Solo Energy Ltd.

# RDD00154 eStore

Final Report

# Document Management

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# Table of Contents

# Table of Figures

# List of Tables

# 1 Introduction

The purpose of this report is to serve as supporting documentation for the request of the final grant payment of the Sustainable Energy Authority of Ireland (SEAI) Research Development and Deployment (RDD) project 00154.

The eStore project incorporates the installation of behind-the-meter battery storage devices at several locations with different customer types and use cases. The eStore project is a collaborative project between lead project partner Solo Energy, ESB Networks, and DP Energy.

## 1.1 Background on Project Partners

Solo Energy is a new energy-storage-as-a-service provider based in Cork, Ireland. Solo's business model centres on the deployment of a distributed demand-side energy storage network. Solo charges the storage network from the grid during periods of peak renewable generation and low demand, when wholesale electricity market prices are typically lower, and from on-site solar PV / wind generation where present. When wholesale market prices increase, we switch our customers from grid supply to battery supply, delivering low-cost electricity stored in the battery, rather than high cost electricity from the grid. We offer this service to retail electricity supply partners to minimise their cost of supply. Furthermore, our distributed network also facilitates provision of grid services to system operators that would otherwise have been addressed through network investment.

Solo's cloud-based software platform *FlexiGrid* aggregates batteries within a distributed energy storage network to operate as a centrally controllable Virtual Power Plant (VPP). *FlexiGrid* incorporates a SCADA control system which communicates in real-time across a private IoT network to energy storage assets across the grid.

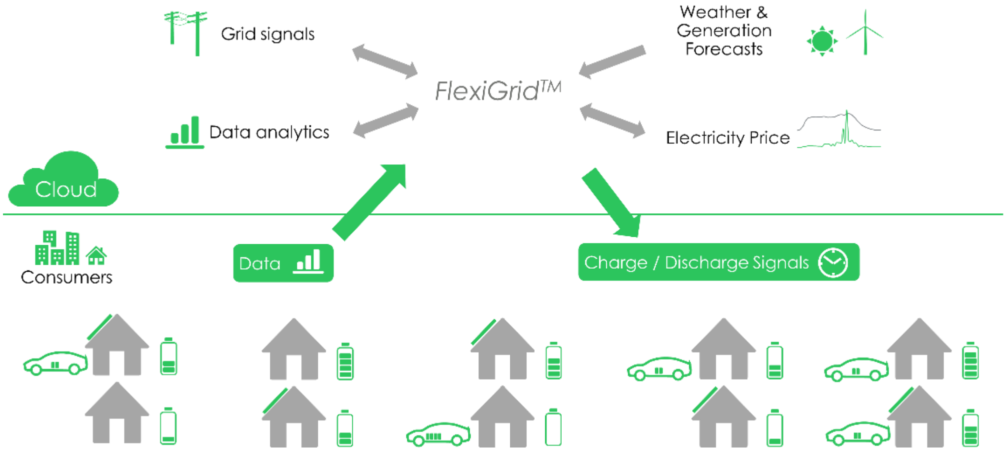


**FIGURE 1 - SOLO ENERGY DISTRIBUTED STORAGE NETWORK**

ESB Networks is the licensed Distribution System Operator (DSO) in Ireland and, as such, is tasked with operating the Distribution Network within the standards outlined in the Distribution Code. The advent of distributed energy resources (DERs) on the LV Network will bring challenges to keep the network operating within these standards. To this end the eStore project offers the opportunity for ESB Networks (ESBN) to assess the impact of energy storage solutions on the LV and MV Network.

DP Energy is a renewable energy and sustainable development specialist operating globally. All DP Energy developments are sustainable and environmentally benign.

## 1.2 Objectives

The overall objectives of the eStore project are as follows:

- Demonstrate how behind-the-meter storage can facilitate the further integration of renewables and enable the transition to 100% renewable energy supply
- Act as a physical demonstration project to follow on from Solo's 2016 power flow study 'FlexiGrid' which detailed the benefits of connecting a cluster of behind-the-meter battery devices, coupled with Solar PV, at a housing development on the distribution system
- Gain an understanding of the connection process, installation and operation, both aggregated and unaggregated
- Compare the operation of behind-the-meter storage under different operating regimes
- Assess the potential of energy storage to reduce consumer's electricity bills
- Act as a case study to empower consumers to move from being passive consumers to active prosumers
- Perform distribution system and load profile monitoring
- Examine the benefits to the DSO (ancillary services, voltage regulation, losses and asset replacement/refurbishment deferral)

## 1.3 Scope

The scope of the eStore project is detailed in Table 1.

**TABLE 1 – ESTORE PROJECT SCOPE**

| Task | Description | Deliverable |
|---|---|---|
| **Task 1: Connection & Installation** | | |
| 1-1 | Submit application to ESB Networks for connection of battery storage and/or PV at each location | Connection agreements |
| 1-2 | Procure battery devices and solar PV | Procurement |
| 1-3 | Installation and commissioning of batteries, meters, solar PV | Operational installations |
| **Task 2: Operating Regimes** | | |
| 2-1 | Develop customer constraint algorithms for input to SCADA control for each location | Customer constraint algorithms |
| 2-2 | Implement regimes; peak reduction, self-consumption, grid charging | Monitoring of effect of different operating regimes |
| 2-3 | Investigate operation in islanding mode | Analysis of battery performance under backup power scenario |
| 2-4 | Operate the battery in aggregated mode - charging and discharging | Operational test of aggregation |
| **Task 3: Monitoring** | | |

| Task | Description | Deliverable |
|---|---|---|
| 3-1 | Monitor load profile before and after battery and/or PV installation | Monitoring data |
| 3-2 | Identify energy use patterns including large loads (heat pump, oven, immersion, etc.) | Data analysis |
| 3-3 | Record effect of different battery operating regimes on load profiles | Monitoring data |
| 3-4 | Post process results – showing effect of storage on daily, weekly profiles using different operating regimes | Detailed analysis and summary of monitoring data |
| 3-5 | Performance monitoring of the 10 kV distribution feeder | Monitoring data under different operating scenarios |
| **Task 4: Market Analysis** | | |
| 4-1 | Examine potential for ancillary services though aggregation – analyse actual provision of reserve services through aggregation. | Desktop analysis of aggregated response for various (reserve) ancillary services |
| 4-2 | Model arbitrage opportunity based on historical data, e.g. day ahead and intraday electricity market price. Sensitivity analysis based on different | Desktop analysis of potential revenue |
| 4-3 | Perform sensitivity analysis of different % mix of ancillary services and arbitrage | Sensitivity analysis of revenue using different operating regimes |
| **Task 5: Customer Benefit Analysis** | | |
| 5-1 | Examine impact of different operating regimes on customer net consumption and resulting charges | Consumer electricity savings report |

## 1.4 Timeline

SEAI's letter of offer was issued on 15th August 2017 and, as such, serves as the project's start date. The project completion date is 14th February 2018.

**TABLE 2 – ESTORE PROJECT SCOPE**

| Milestone | Description/Deliverable | Date |
|---|---|---|
| Project Start Date | Commencement of project | 15th August 2017 |
| Milestone 1 | Interim update on procurement, installations and monitoring | 15th November 2017 |
| Completion | Final report on monitoring results and analysis | 14th February 2018 |

## 1.5 Costs

SEAI's grant payment is payable solely in respect of eligible costs. The eligible costs for eStore are listed in Table 3.

**TABLE 3 – ELIGIBLE COSTS**

| Category of Costs | Maximum |
|---|---|
| Materials & Equipment | €8,260 |
| Internal Staff | €29,580 |
| External Consultants | €11,707 |
| Travel | €4,500 |

# 2 Connection & Installation

The status of the of the connection applications, procurement of equipment an installation associated with the final five chosen sites is shown in Table 4. Images of the completed installations are shown in Figure 2 to Figure 4.

**TABLE 4 – STATUS OF CONNECTION APPLICATIONS, PROCUREMENT & INSTALLATIONS**

| Site | Task 1-1 ESBN Connection Application | Task 1-2 Procurement | Task 1-3 Installation |
|---|---|---|---|
| Ballyvolane, Cork | Approved | Complete | Complete, 22nd & 23rd Aug 2017 |
| Ovens, Cork | Approved | Complete | Complete, 21st Aug 2017 |
| Dún Laoghaire, Dublin | Approved | Complete | Complete, 15th Sept 2017 |
| UCC, Beaufort Building, Ringaskiddy, Cork | Approved | Complete | Complete, 18th Jan 2018 |
| DP Energy, Buttevant, Cork | Approved | Not completed within project timeframe | Not completed within project timeframe |

## 2.1 Connection Process & Applications

In Ireland, micro-generation is defined as a source of electrical energy and all associated equipment, rated up to and including[1]:

- 25 A, circa 6 kW, at low voltage [230 V], when the Distribution System Operator (DSO) network connection is single-phase
- 16 A, circa 11 kW, at low voltage [230/400 V], when the DSO network connection is three-phase

Where multiple generating sources [of the same or varied technologies] are on the same site and share access to the same ESB Networks connection point, the aggregate rating must not exceed:

- 25 A at low voltage, when the DSO network connection is single-phase
- 16 A at low voltage, when the DSO network connection is three-phase.

The above requirements relate to the equipment that interfaces with the DSO network, for a solar PV or battery installation this means the AC/DC inverter. Therefore, it is possible to have, as an example, a single

[1] Conditions Governing the Connection and Operation of Micro-generation, DTIS-230206-BRL, ESB Networks March 2009

phase solar PV installation greater than 6 kW so long as the interfacing AC/DC inverter is no greater than 6 kW (PV installations are generally oversized when compared to the rating of the solar PV inverter).

If there is more than one generation source and/or interfacing equipment installed, then the aggregated rating of the inverters must not exceed the 6 kW and 11 kW limits for single phase and three phase installations, respectively.

All micro-generator interface equipment must comply with EN 50438 with the specific Irish protection settings[1].

Connection of micro-generation is a straightforward three step process:

- submit microgeneration connection application form (NC6), including proof of EN 50438 compliance. There is no associated fee.
- If ESB Networks become aware of any other technical or location specific reason why installation should not proceed, then ESB Networks shall inform the customer within 20 working days of receipt of the connection application form. If no such notice, or request for type test certification, or instruction to suspend installation, is received by the customer within this time-frame, then the installation can proceed without any further correspondence with ESB Networks.
- proceed to install

Connections with equipment ratings exceeding micro-generation limits are subject to a more onerous connection process, potentially incorporating network interaction studies[2] and an associated fee of €773 for installations < 50 kW, with the fee rising for larger installations.

As it currently stands, battery storage is classified as generation in Ireland. Therefore, based on the existing micro-generation requirements, under the scenario where, as an example, there is both a solar PV installation and a battery installation on site the combined rating of the inverters must not exceed 6 kW for a single-phase installation. Therefore, should a customer have a solar PV installation, with a 6 kW inverter, already installed, this prevents them for installing a battery storage system at a later date. One possible workaround is to utilise a hybrid inverter, up to a rating of 6 kW/11 kW, which can take both solar PV and battery DC inputs; however, there are a limited number of such hybrid inverters available on the market and, furthermore, this is not a suitable solution for retrofit of a battery where there is already generation on-site.

Whilst the micro-generation limits are not necessarily an issue for smaller installations, for example 3 kW, with a 2.5 kW inverter, and a 10 kWh battery system with a 3.5 kW inverter (total inverter rating coming to 6 kW), it clearly presents an obstacle for larger installations, reducing one of the main drivers of battery storage at a domestic level for the end consumer, i.e. increased self-consumption of on-site renewable generation.

The UK have similar micro-generation requirements to Ireland (G83/2[3]); however, several of the Distribution Network Operators, including UK Power Networks, Western Power Distribution and Scottish and Southern Energy Networks have recently introduced a new process for storage installations, meaning that there is no need to undergo the more onerous G59 process (equivalent to the Non Group Processing approach here in Ireland). The fast track process facilitates the aggregated rating of on-site storage and generation inverters to exceed the G83 requirements so long as each individual inverter complies with G83 itself.

2 https://www.esbnetworks.ie/new-connections/generator-connections/connect-a-renewable-generator

3 Engineering Recommendation G83 Issue 2, Energy Networks Association, 2012

ESB Networks has been looking into the emerging use of this fast track process in the UK and is open to the possibility of its adoption, where it can facilitate connection of storage and also provide further re-assurance of compliance with the capacities applied for by their customers.

For each site forming part of the eStore project, all connection applications were submitted to, and approved by, ESBN.

## 2.2 Procurement

The number of residential battery options available for use in Ireland is, unfortunately, relatively limited at present. The primary issue relates to EN 50438 type test certification of the AC/DC inverter - very few battery inverters currently have this certification as Ireland has a relatively small number of micro-generation installations when compared to other EU countries, for example circa 900,000 homes in the UK have solar PV installed on their roof. As a result, Ireland is not currently a key target market for many manufacturers.

