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ICE REPORT 2.4.2
ICE GENERAL METHODOLOGY VALIDATION STUDY: MOLÈNE

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About ICE

Supported by Interreg VA France (Channel) England, the Intelligent Community Energy (ICE) project, aims to design and implement innovative smart energy solutions for isolated territories in the Channel area. Islands and isolated communities face unique energy challenges. Many islands have no connection to wider electricity distribution systems and are dependent on imported energy supplies, typically fossil fuel driven. The energy systems that isolated communities depend on tend to be less reliable, more expensive and have more associated greenhouse gas (GHG) emissions than mainland grid systems. In response to these problems, the ICE project considers the entire energy cycle, from production to consumption, and integrates new and established technologies in order to deliver innovative energy system solutions. These solutions will be implemented and tested at our unique pilot demonstration sites (Ushant island and the University of East Anglia’s campus), to demonstrate their feasibility and to develop a general model for isolated smart energy systems elsewhere. The ICE consortium brings together researcher and business support organisations in France and the UK, and engagement with SMEs will support project rollout and promote European cooperation.

Molène Island: ICE General Methodology Validation Study

1 Introduction: purpose of this report

This report contributes to fulfilment of task 2.4 of the ICE project. The objective is to provide empirical validation of the 'ICE General Methodology' developed in task 2.1 and presented in report T.2.1.2 through application to four alternative sites. The objective of the task is to consider how the application of the methodology may be affected by local considerations and to suggest refinements to the general methodology where required.

The sites are:

- Chausey, France (report 2.4.1)
- Molène, France (this report 2.4.2)
- Lundy, UK (report 2.4.3)
- Isles of Scilly, UK (report 2.4.4)

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2 Smart energy transition on Molène

2.1 Island overview

Molène (Breton: Molenez) is a small island about 15 km from the west coast of Brittany and one of the Ponant Islands of Northwest France. It is the largest island of the archipelago of some twenty islands. The island measures 1,200 metres by 800 (72 hectares), and its highest point is 26 metres above sea level (*Molène.fr*, 2022).

2.2 Reasons for selection

Among the many challenges facing sustainable energy transition on small islands, the small scale of demand, large seasonal variations in demand, lack of available energy resources and heritage restrictions on development are particularly prevalent. Three generators consume 394,000 litres of fuel oil annually to supply the 1,350 MWh energy consumption on Molène, mainly for the residential and service sectors' use.

2.3 Demographics and location

The permanent population had decreased around from 673 in 1921 to 216 in 2014. In summer, a number of temporary residents increase the population to around 750 for a period of 45 days (Association Les Iles du Ponant, 2010). However, the island receives large numbers of one or two day visitors around 20,000 per year to the island.

The number of people is equivalent to a population of 363 after calculating human pressure through Table 1. The human presence is very uneven since the island is inhabited by thousands on summer days but only hundreds on winter days. It is necessary to have a system to handle the full human pressure in case of the oversized and over expensive time on the island.

Table 1 - Demographic Information for Molène

Residents (365 days)	216	78,840 days
Summer Residents (45 days)	750	33,750 days
Visitors (1 day)	10,000 (ave 2 days)	20,000 days
Sum (man-days)		132,950 days
Average Residents number		363 per year

The location of Molène is shown in Figure 1. The archipelago is located halfway between Cape Saint-Mathieu on the Brittany mainland and Ouessant (EN: Ushant) in the Iroise sea and is acknowledged as one of the richest areas for marine life in the world. Molène is also the first marine natural park of France (*Parc naturel marin | Iroise*, no date). There are eight islands around Molène, which are Bannec, Balanec, Béniguet, l'île aux Crétiens, Litry, Morgol, Quéménès and Triélen. Molène is the largest island among them. The community and port is located to the east of the island and opposite two islands of Lédénez, Lédénez Vraz and Lédénez Vihan, which is connected to the main island at low springtides.

Figure 1 - The Island Location of Molène.

2.4 Economic status

The most significant trade on the island is fishing. Three small fishing boats are utilised to maintain their respective families, and one larger boat is shared between three fishers. They catch shellfish and local fish. Other islanders work as seamen on the boats between Brest, Ouessant and Molène, or in the French merchant navy.

The other important income of the island is tourism, such as kayaking in the Molène archipelago. There is one creperie, one restaurant and one grocery shop on the island. However, there is no electrician and fuel station on the island. The municipality will order the diesel coming every Saturday and then sell it on non-profit to local islanders. The gasoline is shipped by boat due to its flammability. The food prices are only about 5% higher compared to the mainland. Hence people do not need to go to the mainland and stock up. In addition, they can order online and get back via the ferry (Pleijel, 2015).

2.5 Policy and regulatory overview

The following subsections summarise relevant policy and regulatory information from ICE report T1.1.2 covering renewable energy routes to market, network and grid access and social and environmental permitting.

2.5.1 Routes to market: RE production, offtake and remuneration

Offtake and RES obligation

As discussed above, the French electricity system, including the development and integration of renewable energy technologies, has been traditionally dominated by the state-owned utilities company, Electricité de France (EDF), which either owned or acted as offtaker and counterparty[1] for nearly all independent renewable energy projects. Although EDF (or one of its local subsidiaries) remains the primary route to market for independent generators, recent changes make the participation of other offtakers more likely. However, if renewable energy projects are unable to access an offtake contract on commercial terms, EDF will act as an 'offtaker of last resort', letting a contract for a maximum of 80% of the electricity's market value.

Output remuneration policies

France has two primary output-based support mechanisms for renewable energy: a premium sliding tariff for large-scale installations, allocated through competitive auctions, and a feed-in tariff for smaller projects.

Premium tariff (Complément de rémunération par guichet ouvert)

The feed-in tariff has been the main instrument for encouraging deployment of renewables in France to-date. However, the European State aid guidelines updated in 2014 require a major re-design of RES support systems in France.

To this end, the Act on Energy Transition for Green Growth in August 2015 introduced a sliding premium tariff known as the "compensation mechanism" (mécanisme de compensation). This instrument consists in allocating a premium tariff to renewable electricity producers on top of the price they can achieve in the electricity market, in order to cover the costs of their installations and ensure their profitability (art. 104, loi n°2015-992). Depending on the technology, location and size of the installation, the premium tariff is allocated to generators either administratively through first-come, first-served 'open' contracts ("guichet ouvert") or through a competitive auction process. The value of the premium is calculated by the French electricity market regulator, CRE, using a formula that considers the market price, estimated administrative costs, the cost profile of a reference installation and revenues from capacity guarantees. The tariff payable reduces (towards the wholesale market price) once a threshold volume has been generated by the generating plant. Importantly for non-interconnected zones (ZNI), the move to the sliding premium system is only applicable in the continental French electricity system where there is a liquid wholesale electricity market to provide a reference price for these contracts. In electrically isolated territories, a fixed-price contract will remain the primary revenue support structure. Whether the tariff is sliding or fixed, the contract duration is twenty years.

Renewable energy auctions (tenders)

As discussed above, in common with all other EU members, France has moved to a tendering or auction system for allocating all renewable energy support with some exemptions such as installation with less than 1MW installed capacity or fewer than six wind turbines. For mature technologies such as onshore and offshore wind and solar PV, France has been experimenting with the use of tenders for some years. Recently, the government launched a series of tenders for a wide range of types of renewable energy support.

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[1] EDF contracted with generators to both fulfil the physical and financial elements of taking production

In 2016, the government launched a programme of six tenders to be held between 2016 and 2019 to support a total of 3GW of solar PV. At the time of writing, one of these tenders saw 79 projects take contracts for support at an average price of €62.5/MWh. In parallel, a similar series of six tenders was held between 2017 and 2020 for all onshore wind installations with more than six turbines, also letting contracts for up to 3GW[2]. A tender was also opened for 50MW of self-consumption installations, with qualified bidders required to consume at least half of the project's output on-site.

Solar plus storage tenders

In 2015, the French government launched a tender specifically targeting the country's island territories. The 'solar-plus-storage' tender for 25MW of ground mount and 25MW of rooftop solar PV systems over 100kW requires the integration of electrical energy storage. Altogether, the first round of this type of tender fulfilled its 50MW goal with 33 projects on islands in France and her overseas territories in June 2016 (Ministère de l'Environnement de l'Énergie et de la Mer, 2016). In March 2017, the government announced that it would launch a tender for tidal energy projects between 50 and 100MW in designated zones in Normandy and Brittany (OEE, 2017). France has run two successful tenders for offshore wind in 2012 and 2013 and plans to contract up to 3GW by 2023. In addition to the regular tenders, the scale of which may not lend themselves to projects on ZNIs, CRE also allows renewable capacity to be procured on an ad-hoc basis in these territories. These 'over the counter contracts' are "*subject to analysis by CRE and allow the determination of a level of support tailored to the specificities of the project and the territory it is connected to*" (CRE, 2016, p. 29).

Feed-in tariff (Tarif d´achat)

Although the sliding premium is being expanded progressively, a role remains in France for the 'classic' fixed-price feed-in tariff as a support instrument for smaller installations and less mature renewable energy technologies including solar PV plants of up to 100kW capacity.

Other financial elements

Homeowners in France can benefit from a tax credit (crédit d´impôt pour la transition énergétique, CITE) aimed at encouraging energy saving and renewable energy production. The tax credit can be claimed for 30% of qualified works up to a limit of €8,000. There are also value added tax (VAT) concessions for building renovation work that improves energy performance (IEA, 2016).

2.5.2 Network access and grid connection

Renewable energy installations in France must meet the same obligations as any other form of generation when connecting to electricity networks and while they are not given priority, neither can they be discriminated against. Plant owners seeking electricity export to the public distribution system apply directly to transmission system owner, Réseau de Transport d'Electricité (RTE), or the local distribution company, almost invariably Enedis.

Agreements must be held for access to the grid (*Contrat d'accès au réseau public*), connection to the grid (*Contrat de raccordement*) and use of grid connection equipment (*Contrat d'exploitation des ouvrages de raccordement*) (Boekhoudt and Behrendt, 2015). Recent changes introduce strict deadlines for connection. From the point at which a signed contract is accepted, connections of more than 3kVA must be made available within 18 months. As before, smaller connections must be prepared in two months or less.

2.5.3 Social and environmental permits, licences and land-use planning

Formerly complex, onerous and seen as a drag on development, the planning permits required to build renewable energy projects in France have recently been significantly simplified. Until 2017, many permits were required and gaining permission to build a 12MW wind farm took an average of 7-8 years (Lazerges, Gölz and Sauzay, 2016). A single environmental permit issued by the

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[2] http://www.cre.fr/documents/appels-d-offres

departmental prefect, and covering all requirements was introduced in June 2017. The key elements of the new system are:

- Special authorization for national nature reserves and nature reserves that are Government-listed in Corsica;
- Special authorization for registered sites or those pending registration;
- Exemption from measures protecting wild fauna and flora;
- Non-opposition procedure for Natura 2000 sites;
- Authorisation to operate an electricity production installation;
- Approval of private electricity structures using public land;
- Land clearance authorisation; and
- For onshore wind turbines, various authorisations under defence national heritage

(Fornacciari and Verrier, 2017; Martor and Harada, 2017)

Electricity generating plants in France are required to obtain an electricity generation license. Smaller renewable energy generation stations are exempt, however. The exemption threshold was raised in 2017 from 12MW for solar and 30MW for wind farms to 50MW for both, as well as for ocean renewables.

2.6 Key data on energy production and use

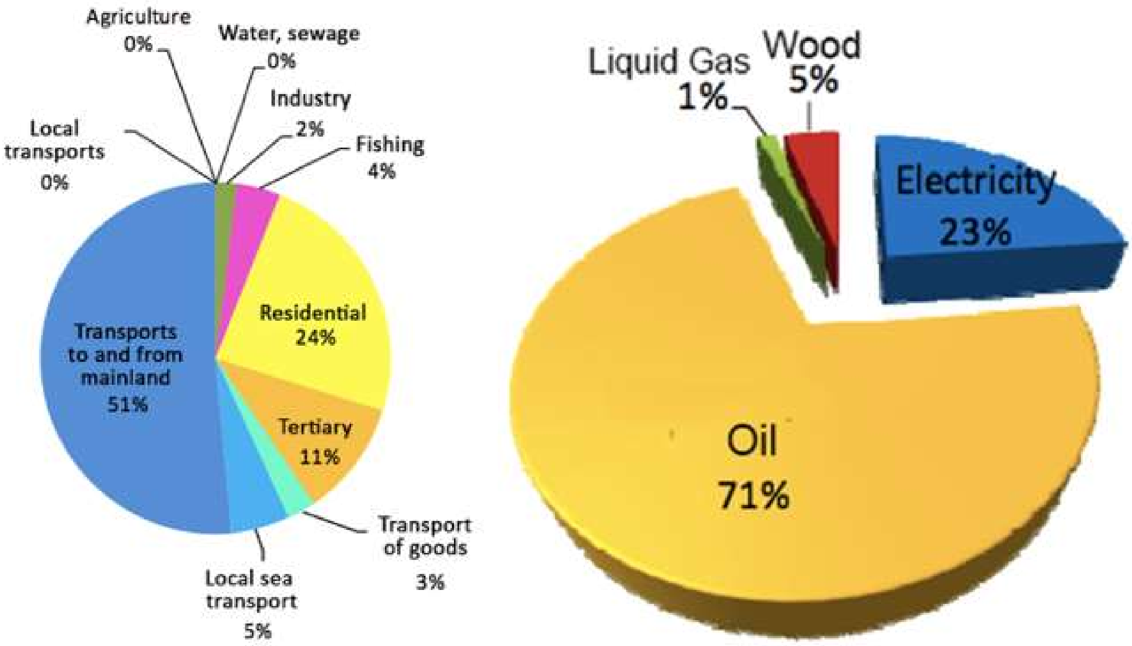

Figure 2 - Sectoral energy consumption and energy sources on Molène (Pleijel, 2015).

Molène island consumed 8,114 MWh in 2014 (Pleijel, 2015). As shown in Figure 2, 59% is utilised for transports, mainly between the island and the mainland for travelling to and from mainland ports. Only 5% is used for local sea transportation and 3% for the transport of goods. Oil is the main energy source (71%) on the island, followed by electricity (23%, which is produced by diesel generators).

The electricity is mainly consumed for residential and tertiary use, see Figure 3. On Molène, about 60% of electricity consumption is used for heating, 20% is for hot water (shower, dishes etc.) and the left

20% is used for other electricity devices. The total energy cost on Molène was 771,790€ in 2011 and the tertiary sectors, such as cafés, hotels and restaurants, used 11% of total energy (900MWh). The electrification of Molène began from 1938. Due to deep and uneven depths, strong and uneven currents and sharp underwater rocks, it is impossible to install a sea cable to provide electricity. Currently, the electricity is produced by three diesel generators, 150 kVA, 225 kVA and 320 kVA, which consume about 100,000 litres of fuel oil every year to serve the island. As of 2018, there is no photovoltaic production on the island and the energy mix remains 100% thermal. No energy storage or management system has yet been deployed, pending the installation of renewable energy installations.

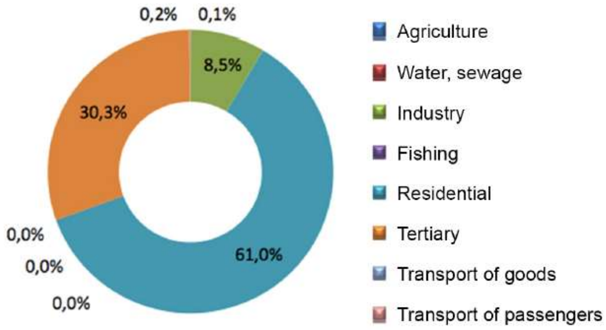

Figure 3 - The use of electricity on Molène (Pleijel, 2015).

In 2017, electricity consumption on Molène totalled 1.2 GWh and the power demand varied between 50kW and 400kW (Le Ministère de la Transition Énergetique, 2019). The residential consumption represents 69% of consumption with a peak between 8 p.m. and 11 p.m. Compared to other islands, there is a larger variation in daily consumption and a comparable electricity consumption between the off-season and the summer linked to a lower tourist frequentation. The deployment of Linky meters started in 2016 and 90% of customers are equipped with them. The objectives of Molène island for the periods 2019-2023 and 2024-2029 can be found as follows (Le Ministère de la Transition Énergetique, 2019):

Table 2 - The Molène Island multiannual energy programming objectives for 2019-2023 and 2024-2028

	2018	2023	2028
MED[1]		-0.2 MWh	-0.3 MWh
PV	0 kW	300 kW	750 kW
Storage	0 kW	300 kW	300 kW
SRE[2]	0 %	30 %	90%

1: Management of Energy Demand (MED) 2: Share of Renewable Energy (SRE)

Molène aims is achieve 100% share of renewable energy by the end of 2030. In order to achieve the objectives, some effective actions must be taken. Demand control actions must be continued, such as the renovation of the building and new LED installation (*Ouest-France*, 2019). These actions should make it possible to reduce annual consumption by 200 MWh from 2023. It is also necessary to start to develop renewable energy, such as the installation of photovoltaic, tidal energy and energy storage technologies. With the goal of a "100% renewable energy" island by 2030, the management, flexibility and storage systems will have to be adapted to increase the storage capacities, investigate new flexibilities and demand-side management strategies.

