SCOTCLUE TECHNICAL REPORT

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Co-creating with partners that help to understand the needs of relevant stakeholders, we team up with intermediaries to provide an innovation eco-system supporting consortia for research, innovation, technical development, piloting and demonstration activities. These co-operations pave the way towards implementation in real-life environments and market introduction.

Beyond that, ERA-Net SES provides a Knowledge Community, involving key demo projects and experts from all over Europe, to facilitate learning between projects and programs from the local level up to the European level.

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ABBREVIATIONS

API	Application programming interface
DER	Distributed energy resources
DSO	Distribution system operators
GCP	Google Cloud Platform
LEC	Local Energy Communities
ScotCLUE	Scottish CLUE project
WoC	Web-of-cells
LDT	Levenmouth Demonstration Turbine
BaaS	Backend as a Service
SaaS	Software as a Service
SoC	State of Charge
GCP	Google Cloud Platform
VIP	Vector Integration Platform
VPN	Virtual Private Network

EXECUTIVE SUMMARY

Facilitating the deployment of low carbon distributed energy resources (DERs) is becoming increasingly challenging for distribution system operators (DSOs) as they try to operate their assets within physical and regulatory limits. With the social and governmental pressure to shift towards a 'net-zero' society in Scotland by 2045 and some cities aiming to be carbon neutral by 2030, this will undoubtedly create challenges for DSOs particularly as heat and transport sectors transition away from fossil fuels.

The concept of energy communities is one that allows for community driven actions to contribute to the clean energy transition and offers a pathway towards facilitating sustainable future deployment of DERs. The ERA-NET SES (European Research Area – Networks – Smart Energy Systems) funded project 'CLUE' (Concepts, Planning, Demonstration and Replication of Local User-friendly Energy Communities) has been established to develop and validate concepts for local energy communities (LEC) across five European demonstration sites in Austria, Germany, Sweden and Scotland.

The Scottish work package (ScotCLUE) is establishing the first steps towards the design of a multi-vector platform around a local community setting. This project aims to study the interactions between different energy vectors (i.e. electricity and gas) through real and virtual pilot demonstrations.

This report summarises the progress so far in the development of concept for a local energy community (LEC) in the chosen area of Levenmouth, which is in the Scottish county of Fife.

Section 1 gives an overview of the UK commitment towards a sustainable energy transition including the existing and future constraints with DERs moving to a more distributed system. This also provides an overview of how community led actions, working towards the web-of-cells (WoC) concept, could contribute towards solving this issue. Finally, this section summarises the objectives of the ScotCLUE project, which looks to create sustainable community based solutions.

Section 2 summarises the design of the LEC based on concept of a web-of-cells (WoC), which coordinates the supply and demand of cells (assets) of the different energy vectors within a local energy community. This provides a description of the different cells within the project as well as their communication interfaces.

Section 3 summarises the design of the operational modes for the web-of-cells (WoC) concept and describes three modes of operation investigated for the pilot demonstration namely; maximising the consumption of local generation, maximising hydrogen production from local PV and wind sources and avoiding wind turbine curtailment due to a grid network constraint. This also lists out the selected demonstration cases within these three modes taken forward for a pilot demonstration and governing rules agreed between the partners of ScotCLUE.

Section 4 gives a summary of the current progress of the project based on the description of the tasks of work package 4. It also gives a summary of the status of the specified deliverables.

1 PROJECT BACKGROUND

Over recent decades, the electricity sector has seen a major shift from being heavily centralised and carbon-intensive towards a more distributed system with significantly more generation connecting at the 'grid-edge'. While the electricity sector has made substantial progress in reducing its reliance on fossil fuels[1], it only accounts for 24% of the final energy consumption in Scotland [1]. There is, therefore, a further challenge to reduce the emissions associated with heat and transport sectors. It is widely accepted that the electricity system will be instrumental in reducing the emissions associated with these remaining sectors (e.g. via storage heaters, heat pumps, electric vehicles and green hydrogen production[2]).

The coordination between various energy vectors will be key to delivering the net-zero (and beyond) targets set by the Scottish Government. It is anticipated that the potential controllability within distribution networks, particularly at low voltage (<1,000 V), will increase significantly with the adoption of new low carbon technologies. For example, all government-funded home electric vehicle (EV) chargers installed after July 2019 must be 'smart-enabled' to allow EV charging to be slowed, or halted, to manage supply and demand [2]

As more DERs connect to the distribution network the associated management and the control of the system will quickly become too vast for DSO control room operatives to manage on an individual basis. To help network operators manage their systems and allow community groups to prioritise local issues (e.g. offering lower tariffs to the fuel poor), the WoC smart-grid concept, often described as a 'divide and concur' approach, has been proposed and studied extensively via simulation and laboratory experiments [3] [4]. The WoC concept essentially splits the distribution network into smaller, more manageable, areas which are controlled autonomously at a local level, while global objectives (e.g. managing a network outage) are set by the network operator. While this concept has attracted much discussion and associated research, there is little operational experience of this idea.

Levenmouth, the trial area for the ScotCLUE project, has local energy assets including several wind turbines, a solar PV park, electric vehicles, hybrid diesel-hydrogen refuge collection vehicles and an industrial CHP network within a community of circa 10,000 households suffering from fuel poverty. The ScotCLUE project plans to utilise this asset base to help create and study the effects of community based energy management systems that can control supply and demand assets across multiple energy cells under a variety of different operational conditions. The project has developed and deploying a software platform which does this and can balance the supply and demand of the energy assets based on a number of operational conditions.

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[1] Final figures for 2018 indicate that the equivalent of 76.2% of gross electricity consumption was from renewables, up from 70.1% in 2017 [5]

[2] Green hydrogen is produced by electrolysis powered by a renewable energy source such as a wind turbine.

2 OVERVIEW OF WEB OF CELLS CONCEPT

2.1 Definition of a cell

The ScotCLUE partners met together for a workshop at the start of the project, were a definition of a cell for the project was established through a round-table discussion with representation from all partners: Smarter Grid Solutions, the University of Strathclyde and the Offshore Renewable Energy Catapult. Based on these discussions, and in the context of an energy system comprising generation, storage and usage, the following definition of a ScotCLUE cell was agreed.

A cell is defined as a managed group of one, or more, related and fixed assets which are operated to achieve an objective or series of objectives.

An asset can only reside within one cell.

A cell could, therefore, be a single asset, e.g. a community wind turbine, or a collection of assets, e.g. an office facility with rooftop solar PV and EV chargers, which are coordinated at a local micro level to achieve a goal, e.g. to minimise the export of generation to the grid.

