islander

ACCELERATING THE DECARBONIZATION OF ISLANDS' ENERGY SYSTEMS

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ABBREVIATIONS

Expanded	Shortened
Active Network Management	ANM
Air Source Heap Pumps	ASHP
Department for Business, Energy, and Industrial Strategy	BEIS
Battery Energy Storage System	BESS
Combined Cycle Gas Turbine	CCGT
Contracts for Difference	CfD
Combined Heat and Power	CHP
Data and Communications Company	DCC
Department of Energy Security & Net Zero	DESNZ
Distribution Network Operator	DNO
Dynamic Line Rating	DNR
Demand response	DR
Driving and Vehicle Licensing Agency	DVLA
European Commission	EC
European Centre for Medium-Range Weather Forecasts	ECMWF
European Marine Energy Centre	EMEC
European Network of Transmission System Operators for Electricity	ENTSO
Electricity System Operator	ESO
Electricity Supply Quality and Continuity Regulations	ESQCR
European Union	EU
Electric Vehicle	EV
Financial conduct Authority	FCA
Firm Generation	FG
Feed in Tariff	FIT
Great Britain	GB
Gas and Electricity Markets Authority	GEMA

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Government Pipeline and Storage System	GPSS
Ground Source Heat Pumps	GSHP
Heavy Goods Vehicle	HGV
Hydrotreated Vegetable Oil	HVO
Information and Communications Technology	ICT
Information Technology	IT
Local Heat and Energy Efficiency Strategy	LHEES
Last in First off	LIFO
Liquid Petroleum Gas	LPG
Low Voltage	LV
Marine Coastguard Authority	MCA
Marine Gas Oil	MGO
Met Office Integrated Data Archive System	MIDAS
Mobile Storage Unit	MSU
National Cyber Security Centre	NCSC
National Energy System Operator	NESO
Non-firm Generation	NFG
New Non-firm Generation	NNFG
Office of Gas and Electricity Markets	OfGem
Oil and Gas Authority	OGA
Orkney Island Council	OIC
Orkney Renewable Energy Forum	OREF
Orkney Research and Innovation Centre	ORIC
Power Purchase Agreement	PPA
Photovoltaic	PV
Research and Development	R&D
Rechargeable Energy Storage System	RESS
Renewable Obligation	RO
Registered Power Zone	RPZ

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Scottish Hydro Electric Power Distribution	SHEPD
Smart metering Solutions	SMS
Scottish and Southern Energy Networks	SSEN
Sea Source Heat Pumps	SSHP
Transmission/Distribution System Operator	TSO/DSO
United Kingdom	UK
Vehicle to Grid	V2G
Vanadium Flow Battery	VFB
Work Package	WP
Wind Turbine Generator	WTG

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EXECUTIVE SUMMARY

The ISLANDER project aims to significantly advance the decarbonisation of European islands through innovative energy solutions, initially demonstrated on the island of Borkum in Germany. A key focus of this project is not only the demonstration of new technologies but also their potential scalability and adaptability to other island settings, including the Orkney Islands in Scotland, UK and other European Islands in Greece and Croatia. This holistic approach includes the integration of renewable energy sources, energy storage systems, electromobility, active prosumers and district heating into the island's existing infrastructure.

This report aims to achieve two things, firstly, a comprehensive overview of the ISLANDER project, detailing the various hardware and software components stated for deployment, the execution of pilot projects within a living lab environment and the exploration of main use cases. These elements are organised into three critical technological aspects: optimal design, deployment of hardware components, and advanced control and operation. These technological aspects are split throughout seven WPs all of which (except Work Package 6 – demonstration and validation) are to be replicated on the follower islands. A brief consideration of an equivalent of WP6 for Orkney is included, nonetheless. Our objective is to ensure the operational optimisation and the resilience of the energy grid, particularly focusing on islands with inherent weak grid characteristics. The forthcoming sections will detail the various Work Packages (WPs) to be implemented on the demonstration island of Borkum and will outline the requirements for replicating these initiatives in the Orkney Islands, considering the current state of renewable energy in Orkney.

Secondly, this document presents the aims and objectives from Work Package 8 (WP8) of the ISLANDER project. This work package will look at replicating previous work packages and implementing these to a targeted island group (the Orkney Islands). The initial work packages, WP1 to WP7, were based on data and an implementation plan for the island of Borkum in the Frisian Islands, northwestern Germany. WP8 aims to use the initial work packages stated and used for the island of Borkum, the trigger island, and replicate these to targeted follower islands. The first of the follower islands to be assessed is the island archipelago of Orkney, Scotland.

This work builds upon previous work carried out by ReFLEX Orkney, which has already evaluated decarbonisation options for the Orkney Islands, and in some cases, attempted implementation of the technologies proposed by ISLANDER. Lessons learned and supporting information from ReFLEX Orkney are therefore also presented here.

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1 INTRODUCTION

The ISLANDER project seeks to offer a blueprint for decarbonisation of island communities. To this end, the island of Borkum in Germany has been used to demonstrate an example approach, comprising of:

- Ultracapacitors for grid smoothing.
- Batteries for energy storage.
- Hydrogen technologies for energy storage and alternate offtake.
- Local heat networks, driven by seawater in the Borkum case.
- Solar and wind generation.
- EV storage and intelligent charging facilities which can assist with grid smoothing.
- Demand response to optimise the costs of electricity as well as local grid load.

This document seeks to offer a plan for replication of these technologies in the Orkney Islands in the UK.

It is structured to mirror the ISLANDER work packages, and then present a plan with activities against issues encountered when considering the ISLANDER solution for Orkney.

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2 WP1 REPLICATION – ENERGY SYSTEM: THE ORKNEY ISLANDS

Orkney is located off the north coast of Scotland, comprising 20 inhabited islands, see Figure 1. Orkney has a population of approximately 22,500 residents, a number that swells significantly during the summer due to tourism, with 450,000 visitors, annually of which approximately half are day visitors (Orkney Islands Council, 2024). The islands are characterized by a cool temperate maritime climate. This climate results in relatively mild temperatures year-round, with average summer highs around 15-16°C and winter lows around 5-6°C. Orkney experiences frequent rainfall and high humidity, which are typical for its northern location in the North Atlantic. Wind is a constant presence, intensifying into strong, frequent gales throughout the winter months.

Despite its pioneering efforts in renewable energy, Orkney faces significant challenges with fuel poverty, recording some of the highest rates of fuel and extreme fuel poverty in Scotland. Moreover, it ranks as the local authority with the fifth highest carbon footprint per capita in Scotland. These contrasts highlight the complex energy landscape in Orkney, balancing between innovative energy solutions and ongoing socioeconomic challenges.

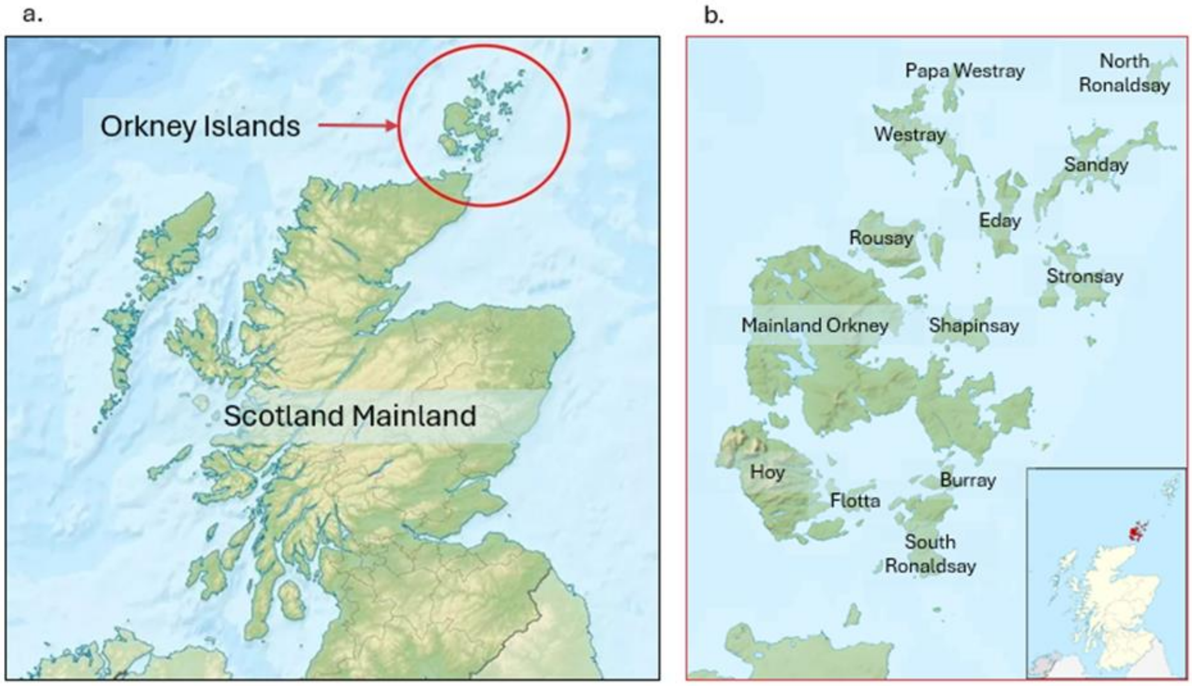

Figure 1 - a. Map of Scotland including the Orkney Islands. b. Inner and outer Isles surrounding Orkney Mainland.

Previous projects have attempted decarbonisation, notably:

- The use of green hydrogen at various locations for heat and power (Kirkwall Pier, Kirkwall Airport, and Shapinsay School).
- Accelerated adoption of renewable technologies such as solar, domestic battery storage, EVs via innovative funding models, including demand-response generation, and integration with the local grid. This project was known as ReFLEX and offers significant lessons learned which are relevant to ISLANDER.

The energy system in Orkney is more complex than that of Borkum, due to its larger size, early adoption of renewables, arrangements for grid connections and practices in the UK energy market. These factors can hinder the adoption of new technologies.

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2.1 Energy Overview – Orkney Islands

Orkney has overcome a series of energy challenges to become a European leader in the testing and application of new energy technologies. Orkney's renewable generation includes wind, wave, solar and tidal power. In 2013, Orkney first became a net exporter of electricity, producing 103% of its own consumption, instantaneously. This increased to 120% in 2016 and further to 133% in 2022. Despite this, 755.7 GWh of fuel is still used each year and the level of fuel poverty is relatively high.

2.1.1 Status of Orkney Grid Structure

Orkney is the most northerly point of the UK National Grid. It is connected by two 33 kV lines totalling approximately 40 MW capacity between them, which terminate at Scorradale on the Orkney mainland. The Orkney archipelago is then split into multiple network zones. Both 11 kV and 33 kV connections are used. Note the existence of a 33 kV ring which traverses the northern isles.

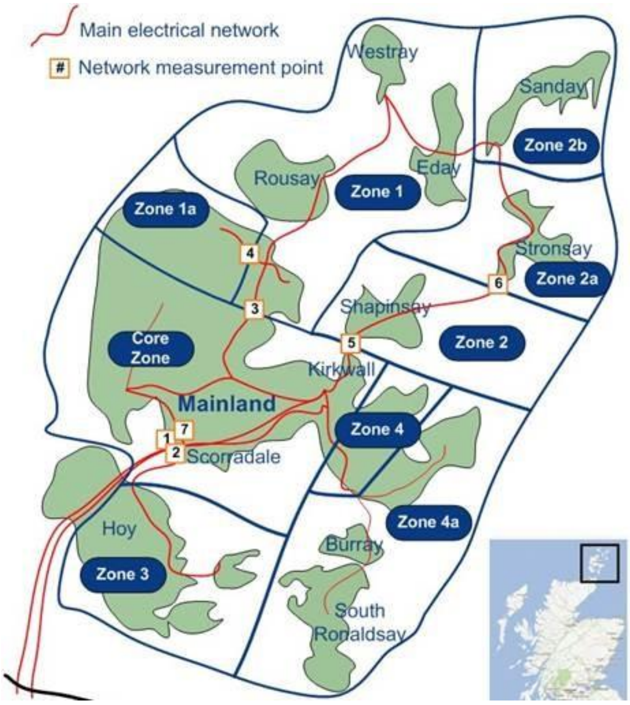

Figure 2 - Orkney Distribution Network and ANM Zones.

The Orkney Active Network Management scheme (Orkney ANM), developed by Scottish and Southern Electricity Networks (SSEN) – previously SSE Power Distribution – and its contractor Smarter Grid Solutions Ltd, was established between 2005 and 2009.

The Orkney ANM was implemented primarily to protect the local grid and the interconnect to Scotland. The ANM is a last-in-first-out style priority queue for connected generators on the Orkney Islands. It was implemented due high levels of wind generation and poor grid capacity, resulting in oversupply. When the local distribution network operator (DNO) finds the current at various points in the grid is reaching the capacity of the cables, then messages are issued via a dedicated communications network to ask generators to shut down, thus reducing the load on the grid at these points. Generators are not reimbursed for time they are idle under this scheme.

The first generator controlled by this scheme was installed in 2009. The power supply in Orkney is guaranteed by a medium-voltage grid connecting Kirkwall and Thurso via the Scorradale 33 kV connections.

Initially, the scheme was set up with 5 zones, a central area covering the three circuits

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connecting Scorradale with Kirkwall and including Stromness and Kirkwall sub stations this was called the core zone, and its pinch points were the two interconnectors to GB.

There were then 4 numbered zones, 1 to 4, see Figure 2.

- Zone 1 covers the Burgar Hill substation and the substations on Rousay, Westray and two substations on Eday.
- Zone 2 covers the sub stations at Shapinsay, Stronsay and Sanday.
- Zone 3 covers the sub stations at North Hoy, Lyness and Flotta.
- Finally, zone 4 covers the substation at St Marys.

However, as more generation was connected under the Orkney ANM scheme, zones 1 and 2 had to be split up because additional pinch points were recognised so there are now zone 1A and 1B along with zone 2A and 2B.

Potentially there are several other pinch points which may appear as more generation is added to the network.

Understanding the ANM and the wider UK energy system is critical to understanding the feasibility of an ISLANDER-style solution to the decarbonisation problem in Orkney.

Scottish and Southern Electricity Networks (SSEN) have commenced a project to improve Orkney Islands connection to the rest of the UK National Grid, which will facilitate the export of excess renewable energy from Orkney to the rest of the UK and help stabilise the local Orkney grid (Scottish and Southern Electricity Networks, 2024). This project will connect a 220 kV HVAC Subsea link between Dounreay and a new substation at Finstown. This connection is intended to provide capacity for export and improve local network resilience. It is expected to come online in 2028.

Secondary projects are under consideration to improve network resilience for Orkney's Northern Isles; Zones 1, 2, 2a, 2b in the above (Scottish and Southern Electricity Networks, 2024). Details of these are unconfirmed but are expected sometime after 2030. In particular, the position marked 3 in the grid schematic above is a pinch point which is the main reason for curtailment amongst existing generators in Zone 1 and 1a. If this pinch point is not removed in any meaningful time frame, the adoption of tidal energy in particular will be affected by ANM in such a way as to make it non-viable.

These new links will not have been sized for peak generation. Some form of ANM will almost certainly be needed post-implementation, so that generation assets can be managed to "fill" the available capacity. It is unclear at present how ANM may evolve, but any demand-response implementation needs to consider how it works at present in its planning. This therefore affects any ISLANDER style solution. (Orkney Renewable Energy Forum, 2014)

2.1.2 Stability of Energy Distribution

Electrical loads both generate and absorb reactive power. Since the transmitted load often varies considerably from one hour to the next, the reactive power balance in a grid varies as well. This can result in unacceptable variations in voltage, including voltage depression or even voltage collapse.

Orkney's approach to stabilising the grid with a high penetration of renewable energy generation involves several innovative strategies:

1. Orkney has implemented an ANM (as previously stated), developed by Scottish and Southern Electricity Networks (SSEN). This system dynamically manages the connection of renewable energy generators to the grid. It monitors the grid in real-time and adjusts the output from these generators to prevent overloading the grid, ensuring stability.
2. Energy storage plays a crucial role in balancing the grid. Orkney has been involved in projects exploring various energy storage solutions, such as batteries and hydrogen production. These storage systems can absorb excess energy when production is high (like during strong winds) and release it when demand exceeds current renewable

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generation.

3. Community participation and innovative tariffs: Encouraging community participation in energy usage patterns and introducing innovative tariffs has helped in balancing the grid. For example, tariffs that incentivise reduced consumption during peak times can lead to a more balanced load on the grid. Some energy suppliers are starting to offer dynamic time-of-use tariffs in the UK, but there are issues with older time-of-day tariffs which are reliant on obsolete radio tele-switching technology, requiring consumer equipment upgrades in poor signal areas, such as Orkney.

Orkney is not directly connected to the mainland grid for large-scale power transmission at present, but this will change when the 220 kV link to Dounreay becomes operational in 2028.

Because the local grid is at capacity, the Distribution Network Operator (DNO) is resistant to adding new generation assets. The DNO definition of generation assets includes grid-connected storage assets, such as batteries – which therefore means there is a reluctance to install these, at least until 2028, when the increased capacity via the 220 kV HVAC link becomes operational. As a result, grid connected storage or smoothing technologies are difficult to implement, due to DNO reluctance and regulatory hurdles.

No new generation >50 kW is being accepted in Orkney, at time of writing, however generation of <3.86 kW per-phase is still permitted/accepted under “G83” legislation.

2.1.3 Orkney’s Existing Energy Use

The following Sankey diagram depicted in Figure 3 illustrates how each of the energy sources are used by sector and end use (ReFLEX Orkney, 2019). The annual energy demand of the island with its 22,500 inhabitants and the influx of guests through the summer months was 755.7 GWh in 2019.

Most of the remaining energy consumed in Orkney is estimated to be used in the agriculture sector, other marine transport users, industry and in crude oil processing, at the Flotta Oil Terminal. In total, this is estimated to amount to 195.5 GWh, or 25.8%, with the Flotta Oil Terminal accounting for 55.4 GWh or 28.3% of this. Shown in Table 1, the energy demand on Orkney covered in 2019 along with the tonnes of carbon, for each sector.

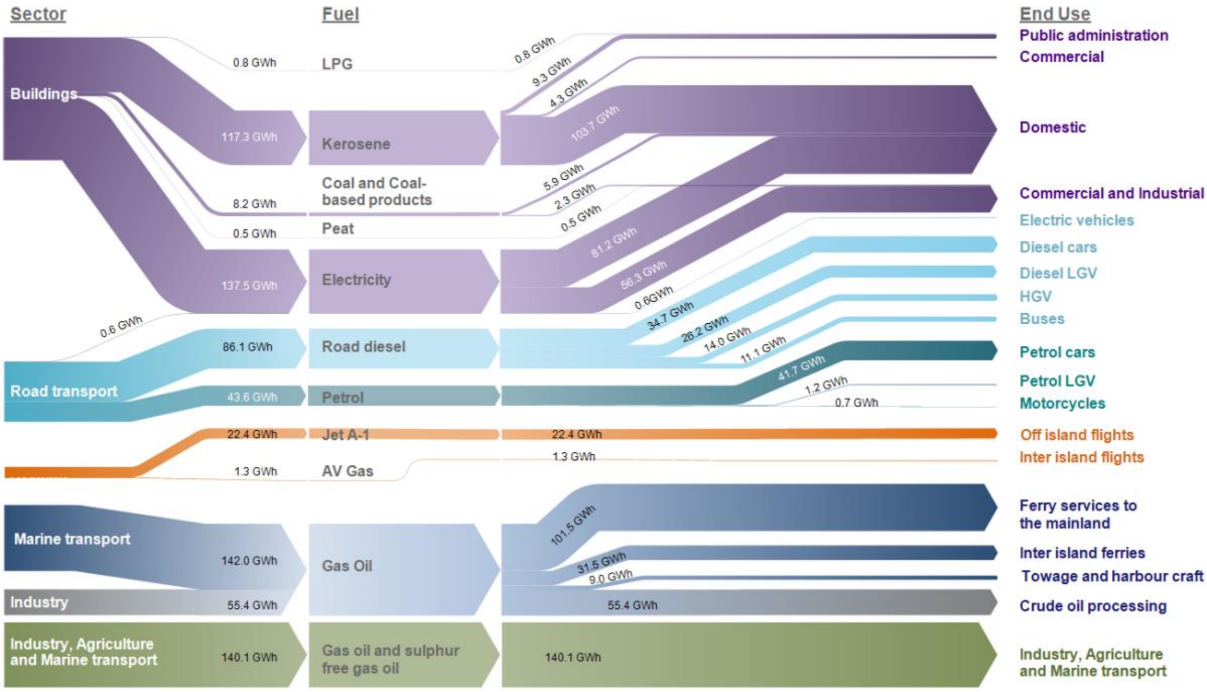

Figure 3 - Sankey diagram showing Orkney's energy use by sector and end use (GWh).

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Sector	GWh	total GWh (%)	Tonnes of CO_2	total tonnes of CO_2 (%)
Road transport	130.2	17.2	32,045	16.6
Buildings	264.3	35.0	69,754	36.1
Aviation	23.7	3.1	5,805	3.0
Marine transport	142.0	18.8	35,991	18.6
Industry	55.4	7.3	14,039	7.3
Industry, Agriculture & Marine transport	140.1	18.5	35,525	18.4
Total	**755.7**	**100.0**	**193,160**	**100.0**

Table 1 - Orkney's energy use and carbon emissions by sector.

Some of these energy sources depicted Figure 3 do not represent a complete picture of the total energy usage in Orkney due to various limitations in collecting data, notably those associated with Kirkwall Power Station, curtailed energy, energy stored as hydrogen or in batteries, self-consumption of energy, energy produced by heat pumps, biomass/biofuels, fuel other than gas oil used at Flotta Oil Terminal, crude oil exported from Flotta Oil Terminal and crude oil transferred during ship-to-ship transfers in Scapa Flow.

2.1.3.1 Electricity consumption

ReFLEX Orkney considered electricity consumption, BEIS (Department for Business, Energy, and Industrial Strategy) statistics, which are reproduced here. (ReFLEX Orkney, 2019)

The average consumption per customer for both domestic and non-domestic is reproduced Figure 4 showing both domestic and non-domestic consumption from 2005 to 2017.

Electricity demand has been collected for Orkney since 2012 and is reproduced in Figure 5, for an average weekend, and weekday for each season showing higher demand in winter and lower demand in summer.

Figure 4 - Average electricity consumption per customer. Reproduced from ReFLEX Orkney 2019 Energy Audit.

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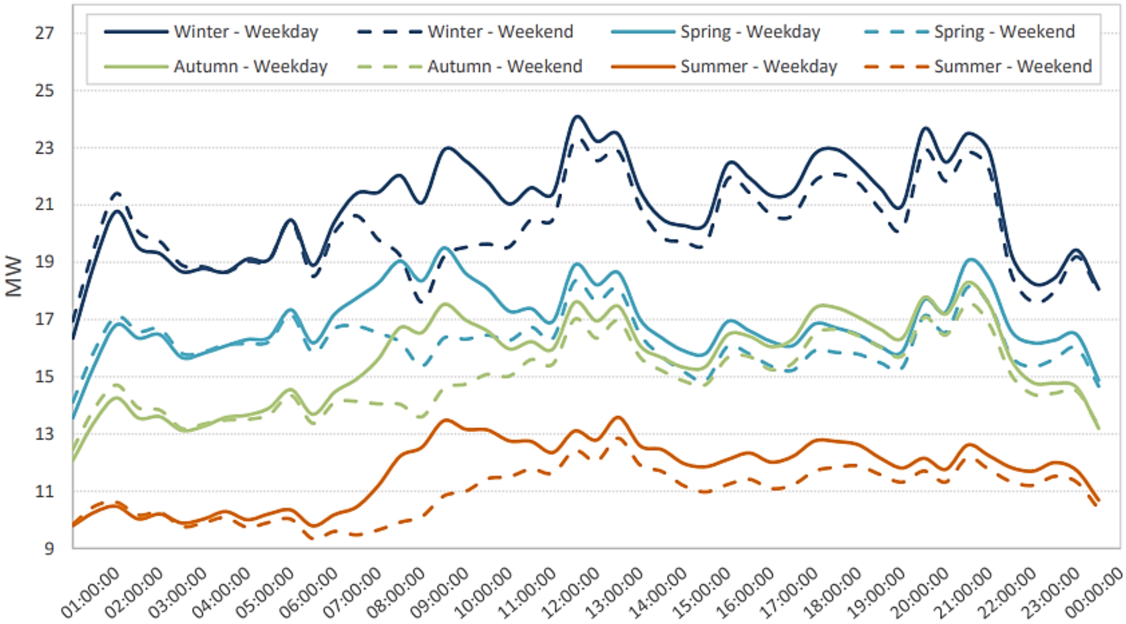

Figure 5 - Half hourly demand averages for an average weekend and weekday for each season (2012 to 2018). Reproduced from ReFLEX Orkney 2019 Energy Audit.

2.1.3.2 Heat pumps

There are three different types of heat pump in use throughout the Orkney Islands:

- Ground Source Heat Pumps (GSHP): use pipes which are buried in the ground to extract head from the ground by circulating a mixture of water and antifreeze around a loop of pipe. This heat can then be used to heat radiators, underfloor heating systems, or warm air convectors and hot water.
- Air Source Heat Pumps (ASHP): absorb heat from the outside air (in the same way that heat is extracted from inside a fridge). This heat can then be used to heat radiators, underfloor heating systems, or warm air convectors and hot water.
- Sea Source Heat Pump (SSHP): work in a similar way to GSHP but the pipes are immersed in seawater rather than buried in the ground.

Ground and air source heat pumps are becoming more prevalent in Orkney, with their installation widespread across both private residences and public buildings. Currently, over 1,700 heat pumps have been installed throughout the region (ReFLEX Orkney, 2019). Analysis of the Orkney Islands Council's (OIC) planning application portal reveals that the majority of new housing constructions propose the integration of heat pumps into their heating systems. Among these, air source heat pumps are the preferred technology, demonstrating their growing adoption for efficient and sustainable heating solutions in Orkney.

Table 2 shows all the current OICs public buildings heat pump installations. Currently there is approximately 2.2 MW of total installed capacity within OICs public buildings.

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Site	Technology	Rating (kW)	QTY	Total Installed Rating (kW)
Braebrun Court Core Unit	ASHP	12	1	12
Childrens Home, Watersfield	GSHP	21	2	42
Evie Primary School	GSHP	112	1	112
Glaitness Primary School	GSHP	12 & 25	8 & 2	96 & 50
Hamnavoe House	GSHP	45	3	135
Kalisgarth Care Facility	GSHP	15	1	15
Kirkwall Grammar School	GSHP	126	6	756
Papdale Halls of Residence	GSHP	126	2	252
Pickaquoy Camp Site	ASHP	14	2	28
Pickaquoy Centre	GSHP	126	2	252
Sanday Junior High School	GSHP	12	4	48
Smiddybrae House	GSHP	40	2	80
Stromness Community Centre	ASHP	16	5	80
Stromness Primary School	GSHP	65.6	2	131.2
Stromness Swimming Pool	GSHP	31.2	1	31.2
Warehouse Building	SSHP	40	2	80

Table 2 - List of heat pumps installed in public buildings.
Reproduced from ReFLEX Orkney 2019 Energy Audit.