3 Implications of the ICE General Methodology

This section examines the applicability, relevance of, and possible challenges to, the seven key elements of the ICE general methodology (GM) developed in ICE report T2.1.2 (Matthew *et al.*, 2018).

3.1 Stakeholder engagement

The ICE GM identifies two area of importance for stakeholder engagement. The first is the purpose of the engagement and the second is an outline of some broad guidelines for engagement practices. The purpose of stakeholder engagement is sometimes seen in purely instrumental terms. i.e., a means of obtaining public consent for a particular technological or organisation change. However, change on the scale implied by smart energy transition on an isolated island requires a deeper, and more participatory, deliberative approach in which both the goals of the transition and decisions about the means by which goals are achieved, are the result of open and inclusive discussion among all interested or affected parties. Consideration of approaches tailored to different constituencies is essential to create such meaningful engagement.

The ICE GM strongly suggests that the further ‘upstream’, or earlier in the decision-making process engagement can occur, the greater the trust between project promoters and the community and, ultimately, the more constructive the engagement. The ICE GM views local communities not as an obstacle to be overcome, but rather a source of knowledge and legitimacy. Engagement is an ongoing relationship that does not stop once a project is completed.

3.1.1 Overview of key principles of GM

The GM therefore:

1. Acknowledges diversity of rationales for both support and opposition to a variety of renewable energy technology options
2. Seeks to ensure that communities have the greatest freedom possible in defining the sustainability challenge at hand, and identifying locally desirable actions
3. Prioritises co-production approaches, where (local) experts (e.g., policymakers, technology and project developers) and publics are brought together to jointly define the problems and potential solutions
4. Considers the needs of various constituencies, with the aim of achieving inclusive and holistic public engagement over the course of energy infrastructure siting
5. Continually engages with stakeholders throughout and beyond the timescale of the project(s)

3.1.2 Limitations to this study

Stakeholder engagement was not possible within this study due to time and resource constraints and severely complicated by the Covid-19 pandemic from February 2020. We were able to integrate some Finistère Government objectives based on a review of publicly available strategies and plans, including the national multiannual energy programme (Le Ministère de la Transition Énergetique, 2019).

3.1.3 Guiding Principles and Considerations

There is no single recommended approach to public engagement on energy issues and case evidence suggests that public engagement exercises tend to be most effective when they reflect the characteristics of both the project and the local area (Alexander, Wilding and Jacomina Heymans, 2013; de Groot and Bailey, 2016; Dwyer and Bidwell, 2019). Specifically, there are at least five areas of consideration:

- Awareness of and attention to local energy and public engagement history
- Understanding and appropriate inclusion of diversity and difference
- Tailoring participation approaches for the whole community and specific groups
- Ensuring a two-way flow of information and integration of stakeholder input
- Flexibility, transparency and good-faith negotiation in discussing and the determination of community benefits

One important consideration is whether the island has had any previous experiences with engagement processes and energy projects, and how these might influence perceptions of new projects (Alexander, Wilding and Jacomina Heymans, 2013; Papazu, 2016). For example, an unsuccessful wind turbine project on Ushant led to local scepticism towards wind energy on the island. Engagement processes also need to consider the wider issues island communities see as important so that, as far as possible, energy projects enhance the economic, social and cultural fabric of islands and limit any negative effects (Devine-Wright, 2009; de Groot and Bailey, 2016). Wider issues that engagement processes might consider include: employment opportunities; reducing out-migration among younger residents; protecting existing economic sectors like tourism; and ensuring projects respect the local natural and cultural environments (Gross, 2007; de Groot and Bailey, 2016). Understanding people's energy needs is also essential for ensuring that energy projects contribute positively to residents' well-being and energy security and access.

Engagement processes also need to reflect the diverse character of island communities and the potential for differences in opinion between permanent and part-time residents, visitors, and between different economic sectors, such as fishing, agriculture and tourism (Colvin, Witt and Lacey, 2016; Dwyer and Bidwell, 2019). Different engagement strategies and methods may also be needed to engage with groups who, for various reasons, may be unwilling or unable to participate in certain types of engagement activity. Issues of representativeness should also be considered in order, for example, to come to reasoned judgements on how, for example, to consider the views of second homeowners compared with those of lifelong or other permanent residents. Understanding local social structures, power relations, and differences in values is often critical in gaining the trust and cooperation of local communities. Engagement strategies additionally need to incorporate mechanisms that allow groups to express disparate views and manage disagreements. These challenges may be especially pronounced in island communities because some groups (such as part-time residents) may be hard to contact, and because of an aggravated risk of divisions if engagement processes do not pay careful attention to the social dynamics of small communities (Colvin, Witt and Lacey, 2016).

Participation strategies should encourage equitable involvement; however, the techniques used must consider both island community as a whole and the needs and preferences of specific groups. Previous research indicates that more intense engagement processes are not always popular or successful. Sometimes individuals lack the time, confidence, or skills to take a more active role in debating and decision-making on proposals and not everyone will want to be involved. Engagement techniques therefore need to be flexible, pragmatic, and tailored to the needs of each community, and to avoid over-consultation, which can be a particular risk in islands and remote areas with small populations (Haggett, 2011; Aitken, Haggett and Rudolph, 2016; Rudolph, Haggett and Aitken, 2017). Case study evidence shows some preference for workshops (Kerr *et al.*, 2014; Heaslip and Fahy, 2018) and science fairs (Sperling, 2017; Dwyer and Bidwell, 2019) that create relaxed atmospheres for discussions without being onerous for participants.

Wherever possible, engagement processes should involve two-way flows of information (Reed, 2008; Devine-Wright, 2011) that allow dialogue on information provided by engagement organisers (Aitken, Haggett and Rudolph, 2016). Two-way exchanges encourage trust by providing platforms for sharing local knowledge about the physical, economic, political, social, and cultural characteristics of areas that may be unknown to developers and decision-makers, and can then be combined with scientific and technical information to produce more informed decisions (Haggett, 2008; Reed, 2008). Attempts should also be made to act on public and stakeholder concerns, or at least for developers and decision-makers to respond so that residents feel valued in the decision-making process (Sorensen *et al.*, 2002; Gross, 2007; Haggett, 2008; Aitken, Haggett and Rudolph, 2016; Sperling, 2017; Dwyer and Bidwell, 2019). It is important that developers communicate their decisions and rationales for particular courses of action, so that communities feel they are being kept informed, rather than being marginalised once initial consultations have taken place. Developers of the Triton Knoll offshore wind farm shared feedback from pre-application consultations with local stakeholders via a report summarising how consultees' views had been considered in the final application (Aitken, Haggett and Rudolph, 2014). Another way to facilitate information sharing is to use trusted community intermediaries (Klain *et al.*, 2017; Sperling, 2017; Dwyer and Bidwell, 2019). Experience suggests that the context in which information is shared and the person presenting information can be as important as the information itself in shaping the dynamics of engagement (Klain *et al.*, 2017).

Careful consideration is needed as to the forms of any community benefits offered as part of the energy project. The types of benefit made available are likely to vary between locations but flexible and transparent processes, with active negotiation with local representatives on their design and distribution, can help to address perceived imbalances between the impacts and benefits of projects. Benefits can include community funds, community ownership, apprenticeships and studentships, educational programmes, and electricity discounts, while indirect benefits, such as enhanced tourism, should also be discussed (Firestone, Kempton and Krueger, 2009; Rudolph, Haggett and Aitken, 2014, 2017). Energy projects can also bring community benefits in their own right, e.g. by lowering energy costs and/or improving reliability of connections, though it should not be assumed that these alone are sufficient. A recurring theme in work on community benefits is that benefit schemes should be tailored to the needs of individual areas, sites and projects (Rudolph, Haggett and Aitken, 2017). For example, Devine-Wright and Sherry-Brennan's (2019) analysis of a community benefit fund for a high-voltage power line in Ireland highlights the need for iterative dialogue with local stakeholders when determining the boundaries of benefit schemes. Negotiated approaches were seen as preferable to more formulaic approaches to 'boundary drawing' in securing acceptance that eligibility for benefits had been determined fairly and reflected local knowledge and interests.

3.2 Assessing energy demand outlook and identifying options

A key determinant of decisions about the future of an isolated or peripheral electricity system is an informed view of demand for electricity, the factors that drive changes in demand, and how these may evolve over time. The first stage in a demand assessment is the gathering of appropriate information. Secondly, consideration needs to be given to how changes in consumers' behaviour can impact energy demand.

3.2.1 Overview of key principles of GM

The GM considers:

- Aggregate demand data across electricity, heat and transport
- Historical demand by sector and geography
- Granular data on domestic energy usage patterns
- Economic and demographic drivers of energy demand
- The interaction of policy and behaviour change, particularly with regard to increasing levels of energy 'prosumption'
- Anticipated changes to energy demand or production

3.2.2 Current Energy Demand Assessment

Molène, like other French islands, has two network voltages, here labelled as High Voltage (HV) and Low Voltage (LV). Normally the HV network is 5.5kV. The Molène power system map is shown in Figure 4.

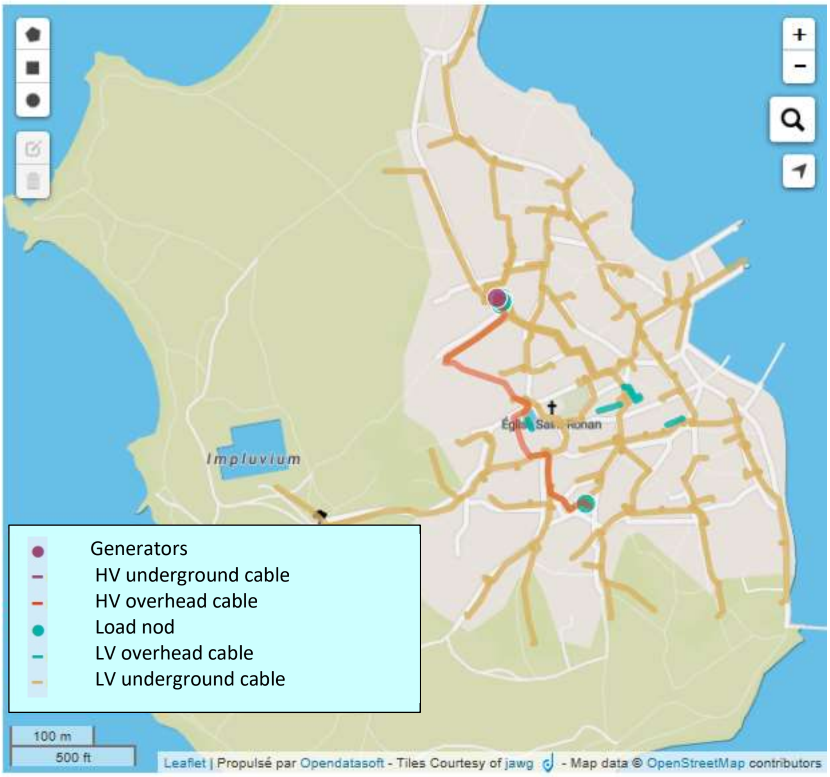

Figure 4 - Molène power system.

The generator unit, shown in Figure 5Figure *4*, is located at the centre of the island and its power rating is 720kW.

Figure 5 - Generator unit.

Only the HV network (as shown in Figure 6) will be considered in power flow and reliability assessment

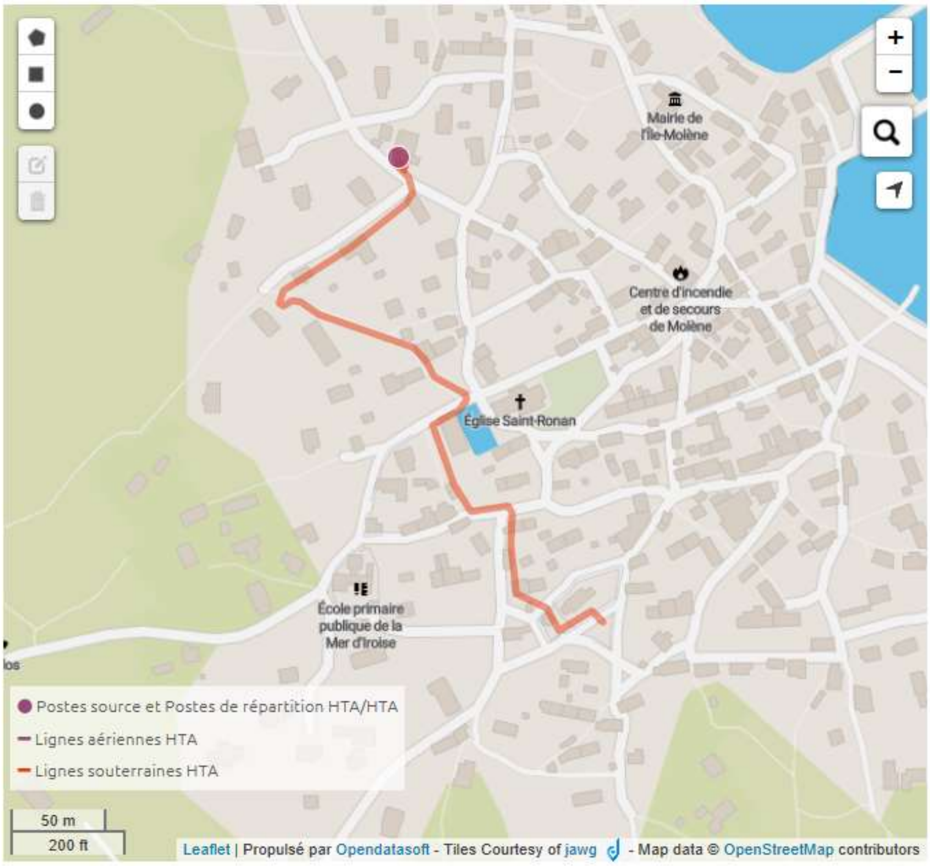

Figure 6 - Molène HV network

Only the total energy demand over a month is available, as shown in Figure 7. The highest energy demand is in April (around 155MWh). The total annual energy demand is 1180MWh.

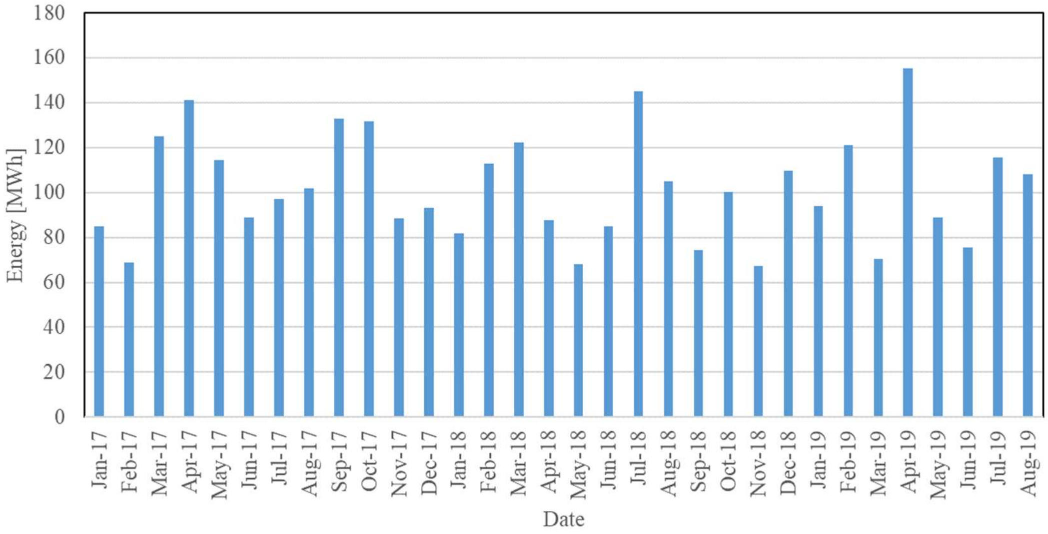

Figure 7 Molène monthly energy demand.

Considering the energy demand data presented in Figure 7, the power demand for the island was calculated, as shown in Figure 8. The maximum monthly power is 216kW (during April 2019). If we assume that demand is similar to Ushant, the highest energy consumption month is about 1.6 times the average consumption for the whole year and the maximum power during the day is about 1.3 times the average daily power. This gives a figure for maximum demand power of 280kW.