A collection of cells may be optimised centrally by a system operator to achieve a global macro objective, such as, to locally manage a network constraint, to provide services during faults, or to deliver wider grid services.

2.2 Description of ScotCLUE Web of cells

In the Scotland demo site, the aim is to develop a smart energy management platform based on the concept of a web-of-cells (WoC). This is a concept that enables the control of energy supply and demand from cells (assets) of different energy vectors (electricity and gas) within a local energy community in Levenmouth Fife Scotland UK.

The ScotCLUE project does this by utilising the unique asset base within the Fife UK area to create and study the effects of such as system. An overview of the proposed ScotCLUE web of cells concepts is summarised in **Error! Reference source not found.**. This concept employs both physical and virtual assets to demonstrate this concept and is made possible through the Cirrus Flex software platform provided by Smarter Grid Solutions (SGS) which provided the capability to balance the supply and demand of the energy assets based on different operational modes and demo use cases.

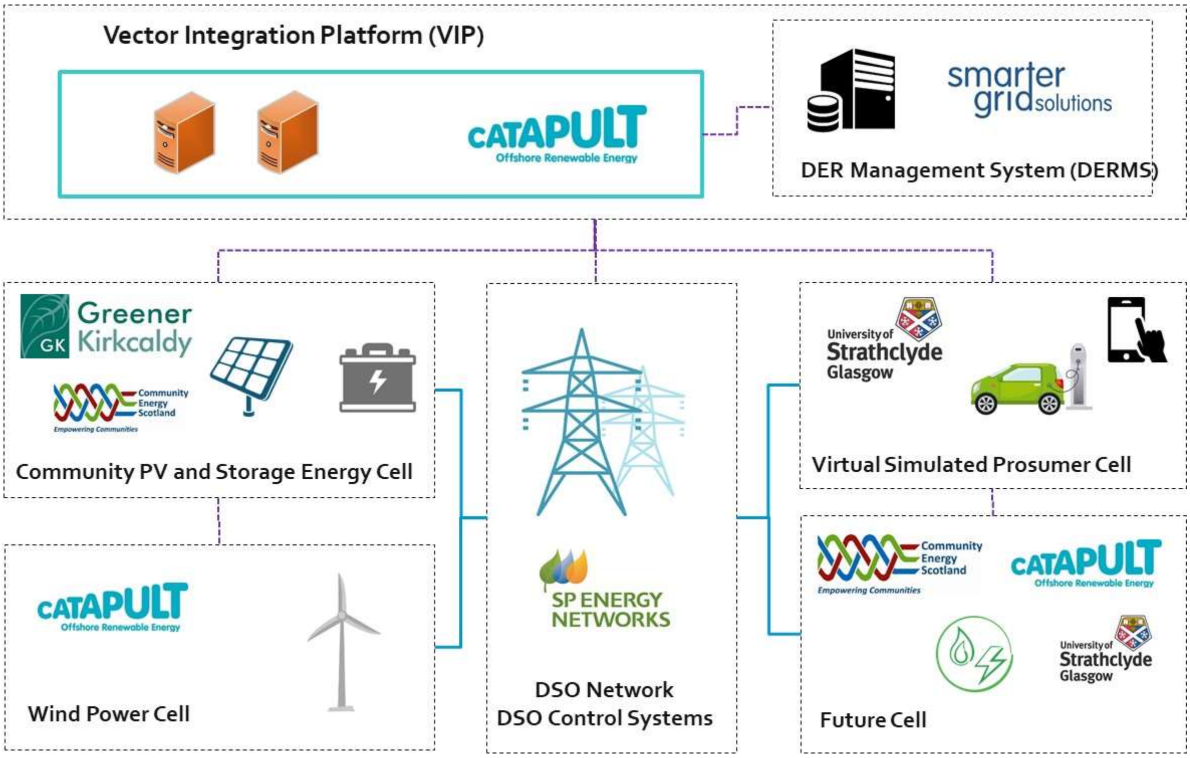

Figure 1: ScotCLUE Web of Cells Concept

To achieve this, this project is testing and validating a new concept design with some existing cells (assets) that we can access through the project. These cells (assets) are described in the following subsections.

2.2.1 Cell 1 - Wind Power Cell

The wind power cell hosts the Levenmouth Demonstration Turbine. This is an open access, offshore wind turbine dedicated to research, development and technology testing and validation (T&V). The LDT is a 7 MW prototype developed and installed by Samsung in 2014, which the ORE Catapult subsequently acquired. **Error! Reference source not found.** summarises the key features of the LDT.

