SUSTAINING DUNBAR

MASTER IN ENGINEERING
ENERGY AND ENVIRONMENTAL
MANAGEMENT

Europa-Universität Flensburg

CREATING A BASIS FOR A WELLBEING ECONOMY THROUGH COMMUNITY-OWNED SOLAR POWER

INTERNATIONAL CLASS
DUNBAR, SCOTLAND
2023

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Contents

List of abbreviations

ADSCR - Annual Debt Service Cover Ratio
AELES - Adaptive enhanced linear exponential smoothing
BEIS - Department for Business, Energy and Industrial Strategy
Bencom - Community Benefit Society
BESS - Battery Energy Storage System
CAPEX - Capital expenditure
CAPM - Capital Asset Price Model
CBS - Community Benefit Society
CfD - Contract for Difference
COP - Coefficient of Performance
CSI - Canadian Solar Inc.
DECC - Department of Energy & Climate Change
DNO - Distribution Network Operators
DNO - Distribution Network Operators
DSCR - Debt Service Cover Ratios
DTM - Digital Terrain Model
EF - Employment factor
EirGrid - Ireland transmission operator
ELES - Enhanced linear exponential smoothing
EMA - Exponential moving average
EPC - Energy Performance Certificate
EPC - Energy Performance Certificates
EREC - Engineering recommendation
EU - European Union
FAI - Fraser of Allander Institute
FES - Future Energy Scenarios
FiT - Feed in Tariff
FSS - Falling Short Scenario

FTE - Full Time Equivalent
GADM - Global Administrative Areas Map
GBP - British pound sterling
GCR - Ground cover ratio
GHI - Global Horizontal Irradiance
GIS - Geographic Information System
GSHP - Ground source heat pump
GW - Gigawatt
HECO - Hawaiian Electric Company
HMA - Hull moving average
IPP - Independent Power Producer
IRR - Internal Rate of Return
kVA - Kilovolt-ampere
kW - Kilowatt
kWh - Kilowatt-hour
kWh/m2 - Kilo Watt hour per square meter
kWh/m2.a - Kilo Watt hour per square meter per year
kWp - Kilowatt-peak
LCCC - Low Carbon Contracts Company
LCOE - Levelized Cost of Energy
LES - Linear exponential smoothing
LiDAR - Light Detection and Ranging
m2 - Square meter
Mth - Month
MW - Megawatt
MWh - Megawatt-hour
MWh/a - Mega Watt hour per year
MWp - Megawatt-peak
NIMBY - ‘not-in-my-back-yard’
OPEX - Operational expenditure
OSM - Open Street Map
PPA - Power Purchase Agreement
PREPA - Puerto Rico Electric Power Authority
PV - Photovoltaic
PVGIS - Photovoltaic Geographical Information System
Pyomo - Python Optimisation Modelling Objects
RR - Ramp rate
SHCS - Scottish House Condition Survey
SIMD - Scotting Index of Multiple Deprivation
SMA - Simple moving average
tCO2 - Tonnes of dioxide
TMY - Typical meteorological year
UK - United Kingdom
UK - United Kingdom
UPRN - Unique Property Reference Number
UPRN - Unique Property Reference Number
uPVC - Unplasticised polyvinyl chloride
VAT - Value Added Tax

WACC - Weighted Average Cost of Capital
WEAll - Wellbeing Economy Alliance
WiFi - Wireless fidelity

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Executive summary

The soaring energy bill triggered by the Russia-Ukraine conflict has increased fuel poverty dramatically among Scotland's population. According to a bill passed by the Scottish Parliament in 2019, fuel poverty is defined as spending more than 10% of a household's net income on energy bills. The target of no more than 5% of households in fuel poverty by 2040 was set by this bill (Scottish Parliament, 2022). To achieve this goal, the contribution of communities and encouraging investment in retrofitting projects is essential.

In this report, a proposed plan for developing a 20MW community-owned solar power plant in Dunbar and East Linton Ward was investigated from technical, financial, and social aspects. It has been assumed that the revenue of this project will be spent on reducing fuel poverty in the community by improving the energy efficiency of houses through retrofitting.

Solar PV design analysis in this report concluded that fixed structure PV plant and single-axis tracker with string inverters are the two best configurations for this project. The annual energy generation from the first and second configurations is 22,400 MWh and 25,600 MWh, respectively. CAPEX and OPEX of Fixed structure PV powerplant with string inverters are estimated as 13.4 million GBP and 297 thousand GBP per year, respectively. Adding a single-axis tracker would increase about 2.7 million GBP to the investment cost in exchange for 3,200 MWh more energy production per year. Grid connection cost is also estimated at 375 thousand GBP. In addition, the visual impact of the solar PV farm on the Dunbar and East Linton area was examined. The result of visibility analysis shows that only 2% of all Dunbar and East Linton properties (39 out of 9,447 address point locations) can see more than 10% of the solar PV farm.

The maximum ramp rate of the solar PV farm was estimated to be 81.6 percent per minute or 16.3 MW per minute. To reduce it to 10%, as in the case of the Germany grid code, an additional 5.3 million GBP in battery storage is required. However, at the time of this study, the grid operator had no restrictions on the solar PV farm ramp rate. As a result, this additional cost was not considered in the project's investment cost.

Moreover, a comprehensive review of the United Kingdom (UK) electricity market was conducted to identify the most appropriate revenue options for the solar PV project. The analysis covered various aspects of the UK electricity market, including the wholesale electricity market, Balancing Market, Contracts-for-Difference (CFD), Capacity Market, and Power Purchase Agreements (PPA). The study also conducted a detailed financial and investment analysis to determine the internal rate of return (IRR) for the 20 MW solar PV project. Based on the analysis, an IRR of 6.83% was projected for this project at a PPA price of £60/MWh. During the review, it was found that Battery Energy Storage System (BESS) has

the potential to enhance revenues if co-located with the Solar PV plant. Therefore, a revenue optimization model was developed to maximize revenue from energy arbitrage by selling electricity to the spot market at higher prices. The study also developed a price forecasting model using a multiple linear regression model, which utilized historical UK electricity system data to forecast the average annual price and daily price spread. The forecasted model predicted a decrease in the average electricity price as the share of renewable energy increases in the future, but an increase in the daily price spread. The forecasted results were used for PPA price setting and sensitivity analysis of the energy arbitrage potential of BESS. As a result, this study recommends co-locating the Solar PV project with BESS to enhance revenues.

Furthermore, in order to make any plan for dedicating the revenue of the solar PV project to improve the energy performance of buildings, knowing the cost and amount of energy that can be saved is of crucial importance. In this report, two different methodologies for the estimation of retrofitting cost and energy saving are proposed. Since the cost of retrofitting depends on several factors such as type, age, and size of buildings as well as the energy efficiency of each element of a building, calculating the precise cost for each property required house by house auditing, was not possible for conducting this study. Hence, a top-down approach based on publicly available datasets was applied. The village of Innerwick was investigated as a case study for a small area without sufficient public datasets. Besides, a general cost estimation model for larger areas like Dunbar and East Linton was developed based on published Energy Performance Certificates (EPCs). Apart from conventional retrofitting measures like insulation, installing a heat pump was also considered as a high-profile low-carbon heating solution.

Although reducing energy demand by retrofitting is an important measure to tackle fuel poverty, another aspect of fuel poverty which is households' income should not be overlooked. Empowering the community through creating new job opportunities and training for practical work skills can help improve the supply chain to addressing fuel poverty and decreasing unemployment and low-income deprivation rates. Solar and retrofitting projects can provide more job opportunities for local people and more profit for local businesses.

However, the high cost of deep retrofitting for all houses requires a significant budget which cannot be met by the profit from the solar PV farm. So, prioritizing households that have the best chances of leaving fuel poverty through the support of retrofitting is an essential step for this project. On the other hand, decreasing the total energy demand of the building sector can benefit all members of society in terms of energy price and carbon emission.

From the perspective that this project should promote the wellbeing of the local economy, it was also relevant to perform activities that helped to prepare a holistic approach to understand community acceptance and expectations from the community owned solar PV farm, fuel poverty awareness and an overview of the community's needs. For these purposes, a series of face-to-face interviews, an online survey and workshops were held during our visit to Dunbar and East Linton. In this way, a baseline can be set to decide on all other project initiatives that will benefit the wellbeing of the community.

1. Introduction

1.1. Motivation

Fuel Poverty

The Scottish Parliament defines, sets targets, and develops strategies against fuel poverty in its Fuel Poverty Act of 2019. In this bill, fuel poverty is defined as when a household spends more than 10% of its net income on energy bills. Additionally, a definition of extreme fuel poverty is presented. A household suffers from extreme fuel poverty if the fuel costs necessary for the home are more than 20% of the household's adjusted net income. The bill sets the target for the fuel poverty rate in households to be no more than 5% by 2040 (Scottish Parliament, 2022).

There are four main factors of fuel poverty. The first is related to the efficiency theory, which states that fuel poverty is mainly driven by housing type and condition. Thus, the efficiency of the heating source and the thermal efficiency of the dwelling are the main drivers of the amount of energy consumed. The second factor is energy prices. As the prices increase the affordability reduces. The third factor is the low household income. The costs of heating a dwelling have a significant impact on low-income households. And the fourth factor is behaviour, or how people use energy, which also influences fuel poverty (Strünck, 2017).

Figure *1* below, taken from the Scottish fuel poverty strategy 2021 report, shows the trends in fuel poverty, median income, and fuel prices. From the figure, we can see that income is the main driver of fuel poverty, while it increases, fuel poverty decreases accordingly.

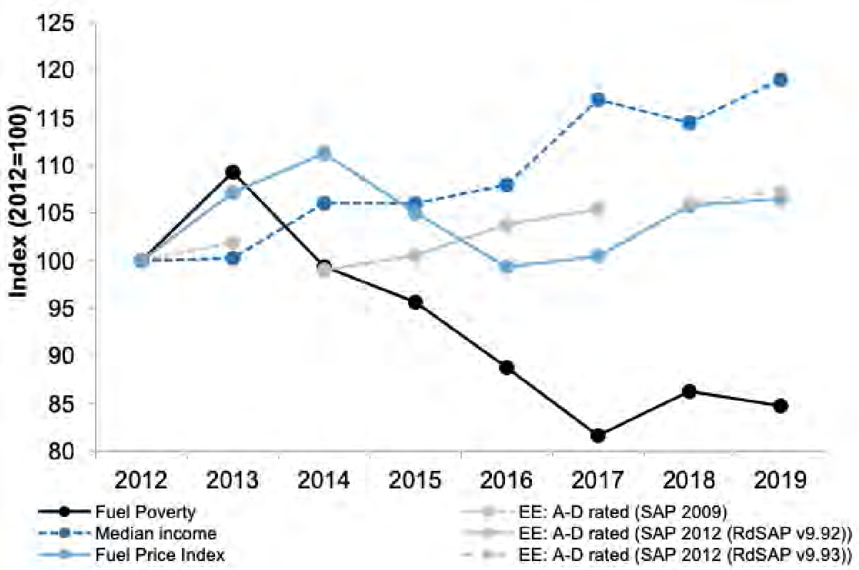


Figure 1. Fuel poverty, income, and fuel price. Source: (Scottish Government, 2021)

The Scottish House Condition Survey (SHCS) provides yearly national figures for fuel poverty. The latest available results from 2019 show that 24.6% of households in Scotland are in fuel poverty. This is 0.4% less than in 2018. 12.4% of households suffered from extreme fuel poverty in 2019, a 1.1% increase from the previous year. Additionally, the median fuel gap was 750 GBP in 2019, 100 GBP higher than the previous year. The median fuel gap is the reduction of fuel costs that a household needs in a year to be out of fuel poverty (SHCS national, 2019).

At the local authority level, there are 50,978 dwellings in East Lothian (Scottish Gov, 2021). Fuel poverty in 2019 affected 24% of said dwellings and 10% were in extreme fuel poverty, just below national levels. On average housing stock built, pre-1982 has a higher, share of people in fuel poverty than those built post-1982. The former has 26% of its total fuel poverty count and the later 20%. Almost half (42.2%) of dwellings in fuel poverty are social housing and 16.4% are owner-occupied. People that live in tenement type of dwellings, or flats, are the most prone to fuel poverty in comparison to other types like detached or terrace (SCHS Local, 2019).

Fuel poverty affects mostly the income poor, 86% of the households with low income, or below the national average, are fuel-poor. Whereas only 8% of the not-income poor are affected. Thus, when reducing fuel poverty, it is more relevant to prioritize those households that are income poor. Energy Performance Certificates (EPC) can be associated with the previously mentioned indicators (SHCS national, 2019).

Wellbeing Economy

Conventional economic growth models have been focused on maximizing productivity and consumption, with the assumption that when the economy gets bigger, it will lead to increased wellbeing and prosperity for individuals and society as a whole (Trebeck, 2020). This approach has been successful in driving economic growth and development, but it has come at a significant cost to the environment and human health (WWF, 2020). It has led to an over-reliance on fossil fuels and an increase in greenhouse gas emissions. The effects of climate change are already being felt around the world, and they are projected to become increasingly severe in the coming years (IPCC, 2022).

A wellbeing economy approach, on the other hand, prioritizes human wellbeing and sustainability. It aims to create a society that is resilient and equitable, and that values natural resources as finite and precious (Trebeck, 2020). The wellbeing economy does not only focus on economic growth, but on sustainability and the participation of each individual as part of a community which then can create a more balanced and holistic economic development that promotes the well-being of individuals, communities, and the environment (Hough-Stewart, Trebeck, Sommer, & Wallis, 2019).

In the context of energy, a wellbeing economy approach would prioritize energy efficiency and a transition to renewable energy sources, such as solar, wind, and hydro power (Coscieme, et al., 2019).

1.2. Background

Population and Dwellings

It is important to notice that Dunbar is a town which is part of an electoral Ward named Dunbar and East Linton. This Ward is part of the East Lothian Council. Therefore, many statistics regarding Dunbar are also accompanied by the Ward and Council data. As of 2021, the population of Dunbar and East Linton Ward is 15,642 in 7,061 dwellings (Scottish Gov, 2021). From these values, we calculated the household size as 2.2. From historical data on dwelling count, we calculated the average growth rate at 1.8% (Scottish Gov, 2022). At this rate, the dwelling count by 2026 will be 7,709.

The most represented age group is aged 16 to 64 with 59.3% of the total. The ages 65+ represent 20.8% and under 16 represent 19.9%. This means that most of the people in the region, 9,271 persons, are of working age, half of them between the ages of 16 to 44 (National Record of Scotland, 2020).

Income and Employment

Data relating to income deprivation and employment deprivation in 2020 from the Scottish Index of Multiple Deprivation (SIMD) can be used as a reference of affordability to pay energy bills or retrofitting as well as to present the highest unemployment rates per zone in the Ward. Income deprivation refers to people that are of working age, have a low income, and recur to government subsidies. Employment deprivation data refers to people that are of working age but are unemployed.

60% of the population is of working age. Of the working-age population, on average, 6.5% is unemployed and 12.9% suffer from income deprivation. The highest income and employment-deprived zones present values between 22% and 25% respectively. These zones are distributed mostly in the vicinity of the Dunbar centre area (SIMD, 2020).

Community Initiatives in Dunbar and East Linton

Scotland's Dunbar and East Linton have developed a reputation as being community-driven towns with a focus on community-owned projects. This is demonstrated by several initiatives in the area. Some of them include the community bakery and the community-run environmental organisation Climate Action East Linton. The Ridge, a community-owned building, provides office and meeting spaces for local businesses and organizations. Through a comprehensive strategy and training, they assist people in realizing their potential and give them opportunity for personal progress. There is also a Dementia network that offers ongoing and specialized support to those who are taking care of people who have dementia or other similar disorders. The community of East Linton also works towards sustainability and environmental consciousness, with projects such as Fixing for a Future, a repair and reuse initiative. The Belhaven Garden is a community garden project where patients, employees, and community members can grow together for a sustainable community.

Sustaining Dunbar Community Trust, a community-led organization based in Dunbar, Scotland, with a mission to create a sustainable and resilient community, work on various projects related to renewable energy, local food production, and affordable housing. The trust aims to empower the local community and promote social, environmental, and economic sustainability. Through its initiatives, the trust has become a model for community-led sustainable development in Scotland and beyond. The strong culture of community ownership and participation in Dunbar and East Linton at large demonstrates the community's commitment to creating sustainable and equitable solutions for the benefit of its residents.

Problem Statement

As previously mentioned, energy condition in Dunbar is still facing several challenges, including high CO_2 emission from housing sector, fuel poverty (choosing between heating and eating) and inefficient heating systems (Sustaining Dunbar, 2015). On the other hand, Dunbar has the potential for renewable energy generation and high community participation (Community Energy Scotland, 2019). This potential can be tapped to overcome those challenges by creating a renewable energy project that implement the wellbeing economy concept.

1.3. Objective

The primary aim of this study is to design a 20MW community-owned solar PV farm to address fuel poverty and reduce the carbon footprint of the community. The outcomes of this study will establish a foundation for a Wellbeing Economy in Dunbar and East Linton and propose a path forward that can leverage the results of this investigation.

1.4. Scope of Study

The scope of this study are as follows:

- To study the community acceptance on the solar PV farm.
- To analyse the most suitable utility solar PV farm configuration in the proposed location without environmental impact assessment.
- To analyse the annual energy yield and the ramp rate of the solar PV farm from the simulation result.
- To determine the cost of grid connection as well as the capital and operational expenses for the solar PV farm.
- To explore the revenue option available for the solar PV and BESS project in UK electricity market.
- To develop revenue optimisation model for BESS.
- To develop the financial model for solar PV farm and BESS.
- To explore fuel poverty reduction measures through community benefit company in Dunbar and its impact assessment.
- To evaluate energy efficiency measures for the Dunbar and East Linton community, with a focus on retrofitting measures.

2. Community Acceptance Study

Previously in 2012 Sustaining Dunbar planned a 500 kW wind turbine on the site that will be the location of the solar PV project. However, due to East Lothian Council's rejection for landscape and visual reasons, the project did not proceed (Community Energy Scotland, 2019). Some sources stated that social acceptance is one of the factors that often hinder renewable energy development, especially in the wind energy sector (Wüstenhagen, Wolsink, & Bürer, 2007; Enevoldsen & Sovacool, 2016). As a result, it is critical to conduct a community acceptance study to avoid the occurrence of the same problem.

2.1. Social acceptance concept

To understand the term social acceptance of renewable energy, we borrow the concept from Wüstenhagen, Wolsink, & Bürer (2007) who introduced three dimensions of social acceptance, namely socio-political acceptance, community acceptance, and market acceptance. These dimensions are often interlinked with one another. Socio-political acceptance refers to the acceptance of technologies and policies incurred by the project or program by the public, key stakeholders, and policymakers. The second dimension that is community acceptance relates to a more specific aspect and local stakeholders, particularly residents and local authorities. Community acceptance is highly influenced by factors related to distributional justice (cost and benefits sharing), procedural justice (decision-making and participation), and trust (between the community and the external actors). The last dimension is market acceptance or the process of market adoption of renewable energy as an innovation. In this dimension, renewable energy is seen from the point of view of consumers, and investors, which involves the intra-firm relation. On this project, we will focus mainly on community acceptance due to the scale of the project and the stakeholders involved.

2.2. Drivers of community acceptance

As mentioned in the previous subchapter, there are three main factors of community acceptance namely distributive justice, procedural justice, and trust. Hanger, et al. (2016) elaborates on this concept by adding some drivers including geographical factor, and formulate a model out of it as presented in **Figure 2**. The geographical factor is added due to a syndrome that often plagues communities when it comes to renewable energy development. This so-called 'not-in-my-back-yard' (NIMBY) idea suggests that people have positive attitudes toward renewable energy as it is perceived as environmentally friendly and benefits the community, as long as it is not built in their backyard. Once they are confronted with RE development in their vicinity, they mostly oppose the plan (Wüstenhagen, Wolsink, & Bürer, 2007; Batel, 2020).

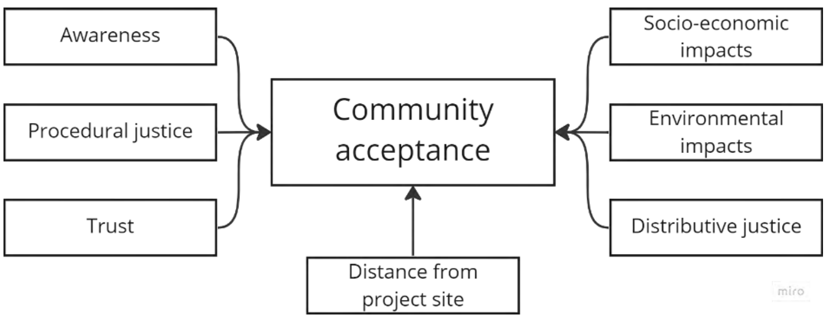


***Figure 2**. Model of community acceptance. Source: (Hanger, et al., 2016)*

This model is expected to be able to investigate community acceptance, especially regarding the NIMBY issue. We incorporate this model into our research method as a foundation for the study.

2.3. Method for community acceptance assessment

The objective of this study is to assess community awareness of solar PV in general and their acceptance of community-owned solar PV in Dunbar. Therefore, the questionnaire is divided into 3 sections; community awareness; community acceptance; and participant's demography. The questionnaire for the survey is designed to reflect the model in Figure 2. The draft of the questionnaire was discussed with Sustaining Dunbar and underwent a pre-testing. The questions varied from open-ended, close-ended, and scale responses. The questionnaire is attached in the Annex 1. The survey was conducted online to facilitate data collection, saving time and resources.

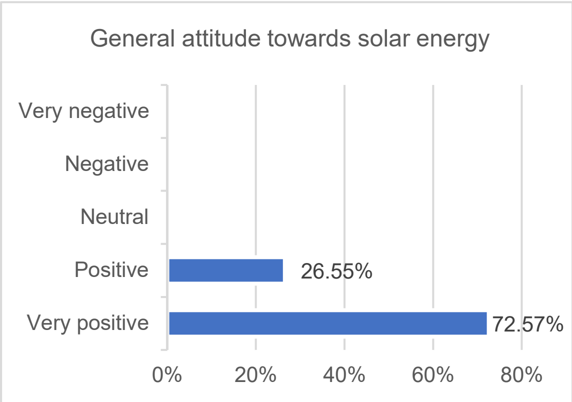
Snowball sampling was chosen as the study's sampling method because it is convenient for research that is difficult to access the target subjects who represent the entire population (Naderifar, Goli, & Ghaljaie, 2007). The first group of respondents is those who attended the Wellbeing Economy workshop on January 31st. The number of samples increased as the first respondents informed others about the survey. The survey information was also disseminated through the channels recommended by the initial respondents.

The number of samples required from the total Dunbar and East Linton population with a level of confidence of 95% and a margin of error of 10% to ensure the representativeness and validity of the data is 98. The number of respondents had reached 113 by the time this report was written, indicating that the margin of error is 9%. The data in this study is nominal with a few exceptions of some interval data. However, the distribution is non-normal, therefore the analysis is inferential and focuses on the distribution frequency.

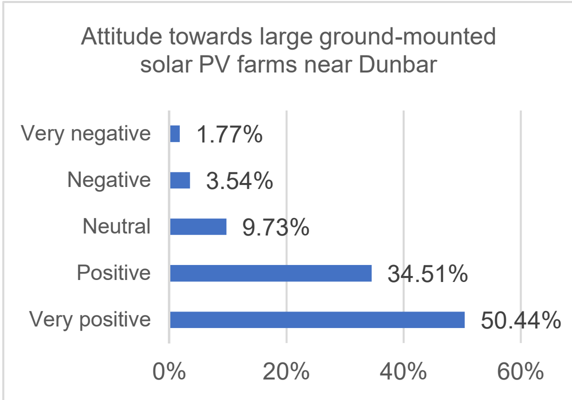
Around 39% of respondents are over the age of 60, with the age group 21 to 60 accounting for 62%. The remaining 2% are under the age of 20. This makes the working age distribution similar to the population proportion. The number of young respondents is much less than the population proportion while the age above 60, most of whom are retired, is larger than the population proportion. This could be because the younger generation has less interest in participating in surveys like this, or because they are not receiving information about the survey.

In the gender section, 58% are women, 38% are men, and 4% are non-binary and prefer not to answer. Postgraduate degrees account for 41% of all education. This is closely followed by graduate degrees, bachelor's degrees, and high school diplomas which represent 21%, 18%, and 10%, respectively.

According to the data on a scale of 1-10, where 1 represents the lowest and 10 represents the highest, the majority of respondents exhibit a strong understanding of the advantages of solar power, with a mean score of 8 and a mode of 10. In general, almost all respondents have a favourable (positive and very positive combined) attitude towards solar energy, with only 0.88% having a neutral attitude. However, when asked about their attitude toward a large ground-mounted solar PV farm near Dunbar, the positive response drops to 85%. This indicates that, while the community as a whole believes in the benefits of solar energy, when confronted with the prospect of a large-scale solar PV project near Dunbar, there is a portion of the community that is not enthusiastic about the project and even opposes the project.