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2.1.4 Energy Mix on the Orkney Islands

The citizens of Orkney developed an awareness of renewable energy at a very early stage. The Orkney Islands have long embraced the concept, recognising that sustainable electricity generation represents the ideal fit for a community in a location with abundant wind, tidal, and wave resource, and economically reliant on an unspoiled landscape and clean oceans, due to tourism and agriculture. Over 100% of the islands' electricity needs are now regularly met from local renewable sources, with one in ten of the total island population generating their own power – well above the national average. A detailed breakdown of Orkney's energy mix is provided in Table 3.

Fuel Type	Energy (GWh)	Percentage of Total Energy (%)	CO_2 Emissions (Tonnes)	Percentage of Total CO_2 Emissions (%)
Electricity	138.1	18.30	38,188	19.80
Coal and Coal-Based Products	8.2	1.10	2,579	1.30
LPG	0.8	0.10	174	0.10
Peat	0.5	0.10	178	0.10
Jet A-1	22.4	3.00	5,494	2.80
AV Gas	1.3	0.20	312	0.20
Gas Oil	197.4	26.10	50,030	25.90
Gas Oil/Sulphur-Free Gas Oil	140.1	18.50	35,526	18.40
Road Diesel	86.1	11.40	21,452	11.10
Petrol	43.6	5.80	10,440	5.40
Kerosene	117.3	15.50	28,788	14.90
Total	**755.7**	**100.00**	**193,160**	**100.00**

Table 3 - Energy mix throughout the Orkney Islands by fuel.

Orkney's renewable energy infrastructure has evolved from pioneering single installations to a broad-based, integrated energy system leveraging multiple renewable sources, highlighting its shift towards a sustainable and self-sufficient energy future.

There remains work to do, however. Considering the relative scale of each of the remaining fossil fuel types in use, a decarbonisation strategy favouring reductions of Gas Oil, Sulphur Free Gas Oil, Kerosene, Road Diesel and Jet A-1 would seem to be beneficial. Decarbonisation of agriculture and marine industries is required, as well as elimination of the use of kerosene for domestic heating.

Coal/Solid Fuels, Peat, and LPG are used in much lower volumes and initiatives designed to transition away from other fossil fuel types are also likely to have an effect on these.

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2.1.4.1 Fossil fuel energy

Coal / Solid fuel

Coal has historically been a significant fuel source for Orkney, primarily used for domestic heating. Although the import quantities have generally decreased over time, coal remains part of the island's energy mix. In 2015, the mode of coal import shifted from bulk carrier to freight via ferry services. In 2015, approximately 981 tonnes of coal were imported, translating to about 8.2 GWh of energy and producing around 2,581 tonnes of CO_2 emissions.

There is a very small amount of peat burning for home heating and some industrial applications (i.e. whisky production). This is due not only to tradition, but also for cost reasons amongst the poorest households, as identified by the Scottish Government's consultation on the ban of the sale of peat (Scottish Government Riaghaltas na h-Alba, 2023).

Liquefied Petroleum Gas (LPG)

Liquefied Petroleum Gas (LPG), which includes propane and butane, is used in Orkney for heating appliances, cooking equipment, and some vehicles. The lack of a mains gas distribution network in Orkney means LPG is an important alternative. ReFLEX Orkney analysed the use of LPG, but data is not reliable or consistent between sources (ReFLEX Orkney, 2019).

Kerosene

Kerosene is another crucial fuel for Orkney, commonly used for commercial and domestic heating. The bulk of kerosene comes through shipments recorded by OIC Marine Services (ReFLEX Orkney, 2019). In 2018, Orkney imported approximately 9,139 tonnes of kerosene, which provided 117.3 GWh of energy and resulted in 28,788 tonnes of CO_2 emissions. This demonstrates kerosene's significant role in meeting Orkney's energy needs.

Focus on decarbonisation of home heating and transition to alternate heat sources is required. This transition must take into account key challenges for Orkney – aging housing stock and cost/disruption to transition.

Older housing stock may not have pipework which lends itself to heat pump installation of any kind (e.g. microbore). Cost to replace heating systems while electricity costs remain high despite high levels of local generation are a disincentive to replacement, and proposed bans on oil boilers can be considered unreasonable. Alternate solutions may be required (e.g. HVO) for properties which cannot be easily converted to efficient heat pumps or district heating (due to remote locations/low density of housing).

Consideration of this and other factors are included in the Orkney Islands Council Local Heat and Energy Efficiency Strategy (Orkney Islands Council, 2024). See Section 3.7.

Petrol and Diesel

Petrol and diesel are essential for transport and some power generation in Orkney. In 2018, around 3,330 tonnes of unleaded petrol were imported, generating about 43.6 GWh of energy and 10,440 tonnes of CO_2 emissions. For diesel (including DERV, used primarily for vehicles), the 2018 imports were about 6,780 tonnes, translating to 86.1 GWh of energy and producing 21,452 tonnes of CO_2 emissions (ReFLEX Orkney, 2019).

Orkney has some of the highest rates of EV adoption in the UK. Charging points are available in urban locations, but these are few in number since distance travelled on the isles is quite low. The islands themselves are small, ~40 miles at greatest extent by road (Birsay – Burwick) for a single journey. This falls easily within EV range, however islanders do regularly need to travel on the Scottish Mainland or Shetland, where range anxiety can be an issue due to the longer distances. It is considered, however, for domestic/business car use at least, that EV adoption is not particularly in need of an adoptive push in Orkney, although intelligent time-of-day use of charging infrastructure may be of benefit. It is noted that the rising taxation burden on fossil fuel transport may be considered unjust by some if poverty indicators are considered alongside the high price of EVs. Market forces are expected to relieve this burden over time, however.

More problematic is the use of agricultural or logistical transport diesel in favour of something

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decarbonised.

- Batteries are heavy and will typically only last a few hours under constant use.
- Logistical vehicles (e.g. HGV) are used extensively to get goods on and off the Orkney Islands. These typically have long supply routes through northern Scotland. Replacement by electric vehicle is not likely to be achievable, although alternate supply routes (e.g. by sea via Aberdeen) exist.
- Since agricultural machinery can be in use for very long periods (sometimes up to 15h-18h per day) it is considered that use of hybrid or electric versions might not satisfy how farmers need to work. The extra weight of batteries can lead to problems with the weight of the machinery on the land itself, which can affect ability to grow crops, as the ground becomes impacted and damaged.
- Certain manufacturers are looking at replacement of diesel with hydrogen engines. This requires the development of a whole new hydrogen supply chain, which may not be easily possible (JCB, 2024).
- There are also advances in battery technology, such as sodium batteries, that may lead to cheaper batteries and active research around charge density of such alternative battery chemistries.
- Taxation arrangements for "Red Diesel" use in agriculture should be considered as part of any proposals for decarbonisation of agriculture.

It is important to avoid disincentivising remote/rural ways of life in the race to net zero and decarbonising agriculture will be a significant challenge due to very tight economic margins.

Regardless, ISLANDER does not really have a concept for decarbonisation of agriculture or long-distance logistics. As such, this is not considered further here, and the approach for Orkney will be to wait for other technologies to address the decarbonisation problem for these industries.

Gas Oil and Sulphur Free Gas Oil

These fuels are primarily used in industry, agriculture and for heating. In 2018, combined imports of gas oil and sulphur free gas oil amounted to 14,355 tonnes, which generated 180.6 GWh of energy and emitted 45,792 tonnes of CO_2 (ReFLEX Orkney, 2019). It is worth noting the use of Marine Gas Oil for shipping, aquaculture, sea transportation, fishing and other marine applications. ISLANDER has no concept for the decarbonisation of the marine sector, which itself is a larger emitter of CO_2 than aviation (OECD Statistics, 2023).

As a result, decarbonisation of the marine sector is deemed out of scope for this replication report, although there are initiatives in Orkney which are beginning to address it. EMEC consider a synthetic carbon-neutral drop-in replacement for MGO as being the most likely outcome for marine decarbonisation, given issues with other fuel types and power arrangements. Shore power will be required (e.g. for berthed passenger vessels) and electric/hydrogen vessels may be effective for smaller vessel types. This will lead to higher demand on the local grid, but accurate forecasts for this are hard to arrive at, given the uncertain/early stage nature of projects in this area.

Additional Non-Renewable Power Generation (Flotta Oil Terminal)

The Flotta Oil Terminal, located on the island of Flotta in the Orkney Islands, Scotland, is a significant crude oil reception, processing, storage and export facility. It plays a crucial role in the North Sea oil infrastructure.

This facility, originally part of the North Sea oil infrastructure (connected to various oil fields via subsea pipelines, including Piper, Claymore, Tartan, and Golden Eagle), has adapted to include electricity generation capabilities using gas from oil processing. Over time, the facility has integrated capabilities to export excess electricity, especially during periods of high gas availability. In 2019, it exported about 16.1 GWh of electricity, leveraging the by-products of oil processing for power generation.

There is potential for hydrogen to be generated or used for synthetic fuel production at the

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Flotta site. This could be a large sink for electricity or used for generation.

2.1.4.2 Renewable Energy

Wind Energy

Orkney has been at the forefront of wind energy innovation for decades, testing the UK's first grid-connected wind turbine at Costa Head in the 1950s. There has been significant growth in both small-scale and large-scale wind energy installations. The installed capacity increased steadily, with significant installations in the 2000s leading to a total installed capacity of 44.7 MW for large-scale and 5.92 MW for small-scale by 2019. Annually, large-scale turbines generate approximately 161.3 GWh, and small-scale turbines generate about 19.7 GWh (ReFLEX Orkney, 2019).

Figure 6 shows the growth in wind turbine installed capacity, spilt by large (> 50 kilowatt (kW)) and small scale (< 50 kW). Orkney has more small-scale wind turbines than any other local authority area in the UK accounting for 11% if the UKs installed capacity of this size.

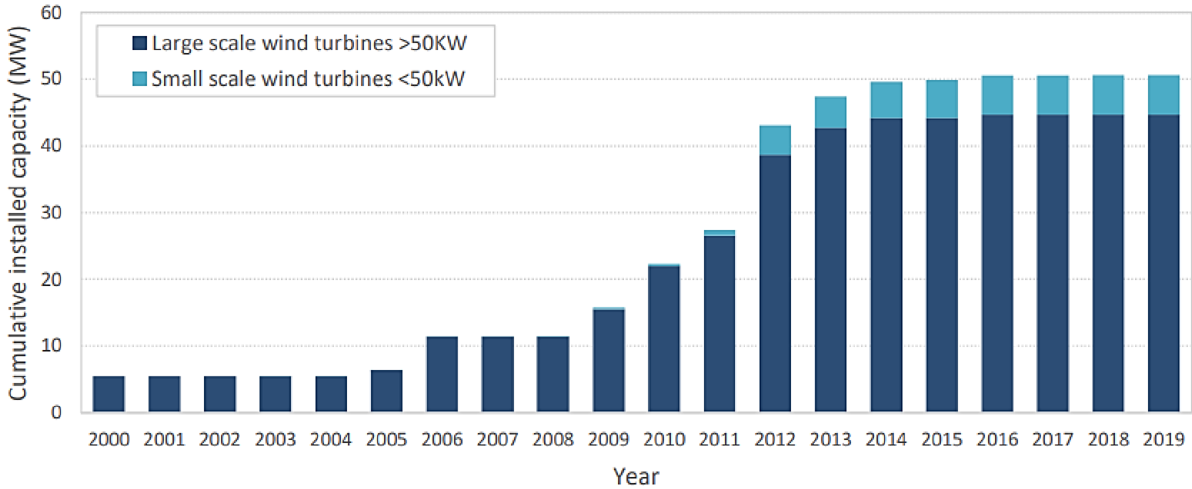

Figure 6 - Cumulative installed capacity of wind turbines in Orkney. Reproduced from (ReFLEX Orkney, 2019).

Due to grid constraints, it has not been possible to install significant new wind generation in Orkney since ANM was introduced in 2012.

Table 4 shows wind turbine installation in Orkney as a percentage of the UK total (accounting for 13% of the installed capacity of the UK total), with figure 7 demonstrating that the majority of these were commissioned in 2012 (Figure 7).

Type of Installation	Total number of installations in Orkney	Total number of installations as a percentage of the UK total (%)	Total installed capacity in Orkney (kW)	Total installed capacity as a percentage of UK total) (%)
Domestic	651	15	4,947	13
Community	9	7	55	5
Non-Domestic (Commercial)	75	8	857	7
Non-Domestic (Industrial)	2	4	60	7
Total	**737**	**14**	**5,919**	**11**

Table 4 - Small wind by type of installation in Orkney compared to the UK total.

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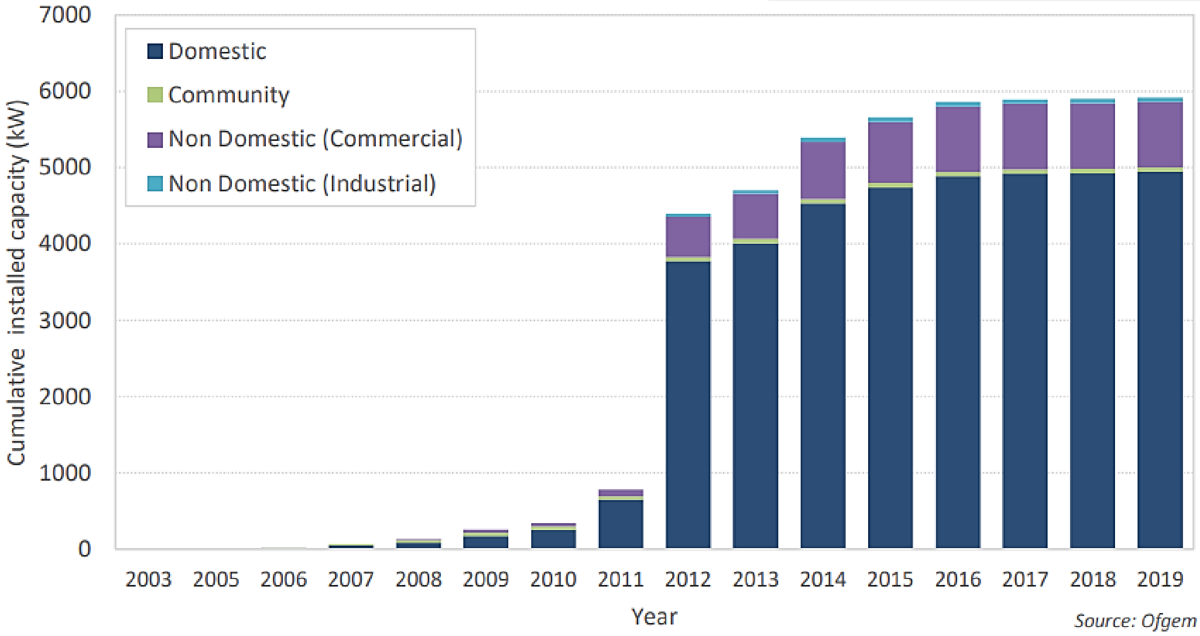

Figure 7 - Cumulative installed capacity by commissioning date (Orkney small turbines up to 50 kW). Reproduced from (ReFLEX Orkney, 2019).

Solar Energy

Orkney began integrating solar energy into its renewable portfolio relatively recently compared to other renewable sources like wind. The adoption has been part of a broader strategy to diversify the renewable energy sources on the islands. Despite less solar irradiance than other parts of the UK, the use of solar PV has proven effective and beneficial for local energy resilience.

The installed capacity of solar PV in Orkney is about 1.4 MW (ReFLEX Orkney, 2019). This capacity contributes an estimated annual energy generation of approximately 1.19 GWh. Solar installations in Orkney are primarily small-scale, involving residential and community buildings which contribute to reducing the reliance on imported energy and enhancing local energy security. Table 5 shows the majority of the PV installed capacity is domestic installations, which total 1,369 kW.

Type of Installation	Total number of installations in Orkney	Total number of installations as a percentage of the UK total (%)	Total installed capacity in Orkney (kW)	Total installed capacity as a percentage of UK total) (%)
Domestic	368	0.04	1,369	0.05
Community	1	0.03	26	0.01
Commercial	5	0.02	35	0.002
Total	**374**	**0.04**	**1,429**	**0.03**

Table 5 - Total photovoltaic installed capacity by type of installation. Reproduced from (ReFLEX Orkney, 2019).

The growth of solar PV in Orkney reflects a broader trend towards embracing a variety of renewable energy technologies to harness the islands' unique environmental resources. The installations are supported by local initiatives and policies that promote renewable energy integration, including efforts by the Orkney Renewable Energy Forum (OREF) and specific projects aimed at increasing the energy self-sufficiency of the islands.

In Orkney installations of PV systems peaked in 2012 and have tailed off since, as seen in Figure 8 (ReFLEX Orkney, 2019), probably due to the decreasing tariffs being offered as well as the moratorium on all new generation, above 3.6 kW installed capacity imposed by SHEPD

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in September 2012.

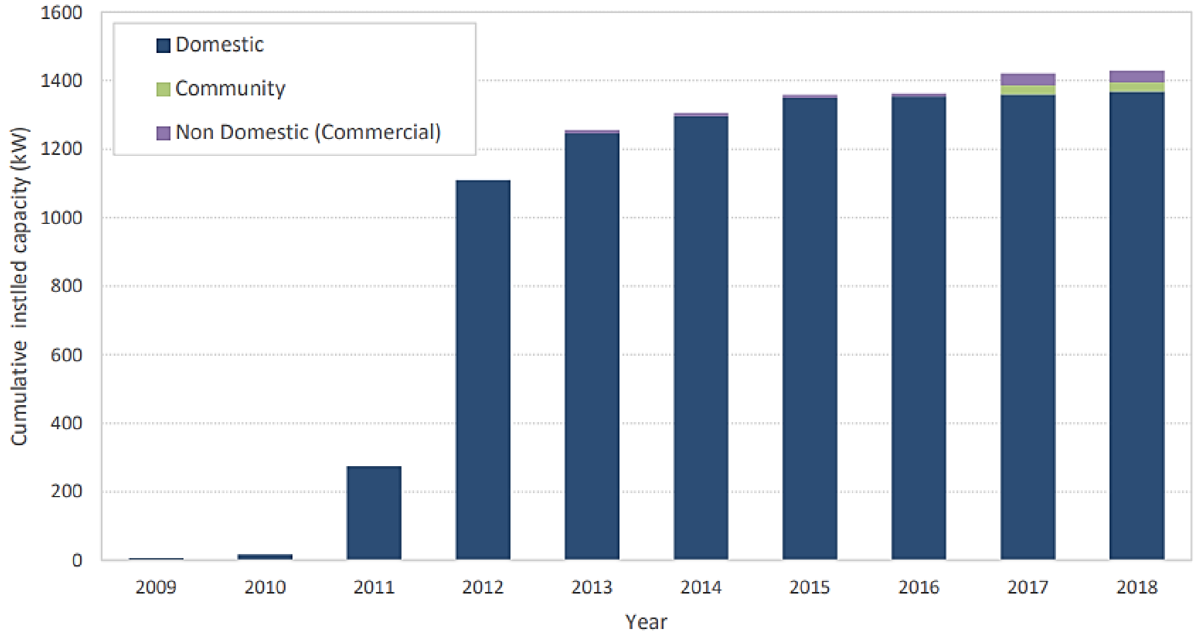

Figure 8 - Cumulative installed capacity by commissioning date for photovoltaic panels. Reproduced from (ReFLEX Orkney, 2019).

Hydro Energy

Small-scale hydro is also part of Orkney's renewable energy portfolio, with installations like the one at Woodwick Mill. The development of hydro power is limited due to the scale and the specific geographic and hydrological conditions required. The current installation at Woodwick Mill is relatively small. The total installed capacity is 11 kW, with an annual generation of about 0.03 GWh.

Marine Energy

Orkney is a global leader in marine energy, hosting the European Marine Energy Centre (EMEC) since 2003, the world's first and only grid-connected test facility for tidal and wave energy. The sector has seen significant advancements with various prototypes tested at EMEC. The waters throughout the Orkney Islands have hosted more grid-connected ocean energy devices than any other single site globally. The generation is highly variable due to the experimental nature of the technologies tested. For instance, in 2017, a prototype tidal turbine generated over 116 MWh in less than a week.

EMEC's tidal test facilities (Falls of Warness) in Orkney have been a hub for the development and testing of tidal energy devices since its inception. Over the years, multiple developers have installed a variety of tidal technologies at EMEC's test sites. Some of the notable developers include Open Hydro, Orbital Marine Power, Magallanes Renovables, Atlantis Resources Corporation, Alstom, ANDRITZ HYDRO Hammerfest, Tocardo, Sustainable Marine Energy, and Voith. Each of these companies have contributed to the array of tidal devices tested, ranging from prototypes to commercial-scale units.

Tidal energy is attractive due to predictability, which means it could be considered baseload generation.

Reported output power for marine energy is currently zero, as this is not guaranteed due to the prototype nature of the devices, of which the grid connected versions are present only at EMECs tidal site at the Fall of Warness on Eday, which currently has a 4 MW connection agreed, and further connections in planning (up to 22.8 MW total) which will be subject to ANM. This is an area that is expected to expand in the years to 2030 and beyond. The site is intended to become operational in the period 2025-2028, and predictions for energy yield in 2027 exceed the capacity of the current links, if all expected devices are deployed.

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EMEC's wave test facilities in Orkney (Billia Croo) have seen numerous wave energy devices deployed over the years as part of various testing and development programs. Some of the notable wave energy converters tested at EMEC include the Pelamis, Wello Oy's Penguin, and AWS Ocean Energy's Archimedes Waveswing. These devices utilise innovative technologies to harness the power of ocean waves and convert it into electricity.

Wave energy is less predictable than tidal, and is affected by bathymetry, and wind, in particular the distance over which wind forcing occurs. Survivability of the wave energy converters (WECs) is a primary concern.

Electromobility

In Orkney, electromobility, particularly the adoption of electric vehicles (EVs), has shown a steady rise. The number of registered EVs in Orkney increased from a small fleet to 247 vehicles by the third quarter of 2019 to a currently estimated >600. This rise has been accompanied by a parallel expansion in charging infrastructure to accommodate the growing fleet. From the 2013/2014 financial year, when there were only 520 charging sessions recorded, this number escalated to around 18,000 charging sessions by the 2018/2019 financial year, this is detailed in Table 6.

Location	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19
Church Road Car Park	-	-	-	7	1,597	1,541
Dounby Primary School	5	16	53	69	1,090	1,506
Ferry Road Long Stay Car Park	-	-	-	9	1,964	2,707
Great Western Road Car Park	-	730	1,612	3,635	5,446	6,742
Kirkwall Council Offices	-	624	946	1,521	2,217	2,343
Kirkwall Travel Centre	-	-	-	-	3	100
Old Academy Business Centre	498	625	599	781	1,117	1,057
St Margaret's Hope Care Home	-	299	442	445	105	63
St Rognvald's House	17	100	65	103	48	62
The Pickaquoy Centre	-	-	338	848	1,313	1,697
Total	**520**	**2,394**	**4,055**	**7,418**	**14,900**	**17,818**

Table 6 - Number of charging events at various locations across several years. Reproduced from (ReFLEX Orkney, 2019).

The increase in EVs and the development of the charging infrastructure reflect Orkney's commitment to sustainable transport solutions and reducing dependency on fossil fuels. Despite the positive trend in EV adoption, 'Vehicle to grid' (V2G) technology, which allows EVs to return stored electricity to the grid, is still under development and not yet operational in Orkney.

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2.1.4.3 Energy Storage

Energy may be stored in number of ways such as electro-chemically (e.g. batteries) in pure chemical form (e.g. hydrogen) or thermally (e.g. hot water tanks or storage heaters). There has been rapid development in battery technologies in recent years with variants in the lithium-ion (or Li-Ion) concept becoming widely available from small/domestic-scale, through their use in electric vehicles to larger, utility-scale applications.

In 2013, a 0.625 MWh lithium-ion battery storage (with 2 MW rated charge/discharge rate) was added to the grid at Kirkwall power station. This was used to trial grid smoothing, to avoid intermittency of renewable generation. This trial ended in 2015, having achieved an increase in technical readiness level from TRL6 to TRL8 (Scottish and Southern Energy Power Distribution, 2015).

However, there remains 16.3 MW of diesel generation capability at Kirkwall in the event of subsea cable outages. Ultracapacitors have not been evaluated.

Stationary storage devices

In December 2018, Solo Energy launched a pioneering housing project in Kirkwall, featuring 30 homes with built-in energy storage: 16 homes featured solar photovoltaic (PV) plus in-home battery storage assets (4 tesla Powerwalls (6.4 kWh each) together with 12 Sonnen Eco (2.5 kWh) units, totalling 55.6 kWh); 14 homes had solar PV plus smart immersion controllers (ReFLEX Orkney, 2019).

The houses with battery assets allow residents to make use of renewable energy throughout the day and, not only when the sun is shining. Whereas the houses with smart immersion controllers can divert excess energy produced by the solar PV into their hot water tanks. The batteries can also import via the connection to the grid and store some electricity from Orkney's wind resource.

Mobile storage: EVs and vehicle to grid

Charging of the battery in an EV provides a means of energy storage, although most systems are designed for the energy flow one way, into the battery, and it cannot then be fed back into the electrical grid. However, 'vehicle to grid' technology (also referred to as V2G) is a system which allows two-way flow of energy. This means that the energy stored in the battery of an EV could be fed back onto the electricity grid at times of high electricity demand. The ReFLEX Orkney project was able to demonstrate a 30 EV charger network being controlled successfully to alleviate ANM constraints, despite V2G being found to be impractical.

Hydrogen storage

Hydrogen production at EMEC's Caldale site on Eday involves the use of electricity generated from tidal turbines to power a 500 kW ITM Power Proton Exchange Membrane electrolyser. This initiative is part of the Surf 'n' Turf project, which also integrates electricity from Eday renewable energy's community-owned 900 kW Enercon wind turbine.

The hydrogen produced is stored as pressurised gas in a 500 kg static storage system at the site. Additionally, the project employs a fleet of Mobile Storage Units (MSUs) to transport the hydrogen to the Orkney mainland. Each MSU comprises 59 gas cylinders, collectively holding 250 kg of hydrogen at 200 Bar pressure.

This hydrogen was then utilised at Kirkwall harbour, where a 75 kW fuel cell converts it back to electricity. This electricity provides shoreside power to several interisland ferries whilst docked overnight, demonstrating an effective use of locally produced renewable energy to support maritime operations. Other projects utilising green hydrogen in Orkney are:

- Heating system at Shapinsay School.
- SATE 1 & 2 project Kirkwall Airport.
- Kirkwall Airport CHP.
- Hydrogen filling station at Hatston.

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2.2 Holistic Energy System design and Deployment

The current energy assets and the future energy assets in a decarbonised scenario are illustrated in Figure 9a and Figure 9b respectively. The energy assets are categorised into generators (electricity and fossil fuels) and consumers (electric and thermal), encompassing transportation as well. According to the scheme, electricity is consumed in residential, commercial and tertiary buildings, including industry, ports and for powering electric vehicle fleets. Fossil fuels are primarily used in road transport (both heavy and light vehicles) and marine transport. Electrical generation relies on non-renewable energy sources (fossil fuels) and occasionally on interconnections with the mainland for imports.

Figure 9b represents future energy assets in a decarbonised scenario for an island. A key difference in future consumption assets is the integration of real-time regulation technologies, known as "demand response (DR)" in energy markets, providing flexibility and enhancing renewable energy penetration. The sector should maximize electrification, with electricity generation entirely decarbonised using renewable sources and energy storage for increased dispatchability and system inertia. Non-electrifiable energy consumers must adopt environmentally friendly technologies and sustainable fuels, with hydrogen being a promising candidate for meeting non-electrical energy demands.