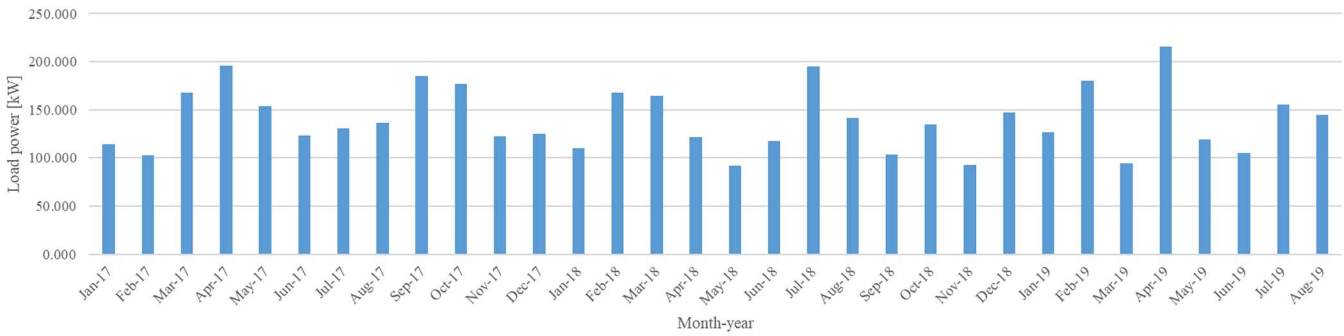

Figure 8 Molène monthly power demand

3.2.3 Potential future changes to energy demand.

Reduced demand

The island of Molène has a stated target of reducing annual energy consumption by 0.3 GWh through energy efficiency savings by 2028. Installing insulation measures as well as more efficient heating technologies (e.g. heat pumps) are both ways to reduce the electricity demand for heat. Ongoing efforts to roll out more efficient electricity devices (e.g. street lighting, LED light bulbs and appliances) will directly reduce electricity consumption. In this study, the future energy scenarios will model future demand assuming the successful achievement of these reductions.

Smart technologies

The increasing deployment of smart technologies for storing energy and flexing electricity demand will help alter the energy load profile to match variable generation. This will enable the community to make maximum use of the cheaper renewable energy. Linky smart meters have already been installed in at least 90% of grid customers allowing for detailed understanding of consumption patterns and the potential to provide smart ‘time-of-use’ tariffs. There are plans to install up to 1,000 kWh of battery storage capacity on Molène. Our modelling of future energy scenarios will determine an optimal storage capacity on the island.

3.3 Energy supply outlook

Developing an understanding of the current and future potential of available energy sources is a key step in the ICE Methodology.

3.3.1 Overview of key principles of GM taken from T2.1.2

There are two main components to this activity:

1. *Evaluating current energy supply:* A comprehensive review of the current energy supply options with its related infrastructures, attributes and options is a good first step in gauging the supply options for the system
2. *Assessing renewable energy potential*: Once the initial data on the current supply options is assessed, the current and potential supply options must be evaluated to gain insights into which of the supply option can be useful. The choice of supply option is intertwined into the stakeholder goals and objectives for the type of energy system pursued. Resource assessments carried out for the renewable generation technologies can provide a basis for their use as a supply option. This enables the quantification of the amount of energy available at a site or sites and to estimate the amount of electricity or heat that is be extracted. Included in the resource quantification can be the estimated power that could be exported to the local grid as a unit commitment with the demand. An assessment on the correlation of generation times with consumption is also needed. Consideration of the technical, environmental and social constraints to deploying the potential technologies should be included.

3.3.2 Current Energy Supply

Electricity

The electricity consumed on the island of Molène is provided entirely by a diesel-fuelled generator set based on the island, with a diesel back-up. This load following system is able to reliably supply power to the island's electricity network running on fuel shipped to the island from the mainland. The essential regular delivery of fuel represents a system cost, an environmental impact, and a system security risk. As of 2018, with the exception of eight panels supplying the communications hub, there is no renewable generation or energy storage installed on the island, though solar PV systems have been scheduled for installation in 2020 and 2021.

Heat

We do not have data from the island about the sources of space heating on Molène. To the extent that the island is similar to Ushant (and the rest of France), it is likely that properties on the island rely heavily on direct electrical heating (Hardwick *et al.*, 2018). At present this electricity is entirely generated from diesel and is therefore carbon intensive. It is also expensive to generate and supply but this cost is not borne by the island citizens, but rather socialised across all French electricity consumers. One advantage of electric heating is that decarbonisation of the electricity supply on the island would directly reduce the carbon associated with heating. As heating from direct electric is three to four times more energy intensive than from a heat pump, deploying heat pumps on the island would reduce the electricity demand. This is an area that future research concerning island communtiies should consider further.

Transport

Transport on Molène was outside the scope of this study. While a shift to electric vehicles might offer some alternative to the need for installation of storage affordability of these vehicles seems likely to be prove to be an issue. Further, at time of writing there did not seem to be a mechanism in place for delivering grid services by household operators.

3.3.3 Renewable Energy Assessment

Solar Resource Assessment

Solar PV is one of the most cost-effective technologies to generate electricity in France. The Îles du Ponant, including Molène, have a relatively high potential for solar PV deployment (see Appendix 1).

Resource Constraints

The available solar resource on Molène has been estimated through PVGIS, using combined satellite data to estimate the irradiance received at a location at a spatial resolution of roughly 6km squares. We used average monthly and hourly data from Brest, as the most appropriate nearby weather station, the specific latitude and longitude used were 48° 45' and -4° 42', respectively.

The global horizontal irradiation (GHI) is 1,106.3 kWh/m^2/year. On a 30^o plane the Global incident irradiation is 1,261.4 kWh/m^2/year and on a plane of 38^o it is 1,261.9 kWh/m^2/year. Over the course of the year, however, the 38^o plane generates more during winter months though with a reduced peak in the summer compared to the 30^O plane. The values are presented in Figure 9 (more detail in Appendix 1). **Error! Reference source not found.** The PV panels are assumed to face due south.

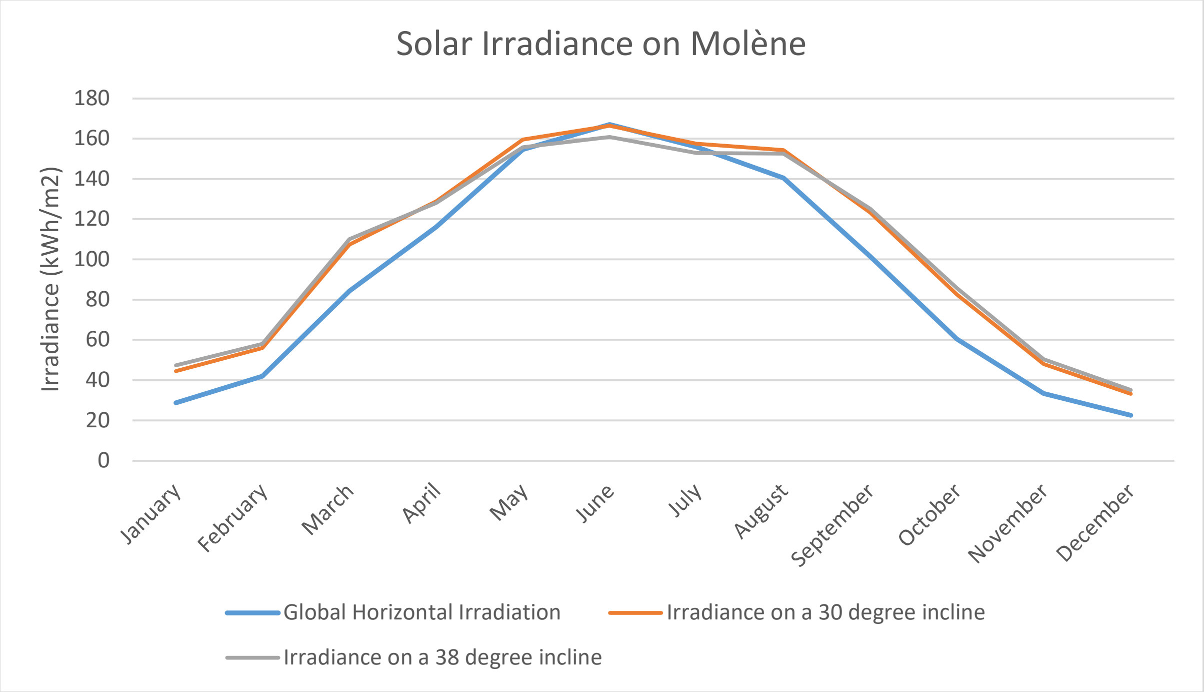

Figure 9 - Global irradiance for Molène from PVGIS

The data show the seasonal variability in solar irradiance. The reduced daylight hours in winter coincides with lower irradiance intensity meaning that the solar resource is much lower in winter than in summer.

Technical Constraints

Equipment used in typical solar installations is not especially large or complex and even the more specialised elements are readily available on the French mainland, if not on the island itself. There are numerous solar installers located in the region who could travel to the island with equipment via ferry without special transport requirements.

Independent solar farms may be installed away from existing grid connections, however, in this case a connection to the network will also need to be constructed. The installation route and methodology should be taken into account when planning a project. Proximity to existing infrastructure will be a key factor is deciding where to site a project. In this case the analysis is focused on a site already identified as plausible in the island's climate plan.

Environmental, Social and Political Constraints

The island of Molène is within a number of environmentally protected areas which will determine where and whether permission to install renewable generation technologies is granted.

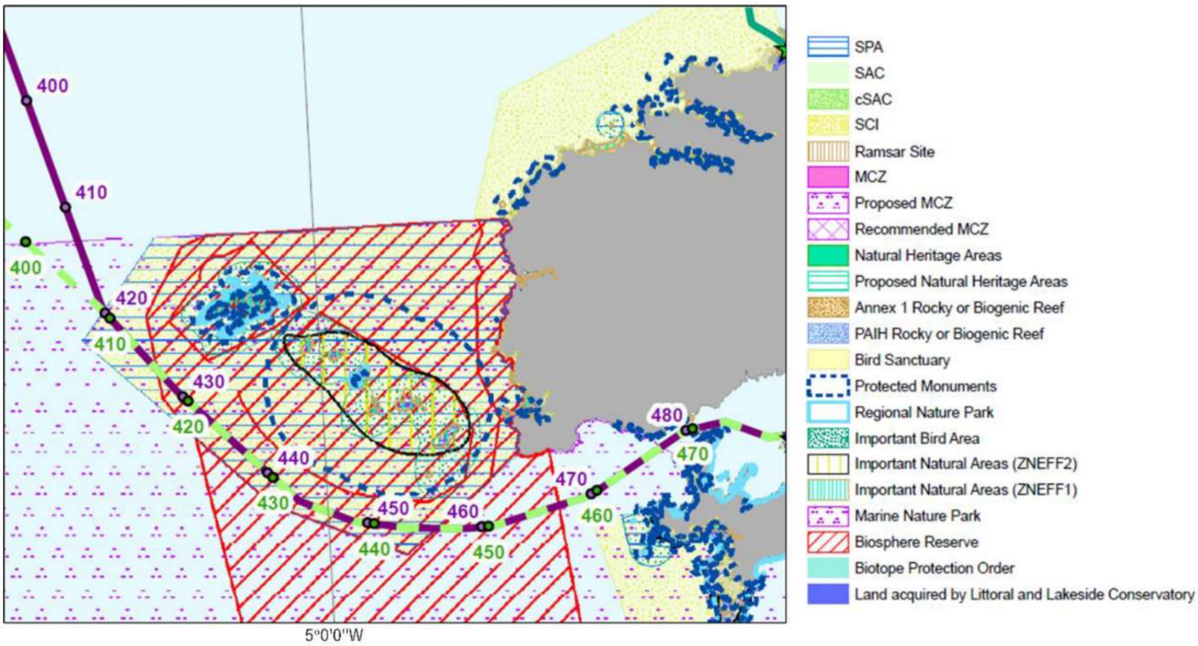

Figure 10 - Marine Environment Protected Areas near Molène

Site Selection and Power Production

The energy strategy for Molène identifies the island's Impluvium as a viable site for ground-mounted solar PV deployment (Le Ministère de la Transition Énergetique, 2019). The impluvium is a large water store on the west coast of the island (see Figure 11), it has a concrete top with an area of around 4,200m^2 and could feasibly be covered with solar PV modules to generate up to 804 kWp.

Figure 11 - The concrete Impluvium measures 4,200 m^2.

Solar PV modules could be installed on buildings' rooftops. Most roofs on the island are pitched at 35° (Hardwick *et al.*, 2018), which is close to the optimum angle of 38° providing excellent conditions for rooftop solar. With regard to domestic sites, there are an estimated 288 dwellings on the island. We have no data on roof types and the proportions of houses and apartments; however, many appear to have potential for solar PV installation (see Figure 12, for example).

Figure 12 - A photo of rooftops on Molène (Source: www.iles-du-ponant.com)

The explicit identification in strategic documents of the impluvium as a suitable site as well as the lack of data on dwelling roofs means that the analysis here focuses on ground-mounted solar PV on the impluvium.

Wind Resource Assessment

Meteorological data show a good potential for wind power off the west coast of Brittany (see appendix). The costs of the technology continue to fall and it is now one of the cheapest sources of electricity (Lazard, 2022).

Resource Constraint

Average wind speed and power data recorded from the airport on Ushant island and obtained from the National Oceanic and Atmospheric Administration (NOAA) is used in this study (NOAA, 2018). The data is recorded at surface level so the wind speed and power calculations are scaled to the nacelle heights of the two turbines modelled in this study for using a log profile (see appendix for more detail).

Surface roughness

We estimate the surface roughness for Molène as $z_0 = 0.03$ (based on normal conditions in areas of farmland with few buildings) which indicates an average wind speed of 9.96ms^{-1} and a maximum speed of 41.91ms^{-1} at 55m hub height.

Average windspeed

Wind speeds on the island vary through the year with higher speeds in winter months, providing a fit to the demand profile which peaks in winter. Wind speeds also vary throughout the day, with speeds on average highest in the afternoon and lowest around 7-8am. The wind direction is predominantly westerly.

Technical Constraints

Technical constraints on the installation of a wind turbine on Molène include requirements for the site to be accessible to large construction vehicles whilst also a safe distance from buildings and roads, as well as having suitable terrain and feasible connection to the local electricity network. Delivery of the turbines and specialist construction equipment will also need to be planned for.

A granite bedrock underlies the majority of the IoS, shown in **Error! Reference source not found.**, covered by a thin layer of soil and vegetation. Where there is bedrock close to the surface drilled piles or gravity bases can be used (Ashlock and Schaefer, 2010).

The route and distance of any high voltage and low voltage cabling will contribute to the cost and complexity of the installation. It will be necessary to ensure that the cables and components are of sufficient capacity to export the maximum power from the turbine(s).

Environmental, Social and Political constraints

In order to obtain the relevant permissions to install a wind turbine, the environmental impacts as well as residents' views will need to be appraised and addressed. Clearly, a wind turbine would constitute a substantial feature on a small island, and therefore has the potential to be a source of controversy. Unfortunately we are not aware of residents' views of wind technology deployment on the island. Appropriate public engagement must be carried out before and during plans to deploy a wind turbine.

Power production

In this study we have examined the power production of a 100 kW (the nED100) and a 250 kW (Vergnet GEV MP C) wind turbines. Both turbines have a height of 55m or less, lower than larger turbines, and installing multiple turbines allows generation to be scaled appropriately. The power curves of the two models are shown in Figure 13.

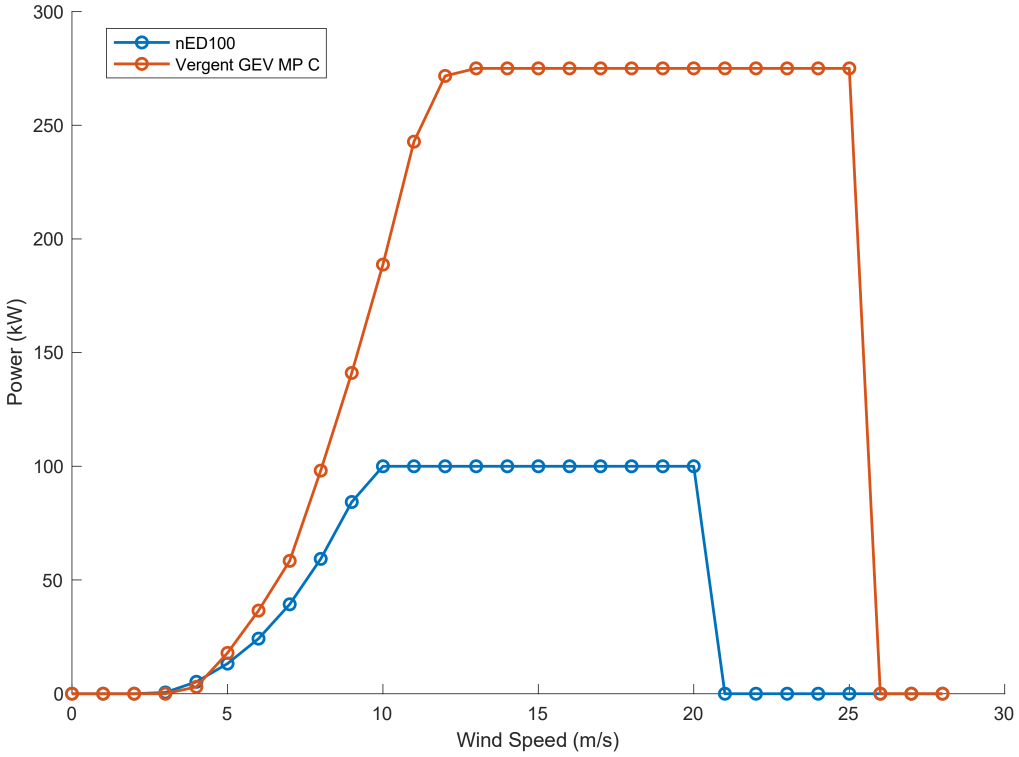

Figure 13 - Power curves of the nED 100 (100kW turbine) and the Vergnet GEV MP C (250kW turbine).