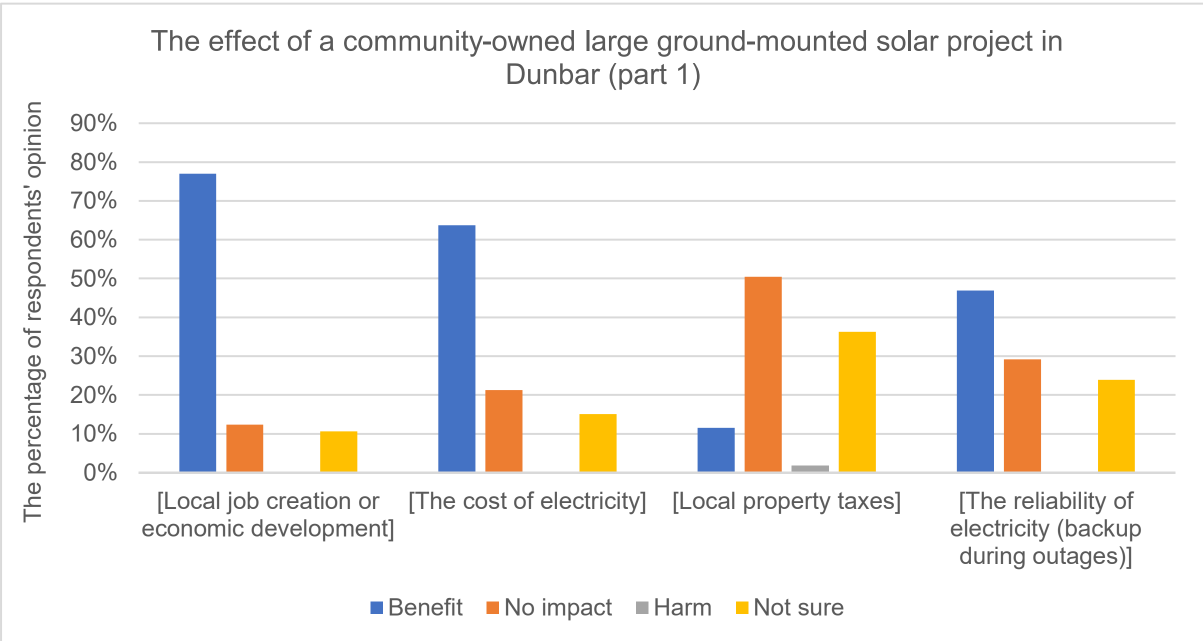


(a)



(b)

Figure 3. *(a) General attitude toward solar energy; (b) attitude towards large ground-mounted solar PV farms near Dunbar. Source: IC2023 Team*



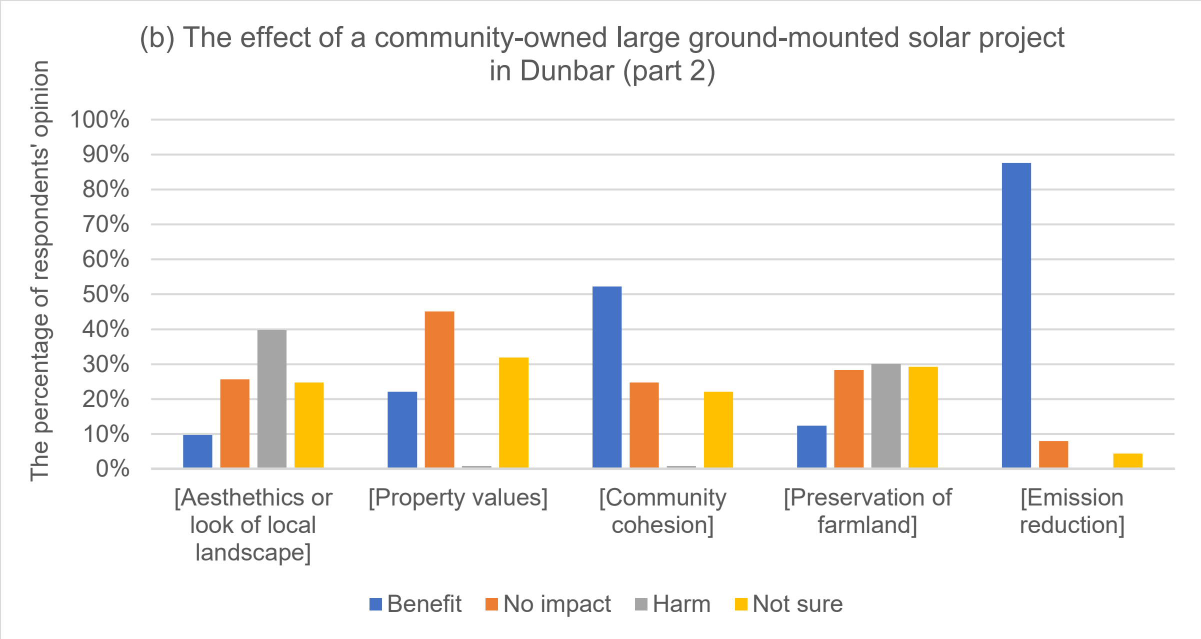


Figure 4. *Respondents' opinion on the effect of community-owned large ground-mounted solar project in Dunbar. Source: IC2023 Team*

When asked for their views on the impact of a large community-owned ground-mounted solar project in Dunbar (**Figure 4**), the respondents generally concurred that it would be advantageous for local job creation and economic development. They also believed that it would have a positive effect on electricity costs and reliability during power outages, as well as contribute to reducing emissions and promoting community cohesion. However, they did not think that it would affect local property taxes or property values. On the other hand, they expressed concerns that the project would harm the aesthetics or visual appeal of the local landscape, as well as the preservation of farmland.

Proceeding to the expected involvement of the community if a large solar PV farm is built in Dunbar (Figure 5), the majority of the respondents agree that information needs to be shared with the public. Access to jobs provided by the project came second, followed by the opportunity to review and comment on the siting and design. The opportunity to be a part owner of the project and the opportunity to communicate concerns directly to the solar project developer was also mentioned. This also confirms that procedural justice, distributive justice, and trust are important in developing such a project.

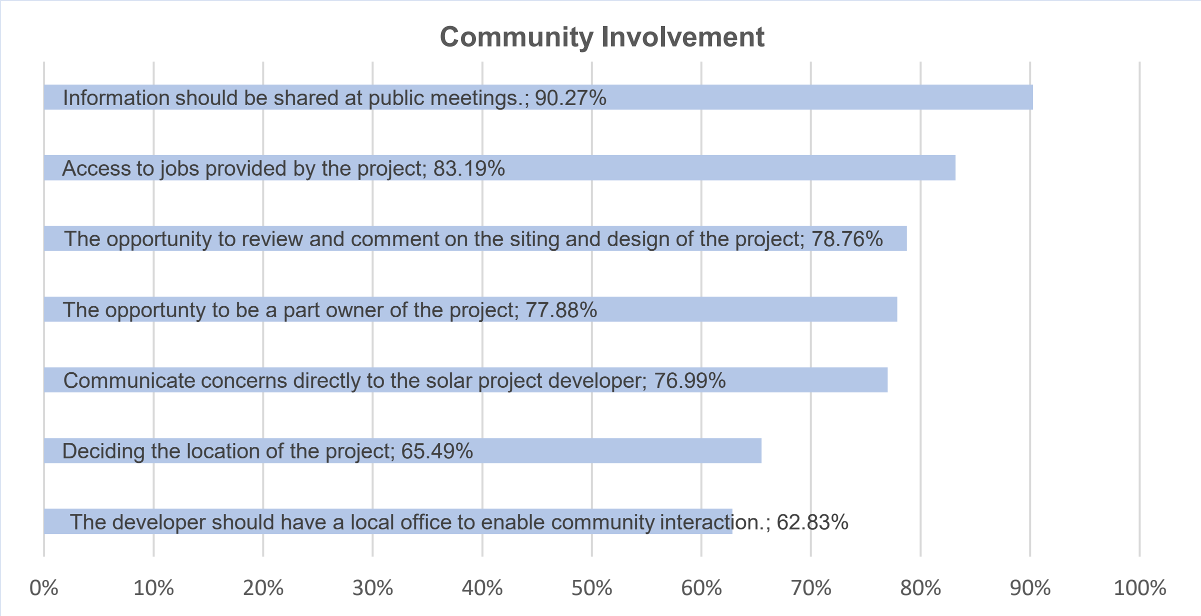


Figure 5. *Expected community involvement in a community-owned large-scale solar PV farm. Source: IC2023 Team*

In terms of profit utilisation, 90% of respondents agree that profits should be reinvested in the community, specifically to reduce fuel poverty. Aside from that, they recommend some other projects (in descending order of polls) such as; education and facilities for youth and children; environmental and biodiversity protection projects; housing and infrastructure; renewable energy projects; green and sustainable transportation; agriculture and food projects; training and upskilling; travel projects; and any other projects that can benefit the larger community. Around 17% of them suggest that the decision on where the profit should be distributed shall be decided by a community forum.

3. Characteristics of the site

The solar farm project will be developed on an area of approximately 50 hectares located at Cocklaw Farm, around 1.24 miles northwest of Oldhamstocks, a small village in East Lothian near the boundary with the Scottish Borders (Community Energy Scotland, 2019). The highest elevation and the lowest elevation of the area stood at 319 metres and 246 metres above sea level. The centre of the site is located at coordinates: Latitude 55.936°, Longitude: -2.447°. These coordinates were used for gathering meteorological data for resource analysis and design for the PV plant.

3.1. Meteorological data

There are several parameters to be considered in the design of the solar farm. In particular, solar radiation, temperature, wind speed, and humidity influence the performance and efficiency of solar panels. The following is a summary of the meteorological characteristics of the area where the project will be implemented. The meteorological data considered for this project is from Meteonorm 8.0, which was directly accessed through PVsyst software (2005-2013). PVsyst is a software designed for studying, sizing, simulating and analysing the performance of solar photovoltaic systems.

3.1.1. Solar Irradiance

Scotland's solar irradiance is generally lower than other parts of the United Kingdom (UK) due to its higher latitude and frequent cloud cover. However, Scotland still receives significant solar radiation, particularly during the summer months. According to data from the Meteonorm Database in Table 1, Global horizontal irradiation (GHI) levels in Dunbar can range from around 11.8 kWh/m^2/mth in winter (December) to over 150.2 kWh/m^2/mth in summer (May).

3.1.2. Solar path

Figure 6 shows the annual sun path at the project location based on hourly sun position (azimuth and altitude) in the sky. From Figure 6, we observed high seasonal variation in daylight hours and sun position from summer to winter, which adds complexity in choosing a suitable solar window for harnessing maximum energy throughout the year.

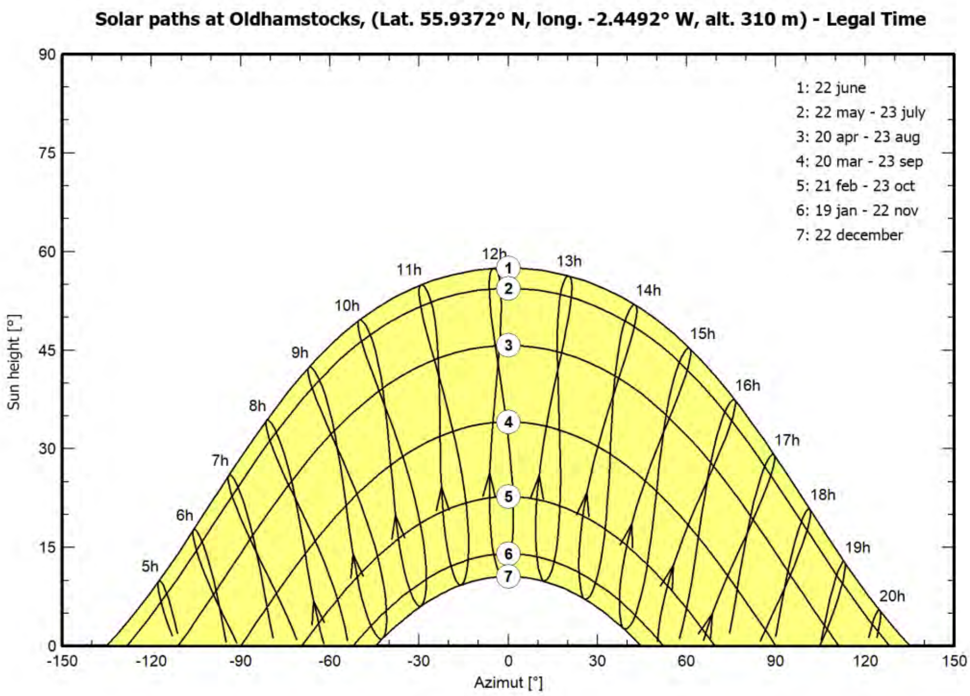
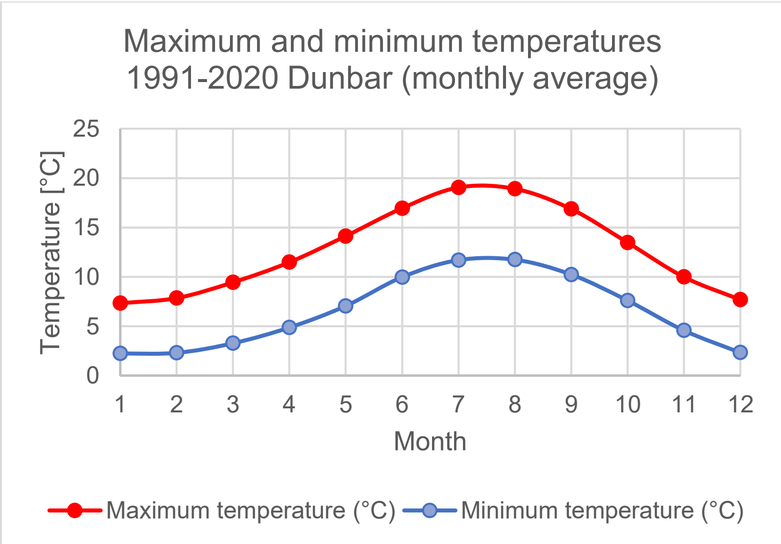


Figure 6. Sun paths in Oldhamstocks, (Lat. 55.9372° N, Long. -2.5592°W, alt. 310 m), Azimuth 0° indicates south Source: (Meteonorm 8.0, 2020).

3.1.3. Temperature

Temperature has a significant impact in determining the efficiency of different components of the PV plant. It relates to the heat dissipation limit of the operating equipment and affects the selection of the equipment, limiting the minimum and maximum array size. According to information presented by the UK Met Office (Met Office , 2020), the annual average of the monthly maximum temperature for Dunbar is 12.79°C. The average maximum and minimum values per month can be found in Figure 7. The maximum temperature is 20.25°C (EC, 2023).

The values lie in the optimum operating range of different equipment available in the market, such as PV modules and inverters. We considered hourly temperature data for determining optimum configuration of plant equipment.



Month	Maximum temperature (°C)	Minimum temperature (°C)
January	7.34	2.25
February	7.86	2.32
March	9.45	3.29
April	11.48	4.88
May	14.13	7.06
June	16.95	9.98
July	19.05	11.7
August	18.91	11.74
September	16.87	10.24
October	13.48	7.61
November	9.99	4.58
December	7.69	2.34
Annual	12.79	6.52

Figure 7. Monthly average m*aximum and minimum temperatures 1991-2020 Dunbar. Monthly average. Source: (Metoffice.uk, 2020)*

3.1.4. Wind speed and wind load

Solar installations are sensitive to strong wind, which can affect their structure. Therefore, wind is considered as a factor when designing solar PV farms. Wind is also important for the cooling of the components in PV systems. According to information from PVGIS (EC, 2023) the typical meteorological year (TMY) data of the project location shows an hourly average wind speed of 5.12 m/s and an hourly average maximum speed of 14.93 m/s, measured at 10 metres height (EC, 2023). PVGIS (Photovoltaic Geographical Information System) is an online tool developed by the European Commission’s Joint Research Centre that provides information on solar radiation, photovoltaic potential, and energy yield for any location in the world.

Figure 8 presents a histogram of wind speeds for the years 2005-2020.

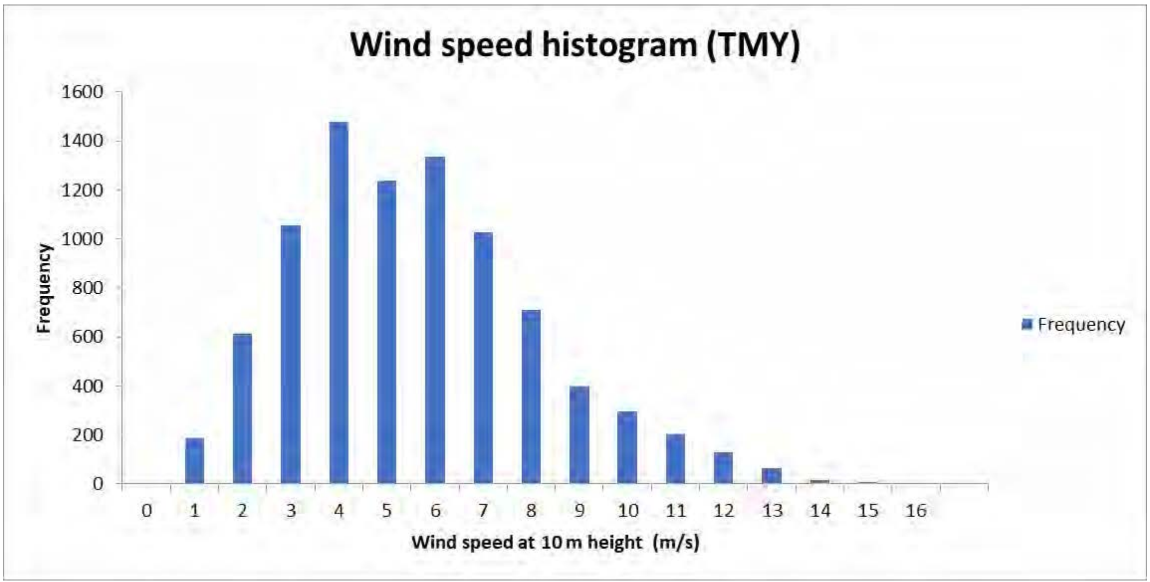


***Figure 8**. Wind speed histogram Dunbar. Source: EU Science Hub (EC, 2023)*

3.1.5. Relative humidity

The article "Humid-free efficient solar panel" estimates that in areas with high humidity in the environment, the power generated by solar panels can be reduced by 10-20% because of thin layers of water being created on them. (Panjwani, Panjwani, Mangi, Khan, & Meicheng, 2017). Relative humidity in Scotland varies between 82% and 87%, so condensation and distortion of irradiance can occur on the panels.

As a summary, the data used in the solar farm simulations are presented in Table 1, all the values were obtained from the Meteonorm 8.0 database.

***Table 1**. Summary of project weather conditions. Source: (Meteonorm 8.0, 2020)*

	Global Horizontal irradiation kWh/m2/mth	horizontal diffuse irradiation kWh/m2/mth	Temperature °C	Wind Velocity m/s	Linke turbidity [-]	Relative humidity %
January	15.6	10.3	3.2	4.90	2.85	85.3
February	33.5	19.1	3.3	4.80	2.84	84.0
Mardi	68.4	35.7	4.8	4.79	3.11	80.7
April	110.8	54.5	6.7	4.39	3.26	78.4
May	150.2	72.8	9.7	4.30	3.21	77.7
June	145.4	85.8	12.3	3.90	3.09	80.5
July	148.0	79.0	14.2	3.60	2.99	79.9
August	115.3	67.6	13.9	3.70	2.93	81.8
September	81.3	46.1	11.8	4.10	2.86	83.2
October	44.6	26.5	8.8	4.29	2.80	85.3
November	20.9	13.6	5.4	4.40	2.76	86.0
December	11.8	8.4	3.6	4.60	2.79	86.0
Year	**945.8**	**519.4**	**8.1**	**43.00**	**2.96**	**82.4**

4. Site suitability for solar

The site survey was done to gain impression of the site, including slope, aspect and surface properties.

4.1. Orientation and tilt of the solar panels

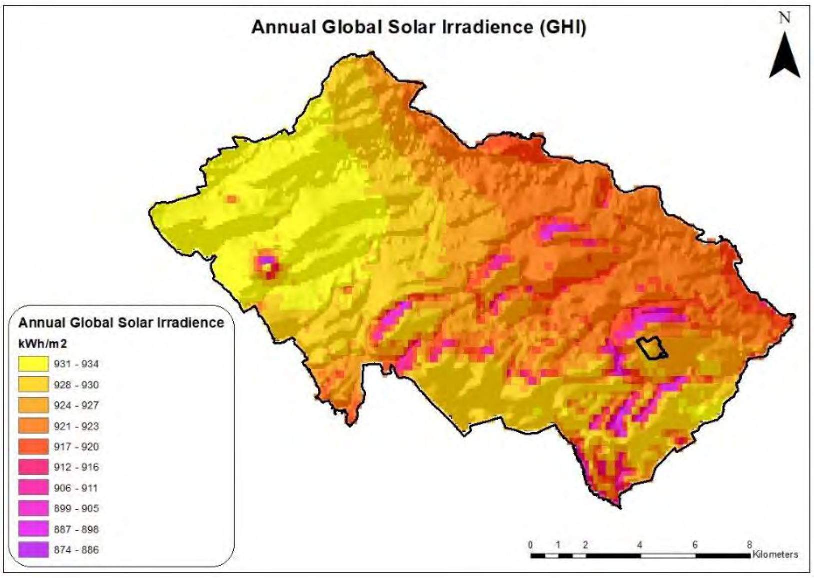


Figure 9. *Annual Global Solar Irradiance (GHI). Source: (Global Solar Atlas, 2023)*

Figure 9 shows the annual GHI in Dunbar and East Linton. The annual GHI ranges from 934 kWh/m^2 to 876 kWh/m^2, represented by yellow and purple respectively (Global Solar Atlas, 2023). The annual GHI in the potential solar farm location is around 925 kWh/m^2 (Global Solar Atlas, 2023).

Additionally, using a MATLAB model the optimum tilt range was found between 30° to 40°. The results are shown in Figure 10.

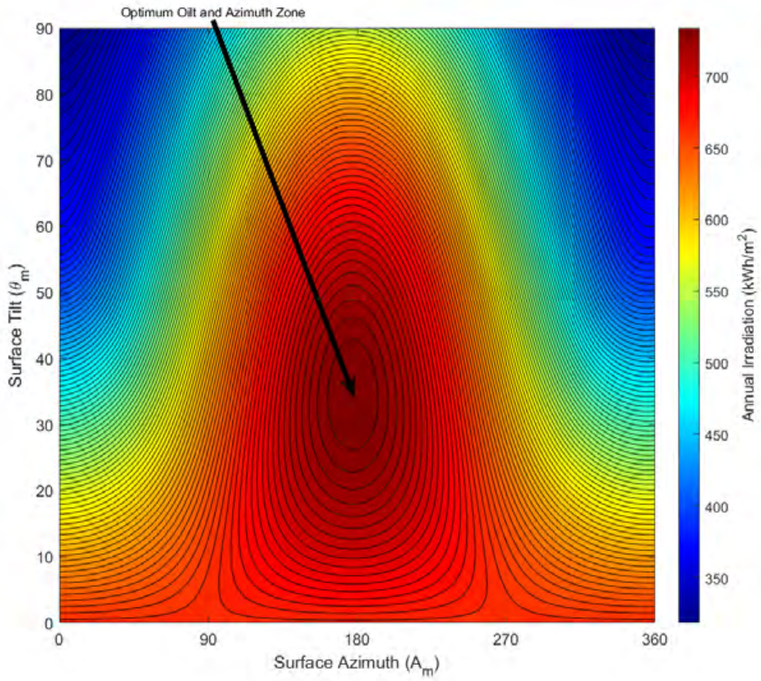


***Figure 10**. Optimum PV module Tilt angle range for fixed structure installation at the site. The range was calculated using the Reindl sky diffuse irradiance model and Metonorm TMY data. Source: IC2023 Team.*

To define the best orientation and distance between the mounting structures, some additional research about existing projects in Scotland was carried out, see **Table 2**. This data was used to verify our design.

***Table 2.** Existing projects in the UK. Source: IC2023 Team.*

Some projects in the UK	Location (°)	Area (hectares)	Power (MW)	Pitch approx. (m) (m)	Structure length approx. (m)	GCR	Tilt (°)	Reference
Errol Estate Solar Farm	56.3674, -3.2788	28.3	13	8.27	3.67	0.44	35	(Gibson, 2016)
Wormit Solar Farm	56.4164, -2.9616	10.9	5	10.29	4.58	0.45	-	(SolarFeeds, 2022)
Mackie's of Scotland's Solar Farm	57.3786, -2.3881	46.1	1.8	7.95	2.75	0.35	35	(Absolute Solar and Wind, 2016)

Pitch is the distance between the beginning of one PV module array to the beginning of the next PV module array. Ground Cover Ratio (GCR) is the ratio of solar PV module area to the total solar PV farm area (NREL, 2022).