In the current Orkney system, grid-connected storage is considered “generation” by the Distribution Network Operator (DNO). This leads to a reluctance to install generation or storage assets as the Orkney grid is at capacity, and already subject to Active Network Management (ANM). The DNO is also very reluctant to implement any new assets without an ANM arrangement, and the ANM solution presently implemented is not deployable at micro-scale as it is designed primarily for wind farms. This means that prosumer battery storage cannot be grid connected at present, limiting the possible implementation of demand-response use-cases in Orkney.

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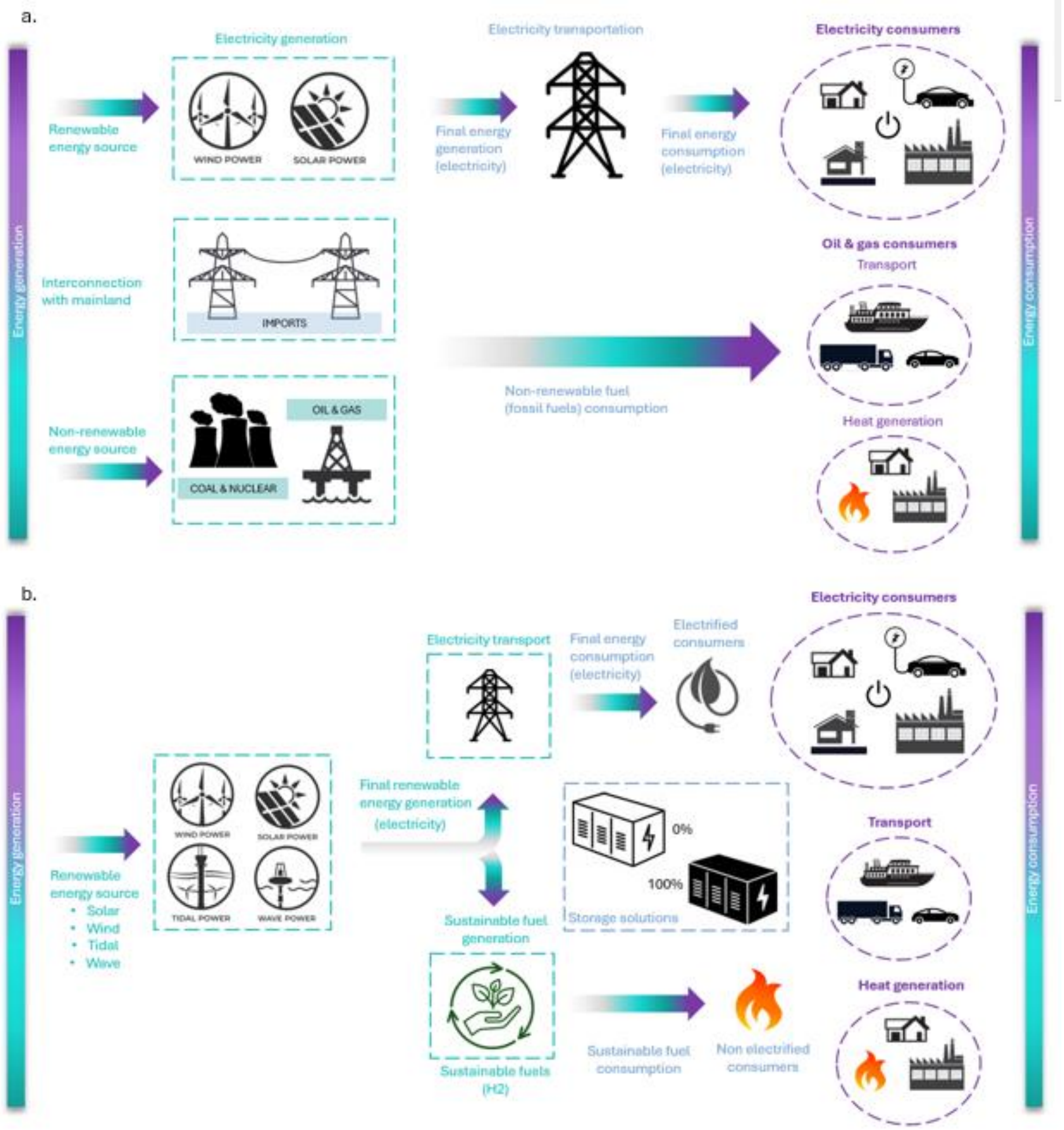

Figure 9 - a. Representation of existing energy assets. b. Representation of a decarbonised energy system.

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2.2.1 Energy Demand

This section articulates the different types of demand on the Orkney energy grid.

2.2.1.1 Electric Vehicle Demand

EV demand can be considered in two forms, unidirectional and bidirectional. Unidirectional electric vehicles are operated only charging from the grid whereas bidirectional electric vehicles can interact with the grid by charging or discharging. Currently, there are approximately 190 charging stations installed on the island for a total of around 600 electric vehicles. The progression of EVs adoption throughout the Orkney Islands annual is presented in Figures 10 and 11.

EV parameter	Value
Car fleet	≈ 600
Max charger power	7 – 51 k W
Energy storage	20 – 100 kWh

Table 7 - Electric vehicle fleet main parameters.

It is worth noting that the ReFLEX Orkney project increased the number of EVs in Orkney significantly. Numbers of DVLA registrations also underestimates the number of EVs due to registrations of leased vehicles being held off-island. ReFLEX Orkney has characterised the adoption of EVs over time as follows.

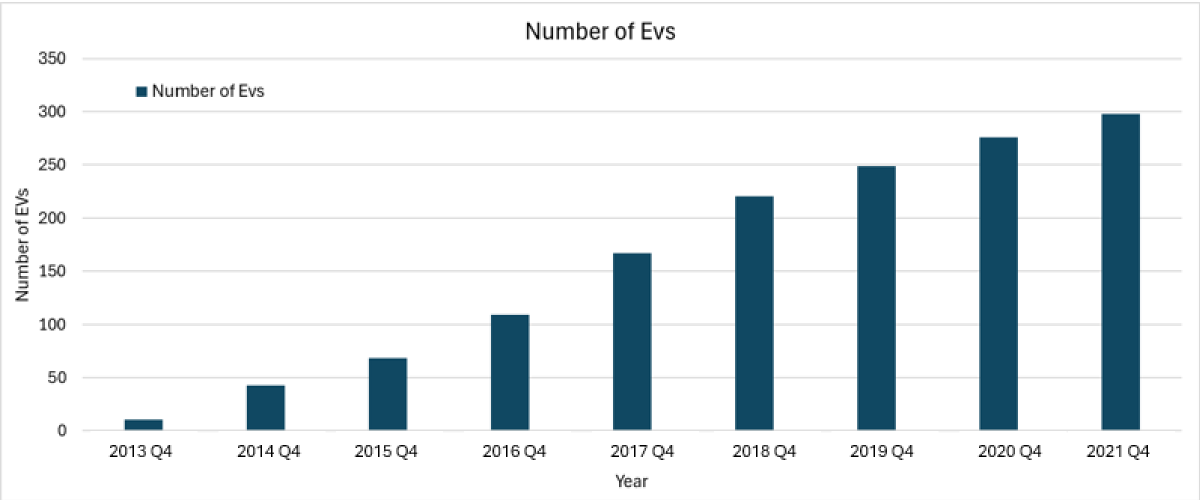

Figure 10 - Progression of EVs implemented throughout the Orkney Islands.

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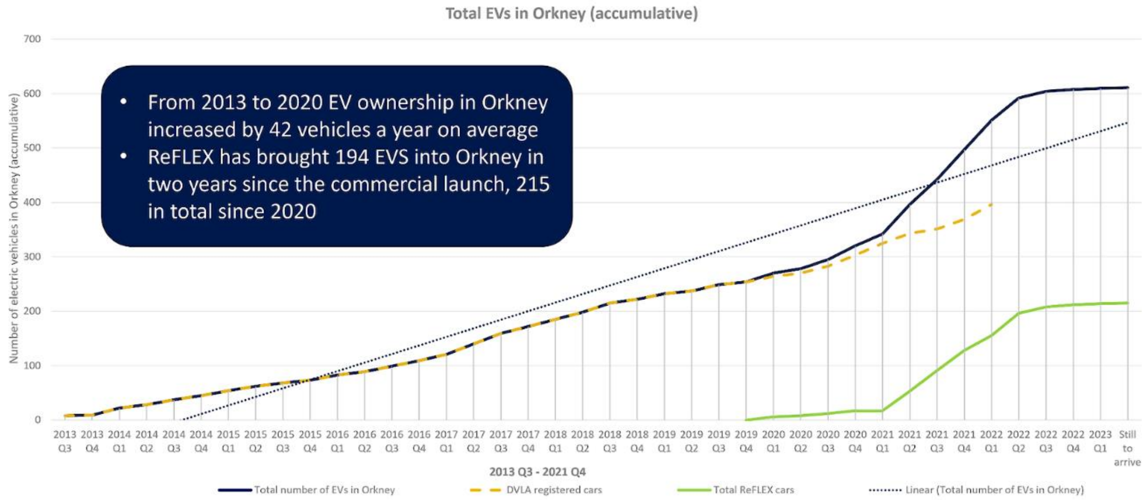

Figure 11 - Progression of EVs implemented throughout the Orkney Islands. DVLA registrations 2013-2021.

2.2.1.2 Street Lighting Demand

The street lighting electricity demand is modelled as an electric energy demand curve. The following parameters characterise the street lighting throughout the Orkney Islands:

- Street lighting lamps: 3000
- Powered by Electricity during the lighting time 1
- Low Voltage network
- Three levels of nominal power consumption 24 W, 27 W or 30 W

Given these parameters the following assumptions have been made:

- Medium consumption power for all street lighting: 27 W
- Total installed lighting consumption power: 81 kW
- Operation mode: ON (Night) – OFF (Day)

Sun profiles and associated street lighting energy consumption in Orkney, considering previous hypotheses, are summarised in Table 8 where the duration is the length of time the streetlights are ON.

Month	Dawn (AM)	Sunset (PM)	Duration (hrs)	Consumption (kWh/Day)	Consumption (kWh/Month)
January	09:00	03:30	17.50	1317	42525
February	08:10	05:10	15.00	1215	36450
March	06:50	06:30	12.33	999	29970
April	05:40	08:20	9.33	756	22680
May	04:30	09:50	6.67	540	16200
June	03:50	10:40	5.17	418	12555
July	04:00	10:20	5.67	459	13770
August	05:10	09:10	8.00	648	19440
September	06:20	07:40	10.67	864	25920
October	07:20	06:00	13.33	1296	32400
November	08:10	04:10	16.00	1296	38880
December	08:50	03:30	17.33	1404	42120

Table 8 - Street lighting monthly consumption.

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According to this street lighting model, the global annual associated consumption would be 332.9 MWh/year. Given the night hours with lighting demand, the monthly consumption of lighting is represented in Figure 12, included is the sunlight hours average per month.

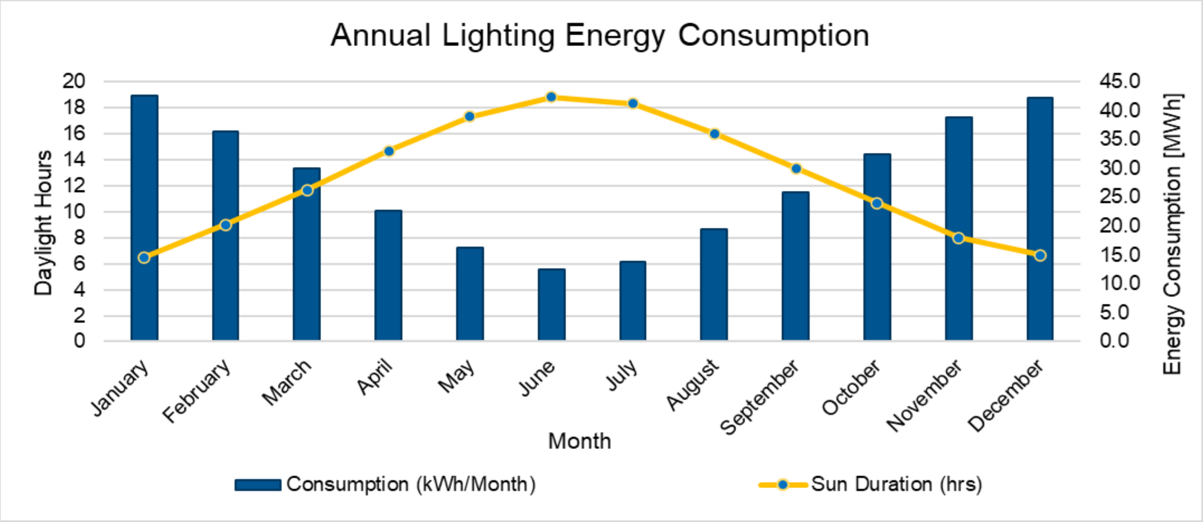

Figure 12 - Street lighting energy consumption and day light hours (monthly).

2.2.1.3 Thermal Demand

Generally, the islands' thermal energy needs are met by fossil fuels, but heat pump adoption is widespread given that Orkney is not connected to the UK Gas Grid.

Specifically for Orkney, the primary thermal energy requirement is highest during the winter months. Therefore, it is suggested to model the thermal energy demand based on the ambient temperature of Orkney. The accompanying Figure 13 displays the average temperatures recorded on the island between 2018 and 2021.

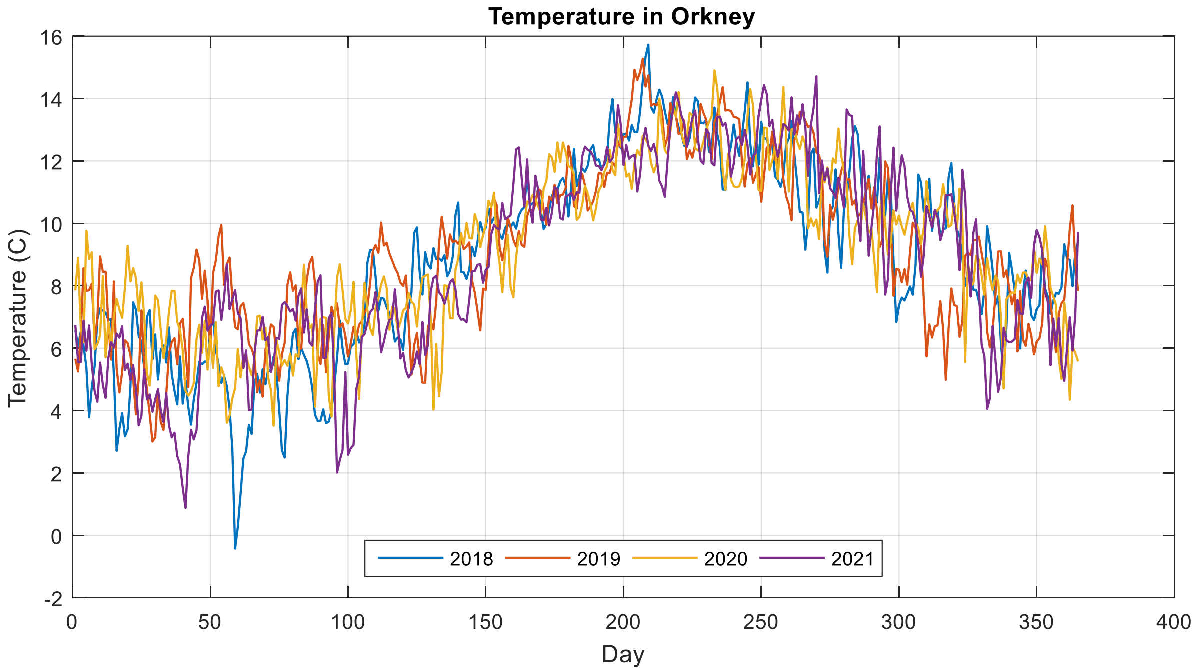

Figure 13 - Annual change in temperature recorded in Orkney.

Figure 14 presents the minimum, average and maximum temperatures recorded within the Orkney islands in 2021.

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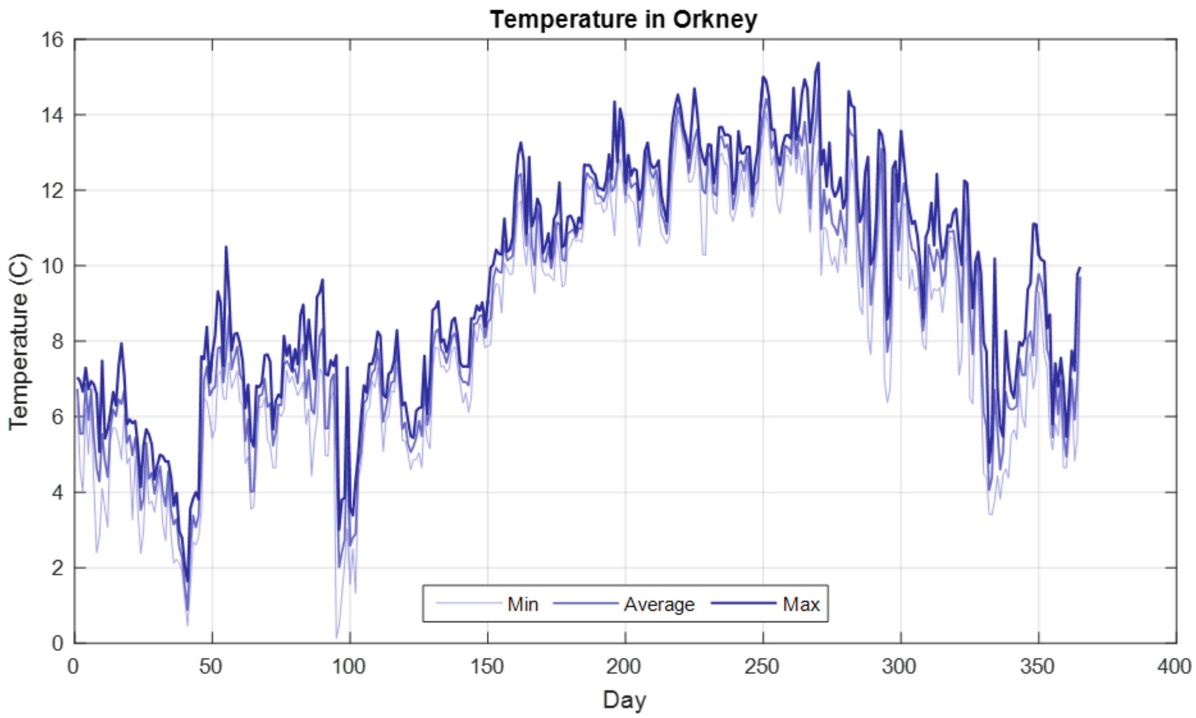

Figure 14 - Range of temperature recorded in Orkney (2021).

2.2.2 Electrical Energy Consumption

The electrical demand has been analysed using the data gathered in Orkney for 2022. The first analysis is the distribution of peaks and average values for the Orkney Mainland. Figure 15 depicts the maximum, average and linear average of hourly consumption in Orkney.

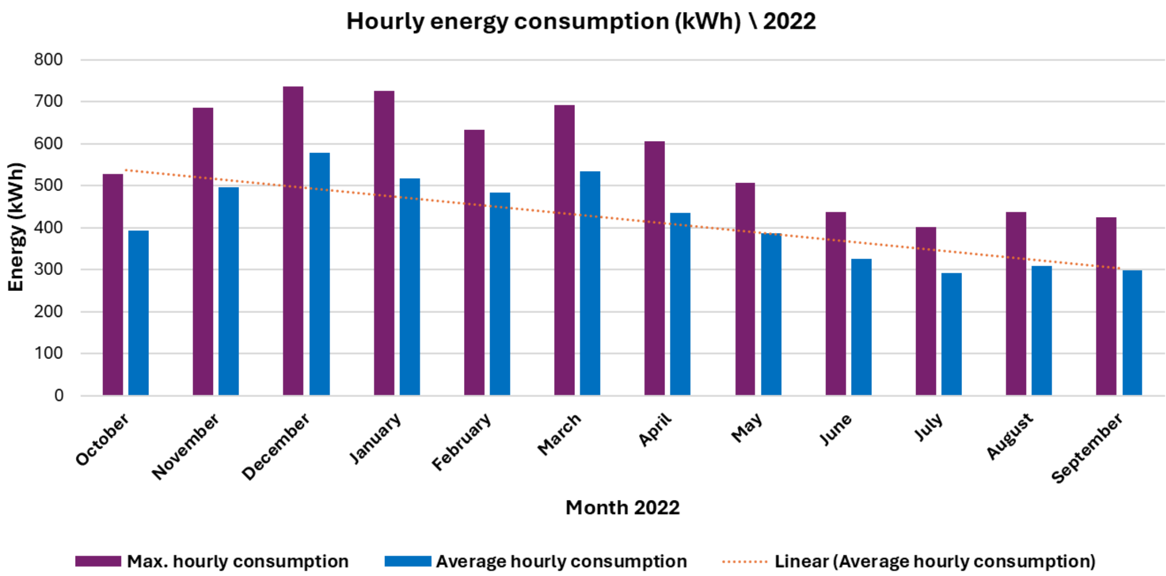

Figure 15 - Hourly energy consumption / 2022 - average and peak monthly values.

The next step is to analyse the minimum and maximum energy consumption, generation and import profiles on the islands. The typical day of consumption profiles of December 2021 and July 2022 are depicted in Figure 16 and Figure 17 respectively.

In July 2022, the maximum consumption peaks around 13 MWh in the early morning and remains relatively high throughout the day, while maximum generation varies between 2 and

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8 MWh, indicating a consistent need for net importation, which fluctuates to balance the deficit. Conversely, in December 2021, maximum consumption hovers around 25 MWh, with generation consistently close, peaking at around 30 MWh. Net importation remains mostly negative, suggesting a surplus of generation over consumption, allowing for possible exports or reduced import dependence during this period.

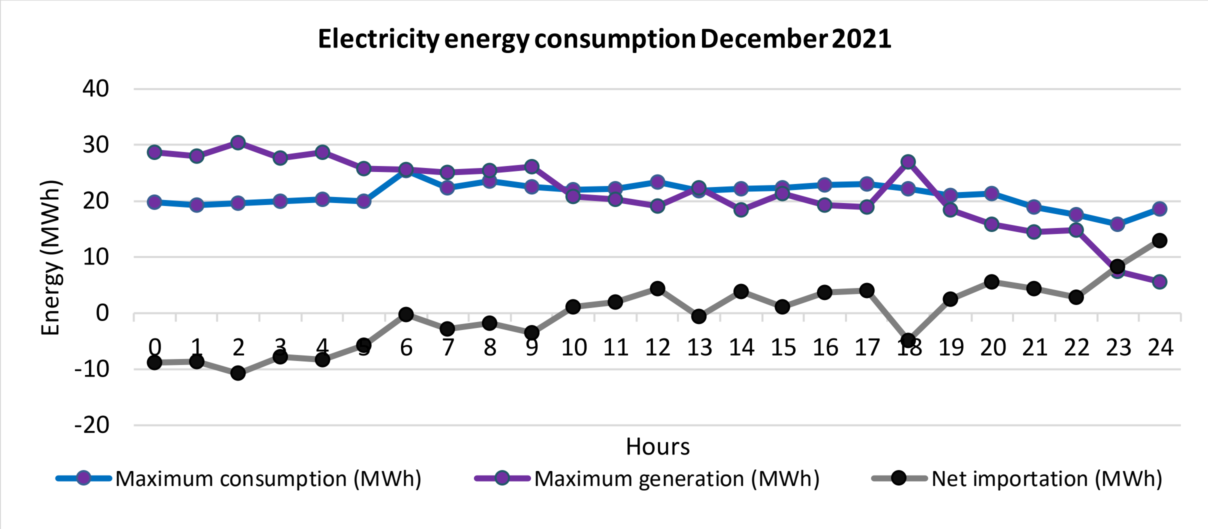

Figure 16 - Electricity consumption for 1 day in December 2021.

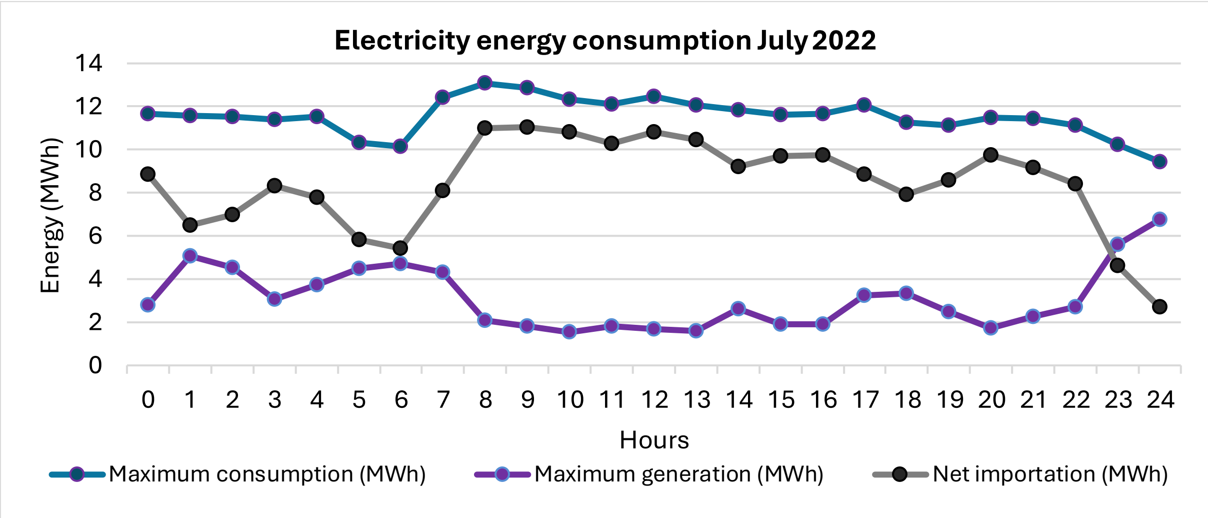

Figure 17 - Electricity consumption for 1 day in July 2022.

2.2.3 Energy Generation

2.2.3.1 Wind Resource

Orkney boasts an exceptionally robust wind resource, making it an ideal location for harnessing wind energy. The islands experience high average wind speeds due to their northern latitude and exposed geographical position. Average wind speeds are typically around 8 meters per second, which is significantly higher than in many other regions. This consistent and powerful wind resource drives the high efficiency of wind turbines installed on the islands.

As a result, Orkney has the potential to generate substantial amounts of wind power; estimates suggest that the installed turbines can produce well over 100% of the local electricity demand at times. This surplus energy provides a significant opportunity for Orkney

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to export clean energy or utilise it for other sustainable practices, such as hydrogen production.

Figure 18 displays the average wind speeds recorded on the island between 2018 and 2021.

