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# Advanced Hydrogen Production and Deployment Feasibility Study for Todhchaí Phobail Acla SEC

Summary Document

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# Contents

# 1 Executive Summary

There are feasible medium-term opportunities in the renewably produced hydrogen sphere that can be availed of by the community of Achill and Corraun. We set these out in a staged process whereby Todhchaí Phobail Acla Sustainable Energy Community (TPA SEC) with wider community support and participation can put itself forward as a meaningful demonstrator location for H2 projects. These projects with the right supports from local, industry and state partners will not only increase the environmental and socio-economic wellbeing of Achill and Corraun but will serve to make the area a model of best practice community participation in the transition to a net zero carbon society.

We identify three hydrogen deployment opportunities and two production opportunities based around the consumption and use of hydrogen in the first instance, and the large-scale production in the second.

These are, in summary:

- The conversion of the local bus service to a H2 powered Fuel Cell Electric Vehicle
- The demonstration of the feasibility of using H2 a manufacturing process requiring high temperature heat
- The creation of a Fuel Cell Vehicle tourism product that will take advantage of the unique position of Achill and Corraun on the Wild Atlantic Way
- The initiation of a licensing and exploration permission process to create a large-scale, far offshore, floating wind turbine project to supply renewable electricity and hydrogen both for local use and export.

We present here the reasons for the selection of these opportunities as the most practical and realistic. We demonstrate their technical and economic feasibility and provide a staged roadmap with annual targets. We discuss partnership opportunities which may provide financial and other resources to help bring about these projects according to the schedule of actions in the roadmap.

In co-operation with TPA SEC through concerted dissemination and consultation actions, we will embark on a process to establish the level of support for these opportunities and assist TPA SEC in bringing them to reality.

# 2 The Context of This paper: Achill SEC

Todhchaí Phobail Acla Sustainable Energy Community (TPA SEC) expresses its aim as 'to turn the Parish of Achill into a sustainable and thriving community, respecting the natural beauty that surrounds us'. The community has expressed its wishes both to reduce its energy consumption and produce its own energy. While it proposes to produce this energy from wind it also seeks to investigate a renewable biomass that may exist which could also address the waste issue in the community. The aims of TPA SEC also describe the wish to investigate how renewably produced energy can be converted into hydrogen, or how electricity can be fed into the grid: whichever proves most viable. The organisation seeks to address its own specific needs, but also sees itself as a potential beacon community to act as an exemplar for other communities, both in the West of Ireland and beyond.

To this end, TPA SEC, held a competitive tendering process for a consultant organisation to conduct a Feasibility Study into hydrogen production and distribution opportunities which would displace fossil fuels currently being used in the TPA SEC area. Energy Co-operatives Ireland were awarded the contract to conduct such a study, which comprises this document.

## 2.1 Energy Co-operatives Ireland

Energy Co-operatives Ireland (ECI website link) is a co-operative renewable energy and energy efficiency consultancy promoting community access to the shared benefits of renewable energy, energy conservation, and sustainable transport.

ECI is engaged in Horizon2020 and INTERREG research projects studying the applications of hydrogen as a fossil fuel replacement in transport and other sectors. In 2019 it completed a feasibility study into hydrogen uses on Valentia Island and has moved this to demonstration stage.

As part of the research for this study, ECI is grateful for the expert contributions of Dr Rory Monaghan NUI Galway, Associate Professor James Carton at Dublin City University, as well as Mr Brian Grant.

## 2.2 Impacts of Covid19

This study was commissioned in the expectation that domestic and business energy use data would be leveraged in a survey of energy use across the TPA SEC area. Unfortunately, this proved impossible as there were understandable health and safety concerns within the community which restricted our access to homes and businesses during the course of the research period.

It has however been possible for the researchers to leverage published data on energy use in the area. We also received data on energy use from businesses on Achill and Corraun which we have incorporated into our models. From our work across other communities, we have been able to model energy use within the community to provide a robust characterisation of the local energy use.

We discuss the Achill and Corraun energy use below in Section 4.

# 3 Achill Island and Corraun: Geography and Demographics

## 3.1 Geography:

Achill Island is located, see Figure 1, off the west coast of County Mayo and is the largest of the Irish Islands at 148km$^2$. Achill is connected to the Corraun Peninsula (and thus to the mainland) via a land bridge. The Michael Davitt bridge connects the settlements of Gob na Choire (Achill Sound) and Poll Raithní (Pollranny). The topography of the island is quite mountainous with its highest point being the Croaghaun sea cliffs standing at 688m.


*Figure 1: Map of Achill Island and Corraun*

## 3.2 Demography

According to the CSO 2016 census[1], Achill Island has a population of 2,459, while Corraun has 673 inhabitants. While both have a sráidbhaile settlement pattern typical of Western Ireland, there are distinct villages in: Keel, Dooagh, Dooega, Doogort, Achill Sound, and Bunnacurry.

## 3.3 Economy

Figure 2 shows employment in Achill and Corraun by industry. It is clear that manufacturing, agriculture, and construction employ fewer people in the area than other sectors. It is not obvious from the CSO categories of industries which 'other' or 'commerce and trade' activities are in question here, but it can be held that the tourism sector plays a large role.

[1] All CSO data for this report is provided by https://www.cso.ie/en/census/census2016reports/census2016smallareapopulationstatistics/

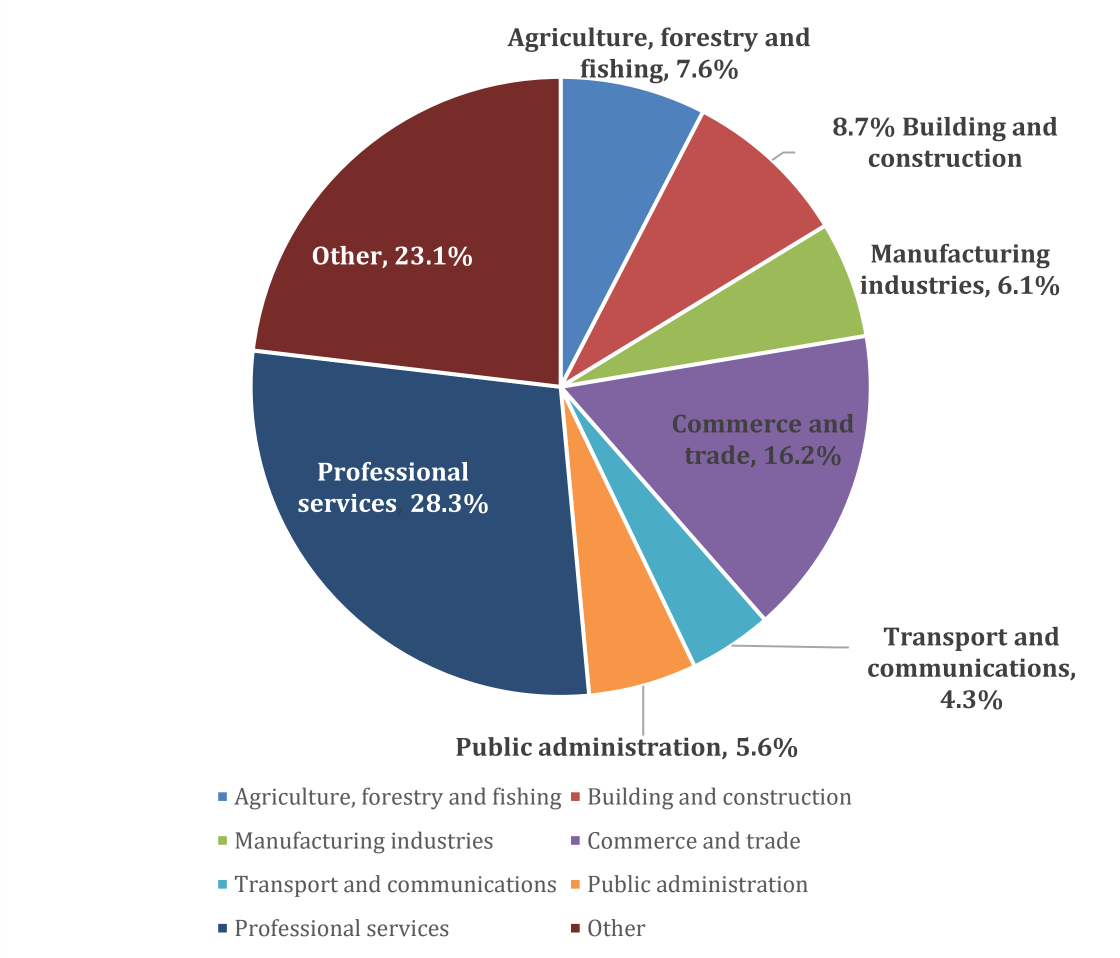


*Figure 2: Employment by Industry*

# 4 Energy Use on Achill and Corraun

As discussed above in Section 2.2, it is necessary in this report to rely on modelled data to identify the majority of the energy use in the area. We use the SEAI's data on Building Energy Rating Certificates (BERs)[2] to gain an overall picture of the level and character of the energy use on the island. We have aligned this with the CSO household makeup and homes data.

## 4.1 BER Ratings for the area

These are provided through aggregation at a granular level of 'CSO Small Areas' geographic units – in the study area, there were 2,616 dwellings. Some of these were unoccupied at census night which is to be expected as there are a large number of holiday homes in Achill and Corraun. Of all homes, according to SEAI figures, there are 283 with a BER certificate (11%). The average BER for each Small Area is shown in Table 1 below along with values for average energy use per square meter for those dwellings with BERs. While this is only a fraction of all homes in the study area, for our purposes it is reasonable to ascribe a global domestic energy use as shown in Table 1.

[2] https://www.seai.ie/technologies/seai-maps/ber-map/

*Table 1 Domestic Energy Use*

| Small Area Number CSO | Total Number of Homes CSO | Number of BERs | BERs as % of total homes | Average BER G-A1 | Average Total Energy Use kWh per m2 | Average Area m² BER homes | Estimated Total Energy Use Per Dwelling BER kWh | Estimated Energy Use ALL homes in area kWh |
|---|---|---|---|---|---|---|---|---|
| 157139001 | 90 | 13 | 14% | E1 | 309.7 | 107.5 | 33,293 | 2,996,348 |
| 157139008 | 113 | 7 | 6% | D1 | 250.9 | 160.6 | 40,295 | 4,553,283 |
| 157074006 | 166 | 7 | 4% | F | 447.8 | 148.1 | 66,319 | 11,008,984 |
| 157060005 | 149 | 20 | 13% | D2 | 271.3 | 112.7 | 30,576 | 4,555,751 |
| 157074004 | 84 | 5 | 6% | D1 | 254.2 | 110 | 27,962 | 2,348,808 |
| 157139003 | 148 | 24 | 16% | E2 | 349.7 | 87.6 | 30,634 | 4,533,791 |
| 157001002 | 97 | 7 | 7% | E1 | 336.3 | 119.8 | 40,289 | 3,908,008 |
| 157060002 | 111 | 10 | 9% | C3 | 210.8 | 81.2 | 17,117 | 1,899,983 |
| 157139006 | 227 | 48 | 21% | D2 | 276.1 | 89.1 | 24,601 | 5,584,316 |
| 157074002 | 83 | 9 | 11% | D2 | 286.4 | 111.6 | 31,962 | 2,652,866 |
| 157074008 | 116 | 1 | 1% | E1 | 308.8 | 40.9 | 12,630 | 1,465,071 |
| 157001003 | 147 | 11 | 7% | D2 | 296.7 | 97.7 | 28,988 | 4,261,176 |
| 157060004 | 106 | 5 | 5% | G | 503.3 | 69.6 | 35,030 | 3,713,146 |
| 157139002 | 113 | 5 | 4% | E1 | 311.1 | 123.8 | 38,514 | 4,352,102 |
| 157001001 | 142 | 8 | 6% | D1 | 252.3 | 117.4 | 29,620 | 4,206,043 |
| 157139010 | 214 | 53 | 25% | E2 | 350.3 | 92.4 | 32,368 | 6,926,692 |
| 157001006 | 77 | 1 | 1% | G | 1290 | 81.3 | 104,877 | 8,075,529 |
| 157001005 | 134 | 2 | 1% | G | 485.3 | 117.7 | 57,120 | 7,654,055 |
| 157060003 | 96 | 13 | 14% | D2 | 273.6 | 132.4 | 36,225 | 3,477,565 |
| 157139007 | 121 | 11 | 9% | D2 | 298.6 | 72.4 | 21,619 | 2,615,855 |
| 157074007 | 82 | 23 | 28% | F | 434.6 | 60.1 | 26,119 | 2,141,796 |
| **TOTAL** | **2616** | **283** | **11%** | - | - | - | - | **92,931,166** |
| **Averages All Homes** | - | - | - | **E2** | **371.3** | **101.6** | **37,732** | **98,706,398 (99 GWh/y)** |

## 4.2 Domestic Energy Use

Table 1 shows that there is an estimated 99 GWh of energy used by domestic consumers in the study area from BER assessments. This is a considerable energy use and represents a large economic cost – virtually all the energy consumed on the island (bar home cut turf) is imported.

*Table 2 Breakdown of home energy use*

| Energy use | % of total | Included in BER | Energy used - select | Cost (€/kWh) | CO2 (kg/kWh) TPER |
|---|---|---|---|---|---|
| **Space heating** | **61%** | **Yes** | **Kerosene** | €0.08 | 0.257 |
| **Water heating** | **19%** | **Yes** | **Kerosene** | €0.08 | 0.257 |
| **Lighting** | **8%** | **Yes** | **Electricity** | €0.24 | 0.295 |
| Appliances[1] | 9% | No | Electricity | €0.24 | 0.295 |
| Cooking[1] | 3% | No | Electricity | €0.24 | 0.295 |
| **Total in BER** | **88%** | | | | |
| **Total in home** | **100%** | | | | |

*Source: https://www.seai.ie/resources/publications/Energy-in-the-Residential-Sector-2018-Final.pdf*

As can be seen from Table 2, the energy requirements of Lighting and Water and Space heating are estimated in the BER certificate. Energy use by appliances (including cooking) is not.

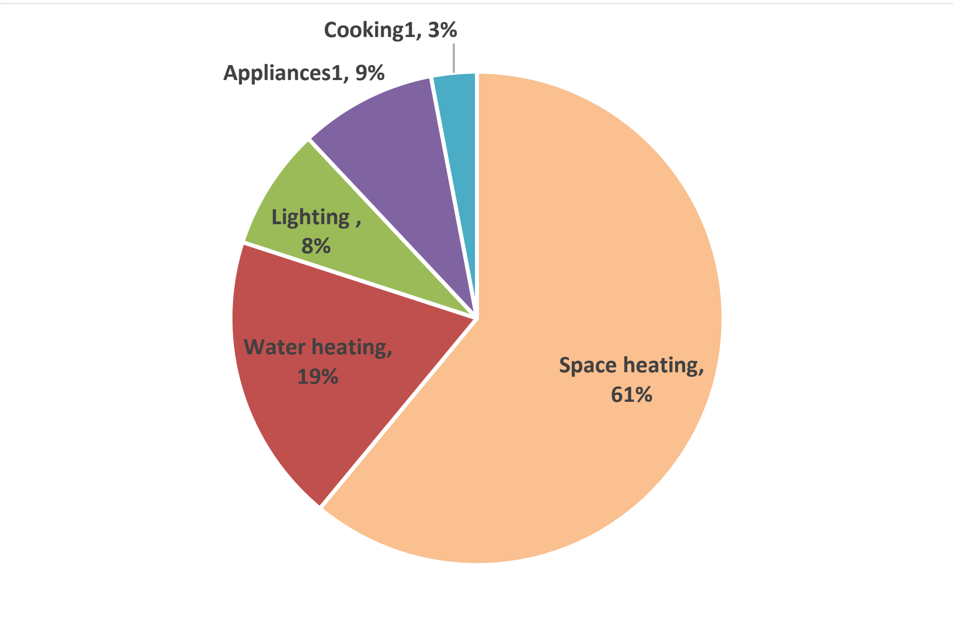


*Figure 3 Breakdown of home energy use*

*Source: https://www.seai.ie/resources/publications/Energy-in-the-Residential-Sector-2018-Final.pdf*

We will therefore adjust our global domestic energy use estimates upwards by an additional 12% accordingly. This provides us with a domestic energy use for the area of 106 GWh. Much of this is amenable to decarbonisation, given extensive retrofitting works on all 2,600 homes, and the conversion of their heat load from fossil fuels to renewable electricity through the installation of, for example, heat pumps. However, the cost of bringing the average home from a E2 rating to a B2, can be considerable. We understand that TPA SEC are investigating the issues involved in achieving these ends in another study.

We will discuss the latest technology and research developments that are relevant to the decarbonisation of heat through novel H2 applications in Section 6.5. We note here however, that the heat use on the island in the domestic sector is considerable.

## 4.3 Domestic Transport

The CSO publishes declarations in the census by households as to the number of cars each household owns. Table 3 shows the total number of cars per Small Area which provides a total number of 1,652 cars for the study area.

*Table 3 Car Ownership Achill and Corraun*

| Small Area Number | No Car | 1 car | 2 cars | 3 cars | 4 or more cars | Total Cars |
|---|---|---|---|---|---|---|
| 157139001 | 9 | 21 | 16 | 15 | 4 | 56 |
| 157139008 | 5 | 24 | 62 | 6 | 4 | 96 |
| 157074006 | 14 | 28 | 34 | 3 | 0 | 65 |
| 157060005 | 14 | 48 | 32 | 9 | 4 | 93 |
| 157074004 | 5 | 19 | 18 | 0 | 0 | 37 |
| 157139003 | 4 | 27 | 32 | 9 | 0 | 68 |
| 157001002 | 7 | 31 | 36 | 15 | 4 | 86 |
| 157060002 | 6 | 40 | 56 | 27 | 0 | 123 |
| 157139006 | 15 | 42 | 52 | 18 | 4 | 116 |
| 157074002 | 8 | 18 | 14 | 15 | 4 | 51 |
| 157074008 | 6 | 28 | 30 | 9 | 4 | 71 |
| 157001003 | 11 | 48 | 58 | 18 | 4 | 128 |
| 157060004 | 6 | 27 | 40 | 18 | 4 | 89 |
| 157139002 | 8 | 30 | 50 | 12 | 0 | 92 |
| 157001001 | 6 | 65 | 32 | 3 | 4 | 104 |
| 157139010 | 12 | 22 | 26 | 3 | 0 | 51 |
| 157001006 | 5 | 24 | 20 | 9 | 0 | 53 |
| 157001005 | 14 | 30 | 34 | 6 | 8 | 78 |
| 157060003 | 2 | 23 | 44 | 6 | 4 | 77 |
| 157139007 | 8 | 25 | 38 | 9 | 0 | 72 |
| 157074007 | 13 | 17 | 20 | 9 | 0 | 46 |
| **All Areas** | **178** | **637** | **744** | **219** | **52** | **1,652** |

*Source: CSO 2016*

We assume that the vast majority of these are diesel or petrol vehicles. Battery Electric Vehicles (BEVs) account for a very small percentage of cars in Ireland, and many of these are based in urban areas. Diesel is the most popular choice of fuel type for private cars in Ireland[3]. This is even more so in the West of Ireland where typical distances travelled are greater than those in the East thus suiting diesel's superior fuel efficiencies. When calculating the global figures for fuel consumption by private cars in the region, we will thus assume diesel use: we feel that this will offer the most accurate approximation.

[3] https://publicpolicy.ie/papers/diesel-powered-vehicles-continue-to-dominate-the-irish-market/

According to the CSO[4], the average kms travelled by domestic vehicles is estimated as 16,352 kms per vehicle (although rural use is likely to be higher than this average). Market sources estimate that the global average fuel consumption by light duty vehicles (in this case passenger cars) is 7.2 litres per 100km[5]. Thus, Table 4 shows the estimated fuel use (assumed as diesel) by domestic vehicles in the study area.

*Table 4 Energy Use and Costs Domestic Cars*

| Small Area Number | Estimated kms per year | litres diesel | GWh | Cost 2021 €[6] |
|---|---|---|---|---|
| 157139001 | 915,712 | 68,678 | 0.69 | €107,138 |
| 157139008 | 1,569,792 | 117,734 | 1.18 | €183,666 |
| 157074006 | 1,062,880 | 79,716 | 0.80 | €124,357 |
| 157060005 | 1,520,736 | 114,055 | 1.14 | €177,926 |
| 157074004 | 605,024 | 45,377 | 0.45 | €70,788 |
| 157139003 | 1,111,936 | 83,395 | 0.83 | €130,097 |
| 157001002 | 1,406,272 | 105,470 | 1.05 | €164,534 |
| 157060002 | 2,011,296 | 150,847 | 1.51 | €235,322 |
| 157139006 | 1,896,832 | 142,262 | 1.42 | €221,929 |
| 157074002 | 833,952 | 62,546 | 0.63 | €97,572 |
| 157074008 | 1,160,992 | 87,074 | 0.87 | €135,836 |
| 157001003 | 2,093,056 | 156,979 | 1.57 | €244,888 |
| 157060004 | 1,455,328 | 109,150 | 1.09 | €170,273 |
| 157139002 | 1,504,384 | 112,829 | 1.13 | €176,013 |
| 157001001 | 1,700,608 | 127,546 | 1.28 | €198,971 |
| 157139010 | 833,952 | 62,546 | 0.63 | €97,572 |
| 157001006 | 866,656 | 64,999 | 0.65 | €101,399 |
| 157001005 | 1,275,456 | 95,659 | 0.96 | €149,228 |
| 157060003 | 1,259,104 | 94,433 | 0.94 | €147,315 |
| 157139007 | 1,177,344 | 88,301 | 0.88 | €137,749 |
| 157074007 | 752,192 | 56,414 | 0.56 | €88,006 |
| **All Areas** | **27,013,504** | **2,026,013** | **20.26** | **€3,160,580** |

Thus, the domestic energy use from cars in the study area is 20.6 GWh

## 4.4 Public Transport

The public transport in the study area is by bus. There are two service providers: Bus Éireann and LocalLink. We focus in this paper on the Bus Éireann service.

The LocalLink service operates five routes: three on-island and two between the island and Castlebar. Although significant to transport for the community, these routes are not frequently operated: The three on-island routes are operated on a return journey basis once each Friday. The Achill to Castlebar route operates a return loop once each on Tuesdays and Saturdays. As the

[4] https://www.cso.ie/en/releasesandpublications/ep/p-tranom/transportomnibus2019/roadtrafficvolumes/
[5] https://www.iea.org/reports/fuel-economy-in-major-car-markets
[6] https://www.globalpetrolprices.com/Ireland/diesel_prices/ last checked Oct 26 2021

distances travelled by these buses (approximately 51km one-way Achill Castlebar) are well within the range of EV Buses, we do not see these as a significant H2 opportunity.

Bus Éireann operates a route from Dooagh to Louisburg via Westport (a rail and bus hub for onward travel to Dublin) at an approximate distance of 81kms one way. The service schedule[7] is summarised in Table 5 below. This represents a considerable energy use which is open to decarbonisation. It must be noted that the distances travelled, and the consumption of fuel involved makes the use of BEV buses less practical from the point of view of recharging times. This represents an opportunity for the deployment of a FCEV (Fuel Cell Electric Vehicle) bus.


