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EXPLORING SEAFUEL HYRDOGEN OPPORTUNITIES FOR WEST OF IRELAND

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1.0 Executive Summary

As part of the SEAFUEL project, we provide a roadmap for the potential for SEAFUEL rollout in the West of Ireland. This roadmap is set out in three phases (discussed in Section 7 below) and illustrated by Figure 13: SEAFUEL West of Ireland Roadmap. This is intended to compliment the roadmaps discussed for the other regions elsewhere in this paper, but it is itself stand alone: specifically tailored to the economic, policy and geographic conditions of the region. The paper finds that over a three-phase period, suitable projects, and partnerships in an early 'focus' phase one demonstration and public acceptance building stage should be chosen which would be built on in an upscaling and rollout phase two. Ultimately these will lead to a large-scale 360^{o} rollout of offshore wind for a national and international market of hydrogen for transport use.

The phases should occur across a 2022-2040+ timescale. However, we feel planning and partnership building for these should occur from now in the expectation that hydrogen will play a central role in the economic sustainability of the West of Ireland.

It should be noted that there is considerable community appetite in the West of Ireland for H2 as a decarbonisation vector: Comharchumann Fuinnimh Oileáin Árainn (CFOAT) through SEAFUEL and HUGE have directly contributed to the debate. Valentia Island Energy Co-operative (VIE) and Rathlin Island Development Association are members of a multi-island campaign group seeking to participate in large scale Hydrogen rollout[1].

While Phase 1 in particular will require state support of up to €5.2m, it is proposed that this investment will create confidence in the commercial sector for greater funding in Phase 2. It does not necessarily include supports per kg of H2 distributed and consumed. It does however require greater policy and regulatory clarity. Phase 3 is expected to be wholly commercially funded and will have a significant revenue benefit to the state.

2.0 Introduction

Determining the hydrogen opportunity for the West of Ireland is initially dependent upon three contexts: the definition of the area in question, the current energy demand for this area, and the extent of the export feasible opportunities. We will look at each of these in turn.

3.0 Definition of the Region

The West of Ireland as it is understood both in this paper and in common usage is a broadly defined non-politically determined geographical region in the Republic of Ireland comprising parts of three distinct NUTS Level 3 areas[2].

Figure 1 below shows a map of the counties[3] of Ireland with the Nomenclature of Territorial Units for Statistics (NUTS) 3 level regions overlayed[4]. Figure 2 shows the area which this report will study as the West of Ireland.

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1 https://www.irishtimes.com/news/environment/west-coast-islands-to-join-forces-to-generate-offshore-wind-energy-1.4463384

2 https://www.cso.ie/en/methods/revnuts23/

3 Ireland is divided administratively into thirty-two counties, six of these are governed by the Northern Ireland Stormont Executive and the UK government, the remaining 26 counties comprise the Republic of Ireland.

4 https://upload.wikimedia.org/wikipedia/commons/2/28/NUTS3_Boundaries_Ireland.png

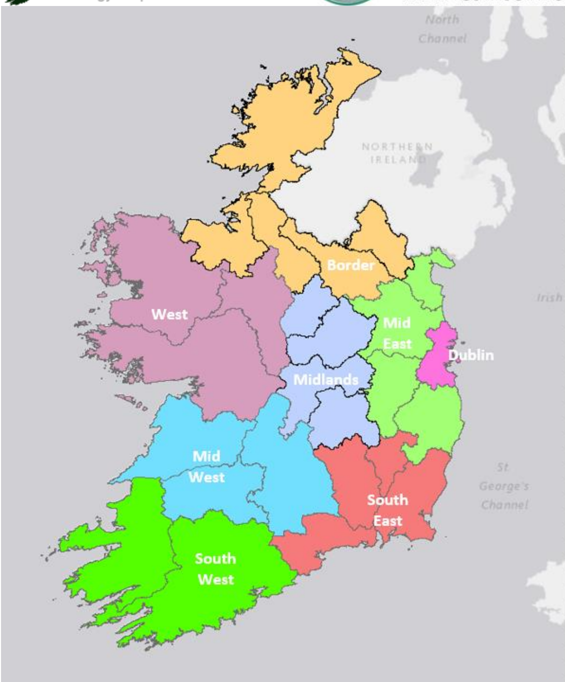

Figure 1: NUTS areas Ireland

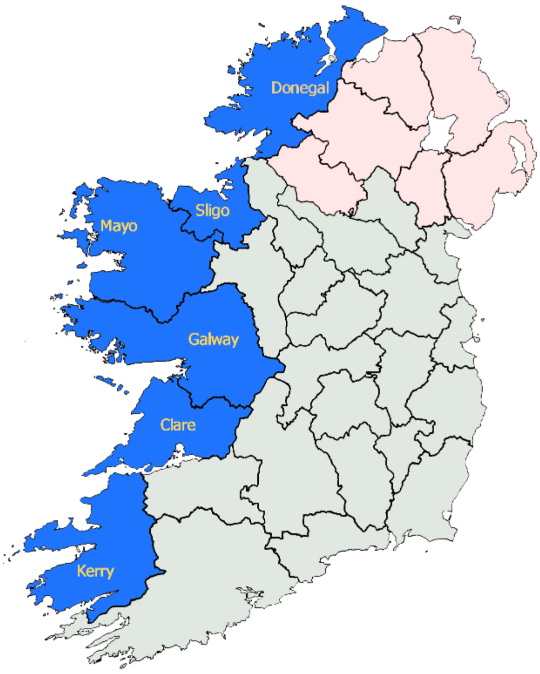

Figure 2: West of Ireland Counties

The authors believe this reflects a *generally* geographically, socio-economically, and culturally homogonous area. While there is some variation across the counties, we consider it useful to use the county area as the base unit of statistical data analysis. The counties that are analysed with respect to this H2 roadmap are listed in Table 1 below.

Table 1. Counties and Population density

County	Population ('000s)	Area (sq. km)	Population Density persons per sq. km
Donegal	159.2	4,861	32.8
Sligo	65.5	1,838	35.6
Mayo	130.5	5,586	23.4
Galway	258.1	6,149	42.0
Clare	118.8	3,450	34.4
Kerry	147.7	4,807	30.7
Total West	**879.8**	**26691**	**33.0**
Rep Ireland	**4,761.90**	**84,142**	**56.6**

From Table 1 we can see that the region in this study is more sparsely populated then the Republic of Ireland as a whole. Galway has the densest population of the six counties studied, as it is home to Ireland's most populous western city, Galway City, but at 42 people per square kilometre, it is still considerably below the national average of 56.6.

4.0 West of Ireland Energy Mix

As discussed above, we will take the energy use of each county as a whole rather than sub-dividing counties further. This we feel is justified: county identity is very strong and is re-enforced by geographical and political considerations. The western coasts of each county are considered the periphery of the administrative capitals and thus there is an economic logic to each being considered within the H2 roadmap. We will examine domestic and commercial energy use.

4.1 Commercial Energy Use in Western Region

Figure 3 shows the use of energy by business in the six counties in the region. At a total of 6,618 GWh, businesses in the region consume just 3.7% of Ireland's as a whole (166,588 GWh/yr). Galway County, which has the largest population in the region, still ranks just 11th of all counties. Data on commercial energy use by sector for each county is not published by the CSO. However, as Figure 4 shows, nationally, businesses consume a total of 14,324 ktoe, with 48% of this on petroleum fuels.[5]

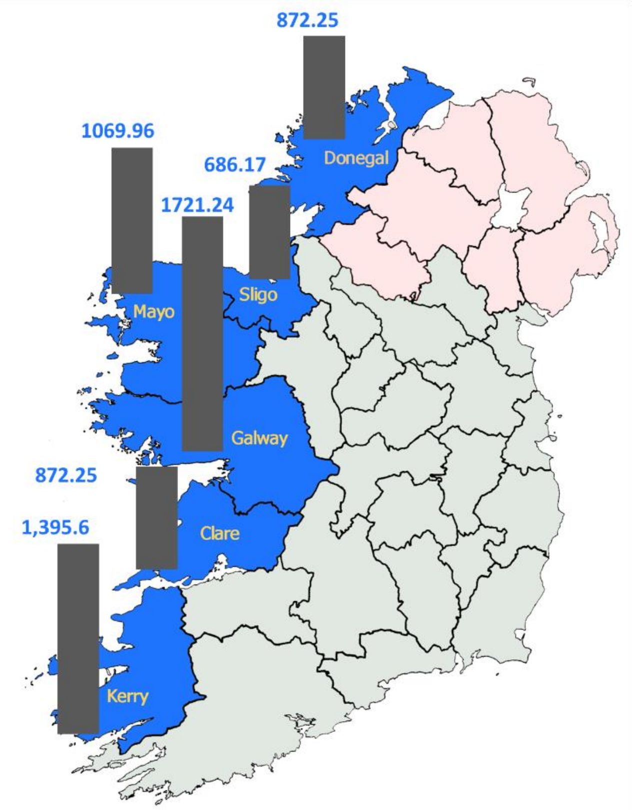

Figure 3: Business Consumption of energy in GWh/yr by County in Western Region 2018[6]

[5] https://www.cso.ie/en/releasesandpublications/er/beu/businessenergyuse2018/ Table 4a
[6] https://www.cso.ie/en/releasesandpublications/er/beu/businessenergyuse2018/

	ktoe
Natural Gas	1891
Petroleum Fuels	4722
Solid Fuels	745
Renewable Energy (incl. Waste)	1145
Road Transport Fuels	397
Rail Transport Fuels	968
Aviation Transport Fuels	42
Total	14,324

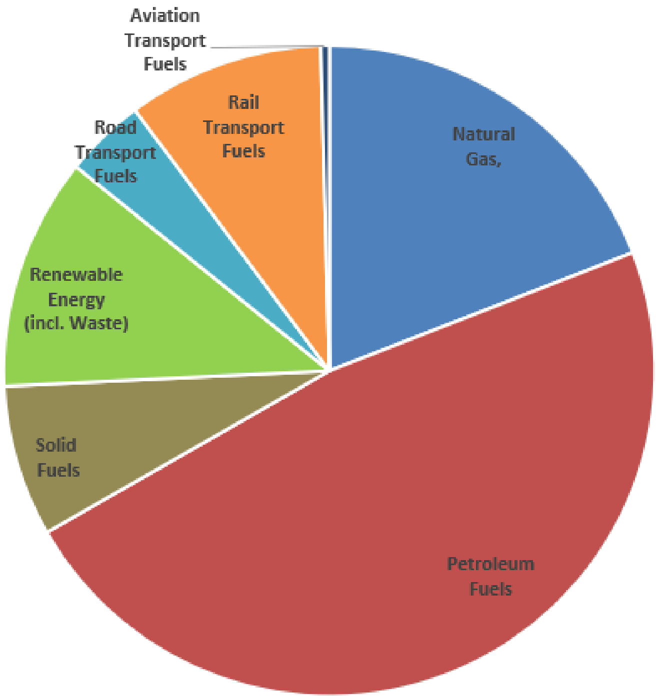

Figure 4: Energy Consumption in ktoe by Summary Energy Product 2018

4.1.1 Commercial Energy Use by Sector

As Table 2 shows, the transportation and storage sector has the highest level of energy consumption. This is significant as it is in this sector that the SEAFUEL technology and roadmap is focused. While this is a national figure, it is not unreasonable to think that it broadly reflects the picture in the Western Region.