Finally, some additional simulations were performed to find the best GCR and tilt. The results are shown in Table 3.

Table 3. Comparison of yield with tilt and GCR variation. Source: IC2023 Team.

Simulations	Yield [kWh/kWp/year]
Fixed structure at 30°	993
Fixed structure at 35°	998
Fixed structure at 40°	997
Fixed structure with GCR 0.40	998
Fixed structure with GCR 0.45	993

From the simulations results obtained it was concluded that the simulations performed in the section called PVsyst simulations will include fixed structures with tilt of 35° and a GCR of 0.4.

4.2. Shading from nearby buildings or trees

From the site survey, we found the two rows of trees located adjacent to the potential solar PV farm as shown in Figure 11. These trees have the potential to cast a shadow over the solar PV module resulting in less annual energy yield.

The first row with a height of approximately 2.5 metres is located on the south side of the area as shown in a green rectangle. The second row with a height of approximately 15 metres is located on the east side of the area as shown in the red rectangule.

To consider the effect of tree shading on the annual energy yield, these trees were included in the PVSyst 3D layout to create near object shadow while simulating the annual energy yield. The result was used further in PV farm layout design.

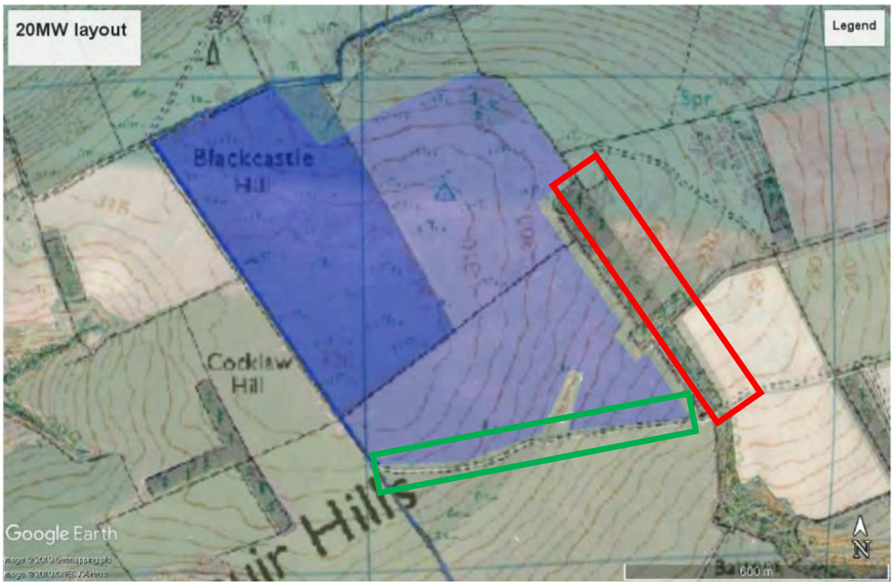


***Figure 11**. Location of Trees adjacent to the potential solar PV farm area. Source: (Community Energy Scotland, 2019)*

4.3. Distribution of solar irradiation at the project area

This analysis was done to locate the most and the least suitable location to place the solar PV module in the potential solar PV farm area.

For the following analysis, we used ArcGIS. ArcGIS is a geographic information system (GIS) software developed by Esri for managing, analyzing, and sharing geospatial data and maps.

The analysis was done by using the tool called Area Solar Radiation in ArcGIS using Light Detection and Ranging elevation data (Phase3) collected from Scottish Remote Sensing Portal as an input (Scottish Remote Sensing Portal, 2023). This dataset reflects the Digital Terrain Model (DTM) and has a resolution of 50 by 50 centimetres. This tool is used to create the map showing the estimated amount of annual energy yield (Wh/m2) that can be generated in each location over the interested area.

As shown in Figure 12, the most suitable area to install the solar PV module is in the area that can generate the most energy yield which is coloured in red while the least suitable area to install the solar PV module is in the area that can generate the lowest energy yield which is coloured in yellow.

The area's maximum and minimum annual energy yields are approximately 916 kWh/m^2 and 766 kWh/m^2, respectively. The maximum annual energy yield is less than that mentioned by the global solar atlas for two reasons. The first reason is that this tool does not factor in diffuse solar irradiance while calculating annual energy yield. The second reason is that this tool considers the shadow effect caused by the differences in terrain elevation.

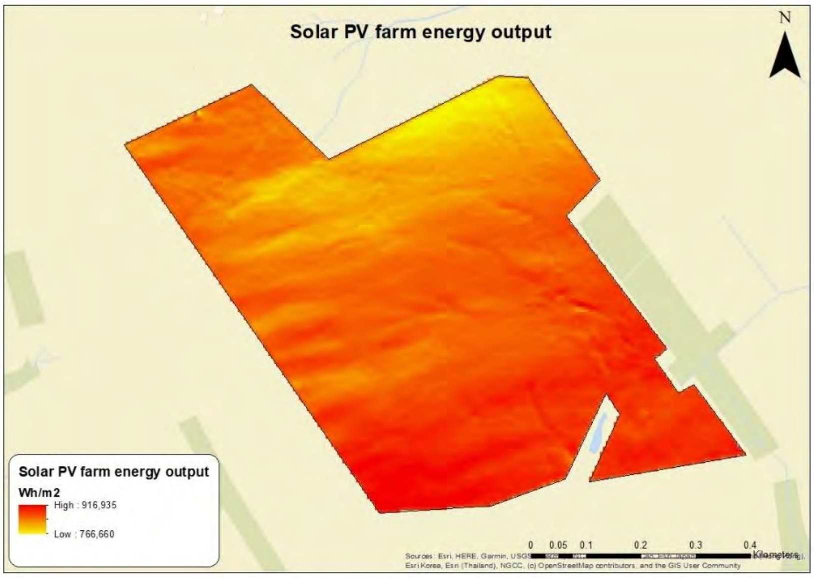


Figure 12. *Solar PV Farm energy output. Source: IC2023 Team.*

4.4. Elevation curves

The elevation of the terrain is an important factor to consider in solar PV plants. Solar panels convert part of the energy contained in sunlight into electrical energy through the photoelectric effect (Bhatia, 2022). This process can be affected by different environmental factors, including terrain. In particular, the elevation and orientation of the terrain can affect the amount of sunlight reaching the solar panels, as well as the angle at which it strikes them.

The terrain on which the project will be developed is hilly and has changes in elevation across its entire surface. **Figure 13** presents the terrain elevation curves, which were constructed in ArcGIS with data from the Light Detection and Ranging (LiDAR) for Scotland Phase III DTM project of the Scottish Remote Sensing Portal (Scottish Government, 2023). The curves in red are the primary curves and correspond to changes in elevation every 5 metres, the curves in grey are secondary curves and are calculated every metre. The maximum and minimum terrain elevations are 319 m and 246 m, respectively. The elevation analysis of this project was used to determine the structures and positioning of the PV arrays to maximise the generation yield.

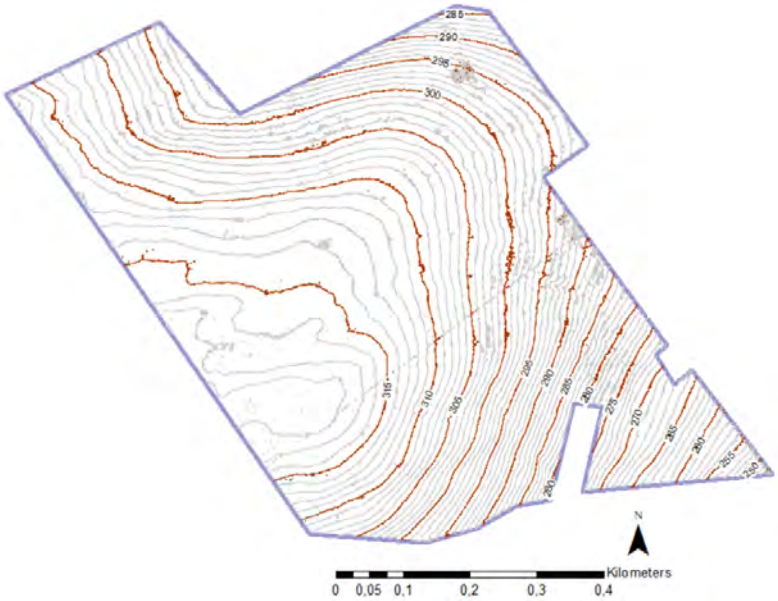


__Figure 13__. Contour curves in the terrain. Source: IC2023 Team

4.5. Slope and aspect analysis

Figure 14 presents the unevenness of the terrain in percentage and Figure 15 presents the orientation towards which the unevenness is located. With this information, it is possible to prioritise the areas of land for the layout of the solar panels.

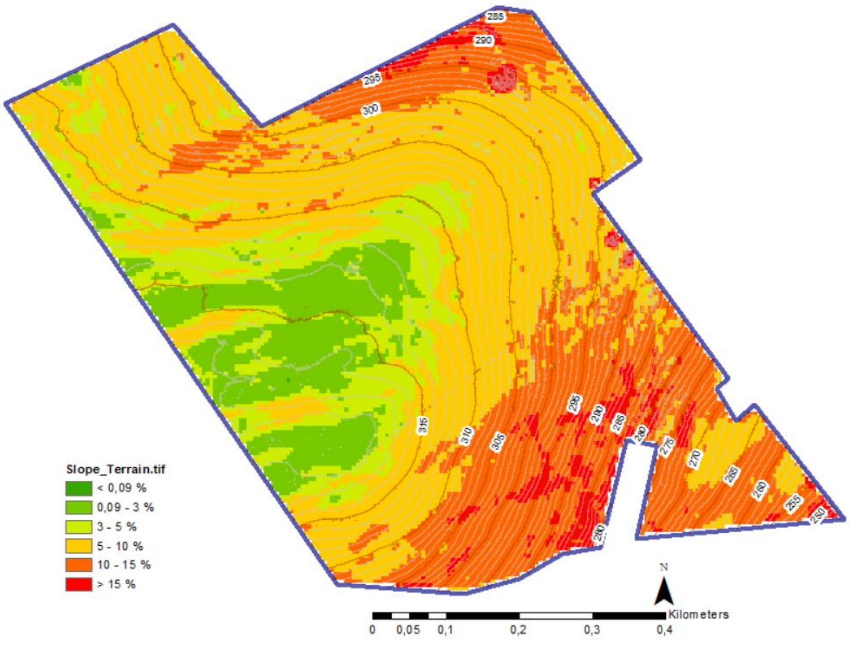


***Figure 14.** The slope of the terrain in percentage. Source: IC2023 Team*

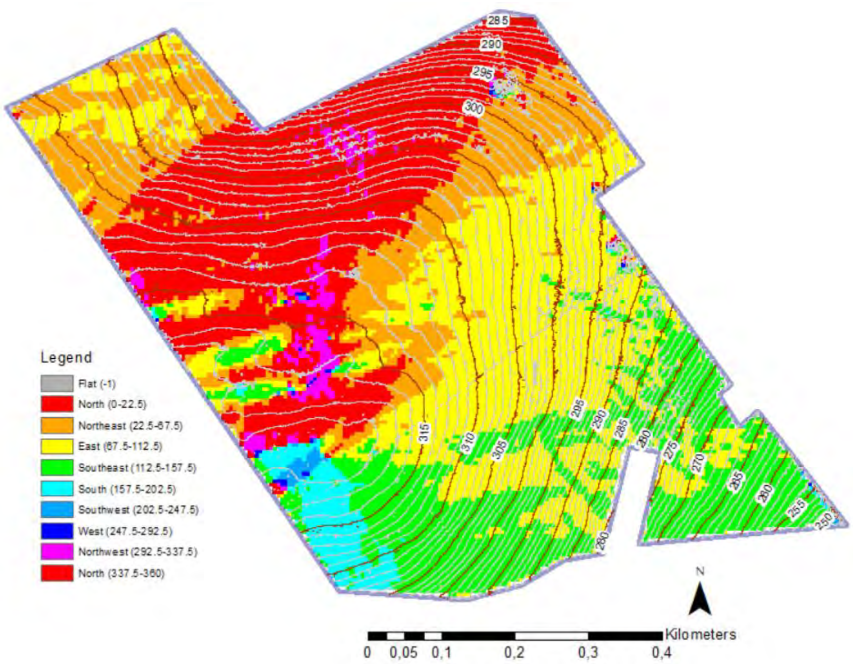


__Figure 15.__ Orientation of slopes in the terrain. Aspect function. Source: IC2023 Team

4.6. Exclusion of areas with water bodies

During the site visit, two water bodies were identified, a pond of approximately 900 m² and a watercourse in the southeast and north part of the terrain respectively, see Figure 16. To reduce environmental impact in the area a buffer of 30 metres from the water bodies were considered in the design.

__Figure 16.__ The watercourse is located on the north side of the terrain. Source: IC2023 Team.

5. Grid connection

The capacity heat map on the grid operator's website showing the available capacities for grids near the project was reviewed. The map uses colours to indicate the status of grid circuits: green for circuits with sufficient capacity, yellow for circuits with limited capacity, and red for circuits that can't transport more capacity. In Figure 17 it can be seen that all the possible connections close to the PV farm in Dunbar have limited capacity.

Figure 17. *Distributed Generation Heat Map. Source: (SP Energy, 2023)*

Therefore, the Dunbar regional electricity grid's capacity may be a significant constraint for the project. This agrees with the previous assessment which concludes that the farm is not viable for 20MW solar PV development mainly due to distribution and transmission grid constraints (Community Energy Scotland, 2019).

However, according to (Community Energy Scotland, 2019) it is expected to become financially and technically viable by 2025 based on the projection that the burden of paying part of the transmission upgrade would be lifted from the developer, leading to a substantial drop in grid connection costs.

5.1. Key components selection

The key criteria considered to select the solar PV modules and inverters included efficiency, durability and reliability, cost, compatibility, availability and delivery time, manufacturer's reputation, local regulations, and environmental factors (Gor, 2021). Choosing solar modules and inverters that meet these criteria will ensure that the PV farm performs well, has low maintenance costs, and provides a good return on investment over the long term.

- Module Selected: Canada Solar Inc. (CS6W-540MS 1500V)

Canadian Solar Inc. (CSI) module is selected due to its high-quality solar panels with excellent performance and reliability. They have a strong reputation in the solar industry, ranking among the top solar modules in the world and being one of the five largest solar module manufacturers (Staff, 2023). In addition, Canadian solar Inc is ranked among the top 10 solar panel brands in the UK (Solar_Feeds, 2022)

- Initial Inverter Selection: Sungrow's inverter, SG250-HX and SMA's central inverter, Sunny Central SC 4000 UP

The choice between a string and central inverter configuration will depend on the energy output, cost-effectiveness, and suitability for the solar PV project. Two simulations were conducted using PVSyst to enable informed decision-making on which inverter is best suited for this project: one simulation was conducted for a system with string inverters, and the other for a system with central inverters. The most cost-effective and efficient system is chosen by comparing the energy output, performance factor and cost of each system in addition to environmental factors.

Sungrow string inverter, SG250-HX was chosen due to its reliability, cost-effectiveness, availability of 10-year warranties, reputation for service and quality, and WiFi monitoring (Sungrow, 2022). Sungrow has been ranked as one of the best grid-tied solar inverters in 2022 and a popular choice in the UK (Svarc, 2022). With its proven track record, the Sungrow inverter is expected to help keep the project's costs down, ensure that the project is reliable, and allow the project team to monitor the performance of the inverters remotely.

The SMA Sunny Central inverter, SC 4000 UP was chosen for this project due to several reasons. Primarily, SMA inverters have a track record of exhibiting excellent service and performance with low failure rates, thus ensuring a reliable selection (Svarc, 2022). Furthermore, SMA offers an optional extended warranty of 10 to 20 years, reinforcing our confidence in the product's durability (SMA, 2022). Additionally, with more than 25 years of service life and their popularity in the UK, SMA inverters are a proven choice for this region (Svarc, 2022). The central inverter would considerably reduce the required inverters from about 80 string inverters to just five central inverters.

- Mounting structure (Fixed tilt, fixed tilt east-west, trackers)

Solar PV mounting structures are an essential component of solar PV systems. Selecting the appropriate mounting structure for a specific location significantly affects system efficiency, durability, and output (Ehsan, 2019). The correct mounting structure is especially critical in areas with varying surface elevations, low annual irradiance, and high wind speeds, like the area under consideration (Rahimi, 2020). Three solar PV mounting structures are initially considered in this project: fixed-tilt, fixed-tilt east-west, and tracking systems.

Optimum fixed-tilt systems are a popular and reliable option with no moving parts making them suitable for uneven terrain and areas with high wind speeds (Al-Sulaiman, 2018). However, they have a fixed angle, which may not be optimal for maximum solar exposure, particularly since the area has a low annual irradiance (Ehsan, 2019). Fixed-tilt east-west systems are oriented in the east-west direction. Unlike fixed south orientation, which maximises generation through the day, east-west orientation aims to maximize generation during morning and afternoon hours. However, they may require more land area compared to fix south orientation to achieve the same annual energy output (Hanif, 2016).

Tracking systems are a more complex and expensive option that can follow the sun's movement throughout the day, maximizing energy production and efficiency (Rahimi, 2020). They can be installed over uneven terrain and can be designed to withstand high wind speeds. However, due to their complexity, they require more maintenance and repair, and they may not be a cost-effective option (Rahimi, 2020).

In summary, the solar PV mounting structure choice depends on various factors such as budget, available land, local environmental conditions, and energy output. During the simulation, it was noted that the energy generated increased by 12% with the tracking configuration compared to the fixed tilt configuration. However, the cost also increased by 16%. On the other hand, the fixed tilt east-west configuration resulted in a slightly decreased energy output with comparable investment costs with fixed tilt. These results are detailed in the simulation section.

5.2. Additional components

- Transformer stations

To have seamless communication between the components of the solar farm, the MVS3150-LV transformer from Sungrow, the manufactures of the inverters, was chosen for this project. Sungrow provides a complete solution which includes inverters and transformer stations. Based on the installed solar PV capacity, five transformers are required. Three of these transformers will be rated at 3200kVA, and each will be connected with 14 inverters, while the remaining two transformers will be rated at 4480kVA, and each will be connected to 19 inverters.

- Energy Storage

Energy storage technologies are considered for arbitrage to maximize revenue from the solar PV plant. Figure 18 shows various energy storage systems currently available on the market. Pump hydro technology requires a minimum elevation of 100 metres between the head and base reservoirs (Hohmeyer, 2015), rendering it unsuitable for the location's maximum height of 60 metres. CAES storage system's energy production ranges from 10 MW to 100 GW (IEA-ETSAP and IRENA, 2012), making it larger than the project's requirements. At rated power, the flywheel discharge duration is only a few seconds, making it unsuitable for the project.

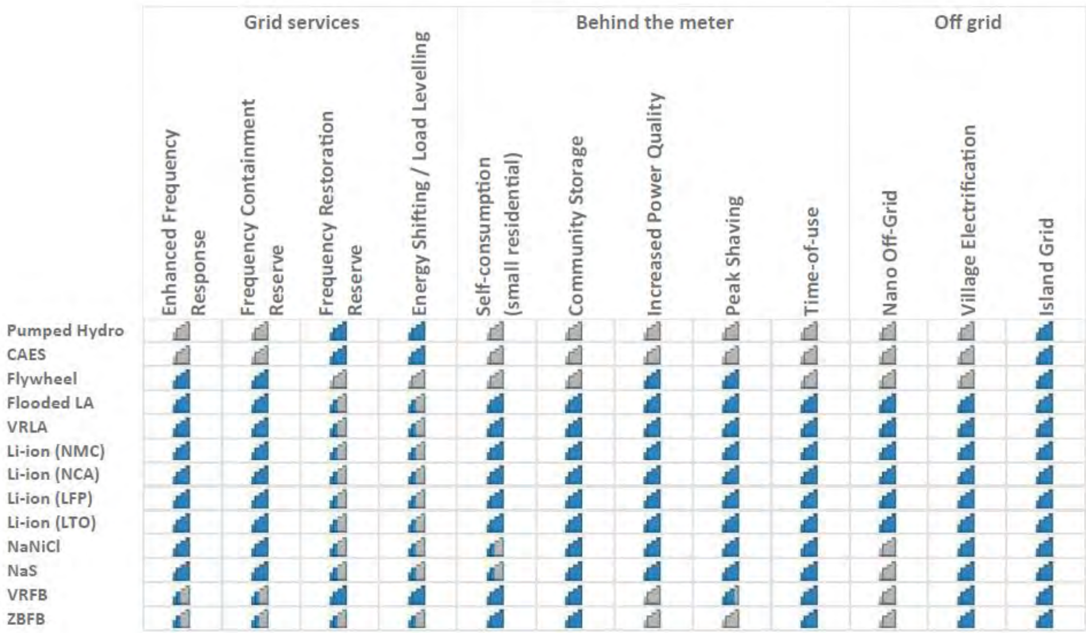


Figure 18. *Suitability of storage technologies for different applications. Source: (IRENA, 2017)*

Lithium-ion batteries were chosen for the project since the system power ranges from 1kW to over 1MW, and the discharge period at rated power is between minutes and hours (IEA-ETSAP and IRENA, 2012). The cost of lithium-ion battery cells has dropped by 97% over the last three decades, and this trend is expected to continue (Ritchie, 2021). See Figure 19.

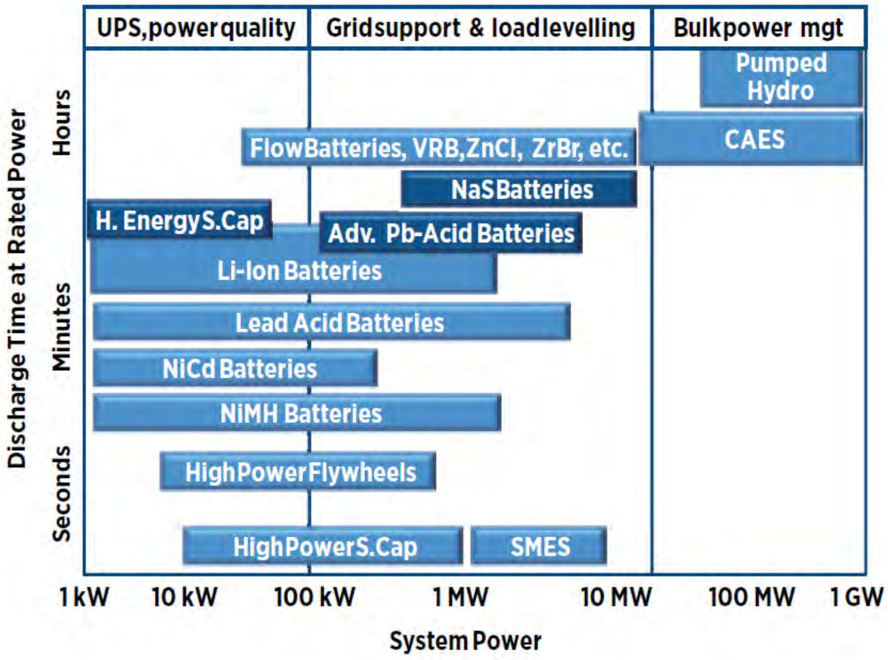


Figure 19. *Typical power output and discharge time of electricity storage technologies. Source: (IEA-ETSAP and IRENA, 2012)*

6. Solar PV design

6.1. Layout

The layout for this project considered the following parameters:

- Alignment of PV mounting structures to the main roads.
- Fixed tilt structures
- The pitch of 11.37 metres
- Main entrance in the southeast part of the terrain
- The transformer station is located aligned with the main roads.

In this preliminary layout, a total number of 41,600 modules with a total power of 22.46 MWp were placed in the terrain. As shown in Figure 20. With this initial information, the first simulation was carried out in PVsyst. Detailed layout can be found attached to this document.

Figure 20. *Preliminary layout. Source: IC2023 Team.*

6.2. Elevation profiles

Due to the characteristics of the terrain mentioned in section 4.4 of this report, the elevation profiles were prepared to give the team a clear image of how the structures will be placed. Figure 21 shows the elevation profiles that were studied.