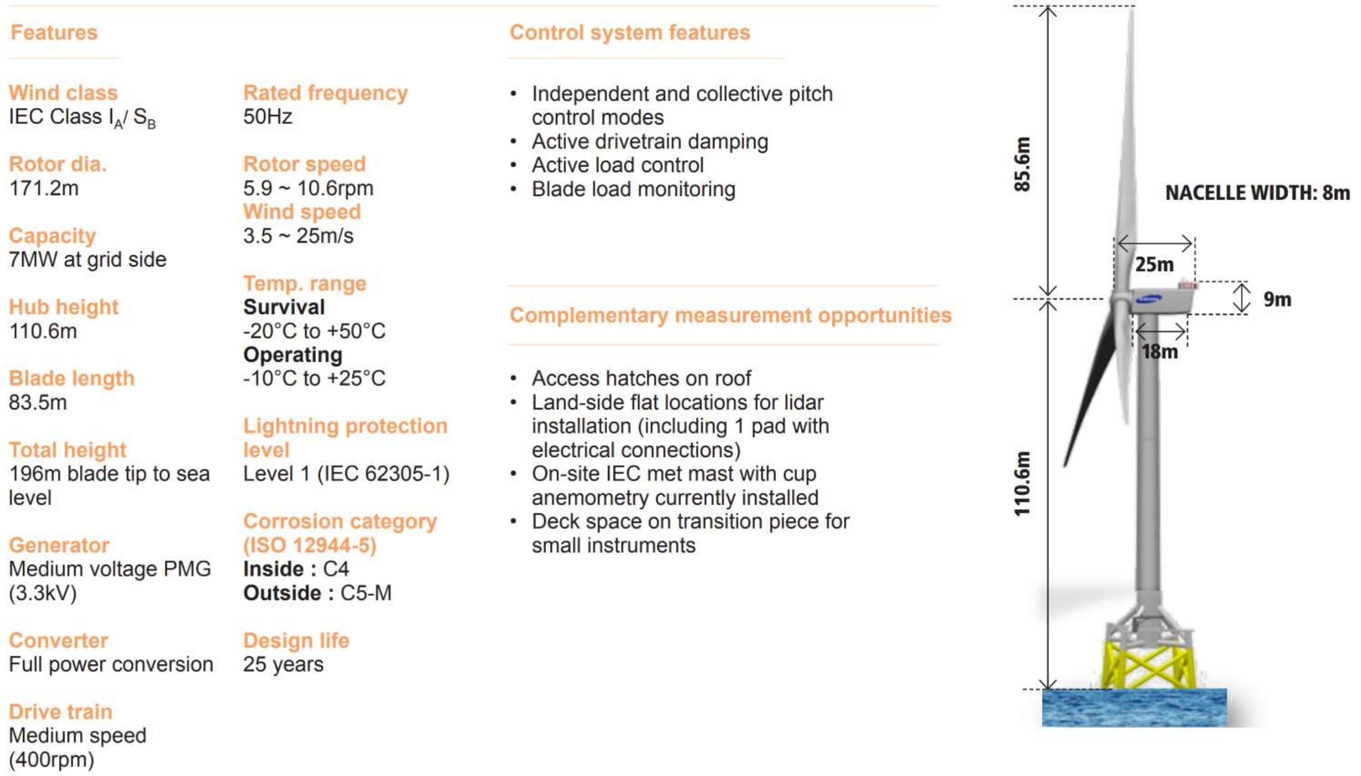

Figure 2: Demonstration Turbine (LDT)

In this project, the Levenmouth demonstration turbine acts as an electricity generator, and demonstrates both the integration of wind power into the network and the functionality of performing third-party control within the WoC. The turbines generation profile is monitored.

2.2.2 Cell 2 - Community PV and Storage Cell

Two community centres, Greener Kirkcaldy and St Bryce Kirk, form the community PV and Storage Cell. Each centre has a solar PV installation. As part of this project, a home battery energy storage was installed at both community centres and these were linked to the smart energy management system; this gave the option to charge and discharge the batteries.

Both community centres have a standard three-phase 400 V supply with 100 A cut-out fuses on each phase (the connection rating is 69 kVA). Both were also instrumented with control and monitoring with a Modbus capable energy meter (**Error! Reference source not found.**) which allows for logging of several power metrics. Using a low-cost computer, these variables are logged at an interval of 1 s.

St Bryce Kirk

Greener Kirkcaldy

Figure 3: Electrical measurement and communication setup for mid-sized community centres

2.2.3 Cell 3 - Future Cell

Virtually Simulated and future cells were used to replicate assets that could not be physically demonstrated during the project. This was necessary in a few cases.

In one case, a virtual cells were required because of a large discrepancy in the rating of the LDT (7 MW) to the readily accessible flexible demand situated in the Levenmouth area. This meant it was necessary to artificially create controllable assets, particularly cross-vector demand, to demonstrate the WoC. This was achieved via the use of virtual cells.

In another case, the hydrogen production facility co-located near to the LDT, which was originally intended to be incorporated into the project, was no longer available. To demonstrate this functionality, a plan was put together to develop and model virtual future energy cells. This was done by the University of Strathclyde; a hydrogen electrolyser future cell was modelled and linked to the other cells via software platform provided by Smarter Grid Solutions.

To supplement the electrolyser future cell, we simulated a representation of a future hydrogen gas network. This was done using available information around a future hydrogen project Fife, H100, which is being developed in Levenmouth.

2.3 Web of Cells (WoC) Control Strategy

With ScotCLUE partners, Smarter Grid Solutions (SGS) are undertaking to pioneer a distributed control architecture which leverages many of the more recent advances in mobile and cloud technologies, including:

- Cloud computing ecosystems and data storage
- Lightweight secure RESTful HTTPS web services

- Internet of Things (IoT) based edge control devices
- Containerisation
- Cloud data storage
- Software as a Service (SaaS) and Backend as a service (BaaS) delivery models
- Best-in-breed security practises

2.3.1 Firebase - Backend as a Service (BaaS)

BaaS is a model for providing web and mobile app developers with a way to link their applications to backend cloud storage and APIs exposed by back end applications. This is a powerful concept for allowing disparate apps to connect and cooperate via a cloud-based ecosystem and avoids the complexities, security risks and lack of scalability of client-server relationships.

For this architecture, the chosen BaaS ecosystem is the Firebase Realtime Database which runs in the Google Cloud Platform (GCP). This provides a cloud-based backend infrastructure with RESTful API, security, resilience and scalability. For this project, each of the participants in the WoC ecosystem will connect to Firebase to pull & push data to form a cohesive collaboration fabric. Furthermore, as each of the participants is connecting out to the cloud, negotiation of local firewalls and NAT gateways is easily achieved without additional configuration or VPNs. An high level of the architecture is shown in Figure 4.

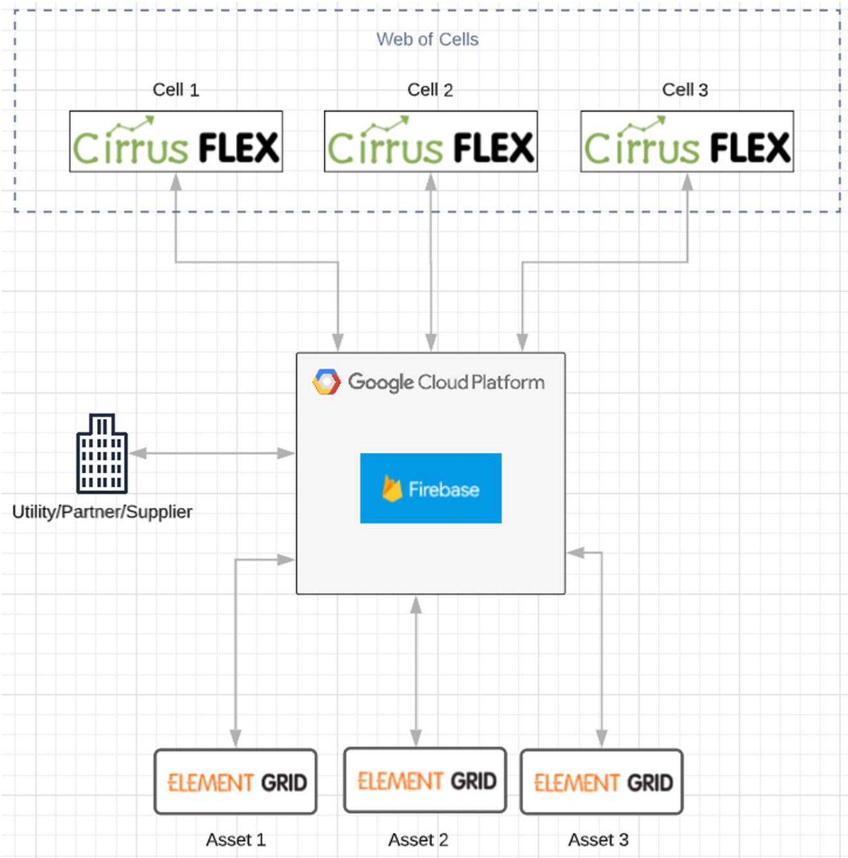

Figure 4: High level overview of Fire base BaaS Architecture

2.3.2 Definition of a cell in a cloud-hosted instance

For the WoC, each "Cell" in the "Web" is defined as being a cloud-hosted instance of SGS platform Cirrus Flex (as shown in Figure 4) and has been configured to have a specific point of control, and associated set of functional objectives, in relation to a collection of DER assets.