Table 2: Irish Commercial Energy Use by Sector

Sector	ktoe	% of total
Mining and Quarrying	79	0.6%
Manufacturing	2,869	20.0%
Electricity and Gas	3,754	26.2%
Water Supply, Sewerage, and Waste Management	140	1.0%
Construction	85	0.6%
Wholesale, Retail, and Vehicle Repair	541	3.8%
Transportation and Storage	5,070	35.4%
Accommodation and Food Services	207	1.4%
Public Administration, Education, Health and Care	880	6.1%
Other Services Sectors	699	4.9%

Table 2 shows that 35% of the commercial sector's energy usage in Ireland is for transport and storage. The commercial transport energy demand offers a strong market opportunity for SEAFUEL which will be addressed in the Roadmap in Section 7 below.

4.2 Total ESTIMATED domestic energy use (from BERs)[7]

As a compliment to the data of business energy use above, in this section we seek to estimate the energy use in the domestic sector, by county and then in the region as a whole. Through this we will estimate the total relevant energy use for the West of Ireland. There are no county- level statistics on domestic energy use and so we have to approximate these on the basis of what published data there is. We caution that the final energy use figures are *estimated*.

4.2.1 National Rating System

The Sustainable Energy Authority of Ireland (SEAI) oversees a Building Energy Rating (BER) certification system for all Irish homes. According to the most recent available data, from the Central Statistics Office[8] 'There were 934,162 unique domestic BERs (one per dwelling) completed in the period 2009 to the end of March 2021. This compares with around 1.7 million occupied private households enumerated in the 2016 Census of Population.' Thus 55% of Irish homes have a BER certificate. While BER certified homes cannot be assumed to represent exactly all homes, the CSO weighted data shown in Figure 5: Dwellings with BERs compared with all dwellings (2009-2021) CSO indicates that for the purpose of this paper energy use by homes in the study area is broadly reflected by available BER data. We can see that the vast majority of homes nationally are rated between B2 and E1.

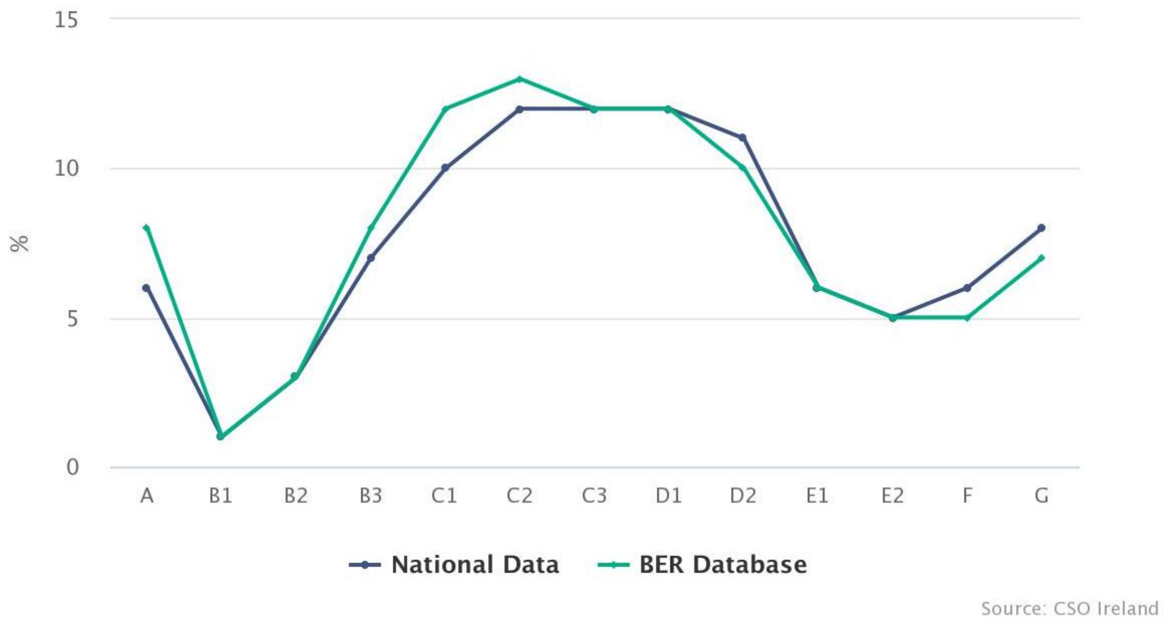

Figure 5: Dwellings with BERs compared with all dwellings (2009-2021) CSO[9]

4.2.2 West of Ireland Homes Energy Use

BER ratings vary across the counties in the areas studied. Table 3 shows the counties according to percentages of BERs A to G.

[7] For an explanation of the methodology used to determine these, please see Appendices
[8] https://www.cso.ie/en/releasesandpublications/er/dber/domesticbuildingenergyratingsquarter12021/
[9] https://www.cso.ie/en/releasesandpublications/er/dber/domesticbuildingenergyratingsquarter22021/

Table 3: BER ratings of homes in the study region

	% of row															
	Energy Rating														Total Homes[10]	BERs as % Total Homes
County	A	B1	B2	B3	C1	C2	C3	D1	D2	E1	E2	F	G	Total		
Clare	3%	1%	2%	6%	10%	13%	14%	14%	12%	7%	6%	5%	8%	23,349	43,348	54%
Kerry	4%	2%	3%	7%	11%	12%	13%	13%	11%	7%	5%	5%	8%	29,420	54,288	54%
Galway County	4%	1%	2%	7%	11%	14%	14%	12%	10%	6%	5%	5%	8%	36,295	62,729	58%
Galway City	4%	1%	2%	6%	10%	13%	16%	16%	12%	7%	5%	5%	4%	14,135	29,242	48%
Mayo	4%	1%	2%	5%	9%	13%	15%	13%	12%	6%	5%	6%	10%	24,507	48,745	50%
Donegal	2%	1%	2%	6%	13%	15%	14%	12%	10%	6%	5%	5%	8%	28,168	58,305	48%
Sligo	3%	1%	2%	7%	10%	12%	12%	13%	12%	8%	6%	6%	9%	14,309	24,761	58%

Table 4 extrapolates the BER for homes in each county based on the total number of homes according to CSO census 2016. We can thus estimate how many homes of each energy rating type there are in each county. This will provide an *estimate* as BER homes may not be directly representative of the housing stock. However, for the purpose of providing a *general* picture of domestic energy, we feel it can be justified as Table 3 shows that on average there is BER data for 53% of all homes.

Table 4: Ratings by Total Number of Households Each County

County	Estimated number of dwellings for each Energy Rating A-G													TOTAL[11]
	A	B1	B2	B3	C1	C2	C3	D1	D2	E1	E2	F	G	
Clare	1300	433	867	2601	4335	5635	6069	6069	5202	3034	2601	2167	3468	43,348
Kerry	2172	1086	1629	3800	5972	6515	7057	7057	5972	3800	2714	2714	4343	54,288
Galway County	2509	627	1255	4391	6900	8782	8782	7527	6273	3764	3136	3136	5018	62,729
Galway City	1170	292	585	1755	2924	3801	4679	4679	3509	2047	1462	1462	1170	29,242
Mayo	1950	487	975	2437	4387	6337	7312	6337	5849	2925	2437	2925	4875	48,745
Donegal	1166	583	1166	3498	7580	8746	8163	6997	5831	3498	2915	2915	4664	58,305
Sligo	743	248	495	1733	2476	2971	2971	3219	2971	1981	1486	1486	2228	24,761

4.2.3 Estimating Energy Use for homes from BER averages

Energy use in the BER certification system is given as kwh/y/m2 of floor area. It is therefore necessary to estimate the average floor area of buildings for each county of BER certified buildings. Table 5 shows such average areas combining all floors of the dwellings surveyed.[12]

Table 5 Average Energy Use in kWh/m2/y for each BER type in each county

kWh/m2/Y

[10] Number of homes taken from CSO 2016 data

[11] These totals do not exactly match the total number of homes in the CSO 2016 data as the CSO has rounded its percentage figures for BER ratings

[12] A full description of this methodology is given in Appendix.

	A	B1	B2	B3	C1	C2	C3	D1	D2	E1	E2	F	G
Clare	54	92	116	140	155	189	214	243	280	321	360	413	668
Kerry	54	90	115	140	150	189	214	243	281	320	360	414	664
Galway County	51	89	116	140	164	188	213	242	280	321	360	413	666
Gaway City	50	88	116	140	164	189	214	243	280	320	361	411	480
Mayo	55	89	115	140	165	189	214	243	280	101	360	415	703
Donegal	53	90	116	140	165	188	213	243	280	320	360	414	635
Sligo	53	88	115	140	164	189	214	243	280	320	360	413	663

This therefore enables us to estimate the total domestic energy use in each county and in the region as a whole as shown in Table 6.

Table 6: Estimated Domestic Homes Energy Use by County

	GWh/yr per home BER													TOTAL
County	A	B1	B2	B3	C1	C2	C3	D1	D2	E1	E2	F	G	GWh/y
Clare	17	12	30	98	171	242	269	277	261	166	153	146	353	2,194
Kerry	29	31	58	145	215	280	320	329	305	209	164	179	417	2,681
Galway County	37	18	47	179	295	376	396	367	330	219	194	225	535	3,217
Galway City	11	5	12	46	77	115	156	165	137	87	69	81	75	1,037
Mayo	31	14	32	97	186	273	325	305	306	54	157	208	542	2,530
Donegal	15	14	37	128	280	349	367	329	300	199	180	201	447	2,847
Sligo	12	6	14	53	86	109	119	136	138	99	87	101	225	1,185
													TOTAL West Ireland	15,691

4.2.4 Total ESTIMATED domestic transport use (from CSO and SEAI averages)

The CSO collects data on the level of car ownership in Ireland. The latest figures available (2019) allows us to estimate the number of cars in each county (Table 7).