3.4 System reliability assessment

The ICE Methodology recommends rigorous reliability analysis of the electrical system to determine the envelope for action.

3.4.1 Overview of key principles of GM taken from T2.1.2

The main purpose of the reliability study is to establish the reliability of the current energy system to then assess the impact different generation/storage/smart energy options may have on the system reliability in the future. Parameters that will be used for this analysis include:

- Reliabilities of energy security and availability
- Target reliability/availability
- Potential for optimised supply and generation mix.

The analysis rests on two distinct studies:

1. *Reliability study of the network:* This is done by translating the physical electrical distribution network into a conceptual Reliability Block Diagram (RBD). Some software to facilitate this process and the subsequent analysis readily exists, e.g., ReliaSoft. The primary objectives of the reliability analysis are to obtain a life distribution that describes the times-to-failure of a component, subassembly, assembly or system. This analysis is based on the time of successful operation or time-to-failure data of the item (component);
2. *Power Flow Analysis:* In order to understand the power flow in the network. This is derived through a power flow analysis, analysing the voltage levels for each load node. Software such as Matlab Simulink will be employed for the power flow analysis;
3. *Options for smart system operation and innovative technologies:* Once the reliability and power flow of the current system is established, the information will be used to model and assess the different generation and supply portfolios. This will incorporate the renewable energy generation and the correct physical locations, i.e., connect to the correct geographical network nodes. Both types of analysis, the reliability study of the network and the power flow analysis, will be carried out for the range of generation/smart technology scenarios.

Accurate data on the following is a prerequisite for the most rigorous analysis:

A. Schematic diagram of the island power-system network and the network voltage.
B. The main components of the island network, such as power cables, transformers, circuit breakers and generator units.
C. Failure rate of the main components of the network or a record of the failure for each network components for 5 years or more.
D. The cables type, length and size.
E. The transformer parameters, terminals voltage, parameters and type.
F. The electrical generator parameters (power, type and impedance).
G. The load (active and reactive power) at each load connection node for a year at least in hourly time intervals.
H. The circuit breaker information, location and type.

However, data collection has proven to be a challenging issue in some contexts. The ICE methodology document (T2.1.2) outlines some of the considerations for accessing suitable data.

3.4.2 Network Load

There are two load nodes on the high voltage (HV) power network. In the absence of node-level power data, the load at each node is estimated according to the percentage of the number of houses within the catchment area for each node as shown in Figure 14. The catchment area is drawn based on the low voltage (LV) network connection to the HV network. The load nodes are the generator node (P01) and the end HV cable load node (P02).

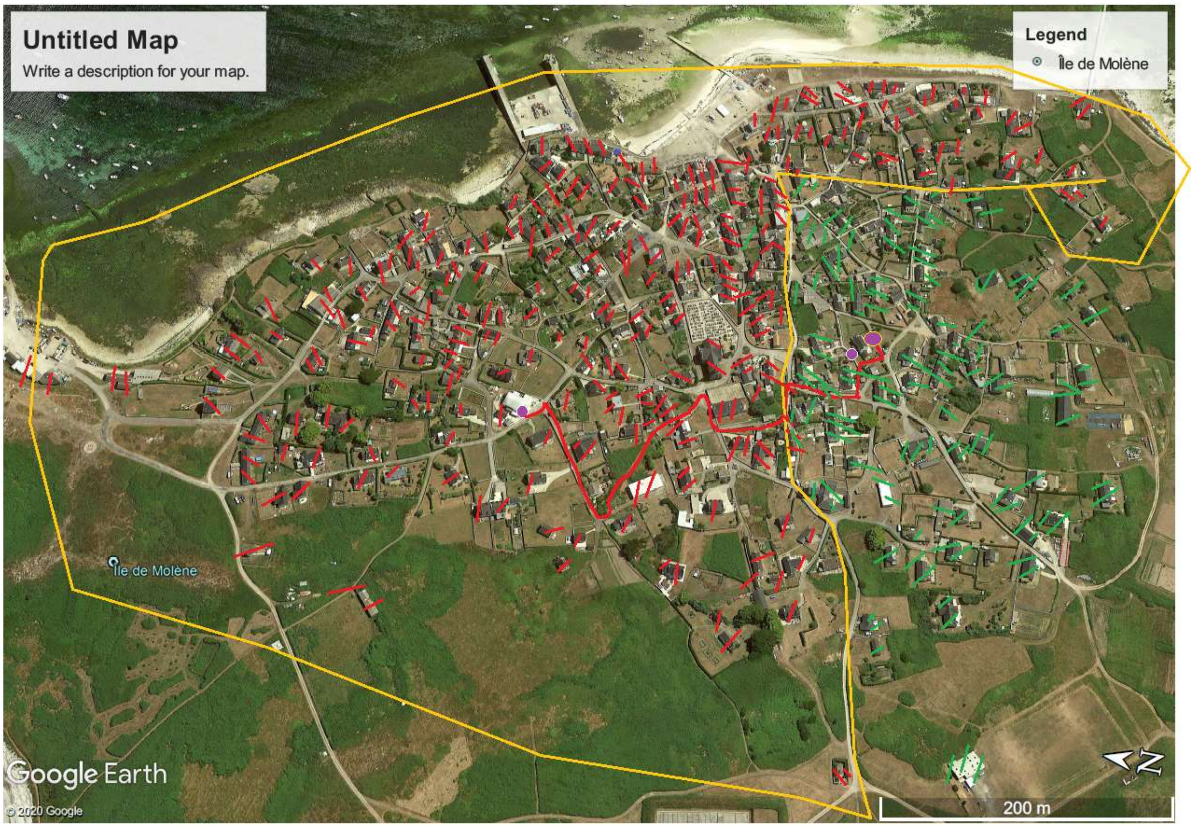

Figure 14 - Catchment area for each load node

Based on the number of houses and the maximum power demand, the load at each load node is shown in Table 3.

Table 3 - Load node power.

Load node	Number of houses	Load [kW]
P01	253	198kW
P02	106	83.2kW

3.4.3 Cable parameters

There is only one cable segment between the P01 and P02. 50mm^2 cable size is assumed with voltage rating 11kV. The cable parameters are shown in Table 4.

Table 4 - Cable parameters.

Cable segment	Length	Resistance	Inductance	Capacitance	Reliability
From P01 to P02	434 m	0.23 Ω	0.345 mH	0.12 µF	0.9831

3.4.4 Power flow and reliability assessment

The power system network diagram, the load node and cable parameters are employed to do the power flow analysis by Matlab Simulink. The reliability assessment methodology for Ushant Island is repeated here (Hardwick *et al.*, 2018). The load nodes voltage drop, reliability and failure rate are shown in Table 5. The cable segment current and capacity usage are shown in Table 6.

Table 5 - Load node power flow results

	Load	Voltage drops	Voltage drops [%]	Reliability
P01	152kW	5.5kV	0.0%	0.928
P02	64kW	5.496kV	0.073%	0.9123

Table 6 - Cable current and capacity usage.

Cable segment	Current [A]	Capacity usage
From P01 to P02	8.88 A	6.5%

Due the simplicity of the power network, there appear to be no problems with the voltage drops, failure rate and cable capacity usage.

3.5 Scenario analysis

Uncertainty about the future is an inherent component of decision making in energy systems. The many different possible futures, each with different social, technical, economic and political characteristics. Which future we arrive at is decided by innumerable decisions and events along the way (Schwartz, 1997), many of which will be beyond the control of individual stakeholders.

3.5.1 Overview of key principles of GM taken from T2.1.2

The ICE Methodology suggests the use of scenario analysis to make decisions about how best to:

- test or examine different plans and policy options, with the aim of exploring which combinations are likely to work more or less well in which scenario(s);
- provide the basis for developing new policies or actions;
- provide the basis of a strategic vision about an organisation's evolving role or opportunity; and
- act as a means of identifying signs of movement towards a particular kind of future

Scenario analysis can use both qualitative quantitative techniques to develop narratives/storylines that describe scenarios which describe how the world might look at some stage in the future. A set of different scenarios is often developed to reflect the range of different possible futures that might take place. In order to be useful, each scenario must be plausible, internally consistent, based on rigorous analysis and engaging (Foresight Horizon Scanning Centre, 2009). These different futures are shaped by different actions, trends and events. The ICE methodology advocates the use of scenarios across the scope of the transition. The scenarios can be developed from the outlook of the demand and supply options and will give insights into the preferred plan/s that will signal the smart energy transition of peripheral communities.

Below, Figure 15 outlines the general scenario analysis process:

Figure 15 - Scenario development process

The Island of Molène has targets for renewable electricity generation aspiring to generate 25-35% renewably by 2023, 70% by 2028 and achieve 100% renewable generation by 2030. Using the second two targets, we developed two sets of scenarios using modelled wind turbines and solar PV generation: three single-technology options for the 2028 target and two mixed options for 2030. Our modelled future scenarios also incorporate the island's target for reducing demand by 0.3 GWh by 2028. Demand in our future scenarios uses a 2015 baseline reduced by 0.3 GWh (23.7%) – future hourly demand is calculated by reducing 2015 hourly values by 23.7%. These scenarios are summarised in Table 7 below. All scenarios have been modelled using hourly generation and demand data over a year.

Table 7 - Future Renewable Energy Scenarios on Molène

Scenario	Description	Renewable energy generated as % of demand
1.1	632 kWp Solar PV generation	71%
1.2	100 kWp Wind turbine	59%
1.3	250 kWp Wind turbine	141%
2.1	804 kWp Solar PV & 100 kWp wind turbine	146%
2.2	632 Solar PV generation & 250 kWp wind turbine	212%

Scenario 1.1

Scenario 1.1 was designed to generate 70% of the energy demand on the island of Molène using solar PV. A 632 kWp solar PV system sited on the impluvium is modelled with future demand, comprising 2,106 modules each rated at 300W connected to nineteen 30kW inverters. The modules all face due south and are inclined at the optimum 38^o angle. This system would generate around 688 MWh of electricity every year – 71% of annual demand. A connection to the island's electricity network would need to be run out to the impluvium. This scenario is summarised in Table 8 and average daily power over a year is illustrated in Figure 16.

Table 8 – Summary of hourly data from scenario 1.1

Scenario 1.1	**Annual**	**Summer (Apr - Sep)**	**Winter (Oct - Mar)**
Generation (MWh)	688	482 (70%)	206 (30%)
Demand (MWh)	968	408 (42%)	560 (58%)
Surplus/Deficit (MWh)	-281	73	-354
Surplus Generation Hours	2192	1577	615
Deficit Hours	6568	2815	3753
Peak Surplus (KW)*		442	416
Peak Deficit (KW)		-191	-301
Usable Energy Generated (MWh -assuming no storage)	330	202	129

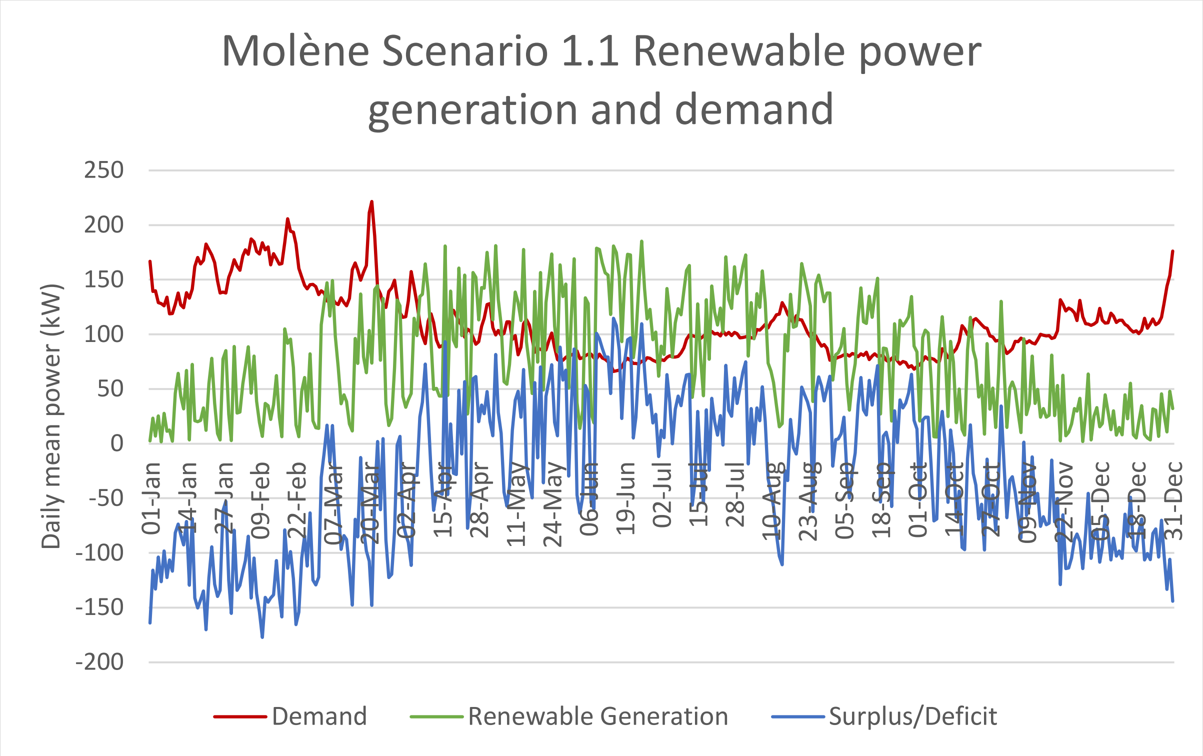

Figure 16 - Daily mean power surplus/deficit modelled over a year based on demand and renewable generation

Scenario 1.2

This scenario models the installation of a 100 kW wind turbine on Molène to assess how it would contribute to the island's electricity supply. We have assumed that the turbine would be installed just to the north of the impluvium – although the wind profile is likely the same across the island, being on the West side will minimise obstruction to the wind resource. The 100 kW turbine would need to be connected to the island's electricity network. The turbine would generate around 576 MWh each year which is 59% of the projected future annual demand. This scenario is summarised in Table 9 and the mean daily power is shown in Figure 17.

Table 9 - Summary of hourly data from scenario 1.2

Scenario 1.2	**Annual**	**Summer (Apr - Sep)**	**Winter (Oct - Mar)**
Generation (MWh)	576	237 (41%)	339 (59%)
Demand (MWh)	968	408 (42%)	560 (58%)
Surplus/Deficit (MWh)	-393	-172	-221
Surplus Generation Hours	1673	994	679
Deficit Hours	7087	3398	3689
Peak Surplus (KW)*		54	55
Peak Deficit (KW)		-183	-220
Usable Energy Generated (MWh -assuming no storage)	545	217	329

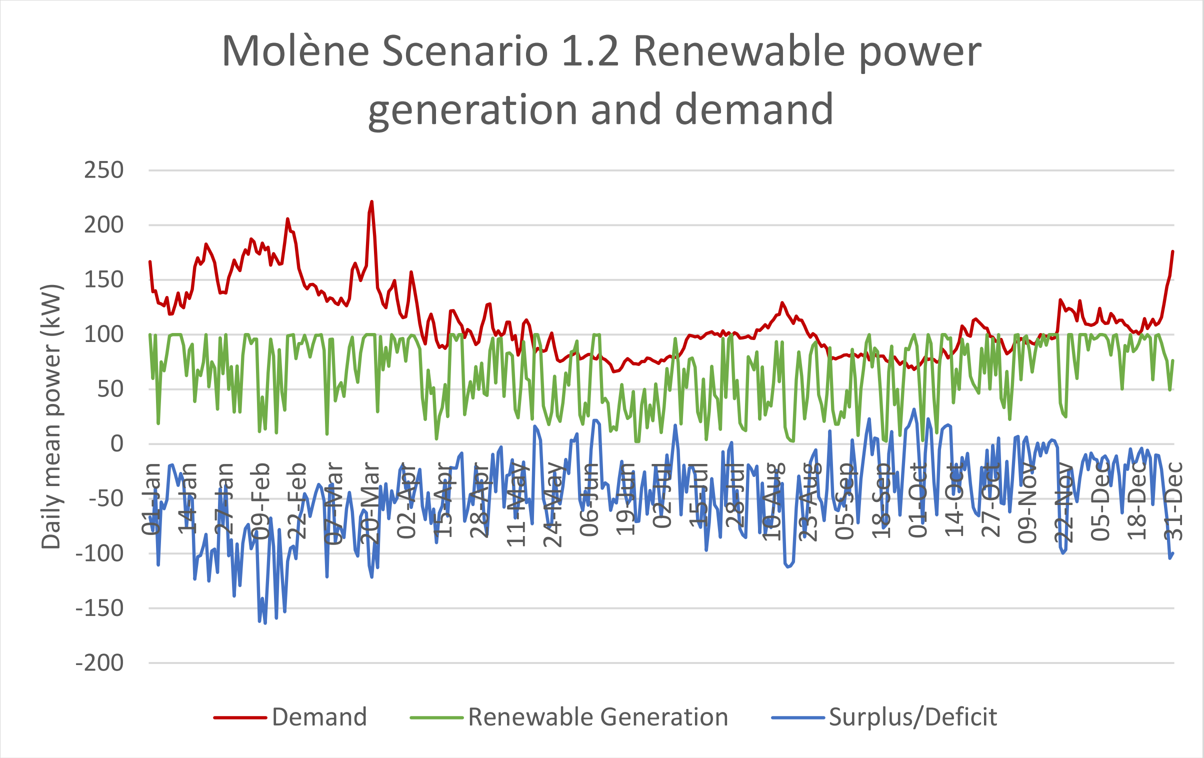

Figure 17 - Daily mean power surplus/deficit for scenario 1.2 modelled over a year based on demand and renewable generation

Scenario 1.3

In this scenario we modelled the generation of a 250 kW wind turbine installed on Molène alongside projected electricity demand. The turbine was assumed to be installed on the west coast of the island just to the north of the impluvium (the modelled generation is unlikely to change significantly between locations across the island, but this location centralises renewable generation systems on the island). According to the model, over a year the turbine generates 1,362 MWh of electricity which is 141% of the projected demand, the majority of which is produced during winter months when demand is also higher. The scenario outputs ae summarised in Table 10 and the power demand is displayed as daily mean values in Figure 18.