The completed installations consist of the following equipment:

- LG Chem RESU7H 7 kWh battery (RESU10H 10 kWh battery in the case of Ballyvolane)
- Solar Edge SE3500 3.5 kW Inverter or Solar Edge HD Wave SE3500H inverter (certified to EN50438 with Irish protection settings)
- Solar Edge 1/3 phase Modbus meter (single meter for sites with generation, two meters for sites with Solar PV)
- Solar Edge 100 A current transformers
- Sierra Wireless LS300 gateway

## 2.3 Installations

Figure 2 to Figure 5 shows the installations completed as part of the eStore project:

1. Ballyvolane fire station: three phase connection, 10.92 kW solar PV, 10 kWh battery, 3.5 kW inverter
2. Domestic premises: single phase connection, 7 kWh battery, 3.5 kW inverter, heat pump
3. Dún Laoghaire Rathdown County Council domestic premises, Dún Laoghaire: single phase, 2 kW solar PV, 7 kWh battery, 3.5 kWh inverter
4. Centre for Marine and Renewable Energy (MaREI), UCC, Ringaskiddy: three phase, 2x10 kWh batteries, 2x3.5 kW inverters.

The works included in (4) incorporate the installation of a battery on two of the three phases within the energy storage research facilities at MaREI. A third battery is planned for installation on the remaining phase within the next few months, but this installation falls outside of the scope of the eStore project. In addition to the use cases for the eStore project, the battery installation will also, in the next few months, be connected to the grid emulator which was installed at MaREI in late 2017. Again, such works fall outside the scope of the eStore pilot; however, it should be noted that the grid emulator was previously part funded by SEAI and the connection of the batteries to same will enable valuable research and testing through use of the emulator. As the name suggests, a grid emulator is designed to emulate grid disturbances such as harmonics, generation trips, voltage dips, frequency changes. Therefore, an unforeseen benefit of the eStore project is that it will facilitate valuable research in the area of interaction with the grid through the grid emulator-battery testing.

Figure 2 - Ballyvolane fire station installation

Figure 3 - Domestic premises, Ovens installation

Figure 4 - Domestic premises, Dún Laoghaire Rathdown County Council, Dún Laoghaire

**FIGURE 5 - CENTRE FOR MARINE AND RENEWABLE ENERGY, UCC, RINGASKIDDY**

## 2.4 Testing

Solo engaged with Edinburgh based storage solution provider Storflow with a view to procuring a unit to install at the premises of DP Energy in early 2018. Their current battery solutions include a battery based on Lithium Iron Phospate chemistry with associated hybrid inverter.

Solo procured a unit from StorFlow in late 2017, incorporating both the hybrid inverter and back up functionality, and proceeded to run functionality and control tests thereafter. However, it subsequently became clear that the inverter would not have the necessary EN 50438 certification in place within timeframe of the eStore project and hence this unit was not considered for installation at DP Energy's offices.

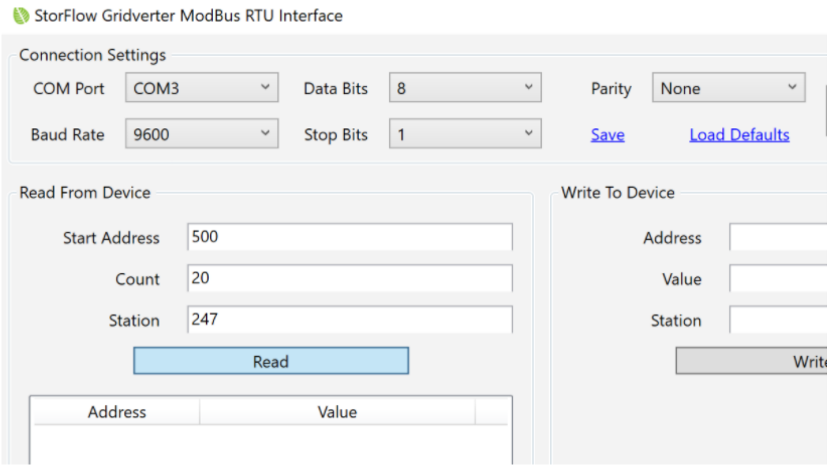


**FIGURE 6 – ALTERNATIVE BATTERY SOLUTIONS TESTING**

# 3 Operating Regimes

All operation control functionality is handled via Solo's FlexiGrid platform. Figure 7 presents an overview of the full Edge to Cloud solution, *FlexiGrid* is hosted on a number of Virtual Machines (VM) and communicates with on-site gateways via a secure and completely private telecommunications network. Each gateway is, in turn, hard-wired to the on-site battery unit and electricity/energy meter(s) (separate to the utility meter). Communications from the gateway to the battery inverter and energy meter(s) is achieved using standard communications protocols (Modbus TCP, Modbus RTU, CAN bus). Where control is not readily available locally through such communication protocols, Application Programming

Interface (API) functionality is instead utilised to communicate and control the battery inverter. The platform can communicate, securely, with customers via a portal/app, system operators through API interaction and can also bring in open source data (such as, for example, weather forecasting data from the web).

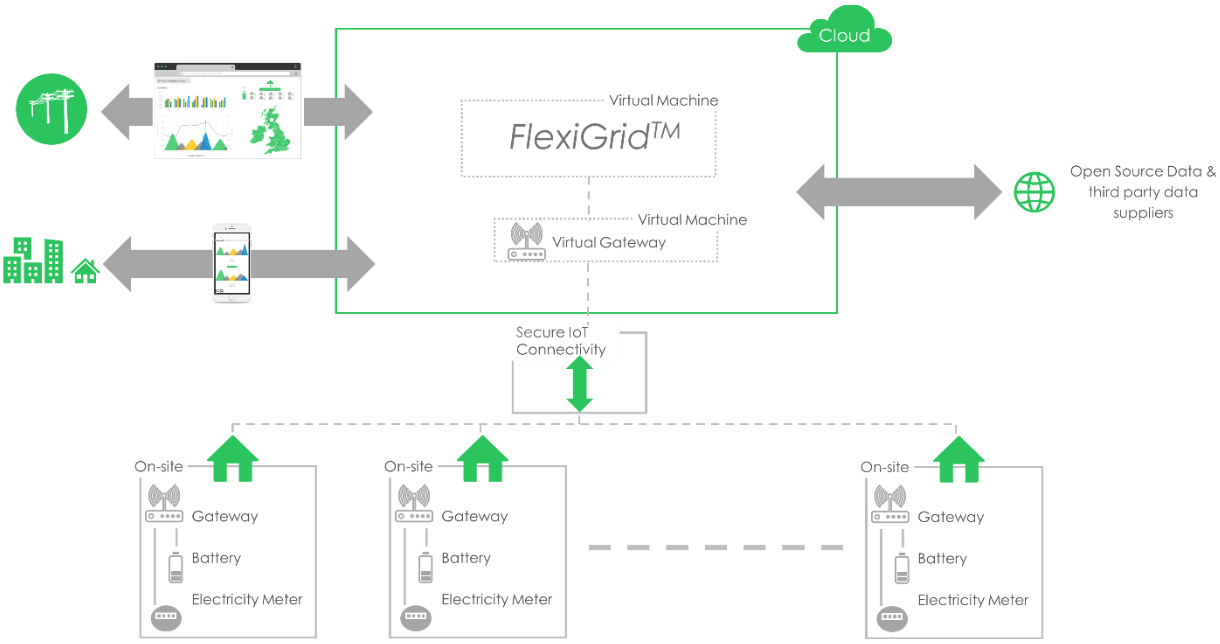


**FIGURE 7 – OVERVIEW OF EDGE TO CLOUD SOLUTION**

The *FlexiGrid* platform has been developed with the facility to scale from a single node to hundreds of nodes without re-architecting the entire application. The platform is object based, facilitating a straightforward drag and drop process to deploy new instances, again, without re-engineering the solution. Data storage, compression and analysis/reporting is achieved via the storage and reporting element with industry Standard Query Language (SQL) providing easy, open access to, and interrogation of, all monitoring, alarm and event data. The visualisation client provides a graphical HMI for operators, enabling the display of graphical symbols for assets and control functions, status and performance monitoring and alarm and event flagging. The development environment hosts the integrated design and development tool from which all objects are configured, deployed and maintained. The framework and communications element handles all device integration (OI servers), database management, etc.

For each site within the eStore project, operational communications were established from the Edge to the Cloud, i.e. from the onsite battery installation to Solo's control and aggregation platform *FlexiGrid*, via the gateway and secure IoT network, following commissioning of each site. Thereafter all control and monitoring is undertaken remotely from the cloud.

## 3.1 Customer Constraint Algorithms

Control can be implemented at individual site level or aggregated at a higher level, i.e. all units within a specified group or region operated in unison. Under the scenario where aggregated mode is selected, it is important that any localised constraints take precedence at a site where there are unique constraint or requirements for that site.

For the eStore project the following customer constraints were implemented:

- at sites where the customer is availing of a dual rate electricity supply tariff, i.e. day and night rate, charging of the battery was limited to periods when the cheaper night rate was in place.

Exceptions were made, with the agreement of the owners of the eStore sites, where functional and control testing was being undertaken for the purposes of the eStore project

## 3.2 Implement Operating Regimes

During the eStore project the following functionality was developed (where required), implemented and tested:

1. Manual and automated grid charging
2. Peak shaving – reduction of customer's import from grid during peak network times (typically, 18:00 to 20:00)
3. Maximise self-consumption of on-site generation and load following – supply the residual load at the customer premises
4. Provision of grid services: export of active power to the grid, voltage support through export reactive power to the grid

Figure 8 shows a plot of the state of charge of the Ovens battery during testing of the scheduled grid charging algorithms. The battery was remotely instructed, from the FlexiGrid platform in the cloud and via the secure IoT network and gateway, to charge at its maximum level, i.e. 3.5 kW, at 09:30. At 10:30, following an hour of charging, the battery was then scheduled to discharge to meet on-site load. Figure 8 shows the battery state of charge increasing from approximately 12.5% to 60% during the period 09:30 to 10:30. During the same period the load is seen to increase on site by approximately 290 W over each five-minute period, equating to approximately 3.5 kW over the full hour. At 10:30, following instruction to commence discharging to load, the battery state of charge was seen to decrease from approximately 60% to 12.5% over the next hour. During the same period there is no import taken from the grid, i.e. all demand is fed from the battery.

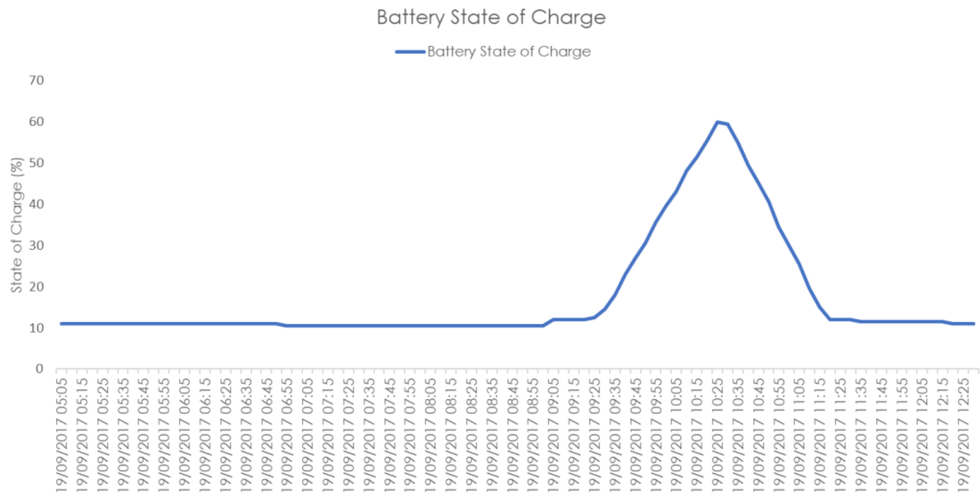


**FIGURE 8 – MANUAL GRID CHARGING FROM FLEXIGRID PLATFORM**

Figure 9 and Figure 10 show generation and battery state of charge respectively and illustrate the scenario whereby the battery is charging from excess solar PV on-site. This excess generation would otherwise have been exported to the grid by the customer, with no benefit accruing to them. Note that this is standard functionality of any residential battery solution.