*Figure 4 Bus Eireann Achill-Louisburgh bus*

*Table 5 Bus Service Energy Use*

| Day | Outward | Inward | Total Distance km/y | Diesel Use l/y | GWh/y |
|---|---|---|---|---|---|
| Mon | 5 | 5 | 42,120 | 10,530 | 0.1053 |
| Tue | 5 | 5 | 42,120 | 10,530 | 0.1053 |
| Wed | 5 | 5 | 42,120 | 10,530 | 0.1053 |
| Thu | 5 | 5 | 42,120 | 10,530 | 0.1053 |
| Fri | 5 | 5 | 42,120 | 10,530 | 0.1053 |
| Sat | 5 | 5 | 42,120 | 10,530 | 0.1053 |
| Sun | 2 | 2 | 16,848 | 4,212 | 0.04212 |
| Total | 32 | 32 | 269568 | 67,392 | 0.67392 |

[7] https://www.buseireann.ie/timetables/450-1605627788.pdf last checked Oct 25 2021

## 4.5 Commercial Energy Use:

There are a number of SMEs in the study area which contribute to the overall energy use. Again, as stated in Section 2.2 there were difficulties in obtaining energy use data for these enterprises. We therefore estimate the energy use (focusing on those heat demands which are more amenable to decarbonisation through H2 deployments).

### 4.5.1 Hotels

Hotels use a considerable amount of energy for heating. While we were unable to access the SMEs to get exact energy usage figures, we were able to estimate the area of each hotel. Research[8] shows a typical heating energy demand for small to medium hotels is assumed as 235kWh/$m^2$. This provides an estimated energy use for heating for all four hotels in the study area. This in turn enables us to provide an overall figure for the heating demand of the sector as shown in Table 6.

*Table 6 Estimated Energy use of hotels in the study area*

| HOTEL | Ground Floor area* m2 | First Floor area m2 | Total Area m2 | Total Heating Energy Use kWh/y |
|---|---|---|---|---|
| Óstán Oileán Acla | 1,712.7 | 1,712.7 | 3,425.3 | 804,950 |
| Achill Cliff House Hotel | 286.3 | 286.3 | 572.6 | 134,570 |
| Óstán Ghob A'Choire | 1,138.0 | 1,138.0 | 2,275.9 | 534,841 |
| The Strand Hotel | 606.3 | 606.3 | 1,212.5 | 284,947 |
| TOTAL | | | 7,486.4 | 1,759,309 |

*Areas estimated through google maps.

The heating demand for hotels in Achill and Corraun is therefore estimated as 1.7 GWh/y. Much if not all of this is derived through fossil fuels (kerosine or LPG). This fossil fuel demand is amenable to replacement through electrification, although this will require considerable energy efficiency retrofitting. However recent technical developments suggest that it is also feasible to replace fossil fuel use with hydrogen.

### 4.5.2 Achill Island Distillery

The Achill Island Distillery (IAD) also known as the Drioglann Oileán Acla is located in the Údarás na Gaeltachta business park in Bunacurry. Distillation of whiskey began at the end of July 2019.

[8] S. Taylor, A. Peacock, P. Banfill, and L. Shao, "Reduction of greenhouse gas emissions from UK hotels in 2030," Build. Environ., vol. 45, no. 6, pp. 1389–1400, 2010, doi: 10.1016/j.buildenv.2009.12.001.

Producing whiskey is an energy intensive process due to the large amounts of heat energy required. The energy required to produce whisky is often described by the Specific Energy Consumption (SEC) which is the energy directly required to produce new-make whiskey[9].

*Table 7: Energy use estimates for distillery*

| Parameter | Value | Unit |
|---|---|---|
| Energy Consumption of Whiskey Production[10] | 11.55 | kWh/L |
| Quantity of Whiskey produced at Achill Distillery[11] | 220,000 | Litres/yr |
| Energy Required | 2,541,000 | kWh/yr |

Temperatures required in whiskey production range between 75-85 degrees Celsius extended in two distillation processes over approximately 12 hours, therefore the heating demand is intensive. This sustained concentrated high heat demand represents a significant opportunity for H2 use in Achill.

## 4.6 Total Estimated Energy Use

Combining each of the identified energy uses identified above, we can provide an evaluation for the total potential H2 distribution opportunity in the study area.

*Table 8 Total Identified Energy Use Achill and Corraun*

| Energy User | kWh/y |
|---|---:|
| Domestic Homes | 110,551,165 |
| Domestic Transport | 20,260,000 |
| Public Transport | 673,920 |
| SMEs Heat | 1,759,309 |
| SME manufacturing | 2,541,000 |
| Total | 135,785,394 |

Some SME energy users were not included in these calculations namely restaurants, supermarkets, and smaller manufacturers and food processors.

There is therefore a considerable energy demand of 135 GWh per annum in the study area. While only a fraction of this will be open to fossil fuel replacement by H2 in the medium term, the scale of

[9] S. Meadows and P. Strachan, "Anaerobic Digestion and Resource Use within the Scotch Whisky and UK Beer Industries," Univ. Strat. Glas., pp. 1–96, 2015. Available: http://www.esru.strath.ac.uk/Documents/MSc_2015/Meadows.pdf

[10] O. Eriksson, D. Jonsson, and K. Hillman, "Life cycle assessment of Swedish single malt whisky," J. Clean. Prod., vol. 112, pp. 229–237, 2016, doi: 10.1016/j.jclepro.2015.07.050.

[11] Reported by Achill Island Distillery

the potential opportunity is considerable. Technical reviews of the feasibility including maturity of H2 deployment is discussed Section 6 below.

# 5 Energy Generation Opportunities

## 5.1 Onshore Wind Opportunity

In this Section we assess the feasibility of a hypothetical onshore wind turbine location. We apply the learnings from this investigation to Achill and Corraun as a whole.

## 5.2 Outline assessment of the suitability of Onshore Wind

The authors were requested to examine the suitability of a non-specified site on Achill.

The requirements of such locations would be:

- Low potential visual impact
- Distance from dwellings
- Low Agricultural land use value

Possible Disadvantages of any such location would be:

- Potential interference with Protected Area (see below)
- Distance from Existing Grid
- Lower Wind Speeds in the area
- Number of turbary rights holders

### 5.2.1 Assessment as to whether such an investigation will represent a value for money proposition

There are a number of factors which would determine a value for money assessment of a potential wind turbine at an onshore site.

These are: the available resource, existing land use alternative value, cost of turbine, planning costs, grid costs, wholesale energy market, environmental impacts, socio-political issues[12]. We have identified that the resource is promising (see Section 5.2.2 below) and the existing land use alternative value is economically moderate (although there are complex ownership patterns and cultural values associated). In sections 5.2.5 to 5.2.8 below, we will examine the impact of the other factors on the viability of the proposed scheme.

[12] Talinli, I., Topuz, E., Egemen and Kabakc, S., 2011. A Holistic Approach for Wind Farm Site Selection by Using FAHP. Wind Farm - Technical Regulations, Potential Estimation and Siting Assessment, doi: 10.5772/17311

### 5.2.2 High level data on wind speed, likely energy production and types of turbines suited to each location.

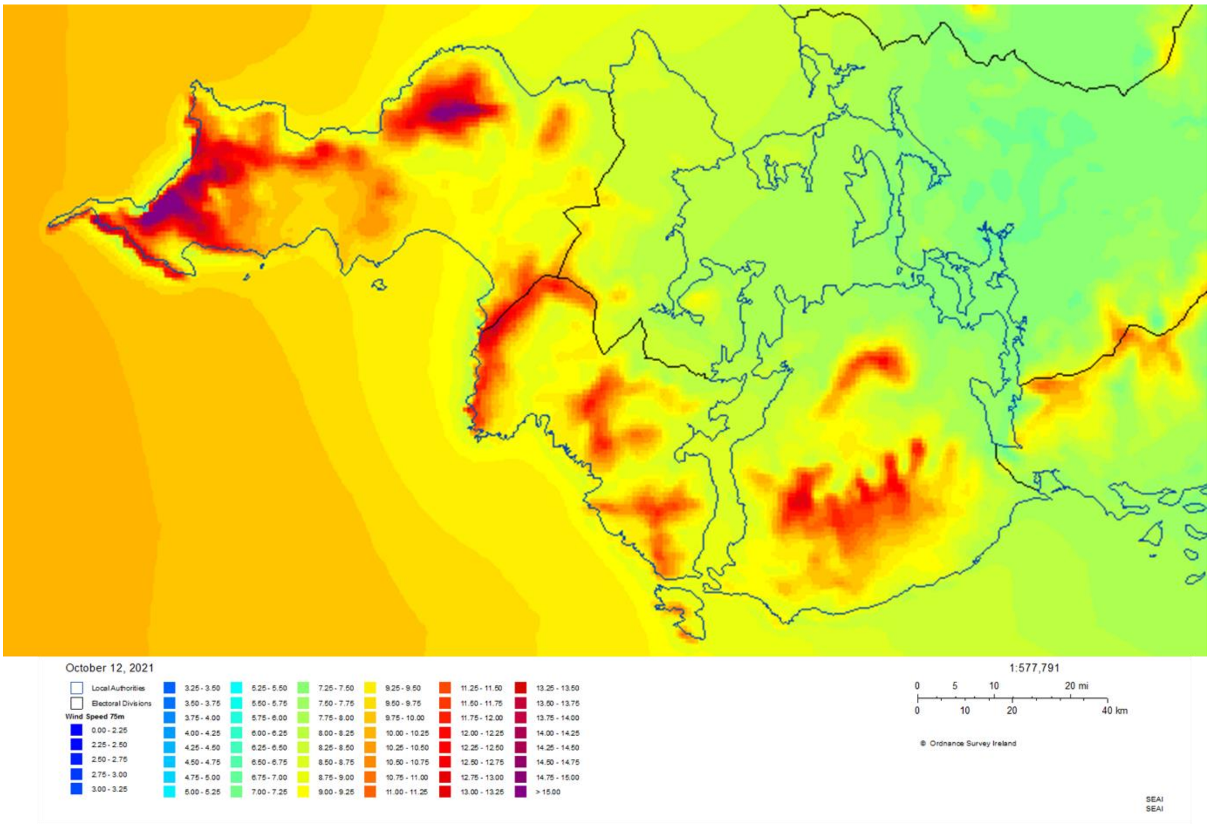


*Figure 5 Wind Speed Data Achill*

*Source: SEAI Wind Mapping System*[13]

Figure 5 shows that as expected for the West of Ireland, the wind speeds at 75m (which would be the proposed hub height for a modern wind turbine development) are averaged at 9m/s, which makes the wind resource very promising subject to a grid assessment and planning policy.

The available wind energy onshore in Achill are determined by the modelled Wind Distribution pattern shown in below Figure 6. The estimated output of a 1.5MW turbine on Achill could produce approximately 4,200,231 kWh/yr or 4,200 MWh/yr – this would on the face of it represent a very productive wind resource, should planning policy and an economic price for grid connection be achieved (see below)

[13] https://gis.seai.ie/wind/ accessed 08.10.21

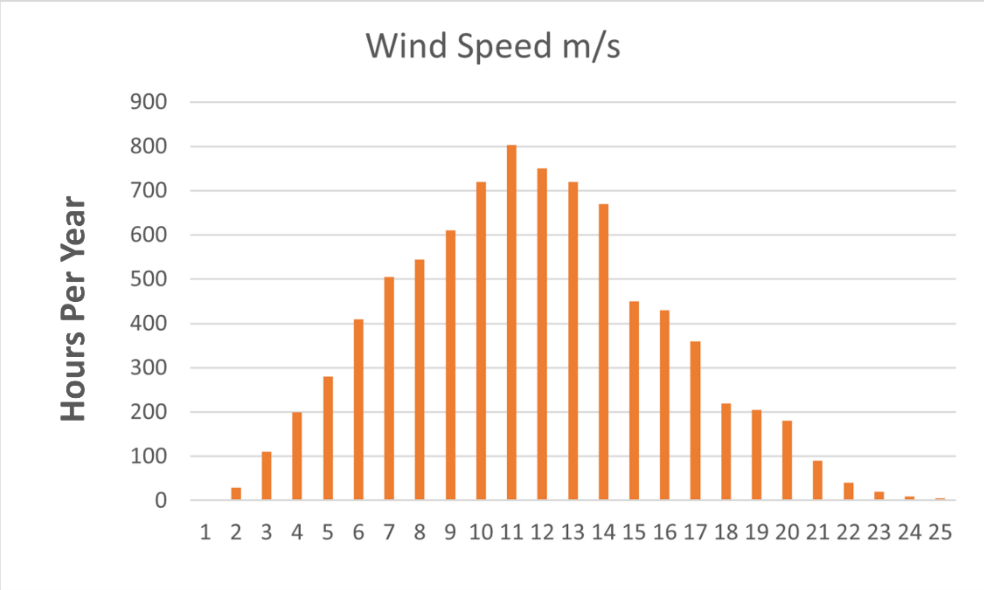


*Figure 6 Wind Speed Frequency Distribution Achill*

### 5.2.3 Wind turbine costs

In 2019, the assumed cost for plant, engineering works and installation for a 1MW turbine in the West of Ireland was €1.4-1.6m/MW installed[14] [15]. This is an average and does not include site specifics, where, for example, there is a need for extensive grid upgrade (see Section 5.2.4 below). Due to Covid19 and supply chain disruption 2020-2021 there has been a noticeable rise in the costs of raw materials as well as deployment ready plant. Labour costs also appear to have greatly increased. However, the project is at consultation phase. We will assume for our calculations that the market will return to normal over the course of the project's assessment, planning and consultation. Therefore, we use 2018 costs for our calculations, choosing the mean value of €1.5m per MW installed. However, we would indicate the above caveats here.

### 5.2.4 Outline Grid assessment

The Irish electricity network is divided into two sections: the distribution network and transmission network. The distribution network includes the (medium voltage) MV and 38kV networks. The MV network supplies domestic load such as the domestic user and SMEs. The MV network is usually supplied via the 38kV substation network. The nearest 38kV substation to Achill is in Achill Sound. It supplies a secondary voltage to the surrounding users of 20kV. According to the ESBN's Demand Capacity Heatmap (Nov 2020 version) it has limited additional capacity. This would increase the cost of renewable generation at the site.

### 5.2.5 Survey of the planning and policy environment

In the Mayo County Development Plan 2014-2020[16], Achill Island is located in 'Policy Area 1, Montaine Coastal Zone': this highly restricts the acceptable forms of development in the area.

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[14] https://www.teagasc.ie/media/website/publications/2018/Teagasc-A4-Energy-Fact-Sheet-No.-17-Wind-Energy_2pp.pdf

[15] Duffy, A., Hand, M., Wiser, R., Lantz, E., Dalla Riva, A., Berkhout, V., … Lacal-Arántegui, R. (2020). Land-based wind energy cost trends in Germany, Denmark, Ireland, Norway, Sweden and the United States. Applied Energy, 277, 114777. doi:10.1016/j.apenergy.2020.11477

[16] https://www.mayo.ie/getmedia/2bacbcba-ad2d-4b6c-ac01-d0edecebb704/1-1-Document1,29000,en.pdf pp 61-62

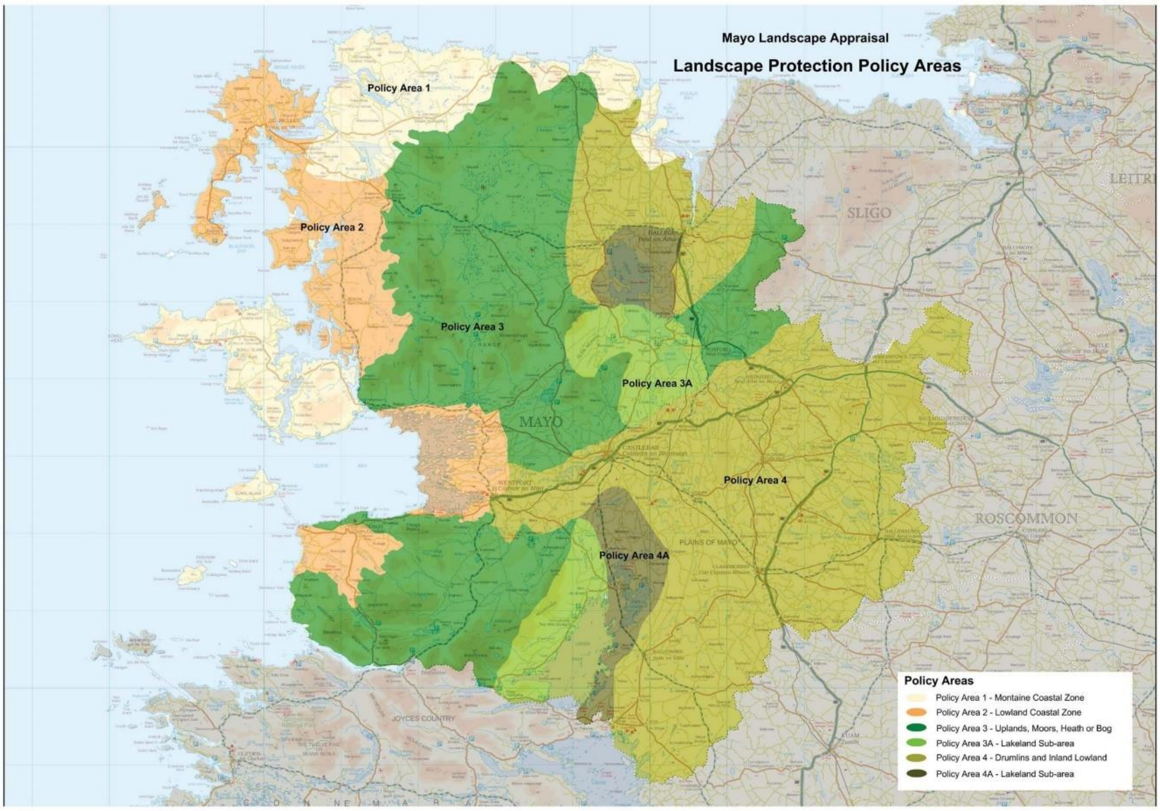


*Figure 7 Mayo Landscape Protection Policy Areas*

*Source: Mayo County Development Plan, 2014 – 2020, p61*

The Policy Area 1 designation restricts wind turbines and grid developments specifically as having:

> *'High potential to create adverse impacts on the existing landscape character. Having regard to the intrinsic physical and visual characteristics of the landscape area, it is unlikely that such impacts can be reduced to a widely acceptable level.'*

The new County Development Plan 2021-27 is in draft form but is expected to be approved by the elected representatives in November-December 2021[17]. Supporting documentation, for example the Landscape Appraisal of County Mayo[18], states that again, Achill and Corraun are designated as within the 'Montaine Coastal Zone' which places restrictions on appropriate development.

[17] https://www.mayo.ie/planning/county-development-plans/2021-2027

[18] https://www.mayo.ie/getmedia/54e093a8-493e-48d1-ba85-d2a899b50eac/Vol-4-Landscape-Appraisal-of-County-Mayo-08.pdf

From the document policy recommendations are:

- Policy 1 Recognise the substantial residential development existing in some locations and the further pressures for residential development in this policy area.
- Policy 2 Facilitate appropriate tourism and amenity development in a progressive and clustered manner, where feasible, that reflects the scale, character and sensitivities of the landscape (Ref. to Housing Policy).
- Policy 3 Encourage development that will not have a disproportionate effect on the existing character of the coastal environment in terms of location, design, and visual prominence.
- Policy 4 Consider development that does not significantly interfere or detract from scenic coastal vistas, as identified in the Development Plan, when viewed from areas of the public realm.
- Policy 5 Encourage development that will not interrupt or penetrate distinct linear sections of primary ridge lines and coastlines when viewed from areas of the public realm.
- Policy 6 Preserve any areas that have not been subject to recent or prior development and have retained a dominantly undisturbed coastal character.
- Policy 7 Consider development on steep slopes, ensuring that it will not have a disproportionate or dominating visual impact on the surrounding environment as seen from areas of the public realm.

*Figure 8 Suggested Landscape Policies for Montaine Coastal Zone*

*Source: Landscape Appraisal of County Mayo, p55.*

These policies would be very significant for any wind generation project onshore at Achill Island which would for example be claimed to 'have a disproportionate effect on the existing character of the coastal environment in terms of location, design, and visual prominence', or 'interrupt or penetrate distinct linear sections of primary ridge lines and coastlines when viewed from areas of the public realm'. Any proposed scheme would have to refrain from impinging on the preservation of 'areas that have not been subject to recent or prior development and have retained a dominantly undisturbed coastal character'. Suitable turbine locations would need to ensure that if a development was to occur on steep slopes, it should 'not have a disproportionate or dominating visual impact on the surrounding environment as seen from areas of the public realm.'

This plan would therefore require a special case to be made for wind turbine developments over much of Achill.

### 5.2.6 National Parks & Wildlife Service Protected Sites

The National Parks & Wildlife Service (NPWS) is responsible for the designation of conservation sites in Ireland. There are a number of designations for protected landscapes and sites, three of which are relevant to this study of feasible locations for renewable energy generation on Achill:

1. Special Area of Conservation
2. Natural Heritage Area
3. Special Protection Area

Each of these have specific criteria for preservation and protection[19] as shown in Table 9 below.

*Table 9 Protected Areas Described*

| NPWS designations | **Special Area of Conservation** | **Natural Heritage Area** | **Special Protection Area** |
|---|---|---|---|
| Description | Prime wildlife conservation areas in the country, considered to be important on a European as well as Irish level. Irish habitats include raised bogs, blanket bogs, turloughs, sand dunes, machair (flat sandy plains on the north and west coasts), heaths, lakes, rivers, woodlands, estuaries, and sea inlets. | an area considered important for the habitats present or which holds species of plants and animals whose habitat needs protection. | Required under the terms of the EU Birds Directive (2009/147/EC) for the protection of listed rare and vulnerable species, regularly occurring migratory species, wetlands especially those of international importance |

### 5.2.7 Implications for protected area designations of Wind Turbine Developments

The Draft Revised Wind Energy Development Guidelines published in 2019 require that:

> *Planning permission cannot be granted where such an assessment shows that the development would adversely affect the integrity of an SAC or SPA, unless, for example, imperative reasons of overriding public interest (IROPI) can be demonstrated in line with Article 6(4) of the Habitats Directive[20].(p15)*
>
> *The impact of wind energy development proposals on the landscape, including the natural and built environment, must be considered along with the legitimate concerns of local communities (p21)*

### 5.2.8 Protected Designations on Achill and Corraun

Figure 9 shows the Protected Area designations on Achill and Corraun taken from the NPWS Designations Viewer[21]. There are eight relevant areas where renewable energy development would be considered problematic.