Table 7: Private Vehicle Use By County[13]

	Private cars			
County of owner	**Vehicles**	**km (million)**	**Fuel Use litres diesel[14]**	**GWh**
Clare	58,669	1,052	48,812,800	488
Donegal	66,327	1,163	53,963,200	540
Galway	117,293	2,069	96,001,600	960
Kerry	73,292	1,259	58,417,600	584
Mayo	62,069	1,121	52,014,400	520
Sligo	29,610	515	23,896,000	234
Total	**407,260**	**7,179**	**333,105,600**	**3331**

[13] https://www.cso.ie/en/releasesandpublications/ep/p-tranom/transportomnibus2019/roadtrafficvolumes/ .
[14] https://ec.europa.eu/transport/sites/default/files/2017-01-fuel-price-comparison.pdf, p21 1 litre diesel = 10 kWh

CSO and Cartell.ie Data

Diesel is the most popular choice of fuel type for private cars in Ireland[15]. This is even more so in the West of Ireland where typical distances travelled are greater than the East which suits diesel's perceived 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. Thus, the GWh per County for private car travel is also shown in Table 7.

4.3 Estimated Global Energy Use for the Region

The various data sources above therefore enable us to provide a global estimate for the energy use for each county and for the region as a whole.

Table 8: Global estimate for the energy use.

	GWh Energy Used			
County	Domestic Home	Domestic Travel	Business	Total
Clare	2,194	488	872	3,554
Kerry	2,681	540	1,396	4,617
Galway County and City	4,254	960	1,721	6,935
Mayo	2,530	584	1,070	4,184
Donegal	2,847	520	872	4,239
Sligo	1,185	234	686	2,105
TOTAL West Ireland	15,691	3,331	6,617	25,639

This does not include energy used to produce imported products or non-car travel such as air or ferry transport outside the region (for example international flights). As Figure 6 shows the domestic homes are the greatest consumer of energy in the region. As most of this is for heat and light, for the purposes of SEAFUEL it may be considered not to represent a critical Phase 1 opportunity for energy source transformation to H2: that is not to say that it is not amenable to replacement by H2 at some stage in the future. It is important to build in this energy use to our Phase 2 and 3 roadmaps.

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

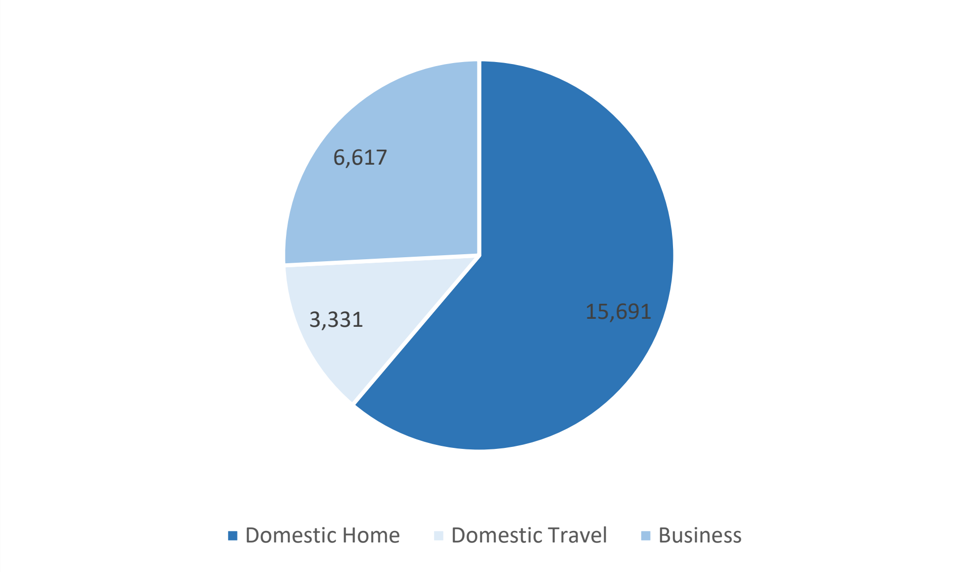

Figure 6: Total West of Ireland Energy Consumption by Sector GWh/annum

The domestic travel consumption (i.e., family cars) is a considerable destination for energy use – the vast majority of this is in petrol or diesel fuelled light vehicles[16]: the exact target of SEAFUEL's technology.

5.0 Energy Sources for the Region

5.1 All energy Sources Nationally

It is not possible to access data on energy use by fuel type by county or region in Ireland. However, we do have national level data which is instructive.

At present, 34% of electricity consumed in Ireland as a whole is generated renewably[17]. However, this amounts to a small fraction of total energy use. In 2019, electricity accounted for just 19.7% of total final consumption and renewables accounted for only 3.9% of final energy use.

[16] A 2019 study by the Irish CSO found that nationally, 1.5% of respondents owned an EV. Interestingly this did not vary greatly from Urban to Rural environments.
[17] https://www.seai.ie/publications/Energy-in-Ireland-2020.pdf (p.34)

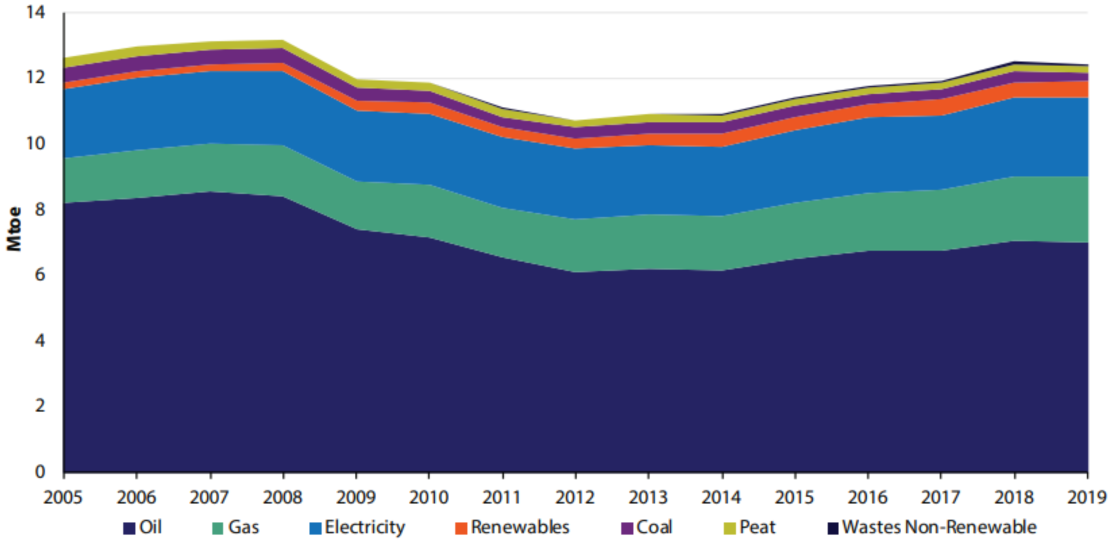

Figure 7: Total final consumption by fuel: Source SEAI[18]

Renewables provided 57ktoe (663GWh) of Ireland's final energy consumption. Oil, which is used in transport, heating and electricity generation provided 7,014ktoe (81573 GWh).

5.2 Onshore Wind Electricity Generation

The MW installed of wind electricity generation for each of the counties in the region is shown in Table 9. The energy demand for each county is thus considerably greater than that generated by Wind. However, as there is significant intermittency of generation there are times when electricity generated exceeds the energy demand.

Table 9: Wind Energy Generation installed Maximum Export Capacity (MEC) in MW

County	Total MEC MW
Clare	151.1
Kerry	621.7
Galway	311.3
Mayo	169.0
Donegal	393.6
Sligo	62.7

Source: Authors collation of data from TSO[19] and SEAI[20] publications.

Wind farm location in the region is very reliant on grid resilience and access. There is a strictly regulated system for connection regulated by Commission of the Regulation of Utilities (CRU) and delivered through the TSO which is Eirgrid a state-owned monopoly and the DSO (ESBN). Therefore, there is a concentration of wind farms and generation capacity where the grid is strong. Plans to strengthen the grid in remoter westerly areas (for example the Grid West project) have not

[18] Ibid p18
[19] https://www.eirgridgroup.com/site-files/library/EirGrid/TSO-Connected-Renewable-Generation.pdf
[20] https://www.seai.ie/technologies/seai-maps/wind-atlas-map/

preceded for a variety of policy, technical and public acceptance reasons documented in Mullaly and Byrne (2016: 10)[21]

There is therefore a practical limit on the amount of wind energy that can be installed in the Western region created by the degree to which public acceptance limits transmission grid upgrades.

This presents an opportunity for hydrogen production technology as a means of coping with energy generation intermittency, grid weakness and lack of interconnection which leads t both curtailment and reduced installed capacity. These factors are examined by Gunawan et al (2019)[22] specifically in the H2 production context.

Thus, there is a significant role for those technologies that can smooth the intermittency effects of variable wind energy on the grid, prevent constraints of wind energy generation and enable wind energy to upscale while not affecting grid stability. In our case we propose Hydrogen generation for transportation initially, and for heat in the future can meet this role: Glenk and Reichelstein (2019)[23], and in the Irish context Gunawan et al (2020)[24]

5.3 Photovoltaic Energy Generation

This form of renewable energy generation deployment is considerably less advanced than wind energy in Ireland in general and in the West of Ireland in particular. This is partly due to an historic absence of an adequate government support scheme. Less favourable solar radiation conditions than elsewhere in Europe also meant that Ireland was initially not ideally suited to the adoption of grid scale PV for projects using PV panels with lower efficiency. In effect it was not until the advances in efficiency from 2015 became available that Ireland's climactic limitations were overcome, and large-scale PV became economically viable.

These barriers have meant that PV at scale has only very recently been begun to be installed. The numbers and locations of PV farms at scale (>1MW) can be examined through the Irish government's Renewable Energy Support Scheme (RESS) documentation. In effect, 2020 was the first year that grid scale PV commenced – and even then, it was through an auctioning process. So, while there are no published figures showing exactly how much PV has been installed since 2020, we do know how much has been authorised by the state via planning and RESS.

