Department of Mechanical and Aerospace Engineering

Modelling and analysis of Local Energy System at Ross Priory with the proposed solar farm

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Abstract

This report outlines the modelling and analysis of local energy system at Ross Priory estate with the proposed solar farm development on the estate grounds. Ross Priory is recreational and conference centre owned by the University of Strathclyde. A new development project to install a 20MW solar fam has been proposed on the estate grounds under the Climate Neutral Estate project to cut down emissions on site. The proposed solar farm and its components were modelled using the PVsyst software platform and the solar energy output was generated. This was used to model possible local energy systems using Homer Energy Pro software platform connected to the local grid that utilised the energy produced at the solar farm. The simulations of individual possible local energy systems modelled were run and results were compared to evaluate the merits of each scenario.

Acknowledgements

It is with great pleasure and pride that I present this report before you. At this moment of triumph, it would be unfair to neglect all those who helped me in the successful completion of this project.

First of all, I would like to thank my supervisor Dr Nicolas Kelly for all the help and guidance he provided. I also would like to thank our Course Coordinator, Dr Paul Tuohy all Faculty and Staff members of the department for the guidance and whole-hearted support that they have given me during the course.

I also wish to thank Mr David Charles, Head of Climate Action, Sustainability & Environmental Management for providing me with the background information and data regarding the proposed projects and daily workings of the Ross Priory Estate.

Above all I would like to thank my family and friends without whose support, I would not have been able to accomplish my goal.

ABEL BIJU THADIKKAL

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1.0 Introduction

The University of Strathclyde has developed a Climate Change and Social Responsibility (CCSR) Plan and is committed to Vison 2025 which aims to reduce greenhouse gas emissions by 70% by 2025 and hopes to achieve NetZero emissions by 2040. The policy calls for transitioning away from fossil fuels and working on renewable energy projects individually and partnering with other organisations with similar goals. Ross Priory estate, located on the banks of Loch Lomond, is a19th-century country house within the Loch Lomond and the Trossachs National Park [1]. It is owned by the University of Strathclyde and currently serves as a recreational and conference centre. In line with the sustainability goals, there have been various feasibility studies and project proposals to build a PV Solar Farm to contribute towards the University of Strathclyde Climate Neutral Estate project aiming to cut down emissions form energy utilised on site and meet the energy demands of the site and adjacent establishments. This study focuses on modelling the proposed solar farm at Ross Priory using PVsyst based on the recommended PV array size and its expected energy output. Further, based on outputs from PVsyst and the field data available regarding the electricity demand profiles of Ross Priory and the surrounding community and limitations of grid infrastructure, the local energy system was modelled using Homer Pro with separate simulations for multiple scenarios pertaining to energy use.

1.1Site details

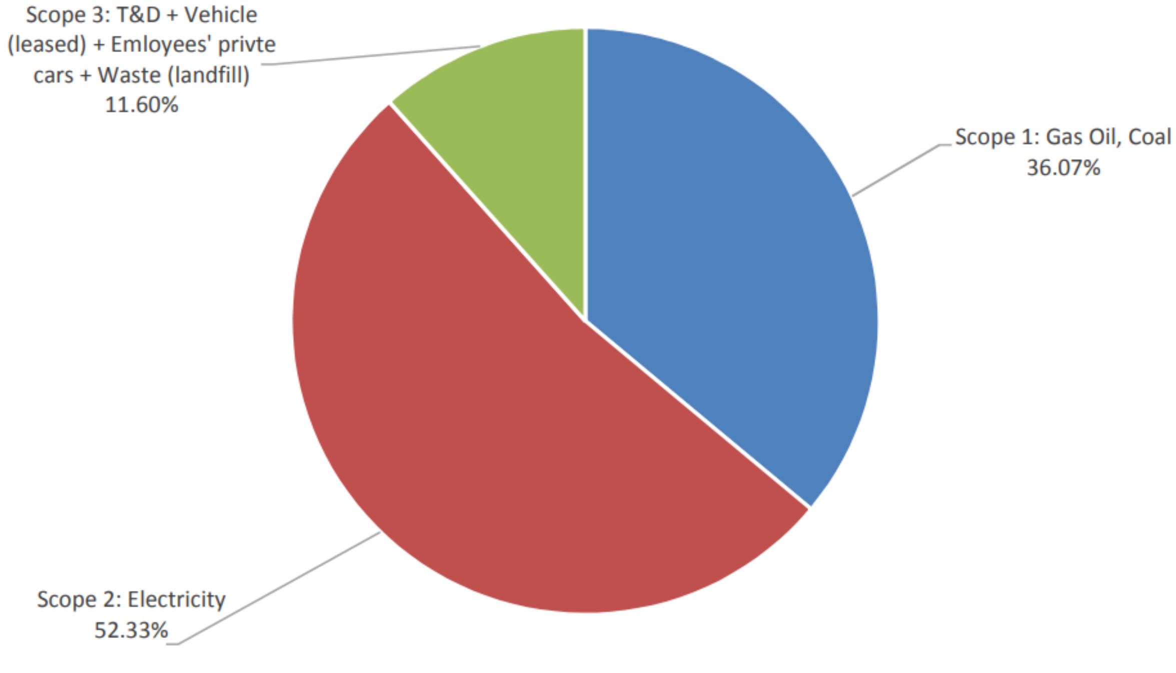
1.1.1 Ross Priory

Ross Priory, currently owned by the University of Strathclyde, is a 19th-century country house located on the banks of Loch Lomond within the Loch Lomond and the Trossachs National Park. Accessed from the village of Gartocharn in the Kilmaronock district of West Dunbartonshire, the site currently serves as a recreational and conference centre. The building itself is protected under Town and Country Planning (Scotland) Act 1947 as a category A listed building, and the grounds are included on the Inventory of Gardens and Designed Landscapes in Scotland, the national listing of significant gardens [1]. The construction of the original structure dates back to 1816. Today the main house has 10 ensuite bedrooms, a dining room and a conference and functions room (the Carnegie Room). The building stands in 173 acres of grounds with sporting facilities for members, including a 9-hole golf course. In addition, the property has greenhouses, guest cottages, building managers' cottages, gardeners' cottages, storage facilities, and outbuildings.

1.2 Proposed Development

1.2.1 Scope

A detailed study on GHG emission emissions from the Ross Priory estate was conducted in 2014 by Sheena Boyd, Juri Kromm and Nikolaos Sofianopoulos as part of the collaborative project between Scottish Business in the Community, University of Strathclyde, and the Carbon Trust. The team identifies scope 1 and scope 2 emissions comprising of Gas oil and Coal burnt and Electricity use from grid as major contributors to the GHG emissions. As evident from the figure below the heating oil and coal burnt under scope 1 emissions amount to 109.54 tonnes of CO2 emissions which is 36.07% of the total 303.68 tonnes of CO2 emissions. The scope 2 emissions comprising of electricity usage from grid in the estate amounts to 158.92 tonnes of CO2 emissions which amounts to 52.33% of the total [2].



- Proportional distribution of emissions by scope

Figure 1: Carbon emissions at Ross Priory [2]

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The proposed Climate Neutral Districts Project at Ross Priory aims to meet the energy demands from heating and electricity use at the facility by using renewable means. The project proposes a solar fam in the estate grounds to meet these energy demands, it also explores the possibility of working with Scottish water to use the excess power generated to be used at the Scottish water pumping station and possibility of exporting excess electricity to the local grid during off peak hours.

1.2.2 Solar Farm

The project proposed in the current stage stretches over 75 aces of field area within the estate grounds. The area is comprised of three individual sites displayed in the figure below with a combined Total Installed Capacity (TIC) of 20.8MW and a Declared Net Capacity (DNC) of 16MW [3].

Figure 2: Site description of the proposed Solar farm

Site 1 accommodates 484 Solar PV Tables comprising of 26,136 Modules yielding 14,113.44kWp. Each PV table consists of 2 panels portrait by 27 modules wide at 20-degree pitch. Site 2 has 155 Solar PV Tables made of 8,370 Modules with a combined generation capacity of 4,519.8kWp and SITE 3 has 75 Solar PV Tables made of 4,050 Modules with a combined generation capacity of 2,187kWp. The total installed capacity of the facility amounts to 20,820.24kWp with Declared Net Capacity being 16,000kW. The Total Yield of the plant is 19,932,000kWh of which 2,473,000kWh is for direct own use and 16,765,000kWh is for grid feed in. The project is expected to use 38,556 JA Solar JAM72S30-540/MR 540W modules and 4 SMA Sunny Central 4000 UP inverters of 4MW [3].

A comprehensive feasibility study during the design stage in future may involve additional site assessment, which can identify locations to avoid (due to, for instance, shade) and regions that may not be acceptable owing, for instance, to the distance from the point of connection, since this might result in excessive expenses cutting down the generation potential mentioned above.

1.2.3 Energy Requirements

According to the consumption study for Ross Priory House, the site might achieve 10% export with a 70kWp solar array, implying that the majority of the energy produced would be utilised inside the building [3]. The consumption profiles for the two MPANS offered are displayed in the graph below. The graphs' x-axis lists the days of the year, with 1 being January 1. Daily energy usage is shown on the y-axis as kWh. Looking at the MPAN504 graph, the daily energy use throughout the summer has decreased. The daily range for MPAN500 is between 60 and 310 kWh. On weekends, greater readings are typically observed.