[19] Taken from The National Parks & Wildlife Service https://www.npws.ie/protected-sites accessed 12.10.22
[20] https://assets.gov.ie/109102/ae9107b8-6a27-4f26-9a12-6b00632ceaf0.pdf p15 accessed 10.8.22
[21] https://dahg.maps.arcgis.com/apps/webappviewer/index.html?id=8f7060450de3485fa1c1085536d477ba accessed 10.10.21

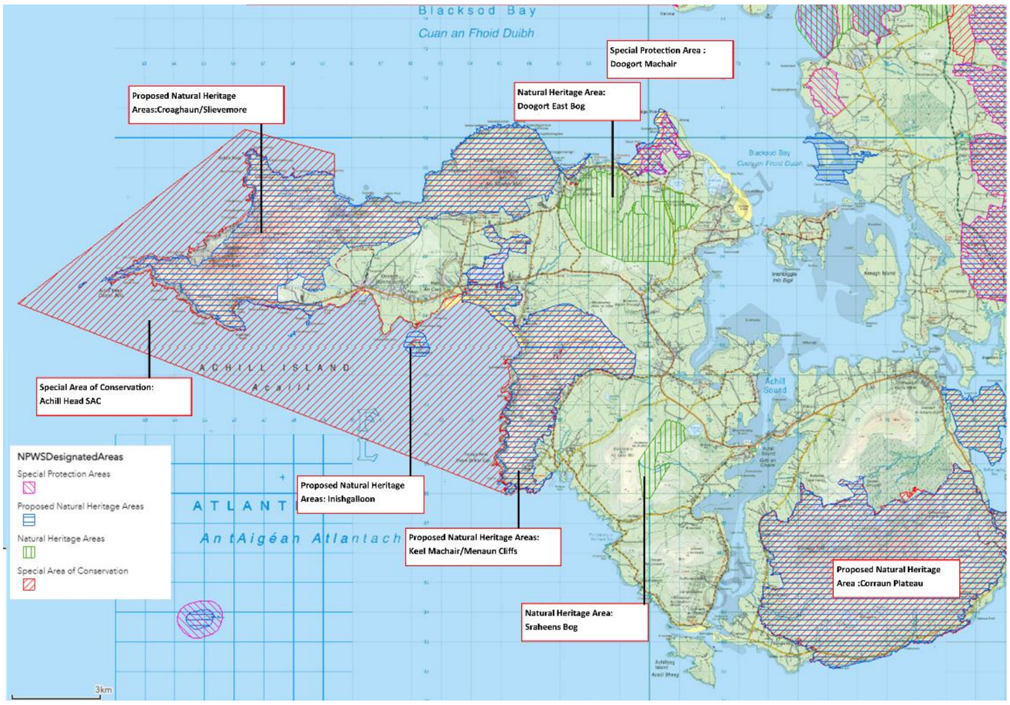


*Figure 9 Protected Area designations on Achill and Corraun*

*Source: NPWS Designations Viewer*

There are therefore few locations on Achill and Corraun that would not be located more than 2km from a protected area. This presents a serious planning obstacle to onshore wind developments on Achill. Planning for a wind turbine on Achill-Corraun, would be very difficult to achieve due to their protected designation.

## 5.3 Photovoltaic (PV) Opportunity

Recent policy and technical developments have led to an increasing focus on PV as a viable renewable power generation in the West of Ireland. There has been a rapid increase in the level of investment by large developers[22] since the creation of the Renewable Energy Support Scheme 2020 where 63 solar projects totalling over 1,000 MW (767.3 GWh) were awarded contracts in the RESS-1 auction [23]. Of these, two were community owned projects at scale (c. 4MW each) in Mayo and North Galway. We will therefore examine PV potential on the island with regard to its ability to facilitate the roll out of a H2 infrastructure on the island.

### 5.3.1 PV farms outline

In this paper, PV farms are considered as ground-mounted arrays of >100kWp. As stated above, Ireland historically had very little engagement in PV at scale. A BNRG development at Enfield in Kildare is set to be the first large-scale (14MWp[24]) solar farm[25]. Over the past 10 years there has been an increase in the efficiency of new PV panels[26] and a reduction in costs per unit owing to greatly increased volumes of production worldwide resulting in an overall reduction in cost per

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[22] https://irishsolarenergy.org/solar-energy-ramping-up-investment-to-e750m/
[23] https://www.energyireland.ie/putting-solar-pv-in-the-mix/
[24] https://www.eirgridgroup.com/site-files/library/EirGrid/RESS-1-Provisional-Auction-Results-(R1PAR).pdf p10.
[25] https://kildare-nationalist.ie/2020/09/30/kildare-leads-ireland-into-the-solar-age/#.X3b13T-SlPZ
[26] https://www.nrel.gov/pv/assets/pdfs/champion-module-efficiencies.pdf

MWh produced[27]. Taken with the policy context, and the planning and environment restrictions discussed in Section 5.2.8 above, these factors require us to fully investigate the PV opportunity in Achill.

### 5.3.2 Potential Locations

We will look at the location options in a very general manner, given that there has been no investigation of specific sites possible. Landowners of suitable locations have not been consulted in the completion of this section of the report, and we have found that there are numerous sites that could accommodate a viable PV scheme >5MWp.

### 5.3.3 PV site choice parameters

In general, 5MW PV sites require approximately 10 hectares of contiguous land in a relatively low-lying flat location (incline <5 degrees) with an unobstructed South facing aspect, sheltered from the sea with a good solar resource. While a proximity of less than 2km to 38kV substation with open capacity is also highly advantageous, in this study we are examining potential for H2 production. We will therefore consider two scenarios: a site availing of proximity to a 38kV substation, and one which does not.

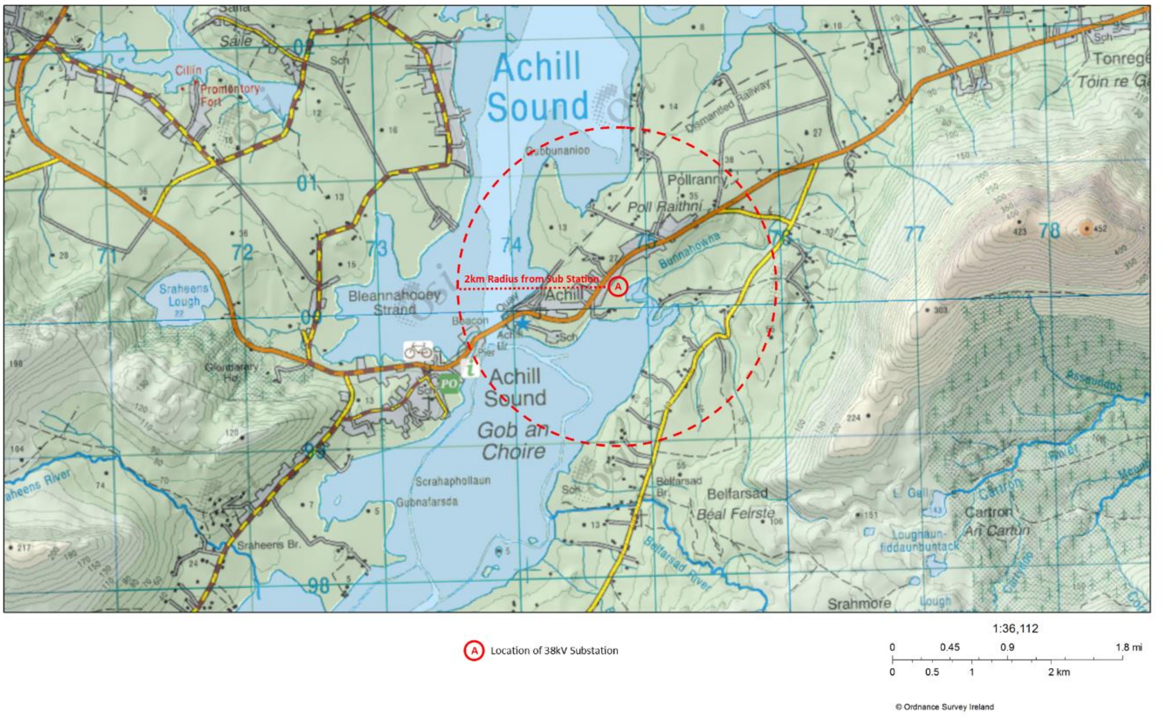


*Figure 10 PV to grid site parameters*

Figure 10 shows the effect of the parameters including grid proximity on the potential locations on Achill which may be suited to a PV development of 5MW. We will refer to this location as 'PV Site Area A.'

In this location there are a limited set of locations which may be suited to such a PV development, should the grid capacity be available.

[27] https://ec.europa.eu/jrc/sites/default/files/kjna29938enn_1.pdf

It should be noted that these potentially feasible options are not subject to any protected designations.

In the event that the PV project is 100% diverted to H2 production, there is a much larger range of locations suitable. Issues of protected status are more relevant. There are areas where there is land that is suitably flat, outside protected areas, with southern aspect. We will refer to these locations as 'PV Sites B'

### 5.3.4 Solar Resource

In comparison to other locations in Ireland, Achill receives less solar radiation. Figure 11 Shows that Achill, in common with the West of Ireland has less PV potential than the South East of the Country. This by no means that PV generation at scale is unfeasible. Indeed, as Figure 12 shows, the estimated output of power for PV Site A is superior albeit marginally than either of the two sites (Mayo and Galway) successful in the RESS-1 auctions in 2020. It is assumed that the 'Community' designation that each of these projects was significant in their economics. For the purposes of this study, we will assume that all Achill sites will share a similar resource in particular as any site that should be chosen will reflect the minimum aspect, distance from sea, and topography requirements.

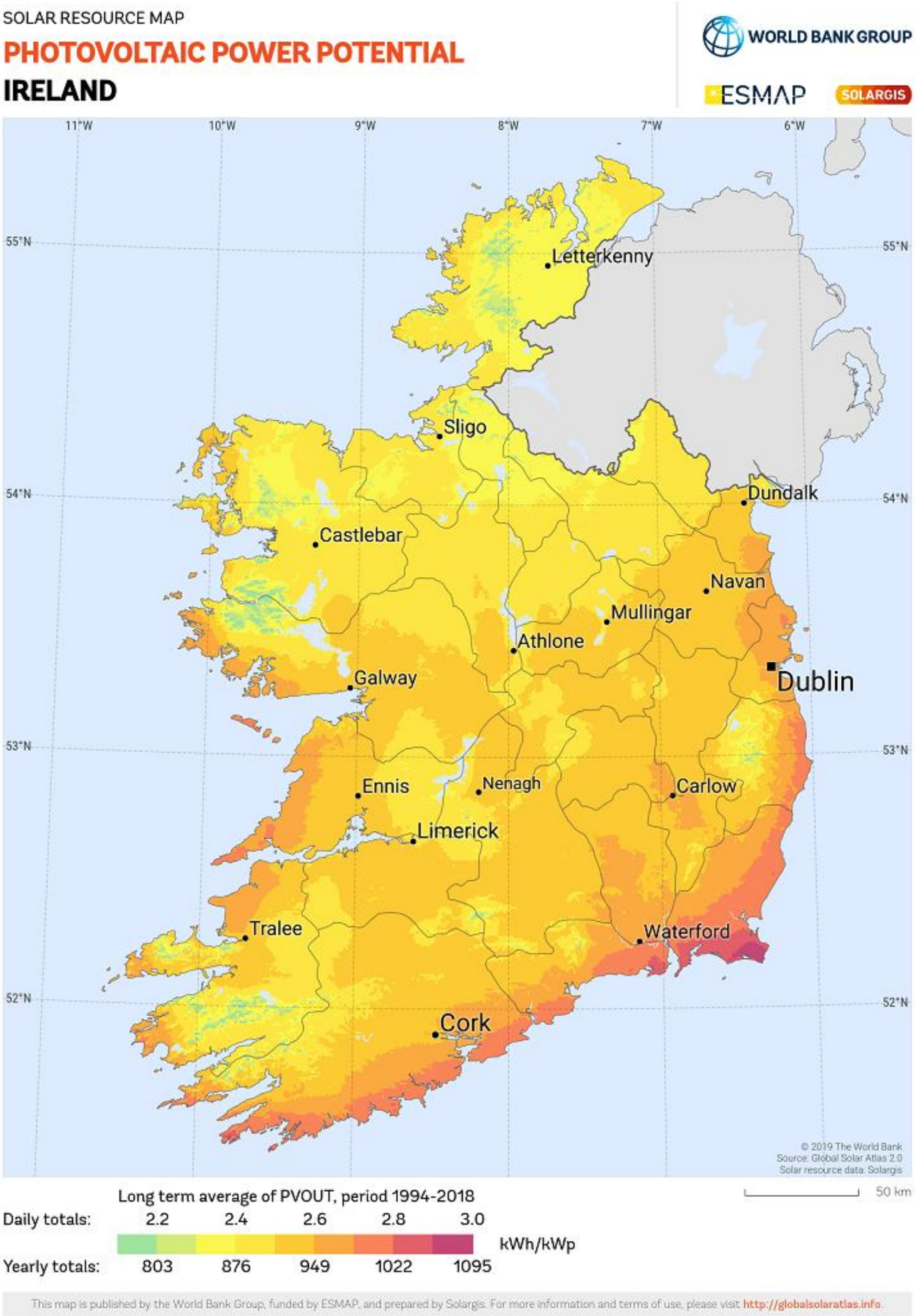


*Figure 11 PV Power Potential Ireland - ESMAP*

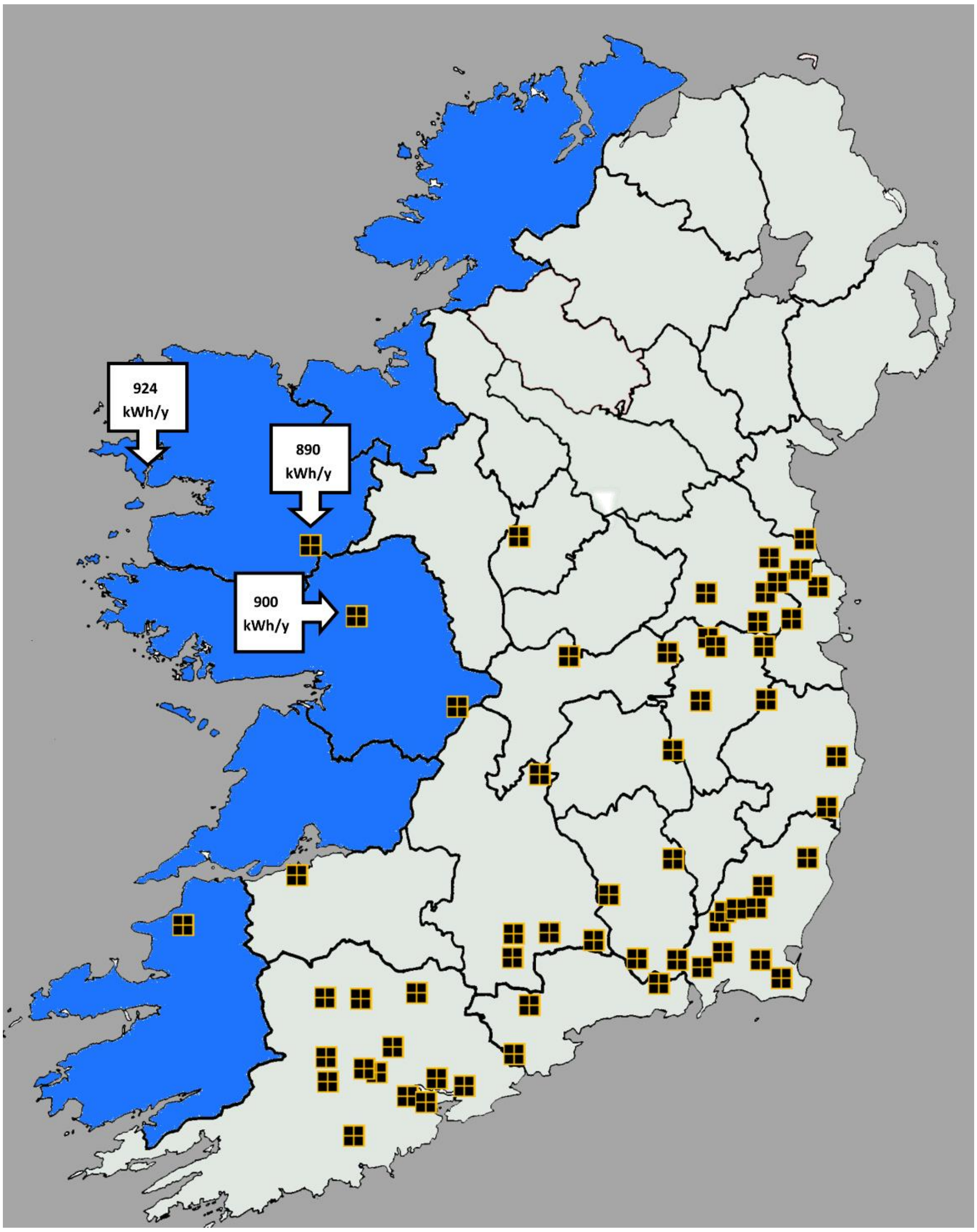


*Figure 12 PV farms successful in 2020 RESS 1 auction. Including solar radiation values for two Mayo sites and Achill:* ***kWh/kWp per annum****.*

*kWh outputs taken from: PHOTOVOLTAIC GEOGRAPHICAL INFORMATION SYSTEM*[28]

### 5.3.5 Energy Outputs for 5MW PV Farm Sites Areas A and B

Figure 13 shows the expected power outputs by month for a ground mounted southern aspect 5MW power solar PV farm at a suitable site on Achill. These figures take into account system losses of 14%. System losses are all the losses in the system, which cause the power actually delivered to the electricity grid to be lower than the power produced by the PV modules. There are several causes for this loss, such as losses in cables, power inverters, dirt (sometimes snow) on the modules and so on.

[28] https://re.jrc.ec.europa.eu/pvg_tools/en/#MR

The kWh/yr/kWp installed is based on Crystalline Silicon panels which are now considered to be high. Thus, the production estimates here are conservative.

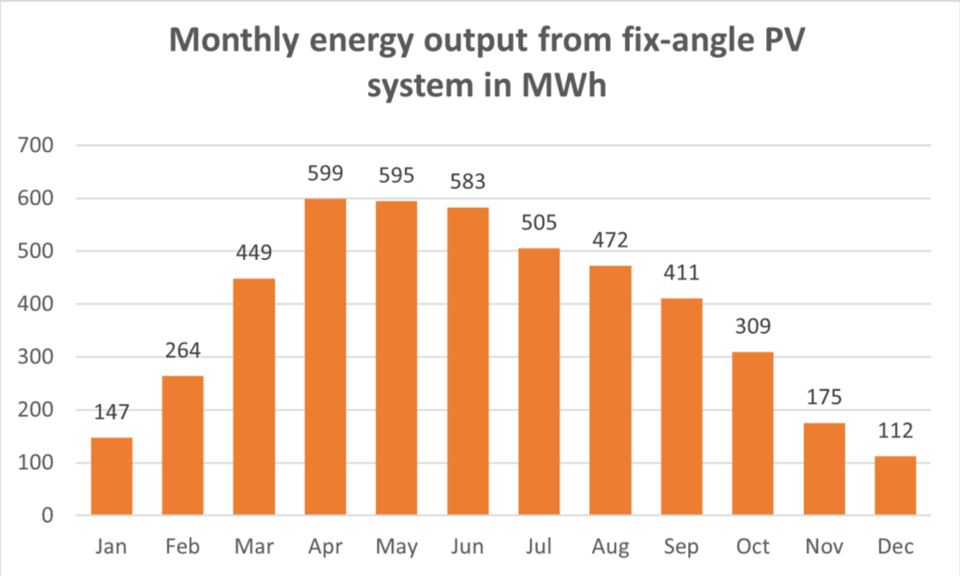


*Figure 13 Monthly energy output from fix-angle PV system in MWh*

### 5.3.6 Economics of Grid connected PV:

Levelized cost of electricity is a measure of the average net present cost of electricity generation for a generating project over its lifetime.

It is described by the following formula in Appendix Section 11.1.1.

The LCOE for a grid connected PV installation at a hypothetical location in Achill is between €100.50/MWh and €134/MWh. This is in large part due to assumed higher than average installation costs, in particular any grid upgrades required, and also the relatively reduced solar radiation available on the island.

Such an LCOE is generally above the *average* auction bid for community-owned power in RESS-1 (which was 104.15 €/MWh). Although it should be stated that this included both wind and PV projects, and that two PV projects had lower radiation values (Figure 12 above). It is likely that the community PV sector will be more competitive in RESS2 and subsequent auctions. There are also likely to be more bids from parts of the island that have better solar resources and easier access to the grid. Thus, a 5MW community-owned PV farm may have to have lower installation costs than average and be willing to be less profitable than other community PV projects.

A non-grid tied PV installation, such as would provide power to a H2 generation project would have reduced installation costs and may present another economic prospect. It is a scheme such as this that will be discussed below in Scenario 4.

## 5.4 Offshore Wind

With the onshore wind option facing an unfavourable planning and heritage context, it is necessary to investigate the option of offshore energy generation. In addition to this wind energy operates very efficiently in the West of Ireland whereas PV does not. While we do investigate a scenario for PV to H2 (Section 7.4), it is essential to investigate the offshore wind option.

### 5.4.1 The West of Ireland Context

Ireland is currently undergoing a rapid expansion of interest in offshore wind electricity generation. Currently there is one operational offshore wind farm (Arklow Bank) in the East of the country with just 26MW installed. There are however a large number of projects undergoing license approval.

The Climate Action Plan, June 2019, set out a strategy for 3.5 GW[29] of offshore wind energy by 2030. While the Climate Action Act[30] (2021) does not mention offshore wind explicitly, the Irish offshore strategy was laid out in the Climate Action Plan 2021[31]. These included a target of up to 5 Gigawatts of offshore wind energy. In the context of the levels of offshore generation already within the application process (see Table 10 below), this may not seem particularly ambitious. The preparatory groundwork has been laid for a regulatory process for applications for offshore wind schemes has been laid out and this it is hoped will bring more clarity to the matter for developers and citizens. This has resulted in the Maritime Area Planning Bill 2021 being passed in the Dáil on 1st December 2021[32].

As things stand at time of writing (November 2021) Table 10 shows the applications for licenses to explore Irish waters with a view to developing offshore wind generation.

[29] https://assets.gov.ie/25419/c97cdecddf8c49ab976e773d4e11e515.pdf

[30] https://data.oireachtas.ie/ie/oireachtas/bill/2021/39/eng/ver_b/b39b21d.pdf

[31] file:///C:/Users/lugho/Downloads/203558_f06a924b-4773-4829-ba59-b0feec978e40.pdf

[32] https://data.oireachtas.ie/ie/oireachtas/bill/2021/104/eng/ver_b/b104b21d.pdf

*Table 10 Pipeline of Offshore Wind Projects West of Ireland*

| **Relevant Projects[33] and Foreshore Licence Applications[34]** | | | |
|---|---|---|---|
| **Project** | **Location** | **Capacity MW** | **Developer(s)** |
| Skerd Rocks | Galway | 100 | Fuinneamh Sceirde Teo |
| Clare Marine Energy Park Off Kilkee | Clare | 1000 | DP Energy |
| Aniar, Co. Sligo | Sligo | 1000 | Aniar Offshore Energy Limited (originally PNG Energy) |
| Clare | Clare | 1500 | ESB |
| Clare (Western Star) | Clare | 1350 | Simply Blue |
| Tralee-Fixed/Floating ORE Wind - west of Doonbeg to Castlegregory | Kerry | Unknown | Mainstream Renewable Power - Tralee |
| Clarus Site, Clare | Clare | 1000 | Clarus Offshore Wind Farm ltd. (DP Energy) |
| Ilen Array, Kerry | Kerry | Unknown | Withheld |
| Arranmore Wind Park, Donegal | Donegal | Unknown | Withheld |
| Malin Head, Donegal | Donegal | Unknown | Withheld |
| Kerry | Kerry | 1000 | Kerry Offshore Wind Ltd (Warwick Energy) |
| Off Kilkee, Clare | Clare | 500 | Munster Sea Wind Ltd (Warwick Energy) |
| West of Valentia Island | Kerry | 1000 | Valentia Island Energy Ltd |
| Floating Offshore Wind - West Coast | West Coast | 1000 | Withheld |
| Saoirse - approx 4Km off Doonbeg, Clare | Clare | 5 | Western Star Wave Ltd - Saoirse (Simply Blue) |
| **Total *known* Offshore Wind Energy Applications West of Ireland** | | **9,455** | |

Of these West of Ireland projects, there are six clustered around Co Clare, where there is considerable infrastructure already in place.