Figure 8 below shows that there are very few PV farms in the Western Region: there are no PV farms in Donegal, Sligo, or Clare, and only one each in Kerry (4MW) and Mayo (4MW) with two in Galway (both 4MW). This is not surprising on account of the fact that as Figure 9 shows the West of Ireland has fewer sunshine hours than the East and the North fewer still.

While there will inevitably be a gradual spreading of PV projects into the West from the current concentration on the East and South, this may take 5-10 years. In addition, PV in the West will be competing with onshore wind economically in the medium term. While there are complementarities

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[21] Mullally, G., & Byrne, E. (2015). A tale of three transitions: a year in the life of electricity system transformation narratives in the Irish media. Energy, Sustainability and Society, 6(1). doi:10.1186/s13705-015-0068-2

[22] Gunawan, Singlitico, Blount, Carton, and Monaghan 'Towards techno-economic evaluation of renewable hydrogen production from wind curtailment and injection into the Irish gas network', https://www.nweurope.eu/media/6438/ecos-2019.pdf

[23] Glenk, G., & Reichelstein, S. (2019). Economics of converting renewable power to hydrogen. Nature Energy. doi:10.1038/s41560-019-0326-1

[24] Gunawan, Singlitico, Blount, Carton, and Monaghan 'At What Cost Can Renewable Hydrogen Offset Fossil Fuel Use in Ireland's Gas Network?' Energies 2020, 13, 1798; doi:10.3390/en13071798

between the two technologies' intermittency (there is more wind in winter and at night, while there is more solar radiation in summer and during the day), this may not be enough to justify the economics of PV in the West of Ireland. This is not to say that non-economic influences may come into play in order to increase PV in the Western region. The Mayo project, Lisduff Solar Park, is community owned. Favourable policies for community owned projects meant that it received a very strong price somewhere near 104.15 €/MWh under the RESS. Much higher than the average Developer led PV price of 72.92 €/MWh.[25].

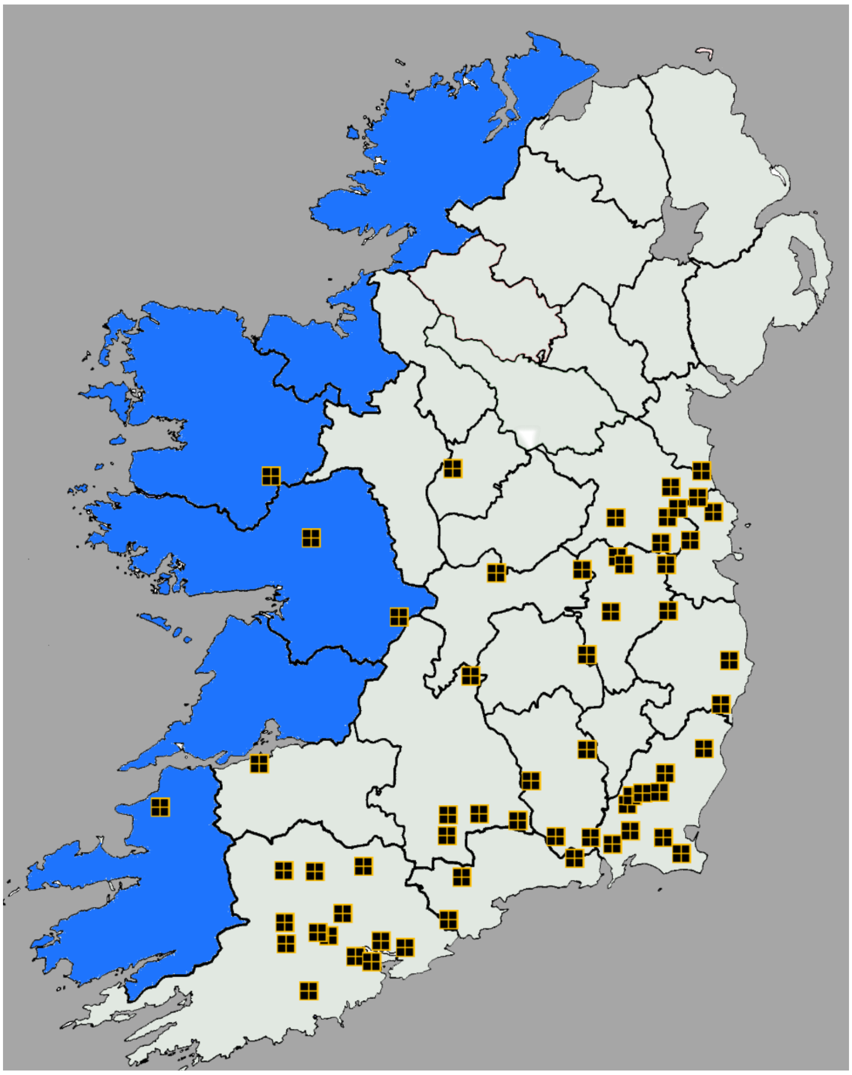

Figure 8: Distribution of RESS supported PV Farms Ireland

Source: author's mapping of RESS successful applicants from: http://www.eirgridgroup.com/site-files/library/EirGrid/R1FAR-Excel-Table.xlsx.

[25] http://www.eirgridgroup.com/site-files/library/EirGrid/RESS-1-Final-Auction-Results-(R1FAR).pdf p7

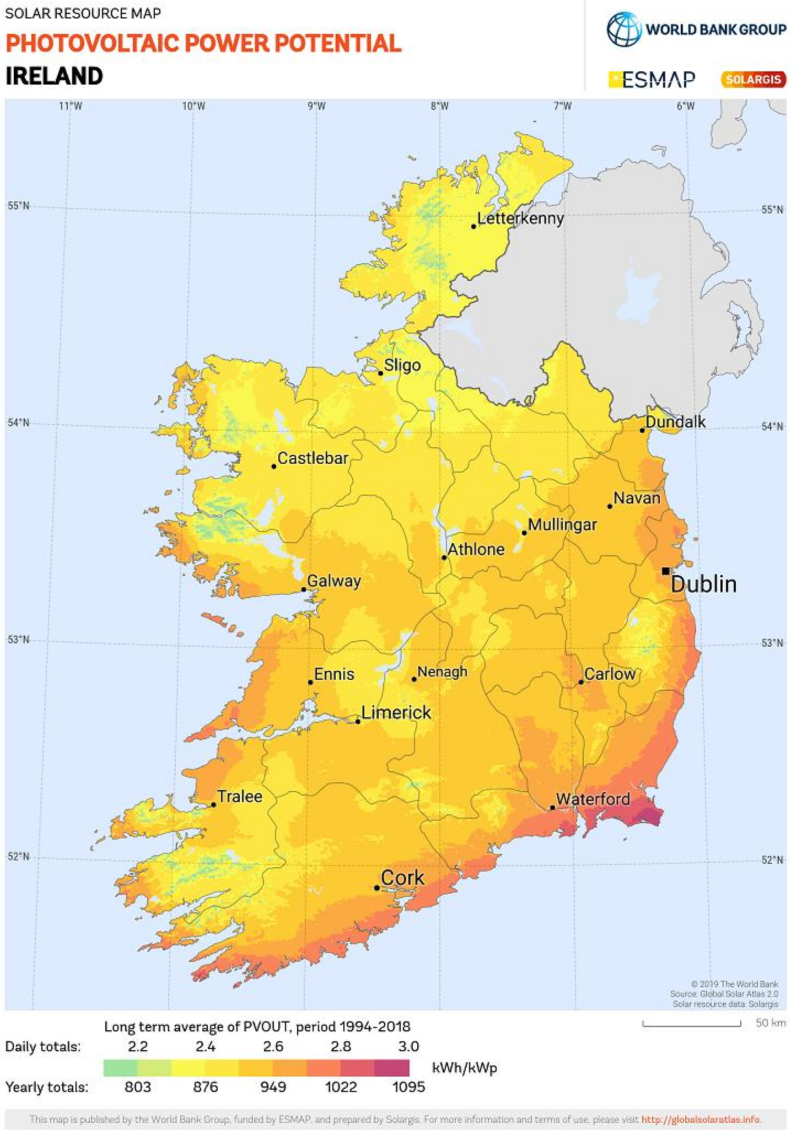

Figure 9: Solar Radiation Values Ireland kWh/kWp

It is the opinion of the authors that PV in the West of Ireland will not play a significant role in the production of hydrogen for transport use as envisaged in SEAFUEL.

5.4 Hydroelectricity

There is significant Hydro Electricity generation in the Western Region. The Shannon hydroelectric scheme is in Ardnacrusha County Clare. Constructed by Siemens-Schuckert and commissioned in 1929, the 86MW turbines played a central role in the electrification of the entire country. The power generated by the scheme is 332GWh/a.

There are two TSO hydro schemes in Donegal: Cliff (20MW) and Cathleen's Fall(45MW)[26].

[26] http://www.eirgridgroup.com/site-files/library/EirGrid/TSO-Connected-Renewable-Generation0719.pdf

There are a number of smaller DSO hydro schemes in the region: there are two in Sligo at Ballisadare: one of 500kW and the other 110kW. Mill at Donegal has 176kW installed. The remaining hydro schemes in the region are less than 100kW[27].

There is generally a negative public attitude to utility scale hydroelectricity projects due to concerns about fish-life and water quality[28]. There are however more positive community attitudes to micro-hydroelectricity. There is also a government supported project for a 360MW hydroelectricity pumped storage using freshwater elsewhere in Ireland[29].

It is not expected that in the medium term that hydroelectricity will play a significant role in the roll-out of SEAFUEL technology in the West of Ireland.

5.5 Offshore Wind Developments

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

The Climate Action Plan, June 2019, set out strategy for 3.5 GW[30] of offshore wind energy by 2030. While the Climate Action Act[31] (2021) does not mention offshore wind explicitly, it is expected that the offshore strategy will be laid out clearly in the upcoming Climate Action Plan 2021[32] will. The preparatory groundwork has been laid for a regulatory process for applications for offshore wind schemes has been laid and this it is hoped will bring more clarity to the matter for developers and citizens.

