Renewable Energy 78 (2015) 648–656

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

A perspective on the potential role of renewable gas in a smart energy island system

Eoin P. Ahern [a, b, c], Paul Deane [a, c], Tobias Persson [d], Brian Ó Gallachóir [a, c], Jerry D. Murphy [a, b, c, *]

[a] Environmental Research Institute, University College Cork, Ireland
[b] Science Foundation Ireland (SFI), Marine Renewable Energy Ireland (MaREI) Centre, Ireland
[c] School of Engineering, University College Cork, Ireland
[d] Energiforsk AB – Swedish Energy Research Centre, Sweden

ARTICLE INFO

Article history:
Received 22 August 2014
Accepted 21 January 2015
Available online 11 February 2015

Keywords:
Biogas
Carbon capture
Electricity storage
Transport biofuel
Power to Gas
Demand driven biogas

ABSTRACT

This paper examines the potential role for Power to Gas (P2G) as applied to an island energy system with high levels of renewable electricity penetration. P2G systems require both a supply of green electricity and a source of CO_2. Cheap electricity is essential for a financially sustainable P2G system. Using a PLEXOS model it was determined that deploying 50 MW_e of P2G capacity on the 2030 Irish electrical grid may reduce absolute levels of curtailed wind by 5% compared to the base case. CO_2 capture is expensive. The cheapest method of sourcing CO_2 for a P2G system is to employ a methanation process whereby biogas from anaerobic digestion is mixed with hydrogen from surplus electricity. Anaerobic digestion in Ireland has a potential to produce biomethane to a level of 10.2% of energy in transport (19.2 PJ/a). The potential CO_2 resource from anaerobic digestion could allow for a further 8.9% of energy in transport (16.6 PJ/a) from P2G production. An optimal model is proposed including for co-location of a biogas system with a P2G system. The model includes for demand-driven biogas concepts allowing electrical grid balancing and the supply of gaseous transportation fuel. Biofuel obligation certificates allows for a financially viable industry.

1. Introduction

1.1. The challenge of increasing levels of renewable electricity

1.1.1. Renewable electricity capacity as a proportion of demand

For many countries, particularly those in Western Europe, wind is expected to play a very significant role in meeting their renewable electricity targets. Fig. 1 shows expected installed wind capacity as a proportion of minimum demand in summer 2020. Even with interconnection, Ireland and Spain will, at times, have in excess of 100% of demand available from wind, meaning curtailment will be required. Looking to 2030 and beyond, renewables will play an increasingly large role in energy systems globally, creating serious technical challenges.

Ireland is located on the Atlantic coast of Europe and presents a very interesting case study, as it is an island grid with very high levels of wind penetration. The Republic of Ireland, in 2030 is expected to have approximately 6800 MW_e of installed variable renewable capacity (dominated by wind) representing approximately 50% of installed capacity.

1.1.2. Dispatch and curtailment

In 2012, the total wind energy generated on the island of Ireland was 18.51 PJ. Dispatch-down of wind energy was 0.40 PJ, representing 2.1% of total available wind energy [2]. The main factors which determine the level of curtailment are the amount of installed wind capacity and the instantaneous limit for system non-synchronous penetration (SNSP) allowed on the grid [3]. SNSP is defined as

$$\frac{wind\ generation + HVDC\ imports}{system\ demand + HVDC\ exports}. \tag{1}$$

all units in MW_e.

* Corresponding author. Environmental Research Institute, University College Cork, Ireland.
E-mail address: jerry.murphy@ucc.ie (J.D. Murphy).

http://dx.doi.org/10.1016/j.renene.2015.01.048
0960-1481/

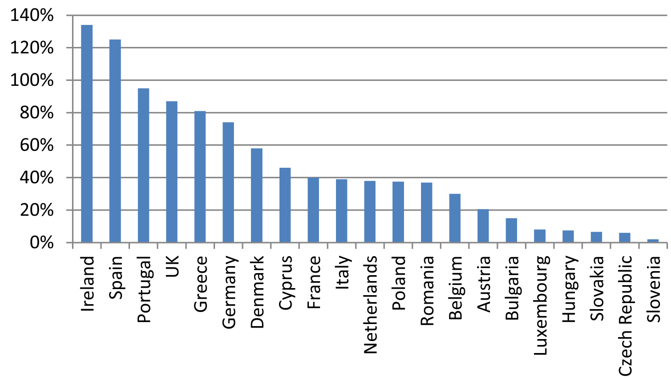

Fig. 1. Wind capacity as proportion of minimum demand in summer 2020 (including for interconnection) [Based on data from Ref. [1]].