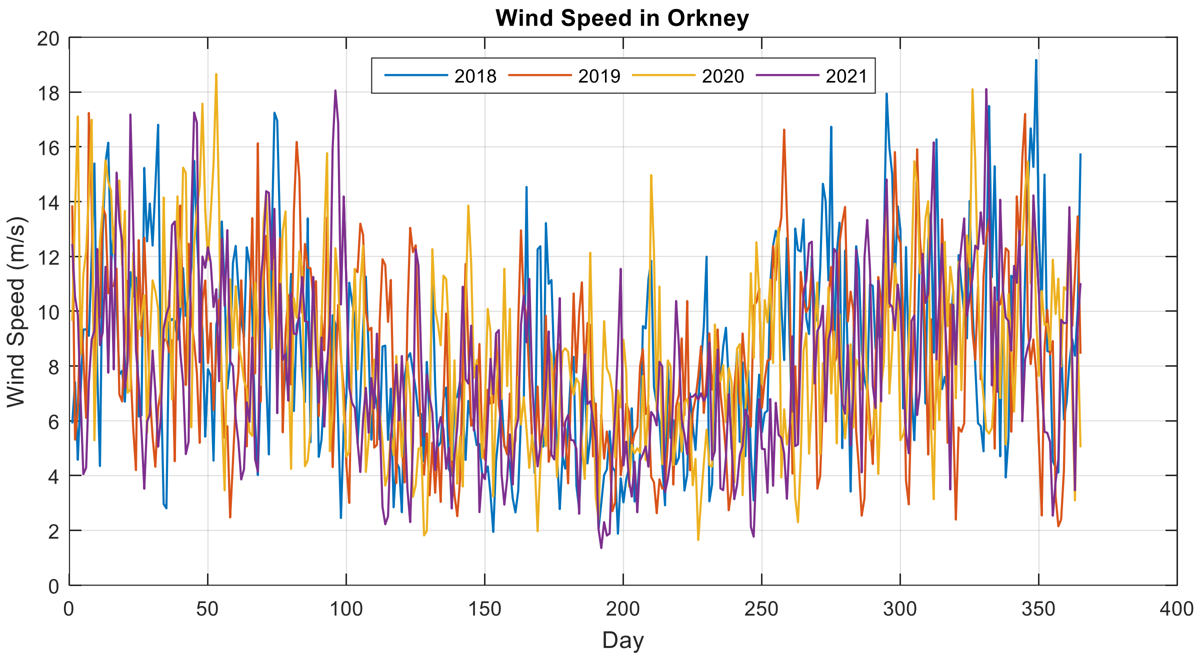

Figure 18 - Wind speed recorded in Orkney between 2018 - 2021.

Figure 19 presents the minimum, average and maximum wind speeds recorded within the Orkney islands in 2021.

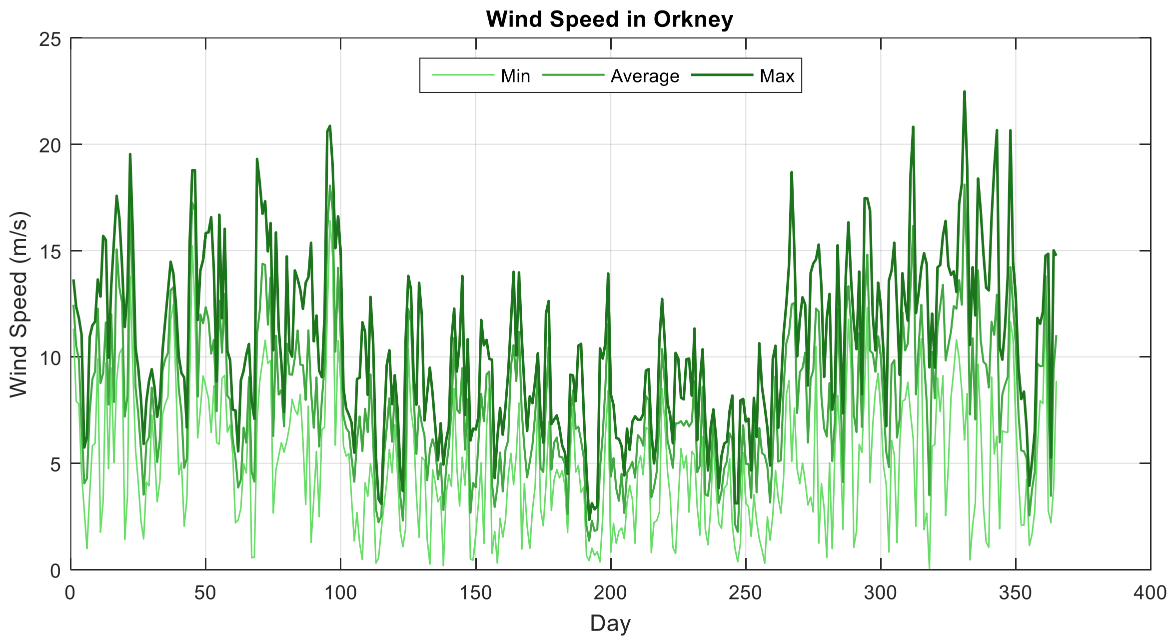

Figure 19 - Range of wind speed recorded in Orkney (2021).

The wind generators installed in Orkney currently range from small-scale to large-scale all with various characteristics of cut-in, rated and cut-out wind speeds.

- Small-scale turbines in Orkney are typically used for domestic or small community applications. Small-scale wind turbines usually range from a few kilowatts to around 50 kW. They are often seen on farms, residential properties, or small businesses.

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A typical small turbine would be around 6 kW, similar to a SD6, supplied by SD Wind Energy, which has a 5.2 kW @ 11 m/s rating, with 2.5 m/s cut in speed, and continuous operation at high speed. (SD Wind Energy, n.d.)

- Large-scale wind turbines are part of larger wind farms and significantly contribute to the electricity supply in Orkney. They are engineered for high efficiency and durability given the high wind speeds in the area.

  ReFLEX Orkney have stated 44.7 MW of installed capacity for large WTGs >50 kW in size.

Figure 20 depicts examples of large WTG power curves that are located in Orkney. The examples are taken from DG Westray (500 kW), Barefoot Wind Farm (900 kW), Barns of Ayre (2,730 kW) and Spurness Wind Farm II (10,000 kW).

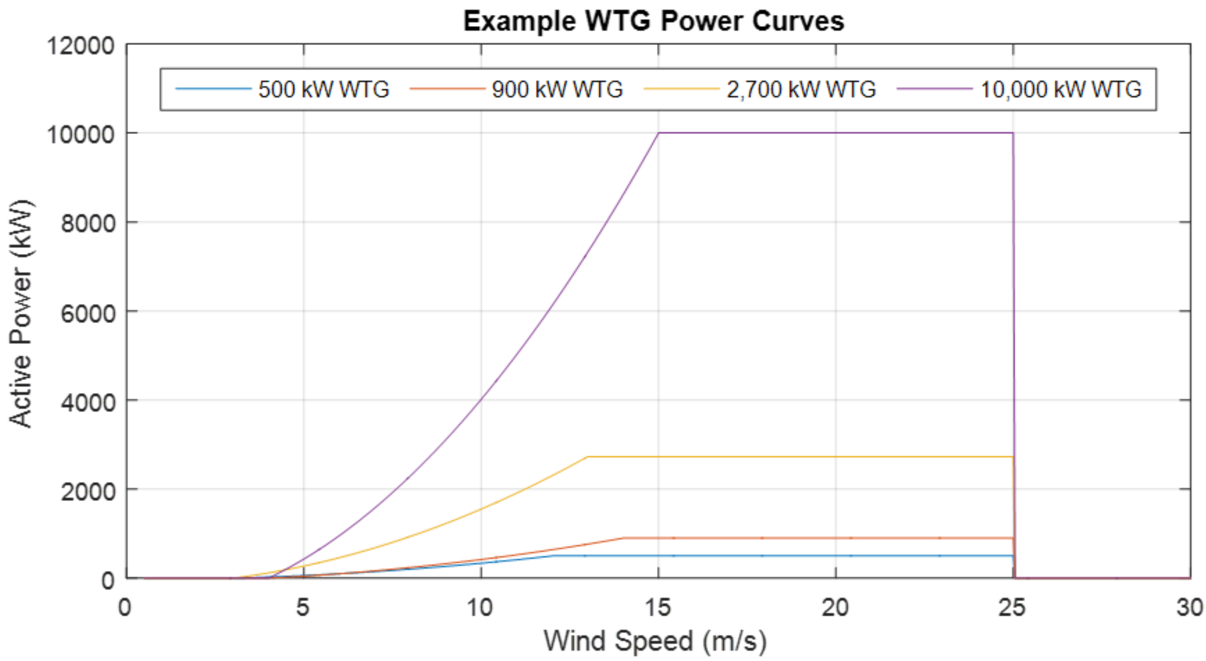

Figure 20 - Example of wind turbine generator power curves deployed in Orkney.

Since 2009, all wind generators (i.e. large-scale wind farms) have been subject to Active Network Management. Given Orkney's oversupply of energy to the grid and current grid constraints, further wind generation on the existing grid is considered non-viable.

ANM may be alleviated in 2028 when the 220 kV link is implemented. However, the local pinch points will not be addressed by this grid upgrade and details on further grid reinforcement has not yet been confirmed.

2.2.3.2 Solar Radiation Resource

Orkney, while renowned for its wind resources, has less potential for solar power due to its geographical and climatic conditions. The islands are situated at a high latitude in the north of Scotland, which results in shorter daylight hours, especially during the winter months. During the summer, while the days are longer, the solar irradiance (the power per unit area received from the sun in the form of electromagnetic radiation) is generally lower compared to more southerly locations. On average, solar irradiance values in Orkney are modest. Solar panels in Orkney generate less energy annually compared to regions in Southern England, reflecting the lower intensity and duration of sunlight.

Despite these limitations, solar power can still contribute to the local energy mix, particularly in the summer months when daylight extends up to 18 hours a day. However, the overall contribution of solar power to Orkney's energy system is significantly smaller than that of wind

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power, emphasising the islands' reliance on their abundant wind resources rather than solar.

Surface downward longwave and shortwave radiation fluxes are two critical components of the Earth's energy budget, each with distinct characteristics and sources:

- Surface downward shortwave radiation flux - This consists mainly of solar radiation, which includes visible light and ultraviolet radiation. It originates from the sun and reaches the Earth's surface either directly or after being scattered by molecules and particles in the atmosphere. Shortwave radiation can be absorbed by the surface, which heats it, or reflected back into the atmosphere and space. The ability of a surface to absorb or reflect shortwave radiation is determined by its albedo (reflectivity). For example, snow-covered surfaces have a high albedo and reflect most incoming shortwave radiation, while darker surfaces, like oceans or forests, absorb more.

  Figure 21 displays the average shortwave radiation flux for the island between 2018 and 2021, as per Copernicus ERA5 reanalysis (Hersbach, 2023).

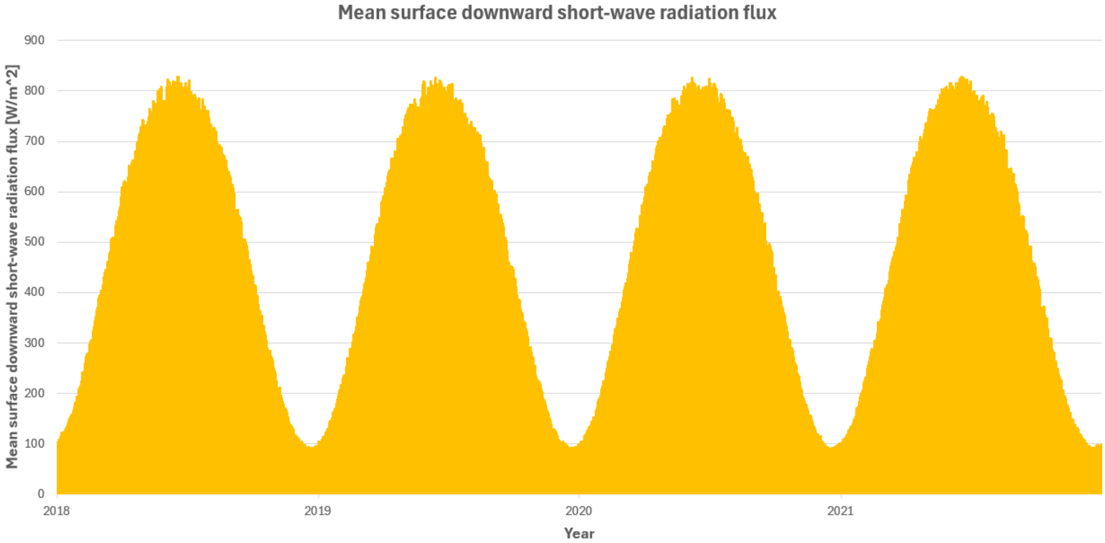

Figure 21 – Short-wave radiation flux from solar activity in Orkney.

- Surface downward longwave radiation flux - This type of radiation is primarily emitted by the atmosphere itself. It is also known as terrestrial or infrared radiation. The atmosphere emits longwave radiation due to the absorption of upward shortwave radiation from the sun and subsequent heating of the atmosphere, as well as the absorption and re-emission of surface-emitted longwave radiation. Longwave radiation is a form of heat energy emitted by the Earth's surface and the atmosphere. It is continuously absorbed and re-emitted in all directions, including back toward the Earth's surface, which helps to warm it. This phenomenon is a fundamental part of the greenhouse effect, where greenhouse gases trap and re-emit infrared radiation, warming the planet.

  Figure 22 displays the average longwave radiation flux recorded on the island between 2018 and 2021.

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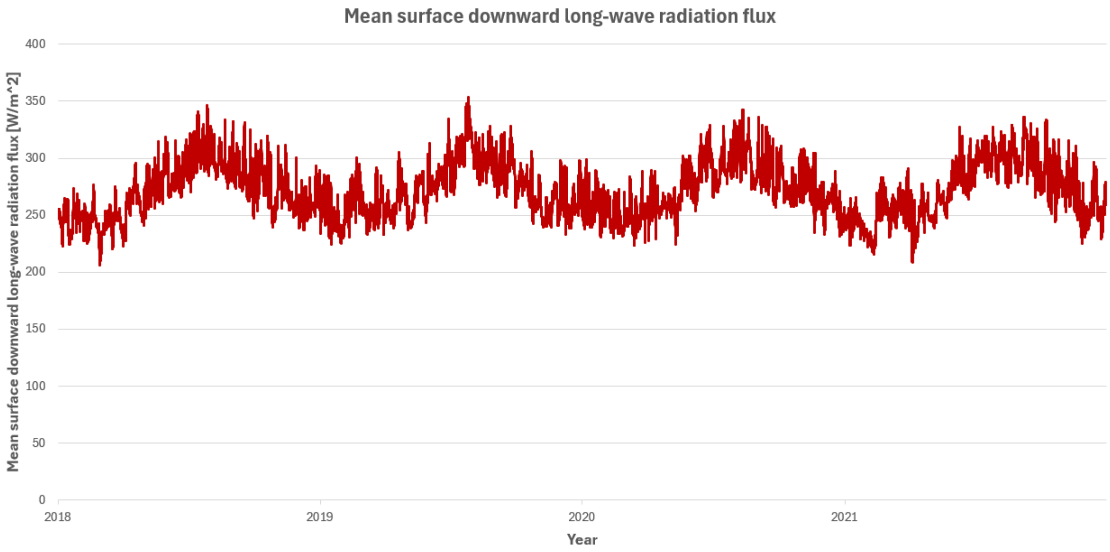

Figure 22 - Long-wave radiation flux from solar activities in Orkney.

The following meteorological data (irradiance and ambient temperature) gathered from Orkney has been collated. The minimum, average, and maximum temperatures, along with the average irradiance, are displayed in Figure 23.

2018

	Max Average Temperature (°C)	Average Temperature (°C)	Min Average Temperature (°C)	Average Irradiance G (W/m2)
Jan	8.3	5.7	2.3	24.6
Feb	7.4	4.8	-0.9	67.0
Mar	7.7	4.5	0.3	140.7
Apr	10.5	6.4	3.0	228.7
May	11.7	8.9	5.6	299.0
Jun	13.1	10.4	8.9	334.5
Jul	17.0	12.7	10.2	314.1
Aug	15.7	13.1	10.6	257.3
Sep	16.0	12.0	8.5	174.0
Oct	14.2	10.6	5.4	93.8
Nov	13.0	9.3	6.6	38.7
Dec	12.3	7.8	3.4	24.0

2019

	Max Average Temperature (°C)	Average Temperature (°C)	Min Average Temperature (°C)	Average Irradiance G (W/m2)
Jan	12.0	7.7	4.4	16.0
Feb	10.7	6.9	2.7	20.7
Mar	10.6	6.5	2.3	55.8
Apr	10.5	6.7	3.4	125.0
May	11.3	7.4	4.3	213.9
Jun	10.9	8.0	3.9	291.5
Jul	11.7	9.7	5.4	332.6
Aug	15.5	11.8	9.3	319.9
Sep	16.4	13.4	11.7	267.9
Oct	15.6	12.3	9.5	188.7
Nov	13.4	11.1	8.1	106.3
Dec	12.1	7.9	4.8	46.5

2021

	Max Average Temperature (°C)	Average Temperature (°C)	Min Average Temperature (°C)	Average Irradiance G (W/m2)
Jan	10.7	7.6	5.3	17.8
Feb	11.6	7.6	4.8	17.8
Mar	9.5	6.5	3.4	47.6
Apr	9.1	5.4	2.5	112.2
May	9.9	6.7	3.2	198.9
Jun	9.8	7.2	2.7	281.8
Jul	11.7	9.7	6.8	327.1
Aug	14.2	11.6	9.2	328.9
Sep	15.0	12.6	10.2	281.2
Oct	15.5	12.4	10.2	204.1
Nov	13.9	11.1	7.8	119.8
Dec	13.1	10.1	7.0	53.9

2020

	Max Average Temperature (°C)	Average Temperature (°C)	Min Average Temperature (°C)	Average Irradiance G (W/m2)
Jan	12.5	8.2	4.1	20.3
Feb	10.5	6.3	2.4	16.3
Mar	7.9	4.1	0.5	40.9
Apr	10.5	6.5	3.5	97.7
May	9.6	5.9	0.1	183.5
Jun	9.1	6.7	4.6	269.5
Jul	13.3	9.2	6.1	323.6
Aug	13.0	11.2	9.3	332.2
Sep	14.7	12.5	10.5	291.5
Oct	15.0	12.8	10.3	216.8
Nov	15.4	12.4	8.9	132.7
Dec	13.6	10.4	6.4	63.2

Figure 23- Meteorological data for Orkney (2018 - 2021).

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2.2.3.3 District Heating

The ISLANDER project aims to use part of the existing district heating in the community of Borkum and to take advantage of the seawater thermal capacity to improve efficiency. This will be considered as part of the optimised energy solution for the Orkney Islands within the replication process. In Orkney, thermal demand in the residential sector has been partially electrified by replacing fossil fuel consumption at boilers by electrical consumption in heat pumps.

The Borkum district heating plant will consist of three distinct circuits:

1. Seawater circuit.
2. Refrigerant circuit (within the heat pump).
3. Steel water circuit.

The Borkum plant operates by providing a flow of hot water that exchanges heat with the air to raise the ambient temperature. Traditionally, the water is heated in a boiler through the combustion of fuel. However, in the ISLANDER project's proposed system, the heat will be supplied partially by a heat pump. This heat pump will utilise seawater to transfer heat to the refrigerant. Seawater maintains a more stable temperature throughout the year and is warmer than alternative sources such as air.

The reference standard water temperature around Orkney is presented in Table 9.

Month	Sea Temperature (°C)	Sea Temperature (°F)
January	7	45
February	6	43
March	6	43
April	7	45
May	8	46
June	10	50
July	12	54
August	13	55
September	12	54
October	11	52
November	10	50
December	8	46

Table 9 - Reference water temperature in Orkney.

Housing stock in Orkney is typically quite old, and a retro-fit of district heating to the building stock may be challenging on economic grounds, as it would require replacement of existing heating systems, and a large amount of building work and disruption to implement the network. It could be considered for large new housing developments (on grounds of economies of scale). The opportunity for implementation of district heating may, therefore, be limited and location-dependent.

Orkney Islands Council have a Local Heat and Energy Efficiency Strategy (LHEES) which informs where they may attempt to implement district heating in future. The building density on Orkney has been found by them to be too low, in general, for an optimally efficient district heating solution. (Orkney Island Council, 2024) See Section 3.7.

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2.2.4 Storage Solutions

Orkney is at the forefront of renewable energy use and experimentation, making it an ideal testing ground for advanced storage solutions like lithium-ion batteries and hydrogen-based systems. These technologies play a crucial role in managing the intermittency of renewable sources such as wind and solar, and their increased deployment could significantly aid Orkney's ambitious decarbonisation goals.

Lithium-ion Batteries Storage

In Orkney, lithium-ion batteries are used widely to store excess energy generated by wind turbines and solar panels. Typically this is used domestically to reduce individual properties reliance on the grid. Connecting a battery to the grid is considered generation, which is then subject to ANM, and cannot be combined with other forms of generation (e.g. solar). This means that the use of small domestic batteries is essentially prohibited by the DNO.

Previously, a large lithium-ion battery has been demonstrated for grid smoothing purposes at Kirkwall power station (Scottish and Southern Energy Power Distribution, 2015).

Expanding the capacity of lithium-ion battery storage in Orkney could further enhance grid stability and allow for greater utilisation of locally generated renewable energy. By storing surplus renewable energy, Orkney could potentially increase its energy self-sufficiency and also export clean energy.

In order for this to be achieved using domestic battery installations, the ANM system would need to be reformed.

Supercapacitors (U-CAPS)

Supercapacitors, also known as ultracapacitors, store energy through electrostatic mechanisms, unlike batteries that do so through electrochemical reactions. This allows them to charge and discharge energy much faster than traditional batteries, though they typically hold less energy per unit volume. Supercapacitors can help with:

- Fast charging.
- Longevity and reliability.
- Complementing existing storage solutions.

Supercapacitors can support applications requiring rapid charging and discharging cycles, such as power smoothing for renewable energy sources (e.g., quickly absorbing excess power from wind turbines during high winds and releasing it during lulls). With their ability to undergo millions of charge-discharge cycles without significant degradation, supercapacitors are ideal for applications where longevity and reliability are crucial. In Orkney, supercapacitors could be integrated with existing battery systems to manage power quality and provide short-term energy storage, thereby enhancing the overall efficiency of the grid. This could be something the operators of larger wind farms could investigate, to establish cost-viability. It would, however mean losing position in the ANM stack, as the supercapacitor would be considered new generation by the DNO. This makes adoption unlikely, as position in the queue becomes the most important consideration under ANM conditions. Some analysis of the use of ultracapacitors beyond 2028, when the new 220kV export connection becomes operational, may be possible.

The DNO has only evaluated lithium-ion batteries for grid smoothing at present. There are no plans to utilise ultracapacitor technology. If this were to be attempted, the DNO would need to be convinced of its reliability and proving trials may be necessary. It is therefore likely that this technology will not be adopted in Orkney.

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Bidirectional Electric Vehicles (V2G)

Bidirectional EVs can not only draw power from the grid to charge their batteries but also supply power back to the grid. This technology turns EVs into mobile energy storage units that can contribute to grid stability.

By allowing EVs to discharge power into the grid during peak demand times or when there is a shortfall in renewable energy production, V2G can help balance the grid and reduce dependence on backup generators that often use fossil fuels.

As Orkney often generates more renewable electricity than it consumes, V2G technology can store excess renewable energy in EV batteries. This energy can later be returned to the grid or used locally, enhancing the overall utilisation of generated renewable energy.

Participation in V2G programs could offer financial incentives to EV owners, providing compensation for the electricity provided back to the grid, thus promoting the adoption of EVs.

ReFLEX Orkney established that, due to grid constraints, V2G is non-viable in Orkney at present, although control of multiple EVs to alleviate grid constraints was possible. An economic model for adoption based upon the ReFLEX Orkney system has not been developed to date. Consumer tariffs associated with the adoption of smart meters in the UK are beginning to explore the charging of EVs at times to suit the energy supplier (and hence grid/intraday market), with economic benefit for the consumer (Octopus Energy, n.d.). These tariffs are contingent upon a working UK smart meter, however, there remain significant problems with the UK smart metering programme, notably performance due to poor WAN, which can affect rural communities disproportionately.

Hydrogen-Based Storage

Orkney is pioneering in the use of hydrogen as an energy storage medium. Projects like the "Surf 'n' Turf" and "BIG HIT" have demonstrated hydrogen's viability, where excess wind and tidal energy is used to electrolyse water, producing hydrogen. This hydrogen is then used in fuel cells for electricity or heating, providing a flexible and clean energy solution.

The hydrogen economy in Orkney has room for significant expansion. By increasing hydrogen production, Orkney can manage larger volumes of intermittent renewable energy, providing a buffer that compensates for the variability in wind and solar power. Additionally, hydrogen can be used in sectors hard to decarbonise directly with electricity, such as transportation and heavy industry, or it can be exported to mainland Scotland and beyond.

Hydrogen is also a transitional stage to synthetic hydrocarbons, which hold the promise of drop-in replacement fuels, for aviation and marine/shipping industries. These industries are extremely difficult to decarbonise.

Export of hydrogen directly can be problematic on safety grounds. This is another reason why synthetic hydrocarbons may be preferable, as they would use existing supply chains and have equivalent safety arrangements.

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2.3 ICT Requirement Specification

The ICT specification produced by ISLANDER is valid and would permit a demand-response system to be established. However, it has conflicts with the UK System in the following areas:

- Metering and control of export vs import at a local grid level.
- Regulatory hurdles to market access.
- Conflicts with Orkney ANM.

It may lack sufficient depth of security to overcome these hurdles – UK grid-connected systems are typically denoted Critical National Infrastructure and are therefore subject to a higher level of security requirement than typical cloud-based IoT infrastructures. The cost of compliance and audit by UK NCSC is likely to be prohibitive for replication.

As a result, the ICT system can only be implemented for certain limited capabilities of the ISLANDER concept without regulatory reform:

- District Heating (in new housing developments).
- Potential use of supercapacitors/batteries at existing large scale generation sites.
- Potential control of large scale hydrogen generation and loads.
- Trial systems of EV demand-response, although it is unlikely these will be commercially viable longer term.

Demand response – the primary rationale for the ICT system – is not viable given the current state of the UK energy market and barriers to adoption. Implementation is not advised at the present time and national energy suppliers will need to be relied upon for implementation of this for domestic properties.

It is unlikely that EV demand-response will be delivered by an ISLANDER or other local solutions. While the ReFLEX Orkney project demonstrated grid smoothing using EVs, a business case for this has not been found to be workable yet.

2.3.1 ReFLEX Orkney Lessons Learned

ReFLEX Orkney aimed to provide cheaper renewable technologies for domestic properties.

- Any solar, wind, or battery installation was deemed "generation" by the local DNO.
- The timeline for assessment of each new "generator" exceeded the timeline of the project – the planning process was too onerous.
- Consumers were asked to sign up to a particular energy supplier for two years, which is the maximum permitted in the UK. This is not enough time to recover the cost of new renewable assets. As a result, funding to make the installations cost-neutral to the consumer was not possible. A better funding model would need to be developed, but any lending needs to be regulated by the Financial Conduct Authority (FCA) and this can only really be achieved by major financial institutions. It may be that government backed energy efficiency schemes would help resolve this problem.

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- It is possible to control EV charging stations en-masse using a system similar to that proposed by ISLANDER. There were still significant challenges, however:
  - Achieving technical integration with the chargers.
  - Providing a compelling reason for the consumer to allow the energy supplier to control the EV charging cycle. This has been broadly addressed by national energy suppliers at the present time.
  - Chargers were not always in the right place to alleviate grid constraints. For example, chargers were in major urban areas, whereas the main grid constraint point is in a rural area, so this curtailment avoidance strategy did not reduce grid power where it needed to. The distribution of load, spatially, must be understood better.
  - Logistics to island communities remains an ongoing concern.

Consumer regulations negatively impacted the ability of ReFLEX Orkney to provide a simplified way to adopt green technologies. Data protection law, warranty terms and conditions and Financial Conduct Authority regulations means that the project itself could not act as an intermediary in all aspects required (ReFLEX Orkney, 2023).