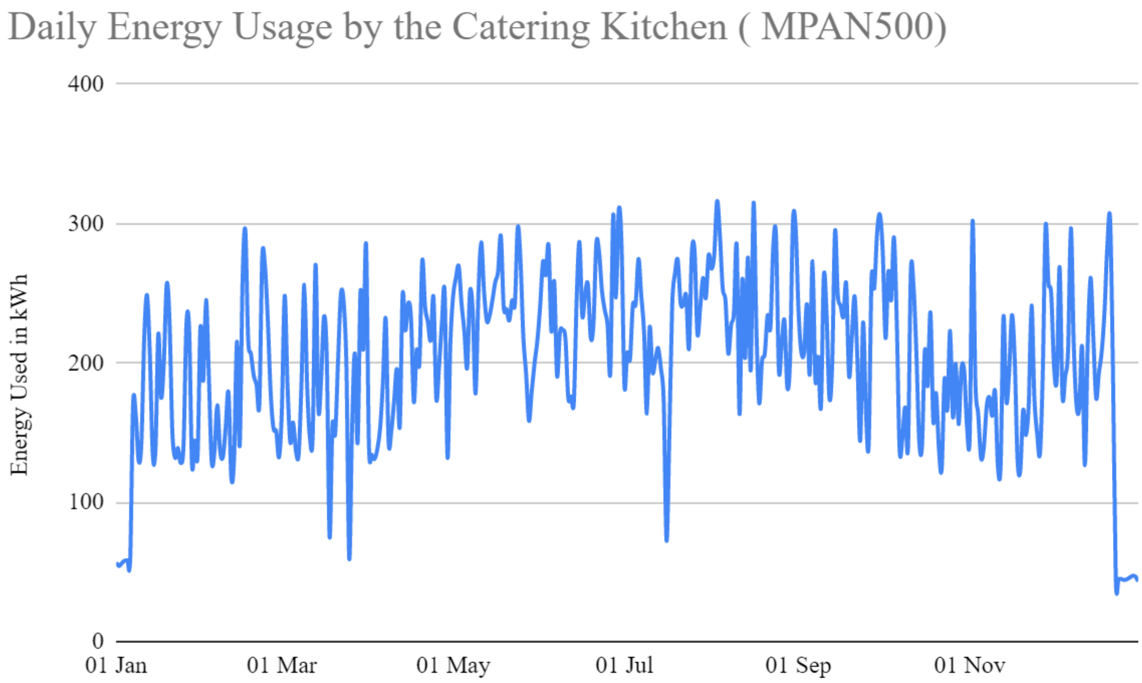

Figure 3: Hourly Energy Usage at the Ross Priory Catering Kitchen

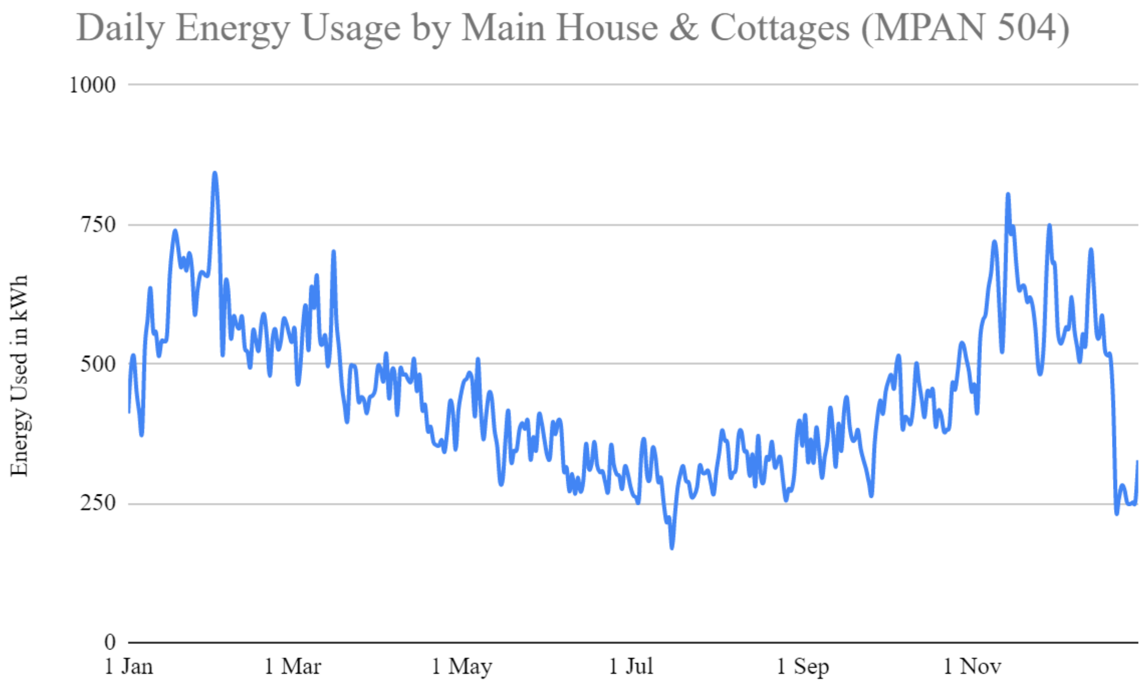

Figure 4: Hourly Energy Demand from the Main House and Cottages at Ross Priory

The HH data also demonstrates that the base load does not decrease from the usage during the day. About 7200 kWh are consumed between 11 night and 5 am. Carbon emissions might be significantly reduced by using a battery system to counteract evening consumption.
Additional research into the site's real loads and the use profile below may help determine how to apply energy-saving measures or the effects of various technologies. Although the HH data shows an average kWh value over a 30-minute period, it does not reflect the real site demand. A load monitor connected to the site's main incoming cables might offer a more precise load profile to determine the peak demand there.

The consumption profile for the Scottish Water pumping station based on the 2018 HH data is also considered in this study. The location contains a 692.5kW hydro network that lowers on-site use and hence lowers baseline carbon emissions. The 2018 data includes utilisation of hydroelectric electricity. The total amount consumed during the time was 7093.05MWh.

2.0 Literature Review

A significant number of solar projects have been implemented around the globe in the resent decades and hence the is sufficient literature available regarding planning, designing and execution of such projects are available. This section outlines the technologies available in solar energy extraction mainly photovoltaic (PV) panels, associated infrastructures such as inverts mounting structures and batteries as well as information regarding simulation and modelling software platforms used in modelling the solar farm and the energy system.

2.1 Solar Technologies

Solar thermal and solar photovoltaic systems are the two main categories for solar energy technology currently being employed. The proposed project relies on photovoltaic or pv systems.

2.1.1 PV Panels

A material or apparatus is referred to as photovoltaic and is considered to have captured solar energy when it can generate electrical energy from photons of light irradiated on the material [5], [6]. The quantum theory provides an explains that in a given material, such as conductor, semiconductor, and insulator there are various energy bands in which the electrons exist [4], [7]. In a nutshell, a material's structure is made up of valence and conduction bands. For instance, silicon has an electron-full valence band but an empty conduction band, unlike conductors, which have a partly filled conduction band. The valence and conduction bands are separated by a forbidden region, commonly referred to as an energy gap or a band gap [4].

The Figure below depicts a basic summary of PV technology. Crystalline silicon (c-Si) is more efficient than the other technologies, but due to its high cost, photovoltaic researchers and manufacturers worldwide are constantly looking for new technologies that can provide a solution that is comparably less expensive. This has led to the development of thin film technologies [4]. When compared to crystalline technologies, thin films provide a reduced material consumption, guaranteeing a cheaper cost of manufacturing. However, their conversion efficiency isn’t as high. In contrast to the attempt to minimise the thickness of c-Si, the researchers are persistent in their pursuit of improving the conversion efficiency of thin films. Research and development have led to the development of organic/polymer photovoltaics in order to solve the negative environmental consequences that some thin film materials (such as cadmium telluride PVs) have. Polymer technology serves as good example as it economical as well as lightweight and environmentally beneficial [4]. Its comparatively lower efficiency of roughly 45%, however, continues to be a limitation [7]. In addition to the previously stated technologies, hybrid technologies such as micro morph and heterojunction with intrinsic thin layers (HIT), which mix crystalline and thin film materials, also exist.

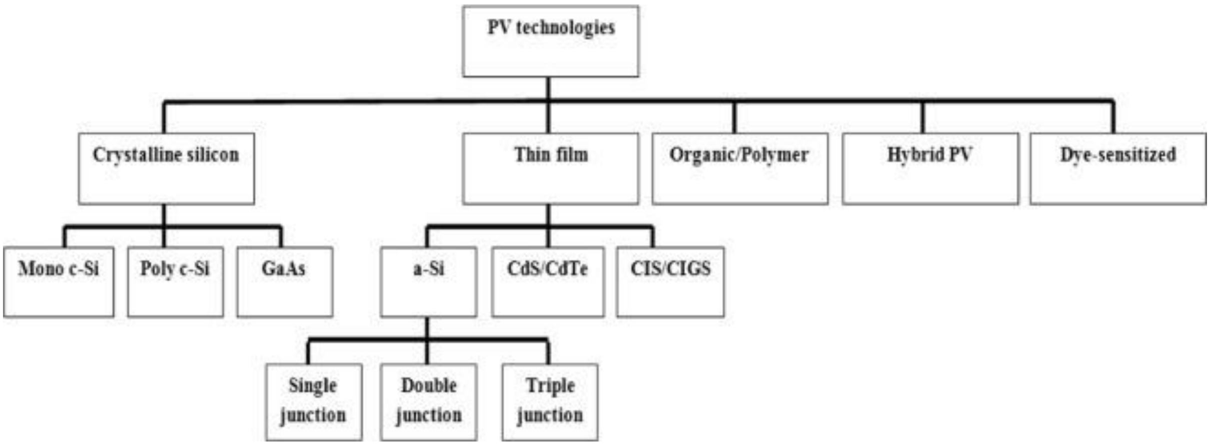

Figure 5: Clacification of Solar PV Technologies (https://ars.els-cdn.com/content/image/1-s2.0-S1364032115001744-gr2.jpg [PV technologies](https://ars.els-cdn.com/content/image/1-s2.0-S1364032115001744-gr2.jpg).)

With silicon serving as the main component for cell production, crystalline silicon systems are regarded as the first generation of PV technologies [4]. Crystalline modules are created by combining the cells [7]. In terms of efficiency, these technologies have advanced through time, and in comparison, to other technologies, they presently dominate the PV industry. Single crystal silicon cells' current state-of-the-art conversion efficiency has been measured at 24.7% at STC [4]. Crystalline cells and modules, particularly mono- and poly-c-Si, are becoming more affordable, making them the favoured PV technology. Monocrystalline (mono c-Si), tricrystalline (tri c-Si), polycrystalline (poly c-Si), emitter wrap through (EWT) [4], and gallium arsenide (GaAs) [4] are the several types of crystalline silicon technology.

The most widely used photovoltaic technique is mono c-Si, which uses silicon p-n junctions in various configurations. It is produced via the Czochralski (CZ) technique [4], which focuses on crystal formation, feedstock melting, and drawing a single crystal ingot using a "seed" crystal. The resultant crystal is referred to as a "boule," which is cylindrical in shape and typically has dimensions of "0.165 m and 2 m," respectively [4]; greater diameter cylindrical boules are also feasible. Silicon wafers are created by cutting the boules into shorter, thinner portions known as "pseudo-square" cross sections. The wafers are then put through a series of steps to create PV cells, including chemical etching, diffusion, edge isolation, anti-reflection coating, formation of metal connections, and grading, which involves measuring the I-V properties under artificial light. Manufacturers typically claim mono c-Si conversion efficiencies of 15% to over 20% on a commercial basis [4], [8].

2.1.2 Mounting Frames

Mounting frames Seasonal fluctuations in the sun's altitude have an impact on the generation profile from solar energy over the course of the year. There are mounting frames that can follow the sun's rays for increased productivity. The panels may be tilted in any direction using single- or dual-axis tracking devices [4]. These systems do add a further mechanical component that needs upkeep and is susceptible to failure. Installing a range of systems on the site would allow researchers to evaluate the increased energy produced by these systems against the ongoing expenditures. Tracking and Bi-Facial modules Over the upcoming years, bi-facial modules are anticipated to be used more often. Global research and experiments have shown that the employment of tracker systems in addition to crop production may boost yield by 5 to 25% [4].

2.1.3 Inverters

Inverters String inverters and central inverters are the two types of inverters most frequently utilised in large-scale solar farms. The size of a single string inverter can range from 1kW to 250kW. Multiple Multi Power Point Trackers (MPPTs) are used in the bigger inverters in order to optimise performance throughout a site where circumstances might not be uniform for all strings. However, it is not always true that more MPPTs lead to higher performance when utilised in an open region because the losses between various strings throughout an array are likely to be fairly minimal [4]. Multiple MPPTs may be advantageous if the array has spots where shading may occur or if the panels are oriented differently. In the past, central inverters were employed on large-scale projects because they were more effective and made installation easier by using a smaller number of big units rather than many smaller ones. A smaller number of cables need to be deployed since strings may be linked in parallel out in the array and the central inverters can sustain very high DC currents. Many medium-sized systems prefer string inverters because they can now be installed without cranes or concrete foundations and are available in sizes up to 250kW. Inverter, transformer, and HV switchgear are typically included in containerized power station solutions for large-scale inverters. This may be a reasonably priced alternative for systems that have an HV connection [4]. The majority of studies done to determine whether string or central inverters are preferable tend to concentrate on cost and installation simplicity. The performance differences between the two, which would be a topic that might be examined on this site, have not received much attention.

2.1.4 Battery

Batteries Energy Storage Solutions (ESS) may be utilised in a variety of applications, including microgrids, smart grids, intelligent buildings, and renewable energy producing facilities. In the past, battery systems were mostly used for off-grid systems since installing a grid connection was either impractical or too expensive. The system needed a wide range of chargers, inverters, fuses, switches, and controllers and would consist of a bank of marine batteries (either lead acid or gel). People who want to store extra power generated during the day for use at night or to have as a backup system in places that are prone to power outages now have more options available thanks to the development of lithium batteries that can be contained in a single unit (for residential size). Tesla, LGChem, BYD, Pylontech, and Alpha ESS are the primary systems available right now, while new ones are constantly being developed [4]. The majority of these manufacturers provide residential and commercial alternatives, and in the majority of situations, they would be positioned next to on-site generating for the storing of surplus energy. Additionally, intelligent devices may be implemented that will charge batteries from the grid during periods of low load demand and strong renewable energy output.

Several major manufacturers provide commercial battery systems. The majority of them employ lithium cells, which typically give 70% of their capacity and may be charged and discharged more frequently than conventional lead acid batteries. They also offer a prompt reaction to unexpected spikes in demand [4].

Unlike traditional batteries, which store energy in a cell and may be drained to 100%, flow energy storage devices employ a patented vanadium redox flow technology to store energy in liquid without deteriorating. Lithium has a lower initial cost, but the demand response may take longer [4].