Generally, for a given installed capacity of wind, the higher the SNSP limit, the lower the level of curtailment [3]. In other words, if a higher proportion of the system demand can be served by wind, less of the available wind generation will need to be curtailed. By 2020, a SNSP limit of 60–75% should be technically achievable [4], based on frequency response and transient stability requirements. McGarrigle et al. [3] carried out a study to estimate the required installed wind capacities which would allow the island of Ireland to reach their 2020 renewable energy sources in electricity (RES-E) targets, which included an estimate of curtailed wind energy. A minimum curtailment level of 6.5% was observed, regardless of what the SNSP limit was set at. In scenarios where more offshore wind was included, curtailment decreased, mainly due to the wider geographical spread. In the most likely scenario, with a "medium" installed offshore wind capacity, McGarrigle et al. [3] estimated overall all island curtailment at 14% for a SNSP limit of 60%, dropping to 7% for a SNSP limit of 75%.

1.2. Approaches to minimise wind curtailment

1.2.1. Pumped hydro electricity storage

Pumped hydro electricity storage (PHES) is the most mature large-scale energy storage option, with the ability to store energy for periods of hours up to days. At times when surplus electricity is available, water is pumped from a low reservoir to a high reservoir. When electricity demand is high, water is allowed flow back down to the low reservoir, passing through a turbine at the exit to the lower reservoir. The round trip efficiency of PHES is typically 75–80%. Globally, there are over 300 PHES facilities in operation, with a total installed capacity in excess of 95 GW_e [5]. However, the potential for new sites in many countries, such as Ireland, is limited by the required topography, geotechnical conditions, and the time scale involved in such major pieces of infrastructure.

1.2.2. Compressed air energy storage

Compressed air energy storage (CAES) systems use electricity to pump air into underground storage sites at high pressure, usually between 4 and 8 MPa [6]. At times of peak electricity demand, the compressed air is released and enters the combustor of a natural gas turbine power plant. The underground storage site is generally an existing rock cavern, depleted gas field, salt dome or disused mine. The efficiency of CAES systems typically ranges from 60 to 80%. A 268 MW_e facility is planned for a salt deposit at Larne, Northern Ireland with a target commissioning date of 2017 [7].

1.2.3. Electric vehicles

Electric vehicles (EVs) have the potential to play a significant role in demand side management, with smart charging and overnight charging. Ireland has an ambitious target to have 10% of the road transport fleet powered by electricity by 2020, equating to roughly 190,000 private cars [8]. However, since 2010, fewer than 500 EVs have been registered in the country (excluding hybrids) [9]. Realistically, EVs are not expected to have a significant impact on the grid until post 2030.

1.3. Power to Gas

Power to Gas (P2G) is a relatively new concept which involves two stages. The first stage converts electrical power to hydrogen via electrolysis. The second stage converts hydrogen to methane either catalytically or biologically through reaction with CO_2. An efficient P2G process requires cheap electricity (such as that which would otherwise have been curtailed), a cheap source of CO_2 and an efficient gas distribution system (such as the natural gas grid). A number of facilities are already producing methane from electricity and injecting it to the gas grid, such as the 6 MW_e Audi e-gas plant at Werlte [10].

1.3.1. Electrolysis

Three main technologies are available for electrolysis; alkaline electrolysis, polymer electrolyte membrane (PEM) electrolysis and high temperature solid oxide electrolysis cells (SOEC). Typical efficiencies for alkaline and PEM electrolysis lie in the range of 50–70%. Far higher efficiencies may be possible using SOEC technology. SOEC systems operate at high temperature (700–1000 °C), allowing for efficiencies of 90–95%. However, this technology is at an early stage of development. A significantly larger proportion of the input energy is required as heat than for alternative electrolysis techniques. This could mean lower running costs if a source of high-grade heat is readily available, such as from a catalytic methanation process.

1.3.2. Methanation

Methanation may be catalytic or biological. The catalytic methanation process is described by the Sabatier reaction, whereby carbon dioxide and hydrogen combine exothermically to give methane, water and heat (Equation (2)).

$$4H_2 + CO_2 = CH_4 + 2H_2O \\ \Delta H_R = -165 \text{ kJ/mol} \tag{2}$$

The catalytic (Sabatier) process is well understood and has been used for many years in various applications, most notably for the removal of trace amounts of CO_2 in ammonia production. The process typically takes place at around 300 °C, and at pressures of 50–200 bar. A catalyst is required to reduce the activation energy of the reaction and allow it to proceed at suitable rates. Such catalysts are typically nickel-based, on an alumina carrier [11].

Biological methanation is carried out by hydrogenotrophic methanogens, a group of microorganisms which consume hydrogen and carbon dioxide to produce methane. These are strictly anaerobic microbes of the archaea domain, and are present in anaerobic digesters. These methanogens generally grow at 35–70 °C [12]. The free energy associated with the biological reduction of CO_2 to CH_4 using H_2 is −131 kJ/mol [13], indicating that the reaction is favourable. The process may be carried out "in-situ" by simply injecting hydrogen into an anaerobic digester. Alternatively it may be carried out "ex-situ" in a separate vessel.