[27] Data from SEAI: https://gis.seai.ie/hydro/
[28] https://www.irishexaminer.com/news/arid-20470984.html
[29] https://silvermineshydro.ie/game-changing-moment-for-silvermines-hydro-gets-critical-eu-status/
[30] https://assets.gov.ie/25419/c97cdecddf8c49ab976e773d4e11e515.pdf
[31] https://data.oireachtas.ie/ie/oireachtas/bill/2021/39/eng/ver_b/b39b21d.pdf
[32] https://data.oireachtas.ie/ie/oireachtas/bill/2021/39/eng/ver_b/b39b21d.pdf

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

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 Applications Power 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 registered a partnership with Equinor for a 1.4 GW floating windfarm[36] which will also

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

potentially produce 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 think 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 immanent. However, it is clear that the policy field for H2 in Ireland is changing rapidly.

6.0 Hydrogen Projects in Ireland

6.1 Context

As was stated in the previous published SEAFUEL policy review document[39], 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 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, not least one of which is SEAFUEL itself.

The technology has only very recently led to real-world projects which demonstrate H2 transport technology directly to the public and the policy makers.

6.2 Production

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, ESB, and Equinor. The significance of the project is indicated by the presence in the consortium of major utility, distribution and energy production stakeholders. The projects goals are '…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).

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[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
[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)

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].

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 963MW Gas and Steam Combined Cycle Power Station, Whitegate, Co. Cork. The EI-H2 project says that it is 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.

6.3 Consumption

INTERREG project GENCOMM[44] conducted a study of the feasibility of decarbonizing city bus networks in Ireland with renewable hydrogen found 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.

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.

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 hoods vehicles (HGVs), buses, and, to a lesser extent, intercity trains.

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[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/

[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/

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

6.4 National Policy 2017-2020

The policy position in Ireland discussed in the previous SEAFUEL paper 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 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 11:

Table 11: 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 10.

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

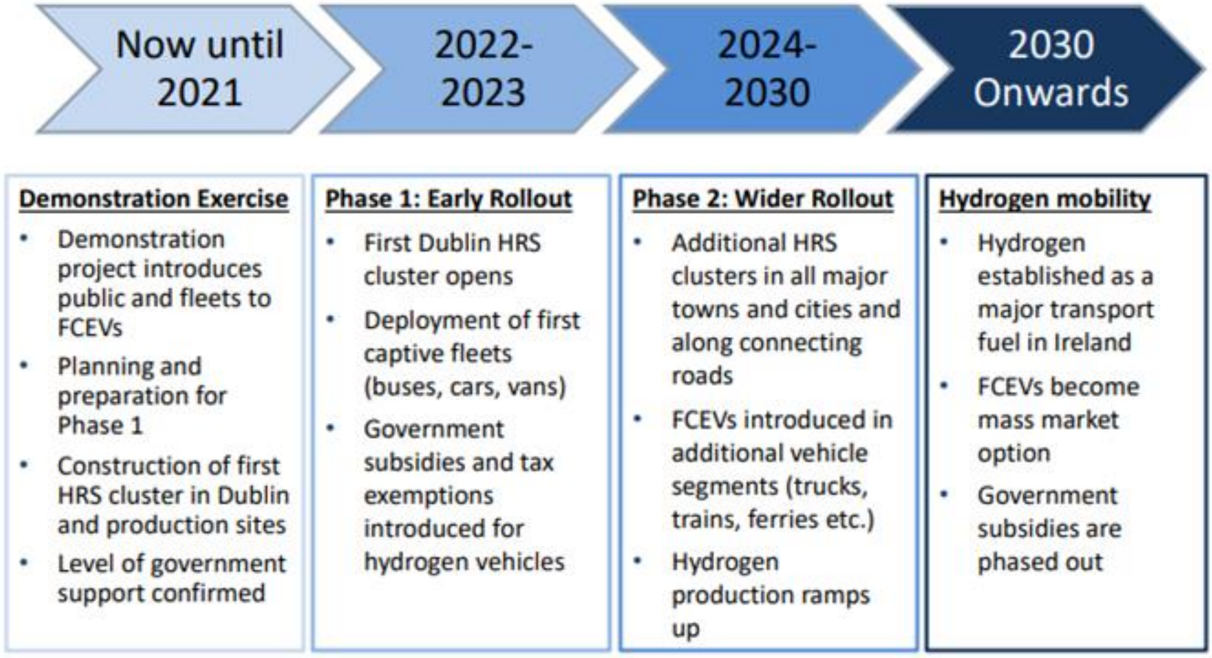

Figure 10: HMI Phased Strategy

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

Published in 2019, the progress of this roadmap to 2021 includes the HMI trials discussed above. The construction of the first Hydrogen Refuelling Station (HRS) in North Dublin, has not occurred. The pilot fleet of three Double Decker busses, built by Wrightbus and costing €800,000 each is proceeding. The relevant decision-making Irish Minister'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.

It must be noted that Covid 19 has had significant effects on technology deployments. The progress of SEAFUEL itself in Tenerife can attest to this. 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.

6.5 National Policy 2020 and onwards

Change in government make-up in 2020 has led to an increased ambition of policy in favour of deeper and wider decarbonization. This has led to the adoption of the Climate Action Bill in 2021[53]. In effect the Climate Action and Low Carbon Development (Amendment) Act 2021 (which we will refer to from now on as the Climate Action Act), places a legally binding onus on the Irish State to achieve specified greenhouse gas reductions on a specified timescale supported by all departments and budgetary decisions.

[52] https://www.nationaltransport.ie/nta-and-bus-eireann-unveil-hydrogen-buses-for-initial-use-on-commuter-route-105/

[53] https://www.oireachtas.ie/en/bills/bill/2021/39/ The Bill was signed into law on 23rd July and is now referred to as Climate Action and Low Carbon Development (Amendment) Act 2021.

A Climate Action Plan which is required under the Act and will set out specific targets for achieving decarbonization including technology will be published in October 2021. It is expected that this will set out specific decarbonization targets for each sector, including transport.

With the success of HMI in driving concrete elements of its strategy forward 2020-21, and the now rapidly increasing ambition of H2 production plans by major players in the utility scale developer, it is expected that the first Climate Action Plan 'budget', to cover years 2021-2026, will include early supports to hydrogen production and consumption.

As regard the progress towards HMI's Phase 1: 2022-23, there is an obvious potential chokepoint in the effect of the pandemic on the production and installation of electrolysers at scale, the installation of an HRS, and the availability of vehicles for the first captive fleets. This was an unforeseen and so any lack of definite progress here does not indicate a failure of policy. The provision or lack of government subsidies and tax exemptions for FCEVs to be announced in the first Carbon Action Plan (due October 2021) will be a key indicator of whether there has been a serious adoption of the policy recommendations made by HMI and others.

7.0 West of Ireland Region H2 Transport Roadmap

It is necessary to tailor a H2 transport roadmap to take into account the demographic, socio-economic, geographical, and infrastructural particularities of the region.

7.1 Context

As seen above the West of Ireland's electricity grid is more distributed than the East of the country's. This creates two barriers to increased renewable energy generation: it is both more expensive and politically controversial to strengthen the grid. This creates a strong early benefit to Hydrogen as a means of increasing energy production while at the same time offsetting the need to strengthen the grid in certain more 'remote' areas.

Transport is typically over greater distances, and frequently over rougher more mountainous terrain. This environment may better suit the range and power of FCEVs

Vehicles in the West, even private passenger vehicles, are larger and more rugged: of the 'four-wheel vehicle' type. They are also more multi-functional, not simply commuter vehicles, but general-purpose transporters. These vehicles are similar to those being demonstrated in Tenerife as part of the SEAFUEL project.

7.2 Phase 1: Demonstration and Public Acceptance 2022-2024

7.2.1 Tourism: Added Value and Complementarity

Tourism is a significant area of economic activity. As in, but perhaps even more so than the other case study SEAFUEL regions, sustainability transport has a potential economic value which could offset any increased vehicle or fuel costs for FCEVs. In addition, the most successful tourism product in the Region for many years has been the designation of 'The Wild Atlantic Way'. This is a tourism pathway some 2,500km in length along the entire region over very mountainous terrain. The Tourism Board of Ireland, Discover Ireland, promotes driving trips on the route[54]. 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 which would probably be based in the transport and commercial hub of Galway city would be within the region.

[54] https://www.discoverireland.ie/wild-atlantic-way/weekend-road-trips-wild-atlantic-way

The fine-grained economics for such a proposal are not within the remit of this paper but would appear to be feasible given some state aid such as envisaged in the HMI roadmap. The assembly of a fleet of some 10-15 FCEVs would cost approximately €900,000[55] (excluding VRT which the state may consider waiving). 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.

7.2.2 Police Vehicles: Visibility and Safety

Other passenger vehicle fleets that would be suitable in phase 1 of a roadmap for the West of Ireland would be police vehicles. In their July 2021 report[56] the Irish police force (An Garda Síochána, or the Gardaí) stated it has 53 marked[57] cars in Galway County. The report also states that of the total cars, 52% of these are of the Hyundai make. The report does not indicate which model, but they are frequently Hyundai i40, i30, and Tucson. Phase 1 of SEAFUEL West of Ireland roadmap proposes that between 2022 and 2023 the Gardaí purchase 5 Hyundai vehicles annually (to a total of 15) redeploying the existing fossil fuel versions elsewhere. An HRS, costs discussed below) for these vehicles could be located off garda property where it could also facilitate the tourist rental FCEVs: there are numerous suitable sites for such an HRS in the City's docklands industrial which are very convenient located to the city centre.

7.2.3 Bus Service: Regional Solutions

Intercity Buses run half hourly between Galway and Dublin. The return two-way route is at a minimum 414km however, which is beyond the 400km range of the Caetano H2City Gold[58] used in the HMI Dublin trials. It is not proposed to twin SEAFUEL West of Ireland Phase 1 roadmap proposals with those of HMI in this instance: the detour required for a Galway-Dublin-Galway route H2 refill during the return journey at a HRS in or near Dublin is non-ideal and not practical.

There is a regular bus route between Galway and Castlebar (county town of Mayo and within the Western Region). The community service route takes in the significant tourist destination of Westport on the 'Wild Atlantic Way' and for much of the journey travels through a highly scenic and topographically varied landscape. The route is approximately 110km and so the return journey is well within the H2City Gold range on a single fill. The proposed general dockland HRS location for the other two fleets in the SEAFUEL West of Ireland Phase 1 roadmap above would be suitable for the proposed bus route as it is very close to the departure bus station in Galway.