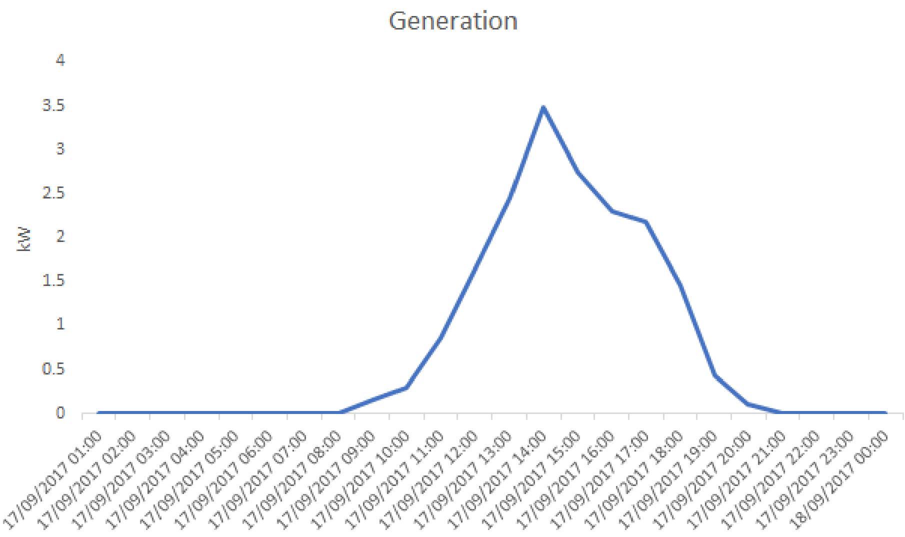


**FIGURE 9 – HOURLY SOLAR GENERATION AT BALLYVOLANE FIRE STATION ON SUN 17TH SEPT**

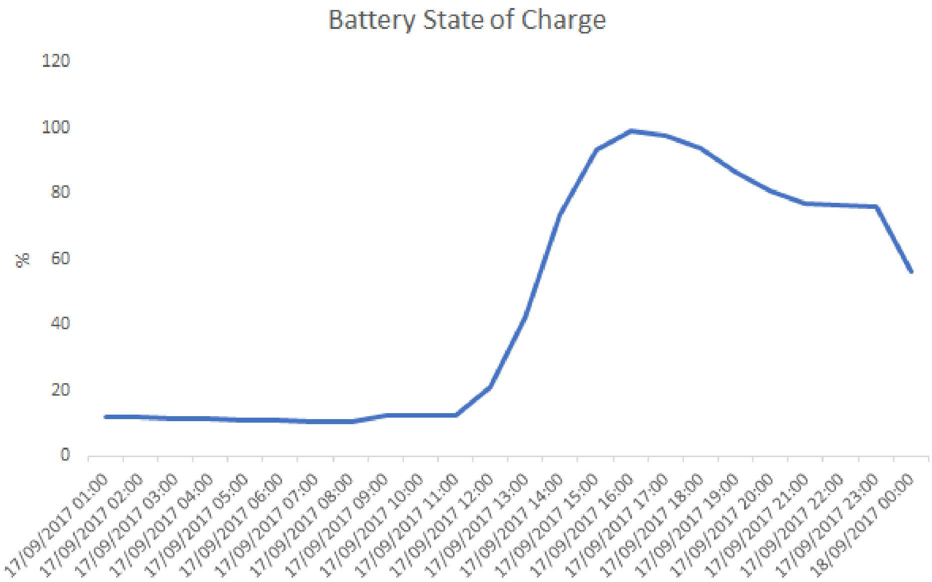


**FIGURE 10 – BATTERY STATE OF CHARGE AT BALLYVOLANE FIRE STATION ON SUN 17TH SEPT**

Figure 11 shows the automated charging of the battery at the domestic premises in Ovens followed by subsequent export of active power to the grid. From 00:00 to 01:00 the 3 kW (geothermal) heat pump is heating the hot water cylinder at the premises. During the 02:00 to 08:00 the heat pump is seen to be operating to provide heating to the premises. The battery is set to charge during the 06:00 to 08:30 period. At approximately 12:40 is battery is instructed to export full active power (3.5 kW) to the grid for circa 50 mins. The actual value of active power exported is slightly less than 3.5 kW as the base load within the home absorbs some of the power discharged from the battery.

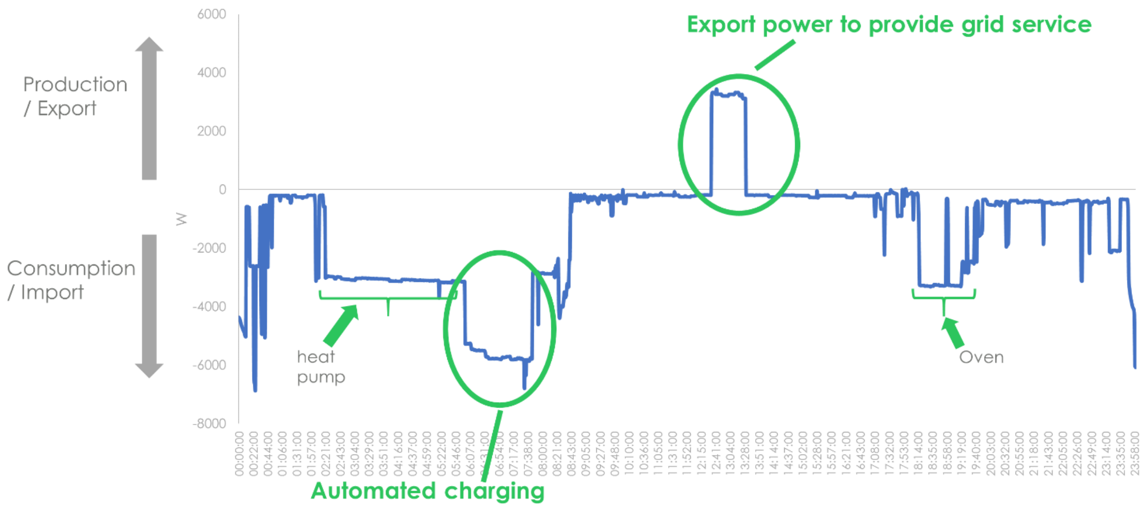


**Figure 11 – Automated charging, demonstration of active power export**

Figure 12 illustrates a successful demonstration of the provision of voltage support by exporting reactive power to the grid.

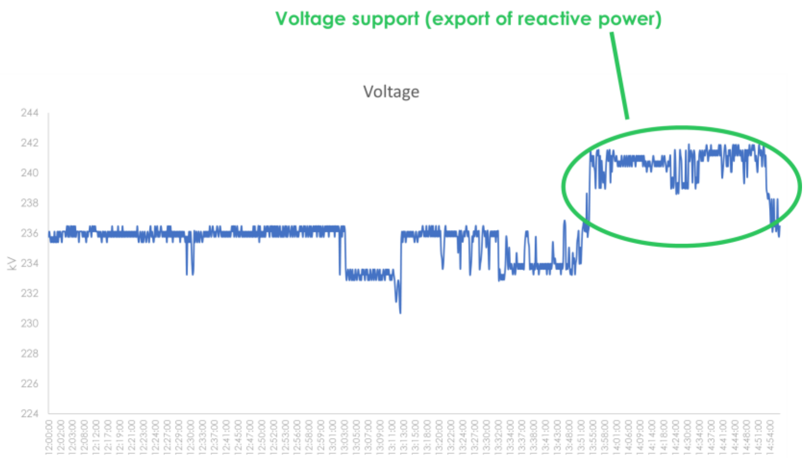


**Figure 12 – Export of reactive power to voltage support**

Similar to the above the operating regime considering reduction of a sites demand during peak times, i.e. 'peak shaving', was implemented by reserving sufficient capacity within the battery to ensure that there was sufficient energy in the battery from which to feed the premises during the peak time period.

### 3.2.1 Mechanism for Verification of Provision of Ancillary Services

Provision of demand response and ancillary services to the Transmission System Operator (TSO) EirGrid from aggregators in Ireland is already well established. Such provision is facilitated by means of a communications link between the TSO and the aggregator. Thereafter the aggregator has its own communication link to individual Demand Side Units (DSUs). The aggregator must supply the TSO with performance monitoring data from sites that meets the minimum standards and compliance requirement stipulated by the TSO.

To date, aggregation has focused solely on C&I scale but the provision of services from aggregated small-scale assets and domestic sites, has begun to gain some real traction, particularly in the UK.

Furthermore, localised grid services markets at the distribution level have also recently begun to emerge in the UK, with Distribution Network Operator (DNO) UK Power Networks launching a local flexibility tender.

In Ireland, ESBN are looking towards the scenario where aggregators can participate in a market for localised ancillary services at the distribution level,

ESBN has developed their own platform, SERVO, to serve as the enabling technology for such distribution markets in Ireland. SERVO consists of three modules each interlinked that take inputs from existing ESB Networks systems and feed outputs to third parties such as DSO, TSO, aggregators and market operator.

- SERVO Modeler is the data gathering and storage module that provides a central location for all network data from assets employed to network topology to switch status to time series data of energy flowing through the network.
- SERVO Live is the engine of the SERVO Platform that continually assesses the available capacity of the network by using the data from SERVO Modeler. With near real time data it can calculate the network state and available capacity that is the input to the SERVO Flex module.
- SERVO Flex is the outward facing module of the SERVO platform and acts as the interface between the SERVO Platform and third parties such as TSO and Aggregators. It is through SERVO Flex that network capacity is advertised, requested and procured from the market.

Through the eStore project, Solo and ESBN have fully tested the interaction between the FlexiGrid platform and SERVO. The interaction mechanism was achieved via an MQTT broker as shown in Figure 13[4]. Provision of on-site monitoring data from Solo's storage network to SERVO was established, tested and verified through a publish and subscribe type interaction. For example, performance data such as active power output, battery state of charge, and power factor has been successfully published to, and received by, ESBN. The work associated with eStore is the first such instance of verified interaction between SERVO and a third party platform.

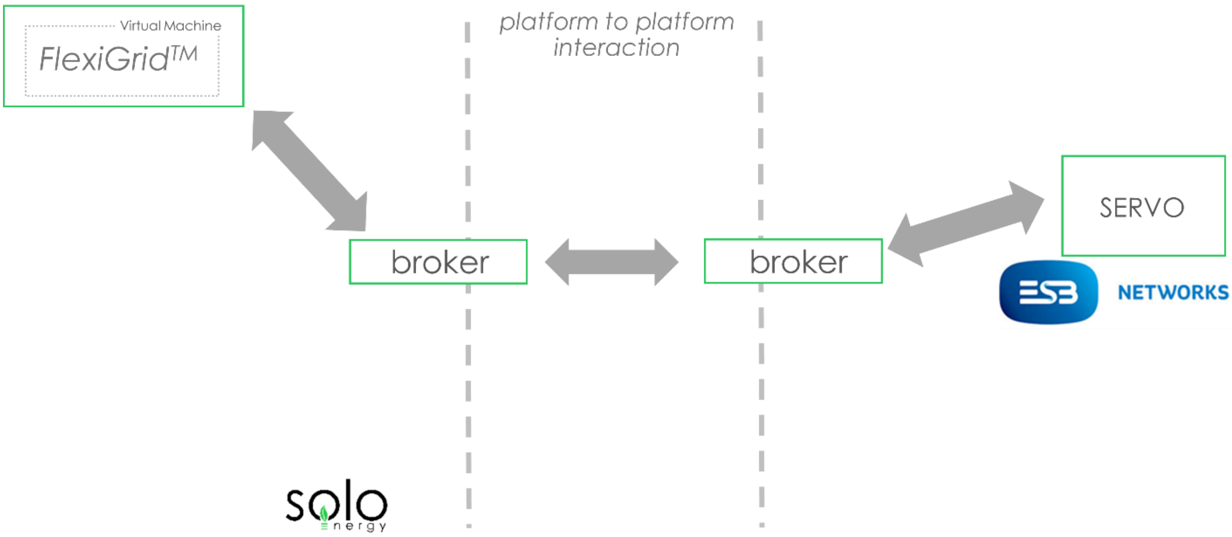


**FIGURE 13 – FLEXIGRID TO SERVO, PLATFORM TO PLATFORM, INTERACTION**

[4] MQTT is a common messaging technology http://mqtt.org/

## 3.3 Investigate Operation in Islanding Mode

As part of eStore it was intended to investigate the operation of a battery system in islanding mode, i.e. the battery serving as back-up to the building if there were to be a power outage.

Whereas a conventional battery installation will connect to the premises main distribution board, an installation that also provides backup functionality differs slightly in that the battery also feeds a separate critical loads panel, separate to the main distribution board, which is automatically isolated from the main distribution board in the event of a power failure. The full battery capacity, or a portion thereof, can be reserved to serve as back-up in the event of such a power outage.

Investigation of this functionality was not achieved within the eStore project for a variety of reasons:

1. The battery and inverter solution provided by Storflow that was originally intended for use at DP Energy's offices, where the back-up functionality was to be tested, does not have the necessary EN 50438 certification
2. Alternative back-up solutions, such as the Solar Edge SE5000-RWS inverter, which could instead be used at DP Energy's offices were not readily available from distributors
3. The other sites were not considered to be suitable. in the case of Ballyvolane back-up supply is already provide via automatic switchover to a diesel generator. The MaREi facility was similarly deemed unsuitable. Finally, the installations at Ovens and Dún Laoghaire were already completed and retrofit of the back-up functionality was therefore not feasible.

## 3.4 Operation in Aggregated Mode

Figure 14 shows Solo's existing distributed storage network in the UK and Ireland, consisting of five operational installations in Orkney, Scotland and five operational installations in Ireland, including the four operational eStore sites (with a total of five batteries across the four sites).