2.2PVSYST SOFTWARE

One of the energy modelling tools used by the solar industry to predict the energy harvest of a proposed project site is the Photovoltaic design and simulation software is called PVsyst V6.64. Depending on the solar module being modelled, PVsyst's parameters can be changed. It is used to research, size, and analyse data for entire PV systems. It covers grid-connected, standalone, pumping, and DC-grid PV systems and has vast databases of meto and PV system parts as well as basic solar energy tools. [9], [11]

Users of PVsyst may select the area of the system they want to work on as well as the sort of system they want, such as pumping, stand-alone, or linked to the grid. Here, a grid-connected method is used to select the project design. It is intended for usage by researchers, engineers, and architects. It provides a method to project development that is user-friendly. PVsyst contains a big collection of meteorological information for several locations across the globe. Additionally, it offers manual data entry for locations that are not included within the software. Outputs are presented as a comprehensive report with relevant charts and tables. It is possible to export the data for usage in other programmes. We must provide the programme certain inputs in order to get results. Meteorological information and incident irradiance in the collector plane are simulation variables in PVsyst. [10] The selection of a PV array is a crucial component of system design that could handle the entire load demand. It is chosen in such a way that the total no of PV panels used in system design is minimum. The PV depends on various factors such as solar irradiance, temperature, voltage, current, its configuration in series as well as in shunt. [11]

2.3Homer Energy Pro

A community-scale tool called HOMER [14] was first created to facilitate the design of off-grid community size electrical energy systems but has now been expanded to mimic grid linked and thermal systems [13]. Modelling a hybrid solar-biomass system for a distant Pakistani location is one instance [15]. This study examined the techno-economic viability of such a system using energy consumption, available solar and biomass resource, and costs. Using an hourly energy balance and minimum net present cost (NPC) as the goal function, HOMER was employed to optimise system size [15][12].

In the past, HOMER has carried out a grid search based on user-defined inputs that indicate the system choices to be included, but a recent upgrade has allowed users to just select upper and lower bounds for the grid search [12]. The HOMER (Hybrid Optimization of Multiple Electric Renewables) tools are the most often used and highly praised in various literature works out of the many tools that are now available [16], [17] [18]. HOMER is a reliable design optimization tool for design optimization [19] that considers the adaptable conditions to study various configurations and the best HRES models [22]. Its design optimization algorithms enable designers and planners to assess the viability of scenarios using a variety of technical standards connected to shifting technological trends and resource accessibility. As a result, HOMER is chosen in this study's techno-economic analysis to identify the most practical solution to satisfy the area's load requirements [22]. With a regular and simple method, HOMER evaluates suitable configuration schemes among numerous potential alternatives. The component sizing is optimised [20]. Its design optimization is solely based on the input parametric values, such as load requirements, generation profiles, economic and technical conditions, modelling constraints, suggested energy management schemes, and GHG evaluation parameters [20], [19], with TNPC as the primary objective of the design optimization scheme. To assess several elements of HRES, including technical, environmental, and economic factors, HOMER calculates a one-year optimal design [21]. To guarantee a consistent generation and consumption balance on an hourly basis throughout the project's lifespan, extrapolation of costs is then applied to the remaining years [19]. The feasible ideas are chosen and rated according to design objective once the testing step for all potential configurations has been completed [22].

The HOMER Pro programme offers a number of advantages for creating, planning, and modelling the microgrid model. These advantages include its capacity to accommodate various renewable elements (RE) as well as a number of other elements needed for the reliable microgrid concept. Under limited circumstances, the programme performs the model's economic and technological viability rather effectively [24]. The many HOMER Pro software components are shown in this portion of the article. The major elements have been discussed in this subsection. The parts and include numerous power sources such generators, the grid, and REs, as well as various types of loads, converter and controller modules, as well as several kinds of storage units [23]. Residential, industrial, and commercial loads are among the numerous types of loads that are accessible after splitting the components. Different renewable and non-renewable power sources, such as solar PV, wind, biogas, utility grid, diesel generators, etc., are available [24]. The input data for resources like GHI, wind speed, etc. may also be acquired from a variety of online/offline sources taking the individual area into consideration. Storage units are crucial for the dependability of microgrid systems used in islanded mode. As a result, the programme supports a wide range of storage devices, including battery and fuel cell systems. Different converter modules are available in the system with an emphasis on microgrid compatibility for the purpose of constructing the AC/DC microgrid model [24]. All versions of the programme include the HOMER-based controller module for computing the optimal value of cost and other parameters [24]. The fundamental procedures for creating the microgrid model using the HOMER Pro programme and development of the microgrid stay the same for developing under a confined and specified circumstance. The first stage in setting up the microgrid is to choose a specific geographic region The second step is to define the load type and determine the appropriate load profile. The utility grid or traditional generator must be included to the model. In step three, the utility grid or traditional generator is included to the model while its various properties are specified. HOMER Pro components for the hybrid microgrid model are included in step four, along with other renewable energy sources like solar, wind, and so on [24].

3.0 Methodology

3.1 PVSyst modelling

The three sites for the propose solar farm were modelled individually on PVSyst. The location was chosen to be 56.05ºN (Latitude) -4.55ºW (Longitude) at an altitude of 41meters above sea level where the Ross Priory Estate is located which provided the sun paths for the simulation. The historical meteorological data was imported from meteonorm 8.0 available in PVsyst which provided the global horizontal irradiation, horizontal diffuse irradiation, temperature, wind velocity, linke turbidity and relative humidity throughout the year. The year-to-year variability factor was 5.1%. The tilt was set to an angle of 20º as described in the proposal and the azimuth angle was set to 0º. The PV Tables chosen for this model are 2 panels portrait by 27 modules wide. Table sizes will always relate to inverter stringing, in this case each string is 27 modules long. The PV panels used were JA Solar JAM72S30-540/MR 540W modules and 4 SMA Sunny Central 4000 UP inverters of 4MW were chosen as described in the proposal. Since required total installed capacity for the entire farm and individual sites were available these individual values were used to define the three sites.

3.1.1 Site 1

The site1 houses 484 Solar PV Tables with 26,136 Modules and has an installed capacity of 14,113.44kWp in an area of 72886m^2. The figures below depict the average energy output for an average day in peak summer and peak winter the hourly energy data for the system was downloaded as CSV file to use as input for energy generation from site1 for modelling local energy system in Homer Pro.

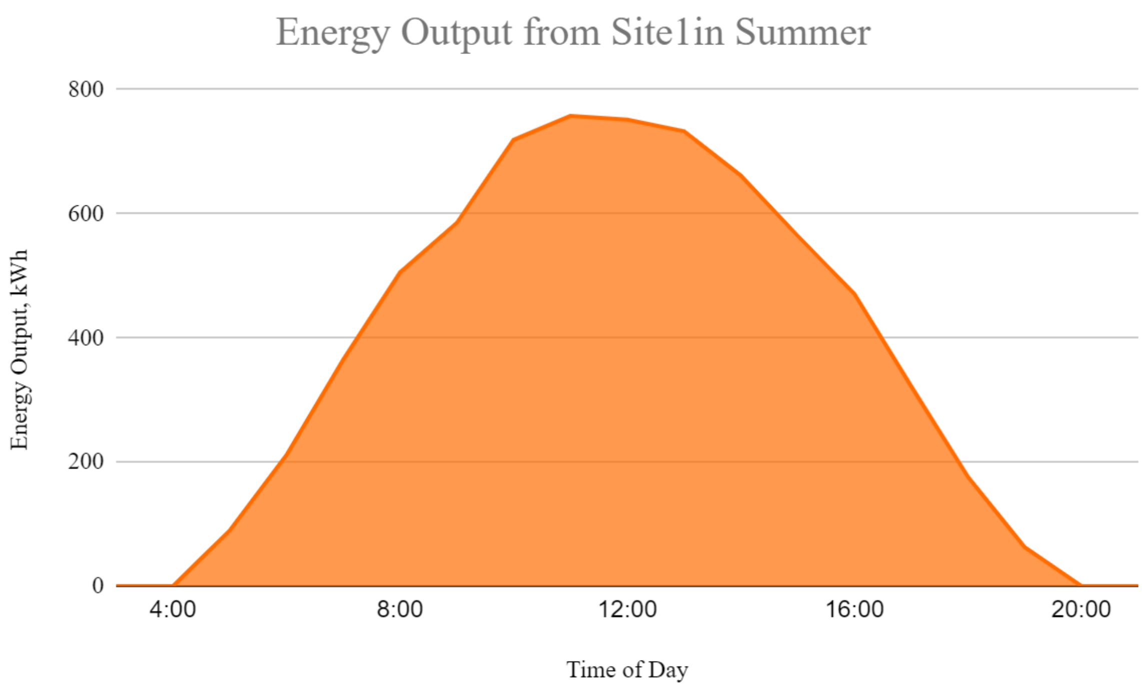

Figure 6: Energy Output from site1 in Summer (July)

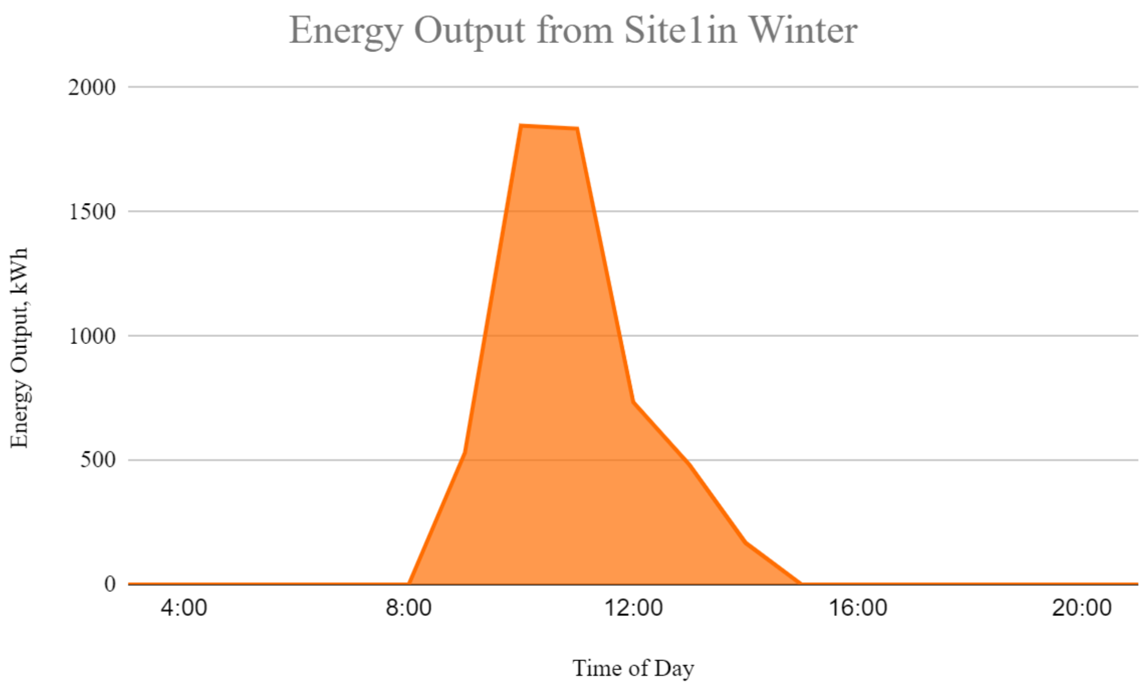

Figure 7: Energy Output from site1 in Winter (Jan)

3.1.2 Site 2

The site2 houses 155 Solar PV Tables with 8,370 Modules and has an installed capacity of 4,519.8kWp in an area of 21622m^2. The figures below depict the average energy output for an average day in peak summer and peak winter the hourly energy data for the system was downloaded as CSV file to use as input for energy generation from site2 for modelling local energy system in Homer Pro.