The Moneypoint Coal Fired Generation station (915 MW) is due to cease operations in 2025[35] and the ESB has proposed plans for a 1.4 GW floating windfarm[36] which will also potentially produce

[33] These are projects which have already been granted foreshore exploratory licenses under the legacy system
[34] These projects will be processed under the new licensing process. The information comes from the Irish Department of Housing.
[35] https://ieefa.org/ireland-to-close-its-only-coal-plant-convert-site-to-offshore-wind-hub/
[36] https://www.irishtimes.com/business/energy-and-resources/moneypoint-power-station-to-become-major-base-for-renewable-energy-1.4532323

hydrogen[37]. There is also much discussion of a project to make the existing deep-water ports of Shannon-Foynes a hub for offshore wind turbine installation and servicing. There is therefore already a strong link in the minds of the developers and utilities between offshore wind and hydrogen.

There are also projects in Mayo/Sligo that have made this link: the Corrib Critical Infrastructure Hub project proposes to link H2 into the National Gas grid via the Corrib Offshore Gas field infrastructure[38]. The proposal from the Irish Offshore Operators' Association (IOOA) is at an early stage and is seen as strategic rather than imminent. However, it is clear that the policy field for H2 in Ireland is changing rapidly.

There is one active foreshore licence for a community offshore wind energy project, that of Valentia Island Energy Ltd (website link here). This is a 1GW proposal to be sited to the south of the Island at a distance of approximately 22km from the coast.

There is clearly a rapidly growing interest in offshore wind energy generation on the West coast which appears to demonstrate an awareness of the realistic potential for such projects. This suggests that this study examines two levels of opportunity in the offshore sector: an offshore development that seeks to meet the needs of the island and its immediate hinterland, and also a development of greater scale that could meet an export market whether that be national or international. These are discussed in Section 7.1-7.3 below.

### 5.4.2 Identification of feasible offshore site

The identification of sites suitable for offshore wind energy generation is a complex and demanding issue. Typically, this identifies any serious constraints to an offshore project. Figure 14 shows the range of issues to be examined. ECI has conducted a preliminary investigation of these constraints and has identified a location off the coast of Achill that is not negatively bound by these potential constraints. This area is indicated in Figure 15 below.

[37] https://www.sfpc.ie/esb-equinor-moneypoint-announcement/

[38] https://www.irishtimes.com/business/energy-and-resources/offshore-operators-propose-low-carbon-energy-hubs-for-cork-and-mayo-1.4559814

- Depth Profile (Bathymetry) & Gradient
- Sea Bottom Morphology
- Marine Traffic and Shipping Lanes
- Grid Connection
- Potential Wind Resource and Distribution
- Cultural Heritage (Shipwrecks)
- Bathing Waters
- Fishing Traffic
- Inshore & Offshore Fishing Areas
- Aquaculture Farms
- Wind & Wave Developments
- Oil, Gas and Aggregate
- Tourism and Recreation
- Sailing Clubs
- Surfing Clubs and Popular Surf Locations
- Inshore Angling
- Harbours, Ports and Distance from Shore
- Proximity To Deep Water Ports
- Marine Protected Areas and Natural Heritage Sites
- Ramsar Sites
- Protected Species
- Physio Chemical
- Visual Impact
- Aviation

*Figure 14 Issues examined as part of an offshore project constraints study*

*Source: ECI constraints report*

### 5.4.3 Proximity to Protected Areas:

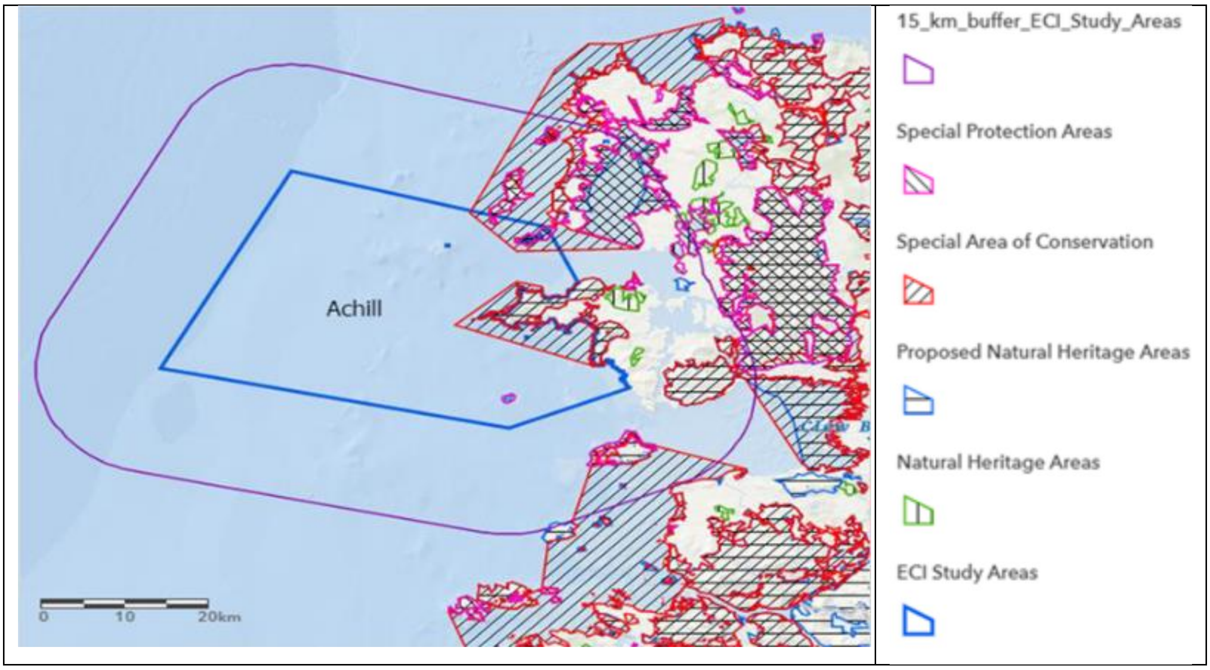


*Figure 15 Achill Island Proximity to Protected Areas & Natural & Proposed Heritage Sites*

Offshore wind energy generation in this study focuses on *far-shore* sites, rather than nearshore sites that are needed for fixed sea bed turbines. As such, the proposed site is >20km from the coast of the island and its surrounding coast. This is proposed to minimise visual and sea bed impact in full recognition of the significance of biodiversity, sustainability, cultural heritage, environmental protection and the tourism industry to Achill and its hinterland. For the purposes of this study, we have identified a potential site for a 630MW project 20km to the West of Achill. While we recognise that Scenarios 1 and 2 do not require a site of such an extent, we believe a 5MW near-shore project is not feasible, given the unique natural and cultural sensitivity of the study area. We recommend instead that a site suitable for floating wind turbines be required.

Based on our initial investigation of the constraints listed in Figure 17, we are confident that there are no significant barriers to an offshore generation project indicated in Figure 18.

## 5.5 Renewable Electricity Generation Opportunities Summary

We consider in conclusion that offshore wind and PV electricity generation are viable for Achill and Corraun. We do not envisage that onshore wind of scale is viable owing to planning and heritage concerns

*Table 11 5.5 Renewable Electricity Generation Opportunities Summary*

| Parameter | 5MW Onshore WInd | 5 MW Offshore WInd | 630MW Offshore Wind | 5MW Onshore PV |
|---|---|---|---|---|
| Planning | ✗ | ✓ | ✓ | ✓ |
| Area Availability | ✗ | ✓ | ✓ | ✓ |
| Viable Power-to-Grid Economically | ✓ | ✗ | ✓ | ✓* |
| Viable Power-to-H2 Economically | ✓ | ✓ | ✓ | ✗ |

*Based on RESS auction price of >€100/MWh, which is possible only with 100% community ownership and reduced competition in the auction pot.

# 6 Hydrogen Use Technologies State of the Art

In this section we review the technologies that are currently or soon to be available which would enable the replacement of fossil fuel use with hydrogen. We will not focus on the economic variables here (this is to follow in Section 7), rather on the level of maturity, market readiness, and regulatory framework of each application. However, to put these H2 technology developments in context, we need to briefly assess the state of play in H2 projects generally in Ireland.

## 6.1 Hydrogen Projects in Ireland

### 6.1.1 Context

Irish policy makers prior to 2018 did not envisage hydrogen as a medium-term prospect. The 'wait and see' approach which we outlined at that time[39] sought to take a late adopter approach which would benefit from technology developments in the sector.

However, the work done by INTERREG projects on the ground in Ireland, in parallel with education and information dissemination by key H2 sector specialists led to the establishment of very useful projects from the point of view of promoting H2 in the policy context.

However, the technology developments and research have only very recently led to real-world projects which demonstrate H2 transport technology directly to the public and the policy makers.

### 6.1.2 H2 projects in Ireland

The H-Wind project (link), led by University College Cork's MaREI Research Centre, is co-funded by Science Foundation Ireland and four industry partners: Gas Networks Ireland, DP Energy, and ESB. The significance of the project is indicated by the presence in the consortium of major utility, distribution, and energy production stakeholders. The project's goals are the investigation of '…cost-reduction measures for large-scale hydrogen production from offshore wind farms, concepts for scalable offshore wind – hydrogen hubs, procedures for hydrogen safety, the customer value chain, and policy recommendations'. At the launch of the project, consortium member Gas Networks Ireland, 'is committed to delivering a net-zero gas network by 2050 by gradually replacing natural gas with renewable gases such as hydrogen. Blends of up to 20 per cent hydrogen with natural gas and biomethane, and subsequently up to 100 per cent are being tested at the organisation's new Hydrogen Innovation Centre in Dublin.' The Gas Network Ireland plan published in October 2019[40] did not envisage significant H2 injection until 2032 rising to just 13% in 2050 – this is in contrast to 37% renewable gas (biomethane), and 50% natural gas which is abated by Carbon Capture & Storage (CCS).

There is considerable stakeholder weight being placed on the roll-out of H2 via the existing Natural Gas grid. This is relevant to certain areas within our study region – in particular Mayo and Galway, with some areas of North Kerry also currently on the grid[41].

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[39] http://www.seafuel.eu/wp-content/uploads/2020/05/Current-hydrogen-policy-frameworks.pdf

[40] https://www.gasnetworks.ie/vision-2050/future-of-gas/GNI_Vision_2050_Report_Final.pdf (p.7)

[41] A map of the existing Gas Grid in Ireland is available at this link: https://www.gasnetworks.ie/corporate/company/our-network/pipeline-map/

HyLIGHT is a 3-year project funded by Science Foundation Ireland (SFI) and a large industry and research consortium led by MaREI. The project aims to study the feasibility of hydrogen production, distribution and use in Ireland.

GREEN ATLANTIC at Moneypoint is an ESB project which is planned to produce H2 from surplus energy produced from a 1,400 MW offshore array in Clare. Announced in April 2021[42] the project envisages hydrogen production, storage, and generation by the end of the decade which it sees as being suitable for power generation, heavy goods vehicles in the transport sector and to help decarbonise industries such as pharmaceuticals, electronics, and cement manufacturing.

EI-H2 Aghada, Co Cork[43], which is a private company, aims to create a 50MW electrolysis plant close to the existing 431 MW Gas and Steam Combined Cycle Power Station, Whitegate, Co. Cork. The EI-H2 project says that it aims to sell its H2 to commercial operators which would presumably include the nearby gas network at Whitegate.

Many of the large-scale offshore wind project applications appear to keep their options open as regards whether the electricity generated will be 100% to grid, 100% towards H2 generation, or a blend of both.

INTERREG project GENCOMM[44] conducted a study of the feasibility of decarbonizing city bus networks in Ireland with renewable hydrogen finding that the total H2 fuel cost from the distributed supply chain would be between €5-€10/kg. Operational cost parity of diesel and H2-fueled bus could be met by 2030 in Dublin.

SEAFUEL is an island focussed INTERREG H2 transport research and demonstration project. Led by NUI Galway the project has installed an electrolyser in Tenerife to produce H2 for a HRS. The HRS supplies light duty works vans as well as passenger vehicles (two Hyundai Nexos and a Toyota Mirai). Árainn in Ireland is also engaged in this research, although there have been no H2 deployments here as of yet.

Hydrogen Mobility Ireland (HMI) conducted a multiweek trial of the first FCEV bus in Ireland[45] during the last months of 2020. This project led to the trial of a Caetano 'H2 CityGold' pre-production bus and involved the Irish National operator Bus Éireann, Dublin Bus, and Dublin City University's Dr James Carton. The findings of the study have not yet been published but appear to have led to H2 city bus deployments discussed below.

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42 https://www.esb.ie/tns/press-centre/2021/2021/04/09/esb-announces-green-atlantic-@-moneypoint

43 https://ei-h2.ie/

44 https://www.sciencedirect.com/science/article/pii/S0360319920344104

45 https://h2mi.ie/hydrogen-fuel-cell-bus/


*Figure 16 Caetano H2 Bus HMI trial deployment*

*Source: Paul Sharp*

The HMI trials led to the purchase of three H2 buses by Dublin Bus in July 2021. The first of these commenced operations in August 2021[46]. The rapid progress from initial trial to commitment to purchase by a major operator and then the commencement of service is highly significant. It demonstrates a rapid shift in policy to include H2 FCEVs alongside EVs in the public transport sector.

At present there is no Irish State policy on the production, distribution, and consumption of H2 in Ireland (see section below). There does however seem to be an emphasis on H2 in the medium to long term as an element in the fuel mix which includes Biogas (biomethane) and natural gas. Exploration of the use of hydrogen in transport appears to be confined in the initial phase to heavy goods vehicles (HGVs), buses, and, to a lesser extent, intercity trains.

### 6.1.3 National Policy 2017-2020

The policy position in Ireland in 2017 was stated as a low-risk late adopter position: i.e., Irish policy would draw on the experiences of other EU countries[47]. It should be noted that this 2017 position was determined during the period following recovery from the financial crisis 2008-2011, and thus a

[46] https://www.gov.ie/en/press-release/fb42f-ireland-takes-next-step-in-testing-hydrogen-buses-in-transport-fleet/

[47] http://www.dttas.ie/sites/default/files/publications/public-transport/english/npf-picture/6186npfalternative-fuelsengv5.pdf

wait-and-see approach to what was then an emergent technology was augmented by pervasive budgetary caution.

The ambition of the state's Climate Action Plan 2019[48] was to achieve a target of 70% of Ireland's electricity. It was expected that this would be provided by renewable (mainly intermittent) generation (i.e., PV and Wind). Some authors have noted that considerable intermittency will need to be mitigated by energy storage solutions[49] of which hydrogen offers considerable advantages in versatility.

The Climate Action Plan 2019 makes only two passing mentions of hydrogen: in relation to transport it was envisaged prior to 2030 to 'Explore renewable CNG expansion and hydrogen as fuel source for medium and heavy-duty trucks'[50]. For light passenger vehicles and buses, emphasis was almost exclusively on BEVs.

In part in response to this lack of discussion of hydrogen in the Climate Action Plan 2019, Hydrogen Mobility Ireland (HMI) published a *Hydrogen Roadmap for Irish Transport, 2020-2030* which stated that the '…availability of both vehicle options offers a more cost-effective pathway to deep decarbonisation of transport than using just one vector'[51].

HMI set out a detailed strategy which would lead to the creation of a hydrogen transport infrastructure and market which would in turn lead to the creation of a hydrogen economy. In summary, the measures proposed are summarized in Table 12:

*Table 12 HMI Roadmap Key Findings*

| |
|---|
| · Hydrogen refuelling infrastructure can be delivered by industry with limited government support only requiring government grant funding to very earliest projects to de-risk the investment |
| · Support required would be in-line with Battery Electric Vehicles (BEVs). |
| · Hydrogen in transport would deliver the additional benefits allowing the easier adoption of hydrogen for industry and heat decarbonisation. |
| · Hydrogen is a complementary fuel to electricity by offering greater range and faster refuelling, making it an ideal solution for vehicles where plug-in vehicles don't meet the users' needs. |
| · Hydrogen can be produced domestically, and can even localize the production of energy for transportation |
| · Hydrogen can support deployment of intermittent renewables by acting as an energy store over many days |

This leads to an HMI Roadmap of measures shown in Figure 17.

[48] https://assets.gov.ie/25419/c97cdecddf8c49ab976e773d4e11e515.pdf (p,97)

[49] https://energyinstitute.ucd.ie/wp-content/uploads/2020/06/UCD-Energy-Institute-The-need-for-a-Hydrogen-Strategy-for-Ireland.pdf p4.

[50] Ibid p35

[51] https://hydrogenireland.org/wp-content/uploads/2019/10/HMI_report_final_Oct3rd2019-2.pdf p5.

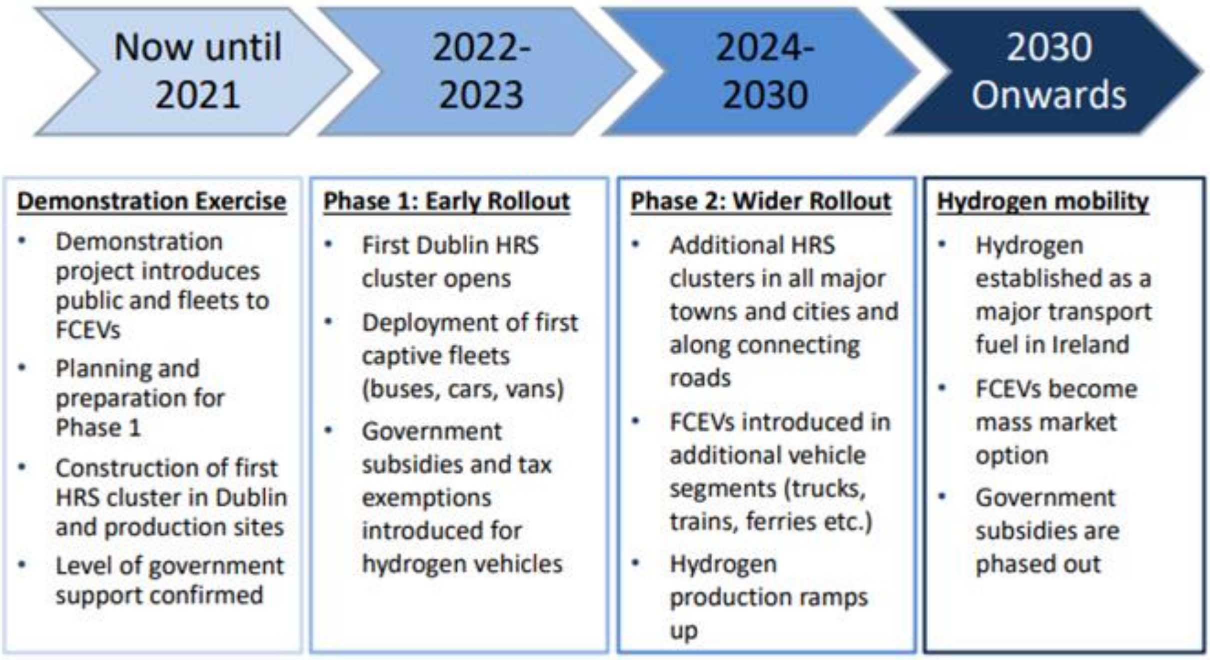


*Figure 17 HMI Phased Strategy*

Source: *Hydrogen Roadmap for Irish Transport, 2020-2030*, Hydrogen Mobility Ireland, October 2019, p8

It must be noted that Covid 19 has had significant effects on technology deployments. The supply chain of key-commodities as well as components requires a re-appraisal of the HMI roadmap timeframe. Indeed, in our opinion it is a cause for wonder that this has moved forward on the ground to the extent that it has.

## 6.2 Hydrogen in Public Transport

FCEV Buses are a market deployed technology in Ireland. However, the construction of the first Hydrogen Refuelling Station (HRS) in North Dublin envisaged by the HMI 2019 Roadmap, has not yet occurred. The pilot fleet of three Double Decker buses, built by Wrightbus and costing €800,000 each is proceeding. Ireland's Minister for the Environment, Eamon Ryan T.D.'s, statement that 'other technologies such as battery-electric, are very well suited to bus services in urban areas, but on longer commuter and inter-urban routes, hydrogen fuel cell technology is an innovative zero pipe emission alternative to diesel[52]' shows that there is considerable policymaker buy-in to elements of the HMI strategy. However, the *level* of government support has also not yet been confirmed.

While the Dublin Bus deployments are 'Double Deckers', as are most of the Wrightbus vehicles available, there are single decker FCEV buses in service[53]. The aforementioned Caetano H2 bus is very similar to what would be needed on a route such as the 450 Dooagh-Louisburgh service, although it is a city bus and may not be suitable for the route.

[52] https://www.nationaltransport.ie/nta-and-bus-eireann-unveil-hydrogen-buses-for-initial-use-on-commuter-route-105/
[53] https://www.solarisbus.com/en/press/solaris-starts-deliveries-of-urbino-hydrogen-buses-to-cologne-1494

The Caetano bus has a range of 400km[54] on a single fill (6 minutes refill time). The FCEV buses cost approximately €800,000 per bus[55]at time of writing, but it can be expected that as demand and thus production raises in the coming years, this price will decrease. A BEV bus costs approximately €700,000-€800,000.

The superior range and shorter filling times indicate that, given a supply of H2, the replacement of the diesel buses on the 450 route should be considered a medium term opportunity.

## 6.3 Hydrogen in Light Vehicle Transport

There is a sizeable opportunity in the medium to longer term for FCEV deployment in the private car ownership sector of transport in the study area. There are market-ready FCEVs. The most prominent perhaps are the Toyota Mirai and the Hyundai Nexo. Both of these are available for purchase by the consumer. Fuel Cell Works[56] estimates that there is approximately 500+ Toyota Mirai in service in Germany. Hyundai claim that there are over 1,000 Nexus on European roads[57]. However, it must be said that there are considerable supply chain issues at present. Toyota Ireland stated in 2020 that it aims to bring a demonstrator vehicle to Ireland in 2021, along with a temporary refuelling station. Toyota Ireland works closely with Hydrogen Mobility Ireland. The company's ambition is to bring limited numbers of the Mirai in 2023, when refuelling stations are available in Dublin.

*Figure 18 FCEV Toyota Mirai*

*Source: Toyota Website: https://www.toyota.ie/world-of-toyota/articles-news-events/2020/all-new-mirai.json*

H2 refuelling stations (HRS) therefore appear to be the key to facilitating roll-out generally. Both Toyota Mirai and Hyundai Nexus require 700 bar pressure tanks and refuelling technology to achieve the manufacturer's 650km range. HRS are discussed below.