7.2.4 HRS: Fuelling the initial demonstrations.

It is vital that the installation of a suitable HRS be made central to Phase 1 rollout. Existing solutions such as the use of small-scale tank H2 from existing Irish-based gas suppliers is expensive. In the Tenerife installation, SEAFUEL will demonstrate the price for H2 for transport production and distribution. Phase 1 West of Ireland Roadmap will provide accurate capex costs for the proposed Galway City HRS, but at this stage, it a conservative prediction that these will be in the region of €2m. Although this may well prove to be an overestimate, we fell it prudent to err on the side of caution. Operationally, it is proposed that the HRS will operate commercially, and so no operational costs are built into the roadmap Phase 1.

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[55] https://uk.motor1.com/news/505291/toyota-mirai-hydrogen-uk-pricing/
[56] https://www.garda.ie/en/about-us/our-departments/finance-services/garda-fleet-management-report-july-2021.pdf
[57] It has 40 unmarked cars – these are not deemed suitable for inclusion in SEAFUEL Phase 1 rollout.
[58] https://caetanobus.pt/en/esta-ai-o-h2-city-gold-o-novo-autocarro-caetano-a-hidrogenio/

7.2.5 Pilot H2Heat Study

There are a number of H2 boilers in development[59]. It is proposed that the roadmap include exploratory studies to investigate their feasibility in certain key buildings that are less amenable to electrification of heating: where it is deemed too costly, too disruptive to the current use of the buildings, or where there are restrictions on the works that can be carried out due to the sensitive architectural significance of the buildings. Much of the West of Ireland is off the gas grid and thus the H2 would compete with more costly and high CO2 emitting fossil fuels: LPG (€0.0993 - €0.1121/kWh) and Heating Oil (€0.0804/kWh)[60]. The Phase 1 roadmap should therefore look to investigate the feasibility of H2 for heat applications in suitable buildings in a small-scale pilot study. In keeping with the locating of the HRS and H2 production in the Galway City area, the pilot building should be selected according to the following criteria:

- Having a heat demand of >40,000 kWh per annum
- A high-profile building, for example a prominent building accessed by the pubic
- A building not amenable to extensive energy retrofits and electrification of load: e.g., a protected structure[61]
- A building where an energy audit found the energy retrofit works to bring it to a BER of >B2 would involve a payback period of greater than 30 years.

There are numerous such buildings in Galway City[62], many in public ownership or open to the public as theatres, libraries, community centres and hotels.

Such a pilot project could demonstrate the viability of Hydrogen as a fossil fuel replacement in heating hard to decarbonize buildings in a very visible manner.

7.3 Phase 2: Upscaling and Roll Out 2024-2030

It is not expected that the large scale H2 production powered by offshore wind energy as discussed in Section 5.5 above will occur during this timeframe. These projects will require a longer timeframe due to regulatory and economic requirements as well as the necessary technical developments to guarantee robust floating offshore H2 electrolysis at scale. The SEAFUEL West of Ireland Roadmap in Phase 2 focuses on building out H2 transport uses, while at the same time providing the start point for H2 use in other sectors which will create the synergies needed for H2 to drive down its production and distribution costs and drive up its socio-economic value.

7.3.1 Deepening the Tourist Product

Through government incentives up to 50% of the hire car fleet in the Western region could be shifted to H2. This would require state supports similar to those provided for BEVs, with the addition of tax concessions for companies who transition to H2.

It is highly feasible for the state to facilitate the rollout of HRSs along the Atlantic way in the 11 large towns or cities on or very near the route. Similar concessions were made to the rollout of fast

[59] https://www.worcester-bosch.co.uk/hydrogen
[60] https://www.seai.ie/publications/Commercial-Fuel-Cost-Comparison.pdf
[61] defined as one 'which a planning authority considers to be of special interest from an architectural, historical, archaeological, artistic, cultural, scientific, social or technical point of view' http://www.dublincivictrust.ie/conserve-your-building/protected-structure-advice--grants
[62] https://www.galwaycity.ie/uploads/downloads/publications/planning/List%20of%20Structures%20on%20the%20Record%20of%20Protected%20Structures.pdf

chargers for BEVs[63]. On a phased basis at a rate of 1 HRS per town/city over the 7-year period of Phase 1 would cost between €2.75 and €3.5m per annum. It is not proposed as was the case in the BEV fast-charger rollout that there be no charge for the H2 fuel. Thus, there is the possibility of state support complimenting commercial investment from many of the partners involved in HMI, for example, electricity and gas utilities as well as car manufacturers to achieve best value for the Irish taxpayer.

The benefit of upscaling in the rental market is that it would in time provide a source of more affordable second-hand vehicles for the local market as car rental companies upgraded the vehicles over the period. This second-hand market driven vector could remove some of the need for the state to support FCEV purchase in the manner it supported BEVs (i.e., €5,000 initially and €3,800 currently[64]).

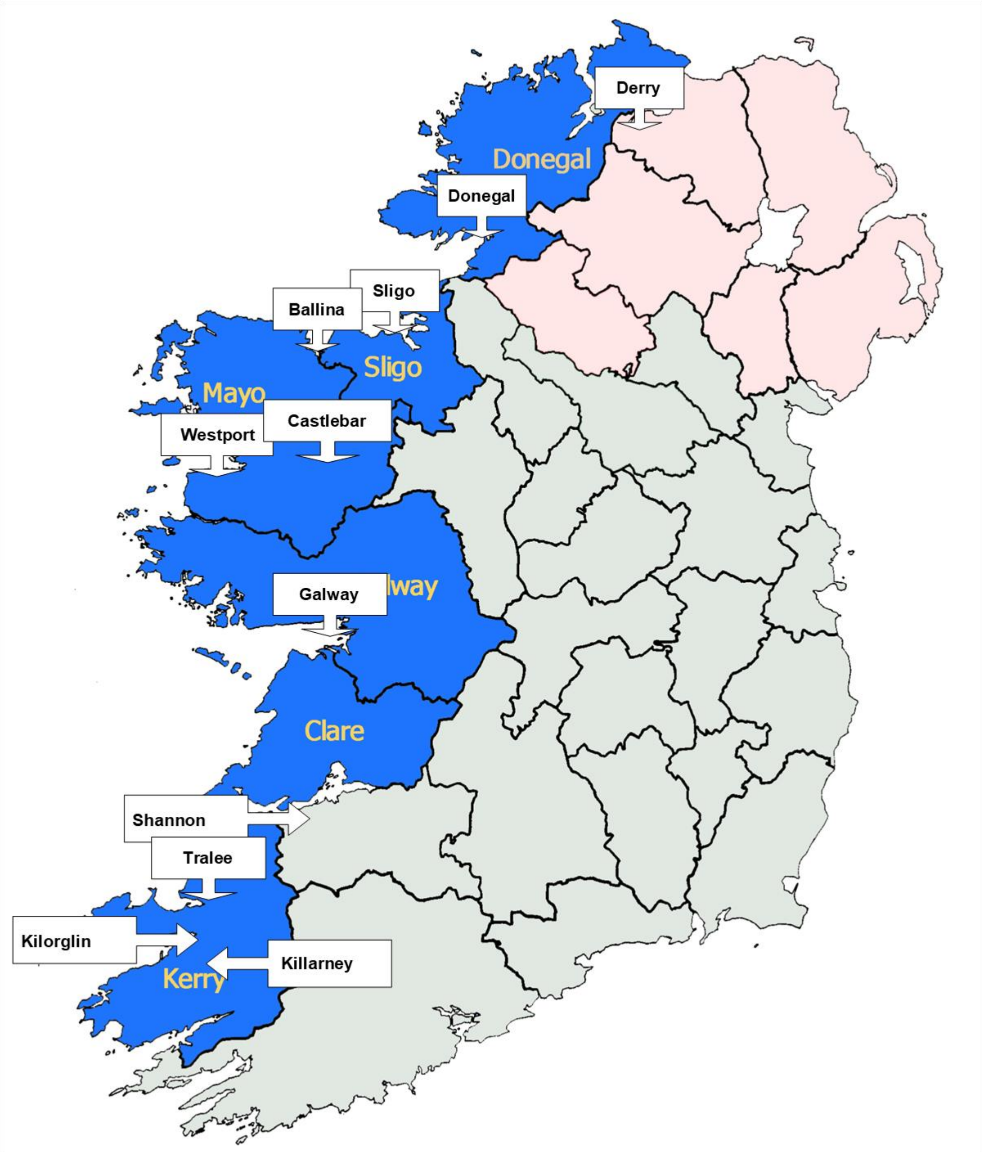

Figure 11: Large Towns or Cities on or near the Wild Atlantic Way

63 https://www.cru.ie/wp-content/uploads/2013/07/cer13240b-esbn-ev-pid.pdf
64 https://www.seai.ie/business-and-public-sector/ev-for-business/grants-and-supports/

7.3.2 Moving Beyond Demonstration in the Public Sector

Climate Action Budgeting requires local authorities and public bodies to reduce their carbon footprint and obliged to take account of the national climate plan in the performance of their functions. As local authorities are largely organized on a county basis, there are six local authorities in the Western Region.[65] Each local authority has a budget which it manages to provide services to its county. Table 12 shows the level of spending for each county. It demonstrates that while there are considerable draws on local authority budgets, there is scope for investment in each county into public service vehicles some of which under Phase 2 be hydrogen vehicles – it should be noted that the necessary HRSs would be put in place in conjunction with the tourist vehicle action.

Table 12: Gross Local Authority Expenditure 2020

County	Euros
Clare	€128,030,207
Kerry	€158,278,893
Galway County	€128,124,932
Galway City	€99,696,970
Mayo	€148,061,202
Donegal	€154,410,629
Sligo	€67,150,439
TOTAL West Ireland	**€883,753,272**

Again, public sector buses are a key rollout option for FCEBs – as is discussed elsewhere in this paper, FCEBs have significant advantages over battery electric buses. The demonstration in Phase1 of the feasibility and benefits of FCEBs for the region will stimulate the increased rollout on the many routes in the region. There are 114 bus routes in the Region[66] (excluding city bus services in Galway City). Many of these would be ideal situations for the deployment of FCEBs – thus it is envisaged in the roadmap for the West of Ireland that as the bus fleet is updated, FCEBs be the preferred choice of new vehicle. It should be noted that a Northern Irish bus company, Wrightbus, manufactures buses that would be very suitable.