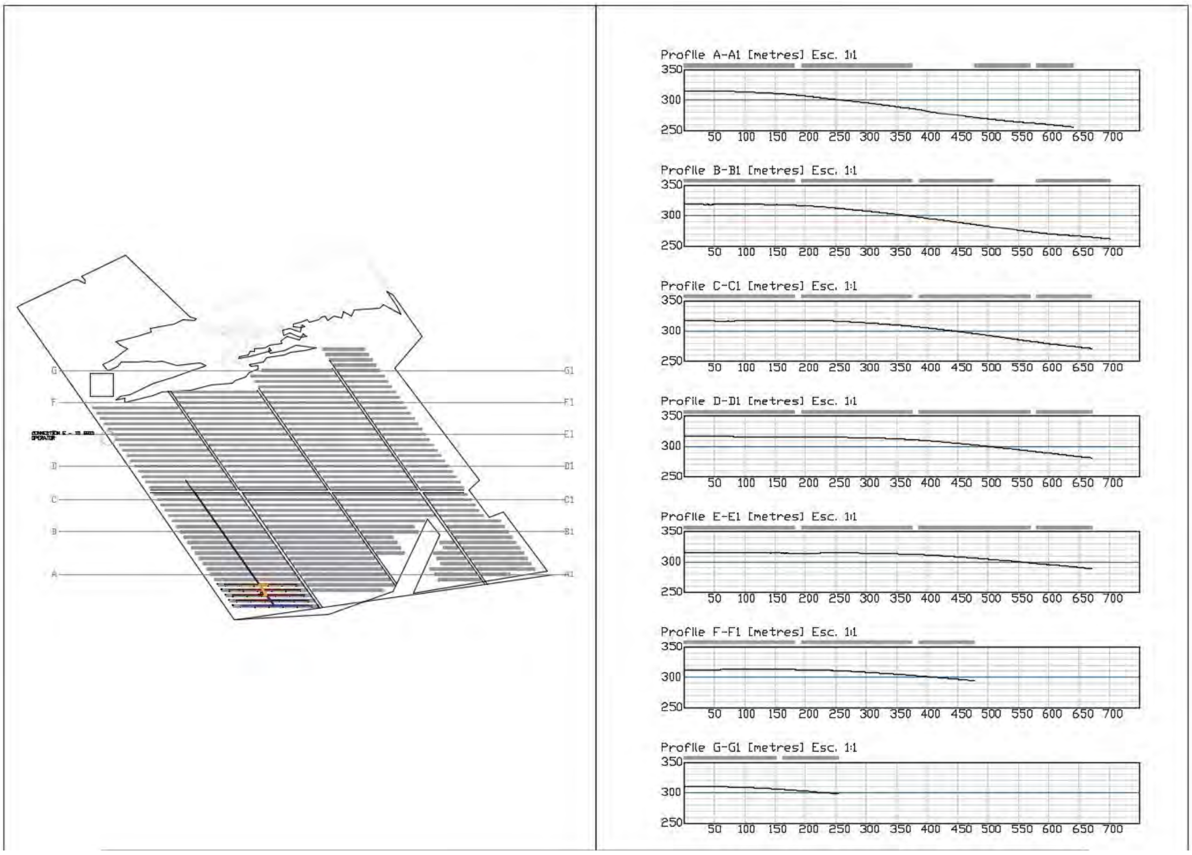


Figure 21. *Elevation profiles. Source: IC2023 Team*

6.3. Roads

To ensure easy access to the different project sites, the design considers that a road of at least 3 metres wide from west to east will be necessary to install an additional transformer station. This path could ensure easy access to the transformer station. Due to the limited scope of this project, the road design and budget are not included in this report.

6.4. Position of equipment

Voltage drop depends on various factors like the length of the cable, the cross-sectional area of the cable, the system current, and the voltage of the system (Desai, Pandya, Mukhopadhyay, & Ray, 2020). Therefore, to reduce the losses, this design proposed the installation of the inverters in a central location. Regarding the Transformer Stations, access plays a major role, therefore, the location for them was considered aside from the main road. The suggested placing of the equipment can be found in the layout attached to this document.

7. PVsyst simulations

To compare the energy results within the different possible options available in the market, the team considered 4 different scenarios to evaluate. The scenarios considered are the following:

- Configuration A: 80 inverters, 41,600 modules, Fixed structure at 35°
- Configuration B: 41,600 modules, 5 Central inverters, Fixed structure at 35°
- Configuration C: 80 inverters, 41,600 modules, East-west
- Configuration D: 80 inverters, 41,600 modules, Single axis tracker

7.1. Considerations

7.1.1. General description

All the simulations were performed with the PV Module Canadian Solar International with code: CS6W-540MS 1500V, as showed in Table 4.

Table 4. *Configurations for the different PVsyst simulations. Source: IC2023 Team*

Configuration	Inverters	Mounting structure	N° of Modules	Operating conditions per string				N° of strings per inverter	N° of inverters
				Voc [V]	Vmpp [V]	Isc (A)	Impp (A)		
Configuration A	Sungrow SG250-HX	Fixed structure at 35°	26	1369	929	13.9	13.08	20	80
Configuration B	Sunny Central 4000 UP	Fixed structure at 35°	26	1369	929	13.9	13.08	320	5
Configuration C	Sungrow SG250-HX	East-west	26	1369	929	13.9	13.08	20	80
Configuration D	Sungrow SG250-HX	Single axis tracker	26	1369	929	13.9	13.08	20	80

7.1.2. Losses of the system

Many losses occur in the solar system from generation to the connection to the grid. Below are some of the main losses set in the different simulations. As shown in Table 5, Configuration B, which used a central inverter, has significantly higher DC losses than Configurations A, C, and D, which used string inverters.

Table 5. *Losses of the system for the different PVsyst simulations. Source: IC2023 Team.*

Losses of the system	Configuration A, C and D	Configuration B
DC losses [%]	0.7	1.5
AC losses (LV) [%]	0.82	2.3
AC losses (MV) [%]	0.3	0.3
Transformation losses [%]	1.1	1.1
Unavailability [%]	1	1
Soiling loss [%]	1	1

7.1.3. Shading scene

The corresponding 3D model was created in PVsyst for each simulation. Due to the slope of the terrain, an average slope of 7% was considered for the simulations with a fixed structure and single-axis tracker simulations, in contrast to the east-west structure simulations, where a flat terrain was considered.

7.2. Simulation results

The results showed that configuration A and D could be potential solutions for this project.

Table 6. *Simulation results. Source: IC2023 Team*

Configuration	Yield (kWh/kWp/year)	System production (MWh/year)	Performance ratio
Configuration A	998	22,419	0.873
Configuration B	992	22,276	0.868
Configuration C	776	17,430	0.839
Configuration D	1142	25,645	0.867

8. Grid integration

The section focuses on analysing the ramp rate of photovoltaic (PV) generators, which is a measure of how fast the active power generation of PV generators changes over a specific period (Maleki & Hagh, 2021). The output of a standard PV generator without storage can have a high ramp rate of up to 90 percent of the rated capacity per minute (de la Parra et al., 2015) This is caused by the movement of clouds through sun irradiance and results in an intermittent output from the PV generator (de la Parra, I., Marcos, J., García, M., & Marroyo, L., 2015).

The high ramp rate of PV generator output can affect power quality and grid stability (de la Parra, I., Marcos, J., García, M., & Marroyo, L., 2015). For this reason, grid operators are now putting a limit on the maximum ramp rate of PV generation as shown in Figure 22. To reduce the ramp rate, various types of energy storage, such as flywheels, supercapacitors, pumped hydro, and battery storage, are available in the market. Among these, battery storage is considered the most suitable storage solution due to its controllability and response time (Huo & Gruosso, 2020).

Grid code	Photovoltaic maximum allowed ramp rate
PREPA	10%/min
HECO	2MW/min and 1MW/min
EirGrid	30MW/min
Germany	10%/min

Figure 22. *Maximum allowed ramp rate. Source: (Maleki & Hagh, 2021)*

PREPA: Puerto Rico Electric Power Authority
HECO: Hawaiian Electric Company
EirGrid: island of Ireland transmission operator.

Engineering recommendation G99 (EREC G99) is the requirement that generators must meet to connect to SP Energy's distribution network. It was issued by Energy Networks Association (ENA). It clearly states that the maximum ramp rate of the PV generator must be informed to the distribution network operator (DNO) (ENA, 2019). However, it states that if the maximum permissible ramp rate is required by the DNO, it will be specified in the Connection agreement (ENA, 2019).

Therefore, the study focuses on two tasks: analysing the maximum ramp rate of the PV generator and obtaining the optimum size of battery storage that can reduce the PV generator ramp rate below the maximum limit that could be set by the distribution network operator (DNO). The PV generator output is measured in kW/MW per minute, obtained from PVSOL simulation which uses the (Hofmann, Riechelmann, Crisosto, Mubarak, & Seckmeyer, 2014) method to synthesize the minute value from the hour value. PVSOL is a software using for designing and simulating photovoltaic (PV) solar systems.

8.1. Ramp rate calculation

Two approaches are used to determine the ramp rate of PV generation. The first approach is to calculate the ramp rate as the change of active power output within one minute period, and the second approach is to calculate the ramp rate as the change of active power as a percentage of rated PV generation capacity within a certain sample period.

The ramp rate can be calculated with the first approach using Equation 1 (Maleki & Hagh, 2021). The unit of ramp rate calculated from this approach is kW per minute if the sample period of the PV generation data is one minute.

$$RR_1(t) = \frac{P_{\mathrm{pv}}(t) - P_{\mathrm{pv}}(t-1)}{\Delta t} \qquad \text{Equation 1}$$

Where RR_1 represents the ramp rate of the PV generator in kW per minute, P_{pv} represents PV generator output power in kW, and Δt represents the sampling time of PV generator output power.

The ramp rate can be calculated with the second approach using Equation 2 (de la Parra, I., Marcos, J., García, M., & Marroyo, L., 2015). The unit of ramp rate calculated from this approach is a percentage of rated PV generation capacity per minute if the sample period is in one minute.

$$RR_2(t) = \frac{P_{\mathrm{pv}}(t) - P_{\mathrm{pv}}(t - \Delta t)}{P_{\mathrm{rate}}} \times 100 \qquad \text{Equation 2}$$

Where RR2 represents the ramp rate of the PV generator in the percentage of rated capacity per minute, Ppv represents PV generator output power in kWh, Δt represents the sampling time of PV generator output power, and Prate represents the rated capacity of the PV generator in kW.

8.2. Ramp rate smoothing technique

To control and smooth the power fluctuation of a PV generator, various techniques, such as simple moving average (SMA), exponential moving average (EMA), low pass and high pass filters, linear exponential smoothing (LES), enhanced linear exponential smoothing (ELES), and adaptive enhanced linear Exponential smoothing (AELES), can be utilized. Among all smoothing techniques, AELES is proven to achieve the minimum energy storage capacity and is selected to be used as a smoothing technique in this study.

Adaptive enhanced linear Exponential smoothing (AELES) is the modification of two techniques, enhanced linear exponential smoothing (ELES) and hull moving average (HMA) (Usaratniwart et al., 2017). AELES can be described by Equation 3 (Usaratniwart et al., 2017).

$$AELES(t) = 2 \times S_{N \div 2}(t) - S_N(t) \qquad \text{Equation 3}$$

Where $S_{N÷2}(t)$ represents the 1st order EMA smoothing with a weight averaging constant of N÷2, and $S_N(t)$ represents the 1st order EMA smoothing with a weight averaging constant of N. Exponential moving average (EMA) can be expressed as Equation 4 and Equation 5.

$$S(t) = \alpha \times Y(t) + (1 - \alpha) \times S(t-1) \qquad \text{Equation 4}$$

$$\alpha = \frac{2}{N+1} \qquad \text{Equation 5}$$

Where Y(t) represents the observed data at time t, α represents the smoothing factor, and N represents the weight averaging constant which specifies the number of periods.

8.3. Ramp rate Modelling Result

Three constrains were used in the model. First, the battery depth of discharge was limited to 80 percent. Second, the round-trip efficiency was 90 percent (IRENA, 2017). Third, the battery was charged during night-time at the end of the day with the same amount of energy used during the day.

Using a MATLAB model, the maximum ramp rate of the solar PV plant is estimated at 81.6 per cent per minute equivalent to 16.3 MW per minute. The Ramp rate can be reduced by adopting the battery storage with the Power and Energy size as shown in Figure 23 and Figure 24.

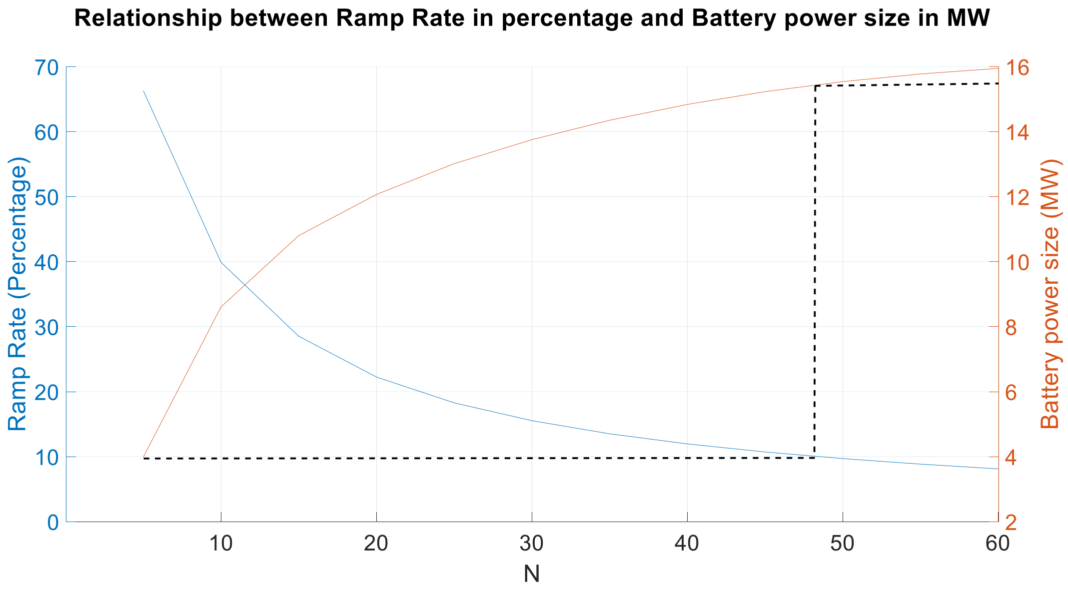


Figure 23. *Relationship between Ramp Rate in percentage and Battery power size in MW. Source: IC2023 Team.*

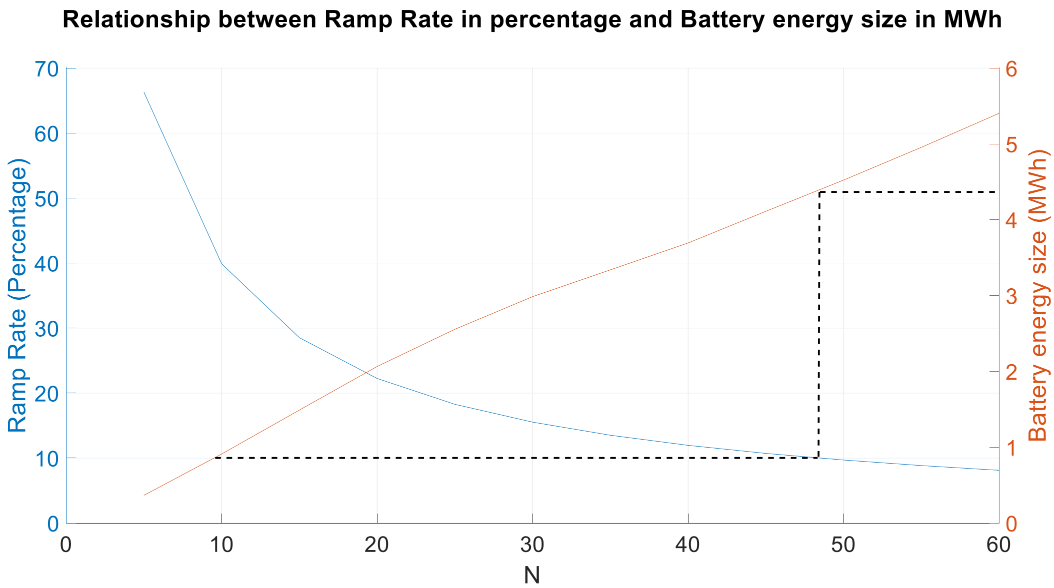


Figure 24. *Relationship between Ramp Rate in percentage and Battery energy size in MWh. Source: IC2023 Team.*

The CAPEX of battery storage is calculated using Equation 6 (NREL , 2022). The Battery energy cost and power cost adopted in this study are 225 GBP/kWh and 261 GBP/kW respectively (NREL , 2022).

$$\text{CAPEX} = \text{Battery size in MW} \times (\text{Energy Cost} \times \text{Storage Duration} + \text{Power cost}) \qquad \text{Equation 6}$$

The investment cost of battery storage required to reduce the solar PV ramp rate is shown in Table 7. For example, to reduce the solar PV ramp rate to 10.7 percent, the investment cost of battery storage is expected to be approximately 5.28 million pounds.

Table 7. *Relationship between Ramp rate, Battery power size, Battery power energy, and cost. Source: IC2023 Team.*

N	RR MW/min	RR percent/min	Battery (MW)	Battery (MWh)	CAPEX (GBP)
5	13.24	66.20	3.98	0.52	1,157,564
10	7.97	39.83	8.59	1.38	2,557,820
15	5.70	28.48	10.79	2.19	3,313,084
20	4.44	22.21	12.05	3.02	3,828,196
25	3.65	18.25	12.99	3.69	4,226,745
30	3.10	15.51	13.73	4.27	4,550,781
35	2.70	13.50	14.33	4.76	4,815,557
40	2.39	11.94	14.81	5.27	5,058,288
45	2.14	10.70	15.21	5.82	5,284,565
50	1.94	9.69	15.51	6.35	5,485,598
55	1.77	8.84	15.75	6.87	5,663,568
60	1.62	8.11	15.92	7.35	5,815,236

8.4. Cost of underground grid connection

The cost of grid connection is a key parameter in determining the feasibility of the project. The cost is usually provided by the distribution network operator. In this case, the distribution network is SP Energy.

The Grid connection cost used in this study is taken from Sustaining Dunbar Cocklaw PV Reassessment (Community Energy Scotland, 2019). The cost is then projected from 2019 to 2022 using the inflation index shown in Equation 7 (Morgan, 2013).

$$C_{2022} = \frac{I_{2023}}{I_{2019}} \times C_{2019}$$

$$C_{2022} = \frac{93.8}{100} \times C_{2019}$$

$$C_{2022} = 0.938 \times C_{2019}$$

Equation 7

Where C is the grid connection cost, and I is the inflation index of Electric Power Transmission, Control, and Distribution. The inflation index was collected from (Office for National Statistics, 2023). This study aims to project the grid connection cost from 2019 to 2023. However, the inflation index data is available only up to the year 2022.

The cost estimation was analysed in two scenarios due to the grid modernization done by SP energy in 2020 to receive electricity generation from Ferneylea, Kinegar and Hoprigshiels windfarms and the Viridor Energy from Waste (EfW) plant at Oxwellmains (Community Energy Scotland, 2019). The first scenario is connecting the solar PV farm to the grid within the first five years of the grid modernization. Connecting the PV farm within this period required a cost contribution to the grid modernization.

The second scenario is connecting the solar PV farm after five years of grid modernization or in the year 2025. Connecting the PV farm to the grid in this scenario is not required the cost contribution as in the first scenario. The cost of grid connection is shown in Table 8.

Table 8. *Grid connection cost. Source: IC2023 Team*

Cost estimated in 2019 (GBP) (Community Energy Scotland, 2019)		**Cost estimated in 2022 (GBP)**	
First scenario	Second Scenario	First scenario	Second Scenario
2,208,000	400,000	2,071,104	375,200

9. Social and Environmental aspects

9.1. Visibility study

The visibility study was done to estimate the visual impact likely to be caused by the solar PV farm to the people living within 30 kilometres radius. The study was done using various tools in ArcGIS. Those tools are view shed, raster calculator, tabulate area, and zonal statistic by the table. The input data are shown in Table 9.

Table 9. *Input data used in visibility study. Source: IC2023 Team.*

Input Data	Resolution	Source
Solar PV farm layout	N/A (Shapefile)	IC2023 Team
Elevation data: Digital Terrain Elevation (DTM)	90 x 90 metres	(USGS, 2018)
Global Human Settlement Layer	100 x 100 metres	(GHSL, 2022)
Unique Property Reference Number (UPRN)	N/A (Shapefile)	(Scottish Government, 2023)
The highest point of PV module from ground	4 metres. (The actual height is 3.59 metres)	IC2023 Team (Annex 2)

The visibility decay factor which is the impact of the distance on theoretical visibility is also considered in this study. This is because the perception of the homeowners towards certain potential risks fades as distance from the risk increases (Lin-Han Chiang Hsieh).

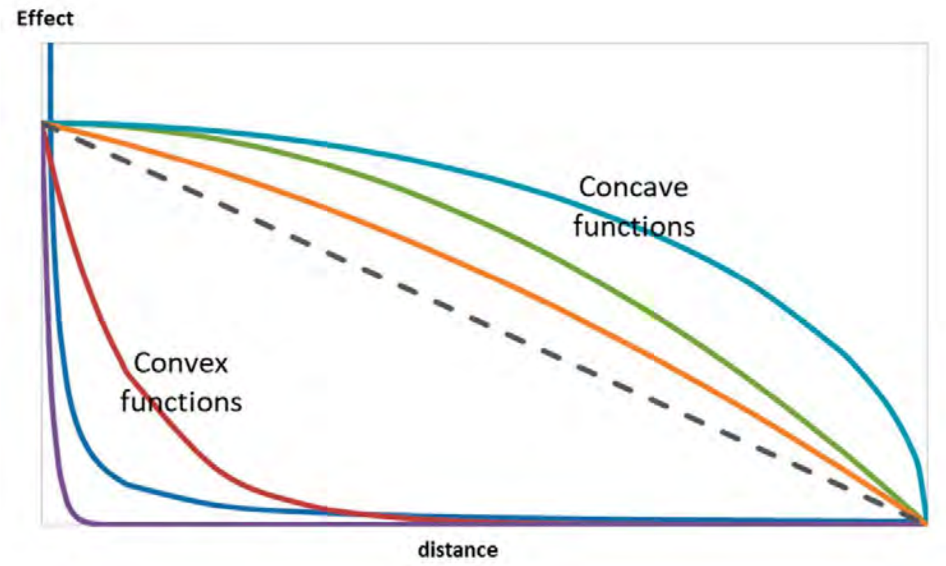


Figure 25. *Distance decay function. Source: IC2023 Team.*

There are two type of distance decay function, concave, and convex function as shown in Figure 25 (Lin-Han Chiang Hsieh). Convex negative exponential decay function, which is used by (Griffin, et al., 2015) in siting decision for coastal energy infrastructure, was adopted in this study. Convex negative exponential decay function can be described with Equation 8 (Lin-Han Chiang Hsieh).

$$y = e^{-x} \qquad \text{Equation 8}$$

Where *x* is the distance.

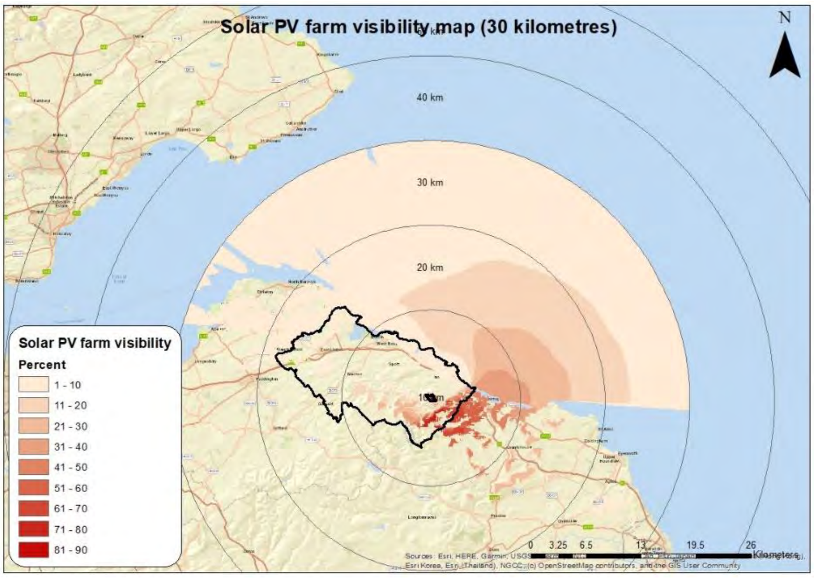


Figure 26. Solar PV farm visibility map (Within 30 km radius of the solar PV farm). Source: IC2023 Team

The map in Figure 26 shows the percentage of the area of the solar PV farm that can be seen from each location within the 30 kilometres radius area. As shown in Figure 27, the majority of visual impact caused by solar PV farms affects the low population density area less than 2 people per hectare.