Aggregated control has been implemented and tested on a hierarchical group and geographic basis. For example, aggregated control can be performed at national level, i.e. all units within Ireland, of at regional level, i.e. all sites within Cork. Alternatively, batteries can be dynamically assigned to specific groups based on operational needs. An example of the value of such capability is a scenario where there are a large number of battery installations on one particular distribution network feeder. The batteries are to be charged sometime over the night-time period. If all batteries were to charge during the same 2-3 hour window then there would be a spike in demand on the distribution feeder. Instead, by assigning the installed batteries to different groups we can smooth out the effect of the charge over the night-time period, therefore resulting in a much smoother load profile on the feeder with no significant spike in demand. After that charging period all of the batteries can then be dynamically reassigned to operate together so, for example, on the DSO's request they all could be instructed to provide reactive power with the purpose of supporting voltage on the network.

**FIGURE 14 – ESTORE STORAGE NODES**

Figure 15 shows a screenshot of aggregated control of two of the eStore batteries located in the Cork area during testing of the aggregation control. The batteries at Ballyvolane and Ovens, were scheduled to charge at 3.5 kW for 3 mins at 10:27 approximately. The middle graph shows the power imported/exported from the grid (import is negative, export is positive). Prior to the grid charging of the battery there is minimal load (grid import) seen at both sites. At 10.27 the import from the grid is seen to increase by 3.5 kW at both sites for 3 mins and thereafter decreases to whatever the on-site load is at the respective sites.

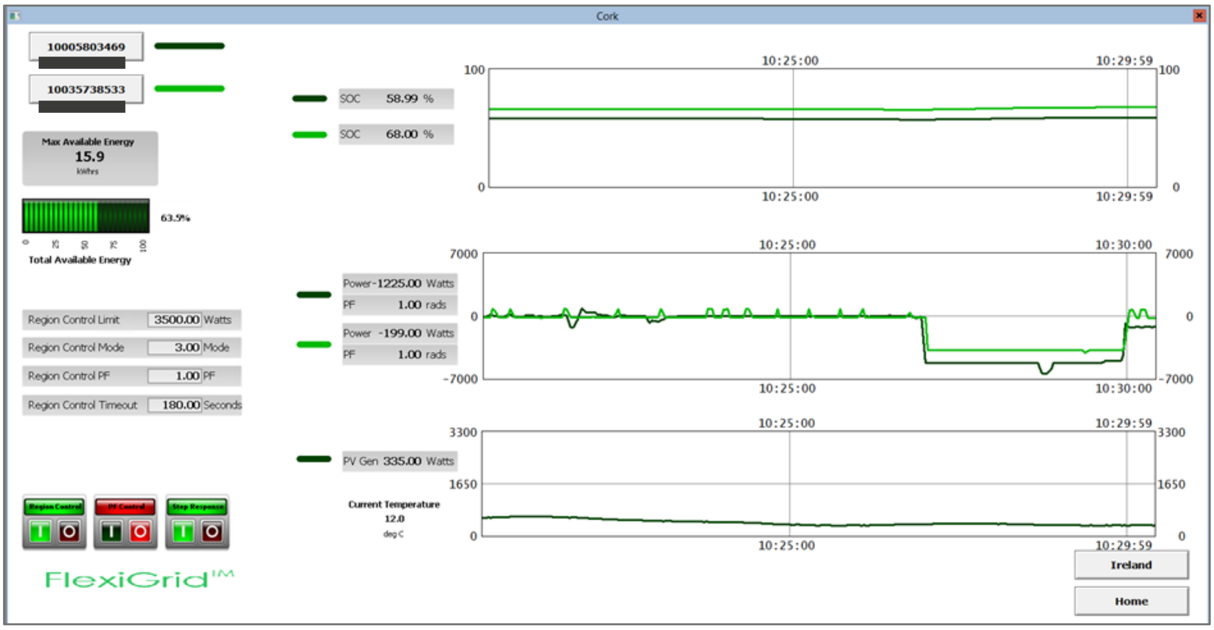


**FIGURE 15 – AGGREGATED OPERATION OF ESTORE NODES**

# 4 Monitoring

Whilst there is a significant amount of information available from the on-site battery installation, for the present time data collation, monitoring and analysis is limited to the following signals/values:

- Total on-site consumption
- Consumption on a per phase basis in the case of three phase installations
- Total on-site generation from solar PV
- Generation on a per phase basis in the case of three phase installations
- Battery state of charge
- Power factor of the inverter
- Power factor on-site
- Instantaneous power
- Voltage

In the subsequent sections the discussion of monitoring data is limited to the sites at Ovens, Ballyvolane and Dún Laoghaire as there was insufficient data available from the MaREI site following installation to enable any detailed analysis.

Figure 16 to Figure 19 shown the type of data that is available from site monitoring. Figure 16 shows the demand at Ballyvolane fire station over a twenty-day period. The fire station is manned and operated 24 hours and hence can have quite irregular patterns of demand depending on circumstances on any given day. Nonetheless, there is a clear pattern to the demand profile over the illustrated period. Figure 17 shows the generation at Ballyvolance fire station over a ten-day period. As expected the generation pattern is common across all days with only the magnitude of generation changing on any given day.

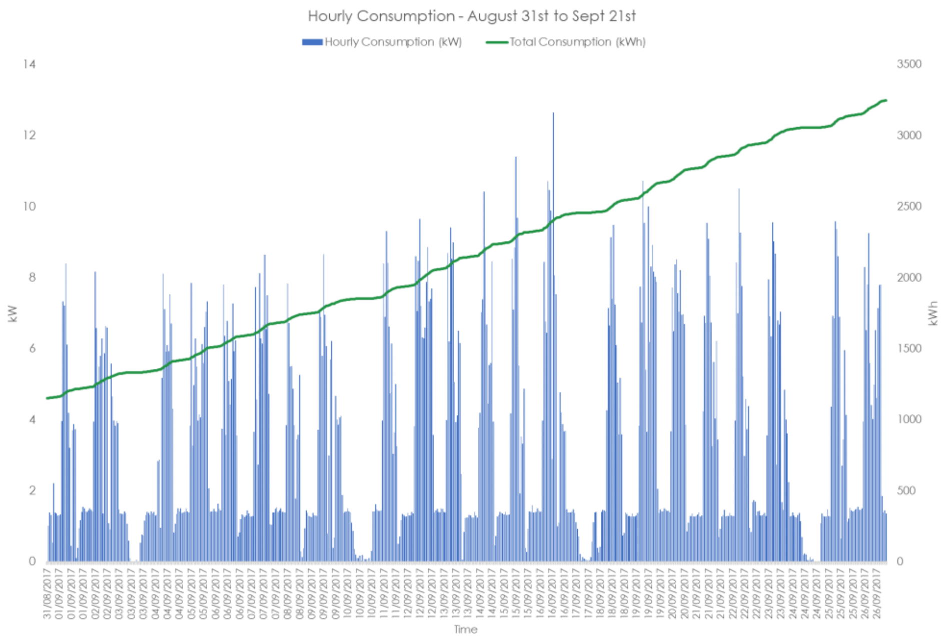


**FIGURE 16 - HOURLY TOTAL CONSUMPTION AT BALLYVOLANE FIRE STATION**

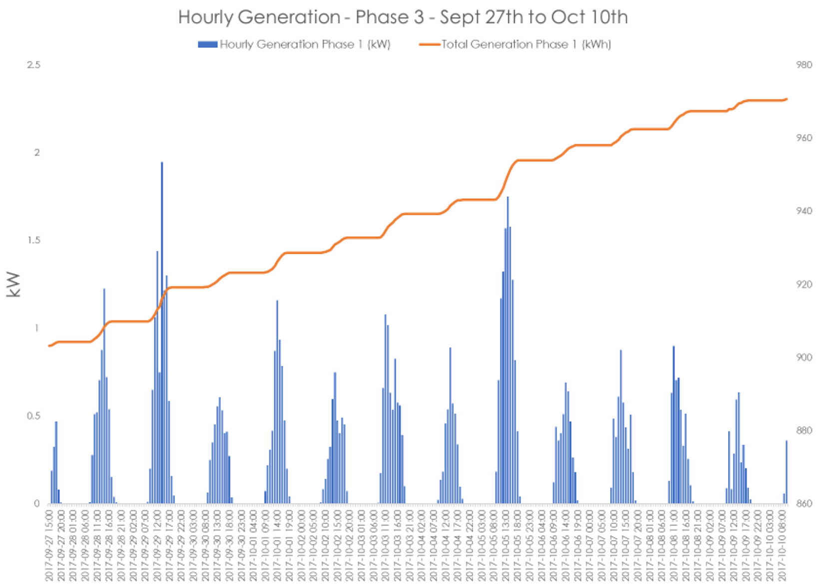


**Figure 17 - Hourly total solar generation Ballyvolane fire station**

Figure 18 shows the battery charge, discharge profile over an extended period. Initial testing was undertaken before grid charging was implemented. Thereafter, the battery can be seen to charge each night prior to releasing energy during the day. The benefits of the monitoring data is clearly visible, allowing for easy performance monitoring and easy identification of faults or issues. For example, communications and eight days of data due to RCD trip and communications scan rate issues were identified and resolved and remedial measures put in in place to eliminate such occurrences and/or reduce the impact of same.

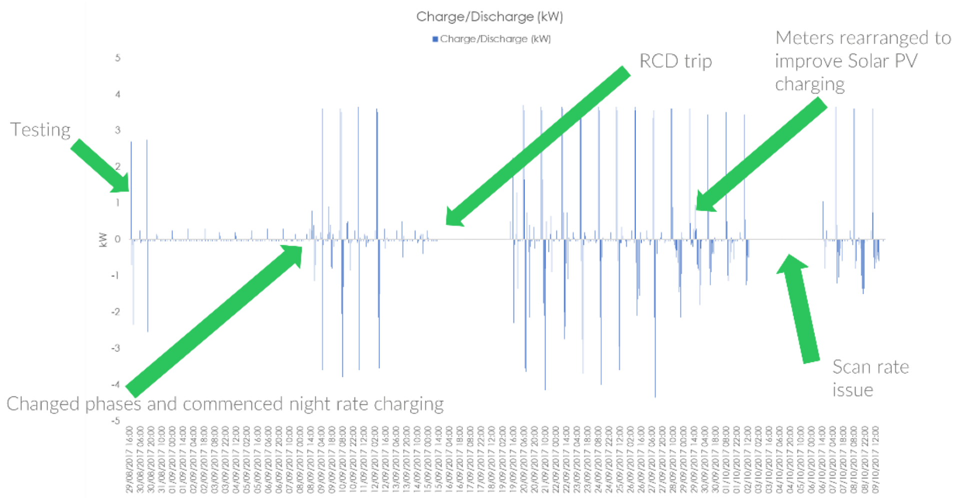


**Figure 18 - Battery operation at Ballyvolane fire station, notable events**

Figure 19 shows the charge-discharge statistics for Ballyvolane fire station over a two-month period.

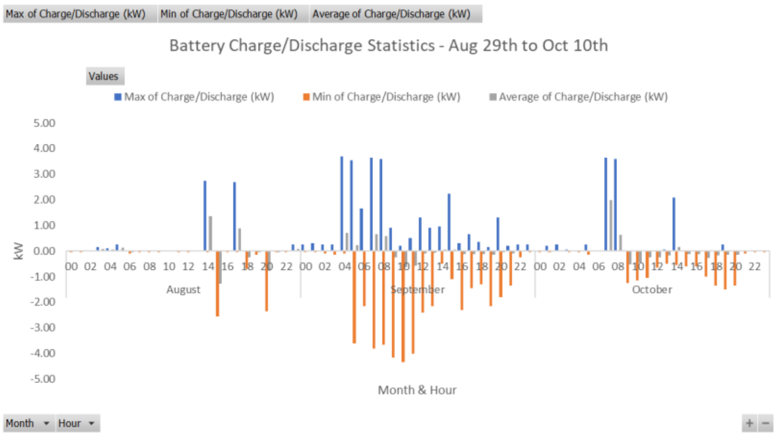


**FIGURE 19 - BATTERY CHARGE DISCHARGE STATISTICS, BALLYVOLANE FIRE STATION**

## 4.1 Monitor Load Profiles & Identify Energy Use Patterns

Both the domestic premises at Ovens and the fire station at Ballyvolane avail of dual rate day/night tariffs utilising dual rate meters. Therefore, the battery at both sites was set to charge during the cheaper night-time tariff. Charging was automated to occur between 06:00 to 08:00 on a daily basis. At the Ovens site this had the effect of shifting energy usage to that period, thereafter the battery fed the home consumption during the day and, typically, also catered for most of the consumption during the peak use period of 17:00 to 20:00 (see Figure 20).

