8 kg/m^3 (CNG Europe, 2018).

Fuel efficiency of NGV = 3.5/0.8 = 4.4 m^3/100 km

Total fuel needed to drive 20,000 km = 880 m^3/a

Incentives on biomethane fuel consumption (Higher end) = 2.95 ¢/kWh = 29.5 ¢/m^3

Total incentives (1) = 880 m^3/a × 29.5 ¢/m^3 = 260 €/a

Avoided emissions (2) = Diesel car emissions = 2.12 tCO_2/a (Box 3.3)

Incentives based on emissions avoided (Biomethane) = (1)/(2) = 260€/a/2.12 tCO_2/a = 123 €/t$CO_{2avoided}$

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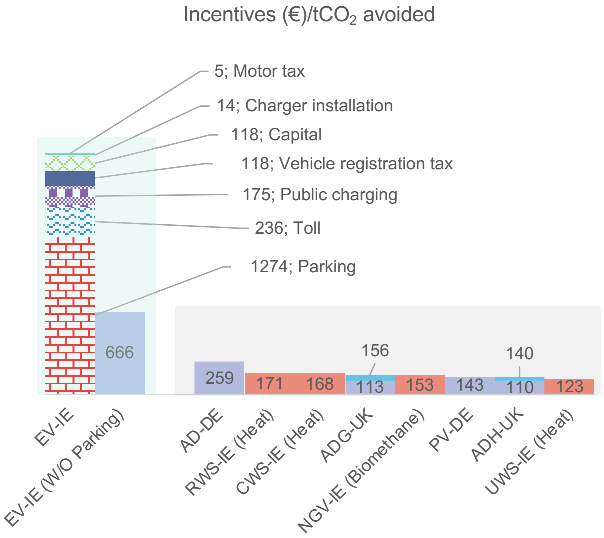

Figure 3.9. EU incentives on a tCO_2 avoided basis. The green bars show the incentives needed in an Irish context, the blue bars highlight the compared renewable technologies and the orange bars represent the upper-bound values of the incentives provided. AD-DE, AD in Germany; ADG-UK, gas to grid in the UK; ADH-UK, biogas to heat in the UK; EV-IE, EVs in Ireland with parking; EV-IE W/O Parking, EVs in Ireland without parking; PV-DE, PVs in Germany. Reprinted from *Journal of Cleaner Production,* Vol. 219, Rajendran, K., O'Gallachoir, B. and Murphy, J.D., The combined role of policy and incentives in promoting cost efficient decarbonisation of energy: a case study for biomethane, pp. 278–290. Copyright 2019, with permission from Elsevier. https://www.sciencedirect.com/journal/renewable-energy

4 Conclusions and Recommendations

4.1 Conclusions

A techno-economic assessment was carried out on feedstocks associated with different regions. In the urban scenarios the model feedstock was source-segregated food waste, in the rural scenarios it was slurry and grass silage and in the coastal scenarios it was source-segregated food waste, grass silage and seaweed. Three upgrading technologies were employed, which were at different TRLs, namely commercialised water scrubbing, power-to-gas systems at demonstration level and microalgae cultivation, which is at concept stage.

As expected, food waste digestion (with an associated gate fee) coupled with the commercialised water scrubbing upgrading system required the smallest incentive to allow financial sustainability. The suggested minimum incentive was €0.13/m^3, equivalent to 13¢/L of diesel equivalent. Urban power-to-gas systems, on the other hand, required a minimum incentive of €0.40/m^3, an addition of 27¢/L of diesel equivalent compared with a water scrubber upgrading system. Food waste in the urban scenario is a limited market and on its own does not have sufficient scale to supply a new green gas industry.

The abundant feedstocks from agriculture in the rural scenarios required larger incentives of between €0.85/m3 and €1.03/m^3. As modelled in this scenario, power-to-gas upgrading had the lowest required incentive. The reason for this is that almost half of the feedstock is sourced from electricity, as opposed to feedstocks that are either weak in methane potential and voluminous (slurry) or need to be purchased (grass silage). This is a crucial output. Hydrogen upgrading when the hydrogen is sourced from electricity via electrolysis can be economically competitive when the feedstock in the biogas facility is expensive to purchase (grass silage) or has a low specific methane yield (slurry).