Part of the objectives explored in this project, is giving the cells the capabilities to cooperate to achieve higher sets of functional objectives involving multiple cell assets. The use of the BaaS model will allow this level of cooperation, without requiring a specific cell-to-cell architecture and protocol model to be established.

2.4 ScotCLUE Network Architecture

The following describes the network architecture across the three cells:

- Cell 1 – The Levenmouth Demonstration Turbine (LDT)
- Cell 2 – The Community Centres (Greener Kirkcaldy and St Bryce Kirk)
- Cell 3 – The virtual electrolyser at the University of Strathclyde

2.4.1 Communication and Interfaces

The overall network architecture of the participating devices is shown in Figure 5

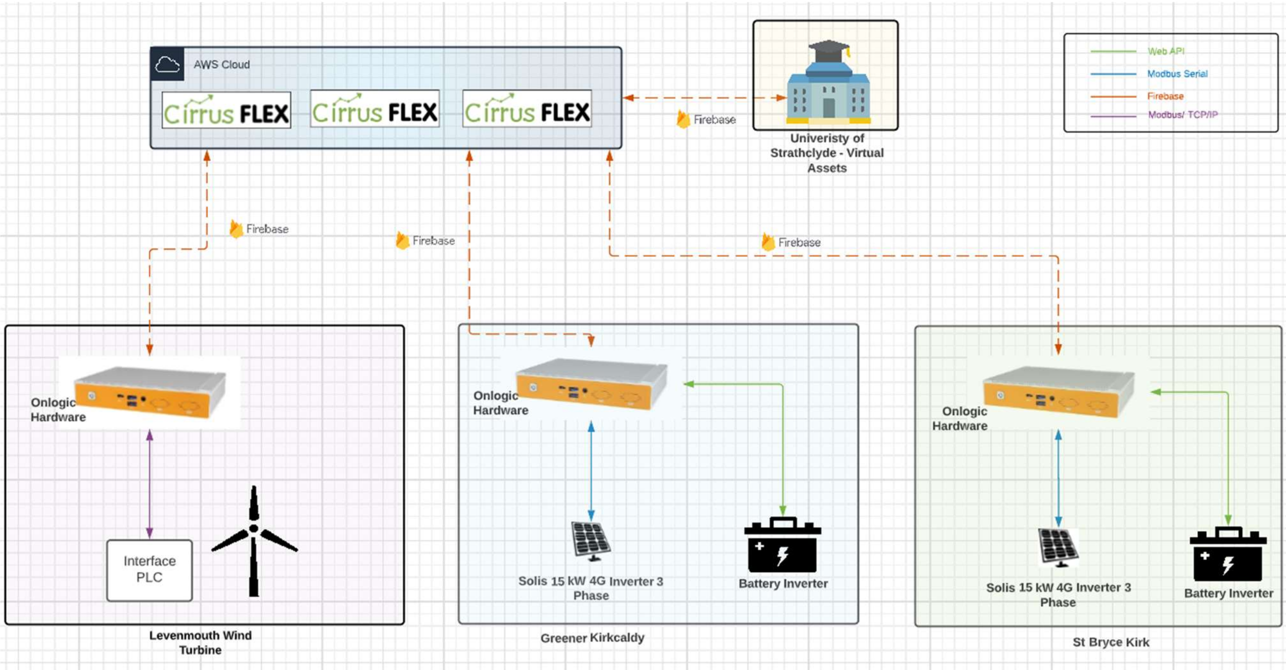

Figure 5: ScotCLUE Architecture

Inter-cell communications between Cirrus Flex and the sites as well as intra-cell communications is handled by Google Firebase using the Firebase REST API over internet. Intercell communications between equipment and the controllable devices is handled via device's native protocol (e.g Modbus, Web API, DNP3 etc.). Each local controller hardware devices are connected to a site-to-site VPN enabled 4G SIM network. The site-to-site VPN is established only to manage devices from a central server. Only management communications are passed through the VPN tunnel.

3 MODES OF OPERATION & USE CASES

As part of the demonstration of the WoC concept, three modes of operation were selected by the ScotCLUE partners for use in the project.

- Model 1 - Maximising the consumption of local generation
- Model 2 - Maximising hydrogen production
- Model 3 – Avoiding curtailment under a grid network constraint

An overview of the setup is shown in **Error! Reference source not found.**. Cell 1 is the Levenmouth demonstration turbine. Site 1 and Site 2 represents the community centres which together comprise Cell 2. Both community centres have solar PV and home battery storage. Cell 3 is the virtual hydrogen electrolyser.