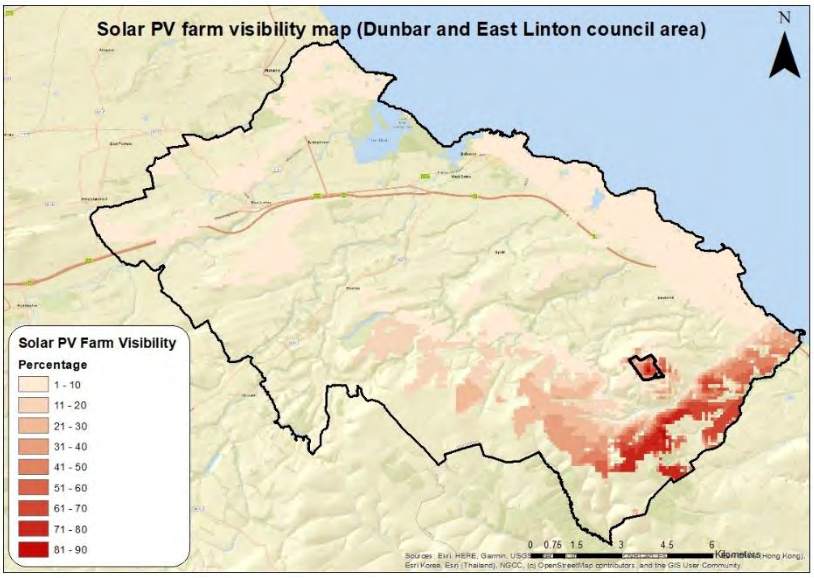


Figure 27. Solar PV Farm visibility map (Dunbar and East Linton council area). Source: IC2023 Team.

Figure 27 show the percentage of solar PV farm that can be seen from each location within the Dunbar and East Linton council area. As shown in Figure 28, the visual impact likely to be caused by the solar PV farm has a major impact on low population density area, less than 2 people per hectare. Approximately 30 percent of total area in Dunbar and East Linton with population density less than 1 people per hectare can see less than 10 percent of solar PV farm.

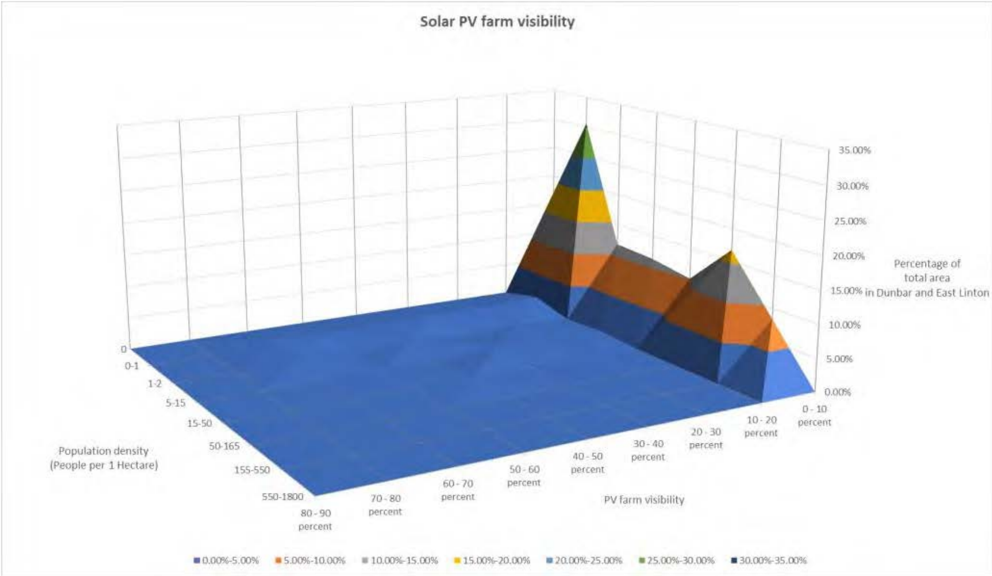


Figure 28. *Relationship between Solar PV farm, Population density, and focused on Dunbar and East Linton council area. Source: IC2023 Team.*

The visibility study was analysed further to estimate the percentage of solar PV farm that can be seen from each property within Dunbar and East Linton council area. This was done by incorporating the 9,447 UPRN address point locators.

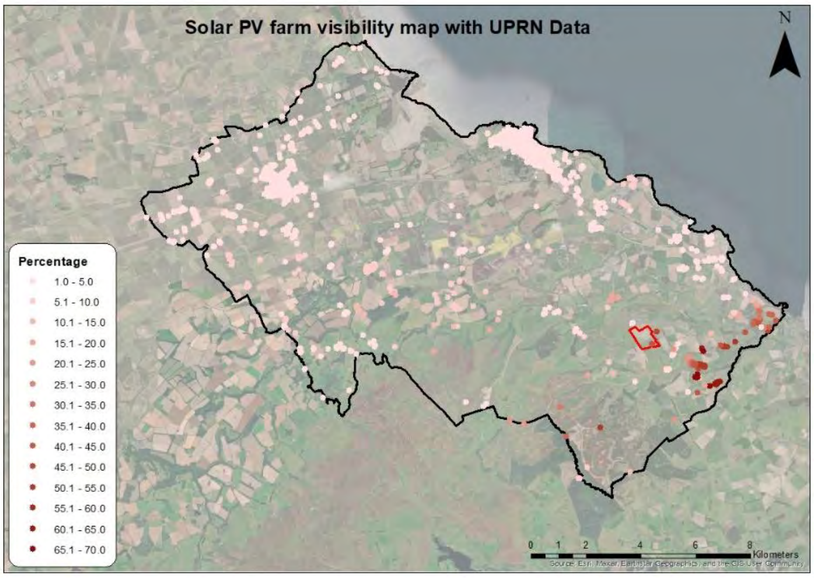


Figure 29*. Solar PV farm visibility map with UPRN data. Source: IC2023 Team.*

As shown in Figure 29, the maximum visibility of solar PV farm among all address locations in Dunbar and East Linton council area is 70 percent. However, the number of properties with high visualization of solar PV farm is very low. As shown in Figure 30, 98 percent of all properties can see less than 10 percent of solar PV farm. The visibility percentage of solar PV farm of each UPRN can be found in Annex 3.

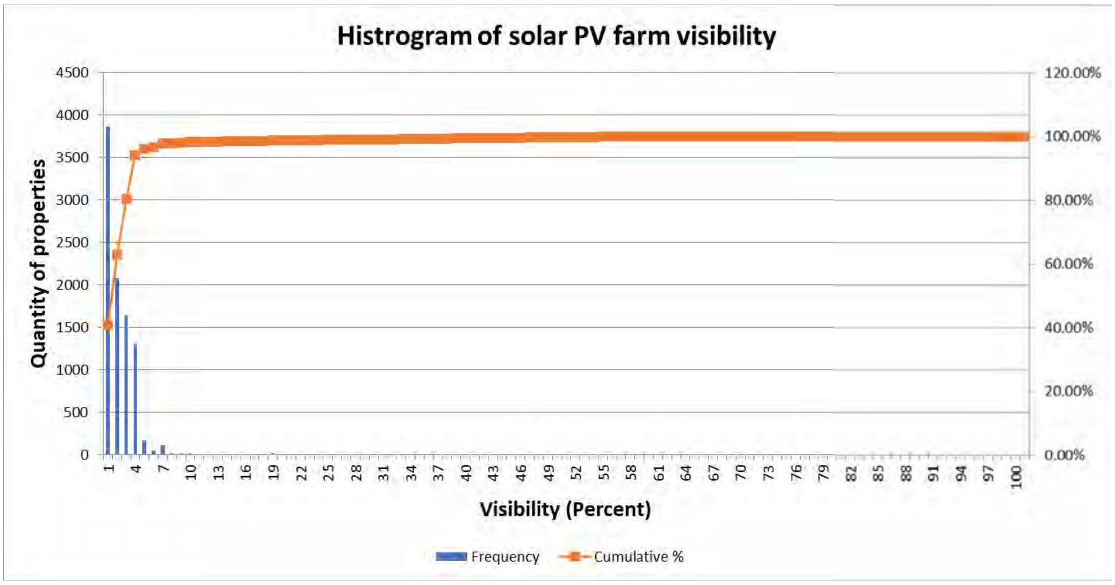


Figure 30. *Histogram of solar PV farm visibility. Source: IC2023 Team.*

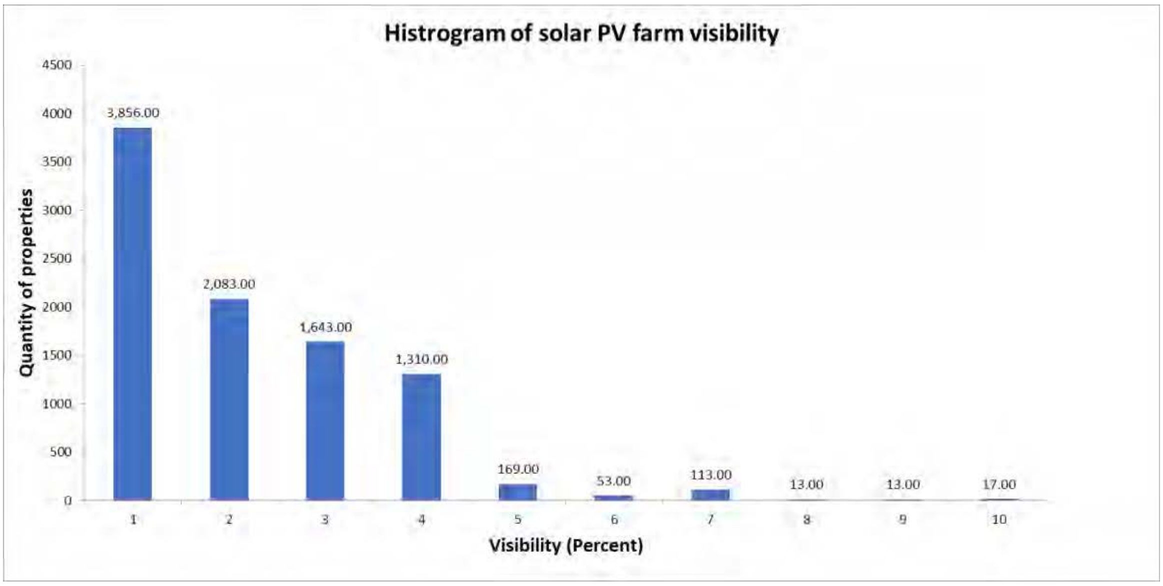


Figure 31. *Histogram of solar PV farm visibility (1-10%). Source: IC2023 Team.*

10. UK Energy market

To determine the optimal solution to produce revenues for this project, a study of the UK's energy market was done. The UK electricity market has undergone significant reform in recent years, with the most significant changes in 2013. These reforms were designed to address several challenges facing the industry. The purpose of these reforms was to increase competition in the power sector, increase investment in renewable energy and ensure the security of supply. The reform was based on four key areas, as shown in Figure 32 (Jinqi Liu, 2022). Two of the four areas are relevant to our project and will be further explained below. A comparison table between all options is summarised in a table at the end of this chapter.

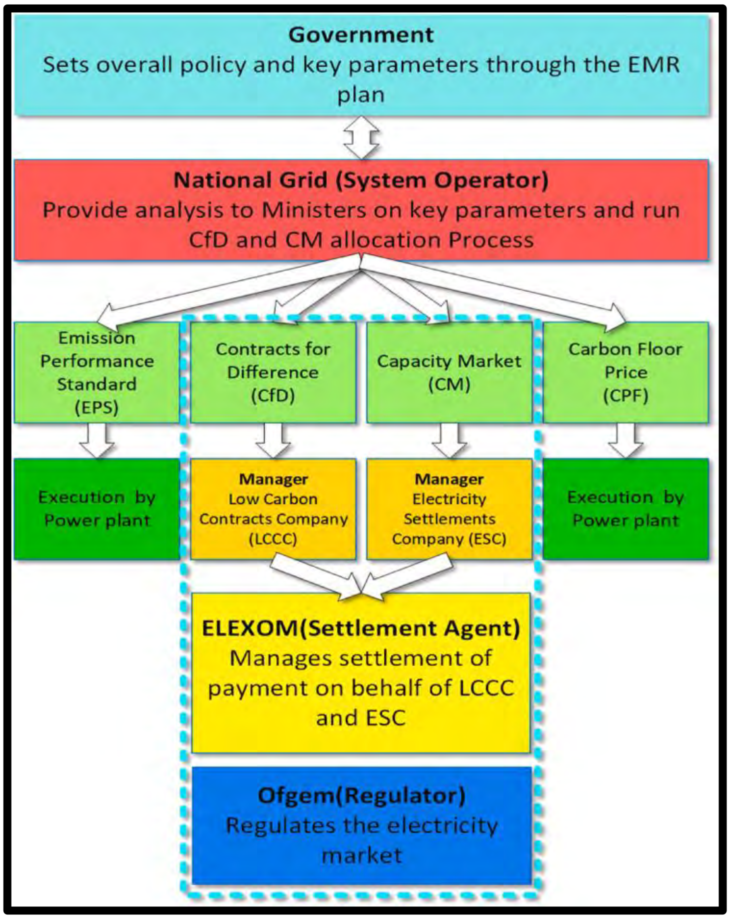


Figure 32: *Electricity Market Reform Mechanism. Source: Jinqi Liu, 2022*

10.1. Contracts for Difference (CfD) Contract

One of the most significant changes in 2013 was the introduction of a new system of Contracts for difference (CfDs). This system allows renewable energy developers to receive a guaranteed price for their electricity, which is designed to encourage investment in low-carbon technologies. This is particularly important given the UK's commitment to reducing its carbon emissions in line with the Paris Climate Agreement. A CfD is a contract between an electricity generator and a Low Carbon Contracts Company (LCCC). The purpose of this contract is to ensure that the revenue of generators is stabilised at an agreed strike price during the contract period (EMR Settlement, 2022). The generator and LCCC agree on a strike price determined through an auction. The generator sells electricity in the market at a spot price. If that price is lower than the strike price, the LCCC will compensate the generator with the amount needed to reach the strike price as shown (blue shaded colour) in Figure 33. Similarly, if the spot price is higher than the Market price, the generator will pay back the revenue above the strike price as shown (red colour) in Figure 33.

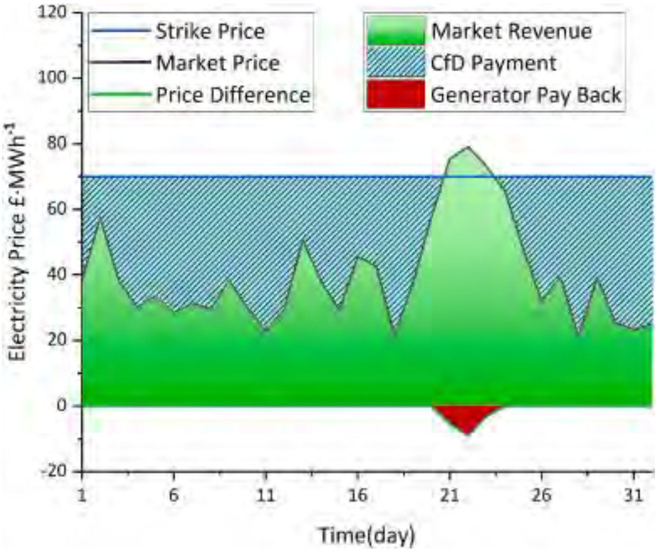


Figure 33. *CfD Mechanism. Source: Jinqi Liu, 2022*

10.2. Capacity Market

This market allows electricity generators to bid for contracts to supply a certain amount of electricity at a set price to ensure sufficient capacity is available to meet demand. This is particularly important given the growing share of intermittent renewable energy sources, such as wind and solar, which can be difficult to predict. This will encourage the investment needed to replace older power stations and provide backup for more intermittent and inflexible low-carbon generation sources (Low Carbon Contracts Company, 2022). There are three types of agreements that are available through this market: 1 year for existing projects, 3 years for generators in need of refurbishment, and 15 years for building new generation plants. This market incentivises investment only in the technologies that are dispatchable as a backup capacity to meet system security needs when there is a tight supply and demand situation. Although solar power plants can participate in this market, their revenue depends on the De-rating factor. De-rating factor helps to meet the Government's Reliability Standard by determining the contribution of each technology in meeting the system security needs. (EMR Delivery Body, 2022). For Solar, wind, and Storage technologies, National Grid ESO conducts power system modelling to determine the De-rating factor of each technology and publishes it each year. The de-rating factor of Solar & Wind and Storage is shown in Table 10 and

Figure ***34*** respectively.

Table E1 – CM De-Rating Factors Proposed for Duration-Limited Storage Class in the 2018/19 T-1 and the 2021/22 T-4 Auctions		
Final De-Ratings Per Duration in Hours	"2018/19"	"2021/22"
Storage Duration: 0.5h	21.34%	17.89%
Storage Duration: 1h	40.41%	36.44%
Storage Duration: 1.5h	55.95%	52.28%
Storage Duration: 2h	68.05%	64.79%
Storage Duration: 2.5h	77.27%	75.47%
Storage Duration: 3h	82.63%	82.03%
Storage Duration: 3.5h	85.74%	85.74%
Storage Duration: 4h +	96.11%	96.11%

Figure 34. *De-Rating factor for Storage technologies. Source:* (National Grid ESO, 2022)

Table 10. *De-Rating factor for Solar & Wind. Source:* (National Grid ESO, 2022)

Target Year	Onshore Wind	Offshore Wind	Solar PV
T-1 2020/21	8.98%	14.65%	1.17%
T-3 2022/23	8.40%	12.89%	1.76%
T-4 2023/24	8.20%	12.11%	1.56%

The government conducts auctions for the Capacity market. The auction price highly depends on the number of technologies participating in the market each year and the government target for the capacity. Therefore, the auction prices are quite volatile.

10.3. Spot Market (day-ahead and balancing market)

The spot market comprises of day-ahead (DA) and a balancing market. In the DA market, the bids are collected one day before the delivery, while in the balancing market, the delivery is in 30-minute intervals on the same day. The energy can be sold both in the DA and balancing market. The spot market is characterised by price volatility, and the price is set by the marginal generator which in the case of the UK is usually the gas power plants. The spot market is one of the avenues where Solar PV plants can sell electricity. However, solar generation is highest during the noon when the demand is comparatively low and thus spot prices are also lower as seen in Figure 35. The figure shows that the prices are highest during the evening demand peak when solar production also diminishes.

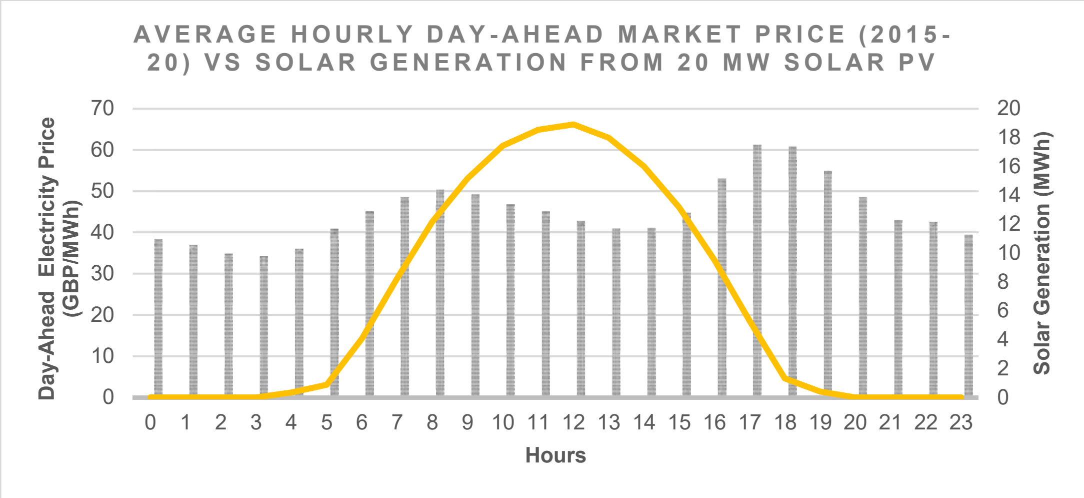


Figure 35. *Day-ahead Market Price vs Solar generation during a summer day. Source:* (Open Power System Data, 2023)*, IC2023 Team*

But this drawback of Solar PV can be overcome by co-locating it with Battery Energy Storage System (BESS) and creating an opportunity for energy arbitrage.

10.4. Energy Arbitrage (Day-ahead & Balancing Market)

Energy Arbitrage is storing the electricity when the prices are lower and then dispatching electricity when prices are high. As the renewable energy share will increase in the future, there will be a greater requirement to match supply and demand. It also means dispatchable power plants like coal or gas will operate for fewer hours and need to recover their costs in those hours. That means prices will be very high in some hours and there will be greater price volatility. This trend has started to appear in the UK, as shown in Figure 36. The graph shows the number of days with a price spread of more than £ 55 and EUR 60 for the UK and German markets respectively. In 2022, almost all days had a price spread greater than £ 55. Although that could probably be due to high gas prices in Europe, the overall trend indicates more price volatility and that means more opportunity for energy arbitrage.

Figure 36. *Price Spread in the Day-ahead market in the UK and Germany. Source: Tion Renewables, 2022*

This trend will create opportunities for BESS to provide flexibility by matching supply and demand. This also means that a greater share of the revenue for BESS will come from the energy arbitrage. To generate revenues from energy arbitrage, optimisation modeling is required, considering different parameters like optimal cycle rates, ideal depth of discharge (DOD), rate of deterioration, and most importantly electricity market prices (Weforum.org, 2022). It requires experienced asset managers who can optimise battery operations to maximise revenue through state-of-the-art algorithms.

The revenue stream of BESS also depends on the storage duration. Shorter duration batteries can draw revenues from the ancillary services market optimally as they can take advantage of fluctuating frequency of the grid, but they are not suitable to earn revenues from the capacity market and energy arbitrage. The relation between battery duration and the most suitable revenue option is conceptualised in Figure 37. The long-duration batteries have the advantage of earning revenue from all three different markets, but it also requires higher investment and battery optimisation modelling. Selection of the most suitable duration for BESS will require detailed battery revenue modelling.

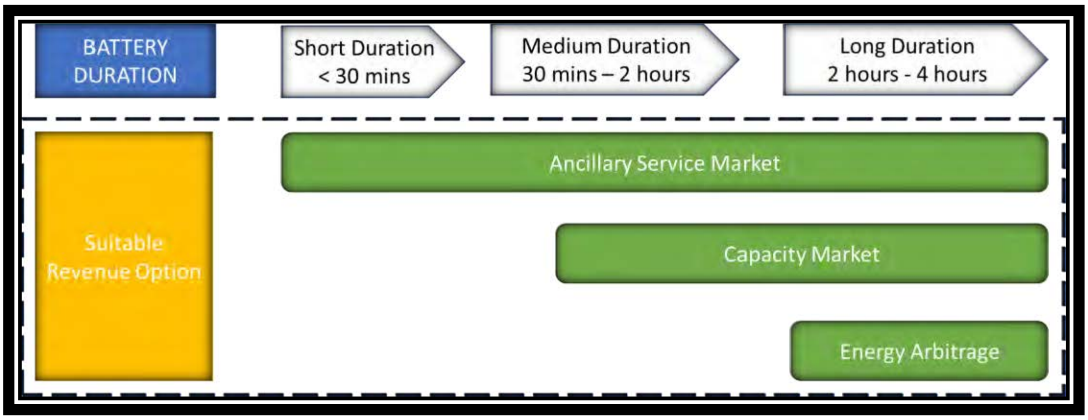


***Figure 37**. Relation between Revenue Option & Battery Duration. Source: IC2023 Team*

10.5. Ancillary Service Market

Ancillary services or Frequency response services are a set of operational services whose role is to ensure the reliable and secure operation of the power grid (IRENA, 2020). In the UK electricity market, three kinds of Frequency response services were introduced recently. National Grid ESO acquires three types of services, namely Dynamic Containment, Dynamic Moderation, and Dynamic Regulation (NationalGrid ESO, 2022), which are obtained through auctions. These services have distinct technical criteria, as illustrated in Figure 38.

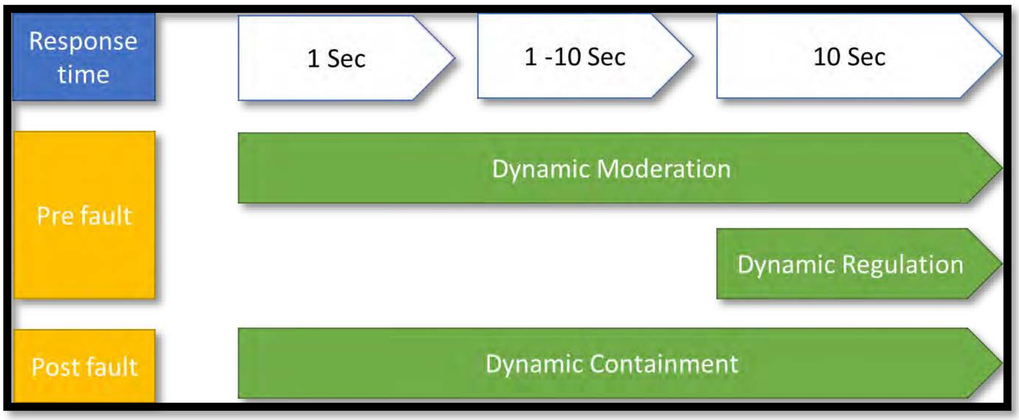


***Figure 38**. Types of frequency response services.*
Source: (National Grid ESO, 2022), *IC2023 Team*

In the past years, most of the revenues generated by battery energy storage systems (BESS) came from ancillary services in the UK. But according to Timera Energy, the market for ancillary services has started to saturate, and as more BESS products will come online in the near future, their revenues are at risk of dropping.