The amortization of assets such as solar panels within the defined contractual lifetime of an energy supplier contract, for example, was not possible. Typically energy assets return on investment is 10-15 years. This is not possible within the lifetime of an energy supplier contract, which is stated by the FCA to be 24 months or less. There is therefore a consumer debt risk which cannot be addressed within the current regulations if renewable energy assets are to be provided for zero upfront cost, as ReFLEX Orkney intended.

There were issues relating to ANM that also affected this, particularly the ability of the DNO to reach behind the meter and disable generation – which then meant that export could not be guaranteed, which affected return on investment. The DNO also has rules relating to use of assets for defined purposes, which makes it difficult for a deployed asset to be used for both local energy supply behind the meter and to also export to the grid. This affects batteries in particular.

Funding for the necessary assets is a critical barrier to adoption. Incentives are therefore still required in this area, unless regulations are amended, or alternative funding models established.

2.4 Open-source tool for the optimal design of island´s energy system

As part of ReFLEX Orkney, a tool called FlexiGrid was used. This used the same sort of architecture as the proposed Ayesa cloud system. As a result, we can say that the ISLANDER offering should be applicable to Orkney, however, it will be limited in scope, because some aspects will not be possible easily or will be irrelevant.

EMEC have the following observations on the Orkney energy system:

- EV Charging and V2G is best handled by existing national energy suppliers, who have essentially solved the scheduling problem. It will be a matter for those suppliers to interact appropriately with the local grid to alleviate curtailment for everyone. It is therefore recommended that there is an exploratory piece of work with an energy supplier to explore this. The most developed solution is currently run by Octopus Energy in the UK.
- The use of Ultracapacitors could be explored. However, the local DNO has already trialled the use of lithium-ion battery technology for grid smoothing. It is unlikely that the whole of Orkney's electricity needs could be met for long using either battery or ultracapacitor technology in the event of subsea cable failure, since 16.3 MW is quite a

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big ask. The 220 kV link and subsequent grid upgrade for the northern isles is intended to resolve the resilience problem.

- Use of district heating networks is already factored into local planning but is hampered by low density housing. Some localised implementations may be possible and these could easily be controlled to alleviate local grid constraints. These heat networks may or may not be seawater based or may be more economically achieved using ambient ground loops. The existing Local Heat and Energy Efficiency Strategy is the appropriate mechanism to achieve implementation here, since it is already under way, but would benefit from an optimised control solution, which could be linked to an ISLANDER style solution. See Section 3.7.

Integration of the Ayesa cloud system then becomes the main future task, but it may be simpler to rely on UK energy suppliers existing systems – and this should be explored in preference, since these already exist.

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3 WP2 REPLICATION – LARGE-SCALE DEPLOYMENT OF DER+HES SOLUTIONS

This section explores the use of Demand Response and Head End System Solutions.

3.1 Revision of the regulatory framework

This deliverable is intended to establish the guidelines for an effective deployment while fulfilling all the national and local regulations which apply.

Deliverable D2.1 "Set of Applicable Local and National Regulations" presents the critical regulatory aspects that need to be considered in order to implement the ISLANDER project following current legislation framework. This covers regulations in low and medium voltage installations, hydrogen installations, district heating, and the relevant energy market.

As regulations are periodically updated, it is imperative that this process is repeated if and when the ISLANDER project is replicated in the Orkney islands. Therefore this section only presents high level information on the Orkney regulatory context.

Following the structure of D2.1, as illustrated in Figure 24, the national regional and local regulations that apply will be elaborated upon in the context of replicating D2.1 in Orkney.

Figure 24 - Regulation Analysis Methodology, D2.1.

D2.1 also outlines the following points with which regulations should be examined:

- Name of the current regulation.
- Scope of the regulation: main objective and targeted audience.
- Name of the institution in charge of regulating mentioned topics.
- Name of the auditing agencies in charge of each system.
- Related policy frameworks involved in the regulated topic.
- Access to the regulation: Link or way to access.
- Analysis of regulation.

3.1.1 RES production of electricity and compensation

The DESNZ (Department of Energy Security & Net Zero) is responsible for setting policy for the electricity sector in the UK, while the market is regulated by the GEMA (Gas and Electricity Markets Authority), which acts through Ofgem (Office of Gas and Electricity Markets) (CMS, 2015). The UK electricity industry was privatised in the 1989 Electricity Act (now Electricity Act), which is the primary legislation for electricity in the UK. Following privatisation, the landscape of the UK electricity market changed to be in line with changes in European Union

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legislation, mostly concerning free competition, transparency, free access to the network and security of supply (CMS, 2015).

The Orkney grid is owned by Scottish and Southern Electricity Networks (SSEN) Distribution, previously known Scottish Hydro Electricity Distribution. As the DNO (Distribution Network Operator), SSEN Distribution operates and maintains the distribution network, including managing new generation and demand connections. It is the distribution network which supplies power from the transmission system to the users. There is currently no transmission infrastructure on the islands and the two 33 kV (~20 MW) subsea cables connecting Orkney to the UK mainland are within the distribution network. The planned cable installation upgrading the connection to 132 kV, will be a transmission link owned and operated by SSEN Transmission, which is part of the SSE plc along with SSEN Distribution (Orkney Renewable Energy Forum, 2014).

In 1998 Orkney had a second 33,000-volt (33 kV) circuit installed connecting it to the Great Britain (GB) grid at Thurso. Since then, generation has been accepted within Orkney on an N-1 basis, which gave capacity to accept generation not under SSENs direct control of 23 MW of which 10.5 MW was already taken up by the gas turbine power station at the oil terminal on Flotta, leaving 12.5 MW available capacity. This was quickly taken up by generation from local onshore windfarms and the European Marine Energy Centre's wave energy test site. Following wind farm upgrades, the generation capacity exceeded the distribution capacity, however, the 23 MW was set based on contingency and it would be possible to export 34 MW under most circumstances. It was decided that additional generation connections could be made on an interruptible basis. This new generation was called "non-firm", whilst the existing generation (within the 23 MW) is known as firm. (These definitions do not align with normal CB electricity supply definitions – under normal definitions all of these generation connections would be considered non-firm).

Between the firm and non-firm generation Orkney was able to export at times and in June 2008 it achieved its first net export month (where exports exceeded imports during the month).

In 2006, Orkney became a Registered Power Zone, an area of the National Grid network designated for the research, development and demonstration of innovative solutions to managing capacity. In 2009, the UK's first active network management (ANM) system was developed and installed in the islands by SSEN, a smart grid system for balancing electricity generation with demand. The ANM uses a stacking basis, with a last-on, first-off (LIFO) arrangement. Those who signed up many years ago are at the bottom of the stack and they will be asked to curtail last, and therefore stay generating the longest. Those who joined later get switched off first when the energy supply is larger than the demand at the time. The level of constraint for late entrants is high and new connections are unlikely to be financially viable (Orkney Renewable Energy Forum, 2014).

Since the installation of the ANM, further renewable generation has been connected as non-firm generation, totalling 21.4 MW, before the Orkney grid was closed to new generation connections in 2012 when SSEN announced a moratorium on connections until significant network investment was approved. The reality of this meant that in 2017, although Orkney generated 160.2 GWh from renewable energy, 77 GWh were exported to the grid, 24 GWh got curtailed, and the islands imported 4.7 GWh (SSEN, 2013) (Orkney Renewable Energy Forum, 2014).

The moratorium was lifted in 2020, following Ofgem granting the conditional Needs Case approval in September 2019 for a new 220 MW capacity electricity transmission link from Orkney to the mainland. This investment approval will significantly boost the export capacity when complete. Construction commenced in late 2024 and is now under way.

When an operator wishes to install a renewable generation technology larger than 3.68 kW per phase (16A per phase) and connect to the grid, there is a need to gain approval from the Distribution Network Operator (DNO). These are covered under the "G99", as illustrated in Figure 27. Smaller connections, such as small turbines and household solar panels that

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generate 3.86 kW or less per phase, require a “G83” connection agreement.

In 2012, SSEN announced a moratorium on connections to the ANM, banning all further connections. This applied to medium and larger energy generators, including “G59” connections of 50 kW or more, that normally had a different connection process to larger projects. Smaller “G83” connections, such as small turbines and household solar panels that generate 3.86 kW or below per phase, were still being accepted in Orkney.

Overall, the ban helped to avoid very high levels of curtailment for large wind generators. The moratorium is in place because SSEN cannot add more generation to the ANM scheme without impacting on the levels of curtailment in the RPZ. At the moment some generators are experiencing very high levels of curtailment – which is out of step with these generators’ expectations (Xero Energy, 2014).

The moratorium was lifted in 2021.

The bottom line is that all generation connected since the moratorium was lifted and before the subsea grid connection upgrade due in 2028, will be new non-firm Generation, subject to curtailment and potentially economically non-viable.

The 3 types of connection on the Orkney ANM system are defined as:

- Firm Generation (FG) – these connections are able to operate without constraint in the event of the loss of either one of the submarine cables to the mainland.
- Non-Firm Generation (NFG) - Additional generation connection capacity has been made available under “non-firm” arrangements. These arrangements allow operators with a Non-Firm Generation (NFG) connection to operate as long as both submarine circuits are operational. 21 MW of additional generation capacity has been realised by this method and has been allocated to contracted generators.
- New Non-Firm Generation (NNFG) – NNFG is actively managed based on the capacity available on the Orkney grid due to the variation in load and the diversity in output from existing firm and non-firm generators. This active management is part of SSE’s ANM that aimed at allowing operators to connect generation to the grid without substantial upgrades being necessary.

Figure 25 shows the Orkney generation connection portfolio as of 2013. This list is known to be out of date and some connections may have fallen through (Orkney Renewable Energy Forum, 2014).

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Total Generation (MW)	Name	Type	Size	
65.94	Braefoot (Shapinsay)	WIND	0.9	
	Burgar Hill Renewables	WIND	2.3	
	Cleat	WIND	0.08	
	Dale Spot	WIND	0.08	
	Eday Community (Eday)	WIND	0.9	
	Fea	WIND	0.08	
	Hammars Hill	WIND	4.5	
	Hatston	WIND	0.9	
	Holodykes	WIND	0.9	
	Kingarly (Rousay)	WIND	0.9	
	Ore Brae (Hoy)	WIND	0.9	
	Rothiesholm (Stronsay)	WIND	0.9	
	Spurness 2 (Sanday)	WIND	2.5	NEW NON-FIRM GENERATION TOTAL (MW) 18.54
	Thorkell	WIND	0.9	
	Tuquoy (Westray)	WIND	1.8	
47.4	Burgar Hill	WIND	6	*
	Burray (St Marys)	WIND	0.9	
	Gallow Hill (Westray)	WIND	1	NON-FIRM GENERATION TOTAL (MW) 21.4
	METC (Eday)	TIDAL	4	*
	Spurness (Sanday)	WIND	7.5	*
	West Hill (Flotta)	WIND	2	
26	Bu Farm (Stronsay)	WIND	2.7	
	Flotta	GAS	10.5	FIRM GENERATION TOTAL (MW) 26
	METC (Wave)	WAVE	7	*
	Siguird (Burgar Hill)	WIND	1.5	
	Thornfin (Burgar Hill)	WIND	4.3	
0				
	Diesel Back-up	*Diesel*	*15*	

* Intertrip Installed for loss of regulator at Scorradale and if export > 20MW

Scottish and Southern Energy
Power Distribution

Figure 25- Orkney Generation Portfolio as of 2013 (SSEN, 2013).

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Figure 26 shows the hierarchy of regulatory documents in the UK electricity system and illustrates how the UK grid regulatory and policy system works.

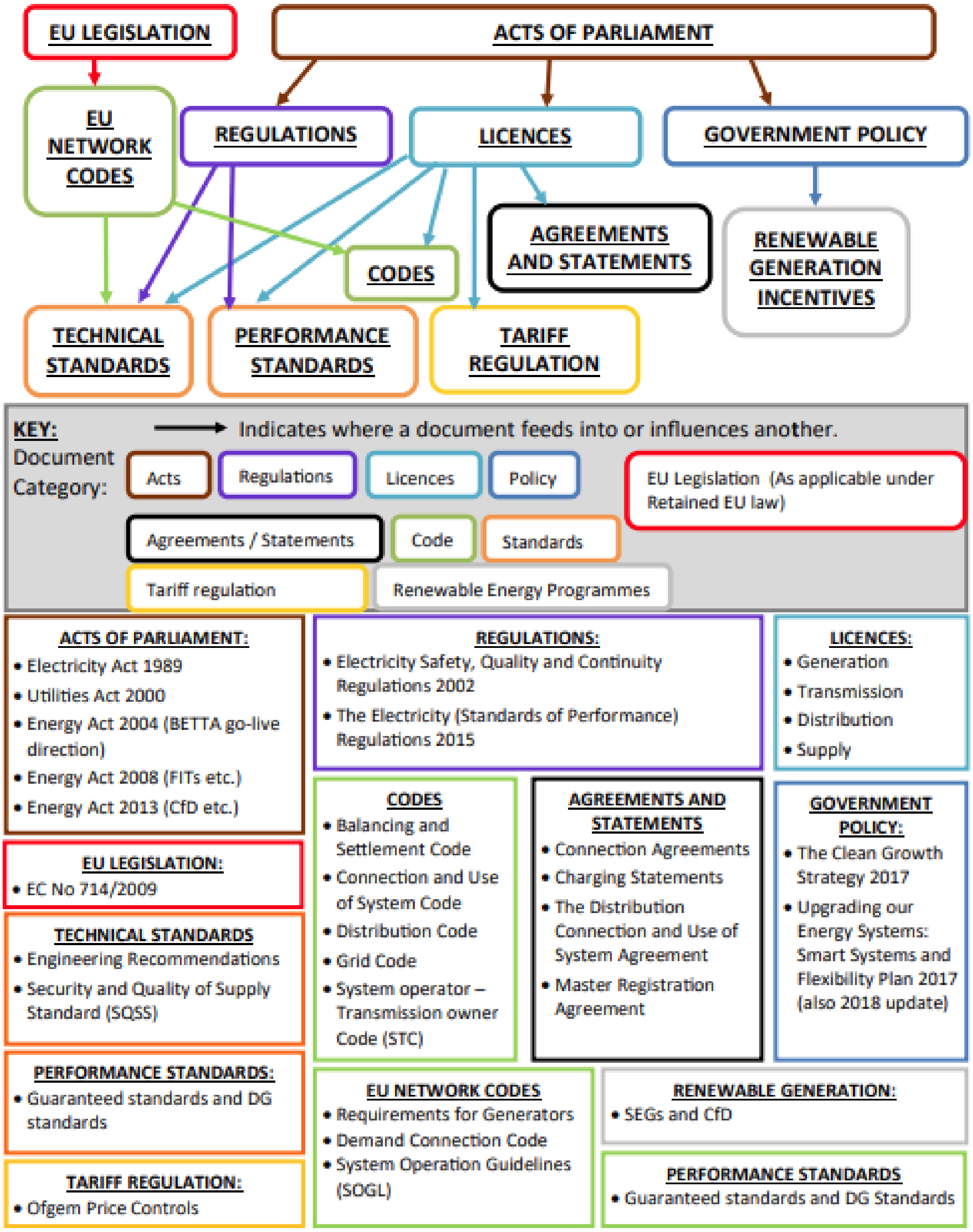

Figure 26 - A diagram illustrating the legislative and regulatory documents in the UK power sector (Energy Networks Association, 2024).

Ultimately, the UK power sector is governed by EU legislation and acts of parliament. Renewable Generation Incentives are driven by government policy.

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3.1.1.1 Relevant EU Legislation

Prior to the United Kingdom's exit from the European Union, GEMA also derived powers from EU legislation in respect of energy regulation which had direct effect in the United Kingdom (Millbank, 2023). The key piece of EU regulation is the EC No 714/2009, which covers rules for cross-border exchanges in electricity, regulates competition in the internal electricity market and establishes mechanisms to ensure sufficient electricity supply during peak periods and regulates emissions.

3.1.1.2 National Legislation

There are several acts which govern the energy sector in the UK: the Electricity Act 1989 (as amended by the Electricity and Gas (Internal Markets) Regulations 2017 (SI 2017/493)); the Utilities Act 2000; the Energy Acts of 2004, 2008, 2010, 2011; 2013 and 2016; and the Energy Prices Act 2022. These are summarised in Table 10.

There has also been a raft of new legislation in recent years introduced as a result of the United Kingdom's withdrawal from the European Union, including the Electricity Trading Regulations 2021, the Climate and Energy Regulations 2021 and the Electricity and Gas Regulations 2020.

Document	Purpose
Electricity Act 1989	UK Law that regulates the electricity industry, including its generation, transmission, distribution and supply. The act has 3 key requirements: 1. Licensing: establishing a licensing framework for the electricity industry 2. Distribution grid access: electricity distributors must connect to the distribution grid when requested by the owner or occupier premises 3. Equal access: transmission and distribution license holders must provide equal access to third parties (CMS, 2015) (Millbank, 2023)
Energy Acts 2008, 2010, 2011, 2013, 2016	• Energy Act 2008 - Covered topics such as gas importation and storage, electricity from renewable sources, decommissioning of energy installations, and management of waste from nuclear installations. FITs (Feed in Tariffs – see Section 3.1.1.4) were brought in through this act • Energy Act 2010 – Built on the UK Low Carbon Transition Plan 2009, which aimed to reduce carbon emissions by 18% by 2020 • Energy Act 2011 - Gave the Secretary of State for Energy and Climate Change the authority to modify gas and electricity licenses to introduce a cost recovery mechanism • Energy Act 2013 - Established a legislative framework for affordable, secure and low carbon energy. It also aimed to ensure the UK could meet its energy demands while decarbonizing as older power plants were taken offline. The CfD (Contract for Difference) initiative was brought in through this act – see section 3.1.1.4) • Energy Act 2016 - Included schedules on transferring functions to the OGA (Oil and Gas

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	Authority) and abandoning offshore installations
	• Energy Act 2023 – Creates a new legislative regime for energy production, security, and regulation. It includes provisions for:
	  o Licensing carbon dioxide transport and storage
	  o Commercial arrangements for carbon capture and storage
	  o Commercial arrangements for hydrogen production and transportation
	Other topics covered by the Energy Acts include:
	• The sale of the Government Pipe-line and Storage System (GPSS)
	• The decommissioning of energy installations and wells
	• Provisions relating to oil and gas
	• Works detrimental to navigation
	(CMS, 2015) (Millbank, 2023)

The Climate Change Act 2008	Sets out net zero and carbon budget targets (CMS, 2015) (Millbank, 2023)
The Climate and Energy (Revocation) (EU Exit) Regulations 2021 (SI 2021/519)	Revoking directly retained EU law relating to reporting obligations under the Paris agreement and Kyoto Protocol and greenhouse gas emissions reduction commitments and reporting obligations that no longer have practical implications in the United Kingdom (CMS, 2015) (Millbank, 2023)
The Electricity and Gas (Internal Markets and Network Codes) (Amendment etc) (EU Exit) Regulations 2020 (SI 2020/1006)	Reflecting the entry into the EU Clean Energy Package. This legislative activity is expected to continue as various retained EU laws are revoked and replacement legislation is enacted (CMS, 2015) (Millbank, 2023)
The Electricity Trading (Development of Technical Procedures) (Day-Ahead Market Timeframe) Regulations 2021 (SI 2021/651)	Implementing new cross-border electricity trading arrangements at the day-ahead market time frame. (CMS, 2015) (Millbank, 2023)

Table 10 – Overview of UK Acts of Parliament relevant to the UK power sector

In order to protect consumers, energy system participants who want to sell electricity to consumers are generally required to hold an electricity supply licence under the Electricity Act 1989.

After the 2024 UK General Election, the incoming Labour Government announced several energy related bills in the King's speech, including the GB Energy Bill (UK Parliament, 2024). These bills are yet to be published but would need to be reviewed when carrying out replication.

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All users of and connectors to the distribution system in Great Britain, including the DNOs, must conform to the Distribution Code. This is in addition to their individual Connection and Use of System Agreements as made between individual parties and Distribution Networks Operators (DNOs). DNOs are licensed by Ofgem, and one condition of their license is to enforce a core industry document called the Distribution Code. Figure 27 shows a diagram illustrating the type of connection process needed depending on the generation capacity.

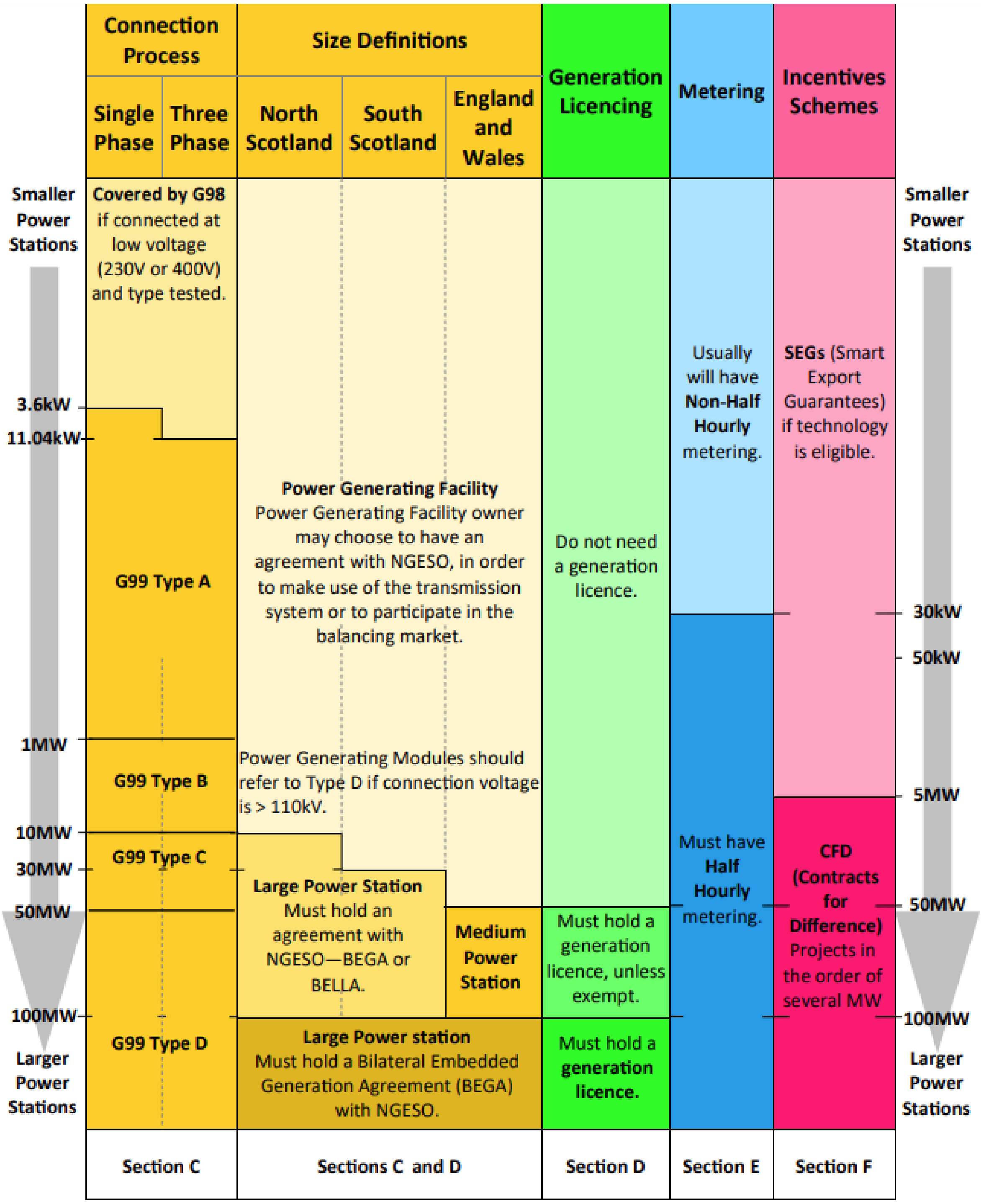

Figure 27 - Diagram illustrating some of the impacts that the capacity of generating units have on the connection process and license requirements of the developer (Energy Networks Association, 2024).

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Generation connections hold an Embedded Generation Connection Agreement with the DNO. The connection processes for distributed generation connection are outlined in the relevant guides, which are compliant with the relevant Engineering Recommendation:

- G98 - For installations of up to 3.68 kW (16 A) per phase or less than one property. This complies with the Engineering Recommendation G98 Standard
- G99 - above 3.68 kW (16 A) per phase

(Energy Networks Association, 2024) (Energy Saving Trust, 2014)

Supply of electricity is a separate function from distribution. Distribution and Supply licenses are mutually exclusive, so the SSEN monopoly on distribution has no influence on the ability to buy or sell power in an open and competitive market.

3.1.1.3 Regional/Local

The Local Heat and Energy Efficiency Strategy is currently under consultation. It identifies four priorities (letters correspond to those in the LHEES itself):

A. Making Orkney's homes energy efficient.
B. Removing energy efficiency as a driver of fuel poverty.
C. Improving carbon efficiency of non-domestic Council buildings.
D. Exploring heat networks for non-domestic Council buildings.

Planning permission is no longer required for an application to the ANM system (SSEN, 2024).

The following table has been reproduced from OIC's Local Heat and Energy Efficiency Strategy (Orkney Island Council, 2024).

Name	Description
Local Housing Strategy 2024-2029 (Orkney Islands Council, 2024)	A five-year development plan for housing across the Council. Prioritises increasing the number of homes in Orkney and providing quality, warm homes. Targets: 96% Council and 99% Orkney Housing Association (OHAL) compliant with the Social Housing Net Zero standard. £4 million in HEES: ABS funding by 2026. Maximise benefits of renewable energy developments to reduce fuel costs in Orkney. Lobby UK Government for lower fuel tariffs in Orkney.
Council Plan 2023 - 2028 (Orkney Islands Council, 2024)	A five-year plan that provides a clear direction for the Council to deliver ambitions for community and businesses. The Council aims to invest in homes and ensure social and private housing is more energy efficient. Targets: 90% of Council dwellings are energy efficiency by 2027/2028 (88% were in 2020/2021).
Local Development Plan (2017) (Orkney Islands Council, 2017)	The vision and spatial strategy for the development of land in Orkney over the next 10-20 years. The Council supports the use of low carbon technologies to heat and power homes and intends to identify potential heat networks.
Strategic Housing Investment Plan (2021-2026) (Scottish Government, 2024)	A five-year development plan for affordable housing provision (updated yearly in line with Scottish Government guidance). Targets: To deliver 297 completed

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	properties and further develop 38.
Orkney Sustainable Energy Strategy (2017-2025) (Orkney Islands Council, 2024)	The aims and actions to become a secure, sustainable, low carbon island economy. Targets: Less than 20% households in fuel poverty by 2030 and 0% by 2032, 50% decarbonised energy use by 2030, 300% renewably generated electricity, 600 sustainable energy jobs by 2030.
Orkney Hydrogen Strategy: The Hydrogen Islands (2019-2025) (Orkney Islands Council, 2024)	Identifies how hydrogen can best be applied to energy systems in Orkney. It is part of the Orkney Sustainable Energy Strategy.
Carbon Management Plan 2016-2026 (Orkney Islands Council, 2024)	Sets carbon targets for various sectors. The Council intends to improve energy efficiency by improving insulation and heating systems in existing buildings and developing a programme promoting energy efficiency among staff in Council buildings. Targets: Total CO_2 emissions in financial year 2025-2026 should be 42% of baseline year 2004-2005.
Indicative Regional Spatial Strategy (2021) (Orkney Islands Council, 2024)	The strategic priorities for development planning in Orkney until 2050. Prioritises future housing that addresses fuel poverty and climate change. It also establishes an Islands Centre for Net Zero Carbon which will aim to accelerate the islands' transition to net zero carbon.
Orkney Integration Joint Board: Joint Strategic Needs Assessment (20121) (Orkney Islands Council, 2024)	Describes partnership working between NHS Orkney and the Council for future health and wellbeing needs. Identifies fuel poverty as a significant health and wellbeing issue in Orkney.