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[54] https://caetanobus.pt/en/esta-ai-o-h2-city-gold-o-novo-autocarro-caetano-a-hidrogenio/
[55] https://www.electrive.com/2020/09/24/barcelona-orders-eight-hydrogen-buses-from-caetano/
[56] https://fuelcellsworks.com/news/record-sales-in-germany-for-toyota-hydrogen-fuel-cell-powered-mirai/#:~:text=A%20total%20of%20525%20fuel,environmental%20bonus%20of%207%2C500%20euros.
[57] https://www.hyundai.news/eu/articles/press-releases/hyundai-nexo-sales-in-europe-exceed-1000-units.html

It is not considered feasible that privately owned FCEVs offer a medium-term opportunity for the study area. However, ECI has produced research elsewhere which provides possible vectors for FCEV adoption using a commercial for-rent network which can underpin the roll out of HRS in the West of Ireland generally and including Achill.

### 6.3.1 Tourism: Added Value and Complementarity

As noted above, SEAFUEL has conducted research into the potential for the tourism sector to act as a demonstrator of FCEV viability. Tourism is a significant area of economic activity in Achill and Corraun. The most successful tourism product in the Western Region for many years has been the designation of 'The Wild Atlantic Way'. This tourism pathway some 2,500km in length stretches along the entire West of Ireland over very mountainous terrain. Achill is a key destination on the Wild Atlantic way. The Tourism Board of Ireland, Discover Ireland, promotes driving trips on the route[58]. There is a clear opportunity for the creation of a high value sustainability product that provides a small FCEV fleet in partnership with either an indigenous or international rental car provider. This fleet would probably be based in a transport and commercial hub within the region. Sustainability transport has a potential economic value which could offset any increased vehicle or fuel costs for FCEVs.

The assembly of a fleet of some 10-15 FCEVs would cost approximately €900,000[59] (excluding VRT which the state may consider waiving in part or wholly as was the case with EVs). With set up costs from which we exclude the cost of the HRS, we estimate that the total cost would be in the region of €1.4m. Of this we assume that the fleet owner could contribute 30-40% of set up costs and would establish the budget for the running costs on a commercial basis. Therefore, the cost of state support would be in the region of €1m.

We address this opportunity in the Case Studies in Section 8.2 below

## 6.4 Hydrogen for Industrial/Commercial Heat

Hydrogen for heat applications currently generally compares uneconomically with cheaper fossil fuel alternatives. Typically, Natural Gas (NG) at commercial levels costs €0.0364 per kWh[60]. Liquid Petroleum Gas (LPG) costs €0.0993. Medium Fuel Oil costs €0.1132.

Supported by the UK government Locogen's study[61] investigated decarbonising the distillation process via direct fuel switching from fossil fuels to hydrogen. They found that the use of hydrogen as a fuel to displace gas oil was a relatively simple technical conversion. The study recommended with minor modifications a Byworth Yorkshireman2 3,000 kg/hour boiler combined with a Limpsfield dual fuel burner that can burn hydrogen as well as biodiesel would be technically feasible and straightforward. Limpsfield have produced a dual fuel burner which can switch between hydrogen and Natural Gas according to supply and have a unit in operation for the past 10 years[62]

[58] https://www.discoverireland.ie/wild-atlantic-way/weekend-road-trips-wild-atlantic-way
[59] https://uk.motor1.com/news/505291/toyota-mirai-hydrogen-uk-pricing/
[60] https://www.seai.ie/publications/Commercial-Fuel-Cost-Comparison.pdf
[61] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/978982/Locogen_Ltd_Phase_1_Feasibility_Report.pdf
[62] https://limpsfield.co.uk/products/hydrogen/

## 6.5 Hydrogen for Domestic Heat

In recent years UK trials H2 in domestic heat applications using blends of up to 20% of H2 to 80% NG have demonstrated their feasibility[63] . It is not yet possible to purchase a 100% hydrogen-ready boiler, however Worcester Bosch, Viessmann and Baxi provide fuel blend boilers with a 20:80 ratio. While these companies are seeking to develop 100% H2 domestic boilers they are not market ready. The lack of a gas infrastructure will also make H2 for domestic use on Achill reliant on tank transport and storage options. We therefore characterise this H2 opportunity as 'long range'.

## 6.6 Summary of Hydrogen technologies ranked by feasibility of deployment in the study area

We have determined opportunities according to their market readiness. Level 1 is ready for deployment within a year. Level 2 opportunities are those that are market ready stage but for supply chain or economic reasons are not ready for immediate deployment. Level 3 opportunities are those where the technology is beyond prototype but still in development and not market ready.

*Table 13 Summary of H2 technology opportunities*

| Technology | Market Stage | Opportunity Levels in Study Area | Roadmap Year |
|---|---|---|---|
| FCEV Buses | Deployed | 1 | 2022 |
| H2 in manufacturing process | Deployed | 1 | 2023 |
| FCEV Tourist Cars | Deployed | 1 | 2024 |
| FCEV Private Cars | Deployed | 2 | 2025-30 |
| H2 Domestic Heat | In Development | 3 | 2030 |

In this study we analyse Level 1 Deployment opportunities only as these are the only market ready and deployed technologies for which we have Achill energy demand figures.

Thus, in Section 8 below, we examine:

- H2 Deployment Opportunity A: FCEV Buses on the 450 Dooagh to Louisburgh Route
- H2 Deployment Opportunity B: H2 Heat for Manufacturing
- H2 Deployment Opportunity A: FCEV Tourism Rental Pilot

[63] https://hydeploy.co.uk/app/uploads/2018/02/21063_HyDeploy_Carbon_Savings_Report1_DIGITAL.pdf

# 7 H2 Production and Distribution Scenarios

Based on the findings from Section 5.5 we have devised the following scenarios for offshore wind to H2 production

- Scenario 1: 5MW offshore wind to H2 only
- Scenario 2: 5MW offshore wind to grid, using only constrained output (backed-up by grid electricity) to produce H2
- Scenario 3: 630MW offshore wind to H2 for consumption and export
- Scenario 4: 5MW PV to H2 only

## 7.1 Scenario 1 - 5MW offshore wind to H2 only

Scenario 1 aims to satisfy the stated energy demands of the island completely using green hydrogen. The scenario models the use of a stand-alone 5MW offshore wind turbine from which it purchases electricity to power the hydrogen production subsystem. This green hydrogen will then be distributed to the energy users across Achill Island using a compressed tube trailer truck. A schematic of Scenario 1 can be seen in Figure 19 below.

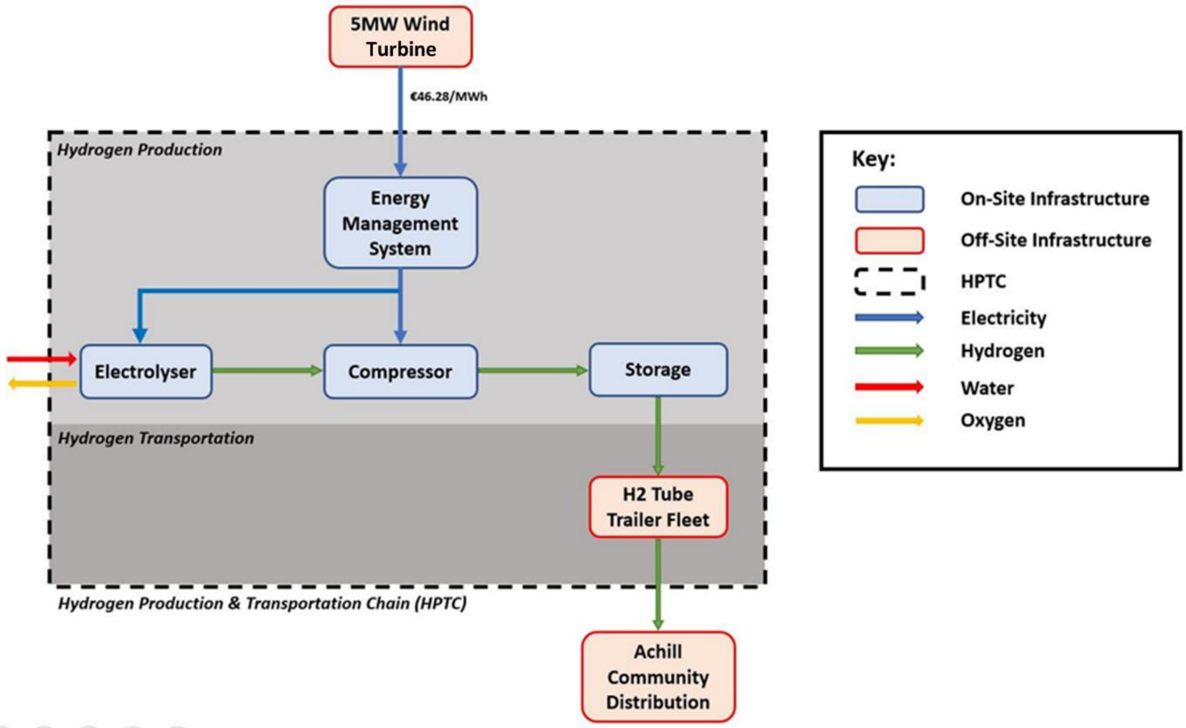


*Figure 19 Scenario 1 Schematic*

## 7.2 5MW offshore wind to grid, using only constrained output (backed-up by grid electricity) to produce H2

Scenario 2 aims to satisfy the stated energy demands using a combination of renewable wind electricity, curtailed wind electricity and grid back up. The grid back up will ensure the constant operation of the PEM electrolyser. Scenario 2 will be producing mixed hydrogen. The scenario models the use of a stand-alone 5MW offshore wind turbine which it will be buying electricity from to power the hydrogen production subsystem. Scenario 2 produces hydrogen from a mixture of renewable energy (55%), curtailed wind energy (10%) and the remainder from the grid at market price (35%). This mixed hydrogen will then be distributed to the energy users across Achill Island using a compressed tube trailer truck. A schematic of Scenario 2 can be seen in Figure 20 below.

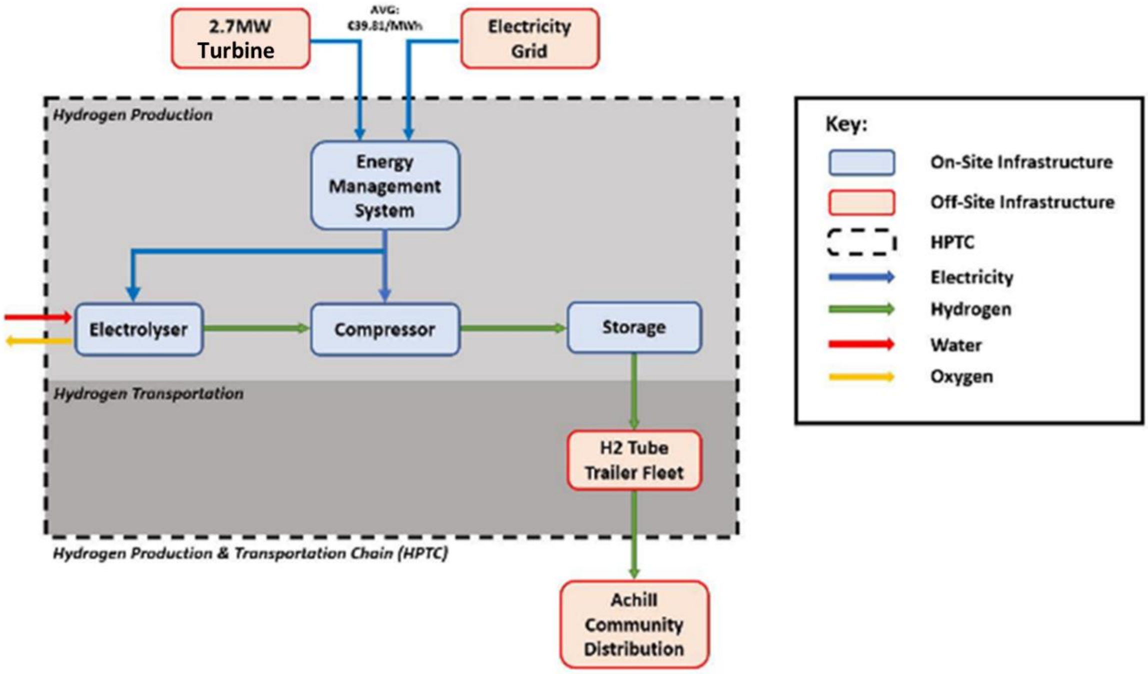


*Figure 20 Scenario 2 HPTC Schematic*

## 7.3 Scenario 3 - 630MW offshore wind to H2 for consumption and export

Scenario 3a aims to satisfy the stated energy demands of the Achill community and in addition to produce a large quantity of green hydrogen for EU export. This scenario models the use of a 630MW offshore wind farm which will supply power to the hydrogen production subsystem. As with scenario 1 and 2, this green hydrogen will be distributed to energy users across Achill Island. In addition to this it is proposed to construct a new gas pipeline to the nearest existing gas grid connection in Westport, Co. Mayo. From there, the hydrogen will be transported to Dublin Harbour where it will be stored and distributed to hydrogen consumers in the EU. A schematic of Scenario 3a can be seen in Figure 25 below.

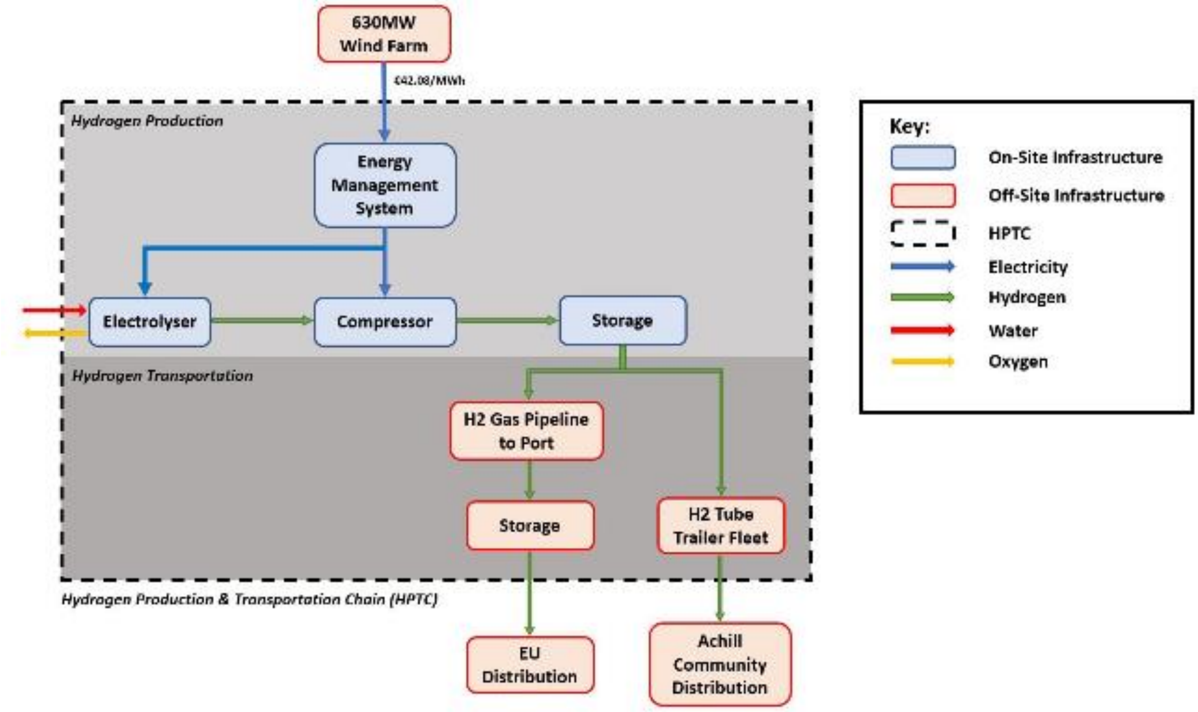


*Figure 25: Scenario 3 HPTC schematic*

## 7.4 Scenario 4 5MW PV to H2 only: island distribution

As in the case of Scenario 1, Scenario 4 aims to satisfy the stated energy demands of the island completely using green hydrogen. The scenario models the use of a non-grid connected 5MW PV farm which supplies electricity to power the hydrogen production subsystem. This green hydrogen will then be distributed to the energy users across Achill Island using a compressed tube trailer truck. A schematic of Scenario 1 can be seen in Figure 26 below.

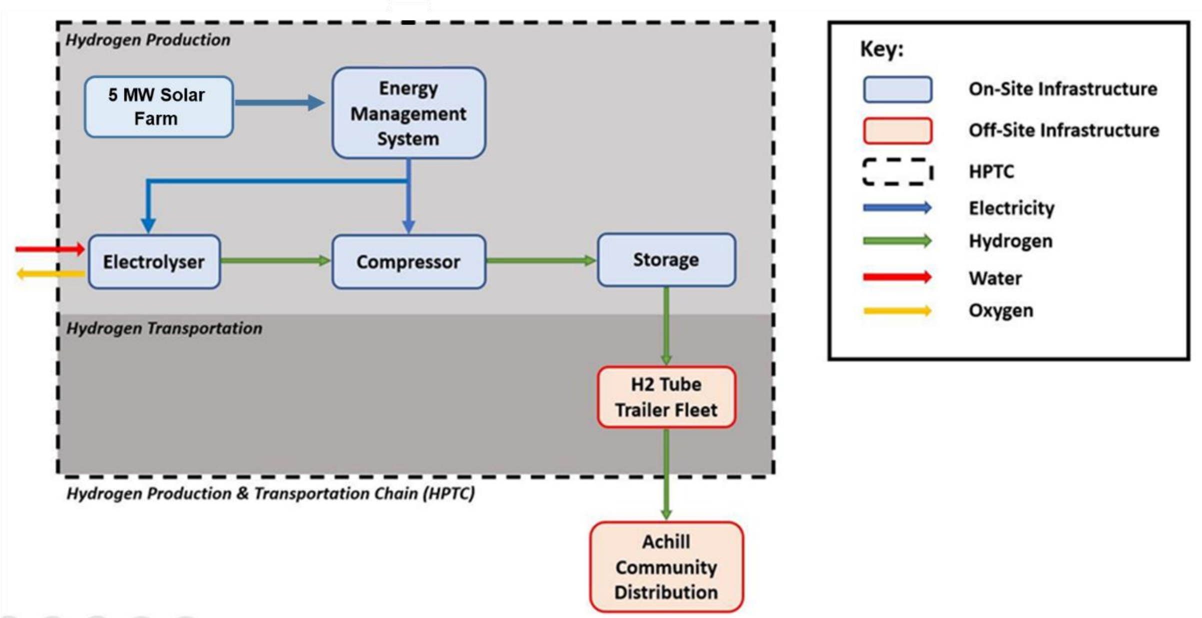


*Figure 21 Scenario 4 HPTC schematic*

## 7.5 Scenario Summary

Table 14 below, provides a summary of the key differences between each of the four hydrogen production case scenarios.

*Table 14 H2 Production Scenarios Summary*

| Parameter | Scenario 1 | Scenario 2 | Scenario 3a | Scenario 3b | Scenario 4 |
|---|---|---|---|---|---|
| Hydrogen for Achill Community | ✓ | ✓ | ✓ | ✓ | ✓ |
| Hydrogen for EU Distribution | ✗ | ✗ | ✓ | ✓ | ✗ |
| Green Hydrogen Production | ✓ | ✗ | ✓ | ✓ | ✓ |
| Electricity Source | Bought from Wind Turbine | Bought from Wind Turbine + Grid | Bought from Windfarm | Windfarm owned by H2 producers | Bought from Community PV Farm |

## 7.6 Economic Evaluation of Scenarios

### 7.6.1 Overview

The economic performance of each scenario is evaluated by calculating the *Levelized Cost of Hydrogen* (LCOH). The LCOH is measured in €/kgH2 and is calculated by summing the totals of the *Levelized Cost of Production* (LCOP) and the *Levelized Cost of Transportation* (LCOT). Every scenario assumes a 25-year lifespan (n) of the project, leaving two years for construction and one year for decommissioning. A discount rate (r) of 6% is also used in all cases. The year of construction is assumed as 2030.

The price of electricity (€/MWh) for each scenario was calculated[64]. A capacity factor of 55% was assumed for the offshore wind facility[65]. The inputs for overnight cost of offshore wind construction per MW, and the operation and maintenance expenses/MWh can be found in Table 15 below.

[64] All formula used in our calculations are given in Appendix A

[65] T. Remmers, F. Cawkwell, C. Desmond, J. Murphy, and E. Politi, "12.5 km Coastal Observations for Off shore Wind Farm Site Selection in Irish Waters," Energies, vol. 12, no. 206, pp. 1–16, 2019

*Table 15 Electricity Production Techno-Economic Parameters*

| Parameter | Symbol | Value | Unit |
|---|---|---|---|
| Project Lifetime | T | 25 | Years |
| Discount Rate | r | 6 | % |
| Capacity Factor (S1, S2, S3)[66] | CF | 55 | % |
| Capacity Factor S4 | CF | 11 | % |
| Overnight Costs (S1, S2)[67] | ONC | €2,200,000 | €/MW |
| Overnight Costs (S3)[68] | ONC | €2,000,000 | €/MW |
| Overnight Costs (S4) | ONC | €850,000 | €/MW |
| O&M Costs[69] | O&M | 3% of Capex | €/Yr |
| Construction time | t_c | 2 | Years |

In the hydrogen production subsystems, the LCOP accounts for the discounted capital costs and the operation and maintenance expenses divided by the discounted total mass of hydrogen produced.

The capital costs and the operation and maintenance expenses for equation LCOP were calculated. The engineering design work and the installation work are set to 15% and 20% of the electrolyser and compressor respectively as per the research conducted by The Fuel Cells and Hydrogen Joint Undertaking[70]. In addition to this for the year 2030, the capital investment cost of PEM electrolysers is projected to fall by 50%[71]. Additionally, find a summary table of the hydrogen production techno-economic parameters (with subscripts) used in the analysis in Table 16 below.

[66]ibid.

[67] A. Y. Wai-Hoo and B. K. Sovacool, "The economics of wind energy," Sustainable matters Asia's energy concerns, green policies Environ. advocacy, vol. 2, pp. 317–340, 2014, doi: 10.1142/9789814546829_0026.

[68] ibid

[69] S. McDonagh, S. Ahmed, C. Desmond, and J. D. Murphy, "Hydrogen from offshore wind: Investor perspective on the profitability of a hybrid system including for curtailment," Appl. Energy, vol. 265, no. September 2019, p. 114732, 2020, doi: 10.1016/j.apenergy.2020.114732.

[70] FCH, "Early business cases for H2 in energy storage and more broadly power to H2 applications, Final Report, Fuel cells and hydrogen joint undertaking, P2H-BC/4NT/0550274/000/03, 2017," no. June, pp. 1–228, 2017, [Online]. Available: http://www.fch.europa.eu/publications/study-early-business-cases-h2-energy-storage-and-more-broadly-power-h2-applications.

[71] Y. Kikuchi, T. Ichikawa, M. Sugiyama, and M. Koyama, "Battery-assisted low-cost hydrogen production from solar energy: Rational target setting for future technology systems," Int. J. Hydrogen Energy, vol. 44, no. 3, pp. 1451–1465, 2019, doi: 10.1016/j.ijhydene.2018.11.119.