Incentivising renewable energies is normally based on a unit of energy. For electricity, the unit is kW_eh, whereas for transport fuel it is L of diesel equivalent. This does not allow for ready comparisons to be made across renewable energy systems. In this report, incentives and financial savings associated with policy are compared using tCO_2 avoided. The excess cost of renewable energy over fossil fuel displaced to avoid 1 tCO_2 is lower for mature technologies, such as onshore wind (€89/tCO_2), but higher for advanced biofuels (€413/tCO_2 for Fisher–Tropsch diesel). The excess cost to avoid 1 tCO_2 for biomethane is €115 for transport and €215 for thermal energy (see section 3.2 and Box 3.1). Therefore, incentives of between €123/tCO_2 avoided and €171/tCO_2 avoided are required for minimum financial sustainability (see Box 3.4). Transport is probably the most relevant sector for biomethane as it is the least decarbonised sector and requires the least incentive per tCO_2 avoided.

The incentivisation scheme needs to be intelligent and granulated, supporting higher returns on investment for more innovative, competitive and sustainable systems. Incentivisation needs to be higher at the initiation of an industry to support the installation of infrastructure, namely charging points or NGV service stations or support for purchase of EVs or NGVs. The biomethane industry needs the incentives and policy associated with the EV industry, as implemented in Norway and, more recently, in Ireland.

4.2 Recommendations

4.2.1 Recommendation 1: biomethane should be used for the thermal and transport sectors

With regard to incentivising renewable energy, it must be asked what the objective is. From a visionary perspective, renewable energy is seen as sustainable in terms of carbon emissions and clean in terms of air quality. From a governmental perspective, there are targets to meet and fines to be paid if these are not met. As such, there is a crude accountancy perspective to be considered. How can governments decarbonise at the lowest possible cost to the tax payer?

In Ireland there has been a significant supporting role for renewable electricity. The country is heading towards 40% renewable electricity, which is a good start; however, electricity makes up only 20% of the final energy demand and, as such, 40% renewable electricity corresponds to 8% of total renewable energy.

This is only half of the 16% renewable energy target for 2020. Ireland has incentivised renewable electricity but is late in incentivising renewable heat and transport and therefore will not meet this 16% renewable energy target by 2020.

Ireland has a mandatory 20% reduction target for greenhouse gas emissions by 2020 under EU legislation. Unfortunately, renewable electricity production (in which Ireland has performed well) is accounted for in the Emissions Trading Scheme and does not count towards Ireland's binding greenhouse gas emissions reduction target. Sectors contributing the most to greenhouse gas emissions in Ireland are transport, thermal energy and agriculture.

Anaerobic digestion has a significant role to play in the circular economy. AD systems treat food waste (reducing emissions from landfill sites), digest slurries (reducing fugitive methane emissions in open slurry tanks), produce biofertiliser (reducing emissions associated with mineral fertiliser) and produce renewable energy (reducing fossil fuel use and associated greenhouse gas emissions in the transport or thermal energy sectors). All of these greenhouse gas reductions count towards Ireland's mandatory targets for reducing emissions under EU legislation.

4.2.2 Recommendation 2: biomethane requires incentivisation levels similar to those in the EV industry

Support of a fledging renewable energy system requires a combination of financial incentives and supporting governmental policy. Ideally, incentives would be bankable over a defined period of time and, as such, would facilitate sustainable investment by developers. Good practice, as exemplified by the support of PVs in Germany, involves significant incentives at an early stage to fund the infrastructural change and build expertise. Granulated incentive schemes that encourage innovation and sustainability lead to competitive systems and reductions in technology costs. For example, power-to-gas systems have the potential to upgrade biogas economically when the feedstock is voluminous and weak (slurry) or costly (grass silage). Increased incentives targeted at power-to-gas systems may lead to improvements in this technology while providing ancillary services to the electricity grid through capture of otherwise curtailed electricity. Targeted granulated incentives improve competitiveness and facilitate reductions in government incentives over time. The EV industry in Ireland, but more significantly in Norway, has benefited from large incentives. In Norway, this has led to a market share of 29% of new car sales.

The provision of incentives can target the producer or the end user. Ireland should consider incentive schemes or policy instruments such as those outlined in the following sections.

Incentives for the producer

A biomethane obligation scheme imposed on all gas suppliers, similar to the biofuel obligation scheme currently imposed on all transport liquid fuel suppliers, would allow definite greening of the gas grid. For example, Gas Networks Ireland proposed a 20% level of renewable green gas in the market by 2030.