Table 11 - Summary of relevant local policies reproduced from OIC's Local Heat and Energy Efficiency Strategy (Orkney Island Council, 2024)

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3.1.1.4 Renewable Energy Schemes

There are several national schemes provided by Ofgem:

- Feed in Tariffs (FIT) are designed to encourage uptake in renewable and low carbon electricity generation with homeowners and businesses. The scheme requires participating licenced electricity suppliers to make payments to generators on both generation and export from eligible installations. The FIT scheme closed to new applicants on 1 April 2019, with some exceptions. Provided eligibility criteria are met, it remains available for people who have installed, or are looking to install, solar photovoltaic, wind, micro combined heat and power, hydro or anaerobic digestion technology types up to a capacity of 5 MW, or 2 kW for micro combined heat and power.
- Contract for Difference are one of the key policy measures to incentivise new low carbon electricity generation. The scheme enables developers to secure large upfront costs for low carbon infrastructure and reducing the risk to investors by stabilising revenues. A Contract for Difference (CfD) stabilizes revenue for electricity generators by bridging the gap between a fixed strike price and the market price. If the market price is below the strike price, the CfD pays the generator the difference. Conversely, if the market price is higher, the generator pays back the surplus. This ensures predictable income for generators and protects consumers from excessive costs.
- The Renewables Obligation (RO) scheme is one of the main support mechanisms for large-scale renewable electricity projects in the United Kingdom. The scheme places an obligation on UK electricity suppliers to source an increasing proportion of the electricity they supply from renewable sources.
- The Smart Export Guarantee scheme launched on 1 January 2020 and is a government-backed initiative which requires some electricity suppliers to pay small-scale generators for low-carbon electricity which they export back to the National Grid (if certain criteria are met). Provided the installations are in Great Britain, up to a capacity of 5 MW, or up to 50 kW for micro-CHP, the following technology types could be eligible: solar photovoltaic (solar PV); wind; micro combined heat and power (micro-CHP); hydro; and anaerobic digestion.
- The Offtaker of Last Resort (OLR) scheme: the OLR is a government scheme that aims to promote the availability of power purchase agreements (PPAs). It is intended as a last resort to help renewable generators who cannot get a PPA through the usual commercial means.

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3.1.2 Energy market

An output from D2.1 of the ISLANDER project was general study of the energy markets in all the follower islands. The results of this study are reproduced below in Table 12.

First considerations		
Is the island interconnected to the mainland?	Yes, connected to the UK grid.	
Is there a monopoly on the island? (only one TSO/DSO that operates on the island?)	The DNO monopoly holder is Scottish Hydro Electric Power Distribution plc, trading under the umbrella name SSEN. The role of the DNO is to operate and maintain the distribution network, including managing new generation and demand connections. Generation connections will hold an Embedded Generation Connection Agreement with the DNO. In the North of Scotland and the Isles, stations with a capacity of 10 MW or above will also hold an agreement (Bilateral Embedded Licence Exemptible Large Power Station Agreement) with National Grid ESO. Supply of electricity is a separate function from distribution. Distribution and Supply licenses are mutually exclusive, so the SSEN monopoly on distribution has no influence on the ability to buy or sell power in an open and competitive market	
Types of energy market.		
Type	Description about how it works (minimum energy to include, organisation to sell the energy, price to sell, taxes, fines for not reaching compromised target, type of company/end-user who can access to this market….	Brief description about key points to consider when participating
Day Ahead	Via a power exchange, where generators can sell power to the exchange and consumers can buy power. Generators and consumers must provide or take their contracted volumes or face imbalance charges. Power is traded in half-hourly blocks. Typically used by large generators, large consumers and licensed suppliers to adjust their established profile (established via bilateral contracts, see below) to match day-ahead forecast generation or demand.	Requires full participation in the Balancing Mechanism and other codes. Exposure to imbalance risk, particularly for small generators or consumers. Small users would normally sell or purchase their power from a licensed supplier (bilateral agreement, see below) and the supplier would then use the power exchange as required to balance the aggregate of all their bilateral contracts.

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Intra day	Via power exchange, as above. Large generators/consumers can fine-tune their contracted position to match near-term forecast generation or demand. Trading can continue down to gate closure, 1 hour ahead of delivery.	UK power exchanges: https://www.epexspot.com/en/tradingproducts https://www.nordpoolgroup.com/
Ancillary services	There are several Ancillary services which can be contracted for, to assist balancing of generation and demand and to support system voltage and frequency. Some are mutually exclusive. All require plant to be suitably flexible and controllable. See appendix 1 for a summary.	The connection rules for generators (EREC G99) include some mandatory services for voltage and frequency support (e.g. fast current injection in response to an external transmission system fault and the ability to reduce power output in response to over-frequency).
Feed-in tariff	Closed to new entrants in March 2019. The Contract for Difference (CfD, see below) is now the main system of revenue support for low-carbon generation.	n/a
Bilateral contracts	Most electricity in the UK is traded via bilateral contracts between a generator and a customer. That customer may be a large electricity user or, more often, a licensed retail supplier. For island-size renewable generators, the bilateral contract is usually a Power Purchase Agreement (PPA) with a licensed supplier.	PPA is usually on a must-take basis, which obliges the counterparty to take all generation. The corollary is that the generator is obliged to offer all power to the PPA counterparty. A standard PPA may need to be customised if there is a need to use significant power on site (e.g. for hydrogen). The PPA counterparty carries the imbalance risk (which arises when actual generation does not match forecast generation). To reduce this, a standard PPA may require the generator to forecast output in half-hour blocks on timescales varying from month ahead

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		to hour ahead. Large demand customers may similarly be required to forecast demand. A worthwhile forecast is problematic for experimental systems, so the need for and usefulness of forecasts should be discussed when the PPA is negotiated. PPA price may be either fixed or variable. Variable rates are usually linked to a reputable power exchange hourly or half-hourly index price.
Contract for Difference	A system under which a generator is paid the difference between a "strike price", at which the contract is agreed, and a reference price, which for intermittent generators are linked to the day-ahead market price, based on hourly volumes. The generator also sells energy in the usual way and therefore receives a total price roughly equal to the strike price. A CfD has a 15-year term.	Contracts are bid for on a competitive basis, with rounds held annually (round 7 is expected to start in 2025). Not all technologies are supported in each round. Round 3 had a "remote island wind" category, to mitigate the additional costs and grid charges associated with island locations. The minimum plant capacity for this category was 5 MW. There are tough eligibility criteria (need to have secured a grid connection and to have relevant consents), a strict timetable for progress to completion, minimal scope to adjust project capacity after contract award and a very detailed bureaucracy for information exchange and other reporting. Invoicing for the difference price is daily.

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Energy market in island and in mainland: main differences		
Type of difference (economic, type of access, regulation….)	Definition	Advantage and/or disadvantage
Type of access	Orkney is connected to the UK mainland grid and is governed by the same codes and standards.	A common regulatory regime simplifies normal power purchase agreements, where off-the-shelf versions can be used. It could be argued the national regime is too heavy and inflexible to facilitate local, small-scale innovative projects.
Capacity	The Orkney distribution network has been at full capacity for a number of years and recent generator connections have had to accept constraints under an active network management scheme (ANM)	The level of constraint for late entrants is high and new connections are unlikely to be financially viable.
National applicable Regulation to access energy market		
Name of organisation	Name of the regulation	Key points covered in the regulation: such as minimum price, installation certification, minimum volume of energy to access the market, kind of end-user, kind of installations…
Organisation 1: National Grid ESO and Elexon.	Balancing and Settlement Code	Rules and governance for trading (including notification of trades in advance of delivery) and for settlement of imbalance. Administered by Elexon.
Organisation 2: National Grid ESO	Grid Code	Technical requirements for connecting to and using the transmission system. The transmission system does not yet extend to Orkney, although sites with generation capacity of 10 MW or more may be captured by some of the requirements. The Distribution Code (below) will be more relevant to most Orkney generators

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Organisation 3: Energy Networks Association	Distribution Code and Engineering Recommendation G99	Technical requirements for connecting to and using the distribution system. EREC G99 contains the detailed requirements for generators and (at least until the end of 2020) was harmonised with the European ENTSO(E) requirements.
Organisation 3: Ofgem	The regulator for the gas and electricity markets.	Has oversight of the electricity market
Obstacles to ease the energy production		
Type of obstacle (regulation/ social/ economical…)	Definition of obstacle	Is there a tentative proposal so solve this obstacle? Who should be involved to solve it?
Obstacle 1: Distribution network capacity	The existing Orkney distribution network is at capacity	Proposed new generation is being asked to subscribe towards a new transmission connection to the Scottish mainland. This will then provide a separate "generation" network of connections for larger projects but does not appear to provide reinforcement for the existing distribution network. It will therefore not alleviate existing constraints under the ANM and will not facilitate connection of small projects (e.g. individual wind turbines) to the distribution network. There are also significant issues around the public acceptability of a separate network of overhead lines, in addition to the existing distribution network. The transmission network owner (SSEN) responsible for the design is constrained by licence terms and by Ofgem to provide what is effectively the lowest cost solution.

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Obstacle 2:	Transmission use of system charges	These charges are locational and are higher for sites further from main centres of national demand. These high charges are a barrier to the larger projects referred to above. The charging methodology is set by Ofgem.
Other key factors to study in the energy market for islands		
Key factor	Definition	Actor involved (national laws, DSO, end-user …)
n/a	n/a	n/a
Access to market		
Which electricity markets / system services / capacity markets / etc is available in your island?	See previous response ("types of energy market.") for general electricity trading and ancillary services. The UK capacity market may also be available for generation and for demand side response, but probably only for parties with a firm rather than constrained grid connection (i.e. not viable for ANM connected generators because the ANM constraints may prevent the capacity being available when called on). The minimum capacity is 2 MW, although this may be aggregated. Capacity which receives revenue support (e.g. feed-in-tariff, renewables obligation or contract for difference) is generally excluded. Capacity market auctions take place for one year ahead and four years ahead.	
How can we reach these flexibility markets within the framework of the ISLANDER project? (Can everybody enter the market or is it restricted to some actors only?)	The supply of electricity normally requires a license, which carries quite onerous conditions and is extremely costly and time-consuming to obtain and subsequently to operate. Most schemes to sell branded power or for peer-to-peer trading between separate sites use the services of an existing licensed supplier to carry out the inner workings of the trade and to fulfil the licence obligations	
Which market/service would you consider for ISLANDER purposes? Can it be replicated to other islands?	i) Making use of the distributed battery storage in EVs. This has been demonstrated by the ReFLEX project, but further work is required to establish a viable commercial proposition. ii) Electrolysers may be able to offer demand side response (upward or downward) as an ancillary service (but note that effective participation in ancillary services requires high plant availability and so may not be suitable for prototype or demonstration plant). iii) Given that hydrogen production may not be on the same site as generation (e.g. windfarm in the outer isles feeding an electrolyser station on the mainland), the "sleeving" services of a supplier may be needed to convey electricity from the generator and to cover any necessary balancing. iv) A community energy scheme ("white labelling", via a supplier) is likely to be well received.	
Regarding all abovementioned questions: do you expect significant changes in the near future? (evolution of the	Proposed new generation is being asked to subscribe towards a new transmission connection to the Scottish mainland. This will then provide a separate "generation" network of connections for larger projects but does not appear to provide reinforcement for the existing	

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distribution, production, markets...)	distribution network. It will therefore not alleviate existing constraints under the ANM and will not facilitate connection of small projects (e.g. individual wind turbines) to the distribution network.
Any other relevant information regarding access to market?	The UK regulator, Ofgem, has an innovation scheme intended to assist development of new services and business models. This can provide detailed guidance to proposed start-ups and includes a "regulatory sandbox" which in certain circumstances allows time-limited derogation of specific rules, see https://www.ofgem.gov.uk/about-us/how-we-engage/innovation-link The ReFLEX project may have experience of this.
Off-grid assets	
Off-grid assets in the islands: regulatory aspects.	Not governed by the grid code or distribution code if there is no grid connection. Systems which are capable of running in "island" mode but also have a grid connection remain bound by the usual network codes. Safety aspects (including privately owned overhead lines, underground cables) are governed by the Electricity Supply Quality and Continuity Regs 2002 (ESQCR)
Off-grid Microgrid (not connected to the main grid) owned by energy communities (not connected to the network like a low populated village)	i) This would qualify as electricity supply and so probably still require some form of supply licence. Although the licence obligations in respect of the (national) grid would clearly not apply, the obligations in respect of customers would remain. There are examples in Fair Isle, Foula and Eigg. (See https://www.gov.scot/news/powering-fair-isle/) ii) The distributors' obligations which would normally fall to the DNO now fall to the community energy company. These are set out in the ESQC Regs and include the permitted range of voltage and frequency (which by agreement may be wider than normal grid limits), the obligation to maintain continuity of supply and the circumstances in which the distributor may interrupt supply or refuse connection
Any other relevant info regarding off grid assets	i) Maintaining continuity of supply without a grid connection will require considerable reserves of dependable backup power. Although this can be mitigated to an extent by maximising diversity of generation types, the reserve capacity is by nature likely to be under-utilised and therefore a cost burden. ii) Maintaining power quality (voltage stability, frequency stability, transient disturbances) as generation and demand changes is technically challenging without a grid connection, particularly for small systems. The importance of these issues depends on what loads the off-grid system is supplying, but in general terms if the supply needs to have a similar dependability and quality as a normal grid supply (e.g. for domestic customers) and a grid supply is available nearby, the grid is likely to be most cost-effective option.

Table 12 - Energy markets regulation analysis for Orkney, United Kingdom

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3.2 Deployment of hydrogen-based storage

Orkney is a pioneer in the development of green hydrogen (hydrogen produced using renewable energy). In 2015, EMEC began exploring hydrogen an as energy storage solution to support and future-proof tidal energy developments. An electrolyser was installed next to EMEC's tidal energy test site on the northern isle of Eday and then the world's first green hydrogen generated using tidal energy was produced in 2017. Since then, EMEC's hydrogen R&D has spanned production, storage, transport and end use, particularly in decarbonising maritime and aviation transport. These projects include providing local shore power with a fuel cell and heating the Kirkwall Airport terminal with a Hydrogen powered CHP (EMEC, 2024).

EMEC's experience in projects and operating hydrogen assets has enabled learning by doing and a better understanding of how hydrogen can be best applied in the energy system. Within hard-to-electrify sectors like industry, aviation and maritime, EMEC believe that hydrogen from electrolysis will play a significant role in supporting decarbonisation. However, rather than using hydrogen directly as a fuel, EMEC increasingly see its potential as a building block for synthetic fuels, which are liquid based and burn cleanly (EMEC, 2024).

EMEC has experienced many challenges and learned a great deal around the maintenance and operation of hydrogen assets, site development and hydrogen logistics and transportation. This first mover experience means we can feed this learning into other projects to advance the industry at large.

Key learning points include:

- Island energy systems are complex and diverse, involving interaction with multiple regulatory frameworks and boundaries at once.
- The hydrogen industry is developing and moving quickly, so the technology is not being given a chance to mature before the next big thing/order comes along. Such flexibility is not uncommon in developing industries, however policy makers should be aware this represents potential technical risks as the market settles on specific features and approaches.
- Nascent supply chain/early technology maturity level: manufacturers in the supply chain are still on early models, so there have been challenges with asset reliability, once deployed in the real world. The process of upgrading the hydrogen equipment has taken longer than expected due to supply chain challenges in the emerging hydrogen sector.
- Reliant on limited pool of suppliers: Asset failures and supply chain issues make project delivery very challenging. There is a small pool of suppliers and they are at an early developmental stage and under-resourced. Sectors is still developing so when suppliers get the work they are overstretched.
- Material selection of components and consideration of operational environment and infrastructure is important, (e.g. marinisation of assets operating in a coastal location). Need to consider: Paint systems to offshore codes, eradication of mild steel components and fittings, weatherproofing (i.e. no electronics just inside the door), hold backs to doors to allow access in wind.
- Carriage of hydrogen on roads and passenger ferries:

Transporting hydrogen from production point to end use across an island archipelago requires interaction with multiple regulatory frameworks and H&S standards e.g. marine and road standards both apply. It is important to work this through early with the regulators.

Mobile hydrogen storage trailers designed to be light weight to comply with weight restrictions on islands roads.

Present limits on ferries are driven by 'Dangerous Goods Exemptions'. This limits total passenger and crew numbers to under 25 people. In addition the evacuation routes on

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the vessel restrict how far forward the containers can be sited, and the prohibition on the placement of the containers under any superstructure (which was not designed against gas ingress) prevents some deck spaces being used. This is despite the fact that the decks are largely open and wind speeds make still air (and therefore gas intrusion) highly improbable.

- Logistics for maintenance and support: Establishing logistical supply chains for mobile hydrogen storage trailers is made more complex by the restrictions on hydrogen transport via ferry, (e.g. Gas codes used in shipping cargo prevent any part of the trailer being within a specific distance of any overhang). This restricts where the trailers can be placed on the ship. Furthermore the escape routes on the ship are old fashioned and pass onto the car deck so some areas of deck cannot store H2 on them. Crew training needed on handling H2 in emergency. Trailers must be specified with suitable props to allow the units to be carried unattached to a tractor unit, otherwise vessel operators may not agree to transport them, and this restricts the numbers of trailers on a sailing.
- Skills and training: EMEC have supported the development of an MCA approved, first of a kind, hydrogen training course for mariners, equipping them with the skills to work on board hydrogen powered vessels. This course was developed by the Maritime Studies Department of Orkney College and supported by Orkney Ferries and EMEC. EMEC's fuel cell at the Kirkwall Harbour has been a key part in the skills development within the Orkney hydrogen territory, both through operational training of the fuel cell and as training ground of handling hydrogen on ferries for mariners.
- Maintenance requirements: It is important to consider the skills and knowledge required to maintain assets beyond funded demonstrations.
- Regulation: Early engagement with regulators is key: because what we are trying to do in the existing framework is hard. Knowing the right questions to ask. Talk the same language of the regulators. When adopting new solutions, have the best possible understanding of the context you are doing it within.

Despite a widespread push to fast-track Hydrogen production as part of the drive to Net Zero, the sector is simply too nascent at present to allow for a successful and cost-effective replication in Orkney.

3.3 Deployment of fast-response peak shaving + intra-day storage (Ultra caps + Li-ion battery)

The deployment of fast-response shaving intra-day storage, in the form of a Battery Energy Storage System (BESS), could be an option to reduce curtailment in the ANM grid and even free up capacity on the network for new connections of low carbon generation.

This has been done before in Orkney where a 2 MW lithium-ion battery was installed at the Kirkwall power station in 2013 as part of a demonstration project (Power Grid International, 2013). This was the first large scale battery connected to the grid in the UK and batteries are now being used commercially across the UK as a result (SSE, 2013).

The planned upgrade to the subsea cable to mainland Britain, expected in 2028, will mean that Orkney's grid is more aligned with the UK grid, and this option will become less advantageous.

In the meantime, there could be value for the constrained sectors of the ANM, however, that value diminishes as grid grade draws near.

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3.4 Deployment of RESS household solutions

As stated in OIC's LHEES (Local Heat and Energy Efficiency Strategy) (Orkney Island Council, 2024), the council is focussed on improving energy efficiency for all homes. The council has adopted a 'fabric first' approach, focusing on improving home insulation as the first priority. Integrating household renewable energy generation is not part of this strategy.

Orkney's current housing stock uses a mix of fuel sources for heating, however up to 56% of domestic properties, which is the majority, are using electricity as their primary heating energy source, with the remainder mostly using oil (37%). Biomass and solid fuel make up a further 6% of properties, and the remaining 1% use LPG. There is no mains gas on Orkney. (Orkney Island Council, 2024).

Considering the high level of green electricity production in Orkney, creating more generation in the household will not necessarily lead to decarbonisation. There are key financial barriers to BESS being implemented at the household level, which are a result of investor uncertainty, arising due to storage being treated as 'generation' in the grid context.

This was a major barrier encountered by the ReFLEX Orkney project when, in 2019, the project attempted coordinating the systematic installations of batteries in houses across Orkney using an innovative financing model. Due to barriers in regulation and finance, the project was unable to find a way for the installations to achieve payback and ultimately no installations went ahead as part of the project. Despite this, it did stimulate community interest and now there are close to one hundred domestic battery installations in the county connected to existing solar and wind installations. These have all been self-funded by interested homeowners who could be called 'early adopters', which has meant that the barriers faced by the ReFLEX Orkney project were avoided and still remain.

The ReFLEX Orkney project aimed to offer funded PV and battery systems with no up-front costs. The key challenge facing the ReFLEX Orkney project initiative lies in overcoming the debt risk for what was relatively high up-front investments per property. The duration required for a return and the merchant revenues used to build the investment case added to this challenge and the complexity of the Orkney grid meant that there are many scenarios through which the system may stop generating revenue, making guaranteeing revenue difficult.

Furthermore, SSEN could not guarantee that curtailment would not occur for 'behind-the-meter' generation. The schemes would still be viable even if grid export was curtailed, but the regulatory steer from Ofgem was that the DNO could de-energise newly installed generators during periods of curtailment on the ANM system, meaning the DNO can effectively reach behind the meter. Furthermore, a supplier cannot lock a customer in for more than 24 months, which is significantly less time than the payback time, further increasing the investment uncertainty in the arrangement.

Metering solutions were identified by SMS (Smart Metering Solutions) that would limit the risk, and alternative financial solutions were identified as part of the ReFLEX project, however, they did not align with the project's aim of no up-front cost to the generator.

To enable this type of scheme to be opened up, the debt risk needs to be reduced. This could be done either through a change in regulation, or with an alternative financial incentive method.

In the context of replication, it is clear that RESS household solutions cannot be implemented until either these regulatory and financial barriers are removed, or alternative up front financing can be identified which has the flexibility and resilience to handle the payback uncertainty.

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3.5 Deployment of RESS building solutions

The "D2.5 RESS Building Solutions" deliverable had a specific focus on integrating PV and storage technologies in buildings. This objective faces much the same barriers as already discussed in Sections 3.1 and Section 3.4.

For the past 10-15 years, all new build projects in the county have employed renewable heating systems (Orkney Island Council, 2024). The Orkney Islands Council is also in the second year of a 10-year project with the Carbon Trust which has already seen 12 retrofits – including community centres, a care home and several schools -focusing on insultation, installing ground source heat pumps and replacing lighting with LED solutions. So far 486 tonnes of annual carbon emissions have been saved by doing this. The current LHEES mainly focuses on phasing out oil based in larger buildings, e.g. candidates schools, ORIC etc. and has multiple upgrades planned in council owned buildings, as well as commercial buildings. There is limited renewable energy solutions that are analogous to RESS planned to be integrated at present.

3.6 EV charging

D2.6 assessed potential EV charging infrastructure in Borkum, with a key focus of aiming to have the EV charging system integrated in the smart grid network and the smart IT platform. To some extent, the state of Orkney's EV sector and infrastructure is further ahead than Borkum's.

As previously mentioned in Section 2.2.1.1, Orkney has some of the highest EV uptake in the UK. At present there are over 600 electric vehicles in Orkney and approximately 190 charging stations (ReFLEX Orkney, 2024). The maximum charging power of the Orkney EV charging stations is between 7 and 51 kW, resulting in energy storage or 20-100 kWh. A significant proportion of the EV uptake in Orkney has been driven by ReFLEX Orkney, with just under two hundred vehicles coming to Orkney as a result of ReFLEX Orkney's leasing scheme (ReFLEX Orkney, 2024).

ReFLEX Orkney has also conducted a project amongst some of its members, demonstrating the alleviation of curtailment using vehicle-to-grid as storage. This was done over a three month trial with Orkney residents with Zappi smart chargers installed in their homes. The trial used a cloud-based software that communicates with smart local energy systems, monitoring and controlling a range of energy resources such as EV chargers. The trial involved using a weather forecasting tool together with wind turbine data to predict when curtailment events may occur. ReFLEX Orkney then controlled the EV charging of the 30 participants such that charging was at a minimum (1.4 kW) when no curtailment was expected, and then all the chargers were increased to their maximum rated output (~7 kW) when curtailment was predicted based on wind forecasting. Grid data received after the event was then analysed to see any impact (ReFLEX Orkney, 2024). The trial showed promise that some element of demand side management, commercially incentivised, would have an impact of reducing curtailment.

At present vehicle-to-grid is not a viable solution. This is ultimately due to the regulatory issues face by the REFLEX Orkney project and is discussed in Sections 3.1.1 and 2.2.4. Any energy storage, such as vehicle to grid, is considered generation. Any vehicle-to-grid system must therefore be connected to the ANM system and so is subject to interruption. As such, any revenue or commercial incentivising on any home smart energy solutions cannot be guaranteed. Ultimately, this problem will need to be solved at the national industry level and cannot be solved at the local level, particularly not in remote island communities. When the grid upgrade happens in Orkney in 2028, the drivers for demand-side management will likely disappear. As such, the ISLANDER solution isn't viable for replication in Orkney in this case.

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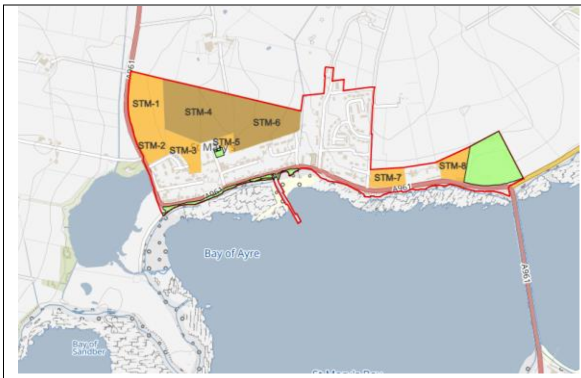
3.7 Seawater district heating network

It is unclear whether it is feasible to retrospectively implement a large scale seawater district heating network. Shetland has implemented a district heating network in Lerwick (Shetland Heat Energy and Power, 2024), which was initially connected to a biomass incinerator; first local properties were connected to the network and subsequently a ring main around the town was implemented. A similar approach might work for Orkney, but for maximum benefit, dense/urban areas could be targeted, to prevent heat losses over distance.

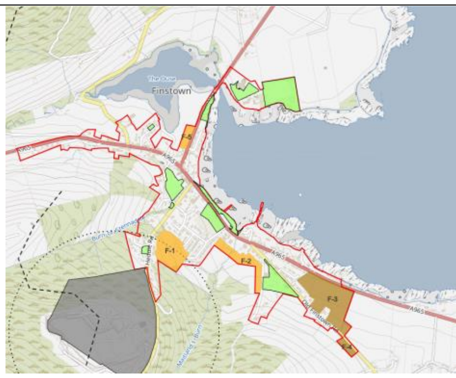
Orkney Islands Council (OIC) have a Local Development Plan and a Local Heat and Energy Efficiency Strategy (LHEES) (Orkney Islands Council, 2024).