*Table 16 Hydrogen Production Subsystem Techno-Economic Parameters*

| Parameter, Symbol | Value | Unit | Value | Unit |
|---|---|---|---|---|
| **Equipment** | **H20 Electrolyser (WE)** | | **Electric Compressor (EC)** | |
| Technology | Polymer Electrolyte Membrane | | Reciprocating | |
| Capital Cost[72], $C_{Capital}$ | 2498 x $P_{WE}$^0.925 | € | 4948 x $P_{WE}$^0.66[73] | € |
| O&M Cost, $C_{O\&M}$ [74] | 0.2011($P_{WE}$^-0.23) x $C_{WE}$ | €/yr | 2%[75] | € |
| Efficiency, η[76] | 63% | % | 73%[77] | % |
| Pressure[78], p | 60 | bar | 350[79] | bar |
| Stack Replacement[80] | 437 x $P_{WE}$^0.925 | €/8yrs | - | |
| **Equipment** | **Electricity Management System (EMS)** | | **Storage Vessel (SV)** | |
| Technology | Converter & Controller | | Steel Cylinder | |
| Capital Cost[81], $C_{Capital}$ | 10% X ($C_{WE}$ + $C_{EC}$) | € | 470 x MH2[82] | € |
| O&M Cost, $C_{O\&M}$ | - | € | 2%[83] | € |
| Efficiency[84], η | 90% | % | - | % |
| Pressure, p | - | bar | 350 | bar |

### 7.6.2 Hydrogen Transportation

In the hydrogen transportation subsystems, the Levelized Cost of Transport (LCOT) accounts for the discounted capital costs added to the operation and maintenance expenses divided by the discounted total mass of hydrogen transported[85]. The LCOT is presented in Table 17 below.

[72] FCH "Study on early business cases for H2 in energy storage and more broadly power to H2 Applications," 2017, [Online]. Available: http://www.fch.europa.eu/sites/default/files/P2H_Full_Study_FCHJU.pdf%0Ahttp://www.hinicio.com/file/2018/06/P2H_Full_Study_FCHJU.pdf .

[73] ibid

[74] A. Buttler and H. Splietho, "Current status of water electrolysis for energy storage, grid balancing and sector coupling via power-to-gas and power-to-liquids: A review," vol. 82, no. February 2017, pp. 2440–2454, 2018, doi: 10.1016/j.rser.2017.09.003.

[75] ibid

[76] ibid

[77] T. Mayer et al., "ScienceDirect Techno-economic evaluation of hydrogen refueling stations with liquid or gaseous stored hydrogen," Int. J. Hydrogen Energy, vol. 44, no. 47, pp. 25809–25833, 2019, doi: 10.1016/j.ijhydene.2019.08.051

[78] A. Buttler and H. Spliethо n73

[79] D. Apostolou and G. Xydis, "A literature review on hydrogen refuelling stations and infrastructure. Current status and future prospects," Renew. Sustain. Energy Rev., vol. 113, no. July, p. 109292, 2019, doi: 10.1016/j.rser.2019.109292.

[80] J. Proost, "State-of-the art CAPEX data for water electrolysers, and their impact on renewable hydrogen price settings," Int. J. Hydrogen Energy, vol. 44, no. 9, pp. 4406–4413, 2019, doi: 10.1016/j.ijhydene.2018.07.164

[81] FCH n71

[82] ibid

[83] ibid

[84] M. Gökçek and C. Kale, "Optimal design of a Hydrogen Refuelling Station (HRFS) powered by Hybrid Power System," Energy Convers. Manag., vol. 161, no. February, pp. 215–224, 2018, doi: 10.1016/j.enconman.2018.02.007.

[85] A. Lozanovski, N. Whitehouse, N. Ko, and S. Whitehouse, "Sustainability assessment of fuel cell buses in public transport," Sustain., vol. 10, no. 5, pp. 1–15, 2018, doi: 10.3390/su10051480.

*Table 17 Hydrogen Transportation Subsystem Techno-Economic Parameters*

| Parameter, Symbol | Value | Unit | Value | Unit |
|---|---|---|---|---|
| **Equipment** | **Storage Vessel (SV)** | | **Gas Pipeline (GP)** | |
| Technology | Steel Cylinder | | Underground Gas Pipeline | |
| Capital Cost, $C_{Capital}$[86] | 470 x MH2 | € | 350,000[87] | €/km |
| O&M Cost, $C_{O\&M}$ [88] | 2% | €/kgH2/yr | 0.12[89] | €/kgH2 |
| Pressure, p | 350 | bar | 85[90] | bar |
| **Equipment** | **Hydrogen Tube-Trailer (HT)** | | | |
| Technology | Diesel Powered Truck | | | |
| Capital Cost[91], $C_{Capital}$ | 232,000 | € | | |
| O&M Cost[92], $C_{O\&M}$ | 2.03 | €/km | | |
| Efficiency, η | - | % | | |
| Capacity[93], m | 540 | kgH2 | | |
| Pressure[94], p | 300 | bar | | |

## 7.7 Limitations/Assumptions Made in Analysis

### 7.7.1 Scenario Development

In the scoping stage of the project, Energy Co-Operatives Ireland intended on developing hydrogen use case scenarios based on Achill Island community input and feedback. The intention was to organise public consultations and assign a community liaison officer for the project to do so. However, due to Covid-19 travel restrictions (see Section 2.2 above) this was not possible in the timeframe of the project. Instead, scenarios were generated through online interactions with Achill community members and following best practices from literature.

## 7.8 All Scenario Levelized Cost of Hydrogen Comparison

Figure 22 shows a breakdown of the levelized cost of hydrogen (LCOH) for each of the scenarios analysed. The LCOH has been divided into the production expenses (Capital and Operation &

[86] FCH n(71)

[87] Council of European Energy Regulators (CEER) and SUMICSID, "Benchmark For Gas Transmission System Operators," Gas asset Report. Guid., no. V1.2, p. 99, 2019, [Online]. Available: https://www.ceer.eu/documents/104400/-/-/5bb53750-6624-e61d-d742-721bcaed651e.

[88] FCH n(71)

[89] IEA, "The Future of Hydrogen," Futur. Hydrog., no. June, 2019, doi: 10.1787/1e0514c4-en.

[90] Gas Networks Ireland, "Safety Advice for Working in the Vicinity of Gas Pipes," 2016, [Online]. Available: http://www.gasnetworks.ie/Global/Safety/BGN Safety Website Content/Safety Documents/SEPT 2016 Safety Advice for Working in the Vicinity of Natural Gas Pipeline.pdf

[91] Scottish Enterprise, "Constrained Renewables and Green Hydrogen Production Study Final Report," no. November, 2018, [Online]. Available: http://www.evaluationsonline.org.uk/evaluations/Documents.do?action=download&id=920&ui=basic.

[92] ibid

[93] F. Barbier, "Hydrogen and Fuel Cells: Fundamentals, Technologies and Applications," 2013.

[94] ibid

Maintenance) and the transportation expenses (Capital and Operation & Maintenance). The total LCOH is then presented in the green box located over each of the columns.

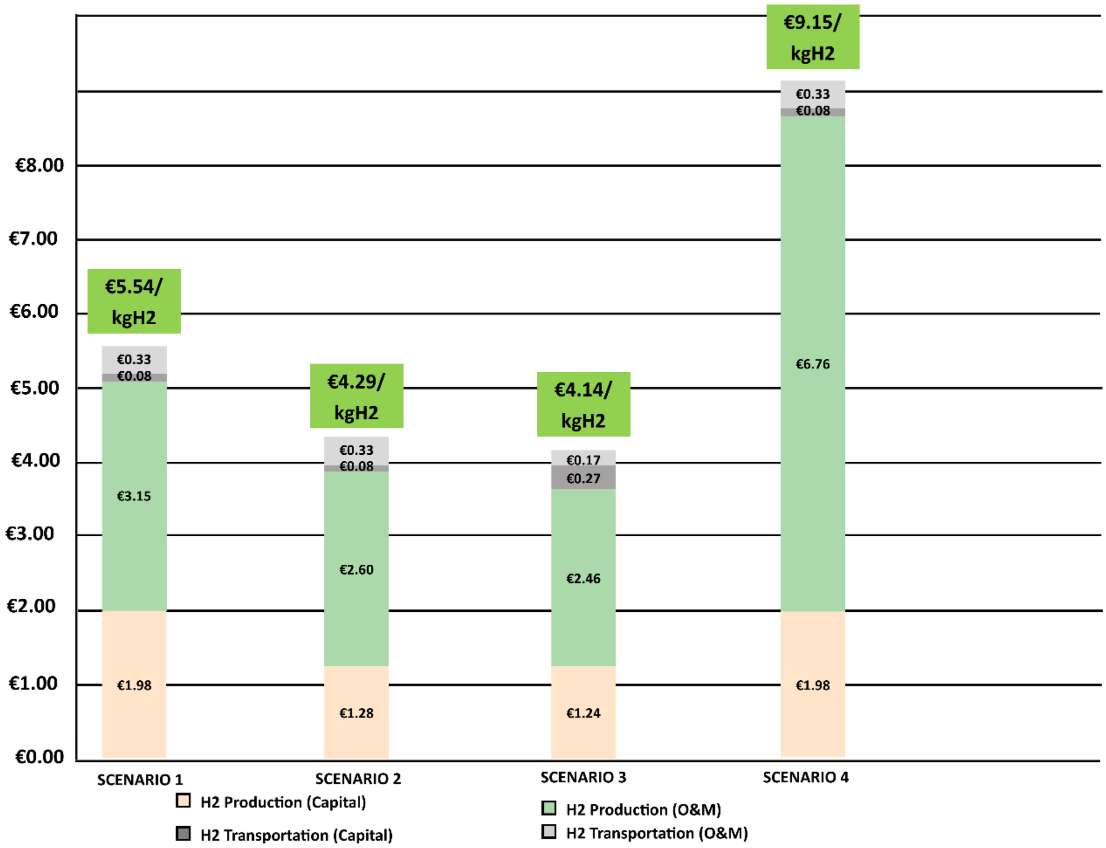


*Figure 22 Hydrogen Scenario LCOH Breakdown*

As we see from above, hydrogen production (Capital and Operation & Maintenance) accounts for the majority of the total LCOH for each scenario.

## 7.9 Net Present Value for All Scenarios

The Net Present Value (NPV) is defined as the present value equivalent of all cash inflows less all cash outlays associated with a project[95]. Therefore, a return figure greater than what is stated in Table 18 is needed for the investment to be profitable. The lack of profit does not necessarily indicate the project is not feasible either for Todhchaí Phobail Acla or the island community as a whole. Attaining net zero carbon in energy use and creating highly skilled jobs which is the primary goal of the SEC may justify the project.

[95] E. R. Andersson, Economic evaluation of ergonomic solutions: Part I - Guidelines for the practitioner, vol. 1. Elsevier Science Ltd.

*Table 18 Net Present Investment for each scenario*

| Scenario | Present Value of Investment (€) | LCOH (€/kgH2) | €/kWh |
|---|---|---|---|
| Scenario 1 | € 15,723,075 | € 5.54 | €0.17 |
| Scenario 2 | € 12,170,830 | € 4.29 | €0.13 |
| Scenario 3 | € 1,487,959,184 | € 4.14 | €0.13 |
| Scenario 4 | €13,473,075 | €9.15 | €0.27 |

## 7.10 Cost Breakdown of H2 Production and Distribution Scenarios

### 7.10.1 Scenario 1

Figure 23 shows a complete breakdown of each of the contributing elements to the LCOH of hydrogen Scenario. The diagram is divided into the following subsections, the capital expenses of production (CAPEXp), the operational expenses of production (OPEXp), the capital expenses of transportation (CAPEXt) and the operational expenses of transportation (OPEXt).

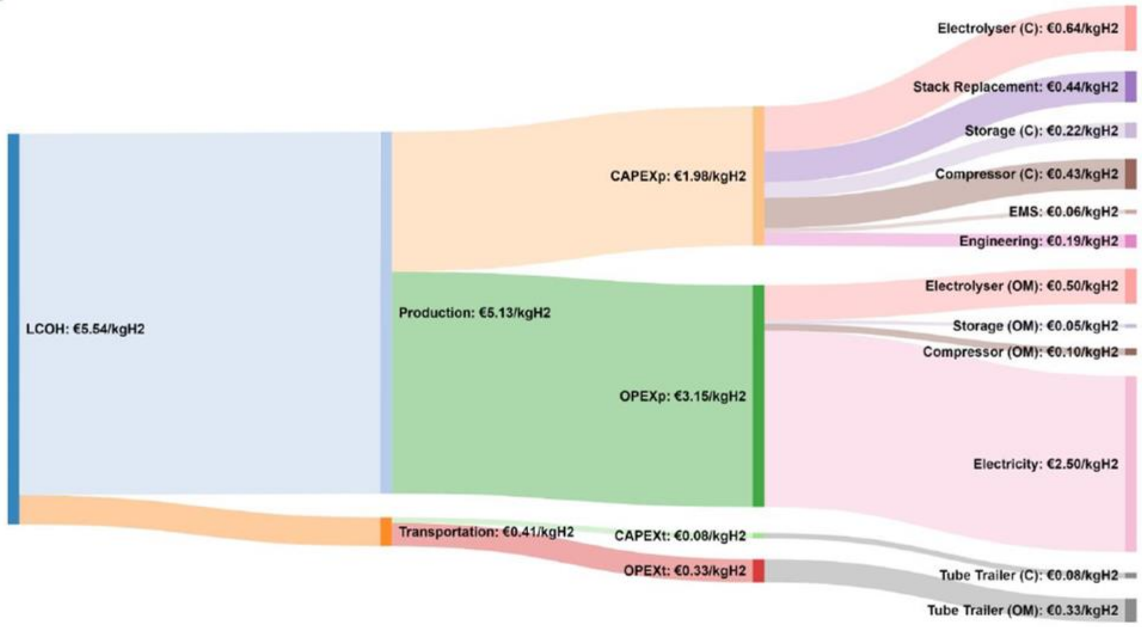


*Figure 23 Breakdown of LCOH for Scenario 1*

Scenario 1 represents small scale green hydrogen production to satisfy local Achill Island energy needs only. The LCOH is €5.54/kgH2, the cost of hydrogen production is far larger than the cost of hydrogen transportation for the project. Furthermore, the largest contributor to the production cost being electricity to power the electrolyser and the compressor. The cost of electricity comes in at €2.50/kgH2, accounting for 45% of the overall cost of the project. It should be noted that we have built in all costs required to construct and maintain the offshore wind turbine that will supply the electricity for H2 production.

## 7.10.2 Scenario 2

Figure 24 shows a complete breakdown of each of the contributing elements to the LCOH of hydrogen Scenario 2. The diagram is divided into the following subsections, the capital expenses of production (CAPEXp), the operational expenses of production (OPEXp), the capital expenses of transportation (CAPEXt) and the operational expenses of transportation (OPEXt).

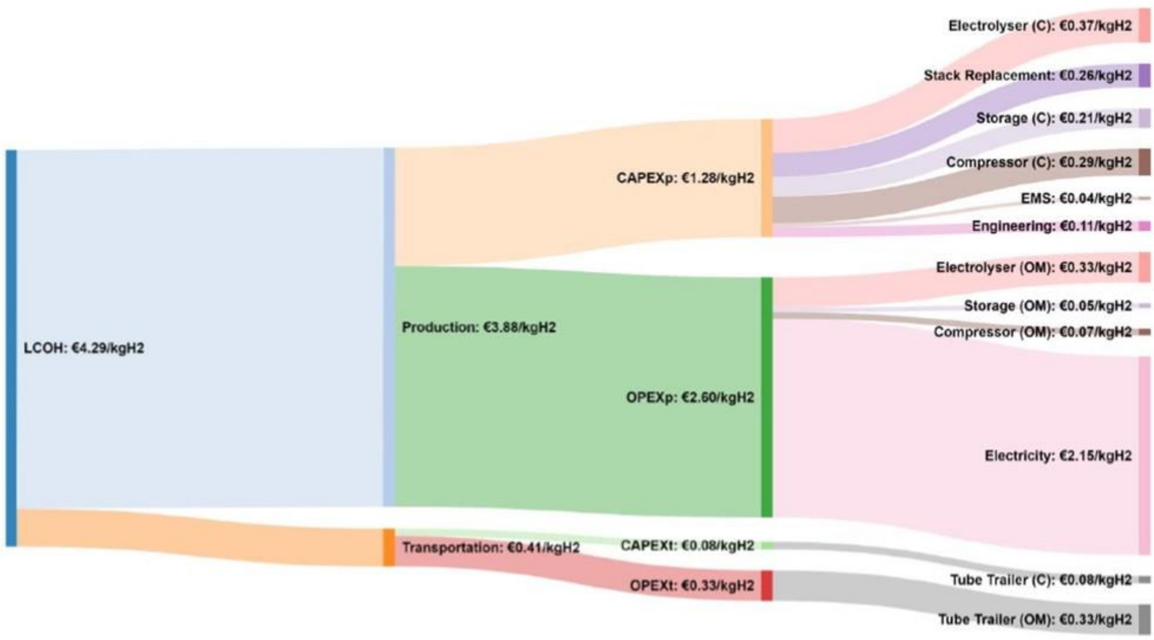


*Figure 24 Breakdown of LCOH for Scenario 2*

Scenario 2 represents small scale hydrogen production from renewables and electricity grid back up to satisfy local Achill Island energy needs only. The LCOH is €4.29/kgH2. Again, the cost of hydrogen production is far larger than the cost of hydrogen transportation for the project. Furthermore, the largest contributor to the production cost being electricity to power the electrolyser and the compressor. The cost of electricity comes in at €2.15/kgH2, accounting for just over 50% of the overall cost of the project.

By allowing the HPTC to draw electricity from the electrical grid at times when the single wind turbine is not operational (insufficient wind energy and curtailed wind), it was possible to reduce the LCOH of the project. This is predominantly due to having a smaller capacity wind turbine coupled with a smaller capacity electrolyser operating year-round to meet the same energy needs of the community. The trade-off is that the hydrogen is being produced using grid electricity which means it can no longer be considered “green” hydrogen. With the addition of greater renewables, the grid becomes ‘greener’ however there is still considerable reliance on NG in the grid.

## 7.10.3 Scenario 3

LCOH breakdown for Scenario 3a which is shown in Figure 25 represents large scale green hydrogen production and exportation to satisfy local Achill Island and European Union energy needs. The LCOH is €4.14/kgH2, as noted in section 4.1 the cost of hydrogen production is far larger than the cost of hydrogen transportation for the project. Furthermore, the largest contributor to the production cost being electricity to power the electrolysers and the compressors. The cost of electricity comes in at €2.28/kgH2, accounting for 55% of the overall cost of the project.

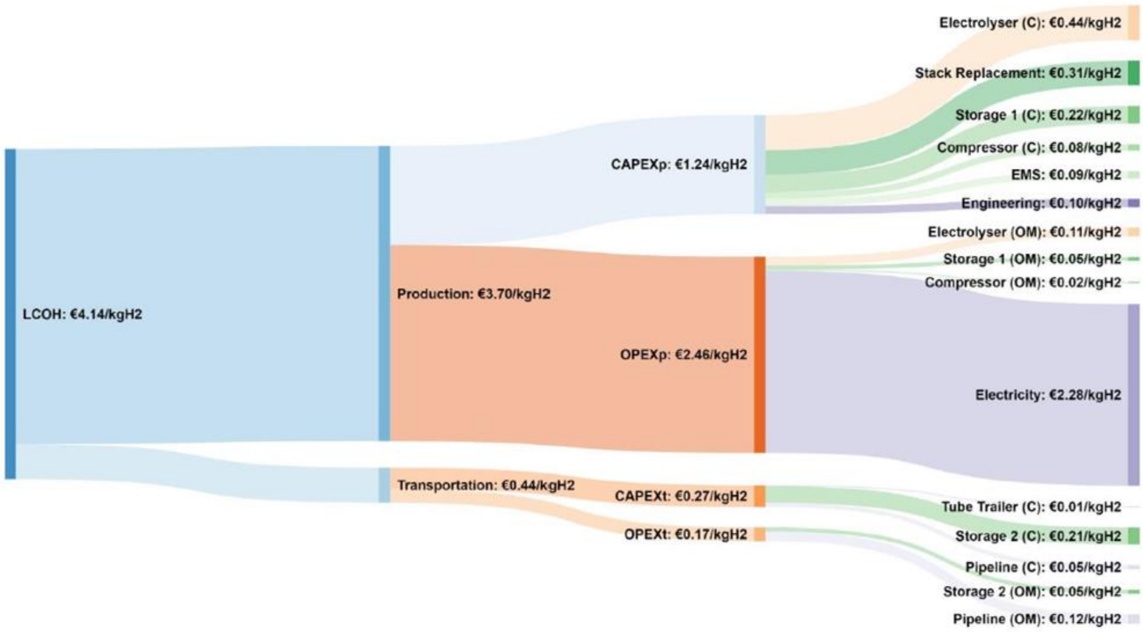


*Figure 25 Breakdown of LCOH for Scenario 3*

Scenario 3a provides the lowest LCOH for all scenarios analysed and is also a producer of green hydrogen. This indicates that economies of scale are a critical factor in the LCOH of a project.

### 7.10.4 Scenario 4

As with Scenario 1, Scenario 4 represents small scale green hydrogen production to satisfy local Achill Island energy needs only. The LCOH is €9.15/kgH2, the cost of hydrogen production is far larger than the cost of hydrogen transportation for the project. The largest contributor to the production cost being the cost of electricity to power the electrolyser and the compressor. The cost of electricity comes in at €6.11/kgH2, accounting for 67% of the overall cost of the project. This is in large part because PV is less suited to energy generation in the Northern West Coast of Ireland in comparison to onshore and offshore wind. However, an advantage that the PV Scenario 4 has over other scenarios is that the technology is proven and shovel ready to be on the ground elsewhere in the county. The initial capital outlay is also less than for offshore wind.