Table 10 - Summary of hourly data from scenario 1.3

Scenario 1.3	**Annual**	**Summer (Apr - Sep)**	**Winter (Oct - Mar)**
Generation (MWh)	1362	502 (37%)	860 (63%)
Demand (MWh)	968	408 (42%)	560 (58%)
Surplus/Deficit (MWh)	393	94	299
Surplus Generation Hours	5320	2106	3214
Deficit Hours	3440	2286	1154
Peak Surplus (KW)*		229	224
Peak Deficit (KW)		-185	-220
Usable Energy Generated (MWh -assuming no storage)	728	266	462

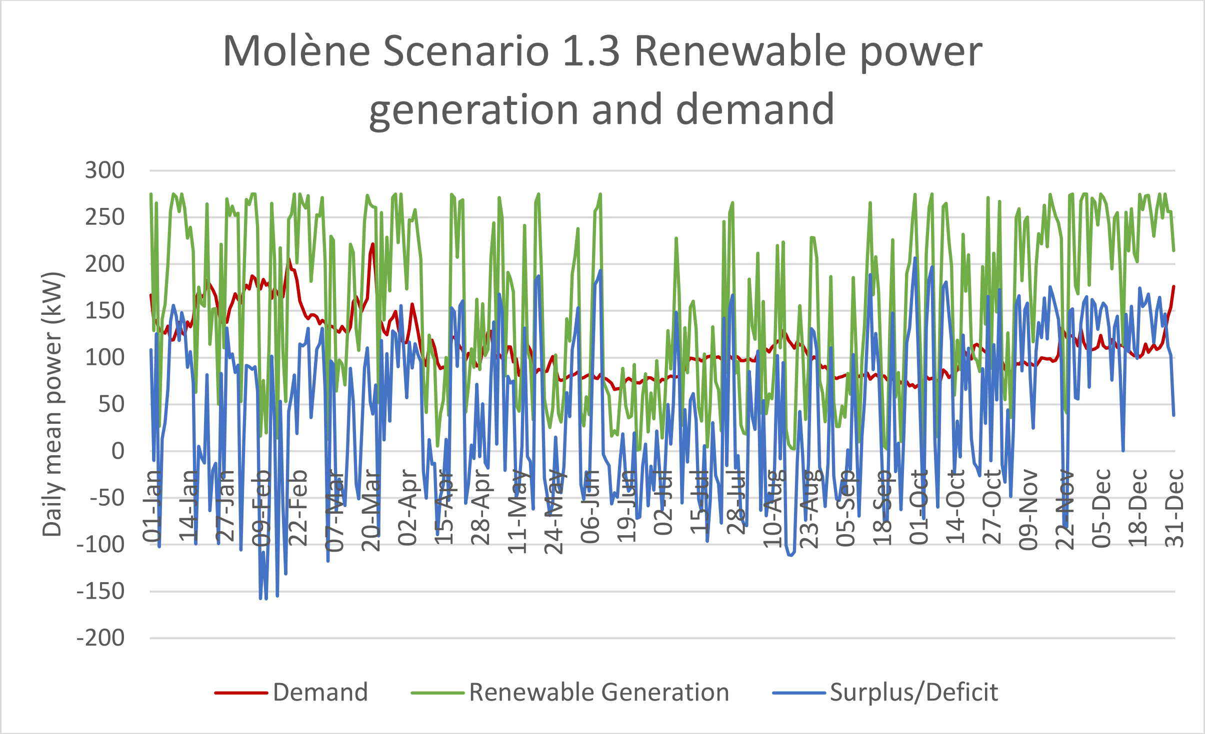

Figure 18 - Daily mean power surplus/deficit for scenario 1.3 modelled over a year based on demand and renewable generation

Scenario 2.1

In Scenario 2.1 we modelled a system which would produce sufficient renewable electricity to meet projected demand using an enlarged solar PV array and the smaller sind turbine. An 804kW solar PV array was modelled (using all available space on the impluvium), using 2,680 panels each rated at 300 W peak output with 23 inverters, each rated at 30 kW AC output. The 100kW wind turbine, also modelled in 1.2, was assumed to be installed to the north of the solar PV array. The solar PV system generates around 888 MWh annually and the wind turbine will export 576 MWh to the grid each year. The peak winter deficit of 220kW at 7pm on a relatively calm February evening is an example of the scale of flexibility which may be required through a combination of demand-side response or reserve battery discharge. Over the year, it is during the winter that there is the greatest generation deficit, particularly in the first calendar quarter. The hourly model for this scenario is summarised in Table 11, and the annual power balance is shown in Figure 19 as daily mean values.

Table 11 - Summary of hourly data from scenario 2.1

Scenario 2.1	**Annual**	**Summer (Apr - Sep)**	**Winter (Oct - Mar)**
Generation (MWh)	1411	813 (58%)	599 (42%)
Demand (MWh)	968	408 (42%)	560 (58%)
Surplus/Deficit (MWh)	443	405	38
Surplus Generation Hours	4156	2559	1597
Deficit Hours	4604	1833	2771
Peak Surplus (KW)*		672	655
Peak Deficit (KW)		-168	-220
Usable Energy Generated (MWh -assuming no storage)	709	319	391

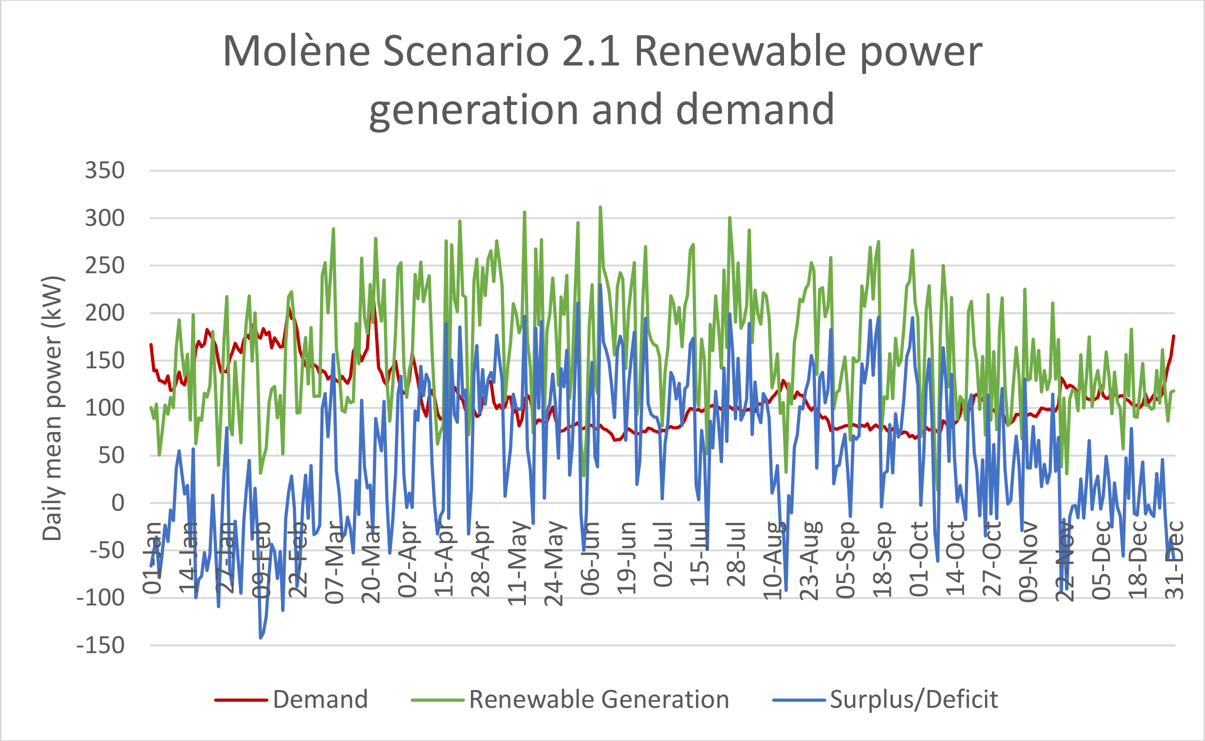

Figure 19 - Daily mean power surplus/deficit for scenario 2.1 modelled over a year based on demand and renewable generation

Scenario 2.2

In this final scenario we modelled the production from the larger 250 kW wind turbine with the smaller 632 kW solar PV array from scenario 1.1 installed on the impluvium. The solar PV generates around 688 MWh over a year and the wind turbine generates 1,361 MWh with a total of 2,049 MWh generated over a year – 212% of projected demand. In this scenario almost three out of every four hours in a year have a generation surplus with generation greater in winter than summer. Compared to all our scenarios, this has the greatest peak surplus generation in both summer and winter, but a reduced peak deficit. The balance and scale of generation technology in this scenario results in a surplus generation in both summer and winter exceeding 500 MWh. The modelled hourly data for this scenario are summarised in Table 12 and the annual power balance is shown in Figure 20.

Table 12 - Summary of the hourly data from scenario 2.2

Scenario 2.2	**Annual**	**Summer (Apr - Sep)**	**Winter (Oct - Mar)**
Generation (MWh)	2049	983 (48%)	1066 (52%)
Demand (MWh)	968	408 (42%)	560 (58%)
Surplus/Deficit (MWh)	1081	575	505
Surplus Generation Hours	6536	3097	3439
Deficit Hours	2224	1295	929
Peak Surplus (KW)*		708	675
Peak Deficit (KW)		-164	-220
Usable Energy Generated (MWh -assuming no storage)	828	343	485

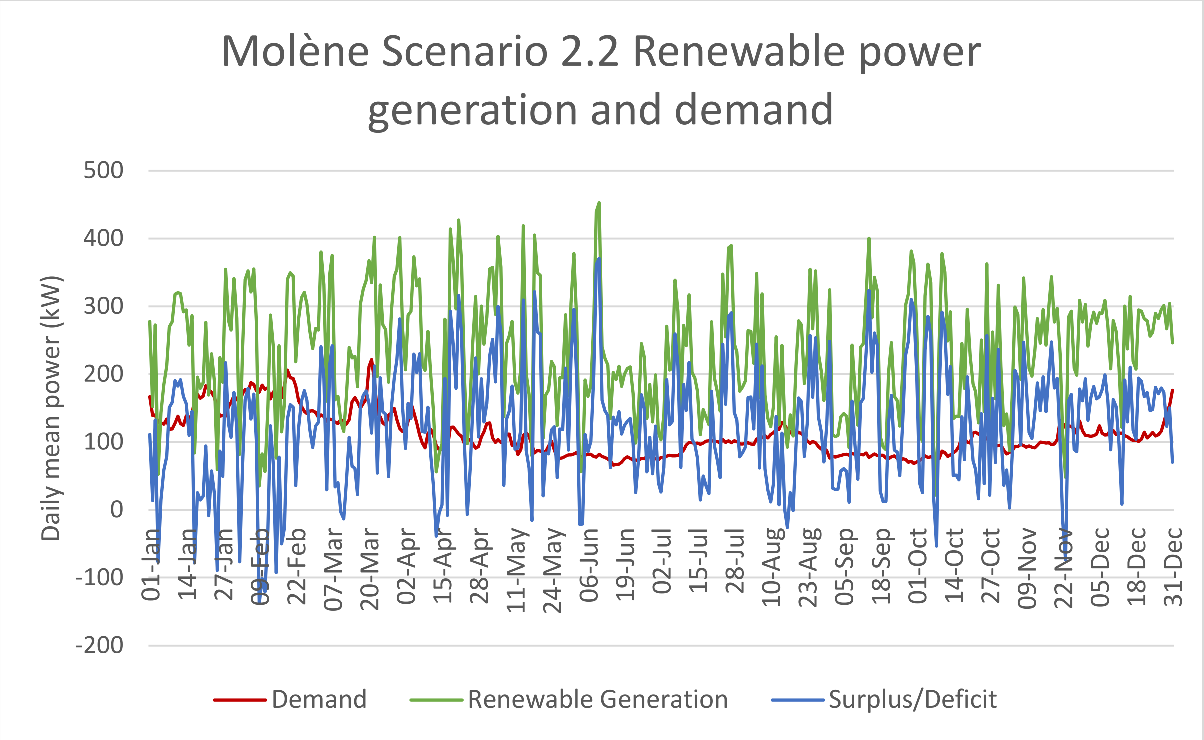

Figure 20 - Daily mean power surplus/deficit for scenario 2.2 modelled over a year based on demand and renewable generation

3.5.2 Scenario Evaluation

Battery Storage Modelling

Based on the analysis in Ushant island for energy storage, lithium-ion is the energy storage technology suggested for this application due to its great suitability for load and renewable energy generation balancing applications. This is one of the most popular types of batteries and may be considered a reliable solution for meeting the requirements.

Based on the hourly load demand and the size of the battery, a battery state of charge is generated for different battery sizes at different renewable energy scenarios. Table 13 summarise the required battery size for each scenario.

Table 13 - Battery size for each scenario.

	Target	RE sources	Battery size
Scenario 1.1	70% from RE	632 kWp Solar PV generation	60MWh
Scenario 1.2	70% from RE	100 kWp Wind turbine	90MWh
Scenario 1.3	70% from RE	250 kWp Wind turbine	30MWh
Scenario 2.1	100% from RE	804 kWp Solar PV & 100 kWp wind turbine	30MWH
Scenario 2.2	100% from RE	632 Solar PV generation & 250 kWp wind turbine	7MWh

The uncovered demand and excess generation at different for each scenario. Each is shown, from Figure 21 to Figure 25.