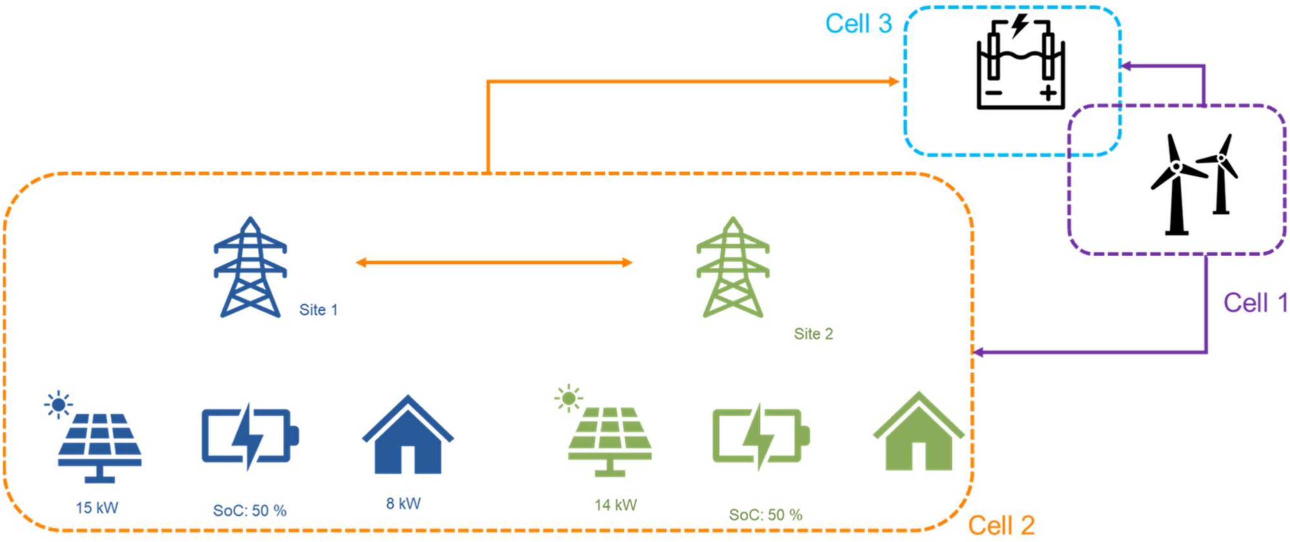

Figure 6: Overview of Web of Cells

3.1.1 Mode 1 - Maximising the consumption of local generation

The priority on this mode is to coordinate all the assets to maximise local electrical generation.

For the demonstration of this mode, a set of rules governing the operation of the mode was discussed and agreed between the partners in ScotCLUE. This is summarised below.

Cell Aim:

Cell 1 – Monitoring uncontrolled generation

Cell 2 – Maximise self-production. Preferentially use local generation and storage.

Cell 3 – Ensure hydrogen storage is always over 50% State of Charge (SoC).

Control Instructions:

Cell 1

- Asset observation only – no control required.

Cell 2

- Community centres should maximise the use of local generation to service demand.
- A community centre should charge local batteries if there is excess PV generation at the site
- Community centres should share excess PV generation only when local batteries are full
- Community centres may share battery storage capacity to meet demand
- A battery should never charge another battery
- Batteries should never be charged from the wider grid
- Batteries may be charged with excess generation from Cell 1
- If batteries are full, and PV export from the cell occurs, energy should be diverted to Cell 3

Cell 3

- Use excess energy from Cell 1 and Cell 2 to produce hydrogen
- Cell 3 should never import from the wider grid, unless the H_2 storage tank falls below 50% capacity

For the mode of operation, a surplus and deficit model was created by Smarter Grid Solutions (SGS) to check on the excess generation (surplus) or demand deficit across the assets in a cell. There are a number of possible use cases under this mode of operation and for the demonstration the following selected uses cases were investigated.

- Demo Case 1.1: Site 1 has a surplus, Site 2 has a surplus, and both batteries SoC is within High and Low limits

- Demo Case 1.2: Site 1 has a surplus, Site 2 has a surplus, and one of the battery SoC is greater than high SoC limit

- Demo Case 1.3: Site 1 has a deficit, Site 2 has a surplus, and battery SoC is within High and Low limits

- Demo Case 1.4: Site 1 has a deficit, Site 2 has a surplus, and one of the battery SoC is less than Low limit

- Demo Case 1.5: Site 1 has a deficit, Site 2 has a deficit, and one of the battery SoC is within High and Low limits

- Demo Case 1.6: Site 1 has a deficit, Site 2 has a deficit, and one of the battery SoC is within High and Low limits

- Demo Case 1.7: Site 1 has a deficit, Site 2 has a deficit, and the battery SoC is less than Low limit

3.1.2 Mode 2 - Maximising hydrogen production from Local PV and Wind Sources

The priority on this mode is maximising the hydrogen production from renewable power sources. In this project, this is equivalent to sending power from Cell 1 and Cell 2 to Cell 3. This helps to avoid using grid electricity in the elecrolyser.to meet the shortfall of hydrogen in the store, along with a strong aversion to using grid electricity for production.

Maximising hydrogen production helps to avoid a shortfall of hydrogen in the store. Sizing of a hydrogen supply system is important to avoid this (considering the capacities of power supply, electrolysis and storage, as well as the magnitude of demand). A well sized system may still run a risk of shortfall during unusual periods of low wind, lasting longer than five days. (Five days is the design capacity of the H100 Fife store).

In the event of a shortfall, this system could switch to this mode of operation (Mode 2); all local renewable power available is used to generate hydrogen, thereby minimising the contribution of grid electricity in meeting hydrogen demand. This may be financially beneficial and increase energy security.

For the demonstration of this mode, the following set of rules govern the operation of the mode, as discussed and agreed between the partners.

Cell Aim:

Cell 1 – Monitoring uncontrolled generation

Cell 2 – Maximise power sent to electrolyser.

Cell 3 – Ensure hydrogen storage is always over 50% State of Charge (SoC).

Control Instructions:

Cell 1

- Asset observation and controlling output generation .
- Provided the hydrogen store is not full, power is sent to the electrolyser as a priority.

Cell 2

- As a priority, PV generation and energy stored in the batteries at the community centres should be sent to the electrolyser.
- If the electrolyser or hydrogen store is at capacity and there is PV generation, use it to charge the batteries which will later be discharged to the electrolyser. Batteries should only discharge to the electrolyser.
- If the electrolyser, hydrogen storage and batteries are at capacity, PV generation can be used to meet local (Cell 2) demands.
- Batteries should never be charged from the wider grid
- Batteries may be charged with excess generation from Cell 1when hydrogen store is full

Cell 3

- Use all available energy from Cell 1 and Cell 2 to produce hydrogen
- Cell 3 should never import from the wider grid, unless
- The H_2 storage tank falls below 50% capacity

To test the mode, we used a similar surplus and deficit model to that used with Mode 1. This was investigated for the following demonstration use cases .

- Demo Case 2.1: Site 1 has a surplus, Site 2 has a surplus, the Battery SoC is within high and low limits, and H2 store headroom is available

- Demo Case 2.2: Site 1 has a surplus, Site 2 has a surplus, the Battery SoC is within high and low limits, and H2 store headroom is available

- Demo Case 2.3: Site 1 has a deficit, Site 2 has a surplus, the Battery SoC is within high and low limits, and H2 store headroom is available

- Demo Case 2.4: Site 1 has a deficit, Site 2 has a surplus, one of the Battery SoC is greater than high limit, and H2 store headroom is available

- Demo Case 2.5: Site 1 has a deficit, Site 2 has a deficit, the Battery SoC is within high and low limits, and H2 store headroom is available

3.1.3 Mode 3 - Avoiding Wind Turbine Curtailment due to a Grid Network Constraint

The priority on this mode is to avoid curtailing wind turbine in a situation where there is a grid network constraint that would have limited the power sent from the wind turbine to the network. In this situation, the excess wind generation, instead of being curtailed, is transferred to the electrolyser to produce hydrogen. This would continue until the electrolyser store is full. Then the turbine would need to be curtailed.