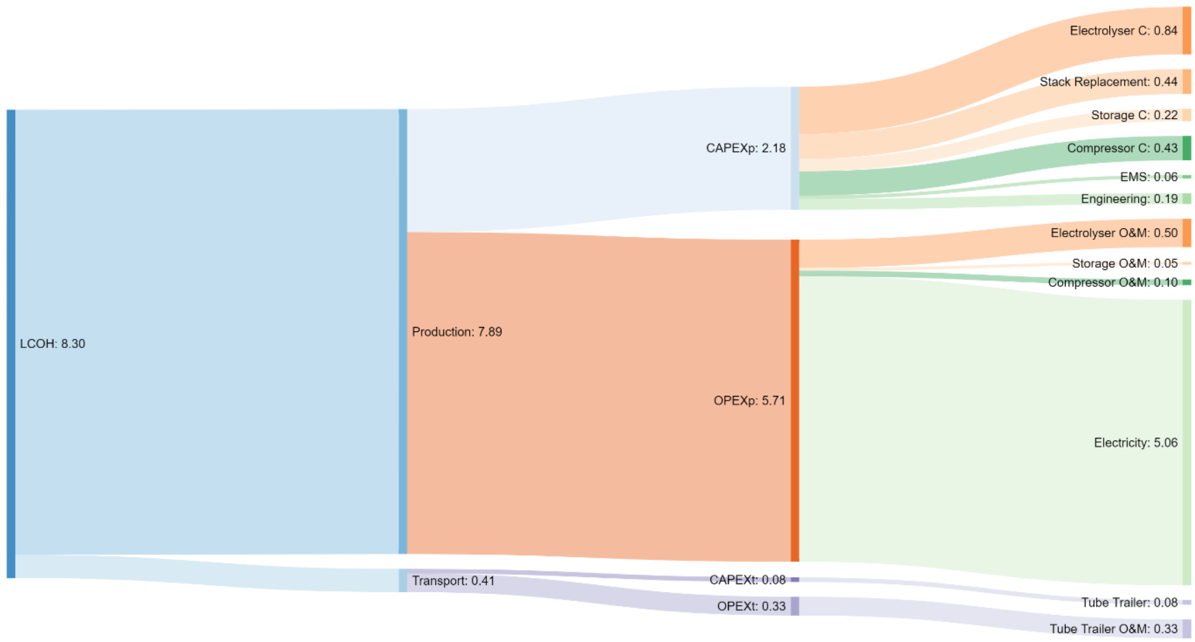


*Figure 26 Breakdown of LCOH for Scenario 4*

### 7.10.5 Summary of findings on LCOH for each Scenario

It is clear that from **Error! Reference source not found.** below, that H2 produced using electricity g enerated offshore in varying scales is competitive with fossil fuels.

It can be observed that the most cost-effective hydrogen use case scenario is Scenario 3, the large-scale green hydrogen production for export scenario. However, as Figure 27 shows, for power delivered, most Scenarios are close to or superior to fossil fuels and electricity.

As observed above, however, we should identify fossil fuels as effectively unsupportable post 2025. Therefore, economic comparisons with them are moot. As regards electricity, H2 is transportable and storable, and our scenarios have transport and storage costs built in. What we reference here is mains electricity. We have not been able to account for increased grid costs (upgrades and disturbance) which would enable the delivery of the levels of power that they would provide.

As we have seen, the H2 opportunities, in particular in transport of all forms, H2 will only need to compete against diesel in the short to medium term. Diesel and petrol use for transport is fast becoming ethically and environmentally unsupportable. There is no longer an issue of ‘will petrol and diesel use be replaced’ rather we have an issue of ‘what will replace diesel and petrol’.

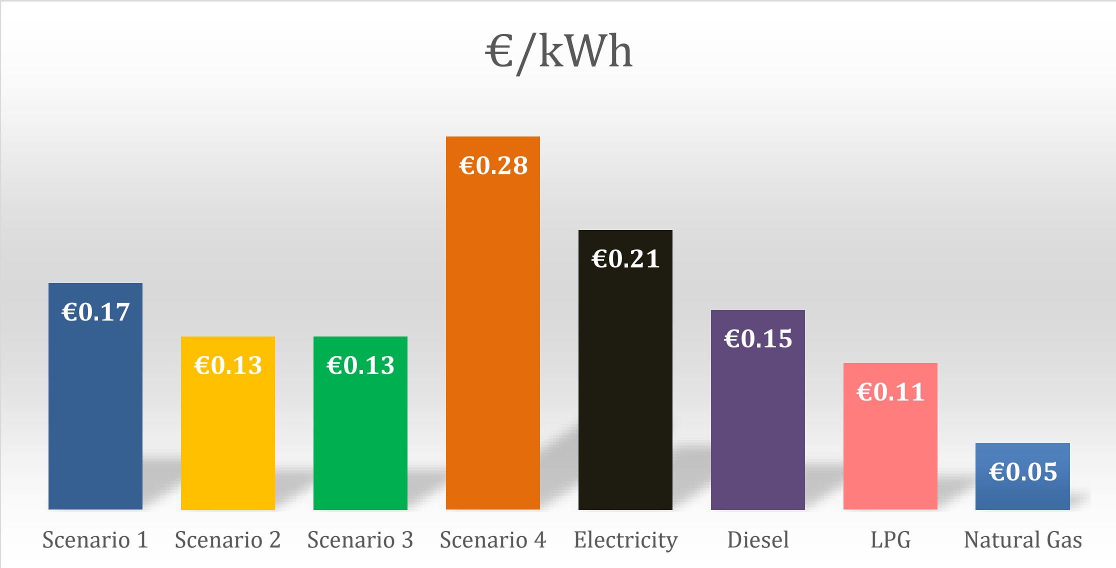


*Figure 27 LCOH price per kWh all scenarios v fossil fuels and electricity*

Thus, the conclusions that can be gained from **Error! Reference source not found.** is that BEVs using d ay rate electricity are less cost effective than H2 kWh from all Scenarios. These are day rates for domestic customers. It may be possible that users of BEVs will use night rate electricity and thus avail of cheaper electricity rates (€0.09 at present). It is highly unlikely that rate will exist in a situation that the owners of the 2.8m cars[96] in Ireland will all wish to charge their BEV at night using a favourable rate. Accordingly, we therefore exclude this rate from our calculations.

## 7.11 Carbon Savings

In this section below, we calculate the net carbon saved by the final end user as a result of each scenario.

### 7.11.1 Scenarios 1 – Carbon Savings

Scenario 1 is a producer of green hydrogen which means all of the hydrogen produced can be used to replace natural gas at the end user. Shows that Scenario 1 replaces 1,651,014 kg of CO2: to remove that amount of carbon from the atmosphere, the Achill community would have to plant[97] 646 hectares of trees (the area of Achill Island is 14,800 ha).

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96 https://www.gov.ie/en/publication/aa05b-irish-bulletin-of-vehicle-and-driver-statistics-2020/

97 Gonzalez Hernandez, S., & Sheehan, S. W. (2020). Comparison of carbon sequestration efficacy between artificial photosynthetic carbon dioxide conversion and timberland reforestation. MRS Energy & Sustainability, 7. doi:10.1557/mre.2020.32

*Table 19 Approximate Quantity of Carbon being offset by Scenario 1*

| Parameter | Quantity | Unit |
|---|---|---|
| Achill Community Hydrogen requirement | 244,410 | kgH2/Yr |
| Energy Density of Hydrogen | 33 | kWh/kgH2 |
| Energy Produced | 8,065,530 | kWh/Yr |
| Carbon Density of Natural Gas[98] | 0.2047 | kgCO2/kWh |
| **Quantity of Carbon Offset by Scenario 1** | **1,651,014** | **kgCO2/Yr** |

### 7.11.2 Scenario 2 Carbon Savings

Scenario 2 (see Table 20) produces hydrogen from a mixture of renewable energy (55%), curtailed wind energy from the grid (10%) and the remainder from the grid at market price (35%). This fact significantly reduces the potential carbon savings of the scenario due to the fact that energy from the grid has an associated carbon footprint.

*Table 20 Approximate Quantity of Carbon being offset by Scenario 2*

| Parameter | Quantity | Unit |
|---|---|---|
| Achill Community Hydrogen requirement | 244,410 | kgH2/Yr |
| Energy Density of Hydrogen | 33 | kWh/kgH2 |
| Energy Produced | 8,065,530 | kWh/Yr |
| Carbon Density of Natural Gas[99] | 0.2047 | kgCO2/kWh |
| Gross Carbon Offset by Scenario 1 | 1,651,014 | kgCO2/Yr |
| Base Energy Demand met by National Electricity Grid | 35 | % |
| Actual Energy Demand met by National Electricity Grid | 4,480,850 | kWh/Yr |
| Carbon Density of Electricity from the Grid (2030) [100] | 0.112 | kgCO2/kWh |
| Carbon Released due to Electricity Grid usage | 500,307 | kgCO2/Yr |
| **NET Carbon Offset by Scenario 2** | **1,150,707** | **kgCO2/Yr** |

Scenario 2 will offset approximately 1,150,707 kg CO2/Year in the Achill Community. This carbon reduction is the equivalent of planting just 450 hectares of forestry.

[98] SEAI, "Energy Units & Conversion Factors," 2020. https://www.seai.ie/data-and-insights/seai-statistics/conversion-factors/ (Accessed Oct 2021).

[99] SEAI, "Energy Units & Conversion Factors," 2020. https://www.seai.ie/data-and-insights/seai-statistics/conversion-factors/ (Accessed Oct 2021).

[100] Assuming that the 2030 target of 70% electricity being provided by renewable sources are reached. The remaining 30% are assumed as being generated from Natural Gas.

### 7.11.3 Scenario 3 Carbon Reductions

Scenario 3 is a producer of 'green' hydrogen which means all of the hydrogen produced can be used to replace natural gas at the end user. This calculation does not account for the carbon released during the shipping of hydrogen from Dublin to the EU. While the Suiso Frontier, the world's first purpose-built liquefied hydrogen carrier, is diesel powered [101], it can be assumed that by 2030 H2 transport vessels will be H2 powered Fuel cell electric vessels.

*Table 21 Scenario 3 Carbon Reductions*

| Parameter | Quantity | Unit |
|---|---|---|
| Hydrogen produced | 30,904 | tH2/Yr |
| Energy Density of Hydrogen | 33,000 | kWh/tH2 |
| Energy (NG) requirement displaced | 1,019,845 | MWh/yr |
| Carbon Density of Natural Gas[102] | 0.2047 | kgCO2/kWh |
| **Quantity of Carbon Offset by Scenario 3** | **208,762,000** | **kgCO2/Yr** |

Scenario 3 will offset approximately **208,762 tonnes of** CO2 per year in Ireland and elsewhere in the EU. To remove that amount of carbon from the atmosphere, the Achill community would have to plant 81,707 hectares of trees (the area of Achill Island is 14,800 ha)

### 7.11.4 Scenario 4 Carbon Savings

*Table 22 Approximate Quantity of Carbon being offset by Scenario 4*

| Parameter | Quantity | Unit |
|---|---|---|
| Achill Community Hydrogen requirement | 91,980 | kgH2/Yr |
| Energy Density of Hydrogen | 33 | kWh/kgH2 |
| Energy Produced | 3,035,340 | kWh/Yr |
| Carbon Density of Natural Gas[103] | 0.2047 | kgCO2/kWh |
| **Quantity of Carbon Offset by Scenario 4** | **621,334** | **kgCO2/Yr** |

Scenario 4 is a producer of green hydrogen thus all of the hydrogen produced replaces NG use. Table 22 shows that Scenario 4 replaces 621,334 kg of CO2: to remove that amount of carbon

[101] https://www.bairdmaritime.com/ship-world/tanker-world/gas-tanker-world/vessel-review-suiso-frontier-japanese-lh2-carrier-sets-the-pace-in-hydrogen-transport/

[102] SEAI, "Energy Units & Conversion Factors," 2020. https://www.seai.ie/data-and-insights/seai-statistics/conversion-factors/ (Accessed Oct 2021).

[103] SEAI, "Energy Units & Conversion Factors," 2020. https://www.seai.ie/data-and-insights/seai-statistics/conversion-factors/ (Accessed Oct 2021).

from the atmosphere, the Achill community would have to plant[104] 243 hectares of trees (the area of Achill Island is 14,800 ha)

### 7.11.5 Summary of Carbon Savings

Table 23 provides a summary of the carbon savings for all scenarios.

*Table 23 Approximate Quantity of Carbon being offset by All Scenarios*

| Scenario | Annual Carbon Savings ($kgCO_2/Yr$) | Irish home equivalent[105] (homes) |
|---|---|---|
| Scenario 1 | 1,651,014 | 175 |
| Scenario 2 | 1,150,707 | 122 |
| Scenario 3 | 208,762,300 | 22,209 |
| Scenario 4 | 621,334 | 66 |

While the smaller scale opportunities will have significant benefits to the local economy, they will clearly not make the island carbon neutral.

## 7.12 Scenarios and Achill Energy Demand

It is not stated in the aims and ambitions of Todhchaí Phobail Acla SEC that it wishes the area to have a carbon neutral status. It wishes instead to 'produce its own energy'. In this regard, all scenarios can be considered successful. However, it is instructive to examine, as Table 24 shows, the proportion of the area's energy use that would be met by each scenario.

*Table 24 Will the energy production from four scenarios meet the energy demand for the study area?*

| | kg $H_2$ | kWh/y | % of Achill Energy Demand |
|---|---|---|---|
| Scenario 1 | 244,410 | 8,065,530 | 6.5% |
| Scenario 2 | 244,410 | 8,065,530 | 6.5% |
| Scenario 3 | 30,904,400 | 1,019,845,200 | 822.8% |
| Scenario 4 | 91,980 | 3,035,340 | 2.5% |
| Achill Energy Demand | 3,755,777 | 123,940,627 | 100% |

The conclusions we can draw are therefore two-fold: any of the 5MW scale renewably produced energy to $H_2$ via electrolysis scenarios will fall far short of meeting the island's requirements. We can however state that 80MW of wind energy would be required to supply electricity to produce the quantities of $H_2$ necessary to achieve 100% of Achill area demand. This may not be a feasible scale of PV in Achill as it would require 200MW of PV installed needing over 400 ha of *suitable* land. An

[104] Gonzalez Hernandez, S., & Sheehan, S. W. (2020). Comparison of carbon sequestration efficacy between artificial photosynthetic carbon dioxide conversion and timberland reforestation. MRS Energy & Sustainability, 7. doi:10.1557/mre.2020.32

[105] SEAI estimates 9.4 tonnes $CO_2$ per home

80MW offshore project supplying wind energy for H2 production would be of very significant scale. It would however beg the question: would not an upscaled project such as Scenario 3 not be preferable? We have shown that ambitiously scaled H2 production provides the best economic and carbon emission reduction outcome.

# 8 H2 Consumption/Deployment Scenarios

## 8.1 Social Factors

It is essential that any study into the development of renewable energy projects take into account the social focus:

> *"Social factors play a key role for electrification projects in rural developing areas"*[106]

In Section 6.6 above we summarised the opportunities for H2 deployment and use in the Achill area. We will now discuss the feasibility of the rollout of each of these opportunities.

## 8.2 Deployment Opportunity A: FCEV Buses

As we saw in Section 6.2 FCEV Public Buses are market deployed. This means that the feasibility of the opportunity on Achill is *economic* rather than technical. However, there will probably be a need to trial a FCEV Public bus in advance of committing to vehicle purchase to ensure that it meets the actual driving conditions in Achill. It may well be possible to come to a vehicle trial arrangement with a bus manufacturer, as has been carried out elsewhere.

*Table 25 Economic assessment of FCEV Bus Deployment as per each relevant H2 production scenario**

| Scenario | Required for Application kWh/y | Output from Scenario | % of Total Output | LCOH €/kg | LCOH €/kWh | 2021 Cost Diesel €/kWh | Positive of Negative Differential [107] |
|---|---|---|---|---|---|---|---|
| Scenario 1 | 1,123,200 | 8,065,530 | 14% | €5.54 | €0.17 | €0.16 | €0.01 loss |
| Scenario 2 | 1,123,200 | 8,065,530 | 14% | €4.29 | €0.13 | €0.16 | €0.03 gain |
| Scenario 4 | 1,123,200 | 3,035,340 | 37% | €9.15 | €0.28 | €0.16 | €0.12 loss |

*Please note the significant caveat about exclusion of profits, taxes and duties below.

Table 25 shows that purely on a price comparison basis, Scenario 2 represents a 'value for money' opportunity for the deployment of an FCEV Bus on the Dooagh to Louisburgh route. This does not take into account any other socio-cultural benefits to be gained from a H2 Zero Carbon transport system – particularly vis-a-vis any tourism promotional benefits to the island as a whole. Nor does it address the local employment opportunities which would accrue.

[106] Kumar, A., Sah, B., Singh, A. R., Deng, Y., He, X., Kumar, P., & Bansal, R. C. (2017). 'A review of multi criteria decision making (MCDM) towards sustainable renewable energy development'. Renewable and Sustainable Energy Reviews, 69, 596–609. doi:10.1016/j.rser.2016.11.191 606

[107] We identify a loss, indicated in red text, as the cost in cents per unit of energy more than the price of the status quo fossil fuel from the Scenario. A 'gain', indicated by black text, represents the cost in cents per unit of energy less than the price of the status quo fossil fuel from the Scenario.

**CAVEAT:** All scenarios are price per kgH2 delivered and include storage, transport and dispensing. The additional cost from the deployment is for bus purchase (€1,600,000 est.) and training. We do not include developer/supplier profits, taxes, or duties. In respect to the effect of profit, these are not in our purview: TPA is a non-profit organisation with social motivations: one can assume that once OPEX and CAPEX costs are met, as they are in our LCOH calculations, that this is sufficient return on investment. As regards taxes on fuel, we have not factored these in here. It is not certain what the policy attitude to a renewable, zero carbon, locally generated fuel will be. It may be that the State will take a tax-neutral attitude to a fuel that has considerable export and thus revenue generating value. There are no taxes paid on hydrogen at the moment apart from VAT which is reclaimable. We add the caveat to these LCOH values that tax and duties are currently unknowns.

The figure of €1.6m as the cost of bus purchase in this opportunity is misleading. In the medium term (c. 2025) Bus Éireann's vehicle purchasing policy will change towards exclusively electrically driven engines. Continued diesel use is unsupportable, and therefore the transport operator will cease purchasing new diesel vehicles. Therefore, it is necessary to evaluate the deployment costs here in relation to BEV Buses. These are currently available at a cost of approximately 15% less than FCEV Buses.

However, these BEV buses are not technically feasible on a route such as the 450 Dooagh-Louisburgh. With even an optimistic BEV range of 350km per charge and charge times again a highly optimistic 5hrs, to replace the current diesel bus with BEVs will require the purchase of an additional two buses bringing the total cost to (see Appendix Section 11.2.2) €2.8m. It would probably also involve the employment of additional drivers. This makes the FCEV Route 450 Bus proposal more than economically feasible.

We therefore identify the Deployment Opportunity A highly feasible economically. It is technically achievable in 2022. It will provide significant socio-economic add-on opportunities and will benefit the entire community by helping to guarantee the continued provision of the service.

## 8.3 Deployment Opportunity B - H2 in manufacturing process

In Section 4.5.2 we found that the distillery in Achill had an approximate energy demand of 2,541,000kWh/yr. Please see caveats on profit, taxes, and subsidies in Section 8.2 above.

*Table 26 Economic assessment of H2 in manufacturing as per each relevant H2 production scenario*

| Scenario | Required for Application kWh/y | Output from Scenario | % of Total Output | LCOH €/kg | LCOH €/kWh | 2021 LNG €/kWh | Additional Cost €/kwh[108] |
|---|---|---|---|---|---|---|---|
| Scenario 1 | 2,541,000 | 8,065,530 | 32% | €5.54 | €0.17 | €0.10 | €0.07 |
| Scenario 2 | 2,541,000 | 8,065,530 | 32% | €4.29 | €0.13 | €0.10 | €0.03 |
| Scenario 4 | 2,541,000 | 3,035,340 | 84% | €9.15 | €0.28 | €0.10 | €0.18 |

[108] See n107 this paper above

Table 26 shows that purely on a price comparison basis, none of the three relevant scenarios represents a simple 'value for money' opportunity for the deployment. Scenario 3 does represent in 2021 terms a higher price per kWh for the power by a margin of €0.03. This would result in an increase in total cost for power over the year from an estimated €252,321 to a projected €330,330 (an increase of 31%). Without subsidy or other support, this deployment opportunity of H2 under Scenario 3 conditions is not economically feasible.

In addition to fuel costs, there would be boiler upgrade costs. As we saw in Locogen (2021)[109] this cost can be estimated at €236,000.

*Table 27 10-year cost H2 Deployment Opportunity B*

| | S1 | S2 | S3 |
|---|---|---|---|
| Boiler Capex | €236,000 | €236,000 | €236,000 |
| Opex | €1,742,587 | €780,087 | €4,522,287 |
| 10-year Cost | €1,978,587 | €1,016,087 | €4,758,287 |

Table 27 shows the 1-year cost of the opportunity. Excluded are the costs of H2 production, transport and storage as these costs are included (as per Section 7.8) in the LCOH.

We note that there are indirect economic benefits to the Deployment Opportunity which would improve the cost benefit analysis represented in Table 28. The added value for the manufacturer presented by marketing opportunities from producing a zero-carbon product are likely to be significant. State supports that could be available for a pilot project that demonstrated the technical feasibility of a real-world H2 manufacturing for heat would assist meeting the costs of the opportunity. There are significant employment and other social benefits to be gained by the community through supporting the H2 production scenarios.

## 8.4 H2 Deployment Opportunity C - FCEV Tourist Cars

While this represents a small-scale opportunity, it is significant as it meets the aims of Todhchaí Phobail Acla SECs aim to be 'a potential beacon community to act as an exemplar for other communities, both in the West of Ireland and beyond' (see Section 2 above). Table 28 shows that this opportunity would represent a small share of the H2 production from Scenarios 1, 2 and 4.

*Table 28 Economic assessment of Deployment Opportunity C as per each relevant H2 production scenario*

| Scenario | Required for Application kWh/y | Output from Scenario | % of Total Output | LCOH €/kg | LCOH €/kWh | 2021 petrol €/kWh | Positive of Negative Differential [110] |
|---|---|---|---|---|---|---|---|
| Scenario 1 | 50,160 | 8,065,530 | 1% | €5.54 | €0.17 | €0.16 | €0.01 |
| Scenario 2 | 50,160 | 8,065,530 | 1% | €4.29 | €0.13 | €0.16 | €0.03 |
| Scenario 4 | 50,160 | 3,035,340 | 2% | €9.15 | €0.28 | €0.16 | €0.12 |

[109] Locogen nX, p.13

[110] See n107 this paper above

It should be noted that the comparison between petrol and LCOH is moot. A high-power state of the art FCEV is very much a high-value tourism product. It is reasonable to assume that costs from the less favourable scenarios 1 and 3 could be recouped through higher rental charges. The H2 INTERREG project SEAFUEL which the authors of this paper are consulting on, is researching the value to the consumer of the H2 rental car product. These have not been published as yet, but initial indications are that there is a potential FCEV premium that the consumer is willing to pay.

*Table 29 3-year cost H2 Deployment Opportunity C*

| | S1 | S2 | S3 |
|---|---|---|---|
| FCEV Capex | €700,000 | €700,000 | €700,000 |
| HRS Capex | €500,000 | €500,000 | €500,000 |
| Opex | €1,938 | -€3,762 | €18,400 |
| 3-year Cost | €1,201,938 | €1,196,238 | €1,218,400 |

*We include **dispenser costs** and some additional compressor costs as 400bar compression and storage are included in the LCOH figures for each scenario.

In Table 29 we estimate the three-year cost of Deployment Opportunity C. We do not propose to estimate longer than this as there may well not be any marketing benefit for FCEV tourism cars beyond 2025 when we expect FCEVs to be beyond the pilot stage as they move to technology maturity. Post 2025 it is likely that the market for tourism FCEVs in the West Coast of Ireland will be market-driven: i.e., FCEVs will be cheaper and more demonstrably suited to the terrain and tourism driving practices than BEVs which they will out-perform.