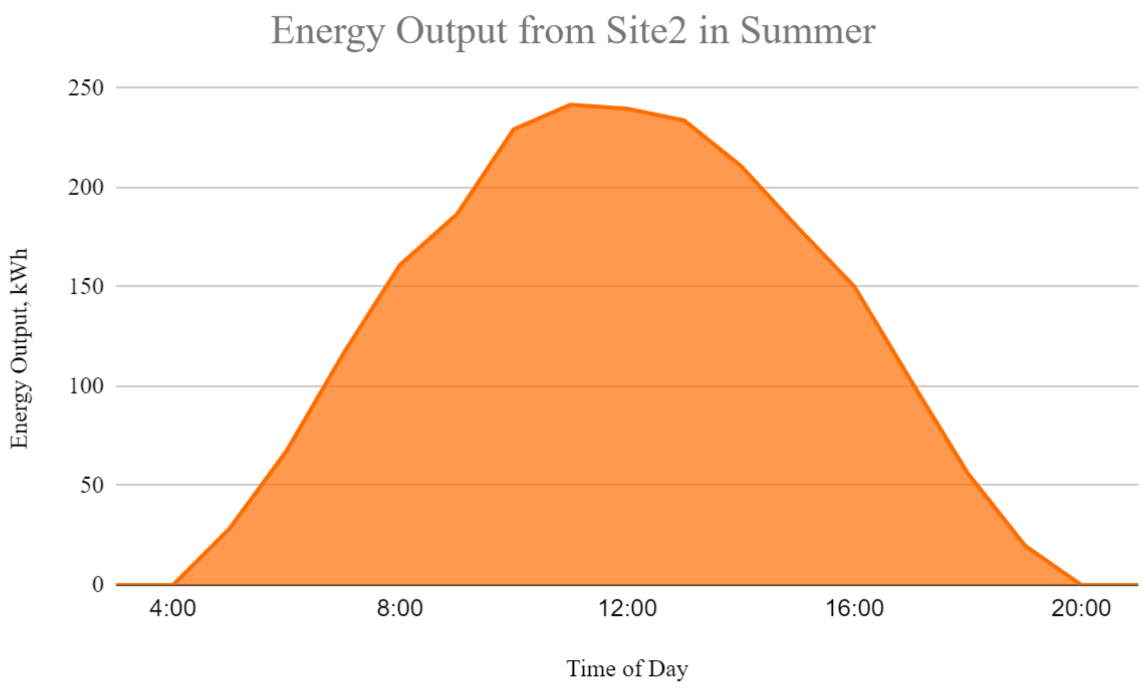

Figure 8: Energy Output from site2 in Summer (July)

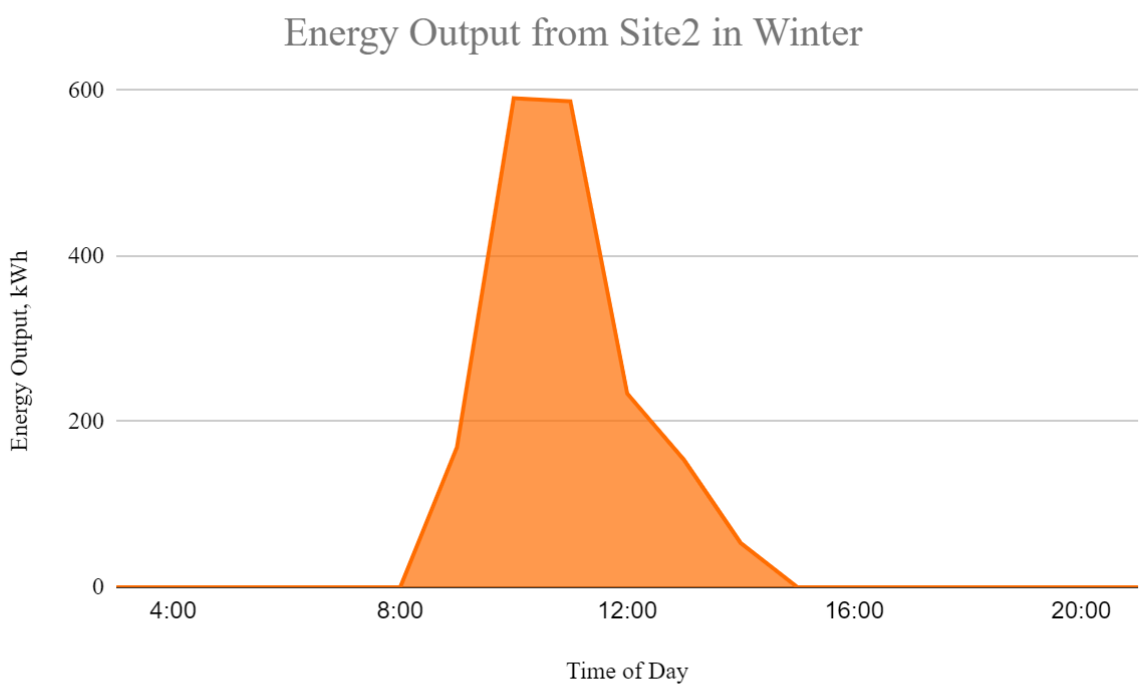

Figure 9: Energy Output from site2 in Winter (Jan)

3.1.3 Site 3

The site3 houses 75 Solar PV Tables with 4,050 Modules and has an installed capacity of 2,187kWp in an area of 10462m^2. The figures below depict the average energy output for an average day in peak summer and peak winter the hourly energy data for the system was downloaded as CSV file to use as input for energy generation from site3 for modelling local energy system in Homer Pro.

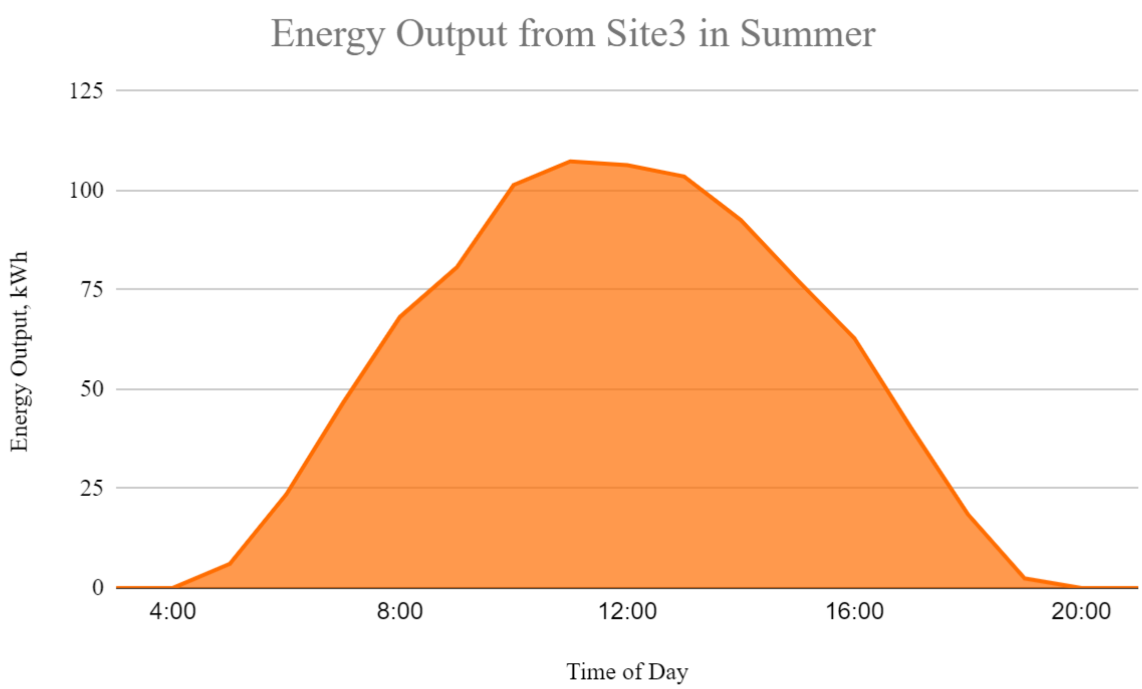

Figure 10: Energy Output from site3 in Summer (July)

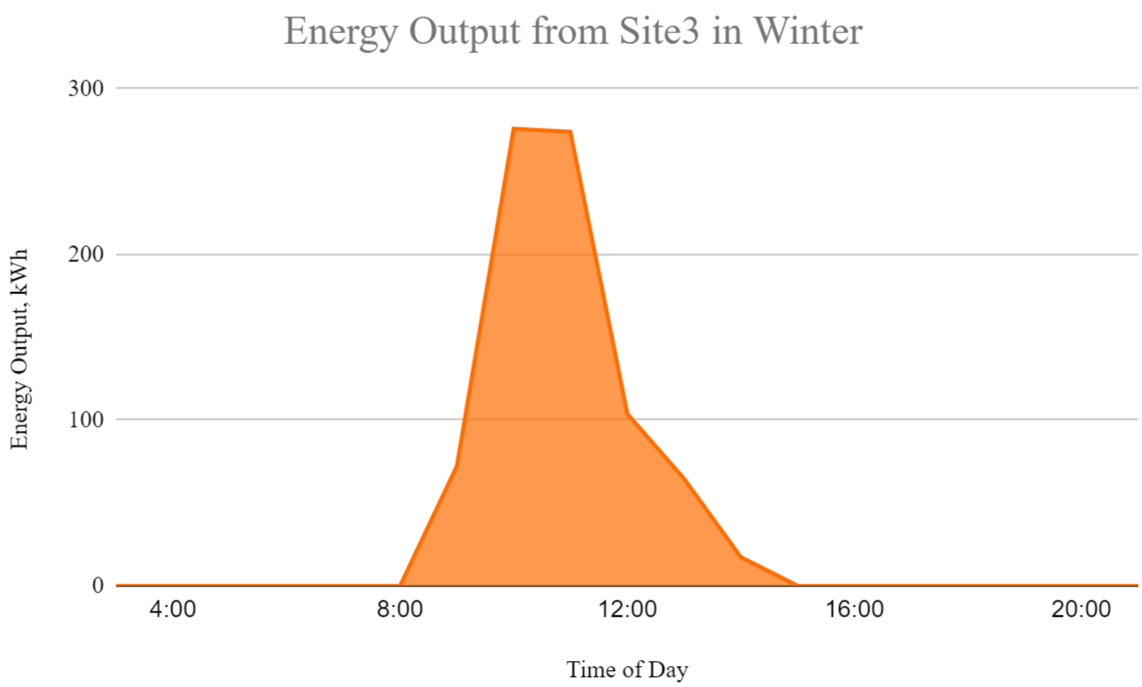

Figure 11: Energy Output from site3 in Winter (Jan)

3.1.4 Combined Output

The solar fam as a whole consisting of the three individual sites houses 674 Solar PV Tables with 38,556 Modules and has a total installed capacity of 20,820.24kWp in an area of 10462m^2. The figures below depict the average energy output for an average day in peak summer and peak winter the hourly energy data for the system was downloaded as CSV file to use as input for energy generation from the entire solar fam for modelling local energy system in Homer Pro.