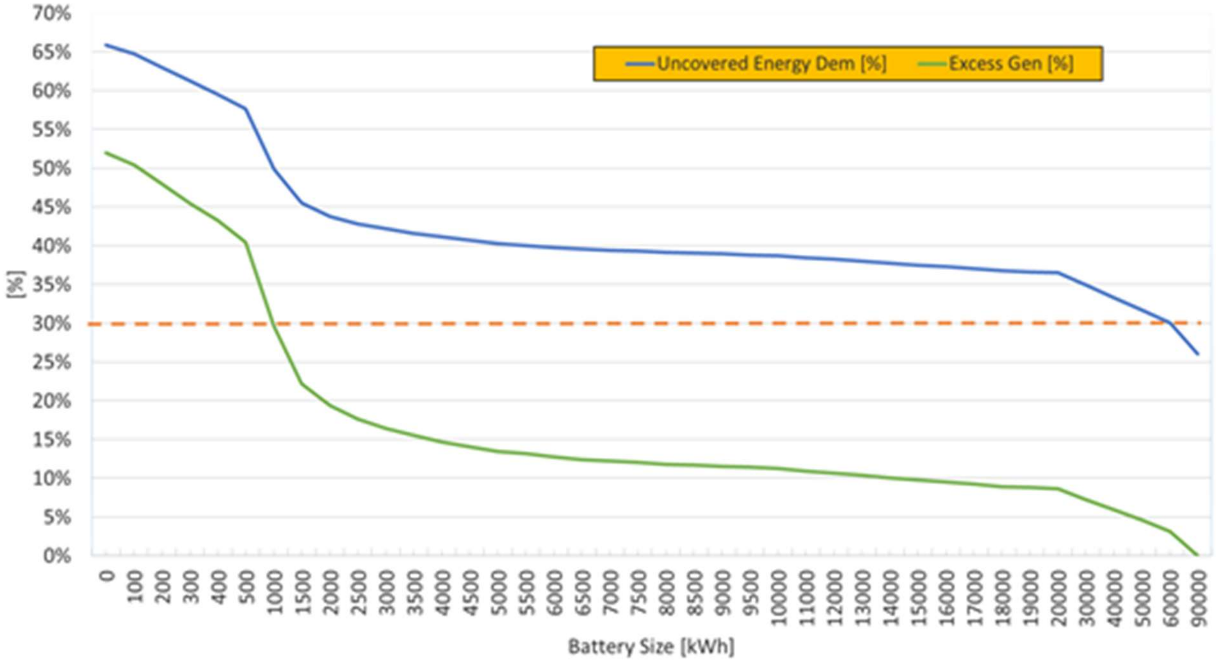

Figure 21 - The uncovered energy demand and the excess generation for scenario 1.1

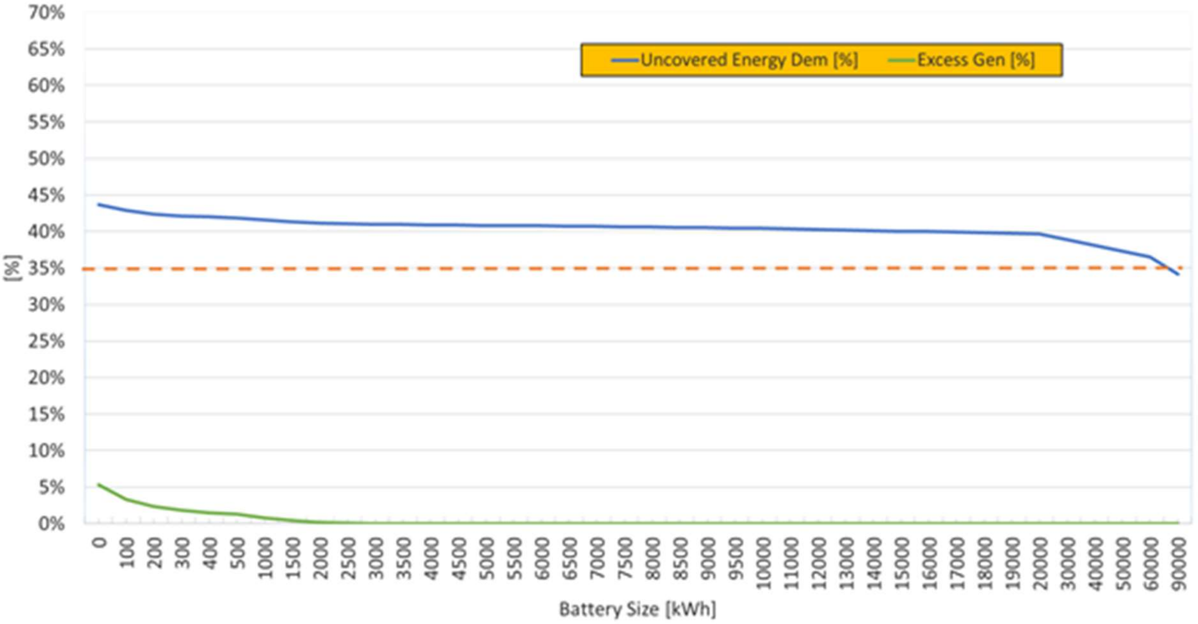

Figure 22 - The uncovered energy demand and the excess generation for scenario 1.2

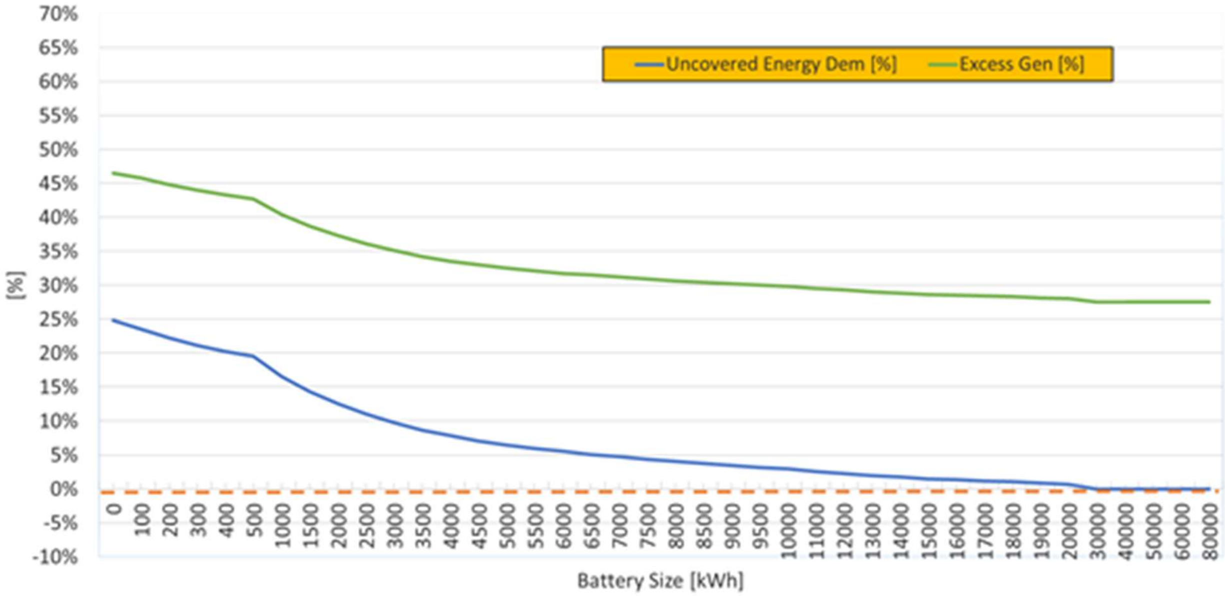

Figure 23 - The uncovered energy demand and the excess generation for scenario 1.3

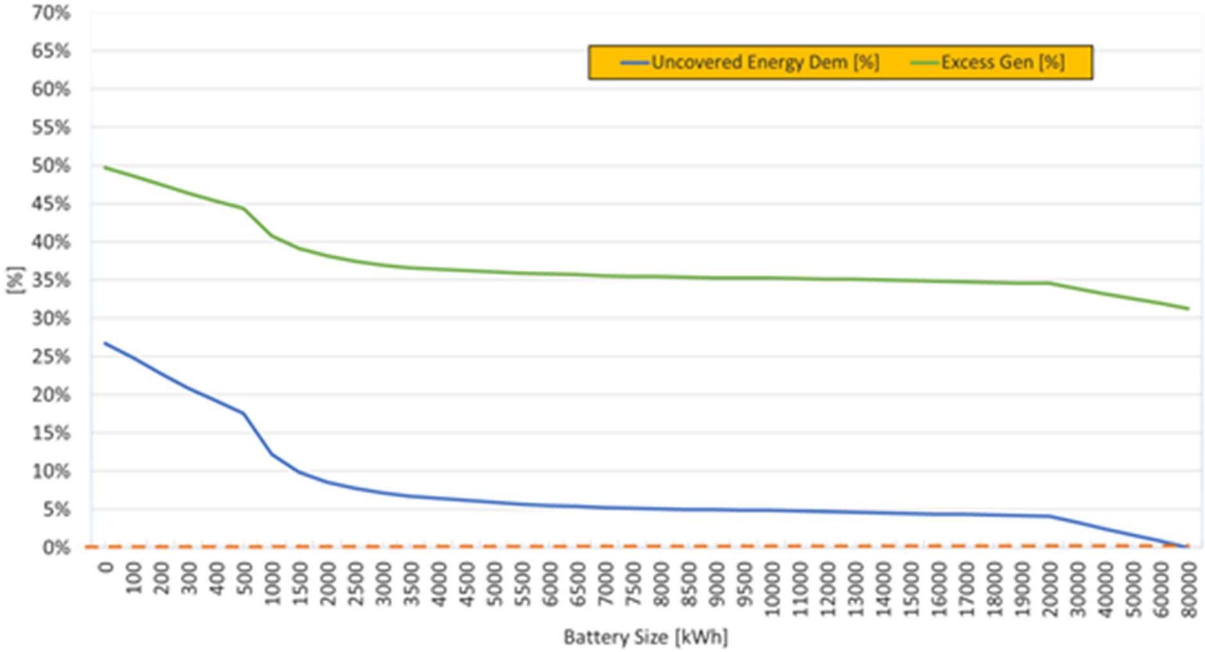

Figure 24 - The uncovered energy demand and the excess generation for scenario 2.1.

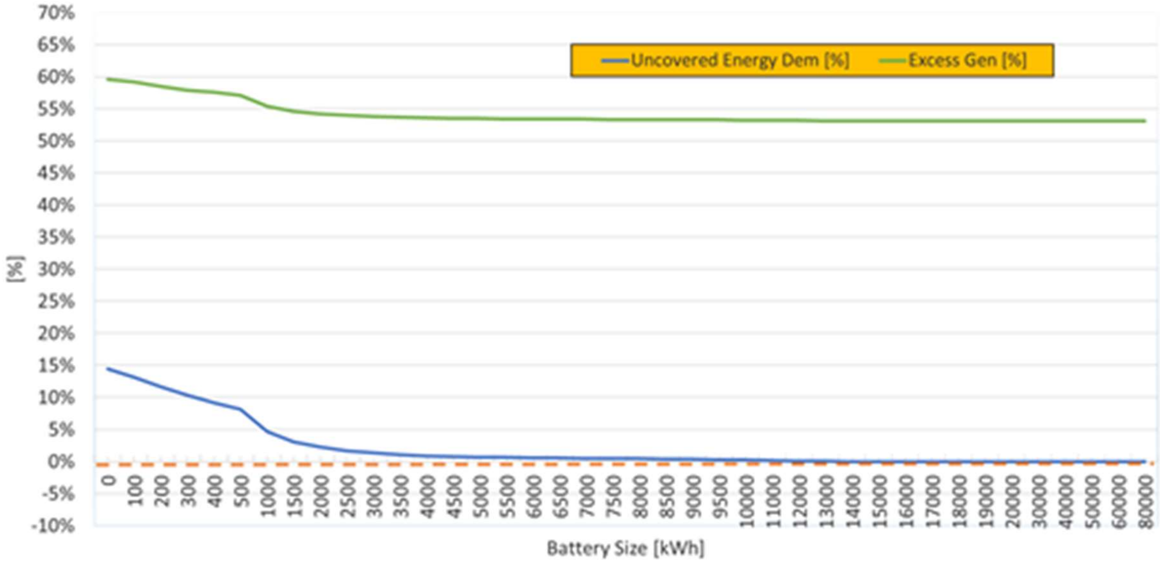

Figure 25 - The uncovered energy demand and the excess generation for scenario 2.2.

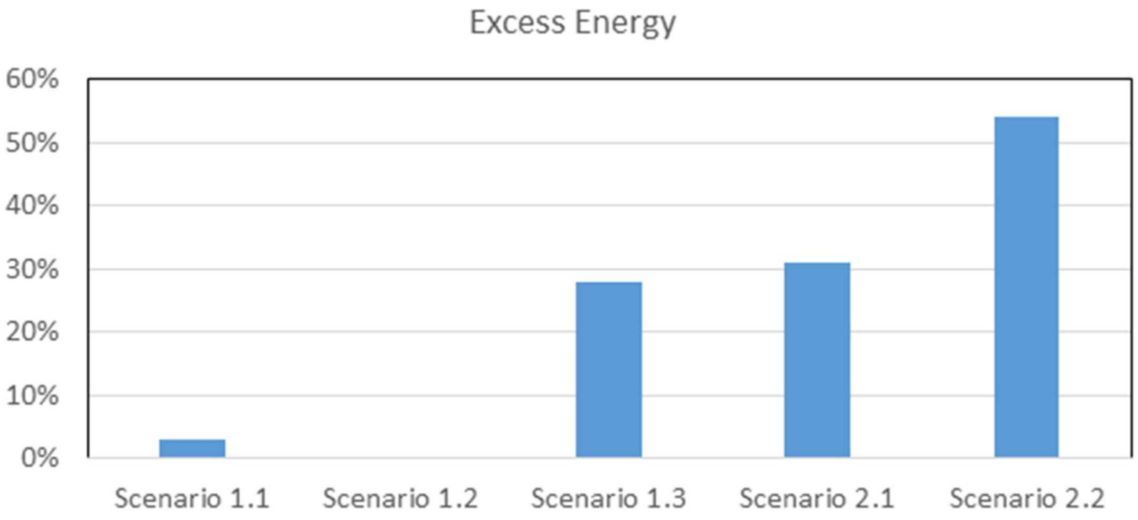

Figure 26 - The excess energy for each of the five scenarios

Figure 26 shows the excess energy in the percentage of the annual load demand for each scenario. From the battery size analysis, a large battery size is required to meet the 70% for scenarios 1.1 and 1.2. Scenario 1.3 seems to be a suitable choice. For 100% RE, scenario 2.2 is the suitable scenario where the battery size is lower than scenario 2.1. However, there is much excess energy (more than 50% of the annual energy demand). To reduce the battery size, some load control topologies are required such as load shifting and heat pump.

Load Analysis

A load analysis was carried out for each RE scenario, assuming any initial PV development to be installed on the Impluvium. The PV thus modelled is assumed to require connection to the main power grid via a 460m cable as shown in Figure 27.

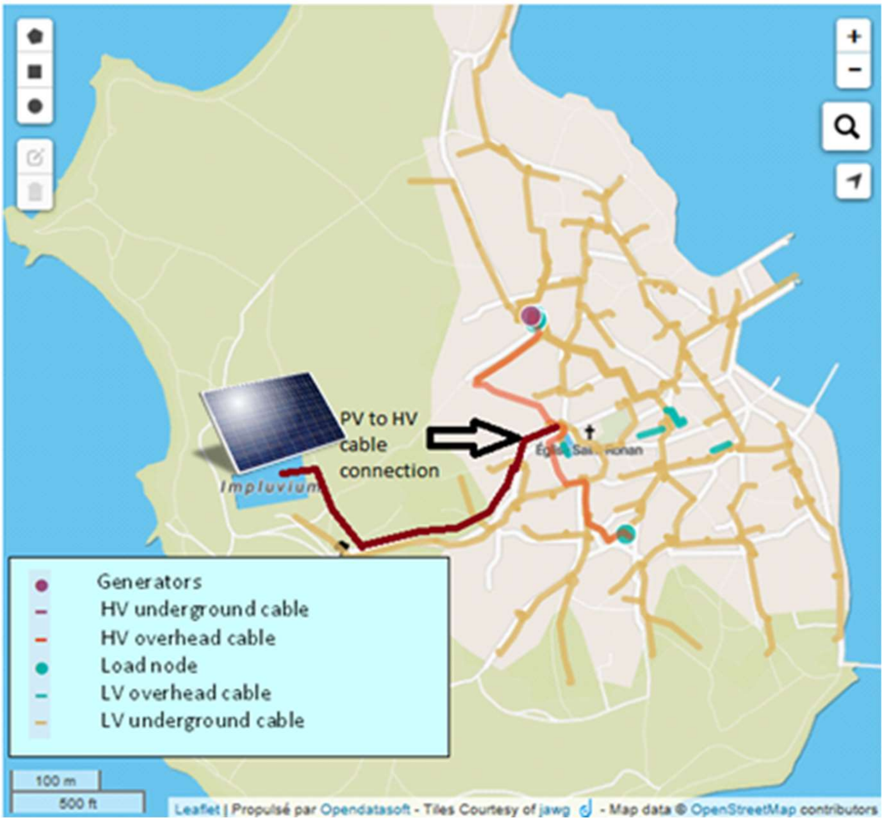

Figure 27 - PV location and connection to the main power grid.

If we apply similar location constraints for Molène as those set out in the Ushant report for a potential wind turbine (WT) siting, there are three suggested locations. These are shown in Figure 28. Location 2 and 3 are quite far from the main power grid making location 1 the more suitable location.

Figure 28 - Suggested locations for a wind turbine.

We assume the WT is to be connected to the main power grid via a cable as shown in Figure 29. The path of the cable is selected to be close as possible to the road for easy installation.

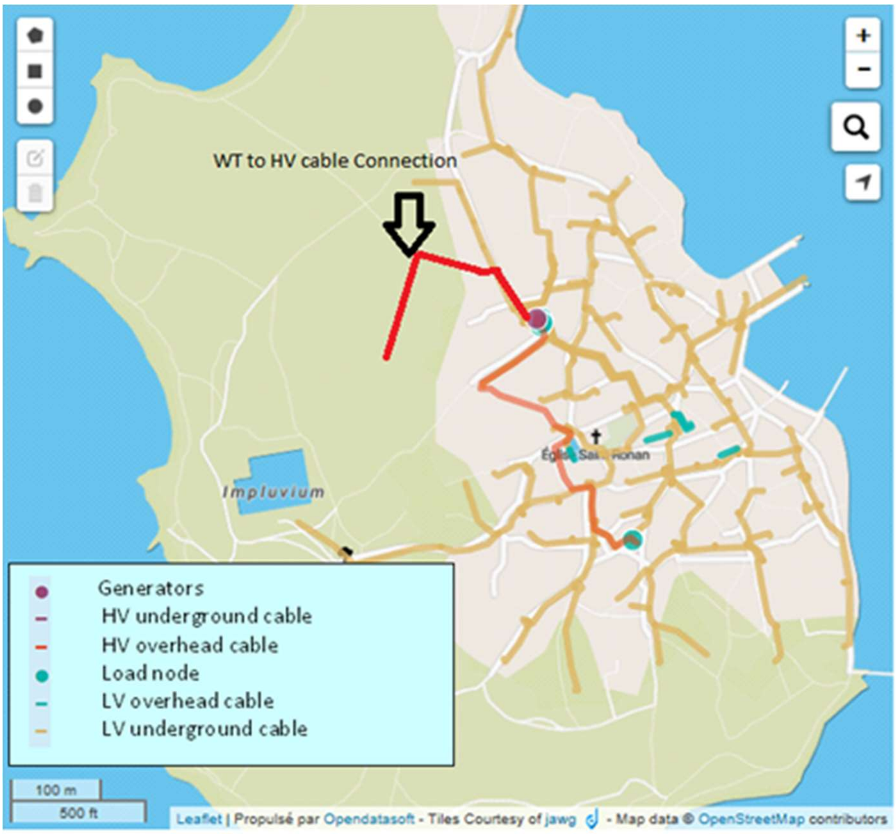

Figure 29 - Wind turbine location and how it is connected to the main power grid.