10.6. Power Purchase Agreements PPA

According to Prospero, 2022, there are many kinds of PPA's including virtual, physical, sleeved, blocked delivery, etc. Below is a brief description of each. The PPA suggested for this project is described further in subsequent sections (chapter 11.3) (Prospero, 2022).

- **Physical PPA**

In this configuration, the independent power producer (IPP), meets the buyer's demand directly through a physical grid that is built for such PPA.

Table 11. *Types of PPA. Source: (Prospero Events Group 2022)*

Offsite PPA	As the name suggests, the renewable energy power plant, in our case, the PV plant, is not at the site of the buyer. Meaning, the power provider agrees to transport power physically or through grids to the buyer's site.
On-Site	The power producer (PV plant) is close to the buyer's site. Most on-site PPAs are corporate PPAs. For instance, a big buyer such as Amazon might have its On-site power plant to cover its demand directly.
Portfolio PPA	The idea of a portfolio power purchase agreement (PPA) is often attractive to a company that wants to buy renewable energy from various projects in different regions across the country. For instance, companies like McDonald's or Apple have numerous branches in different locations, and instead of entering 10 separate PPAs, they will have one covering all the locations.

- **Virtual PPA**

The Independent Power Producer (IPP) generates electrical power, but rather than constructing physical cables to connect the buyer with the IPP, the electricity is transmitted via the grid. The energy generated by the IPP is injected into the grid, and the buyer obtains their required electricity from the grid as well. As a result, there is no need for new grid infrastructure or cable lines to be built specifically from the IPP to the buyer. (Prospero Events Group 2022).

A comparison of all options discussed above is summarised below in ***Table 12*** according to the contracting party, procurement process, and type of income.

Table 12. *Summary of Revenue Options from Solar PV and BESS. Source: IC2023 Team*

Revenue Option	Contracting Party	Procurement Process	Income Type
Spot Market (Day-Ahead & IntraDay Market)	Market Participant	Trading in Market	Variable
Contracts-for-Difference (CfD)	Low Carbon Contracts Company (LCCC)	Auctions	Fixed
Capacity Market	Electricity Settlements Company	Auctions	Fixed
Balancing Market	National Grid ESO	Trading in Market	Variable
Power Purchase Agreement	Corporate Company	Contract	Fixed
Frequency Response Services	National Grid ESO	Auctions, Day-ahead market	Variable

11. Financial Analysis

11.1. Financial parameters

To determine the value of the project as well as the equity and debt structure of financing, a cash flow model providing the following financial parameters was constructed:

- Discounted Cashflow calculation determining NPV (Net Present Value).
- CFADS (Cash Flow Available for Debt Service) and Debt Service (repayment and interest)
- DSCR (Debt Service Cover Ratios), IRR (Internal Rate of Return), WACC (Weighted Average Cost of Capital)
- Graphical representation of the cash flow available to shareholders (dividends)

In simple terms, the cash flow constructed follows the below structure:

(1)Turnover/revenue – (Operating costs +Taxes) = CFADS

(2) CFADS – Interest – Repayment = Cash flow available for shareholders

The parameters mentioned above indicate the financial viability of the project. Therefore, it is crucial to provide a brief description of each parameter and establish the benchmark for determining whether the project is a good investment. It is worth noting that the financial viability of a solar project cannot be determined solely by one parameter. This is the reason, it is essential to consider all the parameters listed below in Table 13 when comparing various revenue streams, as elaborated on in the results section.

Table 13. *Financial Metrics that determine the revenue ability of an RE project. Source: (FHWA, 2023)*

Metric	Abbreviation	Description	Criteria
IRR	Internal Rate of Return	is the rate that makes the net present value (NPV) of a project zero.	Should be higher than the Weighted average of capital cost. And higher than the hurdle rate of the project.
WACC*	Weighted Average of Capital cost	is the average rate that a business pays to finance its assets. It is calculated by averaging the rate of all the company's sources of capital (both debt and equity), weighted by the proportion of each component. (Weighted average cost of capital 2020)	IRR should be higher than the WACC to ensure profit.

Metric	Abbreviation	Description	Criteria
ADSCR	Average Annual Debt Service Cover Ratio	The revenues should always be higher than the costs of the project. ADSCR that exceeds 1.0 offers a safety net against unfavourable events that could take place throughout the project's lifespan.	Generally, the minimum required ADSCR is 1.15 to 1.2 for low-risk projects and between 1.5-2 for high-risk projects.
DSCR	Debt Service Cover Ratio	Similar to ADSCR except that it is not the average annual along the entire lifetime, but it is the annual actual ratio of a specific year.	Monitoring this value is crucial to ensure that the project generates revenue that exceeds its costs, thereby enabling the annual repayment of the debt.

*Weighted Average cost of Capital (WACC)

The weighted average cost of capital (WACC) for a firm is a discount rate used to determine the present value of all capital providers, considering the costs of debt and equity, as well as the tax benefits of interest and the company's capital structure. The WACC is calculated using a formula expressed as follows:

$$WACC = \left(\frac{E}{V}.R_e\right) + \frac{D}{V}.R_d(1 - T_c) \qquad \text{Equation 9}$$

Where,

Table 14. *Parameters to calculate WACC*

Description		Value			Source
E		Equity			
D		Debt			
V		Equity + Debt			
$\frac{E}{V}$	Cost of Equity	Solar PV	Battery storage	Solar PV + Storage	IC 2023 Team
		30%	50%	35%	
R_e	weight of equity	0.925			CAPM method

<table>
<tr><th colspan="2">Description</th><th colspan="3">Value</th><th>Source</th></tr>
<tr><td rowspan="2">$\frac{D}{V}$</td><td rowspan="2">Cost of Debt</td><td>Solar PV</td><td>Battery storage</td><td>Solar PV + Storage</td><td rowspan="2">IC 2023 Team</td></tr>
<tr><td>70%</td><td>50%</td><td>65%</td></tr>
<tr><td>R_d</td><td>Weight of Debt</td><td colspan="3">3%</td><td>Bank of England</td></tr>
<tr><td>T_c</td><td>Tax rate</td><td colspan="3">25%</td><td>Gov.uk</td></tr>
</table>

The cost of equity (a part of the WACC equation) was calculated at **9.25%,** and the Capital Asset Price Model (CAPM) formula was used:

$$E(r_e) = r_f + \beta.(E(r_m) - r_f) \qquad \text{Equation 10}$$

Table 15. *Parameters to calculate CAPM*

Description		Value	Source
r_f	Risk-free rate	4%	Bank of England
β	Beta of the investment	0.86	(European Comission, 2022)
$(E(r_m) - r_f)$	Market risk premium	6.10%	(Business Valuation Resources, 2022), (Statista, 2022)

It is also important to list down parameters that impact the financial model and the viability of the project (***Table 16***). They should be carefully considered.

Table 16. *Parameters that impact the financial model*

Parameter	Comment	Value considered
Inflation	The 1998-2023 average inflate rate was considered taken from the UK government's official records (Source: Office for national statistics)	2.7%
Interest Rate	This heavily varies depending on the type of bank. Some banks incentivise community projects by offering a lower interest rate.	3%
Corporate Tax Rate	According to governmental regulations, companies with a revenue of more than 50,000 pounds fall under the 25% tax rate. However, for this project, a 0% tax is considered since it is a community benefit society project.	0%

Future project finance trends and their effect on debt-equity ratio

In April 2019, the United Kingdom discontinued the feed-in-tariff (FIT) program for new applicants. The elimination of subsidies will have an impact on the volume and stability of future cash flows from renewable energy projects since market-price risk would rise for both equity and loan providers. That leads to opting for PPA scheme at a fixed price which is usually lower than the guaranteed price levels during the FIT regime. Therefore, the project is exposed to market price risk rather than performance risk. Figure 39 demonstrates the market price and fixed PPA trend, which is prone to affect the debt-equity ratio in the future. Regarding this research, we adjusted the debt-equity ratio accordingly.

In comparison with contracts for difference (CFDs), PPA provides a stable revenue stream. Since they guarantee a fixed price for the energy produced over a certain period. On the other hand, CFDs are dependent on market price, subject to fluctuations that can affect the project profitability.

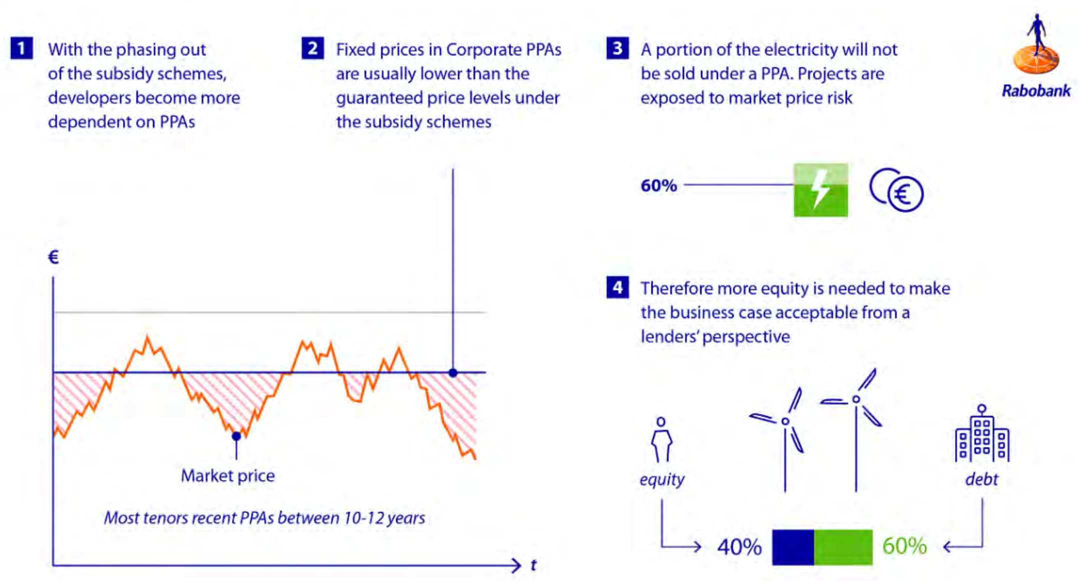


Figure 39. *Effect of subsidy regimes on renewable energy project finance. Source: (RaboResearch - Economic Research 2023)*

11.2. Cost of solar PV plant

A comparative analysis of two technologies—one with a tracking system and the other without—was performed to make an informed economic decision on the best way to mount solar panels. Solar panels with tracking systems cost 16% more than that of the fixed structure CAPEX (Danish Energy Agency, 2022), bringing the project's total cost to 16,072,540.73 GBP, which is 2,225,428.72 GBP more than a fixed structure. The cost of installing the panels without the tracking system is 13,847,112.02 GBP. The annex 4 contains information about the equipment and its cost.

The OPEX for the fixed mounting system for the solar PV plant is estimated at 297,190.38 GBP (IRENA, 2022). The OPEX for the tracking system is 318,230.40 GBP which is 7% higher than the fixed mounting system (Danish Energy Agency, 2022). Details of the OPEX are provided in the annex 4.

11.3. Revenue options from Solar energy PPA

A widely-used revenue option for a solar power plant is a conventional solar PPA contract. The suggested PPA type for this project is a flexible PPA. This means that whatever amount of energy is generated, is sold for a fixed price per MWh produced annually. To make it easier to get a loan. The duration of the PPA should be between 12 to 15 years and should be related to the loan period. After the contract expires, a new PPA can be renegotiated based on current prices, or the energy can be sold on the spot market. According to the Pexapark database, a renewable energy advisory company specialised in PPA transactions, the average price for Great Britain for 2022 can be seen in Figure 40.

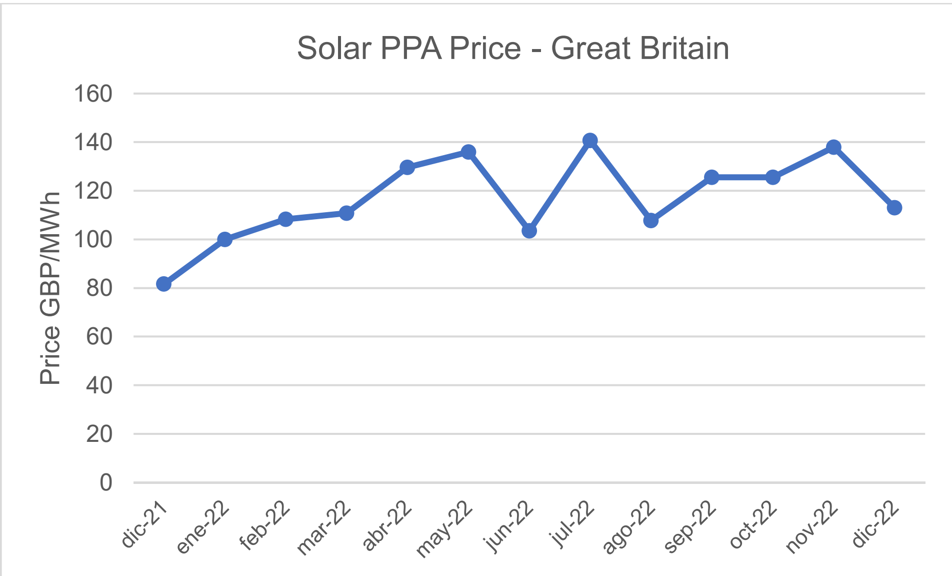


***Figure 40**. Solar PPA Price for Great Britain. Source: (Pexapark 2022)*

For the fixed mounting system solar PV plant, as indicated in chapter 11.2, the investment is GBP 13,847,112 with annual operating costs of GBP 297,190. Based on the financial parameters presented in Table 16 and assuming a cost of connection to the grid of GBP 450,000 and a debt of 70% of the investment cost (WACC of 4,87% according to Table

14), the following financial results are obtained for the project at different PPA prices, as shown in Table 17.

Table 17. *Net Present Value and IRR for Solar PV with a fixed structure. Source: IC2023 Team*

PPA Price (£/MWh)	IRR	NPV (£ million)
55	5.71%	1.16
60	6.83%	3.58
65	7.87%	5.55
70	8.87%	7.51

Therefore considering a debt of 70% of the investment (GBP 10,007,978) with a maturity loan of 15 years at an interest rate of 3%, it is possible to obtain the following cash flow during the 25 years of project operation in the scenario when de PPA Price is 65 (£/MWh), as shown in Figure 41. Further analysis is provided in chapter 11.5, where a comparison with other technical solutions, such as using a tracking system, is made and some sensitivity analyses are developed.

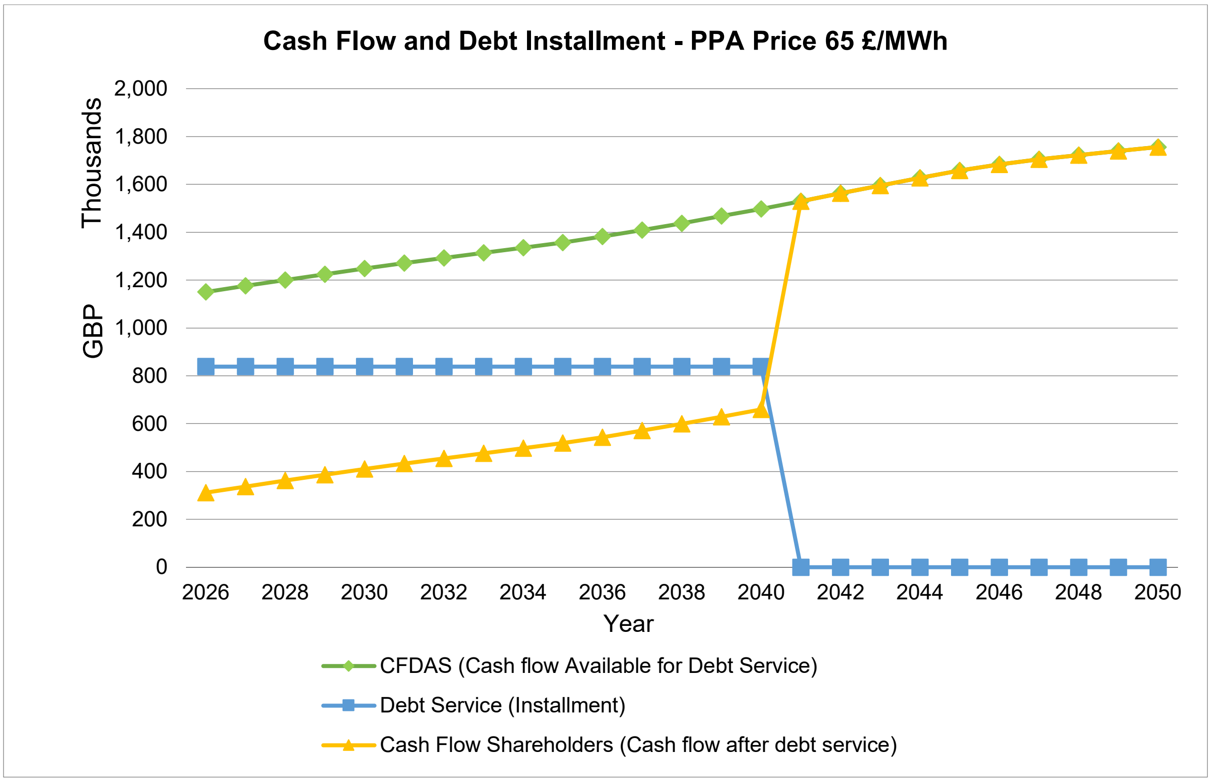


Figure 41. *Cashflow and debt service for Solar PV Fixed Structure. Source: IC2023 Team*

For this financial analysis, it is assumed that a PPA would be in place for the 25-year lifetime of the project. However, it is important to note that under general energy market conditions, these contracts tend to have a duration between 10 to 15 years, so when this term ends it would be necessary to renew the PPA and renegotiate its conditions, analysing the conditions of the energy market at that moment.

11.4. Battery Energy Storage Systems BESS Market Opportunities

As described in chapter 10.3, solar generation is highest during the noon when the wholesale electricity prices are lower. With an increase in the share of renewable energy sources, particularly solar, in the system, prices during the day will continue to decrease. Therefore the capture price of Solar will remain lower than the baseload PPA price. However, the Battery Energy Storage System (BESS) could provide an answer to this dilemma by generating revenues by storing electricity when the prices are lower and then selling the electricity back to the grid; when its most needed, meaning during the period of high prices. That's why we considered BESS as the second technology option for generating revenue by co-locating Solar PV with BESS. Solar PV and BESS can complement each other, with electricity from solar PV being sold through a long-term PPA that generates stable cash flow income for 12-15 years depending on the contract type and BESS can generate revenues from Capacity Market and Energy arbitrage. An overview of the revenue streams for this project is conceptualised in Figure 42.

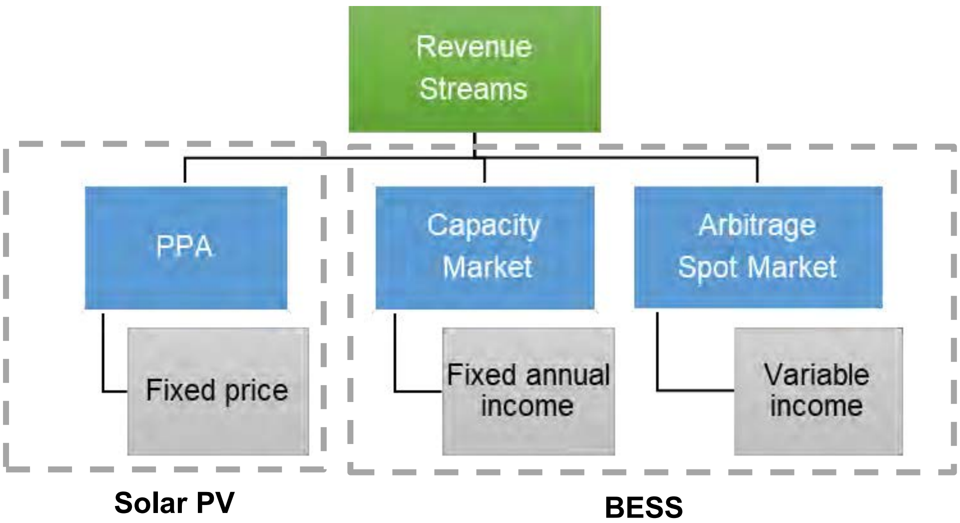


Figure 42. *Revenue streams are considered for solar PV and BESS combined projects. Source: IC2023 Team*

11.4.1. Price Forecasting Methodology

As previously discussed, maximising revenue from Battery Energy Storage Systems (BESS) requires a comprehensive optimisation of the battery asset. To achieve this, future price development must be considered in the optimisation model. This is because the increasing penetration of variable renewable energy generation in the electricity system is expected to result in a greater daily spread of wholesale electricity prices. Such a daily spread of hourly electricity prices will have a direct impact on the profitability of BESS from energy arbitrage. Additionally, accurate estimation of the Power Purchase Agreement (PPA) price for Solar Photovoltaic (PV) will require consideration of future wholesale electricity prices. Hence, a price forecasting algorithm was built using linear regression to forecast future prices in hourly resolution.