For the demonstration of this mode, the following set of rules governing the operation of the mode was discussed and agreed between the partners.

Cell Aim:

Cell 1 – Monitoring and controlling generation

Cell 2 – Maximise self-production. Preferentially use local generation and storage.

Cell 3 – Ensure hydrogen storage is always over 50% State of Charge (SoC).

Control Instructions:

Cell 1

- Observation and control required.
- Provided hydrogen storage tank is not full, and there’s curtailed generation, send the excess power to the electrolyser

- If the hydrogen storage tank is full and the grid network constraint still exists, curtail the wind turbine power output.

Cell 2

- Community centres should maximise the use of local generation to service demand.
- A community centre should charge local batteries if there is excess PV generation at the site
- Community centres should share excess PV generation to the other community centre before charging batteries
- A battery should never charge another battery
- Batteries should never be charged from the wider electricity grid

Cell 3

This cell has two options.

1) For high renewable energy generation conditions (i.e. mid/high wind speeds and PV export):

Use excess renewable export from Cell 1 & Cell 2 to produce hydrogen (in Cell 3) when there's an electrical grid network constraint. There are two possibilities:

- Condition 1: If there is spare capacity in the hydrogen store
  - Avoid curtailing turbine by diverting excess power to produce Hydrogen (Cell 3)
  - When powering the electrolyser, excess LDT power takes priority over excess PV power
- Condition 2: If the hydrogen store is full
  - Curtail the LDT turbine power (Cell 1) to match the total demand of Cell2.

2) For low renewable energy generation conditions (i.e. low/no wind speeds and low/no PV export), implement the follow rules:

- Condition 3: If renewable generation from Cell 1 and Cell 2 doesn't meet the demand and/or the H2 storage tank falls below capacity, import from the wider grid.

A demonstration model for this mode operation was developed tested and validated and worked as intended.

4 SUMMARY OF PROGRESS WITH TASKS

This section summarises the progress so far with the tasks within work package 7 of the ScotCLUE project.

4.1 Task 7.2 Specification of local cell requirements and communication strategy

Aims

(i) To define the requirements for each of the cells to be deployed as part of the web-of-cells architecture within the Levenmouth area.

(ii) To define the inter cell communication requirements which will be necessary to ensure balancing of generation and demand within the local energy system.

Outputs

4.1.1 Technical report confirming Scottish cell assets, control points, grid arrangements, network model and available data sets. -

A report produced for this task details the definition of an asset, cell, and web on which the ScotCLUE project builds. Control integration points and common/desired measurement parameters are highlighted for several assets including the Levenmouth demonstration turbine. An overview of standard industrial control interfaces and protocols is provided.

2.1.2. Report defining the communications and security requirements for inter-cell communications.

A specification has been created covering communication and security requirements, including the ability for a controller in one cell to validate the authenticity of a controller in another cell, or, for resilience purposes, a controller (or element) in one cell to validate the authenticity of a device from another cell. It also covers the ability for any participant in the inter-cell communications approach to fall back to a predictable and safe mode of operation where communications fail or cannot be secured.

4.2 Task 7.3 – Development of ICT architecture, interfaces and controls

Aims

(i) To define and develop the ICT architecture required to host the Web-of-cells architecture.

(II) To develop the IoT protocol for communication between multiple cells within the web of cells architecture.

Outputs

4.2.1 ANM Strata based cell controller that can provide services to multiple "cells".

Cirrus Flex (a newer platform based on previous version of ANM Strata) acts as a cell controller which can provide services to multiple "cells". The Cell Controller is hosted in Amazon Web Services (AWS), a cloud-based environment. Cirrus Flex issues commands to apply setpoints to the site's Local Controller (Element Grid) as well as publishing requests to neighbouring cells.

4.2.2 Centralised ANM Strata deployment that presents data from multiple cells and is capable of historical analysis on those cells.

Cirrus Flex is hosted on an AWS environment and all cell to cell communication is established using Google Firebase. Cirrus Flex records all the data transferred between the cells in a central historian database.

4.2.3 Low-cost ANM Element device deployed at two different cells.

An industrial single board computer (OnLogic) is acting as the Local Controller running a simplified version of SGS' Element Grid software. The Element Grid provides the Cirrus Flex with live measurements and the status of the site.

This setup is deployed at three sites across two "cells" – Levenmouth Demonstration Turbine (Cell 1) and Greener Kirkcaldy Community Centre & St Bryce Kirk (Cell 2). Cell 3 does not utilise this setup as it is currently a virtual cell.

4.2.4 ANM Element devices at cells provisioned into ANM Strata cell controllers.

Each Local controller (Element Grid) supplies the Cell controller (Cirrus Flex) with measurements from the site. The site's Local Controllers interface with the Cell Controllers via Google Firebase using a database API that allows data to be synchronised and stored in real time. The Local Controllers calculate the setpoint value to be applied to the controllable device based on the live measurements of the site.

4.2.5 Secure cell-to-cell communications protocol.

A secure communication protocol has been designed based on TLS connections between the elements and then sending within those HTTPS packets a JSON-based API for information transmission. The protocol also covers authentication of the different nodes through the use of certificates which could allow cross-cell node validation if required, as well as handling certificate expiry and the compromise of devices.

4.2.6 ANM Element successfully communicating with the ANM Strata over an IoT protocol.

Element Grid has been deployed in place of the previous version ANM Element. This is a newer version of the platform with functionality relevant to the CLUE project; this platform is a successor to the previous version of ANM Element.

SGS hardware is connected to the internet (with restrictions) via an industrial 4G router. Element Grid talks to the cloud hosted Cirrus Flex through Firebase REST APIs. The APIs are secured with authentication key and user rules.

A back-and-forth watchdog value is exchanged between the Cirrus Flex and Element Grid to determine the communication status. Failure on the watchdog value update is treated as a communication failure and failsafe actions are executed at the Element Grid level.

4.3 Task 7.4 – Optimisation of developed cell platform

Aims

(i) To ensure the developed Web-of-cells architecture is a secure and resilient local energy system.

(ii) To utilise consumer load profiles to simulate consumer demand as a virtual cell within the web of cells architecture.

Outputs

4.3.1 A numerical data set of operationally valid customer profiles that are available for cell characterisation.

Several publicly available datasets were identified as part of this task. These datasets were obtained from smart-meter readings. Interpolation techniques were applied to migrate these profiles from half-hour energy readings towards a dynamic profile sets.