A renewable energy FiT for biomethane injection into the gas network (supported by a public service obligation that spreads the cost over all gas customers), as carried out in the electricity market, may be used.

Including for granulation of this proposed FiT could lead to increased revenues for biomethane, depending on the sustainability of the biomethane system. This could be administered by a green gas certification scheme. In essence, it is plausible to have higher incentives for more sustainable feedstocks and more technical innovation such as power-to-gas systems.

Incentives for the end user

In the short term, it makes sense to use biomethane injected into the gas network to seamlessly integrate renewable gas into heating. If this is supported by a biomethane obligation scheme, end users do not have to make an active decision to convert to renewable gas, thereby facilitating its rapid uptake.

However, this will not work for transport fuel. Provision of Vehicle Registration Tax relief on purchases of NGVs, allowing hauliers who utilise NGVs not to pay tolls and provision of capital grants to compressed natural gas service stations would stimulate the infrastructure associated with NGVs. A carbon tax on fossil compressed natural gas for use as a transport fuel can incentivise the use of green gas and ultimately lead to a decarbonised transport system. Biomethane use for transport, in particular freight transport, would complement the roll out of EVs for passenger car transport.

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Abbreviations

AD	Anaerobic digestion
BMP	Biomethane potential
C	Coastal feedstock
CAPEX	Capital expenditure
EU	European Union
EV	Electric vehicle
FiT	Feed-in tariff
LCOE	Levelised cost of energy
MA	Microalgae upgrading
Mtoe	Million tonnes of oil equivalent
NGV	Natural gas vehicle
OPEX	Operating expense
P2G	Power-to-gas system
PV	Photovoltaic
R	Rural feedstock
SSRH	Support Scheme for Renewable Heat
STP	Standard temperature and pressure
TRL	Technology readiness level
TS	Total solids
U	Urban feedstock
VAT	Value-added tax
VS	Volatile solids
WS	Water scrubbing

Appendix 1 Peer-reviewed Publications

The following papers were written while undertaking this research project:

Rajendran, K., Browne, J.D. and Murphy, J.D., 2019. What is the level of incentivisation required for biomethane upgrading technologies with carbon capture and reuse? *Renewable Energy* 133: 951–963.

Rajendran, K., Ó Gallachóir, B. and Murphy, J.D., 2019. The combined role of policy and incentives in promoting cost efficient decarbonisation of energy: a case study for biomethane. *Journal of Cleaner Production* 219: 278–290.

Vo, T.T., Rajendran, K. and Murphy, J.D., 2018. Can power to methane systems be sustainable and can they improve the carbon intensity of renewable methane when used to upgrade biogas produced from grass and slurry? *Applied Energy* 228: 1046–1056.

AN GHNÍOMHAIREACHT UM CHAOMHNÚ COMHSHAOIL
Tá an Ghníomhaireacht um Chaomhnú Comhshaoil (GCC) freagrach as an gcomhshaol a chaomhnú agus a fheabhsú mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ó éifeachtaí díobhálacha na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialú: *Déanaimid córais éifeachtacha rialaithe agus comhlíonta comhshaoil a chur i bhfeidhm chun torthaí maithe comhshaoil a sholáthar agus chun díriú orthu siúd nach gcloíonn leis na córais sin.*

Eolas: *Soláthraímid sonraí, faisnéis agus measúnú comhshaoil atá ar ardchaighdeán, spriocdhírithe agus tráthúil chun bonn eolais a chur faoin gcinnteoireacht ar gach leibhéal.*

Tacaíocht: *Bímid ag saothrú i gcomhar le grúpaí eile chun tacú le comhshaol atá glan, táirgiúil agus cosanta go maith, agus le hiompar a chuirfidh le comhshaol inbhuanaithe.*

Ár bhFreagrachtaí

Ceadúnú

Déanaimid na gníomhaíochtaí seo a leanas a rialú ionas nach ndéanann siad dochar do shláinte an phobail ná don chomhshaol:

- saoráidí dramhaíola *(m.sh. láithreáin líonta talún, loisceoirí, stáisiúin aistrithe dramhaíola)*;
- gníomhaíochtaí tionsclaíocha ar scála mór *(m.sh. déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta)*;
- an diantalmhaíocht *(m.sh. muca, éanlaith)*;
- úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe *(OGM)*;
- foinsí radaíochta ianúcháin *(m.sh. trealamh x-gha agus radaiteiripe, foinsí tionsclaíocha)*;
- áiseanna móra stórála peitril;
- scardadh dramhuisce;
- gníomhaíochtaí dumpála ar farraige.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil

- Clár náisiúnta iniúchtaí agus cigireachtaí a dhéanamh gach bliain ar shaoráidí a bhfuil ceadúnas ón nGníomhaireacht acu.
- Maoirseacht a dhéanamh ar fhreagrachtaí cosanta comhshaoil na n-údarás áitiúil.
- Caighdeán an uisce óil, arna sholáthar ag soláthraithe uisce phoiblí, a mhaoirsiú.
- Obair le húdaráis áitiúla agus le gníomhaireachtaí eile chun dul i ngleic le coireanna comhshaoil trí chomhordú a dhéanamh ar líonra forfheidhmiúcháin náisiúnta, trí dhíriú ar chiontóirí, agus trí mhaoirsiú a dhéanamh ar leasúchán.
- Cur i bhfeidhm rialachán ar nós na Rialachán um Dhramhthrealamh Leictreach agus Leictreonach (DTLL), um Shrian ar Shubstaintí Guaiseacha agus na Rialachán um rialú ar shubstaintí a ídíonn an ciseal ózóin.
- An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

Bainistíocht Uisce

- Monatóireacht agus tuairisciú a dhéanamh ar cháilíocht aibhneacha, lochanna, uiscí idirchriosacha agus cósta na hÉireann, agus screamhuiscí; leibhéil uisce agus sruthanna aibhneacha a thomhas.
- Comhordú náisiúnta agus maoirsiú a dhéanamh ar an gCreat-Treoir Uisce.
- Monatóireacht agus tuairisciú a dhéanamh ar Cháilíocht an Uisce Snámha.

Monatóireacht, Anailís agus Tuairisciú ar an gComhshaol

- Monatóireacht a dhéanamh ar cháilíocht an aeir agus Treoir an AE maidir le hAer Glan don Eoraip (CAFÉ) a chur chun feidhme.
- Tuairisciú neamhspleách le cabhrú le cinnteoireacht an rialtais náisiúnta agus na n-údarás áitiúil *(m.sh. tuairisciú tréimhsiúil ar staid Chomhshaol na hÉireann agus Tuarascálacha ar Tháscairí)*.

Rialú Astaíochtaí na nGás Ceaptha Teasa in Éirinn

- Fardail agus réamh-mheastacháin na hÉireann maidir le gáis cheaptha teasa a ullmhú.
- An Treoir maidir le Trádáil Astaíochtaí a chur chun feidhme i gcomhair breis agus 100 de na táirgeoirí dé-ocsaíde carbóin is mó in Éirinn.

Taighde agus Forbairt Comhshaoil

- Taighde comhshaoil a chistiú chun brúnna a shainaithint, bonn eolais a chur faoi bheartais, agus réitigh a sholáthar i réimsí na haeráide, an uisce agus na hinbhuanaitheachta.

Measúnacht Straitéiseach Timpeallachta

- Measúnacht a dhéanamh ar thionchar pleananna agus clár beartaithe ar an gcomhshaol in Éirinn *(m.sh. mórphleananna forbartha)*.

Cosaint Raideolaíoch

- Monatóireacht a dhéanamh ar leibhéil radaíochta, measúnacht a dhéanamh ar nochtadh mhuintir na hÉireann don radaíocht ianúcháin.
- Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha.
- Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta.
- Sainseirbhísí cosanta ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Faisnéis Inrochtana agus Oideachas

- Comhairle agus treoir a chur ar fáil d'earnáil na tionsclaíochta agus don phobal maidir le hábhair a bhaineann le caomhnú an chomhshaoil agus leis an gcosaint raideolaíoch.
- Faisnéis thráthúil ar an gcomhshaol ar a bhfuil fáil éasca a chur ar fáil chun rannpháirtíocht an phobail a spreagadh sa chinnteoireacht i ndáil leis an gcomhshaol *(m.sh. Timpeall an Tí, léarscáileanna radóin)*.
- Comhairle a chur ar fáil don Rialtas maidir le hábhair a bhaineann leis an tsábháilteacht raideolaíoch agus le cúrsaí práinnfhreagartha.
- Plean Náisiúnta Bainistíochta Dramhaíola Guaisí a fhorbairt chun dramhaíl ghuaiseach a chosc agus a bhainistiú.