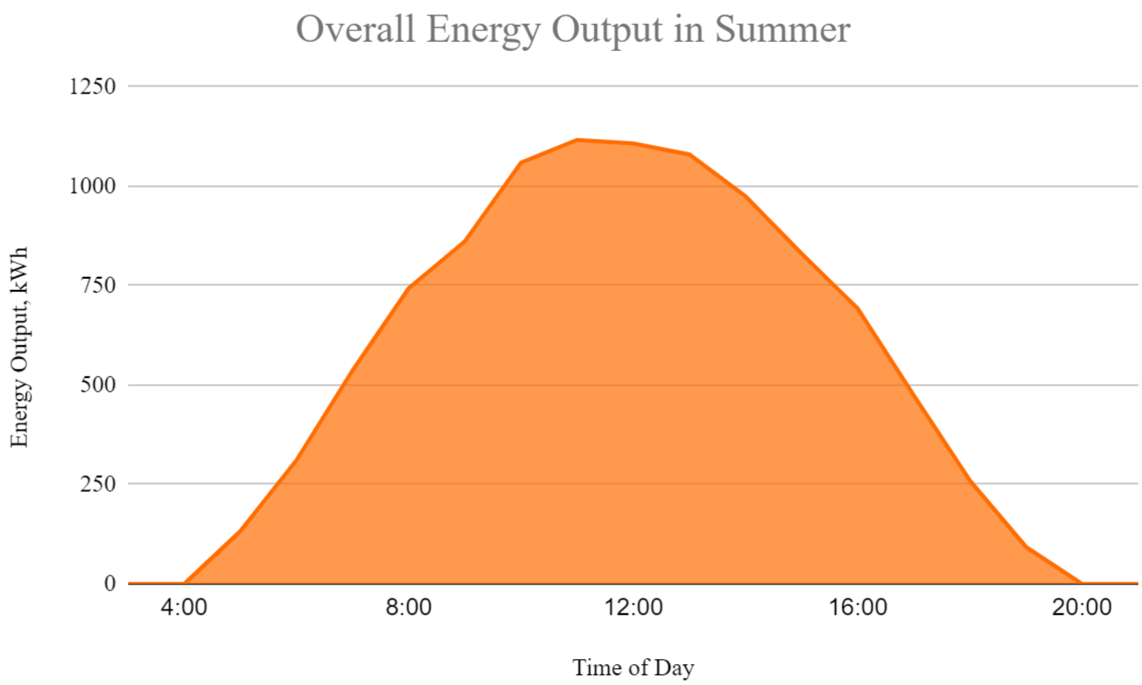

Figure 12: Combined energy output from the solar fam in Summer (July)

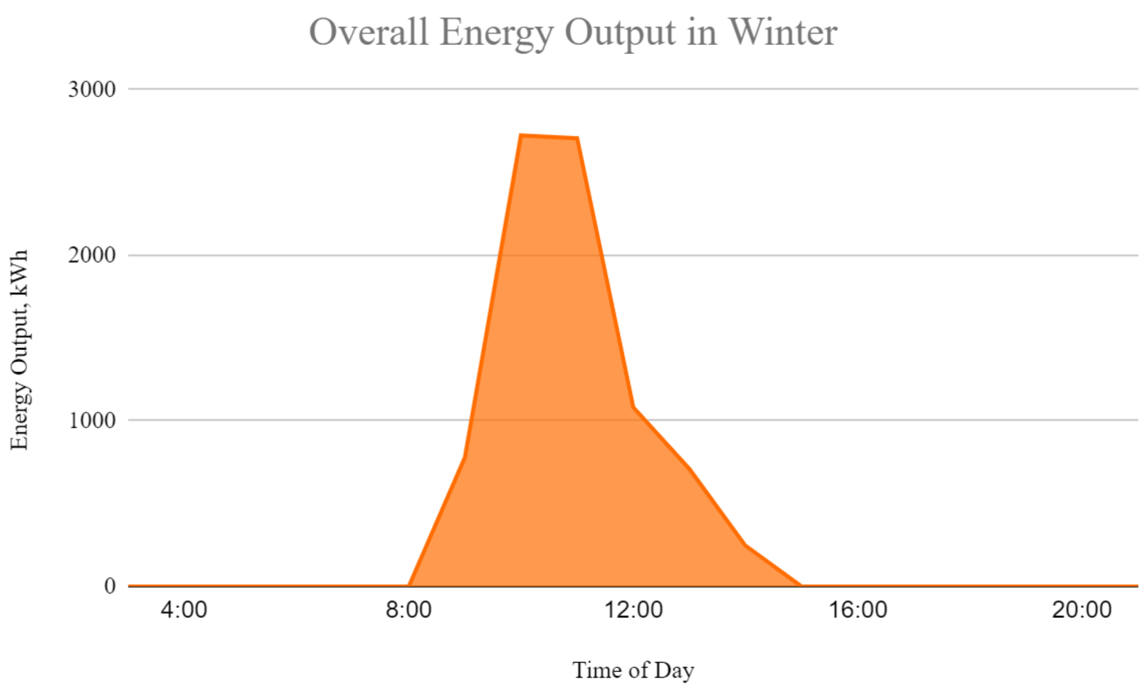

Figure 13: Combined energy output from the solar fam in Winter (Jan)

3.2 Energy system model

Various software platforms were considered to model the local energy system at Ross Priory. The initial platform of choice was PyLESA (Python for Local Energy Systems Analysis) but it was found to be difficult to use and in depth knowledge of python seemed necessary as the user interface was achieved through Python. Homer Energy pro was later chosen to be the ideal platform to do the energy system modelling due to its user-friendly interface, versatility and reliability.

Three individual models were made to account for three different suggestions made in the feasibility study.

The initial case here after referred to as case 1 considers the current energy usage as the electrical load the heating demand at the site is involved in the model as a boiler to account for the emissions and expenses associate with purchase and burning of fuel oil.

Case 2 looks at electrification of the heating hence the electrical load includes the heating demand as well.

Finally, case 3 looks at the possibility of a partnership with the nearby Scottish water pumping station where excess electricity generated can be utilised.

In all cases the energy inputs were from the grid and the three forementioned sites associated with solar farm. The grid input is AC no constrain was placed on input or export to the grid as each individual cottage, main house and catering unt had sperate connections to the grid, furthermore the grid meets the current demands of the site so it is safe to assume that the demand would not overload the grid. Simple rates of 20.4p/kW for energy import and 10p/kW for energy export were set for simplicity. Inflation rate was set to 5.2% which is the average inflation value for the UK for the past 5 years.

The energy generated from the solar farm was obtained from PVsyst outputs and the three sites were modelled as renewable inputs to the DC bus. The initial capital cost of the project was divided between the three sites in relation to their generation potential. As for the operations and maintenance of the plant a detailed calculation was performed using Microsoft excel as described in a NERL report published in 2020 [25] which accounted for all genal expenses that may arise for the plant and site maintenance as described in the tables below

Table 1: O&M cost for solar farm assosiate with sevices required o site

Lifetime NPV by Service Provider			
Service Provider	**Avg. Cost/Yr**	**NPV (Life)**	**% of Total**
Administrator	$6,008	$68,997	2%
Cleaner	$47,391	$544,354	15%
Inverter specialist	$11,913	$107,500	3%
Inspector	$49,723	$558,921	15%
Journeyman electrician	$22,378	$1,155,304	31%
PV module/array Specialist	$52,603	$637,425	17%
Network/IT	$152	$1,531	0%
Master electrician	$8,904	$99,781	3%
Mechanic	$4,415	$108,163	3%
Designer	$0	$0	0%
Pest control	$3,138	$36,042	1%
Roofing	$0	$0	0%
Structural engineer	$12	$139	0%
Mower/Trimmer	$31,250	$358,947	10%
Utilities locator	$4	$44	0%
Total	**$237,892**	**$3,677,149**	**100%**

Table 2: O&M expeses fo the solar fam from matials and products

Lifetime NPV by O&M Category			
O&M Category	**Avg. Cost/Yr**	**NPV (Life)**	**% of Total**
AC Wiring	$4,078	$44,246	1%

DC Wiring	$65,788	$830,710	23%
Asset Management	$4,549	$52,249	1%
Documents	$1,406	$16,146	0%
Electrical	$2,181	$24,818	1%
Mechanical	$10,634	$106,608	3%
Inverter	$12,955	$117,299	3%
Meter	$18	$205	0%
Monitoring	$3	$18	0%
Roof	$0	$0	0%
Rack	$211	$2,442	0%
PV Module	$112,284	$2,211,411	60%
Tracker	$15,087	$173,293	5%
Transformer	$8,663	$97,307	3%
Whole System	$35	$397	0%
Total	**$237,856**	**$3,676,752**	**100%**

Table 3: Net O&M expenses for the solar farm

Results	
Annualized O&M Costs ($/year)	**$258,345**
Annualized Unit O&M Costs ($/kW/year)	**$12.92**
Maximum Reserve Account	**$2,946,654**
Net Present Value O&M Costs (project life)	**$3,677,149**
Net Present Value (project life) per Wp	**$0.184**
NPV Annual O&M Cost per kWh	**$0.012**

Also a battery for storage was connected to the DC bus for storage which was optimised by Homer for each case. Also, a generic converter was added to act as a bridge between DC and the AC bus. Since the capital cost of the solar farm included the inverters the capital associated with this component was dropped.

3.2.1 Case 1

For case 1 the individual MPAN hourly data from the catering and the mainhouse mentioned previously were combined to obtain the total electrical demand at site which is depicted in the figure below.

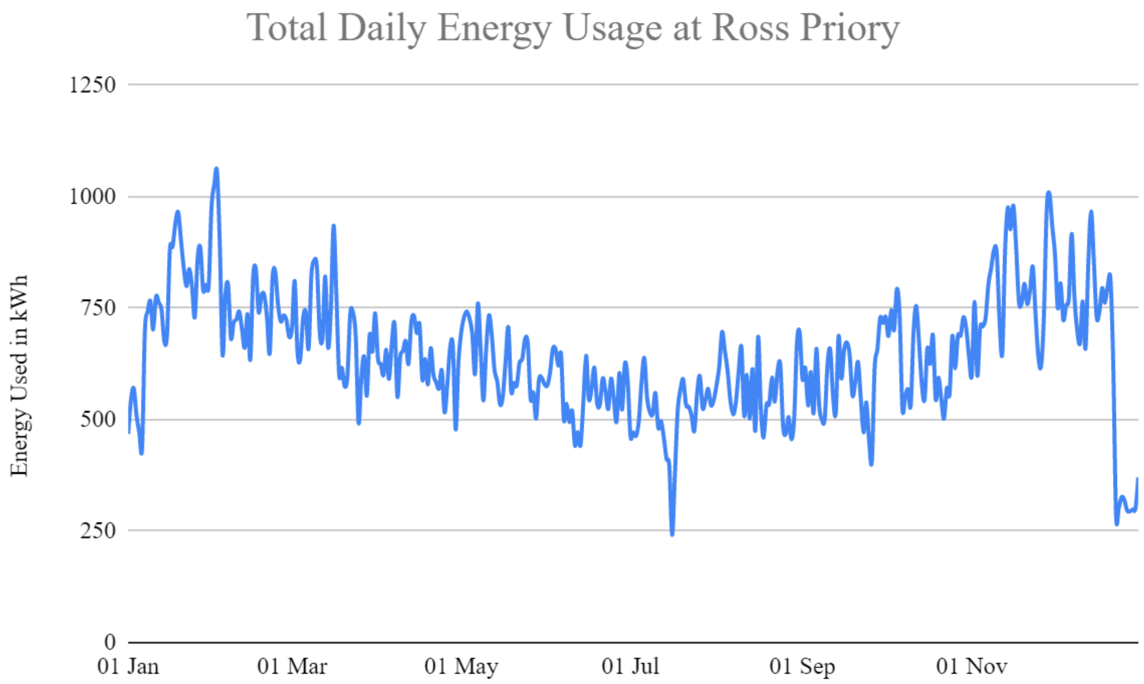

Figure 14: Combined Energy Demand at Ross Priory

This was placed as load in the System mentioned above. An additional thermal load and boiler was added to account for the heating expenses from purchase of gas oil. This was derived from the converting the energy produced by burning oil purchased into kWh assuming a boiler efficiency of 85%. A schematic of the energy system is given below

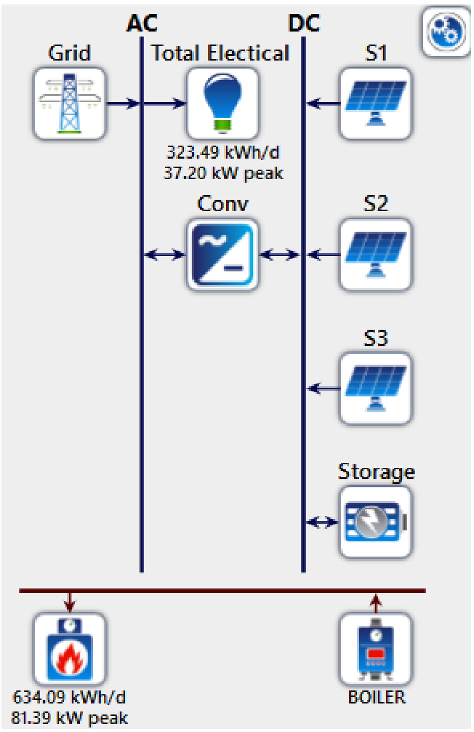

Figure 15: Energy system schematic with electrical demand at Ross Priory

3.2.2 Case 2

Case 2 follows a similar schematic to that of case 1 except having an electrical heating system. This is achieved by replacing the thermal load by an equivalent electrical load and eliminating the boiler. Since only data available regarding het usage is the overall energy demand from net gas oil used, the heating demand profile was assumed to be that of a hotel. Due to lack of data availability from any local hotels or similar establishments the data of a large hotel from Erie, PA, US from homers database was used. This was done considering the similarity in climatic conditions of the two locations as per Koppen- Geiger climate classification system [26]. Both locations are classified as Cfb representing oceanic climate. The total energy demand from heating was mapped to this profile to generate the hourly data. The following images shows the average daily profile for each month and scaled average monthly demand.