In addition to these profiles, higher resolution datasets were recorded for:

- a domestic dwelling with battery storage and solar PV,
- the heating system for a community centre including flow and return temperatures, room comfort levels, boiler control set-points and boiler power, and,
- grid-side parameters for journey, destination, and home EV charge points.

Additional datasets included energy data for assets on the University of Strathclyde including:

- a campus-wide combined heat and power systems,
- incoming primary transformers
- solar PV arrays, and,
- building demands.

Datasets allow historic events to be 'played' into the web-of-cells platform thus allowing state-machine and logic control on Cirrus Flex to be benchmarked against known-good data. This allow control and systems to be de-risked prior to deployment on physical assets.

4.3.2 A set of data driven forecasting models that capture available technology behaviours at different time scales.

To enhance the static datasets outlined in the previous deliverable, several dynamic virtual models were developed for this task. Models include:

- Community sportsground floodlighting,
- EV charging hub consisting of 6 journey charge points,
- A hydrogen electrolyser, and,
- The demand of a hydrogen train.

These virtual models integrate to Cirrus Flex via Firebase API. Models are produced using a range of integration paths including python scripts and interactive Node-Red based integrations. Additionally, a module allowing historic and real-time data-injection was also developed.

Virtual models allow for the performance of future assets to be examined prior to deployment. An additional benefit is that edge use-cases, which cannot be demonstrated physically due to regulatory constraints, can be benchmarked.

4.3.3 Optimisation capabilities for cell management and operation.

Cirrus Flex system operates in three modes. It uses SGS' algorithm called Synergy, State Machine logics, and ANMPP Groovy script to enable optimisation capabilities for cell management and operation. Depending upon the mode of operation, SGS uses a combination of each for optimisation. To recap Section 3, the three modes are:

1. Maximise Local Electrical Generation
2. Maximise Hydrogen Production
3. Grid Network Constraint (avoid curtailment of wind turbines during constraint, instead transfer excess generation to the Hydrogen electrolyser)

The Cirrus Flex logic for each mode of operation is described in the Web of Cells design specification.

4.3.4 Report detailing protocol performance and suggested enhancements.

Initial implementation and testing of the communication between the different components has now been completed. Data will be collected in the coming months to allow performance of the protocol to be assessed. A report on the results is due at the end of the year.

4.3.5 Hardware in the loop demonstration platform and demonstration of control of remote flexible assets

This task will be completed towards the end of the year.

4.4 Task 7.5 – Cell integration and demonstration

Aims

(i) To physically interface the developed control software and web of cells architecture with local assets in Levenmouth and related areas.

(iii) To demonstrate the web-of-cells architecture between the three cells of the CLUE project.

Outputs

The ScotCLUE project has employed both physical and virtual assets to demonstrate a distributed web of cells (WoC) concept. Each cell within this concept provides inherent flexibility and is useful for providing power and energy balancing requirements to serve the community.

In this project, the LDT is a controllable generator, and can be curtailed using the Cirrus Flex platform. It two primary purposes

- send power into the electrical network
- send power to a virtual electrolyser cell

In the future, the virtual electrolyser cell could be replaced with a real electrolyser, which is planned to be deployed through the H100 Fife project. The resulting hydrogen could then be sent to a 100% hydrogen gas network, also deployed through the H100 Fife project.

Figure 7: Overview of communications interface between the LDT and Cirrus Flex Platform

4.4.1 Simulation results from turbine integration studies

Task 2.4.1 within the project was to validate that the LDT could be integrated into the wider WoC. This involved the following steps.

1. Installing the SGS “Element Grid” hardware next to the turbine and interfacing this with the turbine PLC to monitor measurements and enable power control.

2. Running system integration tests to validate that the required turbines data sets can be measured and monitored properly

3. Running system integration tests to validate that the wind turbine can be controlled for safe operation within the project.

The following steps were undertaken under this task and the LDT was successfully validated as a controllable generator cell (Cell 1).

Figure 8 shows results from the successful wind turbine test. This test was conducted remotely under moderate wind conditions; the turbine was not generating at full power. The SGS hardware “Element Grid” sent curtailment setpoint (in W) to turbine PLC and the power output ramped down upon receiving the setpoint along with the relevant control flag and watchdog signal. The no watchdog condition was also tested, in which the turbine is released to its full power (if wind conditions allow).

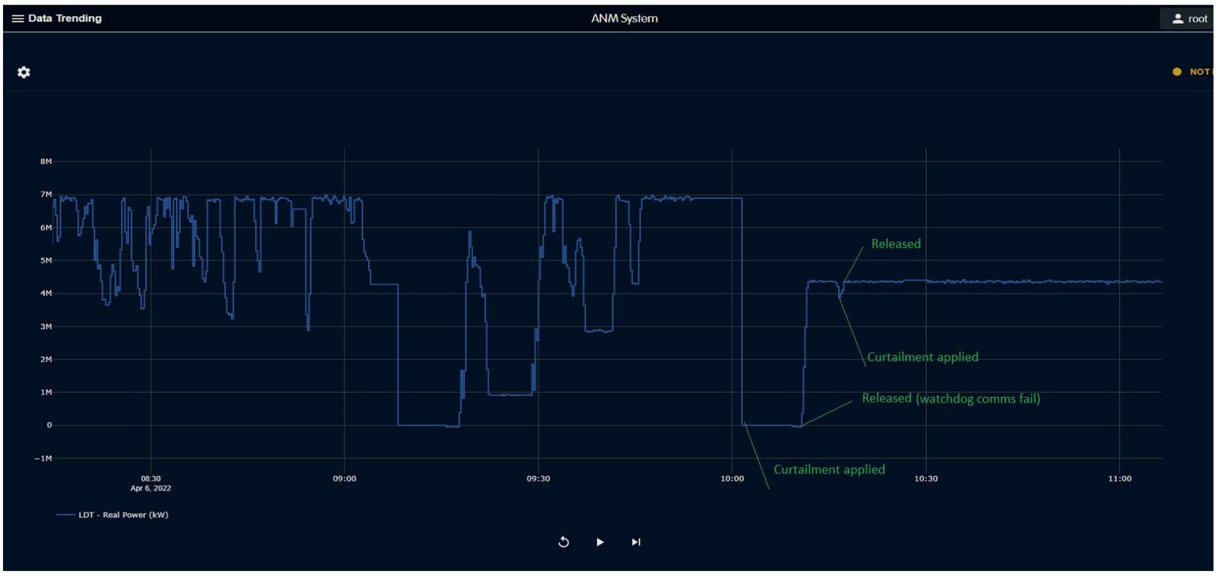

Figure 8: Successful demonstration test results of controlling output of the LDT Turbine

4.4.2 Demonstration of integrated web of cells system

This tasks focus on the demonstration of the integrated web of cells systems with all cells within the project, namely the LDT, the community centres and the virtual electrolyser.