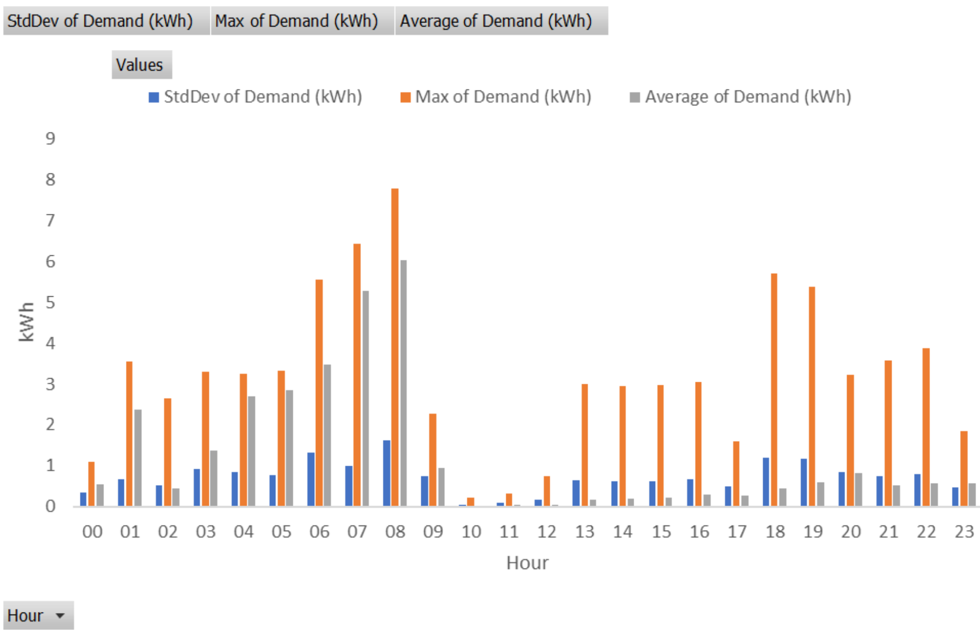


**FIGURE 20 – GRID IMPORT PROFILE, DOMESTIC PREMISES (OVENS) WITH BATTERY & GRID CHARGING**

At Ballyvolane, the annual consumption is of the order of 50,000 kWh of a year. Therefore, the battery has much less noticeable an effect on the in shifting energy in the demand profile (see Figure 21).

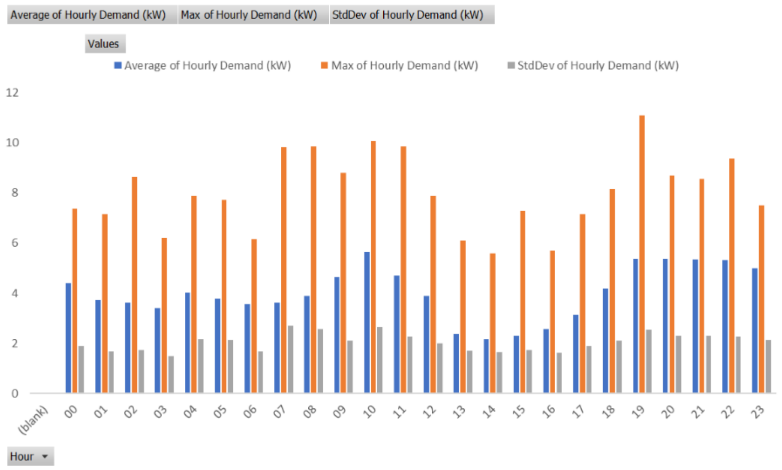


**Figure 21 – Grid import profile, Ballyvolane fire station with battery & grid charging**

The premises of Dún Laoghaire does not avail of a dual rate tariff. There the battery was operated solely to maximise self-consumption of the on-site solar PV. The demand profile is as seen in Figure 22.

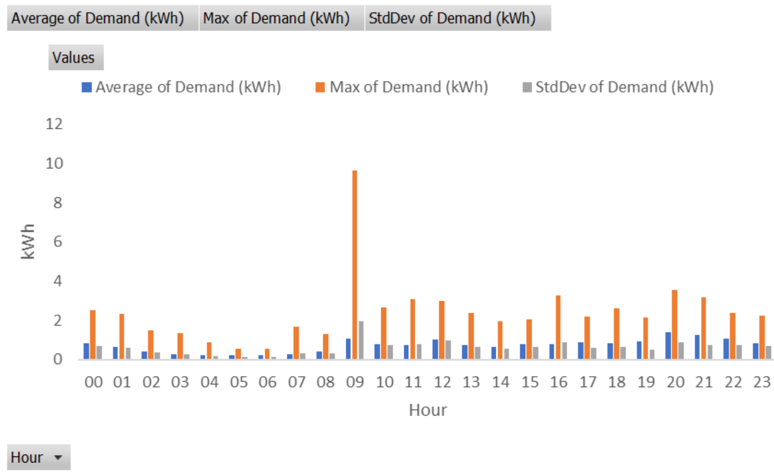


**Figure 22 – Grid import profile, domestic premises (Dún Laoghaire) with battery & grid charging**

Figure 23 shows instantaneous power over a 24 period, read at a resolution of 5 seconds, at the domestic premises in Ovens. On the day in question the following was observed:

1. Heat pump heating hot water cylinder
2. Cycling of heat pump, providing heating to the home (circa 3 kW)
3. Fully on heat pump, providing heating to the home (circa 3 kW)
4. Battery charge (3.5 kW)
5. Immersion running for 30 mins (circa 2.8 kW)[5]
6. Battery supplying demand within the home during the morning period
7. Peak load at the home, consumption primarily dictated by use of the electric oven

[5] Standards and guidelines addressing Legionnaires Disease, require that domestic hot water is to be stored and supplied at a temperature of 60°C. Non integral heat pumps can often bring hot water to a max of 55°C, thereafter a short period of immersion heating is required to bring the hot water to the correct temperature.

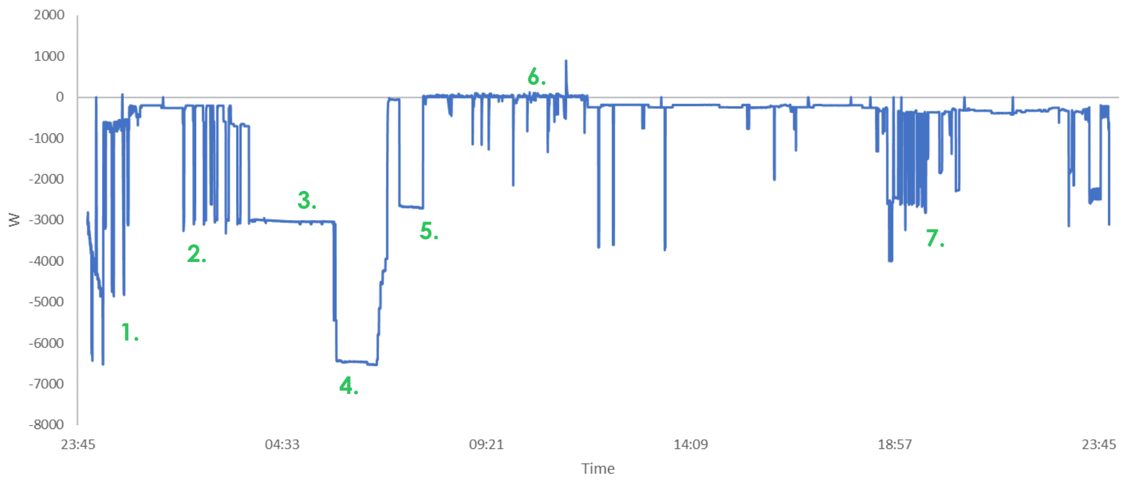


**FIGURE 23 – INSTANTANEOUS POWER, DOMESTIC PREMISES (OVENS) WITH BATTERY & GRID CHARGING**

## 4.2 Effect of Battery Operation on Load Profiles

As discussed in Section 4.1, the effect of the battery at the domestic premises Ovens, when coupled with gird charging from night rate, was to shift the energy usage to the early morning, during the period 06:00 to 08:00, and thereafter to reduce or entirely eliminate import from the grid.

In terms of generation:

- Of the 158 kWh of solar PV generation at Dún Laoghaire, from the date of battery installation, less than 6 kWh exported, i.e. a 96% self-consumption rate.
- Of the 1331 kWh generated at Ballyvolane to date, less than 80 kWh was exported, mostly due to system being offline due to the faults/issues identified in Figure 18. This equates to a self-consumption rate of 94%.

It should be noted that, at both sites, installations were completed after the key solar PV generation period of April to August.

Figure 24 and Figure 25 show the energy balance over a single day for Dún Laoghaire and Ballyvolane fire station.

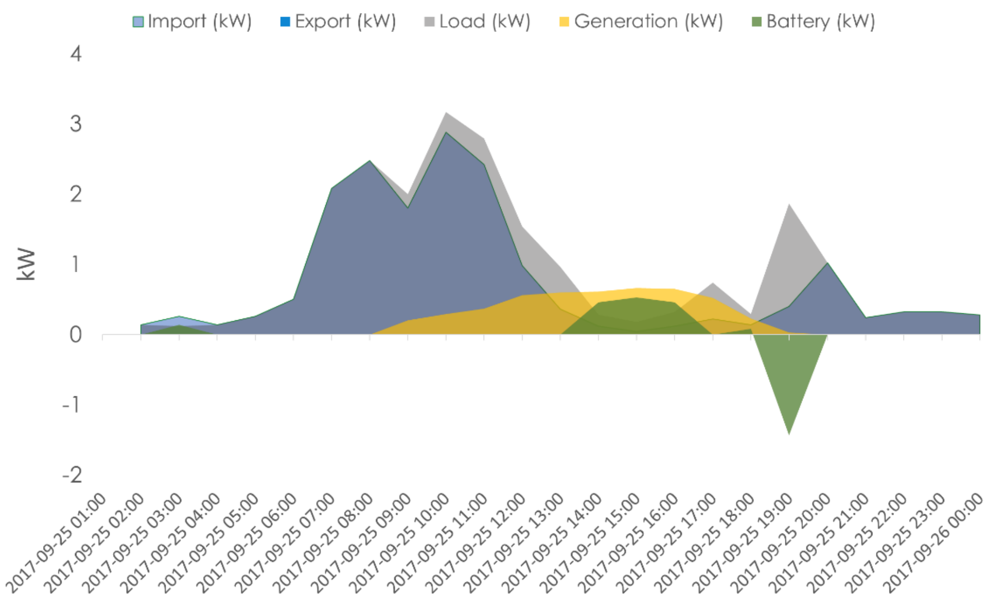


**Figure 24 – Domestic premises (DLRCC) over one day, with battery & no grid charging**

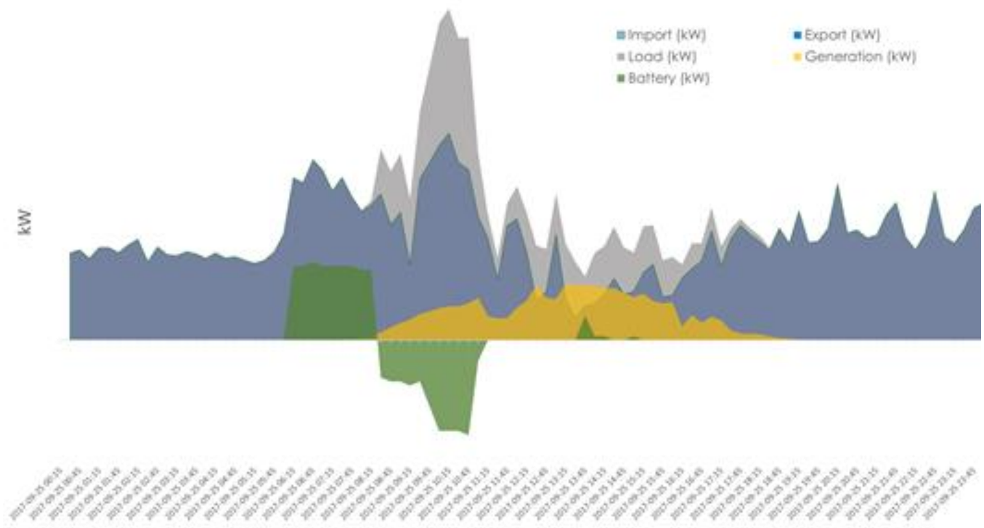


**Figure 25 – Ballyvolane fire station over one day, with battery & grid charging**

The below assesses the energy savings at each of the sites over the period of the project.

- 1725 kWh of battery charging over 175 day period from both night rate grid charge and solar PV charge (80% of that is attributable to charging from night rate, 20 % from solar PV). A saving of approximately €163.
- 152 kW of solar PV generation consumed at the domestic premises in Dún Laoghaire, equating to a saving of approximately €23.
- 1128 kW of night rate charging at the domestic premises in Ovens, generating a saving of approximately €90.

## 4.3 Performance Monitoring on Distribution Network

It was originally envisaged that three of the sites were to be fed from the same 10 kV feeder and hence ESB Networks would perform monitoring on the relevant feeder. However, once the final sites had been selected, it was decided by ESBN to proceed without such monitoring as no two sites are fed from the same distribution feeder (a single site will have a negligible impact on a 10 kV feeder, meaning that any such monitoring would not be of value). Instead ESB Networks and Solo have collaborated to provide direct visibility and monitoring of the status and operation of each of the battery assets from Solo's platform *FlexiGrid* to ESBN's internal platform SERVO via a broker interface as described in Section 3.2.1. This functionality allows ESB Networks to ascertain the performance of behind-the-meter assets and will, once storage and other distributed energy resources become more prevalent, be used to influence their forecasting of the operation of the distribution network. Whilst this is a different form of monitoring from that originally envisaged as part of the scope of the eStore project, it is undoubtedly an important addition to the monitoring element of the project.