Partnership with Hydrogen Mobility Ireland members will be key to this opportunity. The authors note that there is already considerable interest from other communities on the West Coast for a pilot project such as this. We also must note that we have included the entire FCEV price in the costs. In reality the project will not be liable for the entire *estimated* cost of €70,000 per FCEV. The partner responsible for car leasing (and thus rental income) can be asked to contribute a proportion of this amount. For comparison, a BMW i-4 BEV retails in Ireland at €63,565[111].

The secondary benefits to the wider Achill community from H2 Deployment Opportunity C could be considerable. Increased high-value tourism, additional employment developing a car-rental product, high visibility engagement with a sustainability pilot scheme, and the potential for community access to second-hand FCEVs as the rental fleet is upgraded. The presence of the 700-bar dispenser (which may or may not have restricted public access) in the locality could also have significant benefits to the community.

## 8.5 Deployment Opportunity D H2 Domestic Heat

We found that this is a **long-term opportunity** for the following reasons:

There are no H2 domestic boilers on the market until post 2025

The deployment of domestic H2 boilers is currently unregulated and not approved in Ireland.

It is likely that the Irish state will take a ‘technology follower’ approach in domestic H2 boilers – much as it did in FCEVs

[111] https://www.bmw.ie/en/all-models/bmw-i/i4/2021/bmw-i4-highlights.html

Where H2 is deployed for home heating, it is certain that the gas grid utility will focus on increasing the H2 blend in the NG grid. It is likely that this will take up most of the renewable H2 set aside for heating well beyond 2030. We estimate that the amount of H2 required to achieve a 20%-80% H2:NG blend in the Irish gas grid will be 315,772 tH2. We do not consider H2 off-mains grid 100% H2 boiler deployment a feasible opportunity until this H2 gas blend milestone of production is achieved.

## 8.6 Summary of Deployment Opportunities matched with Scenarios

As we have seen, only Scenario 2 (S2) provides an LCOH that makes Deployment Options A-C feasible. Scenario 1 (S1) does prove feasible when taking into account indirect non-economic benefits that have been identified to us as significant by Todhchaí Phobail Acla. It is also 100% sustainable green H2, while S2 is not. In no cases was Scenario 4 (S4) feasible economically – we therefore at this point remove it from the list of feasible scenarios.

As regards Deployment Opportunities: Deployment Opportunity A (DO-A) is highly feasible and could be embarked upon in 2022. It is possible that S1/2 is not necessary for the feasibility of DO-A: there are H2 production projects being planned that could supply the H2 required. We recommend that DO-A is pursued during 2022 using imported green H2 from elsewhere in Ireland. The community should initiate the process whereby S1/2 (and S3) can be brought about. This will include foreshore licence application, planning permissions, Maritime Area Consent (MAC), and finance raising (see Section 8.7 below).

There are significant partnerships possible through TPA SEC's engagement directly with industrial and research partners in Hydrogen Mobility Ireland (HMI). HMI's members include CIE who would be central operating DO-A.

Local engagement is more significant in DO-B as the key partner for TPA SEC would be the local distillery. The opportunity is feasible but would require support from outside sources. We have prepared a confidential list of contacts of bodies who would be finance contributors. We have also identified organizations that manage funds which are relevant to this opportunity which we have shared with TPA SEC.

Deployment Opportunity C – FCEV Tourist Cars will require partnership with a commercial car-rental entity in addition to the relevant HMI members (for example DECC which now includes Transport, Toyota Ireland, and Hyundai Ireland). While DO-C is economically feasible in 2021, supply chain issues are significant. Thus, we recommend that TPA SEC initiate contacts with the relevant stakeholders in 2022 with a view to rollout during 2024, adequate supply of FCEV permitting. The planning and construction of a HRS, as well as safety and other regulatory issues will take time to put in place.

## 8.7 H2 Production Offshore Wind Scenarios S1, 2 and 3.

H2 Production Scenarios 1, 2 and 3 have all been demonstrated as feasible – with caveats for S1. All three feasible wind generation to H2 production scenarios are realizable over the medium to long term but will require considerable expenditure at each stage of the scoping, licensing, and exploration phase.

We saw in Section 5.4.2 that the application for an offshore licence involves an initial assessment of the suitability of the proposed site area. We now discuss the steps that must be taken in order to proceed through each stage of the process.

### 8.7.1 Foreshore License application:

This is a comprehensive 200 page plus document that is prepared by a licensing consultant.

A legal requirement of the Foreshore licence process involves stakeholder engagement. This must be professionally managed and recorded at every step for every communication with members of the public and relevant community and state bodies. For example, the Valentia Island Application has received and recorded over 2,000 communications: thankfully as said above, these have been overwhelmingly positive and supportive.

This work is best done through an external consultancy as it requires considerable expertise. The process usually takes 3-6 months. The cost of such a licence application process ranges from €150,000 to €360,000.

### 8.7.2 Exploration Process

On receipt of a foreshore license the project carries out an extensive exploration process of the site.

This involves a 2–3-year investigation of every aspect of the site: the hire of survey ships, aircraft, and onshore personnel. This is carried out by external consultants and the costs for this phase range from €5-10m.

### 8.7.3 Maritime Area Consent process (MAC)

This gives the holder the right to occupy a part of the maritime area for a defined period of time for an offshore floating wind energy generation. A MAC is granted by the relevant Minister, in this case the Minister for the Environment, Climate and Communications. A MAC will require payment of a considerable levy to the state[112]. At this stage there is a need for very large outside investment.

## 8.8 Deployment Opportunities as standalone non-production projects

As we have seen in the preceding discussion of offshore wind projects, there is a considerable timescale involved to move from scoping to production: up to 10 years. Conscious of this fact we address here the possibility of examining each Deployment opportunity as stand-alone using H2 imported form an Irish-based 3rd party. Only green H2 is considered.

### 8.8.1 Deployment Opportunity A(i) FCEV Bus using transported green H2

The total funding level of the opportunity as a stand-alone project in the absence of H2 production on the island is summarised in Table 30.

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[112] It has been widely reported that in the UK where the relevant body is the Crown Estate, a levy of approximately €100,000 per square km of seabed is required at the Exploration and MAC equivalent stages. It is possible that the Irish State may require projects to be funded at a similar level.

*Table 30 Deployment Opportunity a Stand-Alone Project Costs (DO-A(i)*

| | Item | Description | Cost |
|---|---|---|---|
| Capex | FCEV Bus | 2 X Caetano Single Decker Buses | €1,600,000 |
| | H2 Storage (120kg) | 2X 50 | €240,000 |
| | Dispenser 350 bar | 1 | €127,000 |
| OPEX* | H2 Cost | 19,401 kg H2@€7.00 /kg, less 2021 cost diesel per L/kWh equivalent[113] | €331,429 |
| | Dispenser | Operation | €75,000 |
| | Maintenance | Maintenance | €25,000 |
| | Total | For 5 years | €431,429 |
| TOTAL COSTS | | | €2,398,429 |

*The OPEX costs shown here are for the full 5-year term of the project.

We do not include H2 generation costs which are borne by the H2 supplier and included in the H2 Opex costs.

It is clear that this represents a middle-range funding target which is achievable for the community given the funding option – see section 9 below

### 8.8.2 Deployment Opportunity B(i) H2 Heat Manufacturing Application using transported green H2

We have reworked DO-B to take into account the likelihood of an unavailability of on-island produced H2 in the medium term. We have based our calculations on a 5-year project lifespan. This is not to say that the equipment purchased in yr1 will not be operational in yrs. 6-10, rather it is to take into account changing H2 prices over the period. By 2020 it can be hoped that one of the production scenarios 1-3 will apply.

The significant caveat here is that contact with the key on-island commercial partner/stakeholders is the remit of TPA SEC.

*Table 31 Deployment Opportunity B DO-B(i) Stand Alone Project Costs*

| | ITEM | Cost* |
|---|---|---|
| CAPEX | Boiler | €236,000 |
| | Storage (120kg) | €240,000 |
| OPEX | Maintenance | €25,000 |
| | Opex | €1,433,394 |
| Total | 10 year Cost | €1,909,394 |

*Opex is calculated over the life of the project – in this case 5 years

Again, as with DO-A(i) we note that this is a medium scale funding requirement which while it will require funding whether state or commercial partnerships as well as innovation/research funding

[113] IL diesel = €1.50 = 10kWh = €0.15/kWh

(Section 9.2). Given the potential innovation and research benefits at a regional and national level, we feel that it represents a feasible opportunity.

### 8.8.3 Deployment Opportunity C(i) FCEV Tourism vehicles using transported green H2

Table 32 shows that Deployment Opportunity C H2 Transportation Scenario (DO-B(i), given the right partnerships and funding support is feasible.

*Table 32 Deployment Opportunity C (DO-C(i)) Stand Alone Project Costs*

| | Item | Cost* |
|---|---|---|
| Capex | FCEV | €700,000 |
| | HRS | €1,700,000 |
| | Maintenance | €12,000 |
| Opex | H2** | €10,876 |
| | Dispensing | €10,000 |
| TOTAL | 3-year Cost | €2,432,876 |

*Capex costs are Y1, Opex costs are Yr1-3. We do not include vehicle resale values (est €30,000 per vehicle). Nor post project value of HRS (est 10-15yrs)

**We assume €7.50/kg H2 which is the median range for H2 predicted by HMI

This 3-year project does not require cheap green H2 in the short to medium term. As the pilot matures, the supply of H2 is expected to increase which will drive the market price of H2 close to parity with petrol. The cost differential between FCEVs and BEVs will remain possible until 2030 and beyond as both make concomitant product price reductions through upscaling. As we have stated before, it is the driving practices and geography of the Western region that may well drive the adoption of FCEVs once the HRS infrastructure is rolled out to match demand.

# 9 Potential Funding avenues

The authors of the report are aware of TPA SECs desire that the feasibility study includes both recommendations to act, and the promotion of the chosen projects within the policy and commercial spheres. We have prepared a list of funding opportunities. We have also prepared a confidential briefing document for TPA SEC on funding opportunities and contacts which it is not possible to publish on account of GDPR regulations and Commercial confidentiality.

The establishment of a market for hydrogen is a key requirement of the work being done by H2 technology developers and producer groups. The value of making alliances with these groups is discussed throughout this section.

## 9.1 Potential Partnership opportunities Deployment Opportunity A: Public bus service

The Service is operated by Bus Éireann and so that body is the only viable partner. Additional support from the Department of Communications and Climate Action will also be required and could help to the project garner support from the Climate Action Fund.

While this is, on the face of it, a considerable cost requirement, it should be noted that transport operators will be needed as funding partners. There are national and EU finding programs that are committed to supporting innovation in the face of climate change. We feel that this is a very feasible opportunity and should be pursued vigorously.

There are potential partners from the producer sector that seek to operate in the West of Ireland. Their support will be very useful in realising this opportunity. We cannot publish the details of some of these potential producer partners here. We will present these contact details directly to the TPA SEC committee.

## 9.2 Deployment Opportunity B(i): H2 heat for manufacturing Distillery

As previously stated, the key partnership here is a local partnership between TPA SEC and the manufacturing stakeholders.

If this is secured, funding opportunities from Bord Bia, Údarás na Gaeltachta, Enterprise Ireland, and other commercial bodies. ECI is providing the relevant contacts or made introductions for TPA SEC.

Irish Whiskey is an internationally recognised drink. It is produced in very large quantities in Ireland with estimates of litres produced per annum as high as 8.9 million litres[114]. Meeting this energy demand from an iconic product through innovative zero-carbon technology will be highly valuable to the Whiskey industry as a whole. Partnerships between large established distilleries and smaller innovative ones are potentially very beneficial to both.

## 9.3 Deployment Opportunity C(i): FCEV tourist car rental product

There are many companies who have an existing car-rental infrastructure in Mayo and further afield in the West of Ireland. These companies should be approached as partners. Similarly, while the car manufacturers themselves have identified long lead-in times for FCEV access, we have classed this a 2nd stage opportunity (potentially commencing in 2023) by which time it may be feasible to assume some FCEV availability.

Other partnerships in this opportunity from the commercial sector, beyond technology developers and H2 producers) are those energy companies that have shown a desire to enter the H2 deployment space. Again, some of these are HMI members. There are international players who are not, however. Some of these operate within Ireland and should also be approached.

## 9.4 Research Funding Partnerships

There is a large number of research projects in planning, underway, and recently completed that are working in the field of Hydrogen deployment in Ireland. Below in Section 10.4 is a non-exhaustive list of Hydrogen sector projects recently completed or currently underway in Ireland. The Irish partners in each of these projects can act as a guide for TPA SECs. We have facilitated introductions for TPA SEC with the relevant parties.

[114] https://usaspiritsratings.com/en/blog/insights-1/top-whiskey-producing-countries-of-the-world-99.htm

# 10 Todhchaí Phobail Acla H2 Roadmap

## 2022

**DO-A(i) Public Service Bus Route 450 Trial**

Potential Deployment: Q4 2022
**Est Cost: €2,398,429**
Potential Partners: Bus Éireann, DECC, H2 producer.
Feasibility: HIGH

**DO-B(i) H2 Heat for Manufacturing**

Planning and Partnership Building Phase
Potential Partners: Local Distillery, Bord Bia, Údarás na Gaeltachta, Enterprise Ireland, and other commercial drinks producers
Feasibility: HIGH

**DO-C (i) FCEV Tourism Car Product**

Planning and Partnership Building Phase
Potential Partners: Car Rental Companies, HFI, Toyota, Hyundai, Discover Ireland, DECC, H2 Producer, HRS provider
Feasibility: HIGH

**Scenario 1,3: Offshore Wind to H2**

Foreshore Licence Application
**Est Cost: €150,000 to €360,000**
Potential Partners: Identified
Feasibility: High

## 2023

**DO-B(i) H2 Heat for Manufacturing**

Potential Deployment: Q2 2023
**Est Cost: €1,909,394**
Potential Partners: Local Distillery, Bord Bia, Údarás na Gaeltachta, Enterprise Ireland, and other commercial drinks producers
Feasibility: HIGH

**DO-C (i) FCEV Tourism Car Product**

Planning and Partnership Building Phase
Potential Partners: Car Rental Companies, HFI, Toyota, Hyundai, Discover Ireland, DECC, H2 Producer, HRS provider
Feasibility: HIGH

**Scenario 1,3: Offshore Wind to H2**

Potential Commencement: Q4 2023
MAC Exploration Process Phase 1
**Est Cost: €7-10m**
Potential Partners: Identified
Feasibility: Moderate

## 2024-2026

**DO-C (i) FCEV Tourism Car Product**

Potential Deployment: Q2 2024
**Est Cost: €2,432,876**
Potential Partners: Car Rental Companies, HFI, Toyota, Hyundai, Discover Ireland, DECC, H2 Producer, HRS provider
Feasibility: HIGH

**Scenario 1,3: Offshore Wind to H2**

Potential Completion: Q4 2026
MAC Exploration Process Continuing
**Est Cost: €7-10m**
Potential Partners: Identified
Feasibility: Moderate

# 11 Appendices

## 11.1 Formulae

### 11.1.1 Levelized cost of Electricity

$$\text{LCOE} = \frac{\text{Sum of Costs over Lifetime}}{\text{Sum of Electrical Energy Over Lifetime}} = LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

$I_t$ = Investment expenditures in year t (including financing)

$M_t$ = Operations and maintenance expenditures in year t

$F_t$ = Fuel expenditures in year t

$E_t$ = Electricity generation in year t

r = Discount rate

n = Life of the system

### 11.1.2 Levelized Cost of Hydrogen Production

$$\text{LCOP} = \frac{\sum_{Y=0}^{Y=n_{HPS}} \frac{C_{Capital,P}}{(1+r)^Y} + \frac{C_{O\&M,P}}{(1+r)^Y}}{\sum_{Y=0}^{Y=n_{HPS}} \frac{M_{H2,P}}{(1+r)^Y}}$$

### 11.1.3 Capital Costs

$$C_{Capital,P=}\, C_{WE+}\, C_{SV+}\, C_{EC+}\, C_{EMS}$$

### 11.1.4 Operation and maintenance costs

$$C_{O\&M,P=}\, C_{OM,WE+}\, C_{OM,SV+}\, C_{OM,EC+}\, C_{OM,E}$$

### 11.1.5 Equation 8 – Levelized Cost of Hydrogen Transportation

$$\text{LCOT} = \frac{\sum_{Y=0}^{Y=n_{HTS}} \frac{C_{Capital,T}}{(1+r)^Y} + \frac{C_{O\&M,T}}{(1+r)^Y}}{\sum_{Y=0}^{Y=n_{HTS}} \frac{M_{H2,T}}{(1+r)^Y}}$$

## 11.2 Assumptions

### 11.2.1 Assumptions for LCOE for PV plant

| | LOW | HIGH |
|---|---|---|
| Lifespan | 25 | 25 |
| Output kWh/y | 1000 | 1000 |
| Inflation | 2.00% | 2.00% |
| Capital Interest | 5.00% | 5% |
| Capex | €850/kWp Installed | €1,100 kWp Installed |
| Power loss per Year | 1.5% | 1.5% |
| Opex per kWp/yr | €7.210 | €7.210 |

## 11.2.2450 Bus Route

### *11.2.2.1 Current Schedule Vehicle Requirements FCEV*

| 450 Schedule With FCEV | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **BUS 1** | **BUS 2** | **BUS 1** | **BUS 2** | **BUS 1** | **BUS 2** | **BUS 1** |
| **Louisburgh** | | 08:00 | 10:00 | 12:30 | 14:35 | 17:15 | 18:50 |
| **Westport Harbour View,** | | 08:22 | 10:22 | 12:52 | 14:57 | 17:37 | 19:12 |
| | | 08:24 | 10:24 | 12:54 | 14:59 | | |
| **Westport Mill Street** | | 08:30 | 10:30 | 13:00 | 15:05 | 17:43 | 19:18 |
| | 05:30 | | | | | 17:45 | |
| **Dooagh** | 07:04 | 10:04 | 12:04 | 14:34 | 16:39 | 19:19 | |
| **Kilometres (accumulative)** | **40** | **121** | **202** | **283** | **364** | **445** | **485** |
| | | **79.8%** **H2 Range Remaining** | | **52.8%** **H2 Range Remaining)** | | **25.8%** **H2 Range Remaining)** | **19.2%** |
| **Dooagh** | **BUS 2** | 07:10 | 10:10 | 12:20 | 14:45 | 16:45 | 19:20 |
| **Westport Mill Street** | 07:25 | 08:44 | 11:44 | 13:54 | 16:19 | 18:19 | 20:54 |
| **Westport Quay,** | 07:31 | 08:50 | 11:50 | 14:00 | 16:25 | 18:25 | **485** |
| | | 08:52 | 11:52 | 14:02 | 16:27 | 18:27 | **19.2%** **H2 Range Remaining** |
| **Louisburgh** | 07:53 | 09:14 | 12:14 | 14:24 | 16:49 | 18:49 | |
| | **40** | **121** | **202** | **283** | **364** | **445** | |
| | **93.3%** **H2 Range Remaining)** | | **66.3%** **H2 Range Remaining)** | | **39.3%** **H2 Range Remaining)** | | |

### *11.2.2.2 Current Schedule Vehicle Requirements BEV*

| 450 Schedule With BEV | | | | | | | |
|---|---|---|---|---|---|---|---|
| Louisburgh - Dooagh | | **BUS 2** | **BUS 1** | **BUS 2** | **BUS 3** | **BUS 4** | **BUS 3** |
| Louisburgh | | 08:00 | 10:00 | 12:30 | 14:35 | 17:15 | 18:50 |
| Westport Harbour View | | 08:22 | 10:22 | 12:52 | 14:57 | 17:37 | 19:12 |
| Westport Mill Street | **BUS 1** | 08:30 | 10:30 | 13:00 | 15:05 | 17:43 | 19:18 |
| | 05:30 | | | | | 17:45 | 202 |
| Newport | 05:49 | 08:49 | 10:49 | 13:19 | 15:24 | 18:04 | **42.3%** **H2 Range Remaining)** |
| Mallaranny Mulrany | 06:08 | 09:08 | 11:08 | 13:38 | 15:43 | 18:23 | |
| Dooagh | 07:04 | 10:04 | 12:04 | 14:34 | 16:39 | 19:19 | |
| KM | 41 | **121** | **203** | **283** | 81 | **81** | |
| | 88.29% **BEV Range Remaining** | **65.4%** **BEV Range Remaining** | **42.0%** **BEV Range Remaining** | **19.1%** **BEV Range Remaining** | **76.9%** **BEV Range Remaining** | **76.9%** **BEV Range Remaining** | |
| Dooagh - Louisburgh | | **BUS 1** | BUS 2 | BUS 1 | BUS 2 | BUS 3 | |
| Dooagh | | 07:10 | 10:10 | 12:20 | 14:45 | 16:45 | 19:20 |
| Mulrany | | 08:06 | 11:06 | 13:16 | 15:41 | 17:41 | 20:16 |
| Newport | **BUS 2** | 08:25 | 11:25 | 13:35 | 16:00 | 18:00 | 20:35 |
| Westport Mill Street | 07:25 | 08:44 | 11:44 | 13:54 | 16:19 | 18:19 | 20:54 |
| Westport Quay, stop 557161 | 07:31 | 08:50 | 11:50 | 14:00 | 16:25 | 18:25 | **121** |
| | | 08:52 | 11:52 | 14:02 | 16:27 | 18:27 | **65.4%** **H2 Range Remaining)** |
| Murrisk | 07:42 | 09:03 | 12:03 | 14:13 | 16:38 | 18:38 | |
| Louisburgh | 07:53 | 09:14 | 12:14 | 14:24 | 16:49 | 18:49 | |
| KM | **40** | 122 | **202** | 364 | **364** | 162 | |
| | **88.6%** **BEV Range Remaining** | **65.1%** **BEV Range Remaining** | **42.3%** **BEV Range Remaining** | **-4.0%** **BEV Range Remaining** | **-4.0%** **BEV Range Remaining** | 53.7% **BEV Range Remaining** | |

### 11.2.3 Deployment Opportunity C: Rental Cars

*11.2.2.3 Calculations*

| Item | Units |
|---|---|
| 200 | km/d |
| 100 | usage days per car/yr |
| 10 | no. of cars |
| 0.76 | kg H2 use per 100 km |
| 1,520 | kg/H2/yr |
| 50,160 | kWh/yr |

## 11.3 Funding Opportunities at a National and EU Level

Disruptive Technologies Innovation Fund: https://enterprise.gov.ie/en/What-We-Do/Innovation-Research-Development/Disruptive-Technologies-Innovation-Fund/

DECC Innovation Fund: https://www.gov.ie/en/publication/bee1c-innovation-fund/#first-call-small-scale-projects

Horizon Europe: https://ec.europa.eu/info/research-and-innovation/funding/funding-opportunities/funding-programmes-and-open-calls_en

European Commission Life Programme: https://cinea.ec.europa.eu/life_en

European Regional Development Fund (ERDF): https://ec.europa.eu/regional_policy/en/funding/erdf/

## 11.4 Large Scale Hydrogen Research Projects in Ireland

GENCOMM: https://www.nweurope.eu/projects/project-search/gencomm-generating-energy-secure-communities/

SEAFUEL: http://www.seafuel.eu/

HUGE: https://huge-project.eu/

Hi-Wind; https://www.marei.ie/project/h-wind/

Hylantic: http://hylantic.com/

HyLIGHT: https://www.marei.ie/project/hylight/

GreenHysland: https://greenhysland.eu/