This is still an ongoing activity and tests are currently underway to examine the chosen use cases. The test documentation and acceptance criteria have been created and the first series of test were undertaken on the 4th of October for the three modes of operation. These were successful. Subsequent formal and live tests (full validation of the functionality) will follow on in the months leading to the end of the project. A timeline is shown below.

- Demo of system for project partners on 10th August 2022.
- Test Documentation for validation of system (formal test scripts) issued 29th September 2022.
- Scheduled formal demonstration for 4th October 2022.
- Subsequent formal testing (full validation of functionality) during October 2022.

4.5 Task 7.6 – Planning tools, business models and stakeholder engagement

Aims

(ii) To develop an intensive stakeholder engagement plan to disseminate and capture feedback to inform the development of the project.

(iv) To increase stakeholder acceptability of moving towards a de carbonised energy system through the utilisation of flexible renewable energy assets in a local energy system.

Outputs

Task 7.6 focuses on community engagement and the ScotCLUE consortium, in collaboration with Community Energy Scotland (CES), undertook a set of activities to engage with the community and present the scope of work explored in the project.

As part of the activities, the following were covered (either complete or ongoing activities) in Task 7.6

CES supported with the installation of batteries and monitoring equipment at the two community sites. This was completed by SGS and contractor Alba Heat and Power in March 2022. This included the installation of required ethernet connections at the sites to allow control/monitoring during the project. The post project plan will allow for decommissioning and handover of the batteries at the conclusion of the project.

As part of community engagement, a workshop was held on 14July 2021 with the local community groups in the Levenmouth area, to raise the profile of the project. This provided a forum for discussion and agreement on an approach for messaging when discussing ScotCLUE with members of the public and at different stages of the project. CES and Greener Kirkcaldy also held the first community engagement event on 14th September 2021, run as an online session due to considerations of covid and accessibility. This provided local individuals and organisations with information about the project, while having a clear practical focus on supporting participants to take practical action to decarbonize their energy usage and thereby become potential nodes in the ScotCLUE web of cells network. The session included detailed information and signposting to assist participants in navigating the installation of solar PV, batteries, and/or EV charging points. There were presentations from CES, Greener Kirkcaldy, Zero Waste Scotland, Local Energy Scotland, and Home Energy Scotland.

An interim stakeholder report was produced by CES and circulated to all partners in April 2022. This included a review of engagement activities conducted to date, and informed discussion with project partners on the timescale and focus of future activities – including an ongoing desire to deepen engagement with expert stakeholders, and the proposal for an additional expert stakeholder focussed event at the conclusion of the project. The final stakeholder report will be produced towards the end of the project in Q1 2023.

The project will also deliver a public demonstration event (expected to take place in early 2023) due to delays in the rollout of live testing at the community centres.

4.6 Summary of Progress with Deliverables

Deliverables	Name	Date	Responsible	Status
7.1.1	SE Claim Report	Various (seven in total)	ODSL	In progress
7.1.2	CLUE ERA-Net Report (ScotCLUE entries)	March 2020, 2021, 2022	ODSL	In progress
7.2.1	Cell Requirement Technical Report	Feb 2020	UoS	Complete
7.2.2	Virtual Cell Definition (Focus Group)	Feb 2020	UoS	Complete
7.2.3	Inter-Cell Comms & Security Requirements Report	Feb 2020	UoS	Complete
7.3.1	ANM Strata Controller Report	Dec 2020	SGS	Complete
7.3.2	Centralised monitoring and	Dec 2020	SGS	Complete

	data collection Report			
7.3.3	Low-cost ANM Element Design	Feb 2021	SGS	Complete
7.3.4	Self-Provisioning Integration and Testing Report	Feb 2021	SGS	Complete
7.3.5	Inter-cell communications protocol design	Dec 2020	UoS	Complete
7.3.6	IoT Protocol Selection and Integration	Dec 2020	UoS	Complete
7.4.1	Modelling load behaviours of assets Report	Jan 2021	UoS	Complete
7.4.2	Comms Protocol Analysis & Optimisation Report	Dec 2022	UoS	In progress
7.4.3	Cell Management and Optimisation Report	Oct 2022	SGS	In progress
7.4.4	Software demo and Hardware in the Loop Verification Report	Dec 2022	UoS	In progress
7.5.1	Turbine integration simulation Report	Aug 2022	ODSL	In progress
7.5.2	System Demonstration & Integration Report	Jan 2023	SGS	In progress
7.6.1	Stakeholder Engagement Plan	July 2021	ODSL	Complete

7.6.2	Briefing event for Fife-based community groups	Aug 2021	ODSL	Complete
7.6.3	Energy usage and generation data set from community facility	Dec 2020	ODSL	Complete
7.6.4	One public demonstration event at Green Kirkcaldy building	Sept 2022	ODSL	In progress
7.6.5	Engagement with local stakeholders	Jun 2022	ODSL	Ongoing
7.6.6	Interim Stakeholder Engagement Report	Sept 2022	ODSL	Complete
7.6.7	Final Stakeholder Engagement Report	Feb 2023	ODSL	Not started

REFERENCES

[1] Scottish Government, "Scottish Energy Strategy: The future of energy in Scotland," December 2017. [Online]. Available: https://www.gov.scot/publications/scottish-energy-strategy-future-energy-scotland-9781788515276/.

[2] GOV.UK, "Government funded electric car chargepoints to be smart by July 2019," 14 December 2018. [Online]. Available: https://www.gov.uk/government/news/government-funded-electric-car-chargepoints-to-be-smart-by-july-2019.

[3] C. Tornelli, R. Zuelli, M. Marinelli, A. Z. Morch and L. Cornez, "Requirements for future control room and visualisation features in the Web-of-Cells framework defined in the ELECTRA project," *CIRED - Open Access Proceedings Journal,* vol. 2017, no. 1, pp. 1425 - 1428, 2017.

[4] M. Chen, V. Catterson, M. Syed, S. Mcarthur, G. Burt, M. Marinelli, A. M. Prostejovsky and K. Heussen, "Supporting control room operators in highly automated future power networks," *CIRED - Open Access Proceedings Journal ,* vol. 2017, no. 1, pp. 1492 - 1495, 2017.

[5] Scottish Government, "Energy Statistics for Scotland," December 2019. [Online]. Available: https://www2.gov.scot/Resource/0054/00549213.pdf.