The updated power grid of the island including the RE sources is shown in Figure 30. The parameters of the cable segments are shown in Table 14.

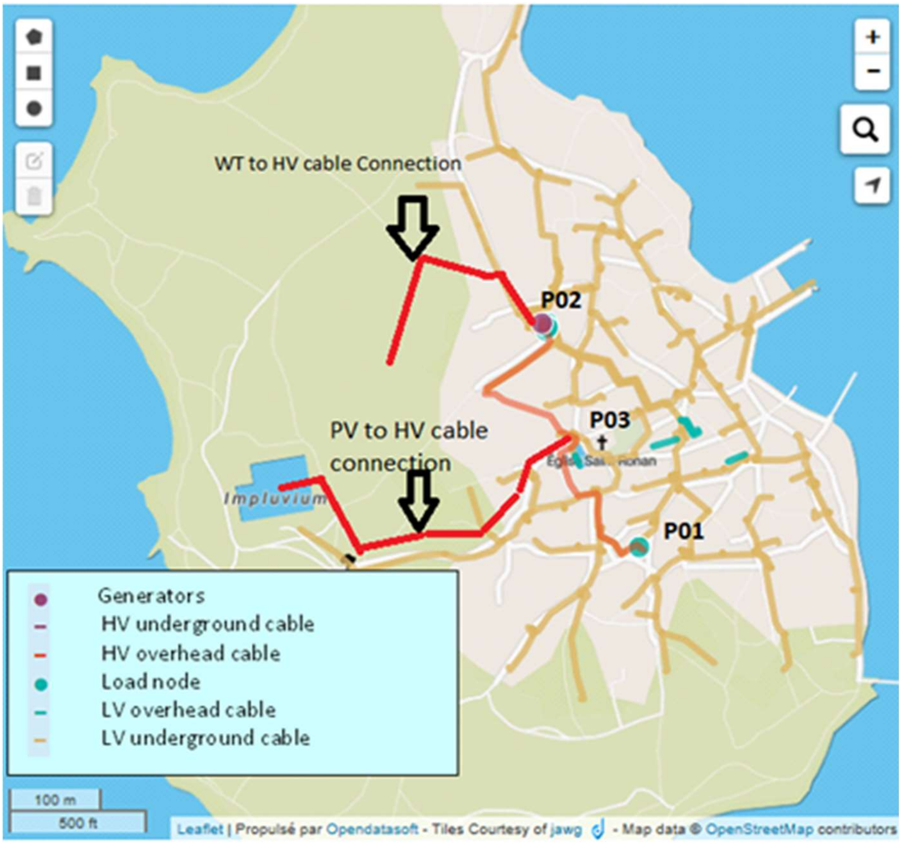

Figure 30 - Updated power grid for the island including the RE.

Table 14 - Cable segments parameters for the updated electrical power grid of the island.

Cable segment	Length [m]	Resistance [Ω]	Inductance [mH]	Capacitance [μF]	Reliability
From P01 to P03	234	0.124	0.186	0.0647	0.991
From P03 to P02	200	0.106	0.1590	0.0553	0.992
From P03 to PV	460	0.244	0.366	0.127	0.982
From P02 to WT	200	0.106	0.159	0.0553	0.992

According to the five island RE scenarios, the load demand, the RE output and the power flow analysis of the power grid can be run to fit either of two main cases; maximum load or maximum RE, as shown in Table 15.

Table 15 - Power Flow cases at different scenarios.

	Maximum Load					**Maximum RE**				
	Total load [kW]	P01 [kW]	P02 [kW]	WT [kW]	PV [kW]	Total load [kW]	P01 [kW]	P02 [kW]	WT [kW]	PV [kW]
Scenario 1.1	301.2	212	89	0	0	100.4	71	30	0	538.24
Scenario 1.2	301.2	212	89	100	0	301.2	212	89	100	0
Scenario 1.3	301.2	212	89	271.7	0	301.2	212	89	275	0
Scenario 2.1	301.2	212	89	100	0	98.74	70	29	93.3	662.996
Scenario 2.2	301.2	212	89	271.7	0	121.14	85	36	275	535.5

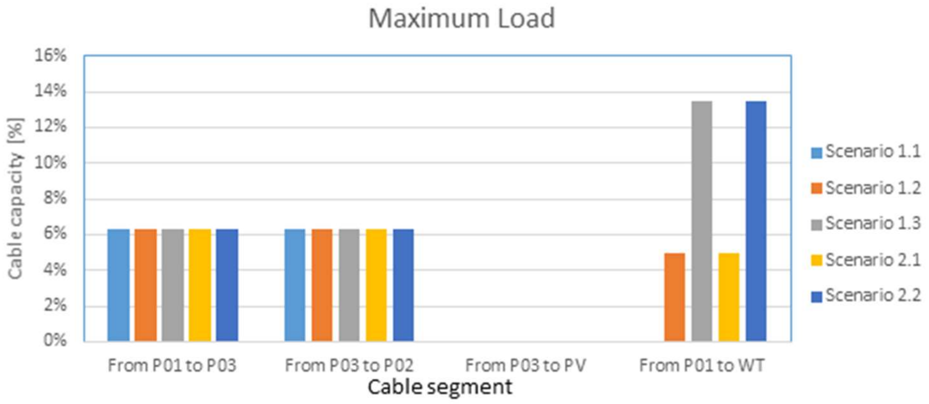

Figure 31 - Cable capacity at different scenarios (maximum load).

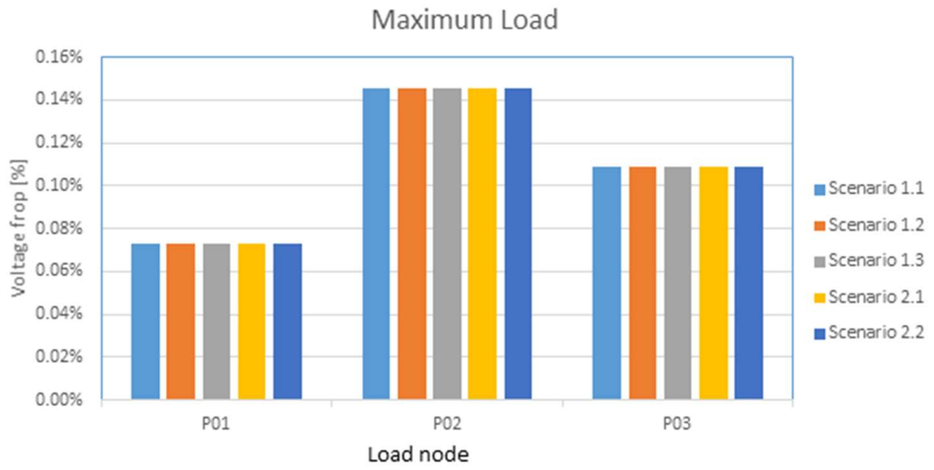

Figure 32 - Load voltage drop at different scenarios (maximum load)

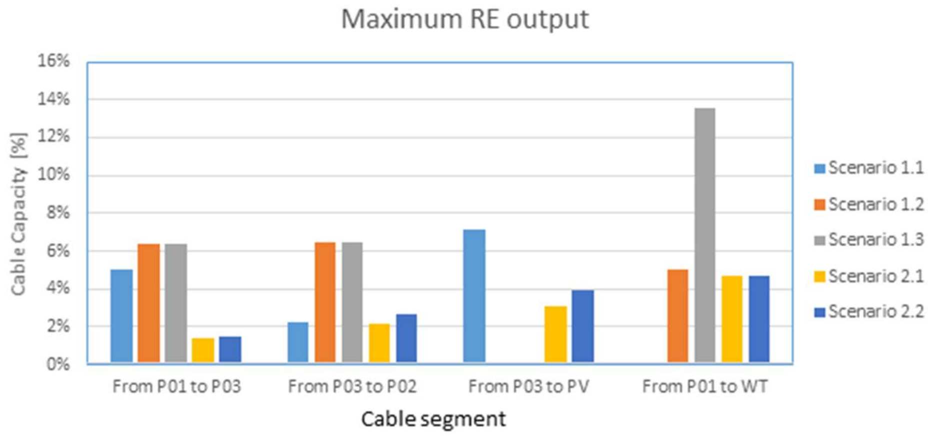

Figure 33 - Cable capacity at different scenarios (maximum RE output).

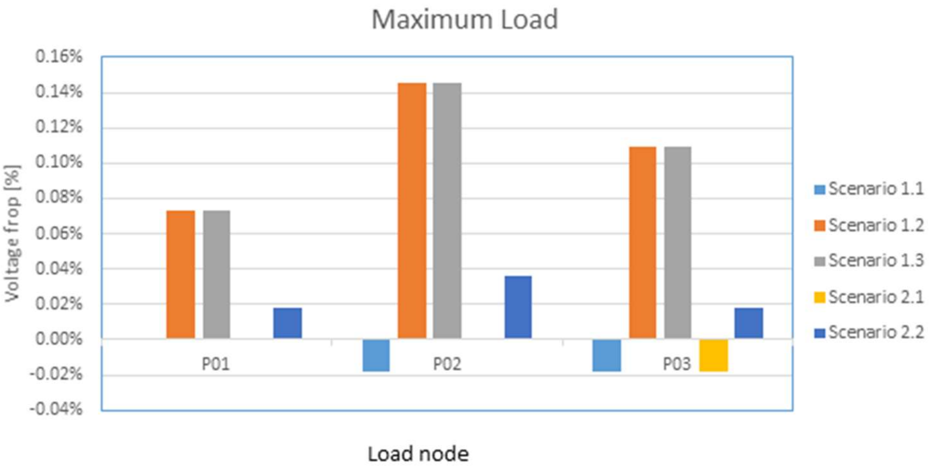

Figure 34 - Load voltage drop at different scenarios (maximum RE output)

Reliability assessment

Based on the methodology, reliability data and the assumptions on Ushant Island (See ICE report T1.2), the reliability of load nodes P01 and P02 at different scenarios are shown in Figure 35. Scenarios 1.3 is the same as scenario 1.2 and scenario 2.2 is the same as scenario 2.1 in terms of the types of the RE, only scenarios 1.1, 1.2 and 2.1 are considered in reliability analysis.

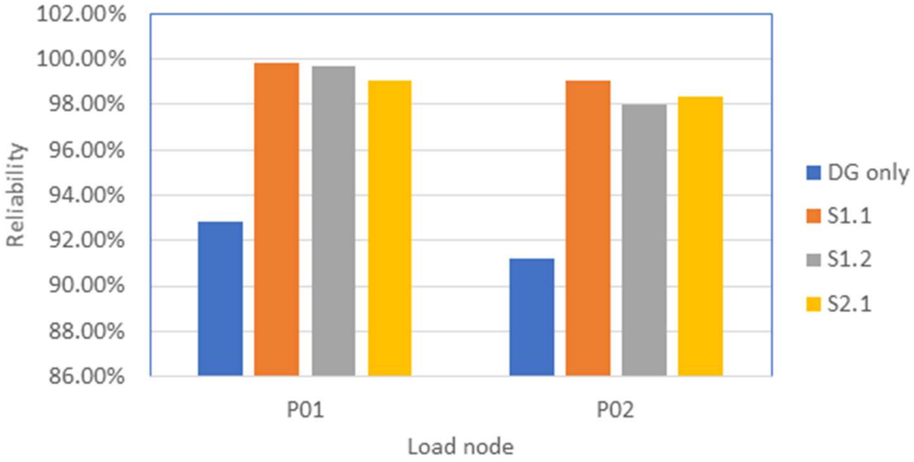

Figure 35 - Load node reliability at different scenarios.

From the power flow and reliability assessments:

1. The caple usage capacity is very small (maximum 14%). There is no need to modify the island power system infrastructure. It was assumed that the cable size is 50mm. If the actual cable size is 25mm, the cable usage capacity is still low (<30%)
2. There is no problem in voltage at the HV network where the voltage drop is low (<0.2%)
3. To supply the island with 70% of the load from RE, scenario 1.3 seems to be a suitable one where the size of the battery is very small. For the 100% RE scenario, scenario 2.2 is the suitable one due to the small battery size.
4. There is much unused renewable energy output that is not used. Therefore, a load shift or any other topology to reduce the load at the peak is recommended.
5. Introduce the RE sources reduce the failure rate of the island by 75%

Economic Analysis

We calculated the levelised cost of electricity (LCOE) for all scenarios on Molène. A description of the data and calculations is available in the Appendix. The analysis revealed that for all but one of the scenarios complementing the renewable generation with a battery reduces the overall LCOE. Scenario 1.2 is the only one in which the analysis suggests that a battery increases the cost of electricity across the system, though it reduces the carbon emissions and enhances the consumption of renewable electricity. A 0.2 MWh battery increases the cost of electricity by just over €2/MWh which may be worth the cost depending on the value of carbon reduction. A 1 MWh battery appears to be most cost-effective for scenarios 1.1 and 2.1, whilst a smaller 0.5 MWh battery appears cost-optimal for scenario 2.2 and a 0.2 MWh battery for scenario 1.3.

On the whole, the analysis reveals the relatively low cost of wind generation for the island. Scenarios 1.3 and 2.2 which have a 250 kW wind turbine show considerably lower LCOE than the other scenarios. At the same time there is evident complementarity between solar PV, wind and storage as scenario 2.1 demonstrates with its LCOE estimates lower than pure solar scenario 1.1 or 1.2 with just the 100 kW wind turbine.

	Scenario 1.1	Scenario 1.2	Scenario 1.3	Scenario 2.1	Scenario 2.2
System LCOE (€/MWh) - no storage	€ 373.68	€ 204.48	€ 139.35	€ 216.92	€ 161.30
System LCOE (€/MWh) - 0.2 MWh	€ 371.02	€ 206.75	€ 136.38	€ 209.94	€ 157.68
System LCOE (€/MWh) - 0.5 MWh	€ 363.08	€ 215.87	€ 136.80	€ 199.79	€ 154.56
System LCOE (€/MWh) - 1 MWh	€ 343.65	€ 233.98	€ 142.78	€ 191.94	€ 155.80

3.6 Implementation challenges

The ICE Methodology recognises that an energy transition is an ongoing process, rather than a discrete event. It is likely that the ideal situation for each island considere within ICE will change over time, obvious factors which will change are the reelvative costs of the wind, solar and storage technologies which form the foundation for our scenarios, but the same will also be true for other technologies, such as tidal energy. Improvements in energy efficiency, and the technologies that help deliver it, are also likely to change over time.

Attitudes to technology may also change. We fond examples of a number of islands where technologies have been tried or considered once and where this has led to islanders having developed either very positive or very negative attitudes to them. This can lead to rejection of technologies which might otherwise seem appropriate, or can mean an attachment to particular options even where this does not seem likely to be economically favourable. Both may require work to get citizes to by into a technology or may mean that a technology is ruled out.

While both Molène and Chausey have sufficient available potential to achieve a target of 100% renewable electricity, other locaitos may need to aim lower initially. This may be due to limited potential, relative economics of renewable costs compared with fossil fuels, or other reasons specific to the island under consideration. The ICE GM makes it clear there is a need for regular reconsideration of goals as regards island energy policy, as well as routes to achieving those goals. Both need to be reappraised on a regular basis. This reapparials should also consider the evolving needs and wishes of the island citizenry and potetially also of other stakeholders.

The GM also makes it clear that state and private stakeholders need to practice transparency with the citizens impacted by changes to the energy system. This means openness about the technologies to be applied, the likely impacts on system performance, impacts on local emisiso and the contribution to wider problems such as climate change, but also the other otetial routes to maig change. Utilities should assume that ordiary members of the public will not be aware of the optios as they are and make efforts to give fair and balanced information to the public. Real data on actual operation of the technologies, and any imacts on costs should also be as transparent as possible.

3.6.1 Challenges specific to Molène

There are some limits on siting of the selected renewable energy technologies on Molène, but there are sufficient sites that this should not pose a problem to the levels of development outlined in the scenarios which could deliver 100% renewables for island electricity.

3.7 Fostering local enterprise

As well as the varying technical nature of the products and services required in a smart energy transition, local factors mean that 'who does what' is likely to vary widely between settings. For example, the precise range of services providers and their contracting arrangements depend on a wide range of contextual factors such as access to capital, risk perception, legal environment, experience of contractors etc. For this reason, it is inappropriate to specify here the scope of particular contract packages. Instead, we draw from the literature that underpins these guidelines to outline the types of products and services that are likely to be needed and present a framework that communities and other stakeholders can use and adapt to map against their specific requirements.