The Local Development Plan is being updated between 2024 and 2027, replacing the current plan (Orkney Islands Council, 2017), which was adopted in 2017. From the current plan it is clear there is little planned development in rural areas or on outlying islands. The main areas where new development is expected are around Kirkwall, Finstown, Stromness, and St Mary's.

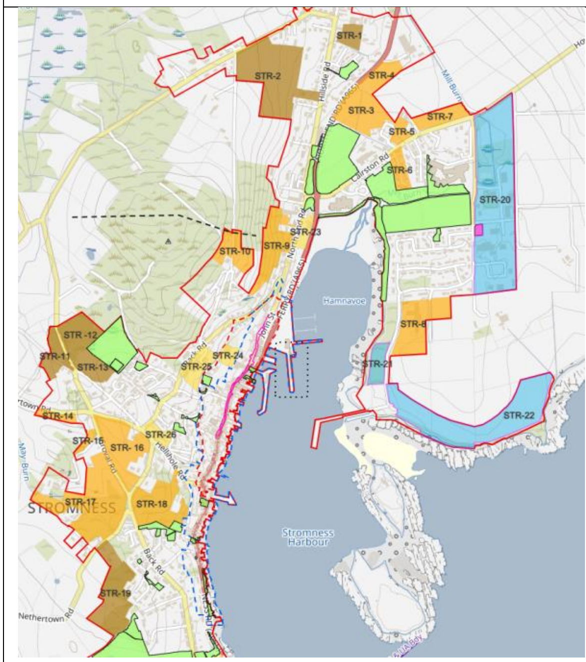
Some of these are in proximity to seawater, and plans could be adjusted to implement seawater district heating.



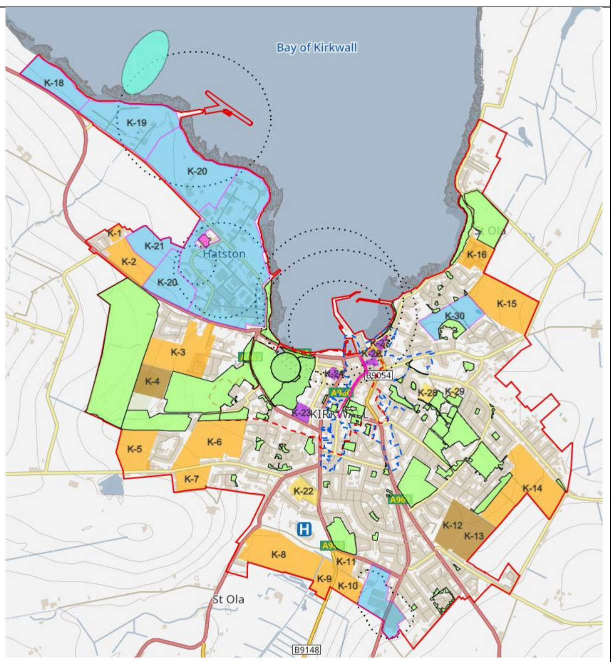
St Mary's – STM1-6 candidates



Finstown – F-3 candidate (35 dwellings)



Stromness – various candidates (est. 91 to 216 dwellings + shared buildings)



Kirkwall – K8-11, K15 candidates (245+80 dwellings)

Table 13: Energy markets regulation analysis for Orkney, United Kingdom

A manual review of proximity to seawater, and number of premises / housing density, suggest

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the following options for implementing seawater district heating in these four locations:

- Kirkwall seawater district heating for new build areas K15 appears feasible and could be retrofitted to K16 as well. If K8-K10 can be serviced from the Crantit canal, there is potential for a further 245 dwelling to be serviced this way. A full evaluation of Kirkwall has not been undertaken as there are a variety of options including industrial areas.
- Stromness has various options for district heating, but the highest density is a cluster of STR-7, STR-3, STR-4, STR-2, STR-6 comprising 91 dwellings. There are several existing buildings that would benefit from shared heating, such as the old primary school, and the ORIC, but these are typically a distance from a seawater source, uphill. A low density south development comprising of 45 dwellings within STR-14 through STR-19 might be possible but is thought to be insufficiently dense when considering heat losses. A higher density cluster of STR-11 through STR-13 may also work but is a large distance from seawater. In general Stromness looks problematic for shared heating networks and this only gets worse when the use of seawater is considered.
- Finstown has planned developments F-3 and F-4 which are adjacent to seawater and comprises 35 dwellings.
- St Mary's has a series of planned developments STM1 to STM-6 comprising 178 dwellings, which could be fed from the Loch of Ayre.

There is a general recognition at OIC that seawater district heating is something that should be pursued, however, it is competing with many other priorities, notably the need to reduce fuel poverty. OIC's Local Heat and Energy Efficiency Strategy has also already identified clusters of buildings and dwellings which could be upgraded for district heating. OIC have not been prescriptive about which technology may be used, whether it is non-seawater district heating, or distributed (multi-dwelling) ground source heat pump arrangements. The use of seawater has not factored highly in the current plans.

The Local Heat and Energy Efficiency strategy also outlines clusters of potential heat networks. Analysis of losses suggests that these would be limited in extent due to the low building density: as a result, multiple heat networks may well be required rather than a single one. Figure 28 identifies some of these clusters.

The use of seawater for the proposed heat networks should be considered by OIC. Beyond that, decarbonisation using seawater heat networks is a matter of planning by OIC themselves.

The implementation of the ISLANDER concept is therefore already being considered in some ways, but the use of seawater would seem to require promotion, since alternate technology choices are being considered such as shared ground source and ambient heating networks.

Local stakeholders, such as the Orkney Renewable Energy Forum (OREF) can continue to promote the use of seawater networks. Adoption of shared heat networks into new-build, high density properties would seem to be an opportunity to reduce running costs for low-income households. Control and optimisation technology for the heat source and pumps, as well as consumption between premises can be optimised via an ISLANDER-style control solution. A recommendation to OIC's Local Heat and Energy Efficiency Strategy should therefore be made to build in control and optimisation technology across these networks as they are being built.

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Figure 28 – Heat Network Opportunities in Orkney Islands (LHEES).

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3.8 Upgrading of street lighting network

Street lighting energy costs are ~£110,000 per annum for the whole of the Orkney Islands. Orkney Islands Council has already implemented a transition from incandescent bulbs to LED street lighting, which is 95% complete as of 2023 (OIC, 2022). The LED replacement lights have a power consumption of approximately 50% of the older alternative (Redway OEM Battery, 2024). A change in maintenance strategy is expected imminently, as this transition has been achieved during routine replacement only, however additional investment in this area is unlikely to be forthcoming by OIC.

As part of Orkney's Road Safety Strategy 2030 (OIC, 2024) from the OIC, it is stated that street lighting will be continuously reviewed and modified accordingly with the aim of achieving Orkney's road safety vision. (OIC, 2024) (OIC, 2024) Orkney, like many rural islands, benefits from a low crime rate and there is a high level of street lighting in main urban parts of the islands.

Orkney has a large variation in seasonal daylight hours, with night lasting approximately 17.5 hours in January versus only 5.17 hours in June. Street lighting is already adapted to different dawn and dusk times across the year. According to the model presented in Section 2.2.1.2, the energy consumption varies from 42 MWh per month at its highest in the winter to 12.5 MWh at its lowest in the Summer.

The benefit of integrating into a smart IT platform could be substantial as much of Orkney's street lighting illuminates areas that have long periods of no footfall. Using smart solutions to improve the energy and cost efficiency, as well as limiting light pollution, should be investigated as part of the replication effort of ISLANDER in Orkney.

3.9 Summary for replication actions

The local context changes rapidly in Orkney and a lot of change is expected in the coming years. When replicating the ISLANDER solutions, many of the aspects discussed in this section will need to be revisited to ensure that the local energy landscape is well understood at that time.

The following tasks make up the plan for replicating the adoption of ISLANDER DER + HER Solutions:

Regulation and Policy

- Conduct review of regulation and policy and assess the landscape of the local and national energy sector at time of regulation.
- Assess whether barriers have been removed.
- Assess whether solutions are still affective or needed post grid upgrade.

Deployment of hydrogen-based storage

Currently, the assessment is that this is unfeasible in Orkney at present and so will not be part of the replication plan. If there are clear indications from the regulatory task above, or anywhere else, that that is no longer the case, then this decision can be reassessed.

RESS for fast response peak shaving

- When replicating, the value of installing BESS in Orkney would need to be reassessed.
- Stakeholder mapping and engagement - In order to achieve this, both the local authority (Orkney Islands Council) and the DNO (SSEN) would need to be on board.

RESS for Household solutions

- Review at LHEES (Orkney Island Council, 2024) and assess what opportunities can be taken advantage of at time of replication – where can RESS be implemented, accelerated or barrier removed.

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- Engage OIC for collaboration – essential.
- Identify funding opportunities for RESS in buildings.
- Identify if barriers have been removed.

RESS for buildings

- Review at LHEES (Orkney Island Council, 2024) and assess what opportunities can be taken advantage of at time of replication – where can RESS be implemented, accelerated or barrier removed.
- Engage OIC for collaboration – essential.
- Identify funding opportunities for RESS in buildings.
- Identify if barriers have been removed.

EV Charging

- Regulatory review.
- Review of impacts of ANM.
- Funding opportunity identification.
- EV Tariff review.
- Map location for batter/storage assets to grid pinch points for control programming.

Seawater district heating network

- Align with local authority plans.

Street lighting

- Impact assessment of street lighting.
- Assessment of benefits case of smart IT platform integration to be built.

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4 WP3 REPLICATION – DIGITALISATION OF THE ENERGY SYSTEM

4.1 DNO plans for modernization

4.1.1 Upgrade of the distribution network and increase of its resilience

The Orkney grid is summarised in section 2.1.1. There have been a number of grid improvements trialled/proposed and some selected for implementation already.

- Grid smoothing: trialled at Kirkwall Power Station with a 1.2 MWh Li-ion battery between 2013-2015 by SSE (now decommissioned).
- New export interconnection to Scotland – 220 kV link (Dounreay/Caithness – Finstown/Orkney) – this has been agreed and consented, and construction is underway, due to complete in 2028.
- Upgrade of the northern isles ring to allow more generation power to be installed there. At present, this is unconfirmed: EMEC understand that this link is 33 kV and up to 50 MW. It is expected sometime after 2030 – but there are no official plans on this at present. It may not happen or be specified entirely differently.
- Resolution of local pinch points. EMEC have not had any indication of any plans to do this, but the main pinch point seems to be north of Finstown. It is possible this particular pinch point could be solved relatively cheaply by installation of taller support structures, as the issue is around cable heating under power, which causes the cable to expand, and therefore get closer to the ground, which would make it unsafe. It is entirely possible this work may not ever be done, if the northern ring is upgraded.

4.1.2 Network automation

Orkney's Active Network Management scheme is expected to endure. It is unclear at present, what effect the 220 kV link implementation will have on ANM.

- It is possible (and expected) that once the 220 kV link is installed in 2028, that the constraint on "no new generation" will be relaxed, if not lifted entirely. At that point, the limit of <3.6 kW solar/battery/wind installations would be raised.
- It is unclear if alternative restrictions will be imposed.
- It is unclear if the existing last-in-first-out ANM queue will be amended – although it is felt this is unlikely as ANM queue positions may be contractual between the DNO and the generating parties.
- The technical system for handling ANM messaging and implementing curtailment is therefore likely to endure for larger generators at least. It may, however, be invoked much less frequently.
- No use of grid smoothing technologies is expected given the previous trials and the large investment made in the 220 kV link, which is intended to provide the necessary export capacity and grid stability.

There are no plans to integrate EV-system control. The ReFLEX Orkney system is proven and could be adapted to interface with ANM in some way. Equally, a commercially run system (such as that provided by Octopus Energy) could be adopted by individual consumers – which would require management at the system/network level by the energy supplier concerned. It is considered that both of these should be explored.

Consideration of the location of the charging stations within the wider grid will be necessary,

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if these are to be used to alleviate grid constraints, ahead of local pinch points being resolved.

Use of hydrogen for grid purposes is not envisaged. Intelligent use of heat networks to offset grid constraint or utilise peak generation power is also not foreseen: the grid itself should be capable of servicing heat and industrial power needs after 2028, due to the large investment in the interconnect that has been made. However, there may still be individual industrial applications for hydrogen and community applications for heat networks. These would be handled as-needed, noting that OIC are evaluating heat networks for decarbonisation.

4.2 Integration to smart IT platform

It is necessary to review the systems in place prior to attempting replication. The systems below align with that in deliverables D3.2 - D3.6.

The structure of the Smart IT Platform itself (D3.1) should not need to change as it appears to be extensible.

Integration with the UK energy markets is unclear. Further work and evaluation is likely to be required in this area. It is also likely that de-scoping technologies would enable a simplified version of the system to be implemented, rather than the current full system not being implemented.

A revised architecture once integration options are fully understood is likely to be needed.

4.2.1 Grid smoothing (UltraCaps/grid-batteries)

There is not expected to be any grid-smoothing technologies such as ultracapacitors or grid-batteries on Orkney, although these technologies could be explored with larger local wind farms, any implementation would be classed as new generation and therefore fall to the end of the ANM queue. This makes it vanishingly unlikely that implementation would be cost effective for the wind farms either.

The 220 kV grid connection upgrade and subsequent local grid improvements are expected to remove the constraints on the network, so grid smoothing should not be required in future, or will at least remain the DNO’s problem.

It is expected that ANM will remain, after the 220 kV connection is operational.

4.2.2 Domestic PV/batteries & building systems

Domestic energy assets below 3.6 kW are permitted to export to the grid. However, if grid export is permitted, local offtake is not. Anything over 3.6 kW must be controlled by the Orkney ANM system.

A review of whether integration is possible is required, which entails a detailed technical discussion with SSEN, who run the ANM scheme. ANM currently acts as a protection mechanism – in that it restricts generation being provided to the grid. There is no concept of control to add extra generation (say from batteries) to the grid. This would be a change to the ANM and it would therefore need to be agreed with SSEN, as it would also break the convention of exporting assets only being allowed to connect to the grid ahead of any local offtake.

An investigation with Orkney Islands Council of opportunities to interface with council buildings control systems may be helpful.

4.2.3 Hydrogen systems

It is not expected that Hydrogen systems will be connected in Orkney. There are very few hydrogen installations that could be considered and these typically will also be connected to the ANM. Integration with the ANM is likely to be sufficient, however a conversation with known deployed hydrogen systems may be helpful to establish operational status and if there

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are any other beneficial control mechanisms that could be used. At time of writing these are:

- Combined Heat and Power (CHP) plant, Kirkwall airport.
- EMEC Electrolyser, Caldale, Eday.
- Kirkwall harbour.
- Big HiT hydrogen fuelling station, Hatston, Kirkwall.

4.2.4 District heating

Contact with Orkney Islands Council to establish a list of deployed district heating systems is required at point of replication, although there are no known district heating networks in place at time of writing, this is being evaluated under the Local Heat and Energy Efficiency Strategy. (Orkney Island Council, 2024)

- Exploration with OIC of control options for existing network assets.
- The status of seawater district heating should also be revisited, with OIC.
- Evaluation of any heat control technology for technical integration with the Ayesa platform.
- Implementation of any hardware system modifications for control by Ayesa.
- Implementation of Ayesa software modifications required.
- Test/proving.

4.2.5 EV charging stations

Investigation of existing energy supplier systems for demand-response control of EVs is required. At the time of writing, it is known Octopus Energy have an intelligent system for EV control and charging, which is integrated with the UK smart metering system. This is a desirable end state in the UK.

- A review of the state of the UK market for energy suppliers intelligent (or "smart") EV charging tariffs and control systems. Contact with the leading providers and evaluation of integration options should occur.
- Evaluation of the Myenergi based ReFLEX Orkney system for integration with the demand response system would be required.
- Evaluation of integration of public charging networks, in particular, Chargeplace Scotland.
- Selection of the most effective integration approach to maximise market penetration and offer a commercially competitive proposition. This is likely to be complex, as the system will need to operate via intermediaries for domestic charge points but may be simpler for public charging networks.
- Extension of the Ayesa demand control system to be able to control connected EV charging via the selected platform(s) for Orkney customers.
- Test/proving.

4.2.6 Street lighting system

Contact with Orkney Islands Council Roads to establish the current state of street lighting control. This is understood to be time-based depending on daylight hours and may not be particularly optimisable. Lighting is also understood to be of energy efficient LED types in most installations, and a plan is already in place for replacement of non-efficient lighting modules.

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5 WP4 REPLICATION – IMPROVED MULTI-SCALE FORECASTING

5.1 Individual energy demand forecast

As part of the ReFLEX Orkney Program, an energy audit of the island was carried out. The most up-to-date version of this report is from 2019, although a new version is expected for 2024 shortly.

It provides an overview of the energy consumption of Orkney and is neatly summed up by the Sankey diagram in Figure 3. When the energy audit report was written, the population of Orkney was 22,190; it stands at 21,338 according to the 2022 Scotland census. Demographic information is available from the Scotland census website (Scotland's Census, 2022).

Recently, SSEN have started to make LV feeder smart meter data available online (Scottish and Southern Electricity Networks, 2024). There is a high volume of data here which should be carefully sampled so as not to create a bottleneck with data processing.

5.1.1 Private (residential) users

The ISLANDER project obtained energy consumption figures on Borkum via questionnaires sent to a sample of households and with seasonal diary surveys; the replication report for Skopelos suggests 5-week diary surveys but acknowledged that this would require extra funding. Smart metering has been extensively rolled out to domestic users across much of the UK, including Orkney. Previously, this data had not been publicly available and had to be requested directly from users, but some of this data is now available online (Scottish and Southern Electricity Networks, 2024). Note: If requesting from users manually, not all smart meters record data with the required half-hour granularity (this must be set up by the user), so care must be taken in the sampling process. The SSEN data is obtained from the DCC in aggregate, but for privacy purposes can only provide data when five or more smart meters are actively reporting at a particular LV feeder location, so care must be taken when utilising this data, as it does not have full coverage of the smart meters deployed at present, and some extrapolation or inference may be required.

Smart Meter data could be a significant improvement on either of these methods with improvements in accuracy, ease of processing and because long-term consumption data could be made available quite quickly. Care should be taken to sample smart meter data carefully because of the high volume potentially available.

Note that the population of Orkney is roughly four times that of Borkum, so any data collection and analysis would entail significant additional processing time. The number of responders who filled out the questionnaires was 26 so, assuming the same sampling, around 100 returns would be needed for Orkney.

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5.1.1.1 Notes on demographics

The population of Orkney is ageing, with over half the population being over 45 and nearly a quarter being over 65, Figure 29.

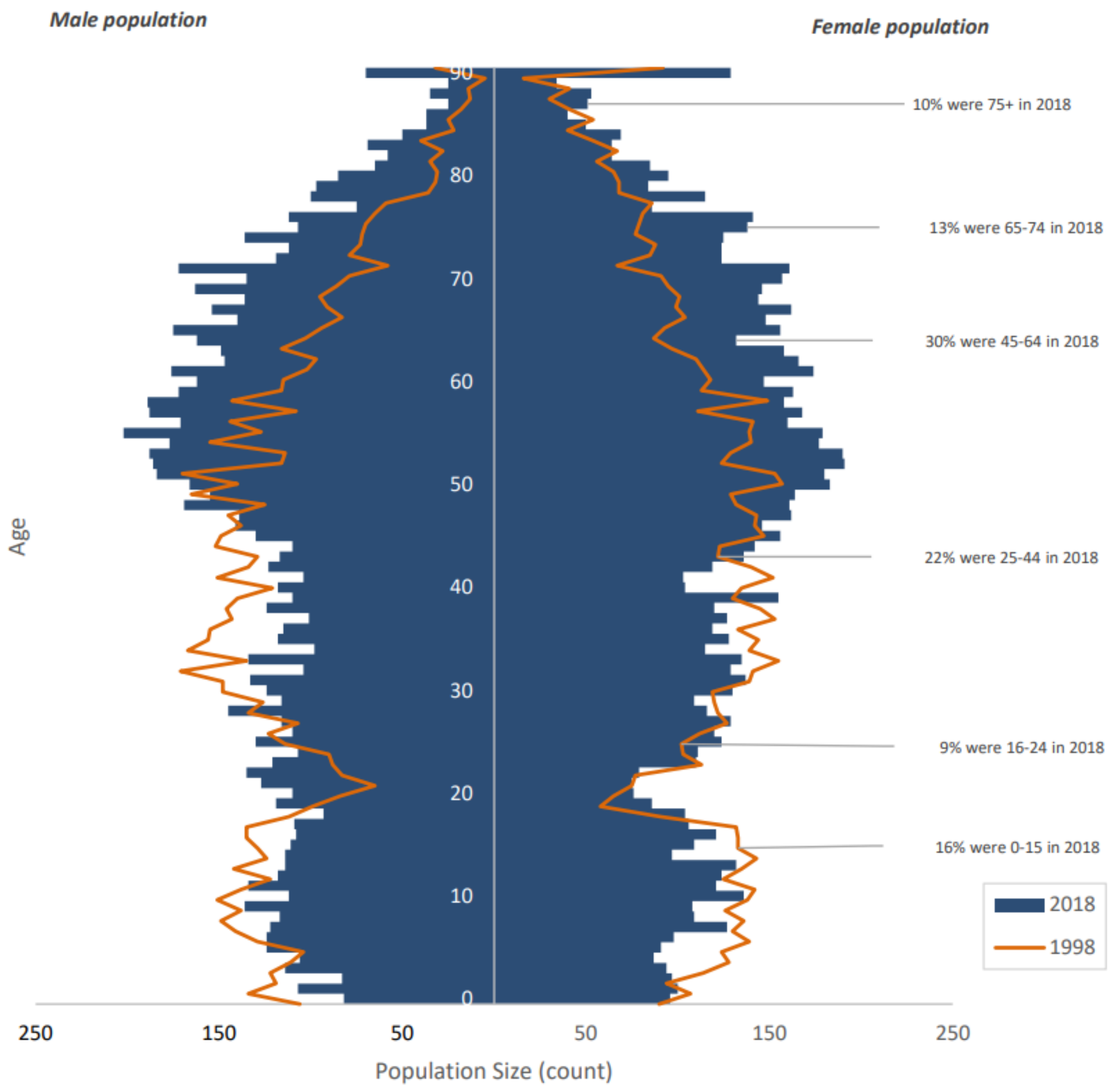

Figure 29: Population pyramid for Orkney - 1998 and 2018. Reproduced from (ReFLEX Orkney, 2019).

Around half the population of Orkney reside in the main town of Kirkwall, the rest are distributed amongst smaller towns, with a large number living rurally, mainly in detached houses. It is clear from Figure 30 how this differs from the rest of Scotland.

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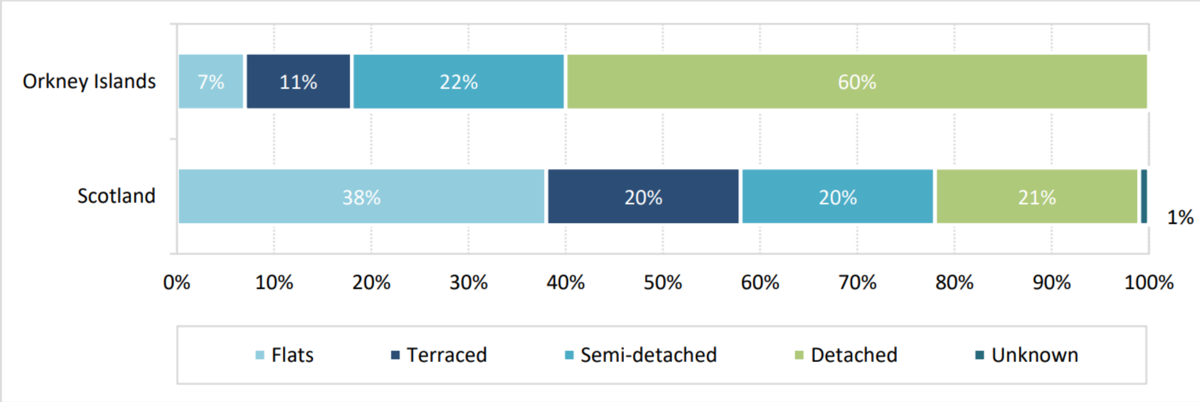

Figure 30: Proportion of population living in different types of dwelling- Orkney against Scotland.

This is an important consideration for sampling due to differences in dwelling type leading to different energy consumption.

5.1.2 Public users

The OIC is the largest employer on the island and is responsible for an array of municipal services. There are the usual services expected of a small town, including a hospital, libraries, emergency service stations, schools, sports facilities and historic buildings.

In the Sankey diagram, Figure 3, electricity consumption is only split between domestic and commercial users. This is likely to be due to how electricity is paid for in the UK: the tariffs are either business or domestic. Public buildings will pay for electricity at business rates. Some estimates will have to be made about how to parse total island business consumption into public and commercial. Lists of public buildings can be requested from OIC, as can energy bills. It may not be possible to neatly say whether a facility is public or commercial. Ferries and ports, for example, can be considered a collection of private, commercial and state-supported stakeholders.

Note: Ferries account for a significant proportion of energy usage, but this is mainly through consumption of marine gas oil to power vessels and addressing this is outside of the scope of ISLANDER.

5.1.3 Commercial users

Orkney has a strong industrial sector encompassing oil processing, marine operations, farming, and a diverse renewables industry. Hospitality is a major source of income with the population of Orkney swelling seasonally due to tourism: it is estimated that Orkney hosts 450,000 visitors per year. A large fraction of these arrive by cruise ship and do not all directly use the island hospitality.

A sector-by-sector breakdown of usage over a year is available in the ReFLEX report but more granular data would be ascertained by questionnaires, smart meter data and requesting of electricity bills. Orkney is much larger and more industrialised than Borkum and collecting the required data entails liaising with different businesses and business types.

As laid out in detail in Section 2.1.1, Orkney is connected to the main UK energy grid by a 33 kV sub-sea cable and has diverse local generating capabilities including wind turbines and solar PV arrays at all scales. Currently, the limit to building more local generation is the capacity of the electrical grid. Curtailment is already a problem for existing installations. Plans to bolster the grid capacity are already in place with initial ground works having commenced for a new 220 kV export-only cable.

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5.1.4 Solar PV

In ISLANDER D4.2, modelling and predicting the power production of a photovoltaic system required two types of inputs:

- The characteristics of the installation
    - Coordinates data.
    - Array angles of the panels and tracking data.
    - Soiling data.
    - Losses data.
- The weather previsions
    - Irradiance (Watts per square meter, W/m²).
    - Time of day.
    - Temperature.
    - Wind speed (as meters per second, m/s).

The UK Met Office operates a weather station in Kirkwall which collects irradiance data by pyranometer. Historic irradiance data is available from the MIDAS Open database. For the purposes of tool evaluation, re-analysis irradiance values from ECMWF have been used.

It may be possible to request generation data from owners of domestic PV systems which would allow for the cross-referencing of generation data with historic irradiance to provide an indication of how useful Kirkwall is as a proxy for the whole of Orkney.

Note that the grid does not regulate input from small-scale domestic generation, so the utility of forecasting is limited to management of other generation around instantaneous solar output. Not all domestic PV arrays feed into the grid: it is possible to divert the electricity into the house, but this may prevent electricity from being exported due to regulations at the DNO. As such, this practice is a matter of consumer preference at each installed location.

5.1.5 Wind energy

For Wind the following data is needed:

- The temperature.
- The pressure.
- The wind speed.