7.3.3 Diversification of Vehicle Types

Phase 2 of the SEAFUEL Roadmap for the West of Ireland would see the expansion in the range of FCEVs. Light goods vehicles (LGVs) for commercial organisations and Small and Medium Enterprises (SMEs) are possibly the best scenarios for SEAFUEL uptake: the distances travelled are typically in the 100-200km range rather than the much greater distances the Heavy Goods Vehicles (HGVs) travel. HGVs often are required to leave the region and travel internationally. While we can predict that the rollout of HRSs in the UK and EU will surpass that in the West of Ireland, we cannot be certain. HGVs as a FCEV opportunity in Phase 2 of the roadmap is provisional and based on developments elsewhere.

7.3.4 Widening the Production Network

INTERREG project GENCOMM which looked at the implementation of smart hydrogen-based energy matrixes. The authors of this report participated in the project which was partly conducted in the

[65] Galway at present is splint between Galway City and County
[66] Data gathered by the authors from the websites of the service providers TFI-locallink and Bus Éireann

Eastern region of Ireland but examined H2 energy matrixes across the Island. Gunawan et al (2020)[67] assessed the potential Hydrogen production for each large-scale windfarm in Ireland in three scenarios for electricity supply to electrolyzers: using curtailed wind energy, available wind energy and using full capacity of installed wind. The authors found that 'at full capacity, the future average LCOH is 6–8 €/kg with total hydrogen production capacity of 49 kilotonnes per year'. Much of this, as their maps in Figure 12: Capacity of annual hydrogen production (MH2) with current parameters of (a) curtailed wind operation, (b) available wind operation, and (c) full capacity operation. below shows, would be produced by windfarms in the West of Ireland region.

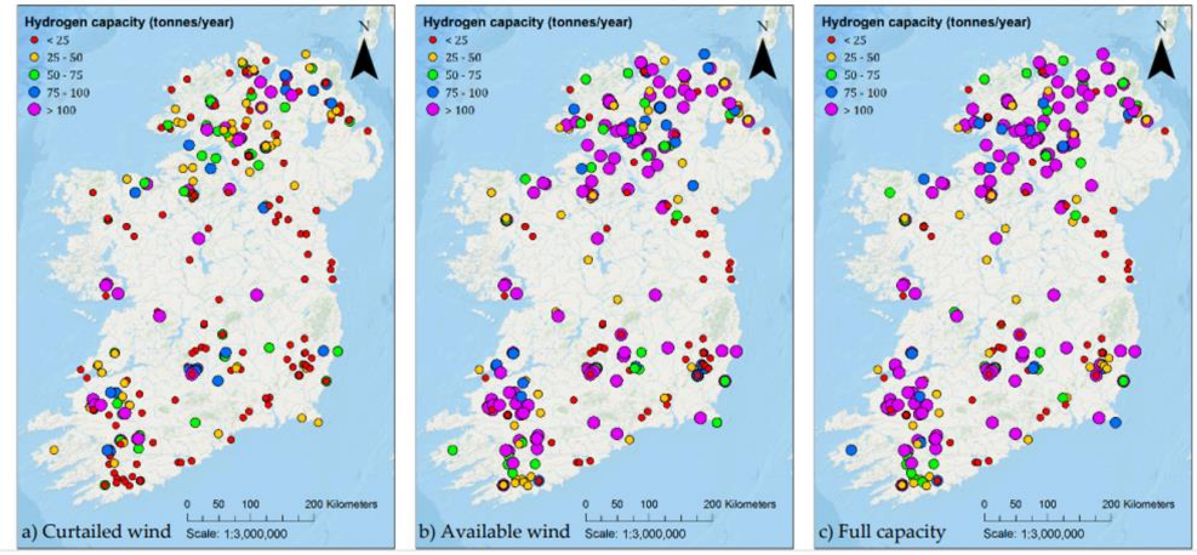

Figure 12: Capacity of annual hydrogen production (MH2) with current parameters of (a) curtailed wind operation, (b) available wind operation, and (c) full capacity operation.
Source: Gunawan et al 2020[68]

Thus, there is considerable capacity, already installed, much of it curtailed in the Western region. As additional wind generation capacity is installed, curtailment is likely to increase, with some estimates (Blount et al, 2020) putting possible curtailment where (as is projected for 2030) Ireland achieves 70% renewably generated electricity at as high as 45%[69]. We can assume that during Phase 2 of the West of Ireland SEAFUEL roadmap, curtailment will reach >20% in the region. This will create significant opportunities for hydrogen production using curtailed wind.

7.3.5 H2 in the Marine Sector

As we have stated elsewhere, there will be a considerable decarbonization opportunity in the West of Ireland through maritime use of hydrogen as an energy source[70]. As our previous paper shows[71], passenger ferries are very significant (if not the most significant) source of CO2 emissions in many of the islands in the Western region. Thus, identifying an efficient means of reducing these emissions will be necessary to achieve Ireland's decarbonization targets.

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[67] Gunawan, Tubagus A., Alessandro Singlitico, Paul Blount, James Burchill, James G. Carton, and Rory F.D. Monaghan 2020. "At What Cost Can Renewable Hydrogen Offset Fossil Fuel Use in Ireland's Gas Network?" *Energies* 13, no. 7: 1798. https://doi.org/10.3390/en13071798
[68] Ibid, p14.
[69] https://www.seai.ie/documents/research-projects/RDD-000326.pdf
[70] http://www.seafuel.eu/wp-content/uploads/2020/03/Pre-trial-studies.-Examination-of-the-existing-transport-in-each-of-the-existing-transport-in-each-of-the-special-regions%10-Arainn-Tenerife-and-Madeira.pdf
[71] http://www.seafuel.eu/downloads/

There are passenger 16 ferries operating in the Western Region[72]. These vary in capacity from 30 to 400 passengers, and two are roll-on roll-off. It must be noted that the sea conditions in the Atlantic Ocean are very testing. No Hydrogen passenger vessel has been launched that experiences similar seas. Maritime use of Hydrogen in ocean-going transport is therefore proposed to be a late Phase 2 SEAFUEL roadmap opportunity. This is not to say that planning for such an opportunity should not commence now. The economics of Hydrogen maritime transport are predicted become favourable in relation to diesel between 2025-30[73]. The issue of safety and passenger confidence in a novel technology in critical environments would need to be accounted for in our roadmap. The commitment to develop H2 powered ferries will cost between €10-15m[74], and real-world testing will have to be exhaustive and over 3-4 years if all conditions are to be examined. Therefore, we would propose the commitment to construct a 250-person passenger ferry in the west coast region during phase 2 with construction, testing and commercial launch to occur in early phase 3. It should be noted that Ireland has a Climate Action fund[75] which runs up to 2027 and would be an ideal source of funding for such a Phase 2 project.

7.3.6 Aviation

As stated in our previous paper, there are aviation H2 technology opportunities in the Western region. Table 13 shows the airports in the region[76].

Table 13: Airports in the Western Region

Donegal	Donegal Airport (Aerphort Dhún Na nGall)	Dublin, Glasgow
Mayo	Ireland West Airport	International, EU
Galway	Connemara Regional Airport	Aran Islands
Clare	Shannon Airport	International, Transatlantic
Kerry	Farranfore Airport	International, EU

Aviation is clearly a transport sector amenable to inclusion in the Phase 2 roadmap. Smaller regional routes using 6-10 passenger twin engine aircraft may be more suited to early demonstration FCE airplanes. An aircraft such as this is currently under trial in the HyFlyer project[77] and thus it is reasonable to suggest that towards the end of Phase 2, passenger aircraft would be available to trial in the region. Late Phase 1 and early Phase 2 should therefore involve the scoping works for a real-world test commercial deployment of FCE Aircraft. This would include identifying partnerships, finance sources, routes, and public acceptance studies. According to airbus, 200 plus passenger commercial H2 aircraft are due to come into service in 2035[78] – therefore an aggressive and innovative H2 roadmap for the West of Ireland Region would see the use of smaller passenger aircraft by 2030.

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[72] Data collected by authors from ferry service providers.
[73] Aarskog, Fredrik G. et al. 'Energy and Cost Analysis of a Hydrogen Driven High Speed Passenger Ferry'. 1 Jan. 2020 : 97 – 123: https://content.iospress.com/articles/international-shipbuilding-progress/isp190273
[74] The HyShip project received €8 in EU funding for a similar FC Vessel design and build: https://www.ship-technology.com/news/maritime-innovation-hyship-project-eu-grant/ . The vessel will not be a passenger ferry, and nor is it truly 'ocean-going', thus we estimate that the cost for the Maritime West of Ireland project will be greater.
[75] https://www.gov.ie/en/publication/de5d3-climate-action-fund/
[76] City of Derry Airport is close to the Donegal border, but is in Northern Ireland and so would fall under the NI Roadmap Section of this paper.
[77] http://www.emec.org.uk/press-release-hyflyer-project-achieves-world-first-hydrogen-electric-flight/
[78] https://www.airbus.com/newsroom/press-releases/en/2020/09/airbus-reveals-new-zeroemission-concept-aircraft.html

7.3.7 H2 Heat Phase 2: industrial sector.

The UK has already funded initial work on the use of H2 in high-heat industrial processes such as required by alcohol distilleries.[79] The study which set out the steps and costs necessary to produce H2 powered distillation found that it is technically feasible. However, included on that economic model was the cost of H2 in comparison to Natural Gas where it performed unfavourably. Taking this, the SEAFUEL roll out could seek to identify a distillery or other high heat process industrial user which is not on the Gas Grid. In the Western Region identified in this study this would be Western Galway City and County.

The ability of H2 to meet industrial high heat demand is examined in a paper from NUIG, HyEnergy and DCU (2021)[80]. The paper found that that larger scale regional and centralized hydrogen production results in costs of £2.53-£4.99 per kg (a median of £3.76). This production cost could be lowered by a rapidly improving electrolyser technology sector. There is no published Irish government policy on H2 for high heat processes, but it has been discussed favourably at ministerial level.

It is therefore envisaged in Phase 2 that supports for industrial heat pilot uses of H2 be supported. This will increase the H2 demand in the city, achieving the benefits of economies of scale so as to potentially bring down the cost of H2 delivered.

7.4 Phase 3: Maximising the H2 opportunity for Western Ireland

The innovative market-building actions of Phase 1 and 2 taken in conjunction with expected technological developments and favourable economics achieved through economies of scale will contribute towards achieving highly significant sustainable H2 interventions. In tandem with this the large-scale production of H2 that can be predicted by the level of applications for offshore wind (some of which make specific reference to H2 production) should be taken as a strong indicator that the potential supply of hydrogen for Phase 3 of the West of Ireland Roadmap will be significant.