# 5 Market Analysis

## 5.1 Ancillary Services & Capacity Market

### 5.1.1 Existing Markets

The Capacity Market is a mechanism to ensure that electricity supply in Ireland continues to meet demand. The market exists to ensure there is adequate supply or load-management capacity on the grid to cope with times of system stress.

The Capacity Market provides generators, aggregators and interconnectors that are successful in the auction with a regular capacity payment that assists with funding existing and future generation capacity. Aggregators can bid demand reduction into the capacity market. Payment is based on demand reduction availability, not utilisation.

Participants can offer into a capacity market auction ahead of the capacity year in which the capacity is to be delivered. In the long term, a capacity auction will be held four years (T-4) before a capacity year with additional auctions for incremental capacity held closer to the capacity year, e.g. in the year prior to the capacity year start (T-1)[6]. The most recent market clearing price was €41,800 €/MW per year[7]

Through EirGrid's Delivering a Sustainable Secure Electricity System (DS3) programme, the power system is moving towards an operational target of 75% of generation coming from non-synchronous generation (wind, HVDC, solar, etc). This metric is known as System Non-Synchronous Penetration (SNSP). With a view to achieving this aim, EirGrid have developed financial incentives for improved performance and the provision of flexibility services, known as ancillary services, from plant. The power system can currently accommodate up to 65% SNSP. Table 7 of Appendix A list the full suite of ancillary services. Batteries can provide all the services outside of synchronous inertial response; in fact, energy storage has previously been identified by EirGrid as being one of the best placed technologies to capture ancillary service revenue.

The value of the ancillary service market for Ireland is shown in Table 5. The expenditure cap for the ancillary services procurement by EirGrid in Ireland will double by 2020[8] due to the increasing need for such services as Ireland moves towards meeting its 40% renewable electricity target.

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[6] http://www.sem-o.com/ISEM/Pages/ISEMCapacityMarket.aspx

[7] Final Capacity Auction Results 2018/2019 T-1 Capacity Auction

[8] DS3 System Services Future Programme Approach Information Paper, SEM-17-017, 23 March 2017

**TABLE 5 – VALUE OF ANCILLARY SERVICES MARKET IN IRELAND**

| Year | Value |
|---|---|
| 2017 | €115 m |
| 2020 | €235 m |

Providers of ancillary services are paid based on availability, on a MWh basis and according to the below formula.

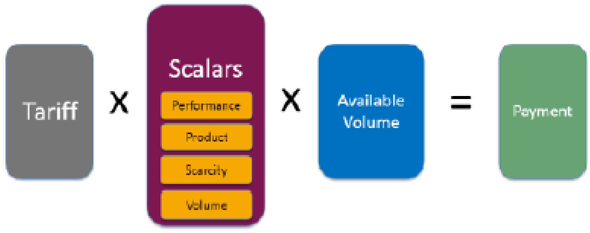


FIGURE 26 - CALCULATION OF ANCILLARY SERVICES PAYMENTS[9]

Scalars will be applied to the unit price of a given service received by a given provider:

- A performance scalar to reward and incentivise high levels of performance and to ensure lower payments from the consumer for a lower level of performance.
- A volume scalar to ensure that consumers are protected from unnecessarily high prices and maintain the integrity of the overall procurement process.
- A scarcity scalar to create marginal incentives for providers to make themselves available during periods or in locations of scarcity, therefore enhancing the performance of the system where it is most needed. It is proposed for two products only: FPFAPR and DRR.
- A product scalar to incentivise both the more effective delivery of a service and for faster response times for certain services.

For battery applications the main ancillary services of interest are Fast Frequency Response (FFR), Primary Operating Reserve (POR), Second Operating Reserve (SOR) and Tertiary Operating Reserve (TOR1 & TOR2). Assuming no performance issues, a battery could earn ~28x the base tariff at periods of 60-70% SNSP and ~38x for SNSP levels above 70%. However, the time spent above this SNSP level will vary significantly from year to year. This is because SNSP level is a function of the generation mix, wind speeds, interconnector flows and demand levels in any given year [10].

All told, consultancy firm Everoze has estimated that for a battery with no performance issues, a dynamic response within 0.5 seconds to a 0.02 Hz deviation in frequency (up or down) and provision of FFR, POR, SOR, TOR1& TOR2 (20 min duration in total) then revenue could be vary between €128k and €300k per MW per year[10].

Whilst Everoze's analysis is focused on a large-scale battery connected directly to the transmission or distribution system, the opportunities for provision of ancillary services from an aggregated distributed battery network are also nonetheless apparent.

[9] DS3 System Services Scalar Design, EirGrid

[10] Time for batteries to scalar up in Ireland', Paul Reynolds, Everoze

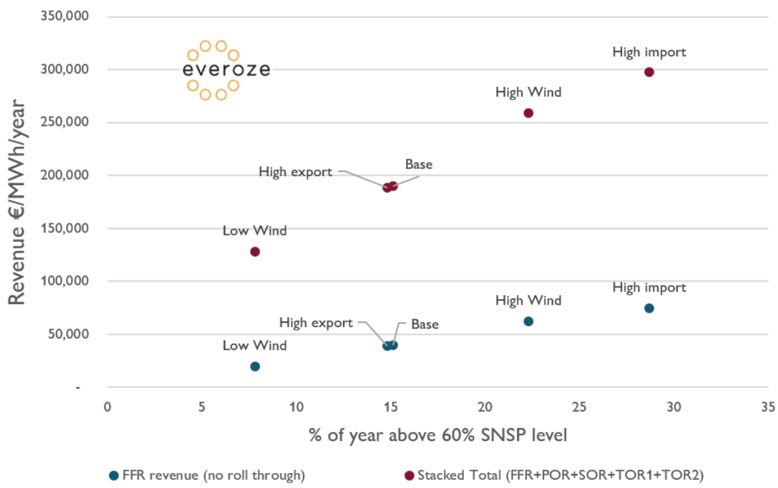


**FIGURE 27 - CALCULATION OF ANCILLARY SERVICES PAYMENTS**[10]

## 5.2 Arbitrage / Minimisation of Wholesale Costs

Section 5.1 discussed the prospective revenue, through aggregation, from participation in the ancillary services market.

This section focuses on the benefits that aggregated control of a distributed energy storage network can offer to retail electricity suppliers.

For a retail electricity supplier the costs associated with supplying a domestic customer are typically made up of the following components[11]:

1. Wholesale market costs – 41 %
2. Network costs – 49%
3. Supply costs – 9%

(1) relates to the purchase of sufficient energy from the wholesale market to supply the customer. (2) incorporates the charges that the supplier must pay to the TSO and DSO for using the transmission and distribution systems, respectively. Supply costs are made up of obligatory costs at circa 9% of supply costs or less than 1% of the overall costs, sales and customer acquisition at circa 40% of supply costs or less than 4% of overall costs, bad debts at circa 13% of supply costs or circa 1% of overall costs and other related business operational costs (coming to 36% of supply costs or circa 3% or overall costs).

Clearly, wholesale costs and networks costs make up most of the costs associated with supplying a customer.

The Single Electricity Market wholesale market costs vary every hour, as shown in Figure 28. In Q1 of 2017 SEM prices averaged around €54, but the differential between the three highest hourly prices and three lowest hourly prices was circa €49[12]. In May 2018, the market is moving to a new model, called the integrated SEM (i-SEM), to more closely align with European markets. The spread between high and low prices is expected to increase substantially following the move to i-SEM; for example, in Great Britain there were a number of days in 2016 where spreads of between £500 and £1000 occurred. I-SEM will have a similar balancing market operation to the market in Great Britain. In addition, negative pricing has already occurred on several days in SEM (where there is an excess of renewable generation at times of

[11] An Coimisiún um Rialáil Fóntas, Commission for Regulation of Utilities, Energy Supply Costs Information Paper, October 2017

[12] FES Battery project presentation, IERC conference, 2017

low peak demand); periods of negative pricing have become a feature of the GB market over the last two years.

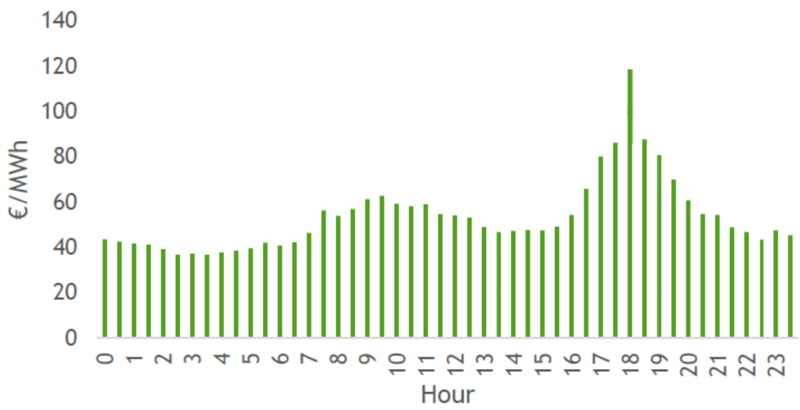


**FIGURE 28 – AVERAGE WHOLESALE (SEM) MARKET PRICE Q1 2017**

Use of system costs are made up of both transmission and distribution system charges.

The latest transmission charges for domestic demand are as follows[13]

- Demand Network Capacity Charge: € 6.0246/MWh for metered consumption energy transferred during day hours. Day hours are 08:00 to 23:00 hours inclusive
- Demand Network Transfer Charge: € 2.8623/MWh for metered consumption energy.
- Demand System Services Charge: € 3.8242/MWh for metered consumption energy transferred in the charging period.

As shown in Table 6, distribution charges also vary depending on the time of day, under the scenario where a day and night rate meter is utilised[14]. Night-time use of system charges are less than 15% of daytime use of system charges. In, the UK, with the advent of smart metering, distribution network usage charges for half-hourly settled domestic customers (with smart meters) incorporates three different tariff bands - red, amber, and green - which apply to different time periods. Figure 30 shows an example of the time bands and tariffs for one of the Grid Supply Points (GSP) in the UK[15].

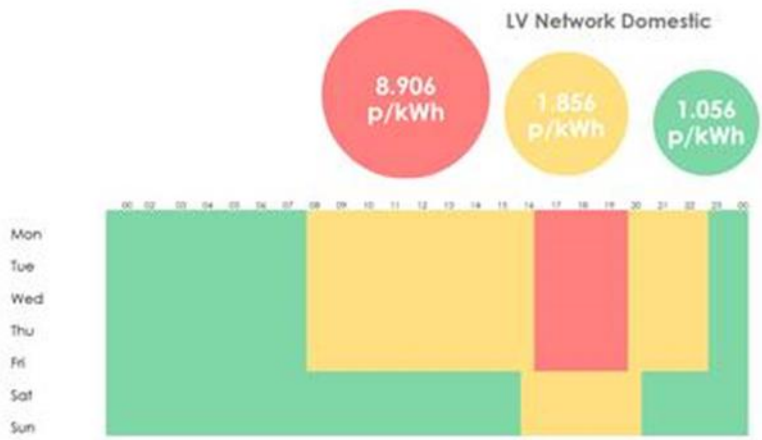


**FIGURE 29 – SAMPLE UK DNO TARIFFS AND TIME BANDS FOR HALF HOURLY SETTLED, SMART METERED, DOMESTIC CUSTOMER**

[13] Statement of Charges Applicable from 1st October 2016, EirGrid

[14] Schedule of Distribution Use of System Charges 1st October 2017 – 30th September 2018, ESB Networks

[15] There are 14 GSPs in the UK, operated by the various Distribution Network Operators there

Typically, retail electricity suppliers have no way of influencing the demand shape of their customers. They are therefore exposed to both the variation in wholesale electricity costs and full use of system charges. One method to reduce exposure to potentially volatile wholesale electricity costs is through hedging, i.e. buying energy in advance of the delivery/usage date (retail supplier can typically be up to 80% hedged six months in advance).

**TABLE 6 – DISTRIBUTION USE OF SYSTEM CHARGES**

| | | Distribution Use of System Charges | | | |
|---|---|---|---|---|---|
| | Charge Unit | Standard Meter | | Day and Night Rate Meter | |
| | | Urban Domestic (DG1) | Rural Domestic (DG2) | Urban Domestic (DG1) | Rural Domestic (DG2) |
| Standing Charge | Per customer per annum | 66.29 | 96.69 | 66.29 | 96.69 |
| Unit Rates | Per kWh 24 hour | 3.963 | 3.963 | N/A | N/A |
| | Per kWh day | N/A | N/A | 4.865 | 4.865 |
| | Per kWh night | N/A | N/A | 0.618 | 0.618 |

Figure 30 show an example of the energy demand for a customer base of 1000 homes of varying type (rental, with solar PV, urban, rural, etc). Clearly, when considering both the use of system charges outlined above, and the wholesale market cost shape as shown in Figure 28, the ability to shape customer demand profiles can significantly reduce the cost-of-supply for electricity suppliers.