Large windfarms will gather meteorological data from met masts, lidars or nacelle mounted instrumentation. It is unclear whether this could be made available to third parties, requests would need to be made to individual wind farms; although NESO require signals from each connected wind farm for operational purposes and so could be a good source of aggregated data for Orkney. Any power data from existing turbines would likely need to be anonymised as was the case in the Orkney Energy Audit. Companies have historically been protective of this data.

Note on direction: Borkum is a small island that has a maximum elevation of 16 m above sea level, it is surrounded by open sea to the northwest; nearby islands and land masses have similar maximum elevation for at least 100 km in any direction.

It is worth considering that Orkney experiences strong winds from all directions and has complex topography varying from 0 to 200 m elevation across much of the island, reaching a maximum of 476 m. To the south is mainland Scotland, which has similar topography. There is open sea to the east, west and north. Direction data is not requested but given the complex

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topography and the varied surrounding landscapes, wind direction will affect the wind at any given site. Prior to installation, existing windfarms will have done site specific resource assessments to account for this.

5.2 Weather forecast

Figure 31 shows the Met office weather stations on and near Orkney . The UK Met Office provides forecast data for this region. Alternative sources also exist, such as ECMWF/Copernicus.

Figure 31: Met Office stations on and near Orkney. Blue: Automatic, Orange: Manual.

(Left to right: Strathy East, Loch of Hundland, Wick Airport and Lyth No 2, Kirkwall Airport, Fair Isle).

In addition to this, meteorological data will be recorded by windfarms. Meteorological mast/Lidar data from wind sites can be of very high quality due to the need to adhere to strict criteria for scenarios like power performance testing. Not all wind farms collect data like this and not all wind farms keep their systems maintained; there may be nacelle mounted anemometry or turbine power used as a proxy for wind speed. Some sites may be willing to sell data or provide it under the condition that it is anonymised; operators would need to be approached individually for this. A list of operational wind farms is presented in the Orkney Energy Audit (ReFLEX Orkney, 2019). Wind farms are typically required to provide a "signal" (meaning wind speed/direction observational data) to NESO. This data is then interpreted by NESO against metering and forecast data for the purposes of balancing the grid.

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5.3 Energy price forecast

Orkney is fully integrated into the UK electricity market. Consumers buy electricity from suppliers (utility companies) who negotiate bulk purchases of electricity units from generators.

The bulk (around 92%) of electricity in the UK is supplied by six companies: Octopus, British Gas/Centrica, E.ON, OVO, EDF and Scottish Power. There are numerous other smaller suppliers who make up the remaining 8% (uSwitch, 2024). Note also that there are some different suppliers for businesses, which are subject to different rates. SSEN (the regional network operator) also operates as a utility supplier for businesses.

Energy is traded on half-hourly markets. It has historically been tightly tied to the price of gas due to the high dependence of UK generation on CCGT. The wholesale price of renewables generation reflects this, but a limit is set with the strike price which has historically been set high to incentivise renewables and to increase competition of novel renewable technologies with established fossil fuel systems. In addition, when the weather allows, renewables generators are usually allowed to export as much as they can within the limits of demand and grid capacity.

Due to this national market and management, accurate demand forecasting for Orkney would have little immediate local benefit. One way to mitigate this, and to have control over electricity management, would be to create a local supplier where an Orkney utility company preferentially buys from local generating plant and preferentially supplies Orkney. This would need to have strong local 'buy-in' to be viable as it would be in direct competition with the existing suppliers both in selling to customers and bidding on generation. At the national level, weather models are already used for systems like ANM (Active Network Management) and DLR (Dynamic Line Rating).

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5.4 Summary

ISLANDER WP 4 is concerned with the acquisition of data for the use in models developed by the ISLANDER project. A summary of potential data sources is presented below.

Required data		Sources	Comments
Users	*Private*	SSEN online smart meter data Questionnaires	Smart meter data is incomplete and files are large. Local demographics needs to be considered in sampling.
	Public	SSEN online smart meter data Requesting bills from OIC	Smart meter data is incomplete and files are large. OIC manage most public facilities.
	Commercial	SSEN online smart meter data Example questionnaires from each industry.	ReFLEX Energy Audit for breakdown of energy usage. Care required in commercial /public distinction.
Renewable Generation	*PV*	Domestic PV requested from user Estimated from historical irradiance.	Requires contacting individual producers. Midas online data portal from Met Office. ECMWF may also be used.
	Wind	Request from individual Windfarms	Contact local wind farm owners, and/or SSEN.
Weather		Kirkwall Met station (+other local) Windfarm data	ECMWF / Met Office allows procurement of this data, sometimes for zero charge. Likely need to be anonymised and/or bought.
Energy Price		Energy price tied tightly to gas price	Weather, demand etc. have little effect on gas price. Geopolitical events currently driving this. Reform needed nationally. Energy pricing historical data can be obtained from Elexon.
EV usage / charging		Chargeplace Scotland Myenergi Zappi charger network DVLA (EV registrations/ownership addresses)	ReFLEX Orkney links to the Myenergi Zappi charger network for control and monitoring. This is a good starting point for Orkney, but Chargeplace Scotland run the main public charging network. Better understanding of EV registration address would be helpful, and the DVLA could be contacted for this.

Table 14: Summary of data sources for WP4 replication.

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6 WP5 REPLICATION – IMPLEMENTATION OF ISLANDER SMART IT PLATFORM

The AYESA platform consists of two major components:

- A planning tool
- An operational cloud-based system for demand-response

While work package 5 is concerned with the various services of the demand-response system, these are not expected to change significantly, although new integrations may be required depending on the final shape of the Orkney ISLANDER solution. The cloud-based system is therefore considered holistically and not broken down into individual subsystems or services.

6.1 Planning Tool - GridPilot

"Best estimate" parameters to apply to the AYESA planning tool, GridPilot, for Orkney are detailed below. This table is equivalent to the parameters listed in D1.5, but rationale for choosing each parameter is also given in the tables below.

6.1.1 GridPilot sections utilised

Not all GridPilot sections can be completed for Orkney. In particular:

- Lithium-ion battery installations are negligible due to the constraints placed in the grid by ANM. As a result there is no expected installation of standalone batteries. Equally there are no plans for standalone grid-smoothing technologies either.
- There is no planned hydrogen storage. Issues with hydrogen transportation and safety are signalling that synthetic hydrocarbons are a more likely mechanism for decarbonisation than hydrogen.
- Offshore wind turbines are not evaluated. This is because none exist in Orkney at present and planned offshore wind farms, such as the West of Orkney Windfarm, do not connect via the Orkney grid (West of Orkney Windfarm, 2023).

It is also worth mentioning that the remaining sections may not offer enough variance in their parameters to suit the variety of generators/consumers in Orkney. There is not a single WTG type, for example, and every prosumer will be different. Average values may not give good planning assumptions.

The remainder of the GridPilot sections are summarised in the sections that follow.

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6.1.2 PhotoVoltaic

Parameter	Suggested Value	Units	Comments / Rationale
Panel power peak	0.4	kWp	UK installations typically used 400 W panels
Guaranteed minimum performance	80	%	Default value
Panel lifespan	25	years	Expected lifetime.
Temperature gamma coefficient	-0.3	%/°C	Default value – to be checked.
Installed power	0	kWp	Assume nothing installed ahead of ISLANDER. We know this is false but serves as a worst case.
Installation cost	865	£/kWp	Typical £165 panel cost + £700 install cost per panel
Maintenance cost	0.025	£/kWh	Assumed £200 per property per year = 3.6 kW assuming 6 h usage/day = 50% efficiency. 6 h * 365 d = 2190 h, so 3.6 kW * 2190 h = 7884 kWh/yr ~£200/8000 = 0.025 £/kWh
Space required	1.87	m^2/kWp	Panels are 1.7 m x 1.1 m = 1.87 m^2
Installation space	131040	m^2	Assume as # households, 3.6 kW max on each -16.8 m^2 for 10000 households, reduced by 2200 for the number of prosumer households.

Table 15: Orkney GridPilot parameters – PV.

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6.1.3 Prosumers

Parameter	Suggested Value	Units	Comments / Rationale
Panel power peak	0.4	kWp	Same as PV
Guaranteed minimum performance	80	%	Same as PV
Panel lifespan	25	years	Same as PV
Temperature gamma coefficient	-0.3	%/°C	Same as PV
Initial installed power	0	kWp	Assume nothing installed ahead of ISLANDER. We know this is false, but serves as a worst case.
Maximum battery size	16	kWh	Typical size required for a UK household.
Panel installation cost	865	£/kWp	Same as PV
Battery installation cost	1450	£/kWh	Estimate – to be checked.
Panel maintenance cost	0.025	£/kWh	Same as PV
Space required	2.5	m^2/kWp	Added 0.63 m2 for battery rack to PV footprint.
Installation space	37400	m^2	Orkney has 2200 households (estimated 28.77%) with PV – could be considered prosumers at present. 17 m^2 x 2200

Table 16: Orkney GridPilot parameters – Prosumers.

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6.1.4 E-mobility

Parameter	Suggested Value	Units	Comments / Rationale
Vehicle's battery capacity	50	kWh	From ReFLEX Orkney
Slow charger max charging power	7	kW	Default charger model installed by ReFLEX Orkney is 7 kW Type II
Fast charger max charging power	22	kW	Standard fast charging rate.
Slow chargers installed	600		Every EV has a charger.
Fast chargers installed	15		Public chargers are fast chargers. 15 in Orkney.
Population density limit	1250	ppl/km^2	Population density of Kirkwall halved.
Population density of the island	23	ppl/km^2	Population density of the isles.

Table 17: Orkney GridPilot parameters – E-mobility.

Estimates for charger installation costs are not included at present. These need to be evaluated to align with expected growth in EVs.

The time of day each EV spends charging versus being driven has not been evaluated in the GridPilot data file. At present a single daily profile is used. The supporting data file can be supplied as required.

6.1.5 Existing interconnection

Parameter	Suggested Value	Units	Comments / Rationale
Cable capacity	40000	kW	40 MW connection to Scotland over 2 x 33 kV lines.
Network cost	52.5	£/kWh	1.5 M£/km install cost. Replace in 25 years. 1,500,000 * 35 km /25 years * 40,000 kW

Table 18: Orkney GridPilot parameters – Existing interconnection.

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6.1.6 New Interconnection

Parameter	Suggested Value	Units	Comments / Rationale
Cable capacity	220,000	kW	New 220 MW capacity export connection to Scotland
Network cost	14.45	£/kWh	1,500,000 * 53 km / 25 years * 220,000 kW
Installation cost	260,000,000	£	Install cost as per SSEN.

Table 19: Orkney GridPilot parameters – New interconnection.

6.1.7 Onshore wind turbines

Parameter	Suggested Value	Units	Comments / Rationale
Minimum wind speed	3.29	m/s	Average large Orkney wind farms cut in speed. Many different types, likely to be a poor estimate.
Optimal wind speed	15.80	m/s	Average of rated power speed.
Maximum wind speed	30.79	m/s	Average of cut out speed.
Turbine power	1378.57	kW	Average of large Orkney wind farms power.
Power already installed	44700	kW	Current installation power
Cost of installation	1500	£/kW	£1.5 M per MW
Maintenance cost	68	£/kWh	Maintenance cost for a 1 MW turbine.
Space required	50	m^2/kW	Estimate
Available space	0	m^2	No new wind farms planned.

Table 20: Orkney GridPilot parameters – PV.

6.1.8 Observations

The GridPilot tool, as it stands, does not have sufficient nuance to accurately model the Orkney islands energy system, due to various factors:

- Large variations in deployed asset configurations.
  There are many different configurations of household and industrial renewable technologies. One household might have just solar, another solar plus battery, another just a wind turbine. Many different types of wind farm configurations, WTG models used.
- Large variations in output power even within a technology type.
  The range of output power is also large and generation output power is regulated differently depending on magnitude.
- Unclear ways of accounting for existing deployed assets.
  The GridPilot tool isn't clear on how to account for existing assets vs. space for new assets.
- Resolution especially regarding EVs/population density appears simplistic.
  When specifying a population density limit for the islands in order to implement EV shared charging, it feels like Orkney would never achieve the limit. This is partly shown in reality: most EV owners in Orkney charge at home. But it doesn't cover situations

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where a householder travels to remote town or workplace and plugs in to charge there. Movement of individuals could be better accounted for: it was also hard to prescribe a % movement/parked/charging statistic in the data file that is required to run an optimisation.

The following amendments would make the GridPilot tool more relevant to larger islands:

- Ability to add multiple instances of each type of generation.

  For example, group all small PV installations into one type and allocate parameters to that; then set up a separate set of PV installation for shared buildings, like council offices, for example; then maybe another for solar parks. Each of these installation types could be quite different in terms of cost and there might be a lot of space for solar parks, but not much space of roof areas for existing buildings. An amendment like this would make the tool more usable, and more accurate.

  The same is true of prosumer, batteries and wind types.

- It might be helpful to be able to "compose" prosumer installation types.

  This would allow the various combinations and scales of prosumers to be modelled more accurately.

- Provide a mechanism by which the amount of each type can be seen to change from one to another.

  An island may start off with 3 public EV chargers. It might then have space for 10 more, but equally there might be space for 200 private EV chargers as well. Particular types of housing might have capability to support private EV charge sockets (e.g. detached houses), whereas other (e.g. apartments) may not. Some way of modelling these things might be helpful.

- Heat networks aren't really considered in the tool.

  This is unexpected as heat networks are an integral part of the ISLANDER proposal.

- Hydrogen might also be simplistic.

  Hybrid solutions, not just hydrogen storage, are possible – Orkney uses CHP devices, but hydrogen fuel cells might also be an option for offtake. Generation of hydrogen could be tied to other green electricity generation and desalination might also be required. None of this planning is in the tool.

- Better definition of the data file might be required.

  It was difficult to obtain some timestamped data for the data file (e.g. EV ownership, tourist volumes, energy consumption). Greater clarity on each parameter, definition, units, scale etc. would be helpful.

Work is clearly required to establish correct consumption and pricing data, as well as a better understanding of EV movements in Orkney and charging patterns. Data sources for this are listed in section 5.4.

6.2 Cloud based system for demand-response

There are two possible alternatives in Orkney to the AYESA cloud system for providing a demand-response capability.

- Existing FlexGrid tool used by ReFLEX Orkney.
- Existing energy supplier tools for EV Tariffs.

Both of these relate solely to the EV component of the ISLANDER solution, although an energy supplier system will in general have access to the intraday market by virtue of being a market participant.

There is also the complicating factor of the Orkney ANM system.

The FlexGrid system was limited in being able to control EVs, given that ANM was present. It

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is unlikely therefore that this could provide demand-response in a meaningful way, but whoever is to implement a future solution for Orkney would do well to also learn the lessons of the ReFLEX Orkney project. It is recommended time is set aside during implementation to achieve this.

Adoption of existing energy supplier tools is likely the most practical but means that any AYESA implementation would be decoupled from the behaviours of the EV part of the combined energy system, since these would essentially sit behind an energy supplier. The same would be true of any domestic generation like solar PV or batteries, due to the existence of both UK smart metering and ANM in Orkney.

An alternative collaborative approach is therefore needed.

It is recommended that the ISLANDER implementors talk to existing energy suppliers in the UK and the DNO to establish what can be achieved. It may be necessary to involve local energy consultancies to establish a viable plan, particularly in light of the UK regulatory system, around funding, asset amortization and risk.

Adoption of existing energy supplier systems for EV and domestic renewable energy control is likely to be necessary. This might also need to interface with central UK energy system parties such as the Data and Communications Company (DCC - arbiter of smart meter messaging), National Energy System Operator (NESO) and others.

Any integration with central systems needs to understand how those systems work and what opportunities exist for improvement, or workarounds. This is non-trivial in the case of the UK energy market and scope for limiting the implementation of ISLANDER to Orkney as a REC would probably be helpful. It's unclear if this could be achieved on such a scale in a community which is already integrated with the UK grid.

Assuming that is possible, then the AYESA system would need to be changed, potentially to:

- Integrate with the UK intraday market.
- Establish price forecasting for the UK market.
- Integrate with supplier-led EV management systems.
- Integrate with Orkney ANM.
- Integrate with UK smart metering and half-hourly metering systems.
- Weather forecasting inputs would most likely only require minor amendment.

The final shape of the integrations required cannot be established until the scope of what can be delivered is known.

It could be that after initial consideration, the benefits of the AYESA system are delivered by other parties independently.

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7 WP6 REPLICATION – DEMONSTRATION AND VALIDATION

Testing of the AYESA system is well defined in Work Package 6. Any changes to either the AYESA GridPilot or cloud-based demand response system would need to go through system/unit, acceptance and operational test phases.

Orkney has been designated a Registered Power Zone, defined as an area of the National Grid network designated for research, development, and demonstration of innovative solutions to managing capacity.

The ISLANDER solution clearly fits within this category.

The plan here would be for AYESA to open conversations with SSEN to establish a new RPZ phase for implementing demand-response, coupled to the ANM. There is a risk that such thinking is already under way and could be refused (which might happen in any case).

8 WP7 REPLICATION – RENEWABLE ENERGY COMMUNITIES

It is considered unlikely that the ISLANDER initiative would deliver the technical changes required by itself: third parties would do this on behalf of ISLANDER.

Citizen engagement then becomes a matter for those parties to bring the Orkney community with them.

This makes it very difficult to propose a citizen engagement model, as any ISLANDER concept implementation would first need to agree what can and what cannot be implemented. Then each sub-project would need to perform community engagement activities, potentially with any other sub-projects that may be running concurrently.

Regardless, engagement with local stakeholder groups such as OREF is essential.

Key stakeholders are:

- Orkney Islands Council (Roads, Planning).
- Orkney Housing Association Limited.
- Scottish and Souther Electricity Networks – Distribution.
- Orkney Renewable Energy Forum (OREF).
- Tackling Household Affordable Warmth (THAW) Orkney, WarmWorks Scotland (Orkney).
- ReFLEX Orkney.

Once a plan for what ISLANDER can deliver is agreed, whilst being aware that even coming up with such a plan will involve some engagement with a number of the parties above, then a communications exercise to solicit agreement for the plan and subsequent implementation should be undertaken.

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9 SUMMARY – REPLICATION ACTIVITIES AND PLAN

This section summarises tasks and recommendations from previous sections and provides an indication of how ISLANDER might be implemented in Orkney.

It is split into a series of sections:

1. Grid/utility planning and scoping.
2. Local planning and scoping.
3. Data and analysis.
4. Regulatory activities.
5. Tool updates.
6. Implementation.
7. Community Engagement.

These stages are broadly sequential. Planning activities may be carried out in parallel (stages 1-4), but subsequent activities should be considered sequential as it is generally inadvisable to make system changes until a concrete plan for implementation is determined.

It is expected that it would take 3-6 months to hold all necessary meetings and obtain sufficient data to work up a viable plan in steps 1-4.

The agreement of the plan would need to include all stakeholders and would take a further 3 or so months. However, tool updates and some implementation could take place in parallel.

The necessary tool updates, hardware integration, testing, and onboarding of the various assets to the scheme can take place. There would need to be a post implementation period of monitoring and upgrade as with any new system.

This can be broadly depicted as follows:

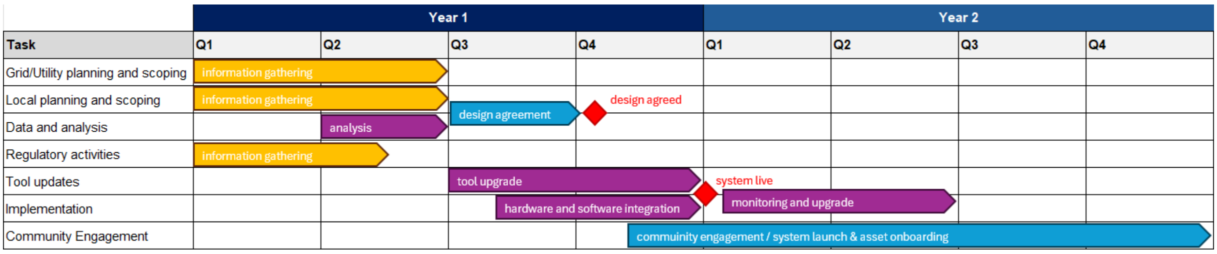

Figure 32: Example high level implementation Gantt.

9.1 Grid/utility planning and scoping

A number if industry stakeholders are required to be consulted with to establish a viable implementation plan.

9.1.1 SSEN-related information gathering

Assessment of the current status with SSEN will be required. There are several activities to address in parallel:

- Review progress of the 220 kV export link, northern ring upgrade and resolution of local pinch points with SSEN.
- Consider ANM, and review how it applies in Orkney.
- Review the thresholds for ANM as these may change when the 220 kV link is implemented.

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- Obtain technical details of the ANM system to determine if the cloud-based demand-response system can integrate with it.
- Discuss the rules around "generation" being required to connect to the grid only if it is exporting. Work with SSEN to establish mechanisms by which batteries can be used to export if also used to support local consumption.
- Obtain a forecast for new generation planned from SSEN.
- Understand if grid smoothing is planned or required and if ultracapacitors are an option at the grid level for SSEN.
- Understand how to receive live half-hourly data from SSEN.

Obtaining this information is likely to take a small number of months.

9.1.2 Wider energy industry information gathering

The mechanisms by which V2G can be achieved, smart metering data is accessed and how the energy markets may be accessed is unclear.

Energy suppliers should be contacted:

- EV tariffs should be evaluated to see if they support demand-response.
- Solar/battery export tariffs should be evaluated.

The Data and Communications Company (DCC) should be contacted for access to smart metering data. This area generally requires further investigation, as the barriers to access are known to be significant. It may be that access to smart metering data for domestic properties is not possible. Partly this is regulatory, and evaluation of the correct approach is also a regulatory activity.

A plan for integration with the following must be developed for demand-response to be a success:

- Smart metering data from domestic properties as well as half hourly data already available by SSEN.
- Intraday Energy Market

9.2 Local planning and scoping.

This section details Orkney-specific information gathering.

- The ReFLEX Energy Audit is being updated for 2024. This should be reviewed to update the information presented in this document.
    - In particular, the Sankey diagram, Figure 3, should be updated, which in turn will improve the understanding of the energy mix on the islands.
    - ReFLEX will also be able to provide information on how to integrate with their Myenergi EV charging solution.
    - If there are question on the ReFLEX lessons learned, these can also be addressed.
- Local energy efficiency and heating support organisations (e.g. THAW, Warmworks, as well as OIC Planning) should be contacted:
    - To understand the barriers to decarbonisation, particularly, of coal, kerosene, peat in the context of the aging housing stock.
    - They will also be able to assist in determining socioeconomic aspects to de-carbonisation to ensure a just transition.
- Orkney Islands Council are a key stakeholder.
    - Obtain more detailed/up to date data on:

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        - The 2024 Development Plan.
        - LHEES.
        - Socio-economic data held by OIC relating to housing stock and the wider population.
    - Consider heat networks:
        - Speak with OIC Planning to establish if there is scope for new-build adoption of heat networks.
        - Understand if there is scope for retrofit of heat networks.
        - Understand technical control options for any heat networks.
- Consult with local generators:
    - Consult local wind farms for their projected output and plans to develop their sites.
    - Consult EMEC for the state of tidal and wave development in Orkney. It is likely that tidal in particular will be outputting to the grid consistently in the coming years. EMEC may also be consulted for details of possible integration with the Kirkwall airport CHP, although other hydrogen assets may also be considered.
- Consult with Chargeplace Scotland to understand if their EV network can be integrated with. Obtain technical details from them if so.

9.3 Data and analysis

- Utilise the SSEN half-hourly data portal to extract metering data for Orkney. This is potentially quite a big task. If data is forthcoming from UK smart metering systems then also ingest this, to try and model consumption more accurately.
- Consult ReFLEX Orkney's Myenergi EV charger system for a better understanding of how EVs are used and their charge cycles.
- Map ReFLEX Orkney's database of battery, solar and EV charger assets to the local grid schematic to understand where these might be used to alleviate grid constraints. ReFLEX Orkney have likely already done this, so this data might be freely available.
- Consult ReFLEX Orkney for funding options regarding EVs and batteries.
- Work up a commercial proposition to avoid the issues encountered by ReFLEX Orkney.
- Consult local wind farms to establish if better generation data can be provided, or better wind resource data from instrumentation can be provided. Determine a better approximation for wind farm parameterization in GridPilot.

9.4 Regulatory activities

- Review electrical connection regulations such as G99, G83 and speak with SSEN Distribution to understand if there is scope for variability in these to better allow demand-response, particularly around batteries. It's worth noting that this might not be possible until after the installation of the 220 kV export link, and reinforcement of local grid pinch points.
- Assess the impact of the connection regulations for batteries on the economic viability of battery systems for domestic installation to better optimize energy use and be as cost-effective as possible.
- Assess incentives needed for the adoption of renewable technologies. Previously EV incentives and incentives around home energy efficiency have been seen to increase adoption speed. These may need to be revisited and consultation with both Scottish

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and wider UK government might need to take place. At the very least an assessment of the schemes currently in place so that a cost-effective ISLANDER proposition can be established will be necessary.

- Review the state-of-the-art in hydrogen storage and consider any new innovations which may help adoption. Hydrogen may need to be descoped from the ISLANDER proposition. There may be opportunity to integrate with existing deployments of hydrogen technology, for example, the combined heat and power (CHP) infrastructure at Kirkwall Airport.
- Consider how the energy industry handles assets from a funding and amortization point of view outside of the scope of a 2-year energy supplier contract for domestic installation. In particular, the metering industry uses Metering Asset Provider organisations to do this. This would be similar to how EV leases work. ReFLEX Orkney will have information to share in this area.
- Consider the evolution of "Local Energy Markets". It may be necessary to consult the government on this issue.
- Review regulations around access to the UK Intraday market to evaluate for integration with the Ayesa demand-response tool.

9.5 Tool updates

- Update GridPilot to cope with more than a single case of each type – this would allow more granular predictions to be made and make it easier to represent complex energy ecosystems in the tool.
- Consider upgrading GridPilot to take account of expected ANM behaviour.
- Integrate the demand-response tool with the Orkney ANM system, if found to be viable after discussions with SSEN. This particularly relates to domestic battery installations, which may need modifications to their connection to allow this.
- If battery system control is possible, it will need to be trialled.
- Consult OIC roads to establish whether street lighting can be controlled by the demand-response system. If so, gain agreement and modify the demand-response system to do this. It may be necessary to trial this in summer months, when street lighting is relied upon less.
- Update the demand-response system to take any differing inputs and integrate with any systems found to be viable.
    - Intraday market forecasts and data.
    - Met forecasts and generation signals.
    - Heat and hydrogen network control.

9.6 Implementation

This stage is really building out any modifications needed to the demand response system, the Grid Pilot tool and any hardware or software integrations needed.

It is also helpful to review the system for efficiencies, as the Borkum implementation may need to be adjusted to make sense for Orkney and may not therefore be designed with optimal efficiency in mind.

A test/acceptance cycle will be required. There may need to be staged deliveries for each subsequently modified feature.

Post-implementation, it is likely that there will need to be adjustments made. The system

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should be monitored, such that anomalous system behaviour can be rectified and improvements made.

9.7 Community Engagement

- Prepare and document the ISLANDER proposition for Orkney.
- Socialise this with OIC, OREF, ReFLEX and begin to publicise it in local channels.
- Prepare launch workshops/events to publicise and gain consensus agreement from stakeholders to the actual Orkney ISLANDER plan.
- Prepare and run education events for the public to be aware of ISLANDER, and update on progress. OREF is a good forum for this, but wider engagement will be necessary, via local media channels.

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DEVIATIONS

Delivery of the content is on time and to full satisfaction, without any deviations to actions planned.

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