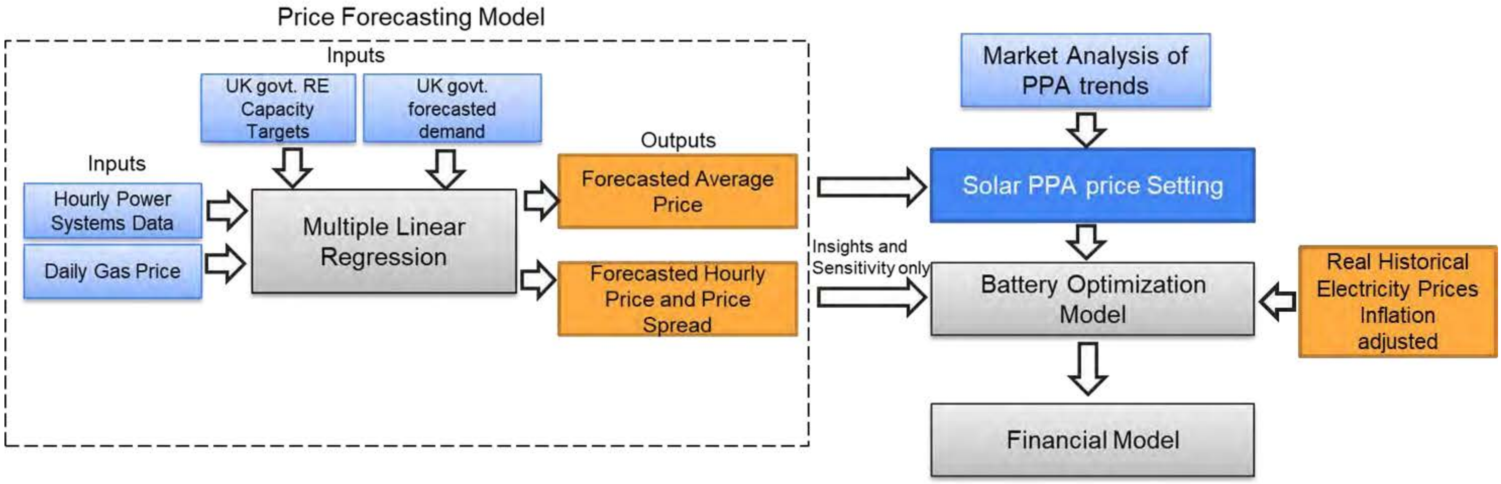


Figure 43. *Price Forecasting Model and its link to other parts of project. Source: IC2023 Team*

Figure 43 illustrates the methodology used for Price forecasting in this project and its interconnection with other parts of the project. The hourly power systems data and gas price data were used to construct a multiple linear regression model. This model was used to predict the future electricity average price, hourly price, and price spread by incorporating the UK government's renewable energy capacity targets and forecasted demand data. While the hourly electricity price and price spread generated useful insights, their results were not directly integrated into the Battery optimisation model due to the inability of forecasted hourly prices to capture actual price spikes. The average forecasted electricity price was used to benchmark the Solar PV PPA price, which was supplemented by the PPA market analysis. The gas dataset was obtained from the National Grid website (National Gas Transmission UK, 2023). The UK wholesale electricity market's hourly price data from 2015 to 2020 was obtained from the open power systems data website, which included hourly price, actual load, and solar and wind generation at each hour (Open Power System Data, 2023). The residual load for the whole UK was calculated from this data using the following equation.

$$Residual\ Load\ (MW) = Load(MW) - Solar\ Gen.(MW) - Wind\ Gen.(MW)$$

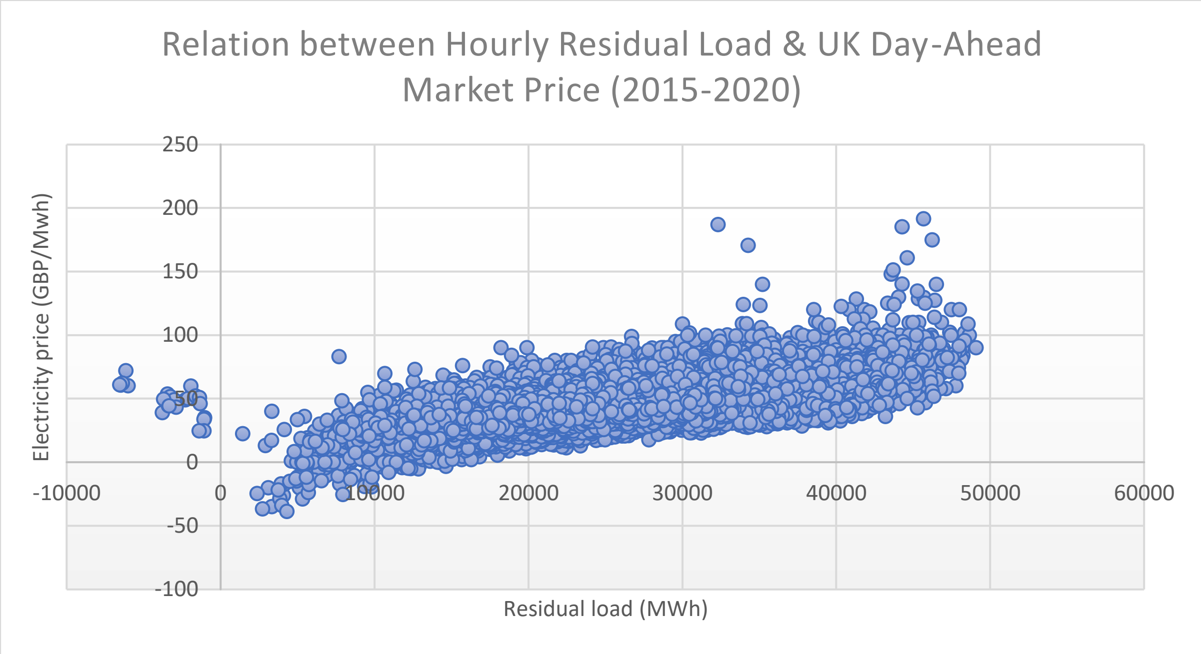


Figure 44. *Graph between Residual Load & UK Day-ahead Market Price. Illustration: IC2023 Team, Source: (open-power-system-data.org, 2023)*

The relationship between residual load and electricity prices has been observed to be proportional as depicted in Figure 44. The increase in residual load leads to an increase in electricity prices, and similarly, a decrease in residual load leads to a decrease in electricity prices. This is primarily attributed to the marginal cost of production for wind and solar plants, which is close to zero, leading to a decrease in wholesale market prices. The negative prices could occur when the generation from solar and wind (including renewable energy transmission from interconnectors) is higher than the demand. Additionally, even for similar residual loads, there is a variation in electricity prices, which could be explained by fluctuations in gas prices. In the UK electricity market, gas power plants act as peaking plants, setting the marginal price of electricity in the market. Therefore, the correlation between gas prices and electricity prices was also explored by using a 7-day rolling average of gas prices and average daily electricity prices as shown in Figure 45. The results indicate that the average daily electricity price is proportional to gas prices. It is worth mentioning here that the below graph shows only daily variation and the hourly variation in electricity prices is influenced by factors such as load, solar, and wind generation, which cannot be explained by constant gas prices throughout the day.

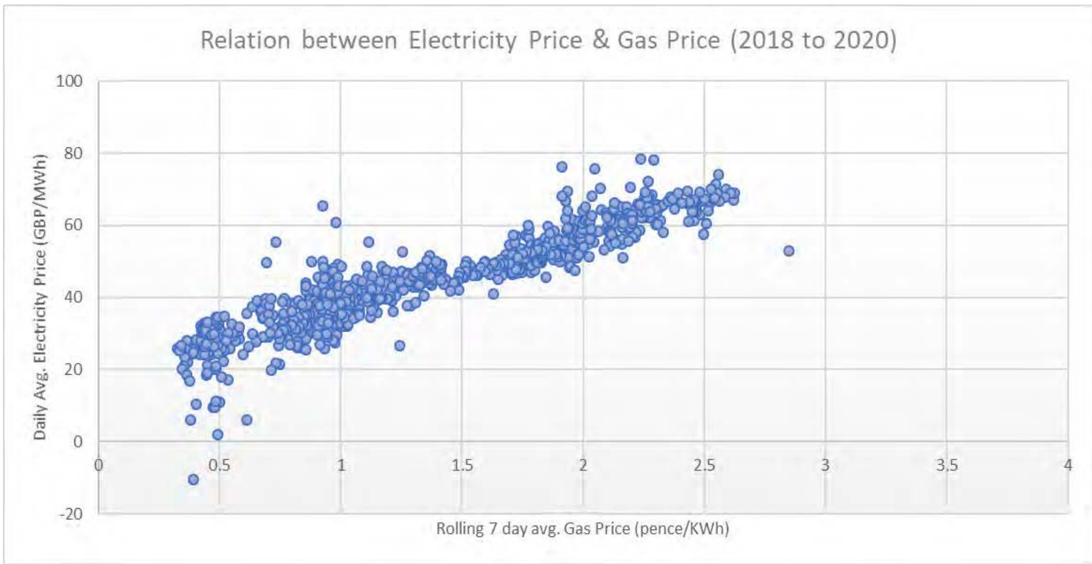


Figure 45. *Graph between Daily Avg. Electricity Price and Gas Price. Illustration: IC2023 Team, Source: (open-power-system-data.org, 2023) & (National Gas Transmission UK, 2023)*

From the preliminary analysis of data, the regression model was created based on load, solar and wind generation, and gas prices as shown in Equation 11.

$$Electricity\ Price \approx 0.000913 * Total\ Load + 1.346 * Gas\ Price - 0.00126 * Solar\ generation - 0.00131 * Wind\ generation$$

Equation 11. Equation for price forecasting based on linear regression

Where,

$Electricity\ Price\ is\ in \frac{GBP}{MWh}\ at\ Hour\ (h)$

$Total\ Load\ in\ MWh\ at\ Hour\ (h)$

$Total\ Solar\ generation\ in\ MWh\ at\ hour\ (h)$

$Total\ Wind\ generation\ in\ MWh\ at\ hour\ (h)$

$Gas\ price\ in\ GBP/MWh\ at\ hour\ (h)$

The regression model gave an R-square value of 0.67, which means 67% of the data points could be explained by the Equation 11.

Data for future price projection

To project future energy prices, it is, therefore, necessary to identify, with the best available information, how the variables defined in Equation 11 will behave, i.e. it is necessary to identify what will be the Total load, Gas prices, Solar generation, and Wind generation. To do this, the Future Energy Scenarios (FES) defined for the UK are used as a reference source, which represents a range of different and credible ways to decarbonise the energy system in the UK to strive towards the 2050 target (National Grid ESO, 2022). For this forecast methodology Electricity Supply Data (National Grid ESO, 2022) for the "Falling Short Scenario (FSS)" was used, which represents the slowest decarbonising scenario. The FSS scenario although conservative provided many realistic capacities of Solar and wind plants. The other scenarios were found to be more ambitious, targeting huge addition in Solar and Wind capacities, primarily due to increased demand for Electric Vehicles (EV) and hydrogen production.

From where the estimated target values for the installed capacity of both solar and wind generation at the end of each year [MW], as well as the total demand per year [TWh], can be obtained. This information is obtained for the years 2025, 2030, and 2035 to be used as a reference for the forecast, as shown in **Table 18**.

Table 18. *Renewable energy targets capacity and demand FSS. Source: (National Grid ESO, 2022)*

	Falling Short Scenario		
YEAR	Solar installed capacity [MW]	Wind installed Capacity [MW]	Demand [TWh]
2025	9,800	22,235	308
2030	11,944	45,436	327
2035	17,831	61,652	374

Total load forecast

Based on the historical hourly load data for the year 2019 (Open Power System Data, 2023), a load profile is calculated, which is subsequently multiplied by the total annual demand projected for the years to be analysed (2025, 2030, and 2035).

Equation 12 is used to forecast the demand in the hour *h* for year i.

$$Hourly\_demand_i(h)[MWh] = Load\_profile(h)[p.u] * Total\_demand_i[MWh]$$

Equation 12. Hourly demand forecast

Solar and wind generation forecast

In the same manner that a load profile was constructed based on 2019 data, hourly solar, and wind generation profiles are generated and their capacity factor is calculated. Using these profiles and the installed capacity from Table 18, Equation 13 is used to determine the generation in hour *h* for each year $i,$ for both solar and wind generation.

$$Generation_i(MWh) = Generation_{profile(h)[p.u]} * InstalledCapacity(MW)$$

Equation 13. Hourly solar generation forecast

Insights and Limitations of the Price forecast model

The price forecast model provides a reasonable explanation of the daily trends and average electricity prices; however, it is not capable of capturing price spikes as shown in Figure 46. This observation suggests that the relationship between residual load, (that incorporates load, solar, and wind generation) and electricity prices are non-linear. This behaviour is similar to the actual merit-order-based market behaviour, where different technologies are used for peaking at various times of the day. However, due to limitations of time and scope, exploration of the non-linear relationship in detail was not possible. The electricity market is complex, and when interconnections with other countries are considered, it becomes increasingly difficult to forecast accurate prices.

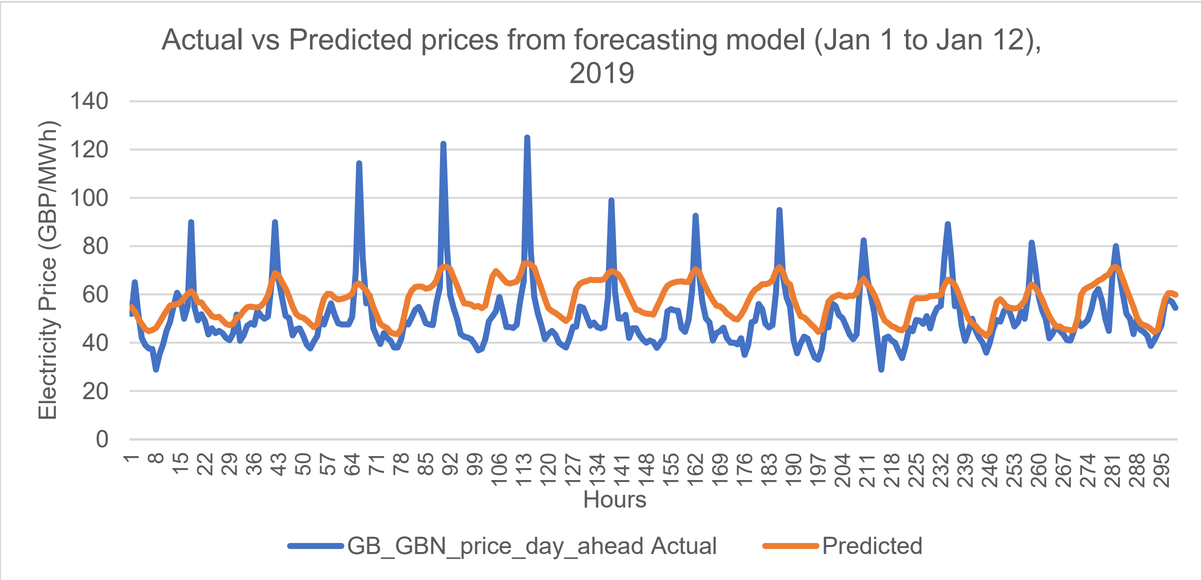


Figure 46. *Actual vs Predicted 2019 Electricity Prices. Source: IC2023 Team*

Nonetheless, the model remains useful for observing long-term trends and analysing whether electricity prices are likely to increase or decrease. According to the forecast, the average wholesale electricity prices are predicted to decrease by 14% between 2025 and 2035, while the annual standard deviation in prices will increase by 73% during the same period. This suggests that there will be a greater need for flexible assets in the future, making a stronger case for Battery Energy Storage Systems (BESS) to generate revenue through energy arbitrage. The model forecasted average electricity prices for the years 2025, 2030, and 2035 as shown in Table 19, assuming a constant gas price of 20 £/MWh and 40 £/MWh for all three years in two different scenarios.

Table 19. *Forecasted Electricity prices for 2025, 2030, and 2035. Source: IC2023 Team*

Years		2025	2030	2035
Electricity Price (£/MWh)	Gas price assumed 20£/MWh	68.66	61.01	59.08
Electricity Price (£/MWh)	Gas price assumed 40£/MWh	102.37	94.72	92.79
Annual Standard Deviation of Hourly Prices (£)		9.34	12.63	16.13

11.4.2. Battery Optimisation Modelling

As previously discussed, Battery Energy Storage Systems (BESS) can generate revenue from various markets. However, for this particular project, only two revenue sources were considered: energy arbitrage from the UK Day-ahead Market and the Capacity Market. The Frequency Response Service (FRS) market was excluded from consideration as it is not possible to combine FRS revenues with energy arbitrage. This is because the BESS asset is utilised for regulating frequency continuously in the FRS market, whereas energy arbitrage involves charging and discharging the battery based on market prices, which may conflict with the requirements of the FRS market.

The regression model used for price forecasting was found to be inadequate for capturing the true revenue potential of Battery Energy Storage Systems (BESS), as it was unable to capture true peaks. Therefore, it was used for sensitivity analysis only. The real inflation-adjusted UK Day-Ahead market prices of 2017, 2018, and 2019 were used to estimate revenues. The optimisation model was created on Pyomo, which is an open-source optimisation modelling language based on Python. The objective of the optimisation model was to maximise profits by determining when to charge and discharge the battery while considering factors such as depth of discharge (DOD), battery life cycle, and the costs associated with battery degradation while charging and discharging. The forecasting algorithm selected the charge and discharge time with perfect foresight of the day-ahead electricity market prices. Figure 47 shows the overview of how the optimisation problem is set in Pyomo.

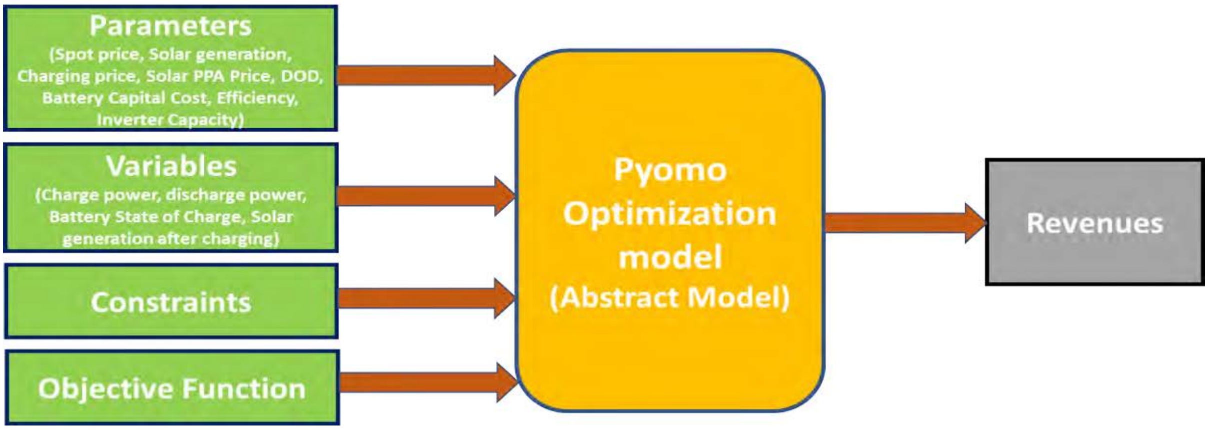


Figure 47. *Overview of Pyomo Optimisation model. Source: IC2023 Team*

The following parameters were used to optimise the BESS.

Model Parameters

$Price_{spot(h)}$; Spot Price at a certain hour (h)

$Solar_{gen(h)}$; Solar Generation at a certain hour (h)

η *:* Battery round-trip efficiency

The total BESS Capital cost is given by the following equation. This cost has been estimated by NREL for Utility-Scale BESS projects for the year 2022. (NREL Utility-Scale Battery Storage, 2022).

$$Total\ System\ Cost\ (\$/kW) = Battery\ Energy\ Cost\ (\$/kWh) * Storage\ Duration\ (hr) + Battery\ Power\ Cost\ (\$/kW)$$

Where,

$Battery\ Energy\ Cost\ (\$/kWh)$ = 224 USD/Kwh

$Battery\ Power\ Cost\ (\$/kW)$ = 221 USD/KW

Model Variables

SOC: battery State of Charge at a certain hour (h)

$P_{c\ (h)}$: battery Charge power at a certain hour (h)

$P_{d\ (h)}$: battery Discharge power at a certain hour (h*)*

C(h): battery cost per hour *h* (£/h)

$P_{c\_solar\ (h)}$: battery charge power from solar (MWh)

$Solar_{gen(ppa)}$: remaining solar generation for PPA after charging the battery at an hour (h) MWh

Model Constraints

Equation *14* constrains the SOC with an upper and lower bound. The upper bound is defined by a maximum battery capacity. The lower bound is defined by a minimum storage level based on an adjustable maximum DOD. The maximum DOD for this was selected to be 90%, after doing the sensitivity analysis of revenue at different DOD. Also, discharging a battery to full capacity can shorten its useful life (Lindon, 1995). The functional relationship between cycle life (CL) and depth of discharge (DOD) for a typical lithium-ion battery can be given by the following equation (Mallon et al. 2017).

CL = β0 × DOD−β1 × exp (β2(1 − DOD)

Where,

β0 = 2731.7, β1 = 0.679 and β2 = 1.614

At the beginning of optimisation, the battery State of Charge is assigned to be in the following order.

$$SOC_{min} \leq SOC_h \leq SOC_{max} \qquad \text{Equation 14}$$

Where,

SOC_{min} = Maximum Depth of Discharge

SOC_{max} = Maximum battery capacity

SOC_h = State of Charge during the hour (h)

Battery capacity at an hour h is defined as the sum of capacity at the previous hour, charging power from the grid, and charging power from solar PV minus the discharge power, which mathematically can be defined as:

$$SOC_h = SOC_{h-1} + P_{c(h-1)}\,\eta + P_{c(solar)}\,\eta - \frac{P_{d(h-1)}}{\eta}$$

Where,

SOC_{h-1} : battery capacity during the hour (h-1)

$P_{c(h-1)}$: Battery charge power during the hour (h-1)

$P_{d(h-1)}$: Battery discharge power during the hour (h-1)

To make sure that battery charge power from solar is not greater than the solar PV generation at that particular hour *h*

$$P_{c(solar)} \leq Solar_{gen(h)}$$

It is ensured in the model that the charging power of the battery remains within the limit.

$$P_c \leq SOC_{max} - \frac{SOC_{h-1}}{\eta}$$

Similarly, the discharge power does not cross the minimum limit of the battery capacity.

$$P_d \leq SOC_{h-1} - SOC_{min}\,\eta$$

It is also essential that the battery can be charged or discharged more than the maximum inverter power capacity.

$$P_c\,(h) \leq P_{max}$$

$$P_d\,(h) \leq P_{max}$$

To calculate the remaining solar generation for PPA after deducting the energy to charge the battery.

$$Solar_{gen(ppa)} = Solar_{gen(h)} - P_{c(solar)}$$

The cost per hour of charging and discharging the battery is also incorporated in the model, which is gotten by the following equation (Pedro Luis Camuñas García-Miguel, 2022).

$$C(h) = RUL_{fade}\,.Cost_{rep}$$

The RUL is the remaining useful life of the battery that is calculated each hour and multiplied by the replacement cost of the battery. The RUL is given by the following equation,

$$\frac{d\,RUL_h}{dh} = \frac{C\,(P_{c(h)} + P_{d(h)})}{2\,n_{cycles}\,SOC_{max}}$$

Where;

C (h): Cost of use during hour h (£).

$RUL_{\text{fade(h)}}$: Remaining useful life during the hour (h)

$Cost_{\text{rep}}$: Estimated replacement cost (£)

P_{max} : *Maximum battery power (MWh)*

$Solar_{gen(h))}$: Solar PV generation during the hour (h)

$\frac{d\,RUL_h}{dh}$: Battery remaining use of life during h hours

C : Capital cost (£)

n_{cycles}: Number of life cycles before reaching the end of life

Objective functions

Two objective functions are established for two different scenarios. In the first scenario, the model optimises the profit using only the spot price and charging the battery from the grid.

$$\text{Scenario 1 : } \sum_{i=1}^{h} \quad (P_{d(h)} \,.\, Price_{spot(h)} - P_{c(h)} \,.Price_{spot(h)} - C(h)\,)$$

The second scenario demonstrates the profit maximisation strategy by also charging from Solar PV whenever the model finds it profitable depending on the difference between the spot price and PPA price. Mathematically,

$$\text{Scenario 2 : } \sum_{i=1}^{h} \quad (Solar_{gen(ppa)}.Price_{ppa} + P_{d(h)} \,.\, Price_{spot(h)} - P_{c(h)} \,.Price_{spot(h)} - P_{c\_solar\,(h)}.Price_{ppa} - C(h)$$

Where,

$Price_{spot(h)}$: Electricity spot price during hour *h* (£/MWh)

$C(h)$: Battery cost per hour (£)

$Price_{ppa}$: Solar PPA price (£)

Results and Sensitivity analysis of BESS profitability

i) Relation between DOD and BESS profitability

The choice of depth of discharge is critical in utilising the true potential of BESS. On the one hand, lower DOD can result in an opportunity loss of not utilising it to its full potential by discharging it fully, and on the other hand, higher DOD could shorten the battery life. The cost of battery use per hour includes the cost associated with the degradation of the battery. To arrive at the most suitable DOD, a range of DOD values with different battery configurations were tested for the 2019 elec9tricity prices. The result shows that 90% of DOD yields maximum revenue as seen in **Figure 48**. The BESS with a 10 MW 1-hour duration proved more beneficial than the 5 MW 2 Hour configuration.

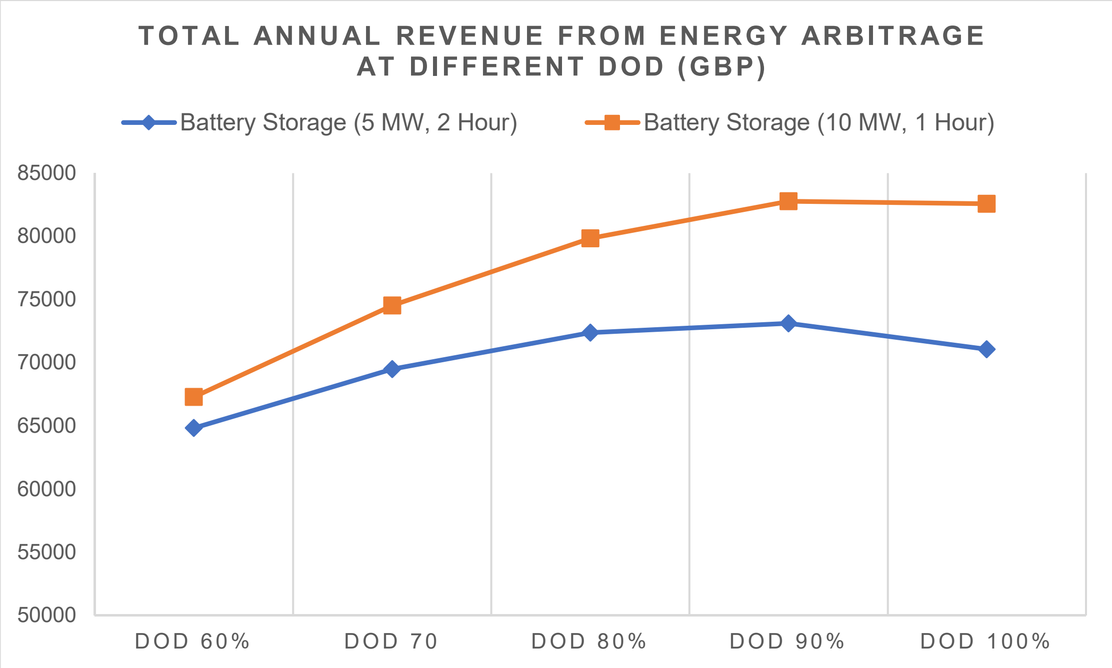


Figure 48. *Energy Arbitrage Revenues at different DOD. Source: IC2023 Team*

ii) Relationship between daily average price spread and Profit

The annual revenue from the energy arbitrage depends on the daily price spread of the Day-ahead electricity market. For the years 2017, 2018, and 2019, the daily average price spread was 31.8 £, 31.3 £, and 25 £ respectively. In all three years, revenue was directly proportional to the daily price spread. In the future, the price spread is expected to increase as the share of renewable energy in the system will increase. Because renewable energy plants have zero marginal cost of production and these plants will meet most of the electricity demand in the future.