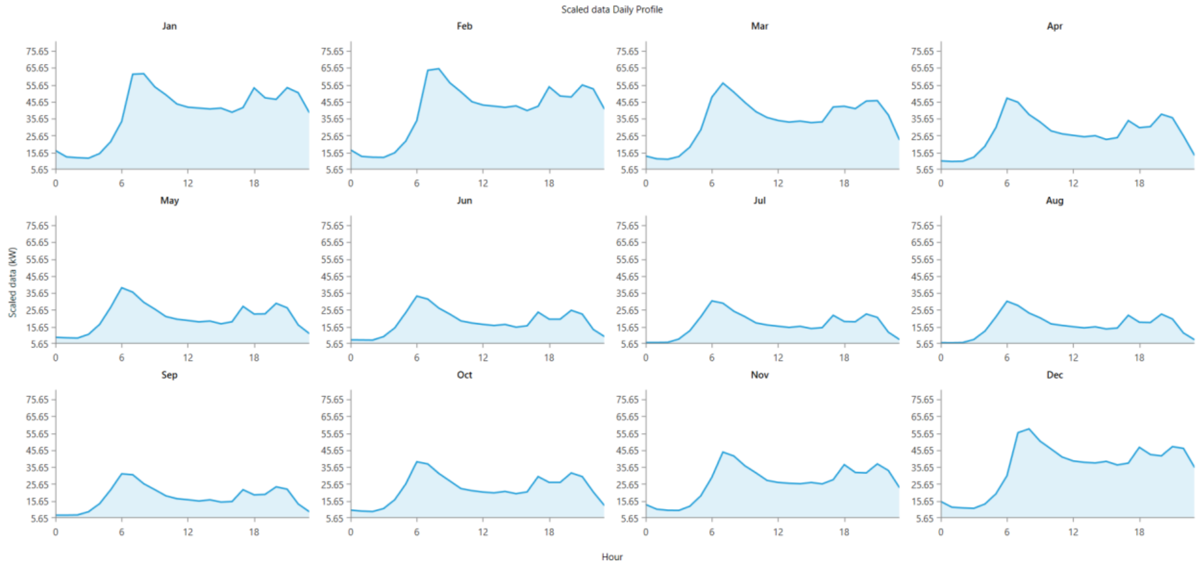

Figure 16: Daily average energy heating demand profiles of each month

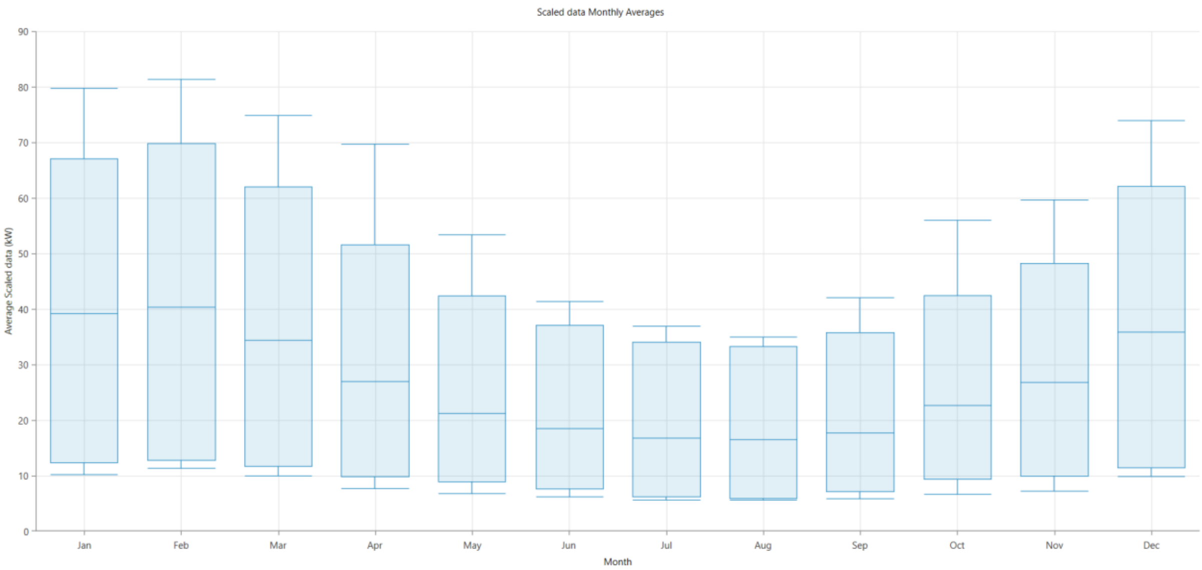

Figure 17: Scaled monthly average heating demand

The daily profile for peak summer and peak winter are also depicted below along with the schematic for the energy aystem.

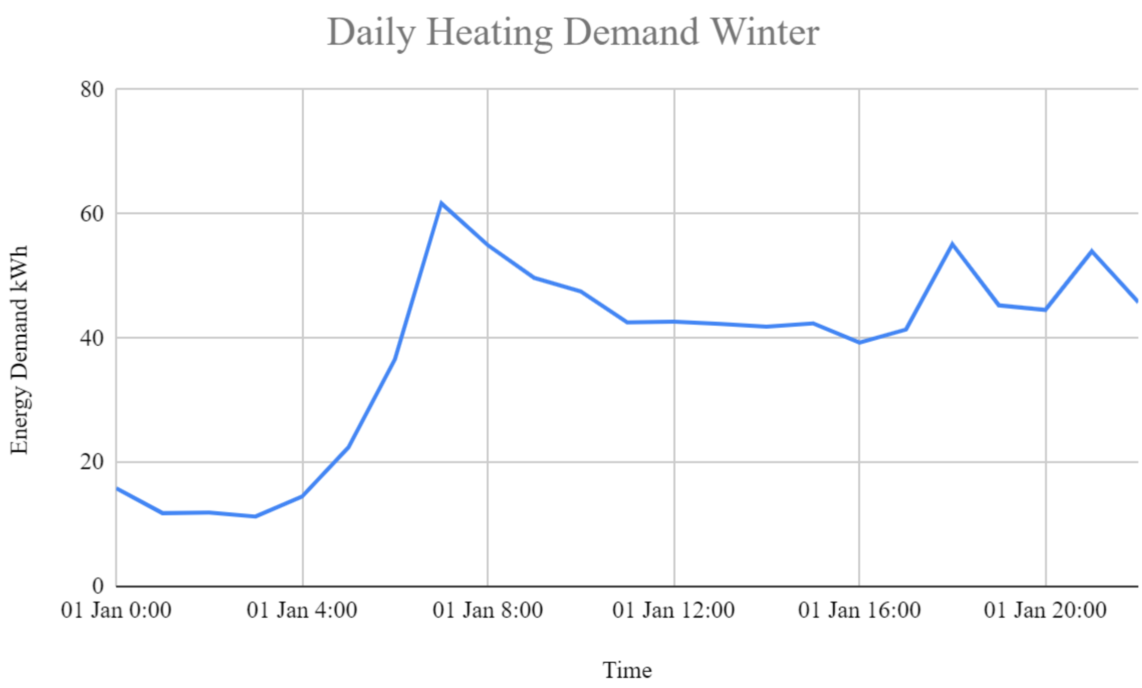

Figure 18: Daily heating demand profile in Winter (Jan)

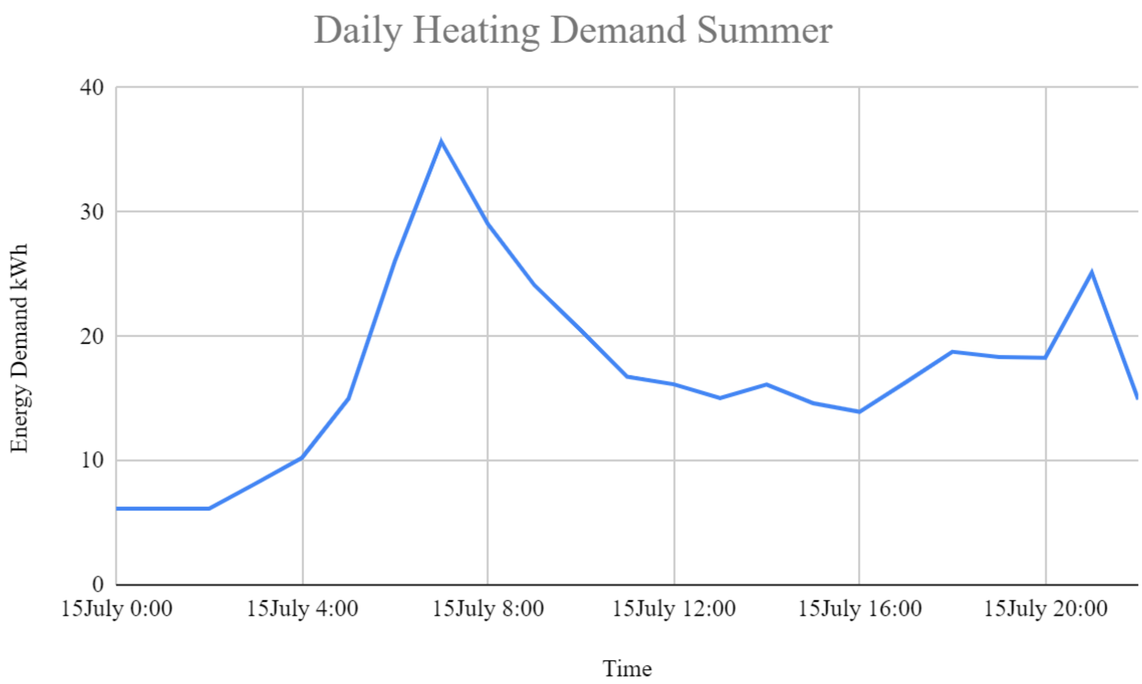

Figure 19: Daily heating demand profile in Summer (July)

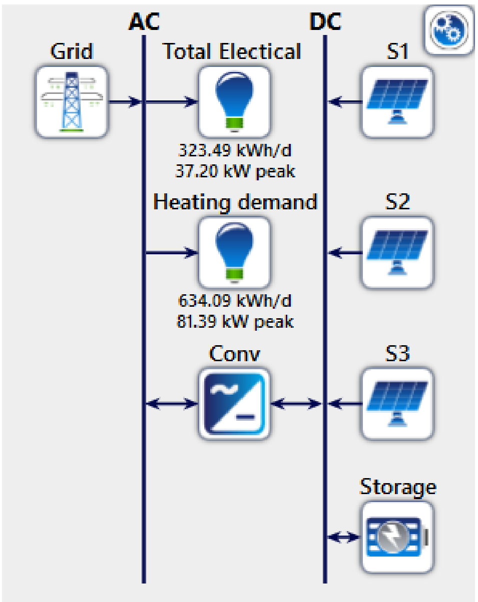

Figure 20: Energy system schematic with electric heating

3.2.3 Case 3

In Case 3 in addition to the loads in case two the energy demand from the Scottish water pumping station is also added to the system.

Since no data regarding the hourly energy consumption data was available from Scottish Water, the graph provided in the feasibility study report was mapped using an online mapping tool and newtons interpolation was performed on the resulting data to obtain hourly values. This was essential as Homer only accepts data in time steps of an hour or less. The resulting profile is shown in the graph below.