Múscailt Feasachta agus Athrú Iompraíochta

- Feasacht chomhshaoil níos fearr a ghiniúint agus dul i bhfeidhm ar athrú iompraíochta dearfach trí thacú le gnóthais, le pobail agus le teaghlaigh a bheith níos éifeachtúla ar acmhainní.
- Tástáil le haghaidh radóin a chur chun cinn i dtithe agus in ionaid oibre, agus gníomhartha leasúcháin a spreagadh nuair is gá.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil

Tá an ghníomhaíocht á bainistiú ag Bord lánaimseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóirí. Déantar an obair ar fud cúig cinn d'Oifigí:

- An Oifig um Inmharthanacht Comhshaoil
- An Oifig Forfheidhmithe i leith cúrsaí Comhshaoil
- An Oifig um Fianaise is Measúnú
- Oifig um Chosaint Radaíochta agus Monatóireachta Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag comhaltaí air agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.

EPA Research Report 279

The Role of Incentivising Biomethane in Ireland Using Anaerobic Digestion

Authors: Karthik Rajendran, Brian Ó Gallachóir
and Jerry D. Murphy

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Climate - Water - Sustainability
Identifying pressures • Informing policy • Developing solutions

Identifying pressure

The 2020 renewable energy target for Ireland is 16%; this can be broken down into 40% renewable electricity, 12% renewable heat and 10% renewable transport. Typically, electricity comprises about 20% of final energy demand. The path to decarbonise electricity is mature because of the commercialisation of wind energy, but this is not the case for transport and thermal energy.

Ireland has mandatory greenhouse gas (GHG) emissions reduction targets of 20% by 2020 and 30% by 2030, both relative to 2005 levels; the 2020 target will not be met and we are not on track to meet the 2030 target. These targets apply to GHG emissions outside the European Union Emissions Trading System (EU-ETS). Renewable electricity does not contribute to our mandatory emissions reduction target because electricity generation is included in the EU-ETS. Transport, thermal energy and agriculture are the largest contributors to Ireland's non-ETS GHG emissions. Biomethane is recommended for use in thermal and transport energy. An outcome of this project is a detailed techno–economic–environmental analysis of biomethane; for example, food waste biomethane was shown to require a minimum incentive of €0.13/L dieselequivalent in converting waste to sustainable green fuel.

Informing Policy

Ireland plans to stop the purchase of diesel buses by Bus Éireann after 2019 and petrol and diesel cars by 2030. Electric vehicles (EVs) offer a solution to cars but electrification is not seen as viable for haulage and coaches. The recast Renewable Energy Directive has capped the production of first-generation biofuels (from food crops) at 3.8% of energy in transport by 2030 and set a target of 6.8% for low-carbon-transport fuels (excluding biofuels sourced from food crops). Biomethane can contribute to this 6.8% target and has significant potential to reduce the carbon intensity of haulage and bus fleets through the use of existing natural gas vehicles (NGVs); this technology is proven and commercially available. However, there are no incentives for the use of biomethane as a fuel for NGVs. There are very significant levels of incentives in place for EVs (more than €10,000 per vehicle in capital incentives and reduced Vehicle Registration Tax). This report highlights that this incentive is in the range of €666–1940/ tCO_2 avoided, compared with renewable energy supports across Europe that typically have incentive levels of less than €260/ tCO_2 avoided.

Developing solutions

According to the latest Intergovernmental Panel on Climate Change (IPCC) analysis, GHG emissions will need to reduce to zero by 2050 to comply with the Paris Agreement. Financial prudence is required at governmental level and, as such, incentives should be targeted at ensuring an optimum replacement of CO_2 per euro of incentive.

A major finding of this report was the extremely high level of incentive per unit of CO_2 avoided for EV systems in Ireland. This may be justified by the need to initiate a significant change in infrastructure associated with charging points and the use of more expensive vehicles. These subsidies may be reduced in the future when the industry is mature. Similar solutions are required for biomethane, which can contribute to the 6.8% low-carbon-transport fuel target, especially in haulage and bus fleets. This report recommends a biomethane obligation scheme (20% of natural gas to be renewable by 2030), reducing the cost to government of support for the industry. However, for transport applications, this should be coupled with Vehicle Relief Tax relief and provision of capital grants for NGVs and NGV service stations.

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