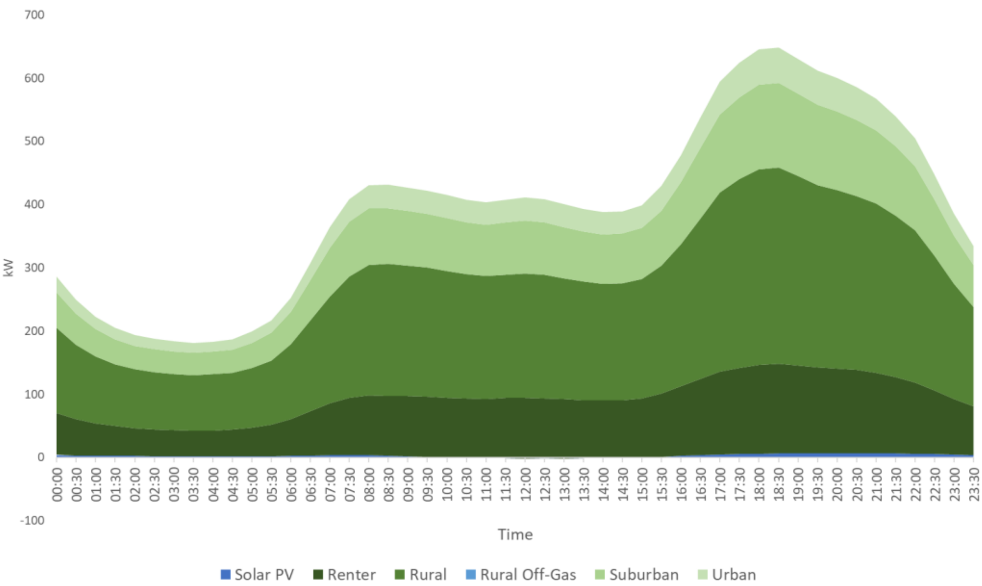


**FIGURE 30 – EXAMPLE ENERGY DEMAND FOR 1000 CUSTOMERS OF VARIOUS TYPES**

A controllable distributed energy storage network provides suppliers with the facility to reduce both wholesale costs and transmission and distribution use of system charges by shaping the demand profile across their customer base. However, it should be noted, that use of system of charges are designed to recoup costs in respect of the operation, maintenance and development of distribution and transmission networks. Volumetric, consumption based, charges are not designed to incentivise behaviour. Any behavioural change, such as shaping of customer demand profiles, will not only result in a more significant cost burden falling on those with no controllable demand, as opposed to a reduction in costs falling on those with such capability, but will also more than likely precipitate a change in network charging structure (e.g. the introduction of a capacity charge). Therefore, the reduction in use of system costs is not considered further here.

At a basic level the profile shaping could look as straightforward as charging the batteries at night-time and releasing that energy to the customer throughout the day and/or including reducing or eliminating their demand during peak times (see Figure 31), albeit in reality there will remain some consumption during peak times (in the event that the load at the home exceeds the rated power of the inverter for example). Clearly, the charging of a considerable number of batteries within geographic areas would be controlled in such as fashion to smooth out the charging over a wider period to ensure that local distribution networks do not see significant spikes in energy. More complex operation of the distributed storage network is also possible, including exporting power at particular times to avail of arbitrage opportunities, exporting power from the customers with storage to net off against overall demand across the supplier's customer base, and also reserving some of the capacity of the storage network to enable supply of grid/ancillary services at particular times.

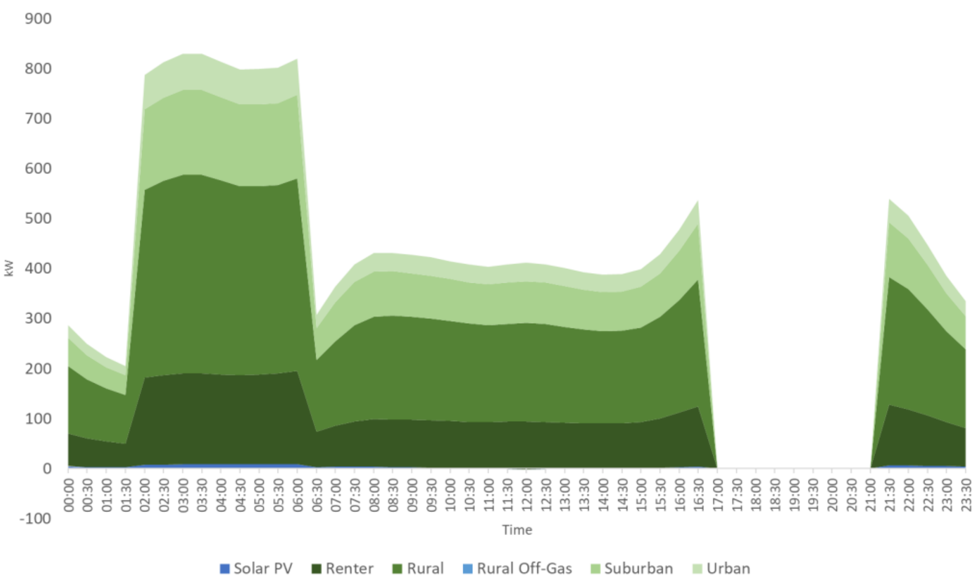


**FIGURE 31 – EXAMPLE ENERGY DEMAND FOR 1000 CUSTOMERS OF VARIOUS TYPES, ALL WITH BATTERIES INSTALLED ON SITE**

Potentially, with a customer base consisting entirely of customers with controllable batteries, suppliers can significantly reduce their wholesale costs.

Currently, a domestic customer's electricity meter simply records total consumption, and the meters are read every two months at the most. Thereafter, to settle a customer's consumption, standard profile shapes, based on historical and test data, are applied to that consumption to give an estimate of what the customer used on an half-hour by half-hour basis.

To capture the value of the deployment and control of batteries at domestic premises it is necessary to settle domestic customers' consumption on the wholesale market in a real, rather than estimated, fashion. This requires both (a) the hardware to enable data capture, i.e. measure the customers consumption and any export to the grid on a half hourly basis, and (b) the necessary market infrastructure to enable customers to be settled on the market.

In terms of the hardware, the roll out of smart meters to domestic premises is a prerequisite. ESB Networks are commencing installation of smart meters in Ireland, with a targeted 250,000 installations complete by end of 2019. However, the necessary supporting market infrastructure is not yet in place.

In the UK market, the where smart meter roll-out is at a much more advanced stage (greater than 5 m installed) and the balancing market operator, Elexon, has the necessary systems put in place to facilitate half-hourly settlement of domestic customers using smart meter data[16],

# 6 Customer Cost Benefit Analysis

At present, the status of small scale battery storage and micro-generation in Ireland is as follows:

- There is no subsidy available, i.e. a feed-in-tariff, generation tariff or other some of payment
- There are no grants for domestic customers; however, the minister for Communications, Climate Action and Environment recently announced that a grant scheme will be rolled out this summer
- Businesses can avail of accelerated capital allowance, i.e. offsetting the investment against their tax, therefore reducing the cost of installation by 12.5%

Given the above, the benefits to a customer of a storage-plus-solar PV (or other form of generation) system is limited to the following:

- Maximise self-consumption of all generation on-site
- Operate the battery in such a way to make best use of a dual rate day/night tariff. Essentially, this means charging the battery from the grid during the time of the cheaper night tariff and releasing that energy back to the and utilise that energy within the home during the daytime.

The results of the desktop analysis are shown in Appendix B. The analysis demonstrates a long payback period for both the business and homeowner (note that a higher capacity battery and solar PV installation is considered in the business owner scenario). In both cases the payback period, at 11 and 14 years respectively, is longer than the typical battery warranty period of 10 years[17]. Whilst battery lifetimes are in the 15-20 year range it is standard across the industry for the battery warranty to guarantee that the usable capacity of the battery is 80% of its original capacity after ten years. Thereafter the warranty is no longer valid.

Introduction of the grant scheme referenced above will reduce the payback period somewhat but is unlikely to have a significant impact (based on the expected grant level we estimate a reduction in the payback period of circa two years, depending on installation and site). Of greater important is the decreasing cost of residential batteries, Telsa recently announced a 10% reduction in the Powerwall prices whilst Lazard's Levelised Cost of Storage forecasts a reduction of 36% in Lithium Ion batteries over the next five years[18].

In the medium to long term those cost reductions, and the reduction in the associated payback periods, will make battery storage much more attractive for individual SME and domestic customers.

[16] CP1469 'Changes to support the implementation of the SRAG's recommendations', Elexon, October 2016

[17] The warranty generally specifies a maximum throughput of energy in MWh, which equates to approximately 1 cycle per day for ten years. Usage in excess of that energy throughput figure will result in faster degradation of the battery's usable capacity

[18] Lazard's Levelised Cost of Storage, v3.0

# 7 Dissemination

To date the eStore project has received considerable press from a variety of sources:

- Solo Energy were selected as the winner of the IT@Cork Smart Tech Innovation Award for our work on the project
- Newspaper articles
- The project featured on an episode of RTE's Ten Things to Know About programme, which was broadcast December 4th on RTE One
- Presentation to Energy Cork stakeholders at the Energy Cork breakfast briefing on Sept 27th 2017

HI-TECH FIRE STATION SYSTEM FEATURES ON RTÉ

Solo Energy's Daniel Dransfield, Killian O'Connor, Liam Breathnach, with RTÉ presenter Kathriona Devereux. The renewable energy company will feature in RTÉ's '10 Things to Know About' in November.

**City Council on Solo run with energy firm**

Roisin Burke

**A RENEWABLE energy company has teamed up with Cork City Council to install a state-of-the-art battery storage system at Ballyvolane Fire Station that will feature in an RTÉ series in November.**

Cork company, Solo Energy, is currently working on a project called the eStore project, which involves the installation of 'behind the meter' battery storage devices, sometimes along with Solar Photovoltaic (PV) panels.

According to the company, they are creating a cloud-connected software platform to control this network of batteries across the grid. This will enable the company to get more from their solar PV systems and access low-cost energy during off-peak times to power the station. The innovative project is the focus of an upcoming episode of *10 Things to Know About*.

Chief Technology Officer Liam Breathnach, who had been working with the ESB for 10 years before making the move to focus on renewable energy, said it was brilliant to be chosen to be part of the programme.

"It is great to be getting the message of sustainable energy out there."

Speaking about the demand for solar energy in Ireland, Mr Breathnach said it was small but growing and it was great of Cork City Council to take the initiative to get involved in a renewable energy project.

"They have been very proactive and innovative. We were very lucky to get to work with them."

The eStore project, which is being carried out in conjunction with ESB Networks, is creating a network of distributed energy storage systems at a number of private and public buildings as part of a SEAI funded R&D project.

It will be the first of its kind for the power system in Ireland.

For more information log onto www.solo-energy.com.

**FIGURE 32 – DISSEMINATION VIA (A) NEWSPAPER ARTICLES AND (B) FILMING AS PART OF RTE'S 10 THINGS TO KNOW ABOUT SCIENCE PROGRAMME**

# 8 Follow On Work

Several opportunities for further work and collaboration have arisen from our work on the eStore project:

- StoreNet Project: StoreNet is an industry led collaborative two-year research project incorporating the installation of batteries at twenty homes in Dingle, Co. Kerry. Industry partners include Electric Ireland, ESB Network and Solo Energy; the research organisation is the International Energy Research Centre (IERC). The objectives of the project are to test the potential of new storage technologies to support the use of variable renewable energy supply resources and to test the provision of services to the grid that would otherwise have been addressed by network investment, as well as informing the shaping of such local flexibility markets into the future. The mechanism for interaction between FlexiGrid and ESBN's SERVO platform, developed as part of the eStore project, will be utilised extensively throughout StoreNet project.
- Research based on the use of SEAI funded grid emulator at the MaREI facility

# 9 Appendix A – Ancillary Services

**TABLE 7 – LIST OF ANCILLARY SERVICES**

| Ancillary Service | Description |
|---|---|
| Dynamic Reactive Response (DRR) | Ability of a unit when connected to deliver a reactive current response for voltage dips in excess of 30% that would achieve at least a reactive power in MVAr of 31% of the registered capacity at nominal voltage. |
| Synchronous Inertial Response (SIR) | SIR is the response in terms of active power output and synchronising torque that a unit can provide following disturbances. It is immediately available from synchronous machines because of their nature. |
| Fast Frequency response (FFR) | FFR is defined as the additional increase in MW output from a generator or reduction in demand following a frequency event that is available within two seconds of the start of the event and is sustained for at least eight seconds. |
| Primary Operating Reserve (POR) | POR is the additional MW output (and/or reduction in demand) required at the frequency nadir (minimum), compared to the pre-incident output (or demand) where the nadir occurs between 5 and 15 seconds after an event |
| Secondary Operating Reserve (SOR) | SOR is the additional MW output (and/or reduction in demand) required compared to the pre-incident output (or demand), which is fully available and sustainable over the period from 15 to 90 seconds following an event. |
| Tertiary Operating Reserve (TOR1) | TOR1 is the additional MW output (and/or reduction in demand) required compared to the pre-incident output (or demand) which is fully available and sustainable over the period from 90 seconds to 5 minutes following an event. |
| Tertiary Operating Reserve (TOR2) | TOR2 is the additional MW output (and/or reduction in demand) required compared to the pre-incident output (or demand) which is fully available and sustainable over the period from 5 minutes to 20 minutes following an event. |
| Replacement Reserve - Synchronised (RRS) | RRS is the additional MW output (and/or reduction in demand) provided compared to the pre-incident output (or demand) which is fully available and sustainable over the period from 20 minutes to 1 hour following an event. |
| Replacement Reserve - Desychronised (RRD) | RRD is the additional MW output (and/or reduction in demand) provided compared to the pre-incident output (or demand) which is fully available and sustainable over the period from 20 minutes to 1 hour following an event. |
| Ramping Margin 1 (RM1)<br>Ramping Margin 3 (RM3)<br>Ramping Margin 8 (RM8) | Ramping Margin represents the increased MW output that can be delivered by the service horizon time and sustained for the product duration window. The three proposed services are not mutually exclusive. Providers capable of providing all three products are eligible to receive payment for all three, similarly for two.<br>Both synchronised and non-synchronised plants are eligible to provide the service. |
| Fast Post Fault Active Power recovery (FPFAPR) | FPFAPR is defined as having been provided when, for any fault disturbance that is cleared within 900 ms, a plant that is exporting active power to the system recovers its active power to at least 90% of its pre-fault value within 250 ms of the voltage recovering to at least 90% of its pre-fault value. |