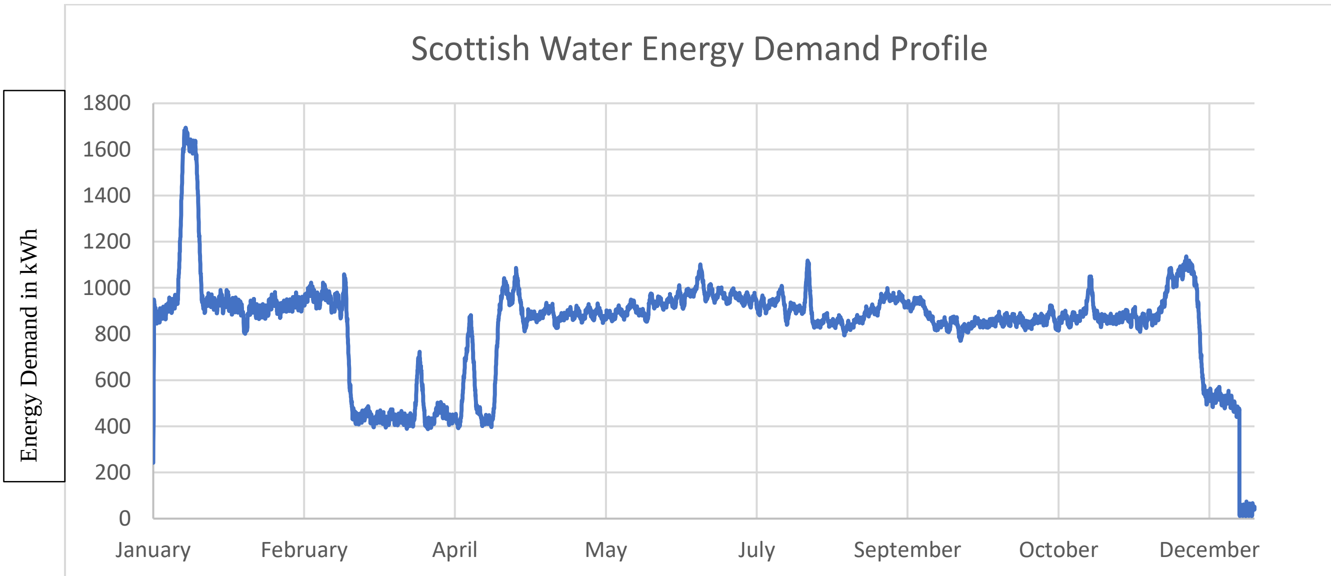

Figure 21: Scottish Water energy demand profile

Since Homer only allows for two electrical loads per model the inputs heating demand were combined with the Scottish water demand profile to generate a an energy system as depicted in the schematic below.

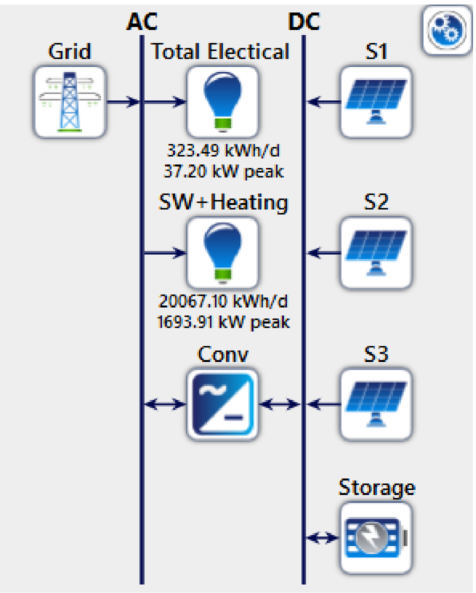

Figure 22: Energy system schematic with Scottish Water demand and electric heating.

4.0 Results and Discussions

Simulations for all three cases were run multiple times by varying variable parameters such as inflation, interest rates and other factors that can change in future. All simulation yielded similar results with negligible differences in cash flow and payback time. The results for the three cases are analysed and discussed below.

4.1.1 Case 1

The graph below depicts the cumulative nominal cash flow with time for case 1 base case being in the absence of the input from the solar farm and lowest cost system being the simulation with all three sites and battery storage. The payback time for the system is 7 years with return on investment being 7.6% and 11% internal rate of return.

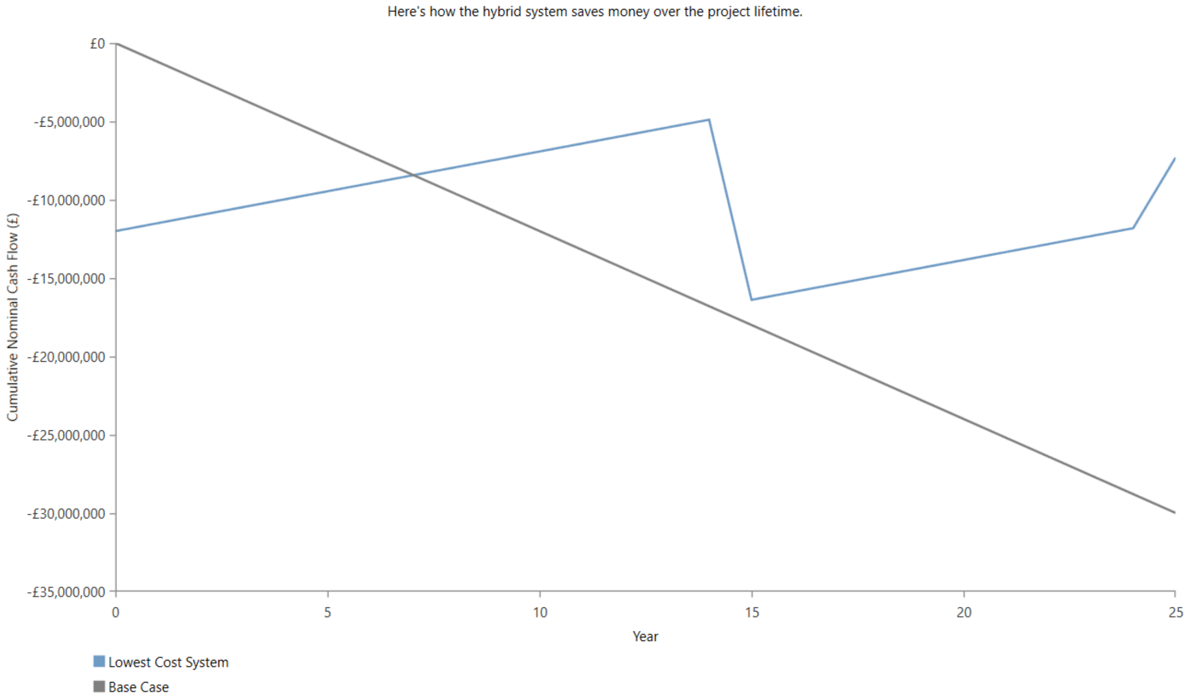

Figure 23: Cash flow for case1 (Ross Priory electrical demand)

4.1.2 Case 2

The graph below depicts the cumulative nominal cash flow with time for case 3 base case being in the absence of the input from the solar farm and lowest cost system being the simulation with all three sites and battery storage. The payback time for the system is 7 years with return on investment being 7.7% and 11% internal rate of return.

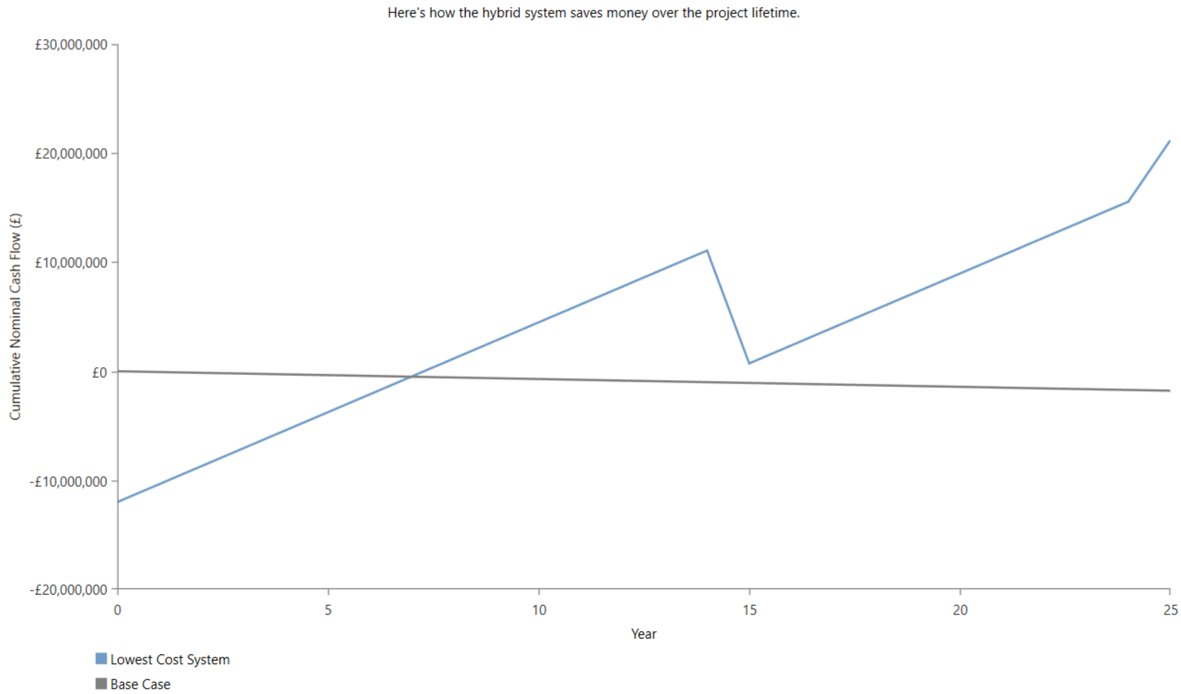

Figure 24: Cash flow for case2 (Ross Priory electrical demand and electric heating)

4.1.3 Case 3

The graph below depicts the cumulative nominal cash flow with time for case 3 base case being in the absence of the input from the solar farm and lowest cost system being the simulation with all three sites and battery storage. The payback time for the system is 5.9 years with return on investment being 10% and 15% internal rate of return.

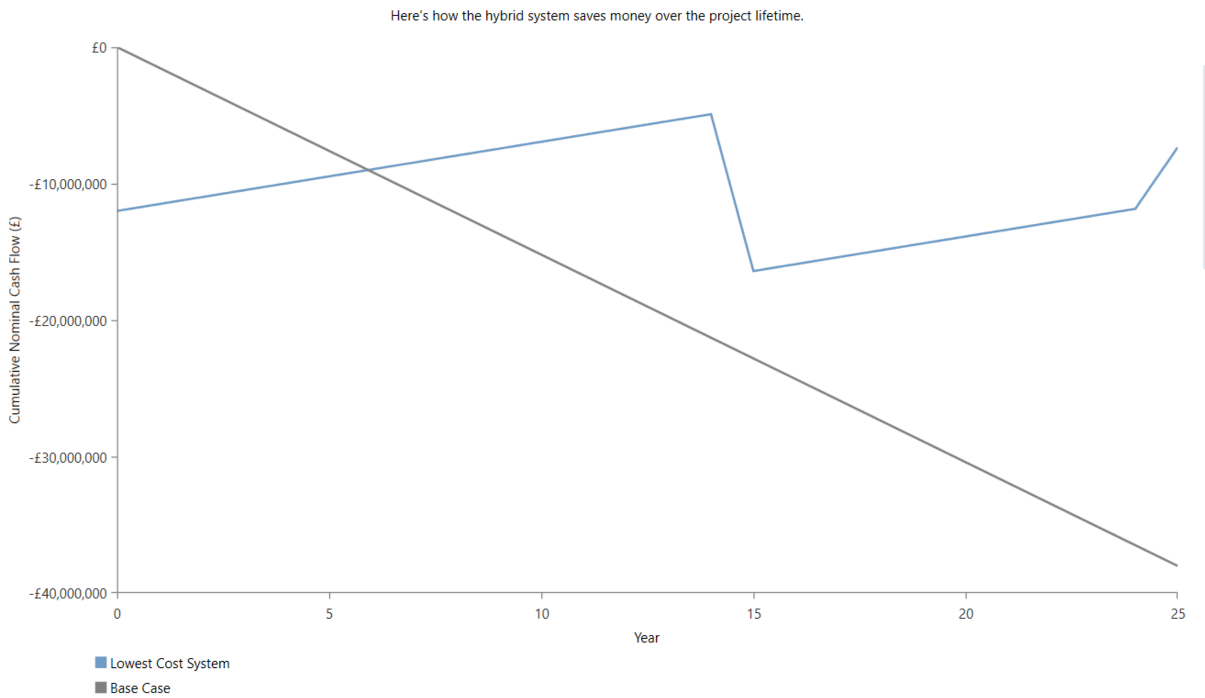

Figure 25: Cash flow for case2 (Ross Priory electrical and heating demand and Scottish Water energy demand)

The increase in cash flow every 15 years observed in cases with the solar input in the graphs is due to replacement and maintenance of the solar farm and ethe equipment every 15 years.