7.4.1 Cross Sector 360-degree Hydrogen for Regional and National Use

Current Irish government policy foresees 5GW of offshore wind being installed in Irish waters by 2030[81]. Some of this will be on the East coast of Ireland close to the Leinster grid which is heavily populated having a large energy demand. As we have seen in Section 5.5 above there are already applications for at least 9.4GW of offshore electrical energy in the Western Region. This will be complimented by onshore energy generation from both wind and PV farms. There is considerable wariness amongst local planners, the TSO (Eirgrid), and the Commission for Regulation of Utilities (CRU) of potential socio-political disruptiveness of massive grid enhancement that 9.4 GW of offshore wind may involve. Therefore, it is highly likely, indeed the authors have been told as much in discussions with developers that the ideal destination for much of that 9GW will be hydrogen.

We take two scenarios of high and lower-level offshore installation during Phase 3 (2030-2040) respectively. These projects[82] would generate between 21,900 and 41,172 GWh/a. This would in

[79] https://www.gov.uk/government/publications/green-distilleries-competition/green-distilleries-competition-projects-selected-for-phase-1#decarbonising-the-inchdairnie-distillery
[80] https://www.nweurope.eu/media/13425/hydrogen-exploring-opportunities-in-the-northern-ireland-energy-transition-march-2021.pdf
[81] https://www.gov.ie/en/publication/5ec24-policy-statement-on-the-framework-for-irelands-offshore-electricity-transmission-system/
[82] It cannot be assumed that all of the projects listed will go ahead – however, these projects represent only those applications that were lodged with the relevant Irish government department by Sept 2021. It is the authors

turn potentially provide between 561,538 and 1,055,70 tonnes of H2. As Table 14 demonstrates this represent a considerable proportion of the energy use of the region.

Table 14: Two H2 Offshore Scenarios

	Installed GWp	Generation GWh	Tonnes H2	Energy Delivered GWh	Proportion of Region's Energy Use All Sectors[83]	Proportion of Region's Energy Use Transport
Scenario 1	5		561,538	**18,530.8**	72%	123%
Scenario 2	9.4		1,055,692	**34,837.8**	136%	231%

Therefore, if the entirety of the offshore generation in the scenarios were to be converted to H2, the West of Ireland could become almost energy independent in the lower offshore H2 rollout by 2040, or entirely energy independent with an exportable surplus in the higher offshore H2 roll-out scenario. This second export level scenario – either internationally or within Ireland.

The gross level of energy use above includes all sectors. However, SEAFUEL is specifically targeted at H2 in transport. We were not able to identify the level of commercial transport energy use in the region. The SEAI reported that 5,197 ktoe were used in the transport sector nationally in 2018[84]. While not ideal we can *estimate* the proportion of this is used in the Western region. The Western Region represents 18% of the total population of Ireland. This would imply that it therefore used approximately 935 ktoe in 2018. However, the area of the region as a proportion of the total area is 32%. This is significant as area implies distances typically travelled, and thus fuel used. In this case it can be inferred that the Western used *approximately* 1,663 ktoe. We will use a mid-point for these figures in both scenarios, i.e., 1,299 ktoe. This is equivalent to 15,107 GWh. Thus as Table 14 above shows, the transport energy demand of the region would be greatly surpassed in both low and high level of offshore to H2. This is particularly significant as the cost comparisons between H2 and diesel are more favorable than with natural gas. It is predicted that with the correct policy supports and predicted economies of scale, H2 could achieve cost parity with fossil fuels such as diesel and petrol by 2025[85]. Two further issues are however critical to the significance of a hydrogen roadmap for the West of Ireland. The first is the undeniable necessity to reduce and then eliminate fossil fuel use: this is now Irish State policy with regard to 2050 but would be achieved much more rapidly through this roadmap. The second point to make is that Ireland does not produce its own transport fossil fuels. In the ambitions high-level rollout scenario above, it would.

7.4.2 H2 Heat at scale:

In 2021 H2 for domestic heat is not yet at a point where it is economically feasible. However, the technology is rapidly being developed that will be economic. By Phase 3 in the SEAFUEL roadmap for the West of Ireland, we are confident that this will have occurred, and thus need to build such a scenario into the roadmap as an indication of the need to take the steps today, and in phase 1-2 that

understanding that there are a large number of project applications yet to be lodged. For the purpose of the roadmap, we will assume the 9GW is justifiable for 2030-2040.

83 From Table 8: Global estimate for the energy use. above.

84 https://www.seai.ie/publications/Energy-in-Ireland-2019-.pdf p23

85 https://cafcp.org/sites/default/files/Roadmap-for-Deployment-and-Buildout-of-RH2-UCI-CEC-June-2020.pdf

will put the region in a position where it can benefit from h2 domestic heat as a decarbonization opportunity.

As we saw in section above, there is considerable heat demand both domestically and industrially in the region. While parts of the Region are on the natural gas grid, there is a considerable area which is not. The learnings from Phase 1 and 2 in the heating sector will determine the feasibility of using H2 to decarbonize hard to reach sectors - off grid homes where electrification has a payback period greater than 30 years and businesses using high heat processes. It is not possible to estimate costs here. However, given that there are 305,853 homes in the West of Ireland region that do not use natural gas for central heating, the region offers a considerable opportunity for H2 heating. The electrification of these homes heating needs will require considerable energy efficiency retrofitting works. In a survey of homes[86] by Energy Co-operatives Ireland of a (admittedly very small) sample of County Galway homes, the works necessary to electrify the heating load of the typical homes ranged from €38,000 to €81,000, with an average of €56,628. If this sample was to be representative of the Western Region as a whole (which we must caution may not be the case), the total cost of the electrification of the heat load of the region could be as much as €17 billion. This is not to say that this level of energy retrofitting and load electrification will not take place over time as homes change hands and are subsequently upgraded and modernized. However, we should note that this natural home recycling process occurs over long timescales. The drive to decarbonize the Ireland as a whole and the region specifically is envisaged to be within thirty years.

It should therefore be proposed that H2 for home heating be built into Phase 3 of the SEAFUEL rollout. It will provide a secondary use for H2 that is generated in the region which would support production at scale – a key component in driving the cost per kg downwards.

With this in mind, we propose identifying communities that are relatively concentrated in population, ideally close to existing renewable energy generation or where such generation is planned in a reduced electricity grid capacity area.

7.4.3 Export Level

The final stage of the SEAFUEL West of Ireland Roadmap involves the upscaling of offshore H2 production to export levels. From 2040 onwards additional wind energy generation could bypass the electricity grid and exclusively be diverted to H2 production. This is a clear energy opportunity for the West of Ireland. There is an estimated 60GW of floating wind generation available off the West Coast. This would generate up to 289,080 GWh per annum, or 123,538 tH2. This equates to 21,032 ktoe – four times the national ktoe used in all sectors of Irish transport. Therefore, Ireland is in a position under Phase 3 of the SEAFUEL West of Ireland Roadmap to become an exported of H2 fuel for transport. This will make a considerable contribution to the regional economy, the national exchequer and to achieving the Climate Action targets.

It is proposed that the actions taken in Phase 1 and 2, although requiring policy ambition, have as their ultimate justification the establishment of a significant economic and social opportunity – and this in a region which has historically been more peripheral to Irish economic developments.

[86] https://www.energyco-ops.ie/resources/energy-audits-10-examples-from-galway-county/

7.5 The West of Ireland SEAFUEL Roadmap Summarised.

Phase 1: 2022-24

Demonstration and Public Acceptance

HRS

Installed in Galway Docklands

Cost Est: €2m

Proposal Partners: HMI, DCCAE, SEAI, CFOAT, NUIG

Tourism

Wild Atlantic Way H2 rental car product centred on Galway City 10-15 vehicles

Cost Est €1.4m—30% privately funded

Proposal Partners: HMI, DCCAE, SEAI, NUIG, Car Hire Co

Police Vehicles

3-5 FCEVs annually. Based in Galway

Cost Est €1m

Proposal Partners: HMI, DCCAE, NUIG, Dept Justice.

Regional Bus Service

Galway to Castlebar via Westport—to use Galway HRS

Cost Est €600,000

Proposal Partners: HMI, DCCAE, NUIG, TFI, Discover Ireland.

H2Heat

Explore trials of H2 for heat in pilot buildings

Proposal Partners: DCCAE, NUIG, SEAI, CFOAT

Cost Est €600,000

Phase 2: 2024-30

Upscaling and Roll Out

HRS

Installed in major Wild Atlantic Way Towns

Cost Est: €20m

Proposal Partners: HMI partnership, DCCAE, SEAI, Local Authorities.

Tourism

Wild Atlantic Way H2 rental car product centred on Galway City 100+ vehicles

Cost Est €4.6m—70% privately funded

Proposal Partners: HMI, DCCAE, Car Hire Co, Discover Ireland

LA Vehicles

Mixed vehicle types with high fuel use

Cost Est €4-5m

Proposal Partners: HMI, DCCAE, 6 LAs.

Regional Bus Service

10-20 Intra-regional bus services

Cost Est €2-4m

Proposal Partners: HMI, DCCAE, NUIG, TFI, Discover Ireland.

H2 Heat in Industry

H2 in high heat processes—distillation, etc.

Proposal Partners: DCCAE, NUIG, SMEs.

Cost Est €3m

Phase 3: 2030-40

Maximize H2 West of Ireland opportunity

Cross Sector 360-degree Hydrogen for Regional and National Use

Offshore wind generation of H2 >9GWp

Connection to Main Ports for storage

Entire Transport Sector converted to H2

H2 Heat >30,000 homes

Export Sector (via main ports)

Japan and the European Industrial zones will offer large markets for renewably produced hydrogen.

Costs

These measures would be commercially funded and will generate income for the state through offshore licences, taxes and rates.

The switch away from imported fossil fuels to regionally generated H2 will create employment, and offset imported costs. The state may consider the suspending of the application of excise duties to H2 during Phase 3—until such time as the necessary economies of scale are achieved.

It is hoped that the switch to a H2 economy during Stage 3 will be cost neutral for the State.

Phase 1 and 2 funding could qualify for Climate Action Fund Support. All of these proposals involve commercial bodies which can be expected to contribute to the costs.

Figure 13: SEAFUEL West of Ireland Roadmap