3.7.1 Overview of key principles of GM taken from T2.1.2

In general, a smart energy transition will present commercial opportunities spanning four broad domains of commercial opportunity:

- **Renewable energy supply -** In most (but not necessarily all) smart energy transitions in peripheral territories, an important goal is increasing the provision of energy from renewable sources.

- **Smart technologies and practices -** Better or 'smarter' management of electricity systems through the adoption of new technologies and practices is a crucial component of a smart energy isolated system.

- **Stakeholder engagement -** Establishing the goals of the energy system, establishing support for action and realising the benefits of action are all crucial parts of a successful transition.

- **Oversight and management -** Planning, guiding and measuring the success of the system transition as a whole.

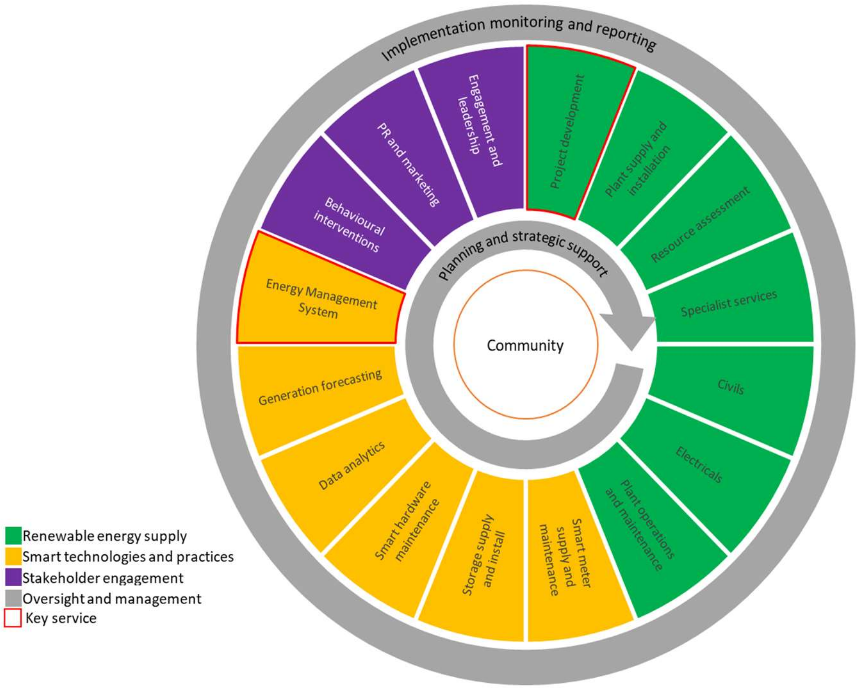

Figure 36 - Domains of opportunity and the likely types of product and service for the transition.

The ICE GM also seeks to build capacity in local businesses by providing advice on topics such as:

- Access to finance
- Innovation funding

Finally, a system of business support based on the creation of a network of businesses invited to participate in a network for collaboration and interaction. Opportunities for businesses form a major component of ICE Work Package 4.

3.7.2 Mapping Local Enterprise Capacity

Analysis of the capacities of local enterprise to service the demands of developing and maintaining the future energy system was carried out as follows: Key characteristics of the future energy system and stakeholders were identified in order to determine the opportunities for services and stakeholder engagement and populate the value chain. These characteristics were then mapped to nearby businesses and organisations in Brest and wider Finistère with relevant expertise produce an initial picture of local capacity to inform an approach to supporting or engaging local enterprise.

Characterisation of the future energy system and stakeholders

The future energy system on Molène in our scenarios is relatively centralised with the solar PV and wind turbine both installed on or near the impluvium as well as a single large battery storage unit. It is likely that these would be installed and operated by EDF-SEI. It is possible that, as on the telecommunications station, individual properties may also invest in micro-generation and storage. Generation capacity targets for solar and wind are specified in the island's energy strategy indicating a degree of certainty around their deployment. The acceptability of the systems within the local community is unknown.

The island has explicit targets for energy efficiency, but the precise measures are not clear – the installation of high efficiency lighting, upgrades to cold storage units and improved building energy efficiency have all been carried out over the past ten years (Le Ministère de la Transition Énergetique, 2019). Linky smart meters have been installed in 90% of properties which enable both the granular monitoring of consumption and deployment of time of use tariffs. Behaviour change by residents (for instance via price incentives and smart appliances) will help optimise the efficiency of the new system. The scenarios we have modelled have incorporated reductions in energy consumption due to additional measures similar to those carried out so far – i.e. requiring the skills of electricians and the building trades.

The network on Molène is owned by the local government, SDEF, and operated under a long-term contract by ENEDIS and this is unlikely to change in the future. Parts of the electricity network on the island are likely to need upgrading for potentially higher generation output, depending on the capacity installed and the configuration of the battery storage.

The immediate stakeholders on the island include the almost 200 residents, local businesses, residents' groups, the island council and the local government of Finistère, as well as ENEDIS and EDF-SEI as utilities. There is a wider set of stakeholders which also includes local transport providers (ferry services), fishermen, conservation organisations, and tourists.

Capacity Mapping

Given the monopoly position of EDF-SEI and ENEDIS in France, a centralised approach to energy system change is likely, but there are nonetheless opportunities for much work to be carried out to local providers.

With regard to renewable energy supply, a limited number of suppliers of general and specialist materials identified in Brest with a larger but still small group across FInistère. For the planning and installation, more organisations were identified with both specialist (e.g. high voltage electricity networks, solar PV) expertise and generalist (e.g. electrical, ground works) competencies.

There were no smart grid specialists identified local to Molène, and only a handful across France. However, a range of building trades suppliers operate in Brest and the region of Finistère who could source and supply equipment and materials for energy efficiency and smart demand management technologies. A number of organisations capable of providing mainstream general (e.g. window and insulation installation, electrical) services in this area were identified locally.

A number of local academic institutions were identified which may have expertise in stakeholder engagement. No private sector organisations were found.

Local logistics and storage providers exiust who may be able to support ongoing operation and maintenance. Organisations identified for installation services (e.g. high or low voltage network specialists or heat pump and solar PV installers) may also be able to provide long-term maintenance. No specialist grid or renewables asset managers could be identified locally.

4 Conclusion

This assessment of the potential for renewable energy on Molène in many ways forms a companion piece to our initial assessment of Ushant. The selection was intended to test the method in a similar environment with a view to seeing how far this pushed the methodology and whether any variables emerged to cause any substantive impact on the resulting scenarios.

Molène has a somewhat smaller population than Ushant, both in terms of permanent residents and in terms of peak visitor levels. The island could be expected to have similar wind and insolation to Ushant given its relative position and similar geography. Nothing emerged during our data gathering to suggest that there would be any issues that made key renewable energy technologies unsupportable. We did not consider the potential for tidal energy which formed a part of the Usahnt assessment as there was no immediate plan to install on the island.

As with other scenarios our initial assessment of the available renewable generation technologies led us to focus on a combination of wind and solar, with a consideration of how storage might best fit with different combinations of either technology in terms of delivering strong reliability while achieving low costs. The relatively low population to available land on Molène meant that pressure on land use should not be a barrier to achieving high penetration of the two key renwable technologies. The proposed addition of storage capacity should also be possible without any issue concerning footprint.

Our assessment suggests that it is possible to achieve generation in excess of 100% of island electricity needs via the deployment of wind, solar and battery storage. Costs tend to drop off with higher levels deployment and are lower in scenaris which mix wind and solar, rather than using one or the other technology. It can be expected that there are upper limits on total consumption which make it less worthwhile to keep installing new capacity.

As with other islands, interaction with Molène’s population is likely to have benefitted this study, but was limited both by covid lockdown and by opportunity. Relevant to all the French islands considered here, It also proved difficult to improve our understanding of the regulatory system as it applies in practice. Several requests to speak to EDF did not lead to dialogue.

As with Chausey, there is some potential to dig further into the provision of heat on Molène and whether the current electrical demand could be more efficiently and effectively met with a roll out of heat pumps. As with Chausey, the issue of meeting the high capital costs of heat pumps would need to be addressed. Here again, there is potential for overall cost savings by different actors (the utility, the state, households) since currently most houses rely on electricity for heating anyway. Such a roll out would mean an overall reduction in electrical usage on the island, meaning that less new renewable energy generating capacity would be needed to decarbonise the island. There is also significant potential for increased comfort by householders. This is a topic that would benefit from further research on the islands, including in relation to public acceptability of the technology by the local population.

4.1 Assessment of validity – does the General Methodology apply in this context?

We consider the application of the ICE General Methodology (GM), and any issues arising from the approach, in an addendum to the GM, which is available as a standalone document “Lessons from application of the ICE General Methodology” from the ICE website.

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6 Appendix 1

6.1 Solar Resource Assessment

The map in Figure 37 shows solar irradiance across France and indicates that the Îles du Ponant, including Molène, have a relatively high potential for solar PV deployment.

Figure 37 - Global Horizontal Irradiance in France

The table below shows the Global Horizontal Irradiance (GHI) and the Global incident irradiance at 30^o and 38^o values for Molène.

Table 16 - Irradiance values for Molène, generated using PVGIS data.

Month	GHI (kWh/m^2)	G(30^o) (kWh/m^2)	G(38^o) (kWh/m^2)

January	28.7	44.5	47.3
February	41.9	55.9	58.0
March	84.2	107.4	110.0
April	116.1	128.8	128.0
May	154.6	159.5	155.7
June	167.0	166.5	160.8
July	155.8	157.5	152.9
August	140.4	154.2	152.6
September	101.4	123.3	125.1
October	60.4	82.5	85.7
November	33.3	48.0	50.4
December	22.5	33.3	35.2
Total	*1,106.3*	*1,261.4*	*1,261.9*

6.2 Wind Resource Assessment

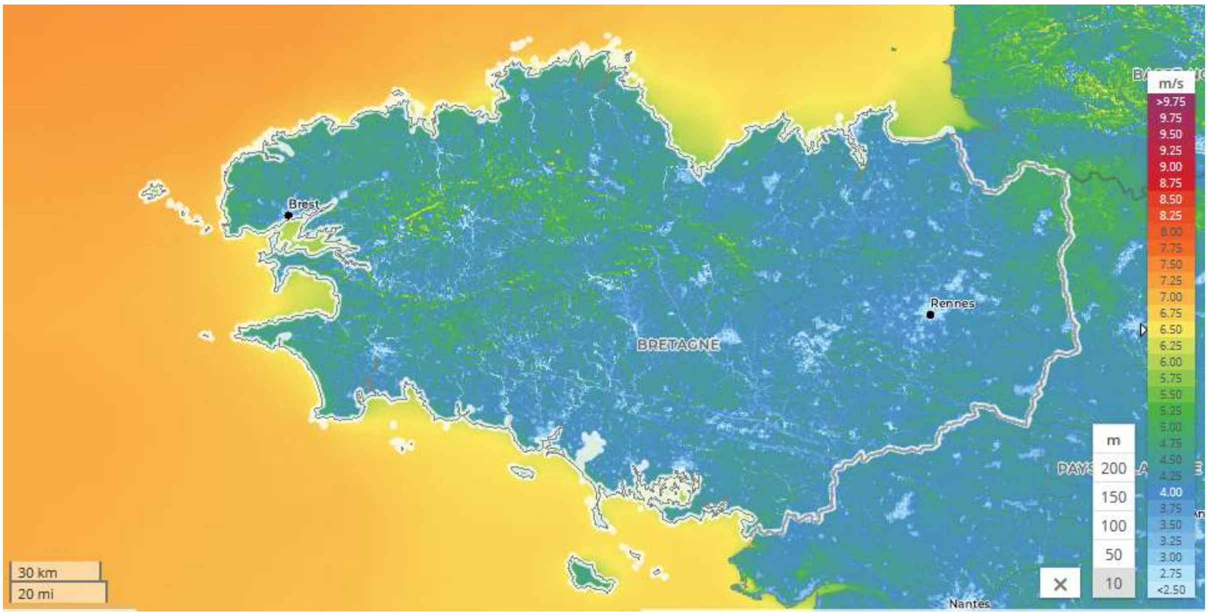

Figure 38 - Distribution of wind speed at a height of 10m in Brittany (Global Wind Atlas https://globalwindatlas.info

Equation 1 - Wind speed extrapolation to a particular height. Where z is the hub height of the turbine, zref is the height that the data is collected at, Vref is the speed at height zref, z0 is the roughness, and V(z) is the resultant wind speed at the hub height. (Burton et al., 2011)

$$V(z) = V_{ref}\,\frac{\ln\left(\frac{z}{z_0}\right)}{\ln\left(\frac{z_{ref}}{z_0}\right)}$$

6.3 Capacity Mapping

Supplier opportunities were characterised based on the draft General Methodology as well as work from ICE work package 4 D4.1.1.

Supplier opportunities	**Requirements/Organisations**	**Opportunities for Island**	**Example Businesses**
Planning			
- Project Rationale	SDEF, EDF-SEI, ENEDIS	N/A	
- Public Consultation	Residents and stakeholders	Consultancy, engagement specialist Universities	Brest: Finistère: Université de Rennes II Université de Bretagne Occidentale (A Lanrédec) Ecole nationale de la Statistique et de l’Analyse de l’information (à Matival, Ille-et-Vilaine) Université de Bretagne Sud
- Surveying and Consenting	Environmental permit to Départment.	Consultancy “Conseil en écologie et en environnement (autres)”	Brest: CEE: 37 Finistère: CEE: 284
Financing	Capital for hardware. Money for planning, engagement and organisational procedures.	EDF/SDEM50	
Grid Design and Engineering	Cable, connections and hardware upgrades.	(ENEDIS) Contracted engineers HV electrical engineers – ‘Installation de systèmes de distribution à haute tension’ Civil engineers: ‘‘Ingéniers civils’ “Conseil en énergie éolienne” “Conseil en énergie solaire”	Brest: ISDHT: 5 CEE: 4 CES: 5 Finistère: ISDHT: 27 CEE: 20 CES: 8
Procurement			
- Generation	PV panels, inverters, connections, mounting Wind turbine, base, connections.	Renewable suppliers - Local building trades suppliers ‘Matériel de production d'énergie solaire photovoltaïque, solaire thermale et héliothermique’ ‘Pièces et accessoires pour le matériel de production d'énergie solaire’ “Matériel, pièces et accessoires de production d'énergie éolienne”	Brest: MPESPSTH: 0 PAMAES: 1 (repeats) MPAPEE: 6 Finistère: MPESPSTH: 1 PAMAES: 2 (repeats) MPAPEE: 17

- Storage	Storage system, controls, housing, connections	Local building trades/electrical suppliers “Accessoires pour câbles et fils de lignes électriques” “Accumulateurs, batteries et piles électriques rechargeables” “Fils électriques isolés” “Commutateurs électriques” “Câbles électriques isolés (par usage)”	Brest: ACFLE: 1 ABPE: 4 FEI: 1 (CGED) CE: 1 CEI(U): 1 Finistère: ACFLE: 5 ABPE(PU): 8 FEI: 2 (CGED) CE: 9 CEI(U): 16
- Interfaces & Services		Specialised N/A	
- Demand Management		Electrical suppliers “Appareils électriques d'éclairage intérieur” Building suppliers “Travaux d'isolation et d'étanchéification des bâtiments”	Brest: AEEI: 0 TIEB: 16 Finistère: AEEI: 16 TIEB: 124
Installation			
- Generation	Wind – by manufacturer	Solar PV installers “panneaux solaires” ‘Conseil en énergie solaire’ “Montage et installation d'éoliennes”	Brest: PS: 1 CES: 5 MIE: 0 Finistère: PS: 12 CES: 8 MIE: 2
- Civils		Ground workers – ‘travaux publics’ “Travaux auxiliaires pour le bâtiment”	Brest: TAB: 16 Finistère: TAB: 154
- Electricals		HV electrical engineers – ‘Installation de systèmes de distribution à haute tension’ Electrical contractors/engineers – ‘Travaux d’installation électrique’ ‘Installation de systèmes basse tension’ ‘Installation de groupes électrogènes’	Brest: ISDHT: 5 TIE: 159 ISBT: 6 IGE: 2 IPSTD: 5 Finistère: ISDHT: 27 TIE: 895 ISBT: 46 IGE: 9 IPSTD: 23

		“Installation de postes et sous-stations de transformation et de distribution”	
- Demand management		Heating engineers – ‘chauffage’ Builders, Window fitters “Travaux de vitrerie de bâtiment” ‘Conseil en économie d'énergie’ Cladding: “Travaux de couverture, de toiture, de Zinguerie et de bardage” “Entreprises de rénovation de bâtiments” “Installation de pompes à chaleur”	Brest: TVB: 168 CEE: 5 TCTZB: 36 ERB: 9 IPC: 0 Finistère: TVB: 925 CEE: 22 TCTZB: 565 ERB: 52 IPC: 12
Operation			
- Logistics	Spares and co-ordination – EDF/ENEDIS or 3rd party		Brest: Finistère:
- Maintenance	Inspection and monitoring	Storage providers – ‘stockage’ Electrical suppliers	Brest: S: 47 Finistère: S: 195
- Billing	EDF-SEI	N/A	
- Management	EDF-SEI/ENEDIS	N/A	
User benefits			