Case 1& Case 2 have similar payback periods and return on investment this is because the system is essentially same except for the transition to electrical heating. However, it can be observed from the cumulative nominal cashflow that there is a significant advantage in case 2 as the rate of increase in cash flow is much slower but this does not take into account the capital involved in updating the current infrastructure at Ross Priory to be suitable for electrical heating.

It is without any doubt clear that the most beneficial scenario would be case 3 with the load from the load from Scottish water with the lowest payback period of 5.9 years and 15% return of interest. This is because of the increased load which results in using maximum energy produced by the solar farm on site, which can be considered as a direct decline in import from grid.

Further simulations were done to find how variations in sell back price and changes in inflation would affect the optimisation process. The inflation rate was varied between 2% and 9% and the sell back price was varied between 5p to10p and the following trend depicted in the figures was observed in each case.

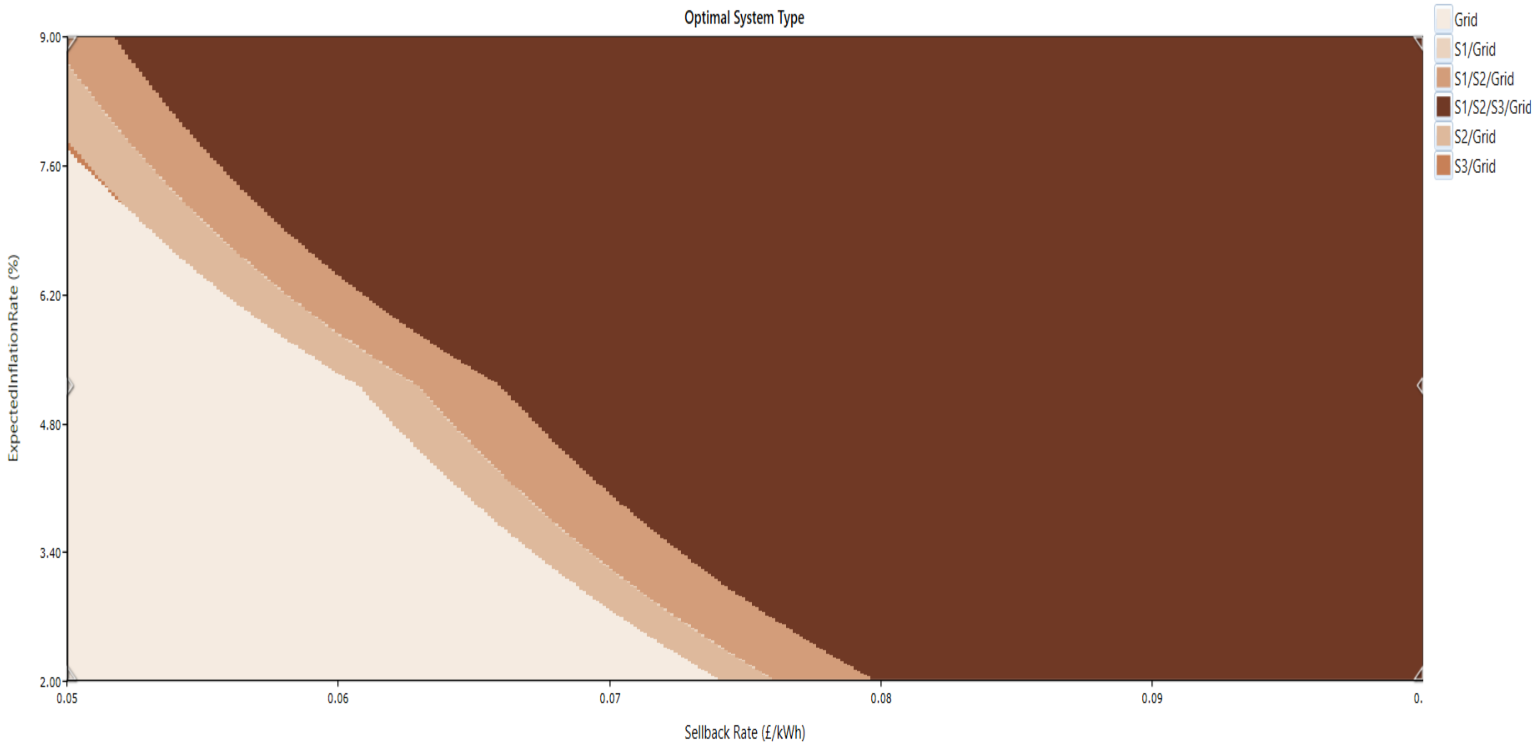

Figure 26: Sell Back Price and inflation rate optimization for case 1

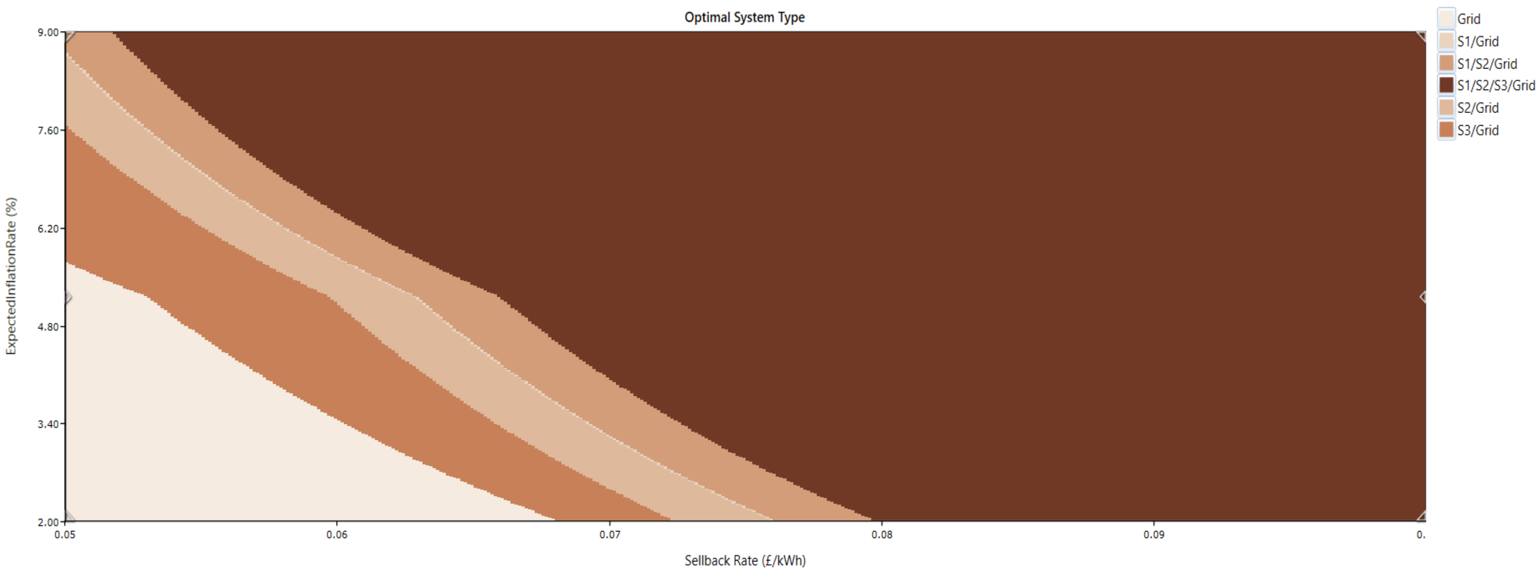

Figure 27: Sell Back Price and inflation rate optimisation for case 2

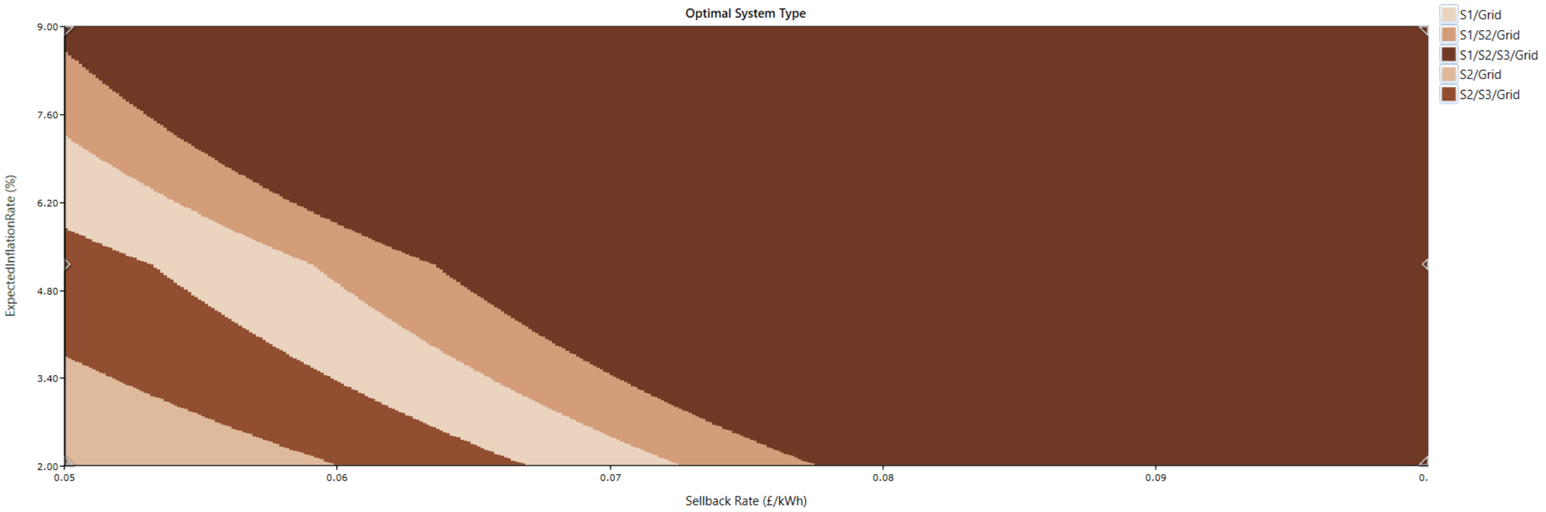

Figure 28: Sell Back Price and inflation rate optimisation for case 3

Observing the above graphs, it can be observed that there is a progression of stability from case 1 to case 3, higher load values ensure there is less energy sold back to the grid reducing the dependency on grid sell back prices, higher inflation rates ensure sorter pay back times as asset value depreciation rapidly reduced with higher inflation.

5.0 Conclusions

The proposed solar farm at the ross priory estate was modelled using PVsyst and the renewable energy outputs were calculated successfully. The outputs were used to model the local energy system at Ross Priory. Among the three possible proposals for energy usage at site it was observed that higher energy utilisation on site was more profitable and efficient. Higher loads also showed more stability when sell back price and inflation rates varied. This is due to the reduced dependency on export to grid.

A major point of consideration regarding the outcomes of this study to look at collaborative efforts with Scottish water and other possible entities that can help utilise the energy produced close to generation site. But this requires careful planning and mutual understanding regarding sharing the capital investments and future profits and especially on how the energy produced would be distributed.

There are various scopes of improvement in the current models described in the study some of which are described here. Primarily the data used for Scottish water and heating demand can be verified with actual hourly demand at site. Another improvement would be to use dynamic systems that respond to the environment such as self-correcting and self-adjusting solar panels that can align itself for optimum output. Battery models, Solar panels and inverters can be reconsidered for better suiting versions specific to the site. Overall, the solar farm can be success fully executed based on the studies done.

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