# 10 Appendix B – Customer Cost Benefit Analysis

| | Unit | Value | Comment |
|---|---|---|---|
| Currency: | € | | |
| Finance: | | | |
| Discount rate (pre-tax) | % | 8.0% | Use interest rate or risk rat |
| Rating: | | | |
| Installed capacity (peak for solar) | kW | 3 | |
| Battery | kWh | 6.65 | |
| Captial Costs: | | | |
| Solar EPC cost | €/kW | 1650 | |
| Capital Cost During Construction | €/kW | 0 | |
| Other Owners costs | €/kW | 0 | |
| Total Solar Capital Costs | €/kW | 4,950 | |
| Battery EPC cost | € | 6235 | |
| Accelerated Capital Allowance or Solar PV grant | € | 0 | |
| Total Capital Costs less Grant Contribution | € | 11,185 | |
| **Operations & Manintenance Costs:** | | | |
| O&M escalation factor | % | 1.50% | |
| Capacity Factor | % | 11% | |
| Degradation factor year 1 & 2 | % per yr | 1% | |
| Degradation factor from year 3 | % per yr | 0.4% | |
| Facility life | years | 25 | |
| First year yield (kWh = 0.8*kW*S*Zpv) or kWh = kW*876C | kWh | 2996 | |
| Assumed self consumption | % | 95% | Not 100% as allowance fc |
| **Costs & tariffs:** | | | |
| Electricity tariff | c/kWh | 17.17 | |
| Dual rate tariff - Electric Ireland day rate | c/kWh | 17.17 | |
| Dual rate tariff - Electric Ireland night rate rate | c/kWh | 7.54 | |
| Electricity inflation | % | 3% | |
| FIT export tariff | c/kWh | 0 | |
| FIT generation tariff | c/kWh | 0 | |
| **Usage:** | | | |
| Assumed annual consumption | kWh | 7500 | |
| Average daily energy usage | kWh | 21 | |
| Number of applicable days per annum | days | 365 | |
| **Levelised Costs:** | | | |
| NPV Cashflow | € | 10,356 | |
| NPV Yield | kWh | 30631 | |
| Levelised Cost of Energy | €/kWh | 0.34 | |
| NPV of Total Cash Flows | € | -42177 | |
| NPV using IRR rate (sanity check) | € | 0.00 | Using a discount rate the |
| IRR | % | 0.1% | |
| Payback | years | 14 | |

| Year | Yield (kWh/yr) | Capital Cost (€) | Electricity Cost (€/kWh) | Electricity Cost - Night rate (€/kWh) | Electricity Savings Due to Solar PV (€/yr) | Electricity Savings Due to Time of Use Charging (€/yr) | Export Payment (€) | Net Saving (€) | Net Cash Flow, excl revenue (€) | Total Cash Flow (€) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | 11185 | | | | | | | 11185 | -11185 |
| 1 | 2996 | | 0.17 | 0.08 | 489 | 234 | 0 | 722 | 0 | -10463 |
| 2 | 2966 | | 0.18 | 0.08 | 498 | 241 | 0 | 739 | 0 | -9724 |
| 3 | 2936 | | 0.18 | 0.08 | 508 | 248 | 0 | 756 | 0 | -8967 |
| 4 | 2925 | | 0.19 | 0.08 | 521 | 255 | 0 | 777 | 0 | -8191 |
| 5 | 2913 | | 0.19 | 0.08 | 535 | 263 | 0 | 798 | 0 | -7393 |
| 6 | 2901 | | 0.20 | 0.09 | 549 | 271 | 0 | 820 | 0 | -6573 |
| 7 | 2890 | | 0.21 | 0.09 | 563 | 279 | 0 | 842 | 0 | -5731 |
| 8 | 2878 | | 0.21 | 0.09 | 577 | 287 | 0 | 865 | 0 | -4867 |
| 9 | 2867 | | 0.22 | 0.10 | 592 | 296 | 0 | 888 | 0 | -3978 |
| 10 | 2855 | | 0.22 | 0.10 | 608 | 305 | 0 | 913 | 0 | -3066 |
| 11 | 2844 | | 0.23 | 0.10 | 623 | 314 | 0 | 937 | 0 | -2128 |
| 12 | 2832 | | 0.24 | 0.10 | 639 | 324 | 0 | 963 | 0 | -1165 |
| 13 | 2821 | | 0.24 | 0.11 | 656 | 333 | 0 | 989 | 0 | -176 |
| 14 | 2810 | | 0.25 | 0.11 | 673 | 343 | 0 | 1016 | 0 | 841 |
| 15 | 2798 | | 0.26 | 0.11 | 690 | 354 | 0 | 1044 | 0 | 1885 |
| 16 | 2787 | | 0.27 | 0.12 | 708 | 364 | 0 | 1072 | 0 | 2957 |
| 17 | 2776 | | 0.28 | 0.12 | 727 | 375 | 0 | 1102 | 0 | 4059 |
| 18 | 2765 | | 0.28 | 0.12 | 745 | 386 | 0 | 1132 | 0 | 5191 |
| 19 | 2754 | | 0.29 | 0.13 | 765 | 398 | 0 | 1163 | 0 | 6353 |
| 20 | 2743 | | 0.30 | 0.13 | 785 | 410 | 0 | 1194 | 0 | 7548 |
| 21 | 2732 | | 0.31 | 0.14 | 805 | 422 | 0 | 1227 | 0 | 8775 |
| 22 | 2721 | | 0.32 | 0.14 | 826 | 435 | 0 | 1260 | 0 | 10035 |
| 23 | 2710 | | 0.33 | 0.14 | 847 | 448 | 0 | 1295 | 0 | 11330 |
| 24 | 2699 | | 0.34 | 0.15 | 869 | 461 | 0 | 1330 | 0 | 12660 |
| 25 | 2688 | | 0.35 | 0.15 | 891 | 475 | 0 | 1367 | 0 | 14027 |

**FIGURE 33 – DOMESTIC CUSTOMER COST BENEFIT ANALYSIS WORKSHEET**

| | Unit | Value | Comment |
|---|---|---|---|
| Currency: | € | | |
| Finance: | | | |
| Discount rate (pre-tax) | % | 8.0% | Use interest rate or risk rat |
| Rating: | | | |
| Installed capacity (peak for solar) | kW | 4 | |
| Battery | kWh | 13.5 | |
| Capital Costs: | | | |
| Solar EPC cost | €/kW | 1650 | |
| Capital Cost During Construction | €/kW | 0 | |
| Other Owners costs | €/kW | 0 | |
| Total Solar Capital Costs | €/kW | 6,600 | |
| Battery EPC cost | € | 7200 | |
| Accelerated Capital Allowance or Solar PV grant | € | 1725 | |
| Total Capital Costs less Grant Contribution | € | 12,075 | |
| **Operations & Manintenance Costs:** | | | |
| O&M escalation factor | % | 1.50% | |
| Capacity Factor | % | 11% | |
| Degradation factor year 1 & 2 | % per yr | 1% | |
| Degradation factor from year 3 | % per yr | 0.4% | |
| Facility life | years | 25 | |
| First year yield (kWh = 0.8*kW*S*Zpv) or kWh = kW*876C | kWh | 3995 | |
| Assumed self consumption | % | 95% | Not 100% as allowance fc |
| **Costs & tariffs:** | | | |
| Electricity tariff | c/kWh | 17.17 | |
| Dual rate tariff - Electric Ireland day rate | c/kWh | 17.17 | |
| Dual rate tariff - Electric Ireland night rate rate | c/kWh | 7.54 | |
| Electricity inflation | % | 3% | |
| FIT export tariff | c/kWh | 0 | |
| FIT generation tariff | c/kWh | 0 | |
| **Usage:** | | | |
| Bimonthly bill consumption figure | | 8117 | |
| Assumed annual consumption | kWh | 60000 | |
| Average daily energy usage | kWh | 164 | |
| Number of applicable days per annum | days | 250 | |
| **Levelised Costs:** | | | |
| NPV Cashflow | € | 11,181 | |
| NPV Yield | kWh | 40842 | |
| Levelised Cost of Energy | €/kWh | 0.27 | |
| NPV of Total Cash Flows | € | -24058 | |
| NPV using IRR rate (sanity check) | € | 0.00 | Using a discount rate the |
| IRR | % | 4.4% | |
| Payback | years | 11 | |

| Year | Yield (kWh/yr) | Capital Cost (€) | Electricity Cost (€/kWh) | Electricity Cost - Night rate (€/kWh) | Electricity Savings Due to Solar PV (€/yr) | Electricity Savings Due to Time of Use Charging (€/yr) | Export Payment (€) | Net Saving (€) | Net Cash Flow, excl revenue (€) | Total Cash Flow (€) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | 12075 | | | | | | | 12075 | -12075 |
| 1 | 3995 | | 0.17 | 0.08 | 652 | 325 | 0 | 977 | 0 | -11098 |
| 2 | 3955 | | 0.18 | 0.08 | 664 | 335 | 0 | 999 | 0 | -10099 |
| 3 | 3915 | | 0.18 | 0.08 | 677 | 345 | 0 | 1022 | 0 | -9077 |
| 4 | 3899 | | 0.19 | 0.08 | 695 | 355 | 0 | 1050 | 0 | -8027 |
| 5 | 3884 | | 0.19 | 0.08 | 713 | 366 | 0 | 1079 | 0 | -6948 |
| 6 | 3868 | | 0.20 | 0.09 | 731 | 377 | 0 | 1108 | 0 | -5840 |
| 7 | 3853 | | 0.21 | 0.09 | 750 | 388 | 0 | 1138 | 0 | -4701 |
| 8 | 3837 | | 0.21 | 0.09 | 770 | 400 | 0 | 1170 | 0 | -3532 |
| 9 | 3822 | | 0.22 | 0.10 | 790 | 412 | 0 | 1201 | 0 | -2330 |
| 10 | 3807 | | 0.22 | 0.10 | 810 | 424 | 0 | 1234 | 0 | -1096 |
| 11 | 3792 | | 0.23 | 0.10 | 831 | 437 | 0 | 1268 | 0 | 172 |
| 12 | 3776 | | 0.24 | 0.10 | 853 | 450 | 0 | 1303 | 0 | 1475 |
| 13 | 3761 | | 0.24 | 0.11 | 875 | 463 | 0 | 1338 | 0 | 2813 |
| 14 | 3746 | | 0.25 | 0.11 | 897 | 477 | 0 | 1375 | 0 | 4187 |
| 15 | 3731 | | 0.26 | 0.11 | 921 | 492 | 0 | 1412 | 0 | 5600 |
| 16 | 3716 | | 0.27 | 0.12 | 944 | 506 | 0 | 1451 | 0 | 7050 |
| 17 | 3701 | | 0.28 | 0.12 | 969 | 522 | 0 | 1490 | 0 | 8541 |
| 18 | 3687 | | 0.28 | 0.12 | 994 | 537 | 0 | 1531 | 0 | 10072 |
| 19 | 3672 | | 0.29 | 0.13 | 1020 | 553 | 0 | 1573 | 0 | 11645 |
| 20 | 3657 | | 0.30 | 0.13 | 1046 | 570 | 0 | 1616 | 0 | 13261 |
| 21 | 3643 | | 0.31 | 0.14 | 1073 | 587 | 0 | 1660 | 0 | 14921 |
| 22 | 3628 | | 0.32 | 0.14 | 1101 | 605 | 0 | 1706 | 0 | 16626 |
| 23 | 3613 | | 0.33 | 0.14 | 1129 | 623 | 0 | 1752 | 0 | 18379 |
| 24 | 3599 | | 0.34 | 0.15 | 1159 | 641 | 0 | 1800 | 0 | 20179 |
| 25 | 3585 | | 0.35 | 0.15 | 1189 | 661 | 0 | 1849 | 0 | 22028 |

**FIGURE 34 – BUSINESS CUSTOMER COST BENEFIT ANALYSIS WORKSHEET**