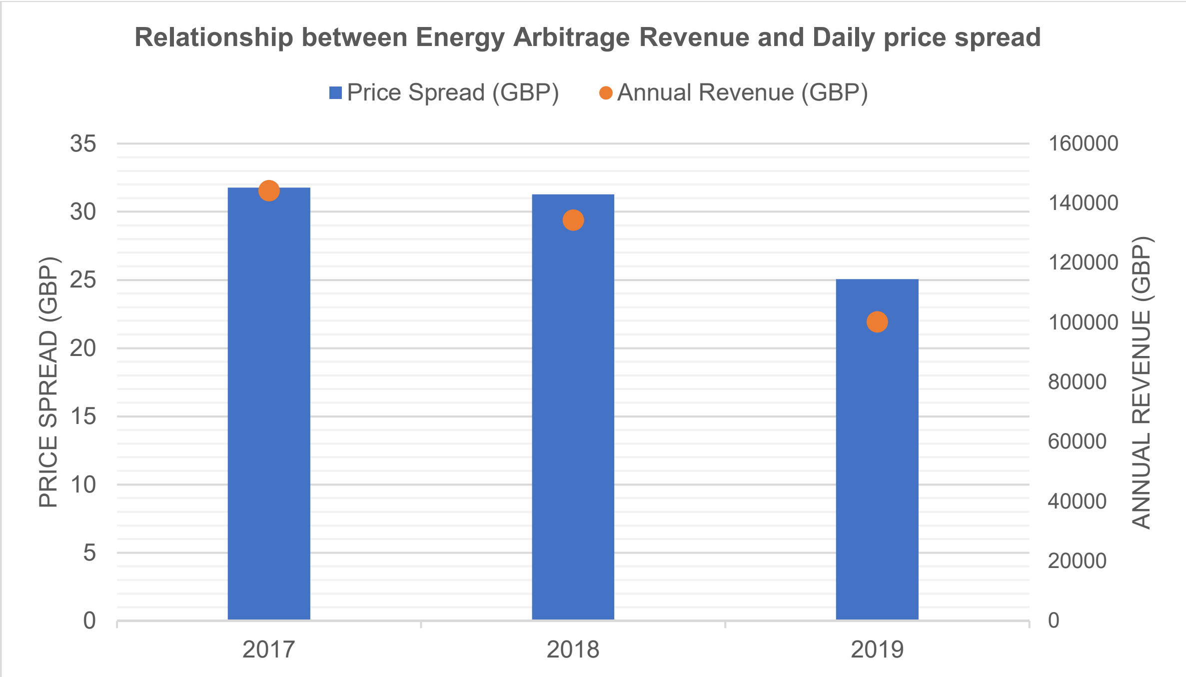


Figure 49. *Relation between Price Spread & Energy Arbitrage Revenue. Source: IC2023 Team*

As illustrated in Figure 49 in the previous section, the number of days with a price spread of more than 55 £ have drastically increased in the last few years. It can be interpreted that running the optimisation model using 2019 electricity prices will yield a very conservative estimate of revenues from energy arbitrage.

Therefore, a sensitivity analysis was carried out to see the effect of price spread on the expected IRR of different battery configurations. For this analysis, it was assumed that doubling the price spread will also double the revenue from energy arbitrage. The reason is that the cost per hour of discharging would remain the same as only the difference between charging and discharging price increases, not the number of cycles. This shows the expected IRR at different price spreads.

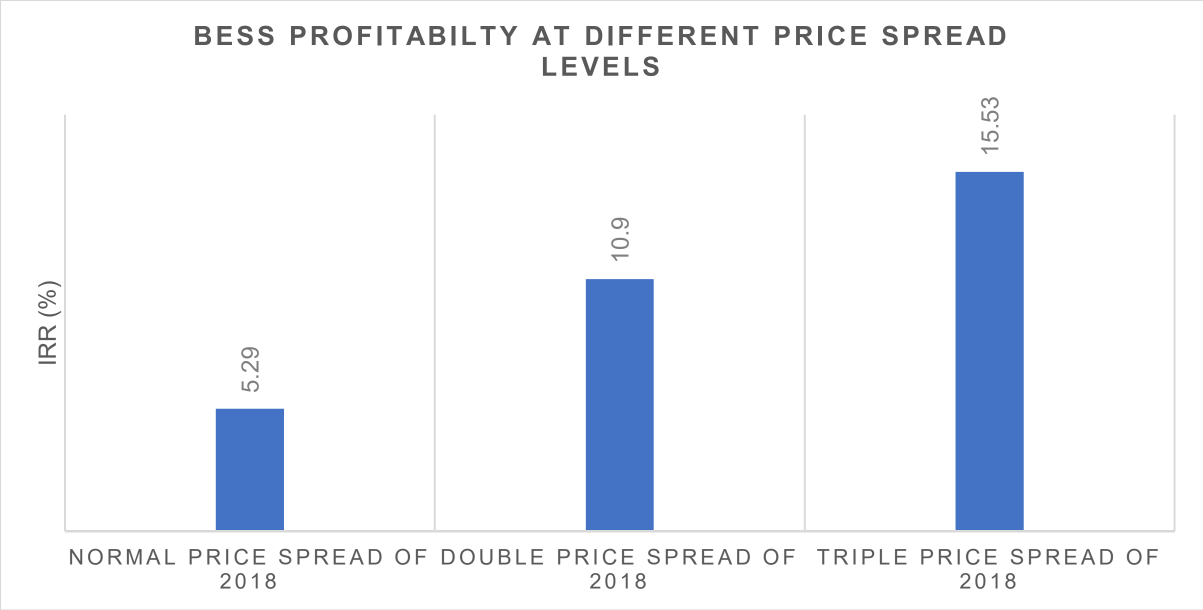


Figure 50. *BESS Profitability at different price spread levels at Debt Equity Ratio of 50:50. Source: IC2023 Team*

iii) Capacity Price Sensitivity Analysis

The capacity clearing price is quite volatile as seen in recent years. The last two T-1 capacity auctions resulted in very high clearing prices of 45 £/KW and 75 £/KW as shown in Figure 51. The latest T-1 capacity auction 2023/24 cleared at 60 £/KW (Reuters.com, 2023), and the T-4 capacity auction 2026/27 cleared at an auction price of 63 £/KW (EMRdeliverybody, 2023). For the base case, we assumed a Capacity price of 45 £/KW.

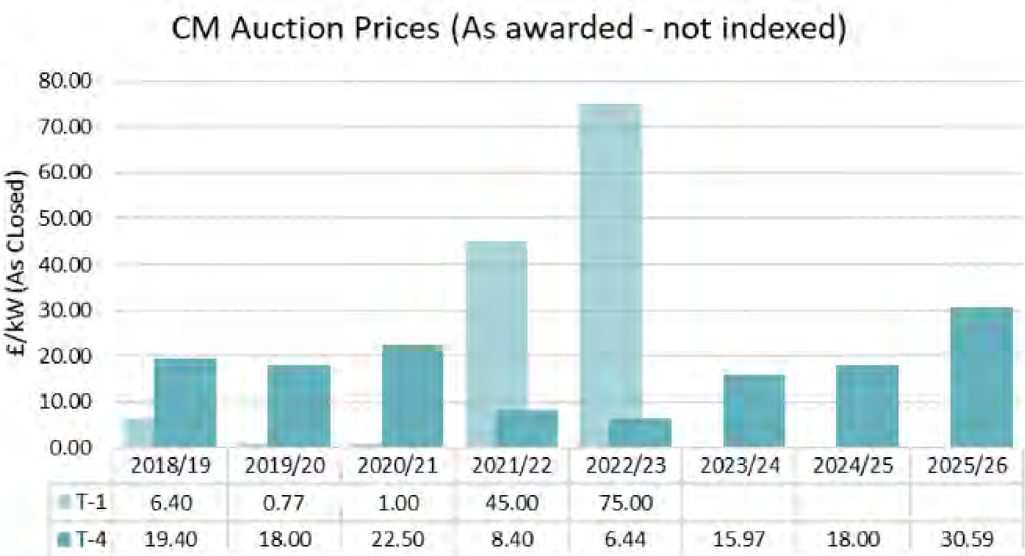


Figure 51. *CM UK Auction price. Source: EnAppSys, 2022*

The profitability of different BESS configurations was analysed at different capacity clearing prices. At 65 £/kW price, the IRR of 10 MW 1 Hour BESS surpassed the 15 MW 1 Hour. It yielded 8.46% IRR. At 45 £/KW price, the 5 MW 1 Hour, 5 MW 2 Hour, and 10 MW 1 hour yielded negative Net Present Value (NPV). Below 40 £/KW, all BESS configurations yielded negative Net Present Value (NPV), which means project earnings will not be profitable after discounting the cashflows. Implying that if the capacity auction clearing price stays below 40 £/KW, the revenues from energy arbitrage and the capacity market will not be enough to recover the investment cost of BESS. Then, BESS will have to seek alternate sources of revenue e.g from the Frequency response services market.

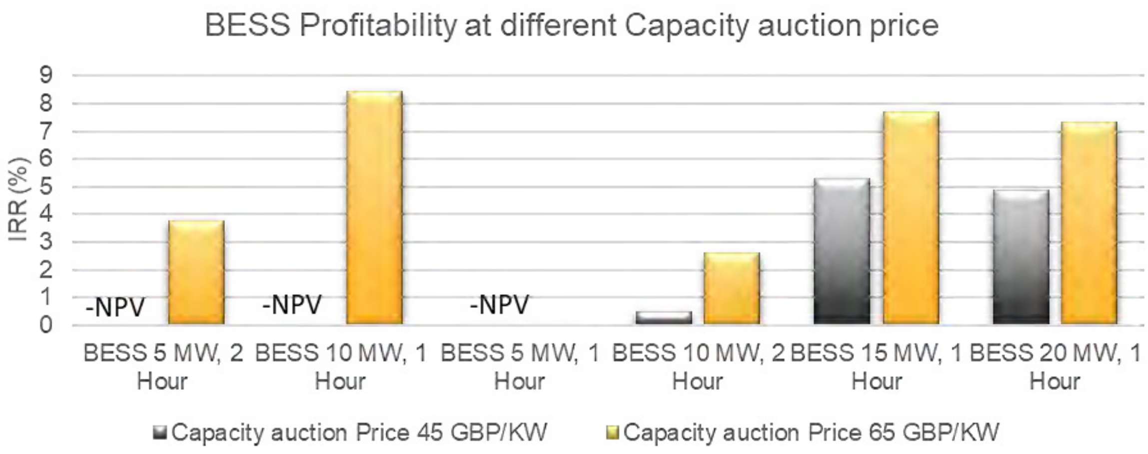


Figure 52. *BESS profitability at different Capacity auction prices. Source: IC2023 Team*

11.5. Results and Sensitivity Analysis

Based on the technical solutions presented in chapter 7.2 and the financial results obtained for these that were presented in chapter 11.2, four scenarios are defined. For these scenarios, some sensitivity analyses were performed to identify how some financial parameters may affect the feasibility and profitability of the project, as well as a comparison of the four scenarios.

The four technical solution scenarios are as follows:

- Scenario PV Fixed: Photovoltaic PV plant with a fixed structure
- Scenario PV Tracking: Photovoltaic PV plant with a single-axis tracking system
- Scenario BESS + PV Fixed: Integrated system of solar PV plant with a fixed structure and BESS 15MW / 15MWh
- Scenario BESS + PV Tracking: Integrated system of solar PV plant single-axis tracking system and BESS 15MW/15MWh

A summary of the initial required investment and annual operating costs for each scenario is presented below in Table 20.

Table 20. *Summary CAPEX and OPEX for different technology solutions*

Scenario	CAPEX (GBP)	OPEX (GBP)
PV Fixed	14,300,000	298,000
PV Tracking	16,520,000	320,000
BESS+PV fixed	19,840,000	298,000
BESS+PV tracking	22,070,000	329,000

11.5.1. Sensitivity analysis related to the cost of connection to the grid

Analysing *Scenario PV Fixed*, if a variation of the Grid Connection between £450,000 and £900,000 is considered, it can be noticed that there is no significant difference in the IRR of the project for different PPA prices, keeping other parameters fixed (interest rate of 3%, inflation 2.7% and equity of 30%), as shown in Figure 53. From this, it can be concluded that the cost of grid connection within these values does not have a significant impact on the return on investment. It is shown that by doubling the connection cost, the decrease in IRR is on average only 0.3%.

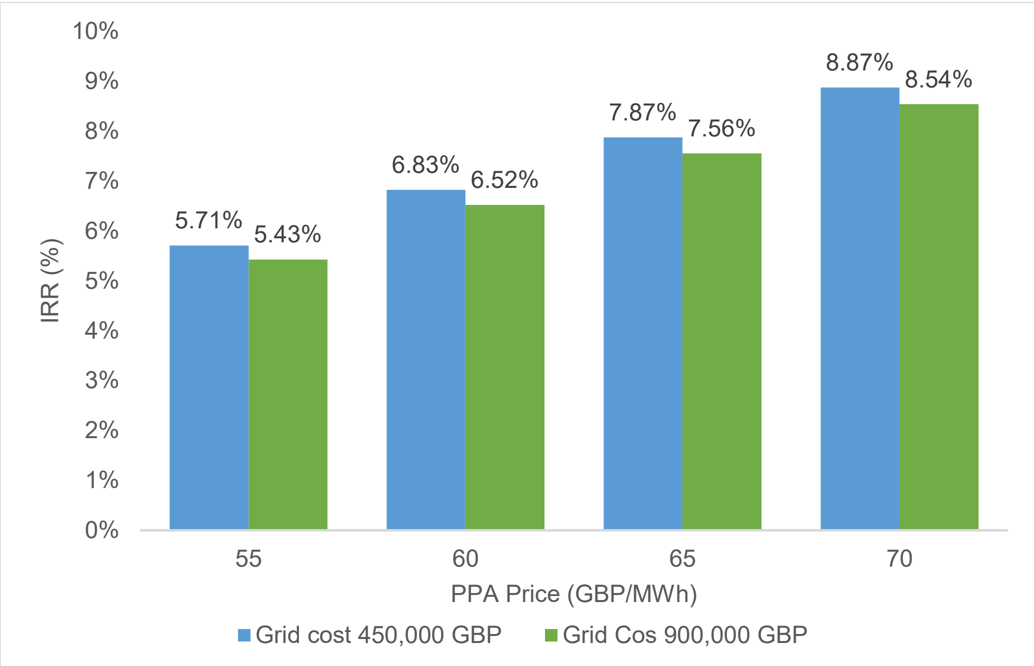


Figure 53. *Sensitivity of IRR for different Grid connection costs in PV Fixed. Source: IC2023 Team*

For the financial analysis realised for *Scenario PV Fixed*, an interest rate of 3% was considered with an equity of 30% and a maturity of 15 years, however, a sensitivity of the estimated WACC for this scenario is presented below in Figure 54. If the loan interest rates vary, all other parameters are held fixed (inflation 2.7%, equity 30%, grid connection cost £450,000, and assuming a PPA price of 60£/MWh). For this scenario, the estimated total investment is £14.3 million. It can be seen in Table 21 that for these different rates, the IRR is still higher than WACC, therefore despite the increase in interest rates, the project will still be profitable with a positive NPV.

Table 21. *Results from sensitivity of WACC at different interest rates Scenario PV Fixed. Source: IC 2023 Team*

Interest rate	Payback Period	WACC	IRR	NPV (£ million)
3.00%	14.92	4.87%	6.83%	3.58
4.00%	15.06	5.57%	6.83%	2.28
5.00%	16.32	6.27%	6.83%	1.12

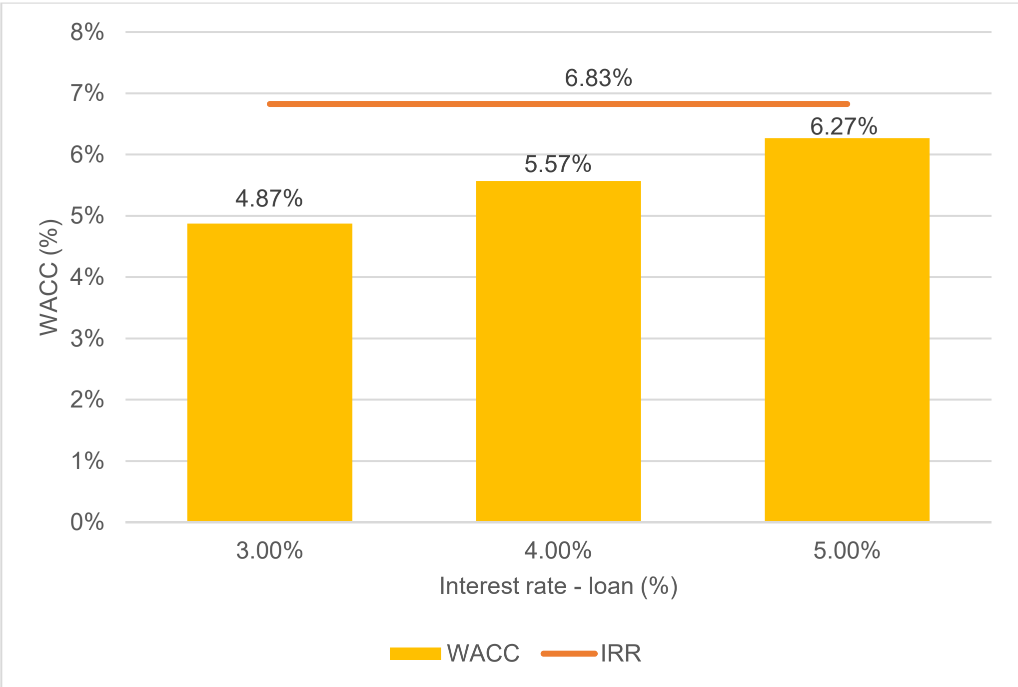


Figure 54. *Sensitivity of WACC for Scenario PV Fixed at different interest rates. Source: IC 2023 Team*

11.5.2. Sensitivity analysis related to the possible increase in CAPEX and OPEX

Since there are some parameters, from a financial and economic point of view, that may change between the time this analysis is performed and the actual date start of the project, as well as other contingencies that may arise at the time of construction, a sensitivity analysis of the impact of a 10% increase in the CAPEX and OPEX of the project on the IRR for the fixed structure Solar PV is performed considering different PPA prices. The results are presented in Figure 55, where it can be seen that with a PPA price of 55 £/MWh, the project becomes unprofitable as the IRR is better than the estimated WACC. For the other scenarios, despite the increase in initial investment and operating costs, the project still is considered profitable.

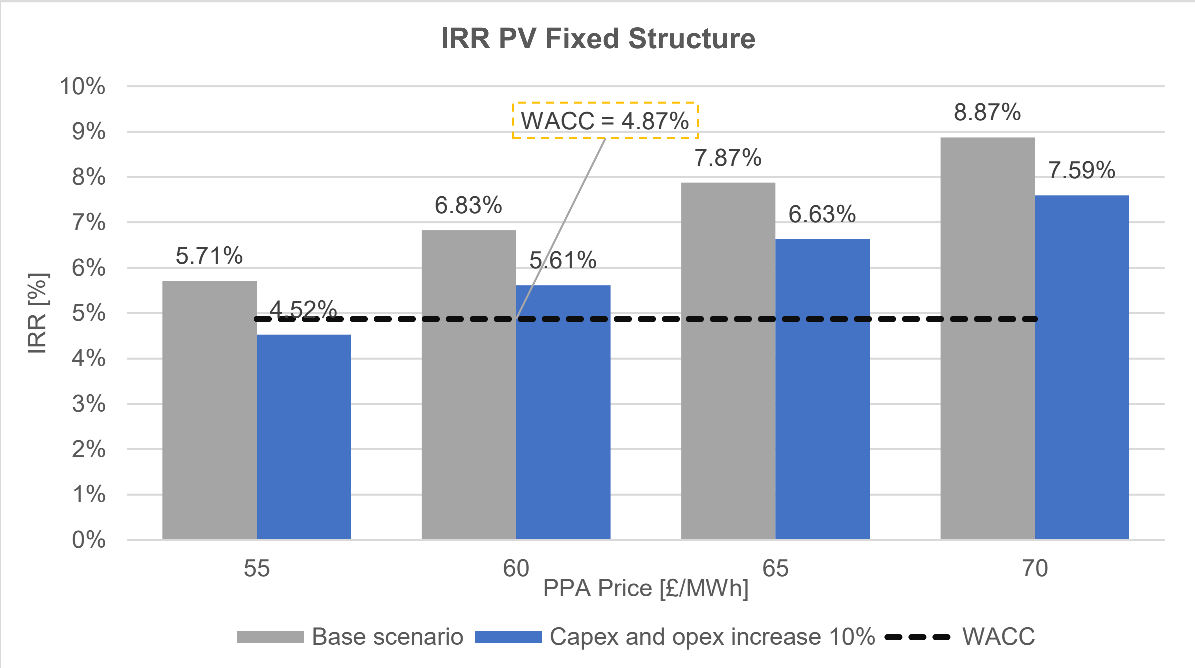


Figure 55. *Sensitivity analysis of IRR for PV Fixed for CAPEX and OPEX increase by 10%. Source: IC2023 Team*

In addition, Figure 56 provides a comparison between the average annual profits, during the first five years of project operation, that could be obtained for these same scenarios if the base case and a 10% increase in CAPEX and OPEX are considered.

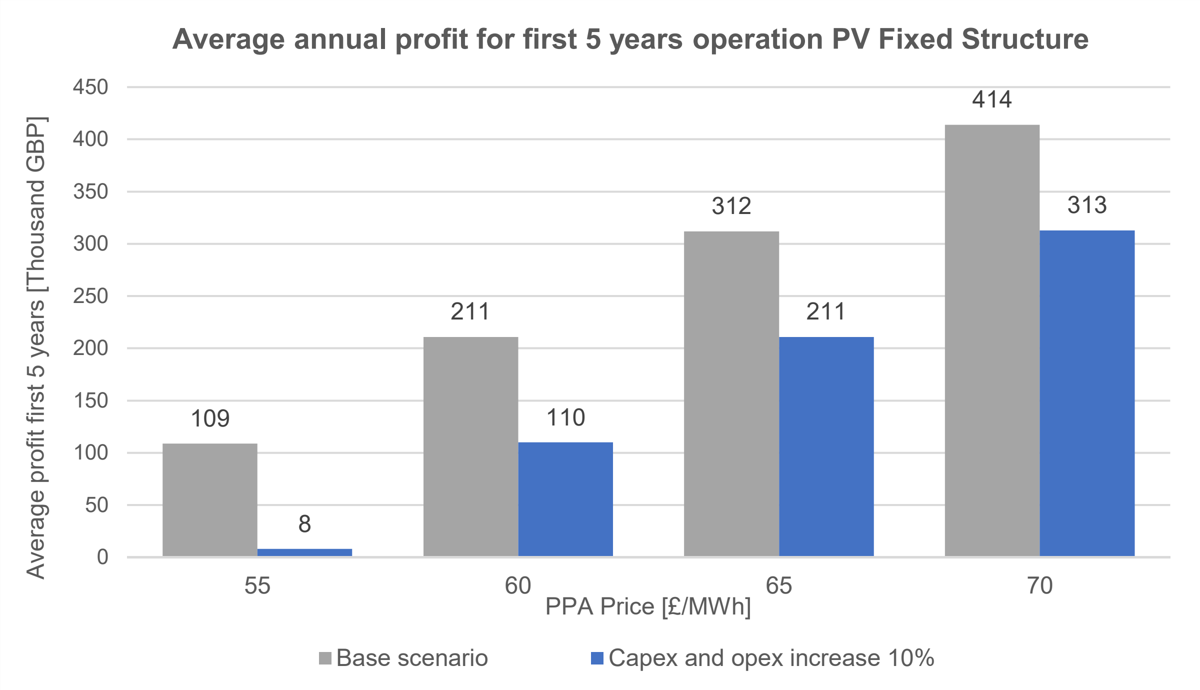


Figure 56. *Average annual profit for PV Solar Fixed for the first 5 years of operation. Source: IC2023 Team.*

11.5.3. Sensitivity analysis for different PPA Prices

The IRR results of the project for different PPA prices for all scenarios are presented in Figure 57 below. It can be seen that under current energy market conditions, the IRR is higher for the PV and BESS systems, in comparison with the solutions of only PV Solar plants when the PPA prices are lower than 60 £/MWh. However, it should be noted that this analysis is made assuming the daily average spread price of 2018, but as explained in Figure 50, as more renewable energy capacity enters the system, this value will continue to increase, therefore the IRR for the BESS could increase.

At a PPA price of less than 60£/MWh, the IRR for the integrated solution (BESS + Solar PV) are higher than the scenarios when only Solar PV is considered. This is because the optimisation model considers battery charging from the Solar PV solution as a result of the comparatively lower price of the spot market in certain hours.

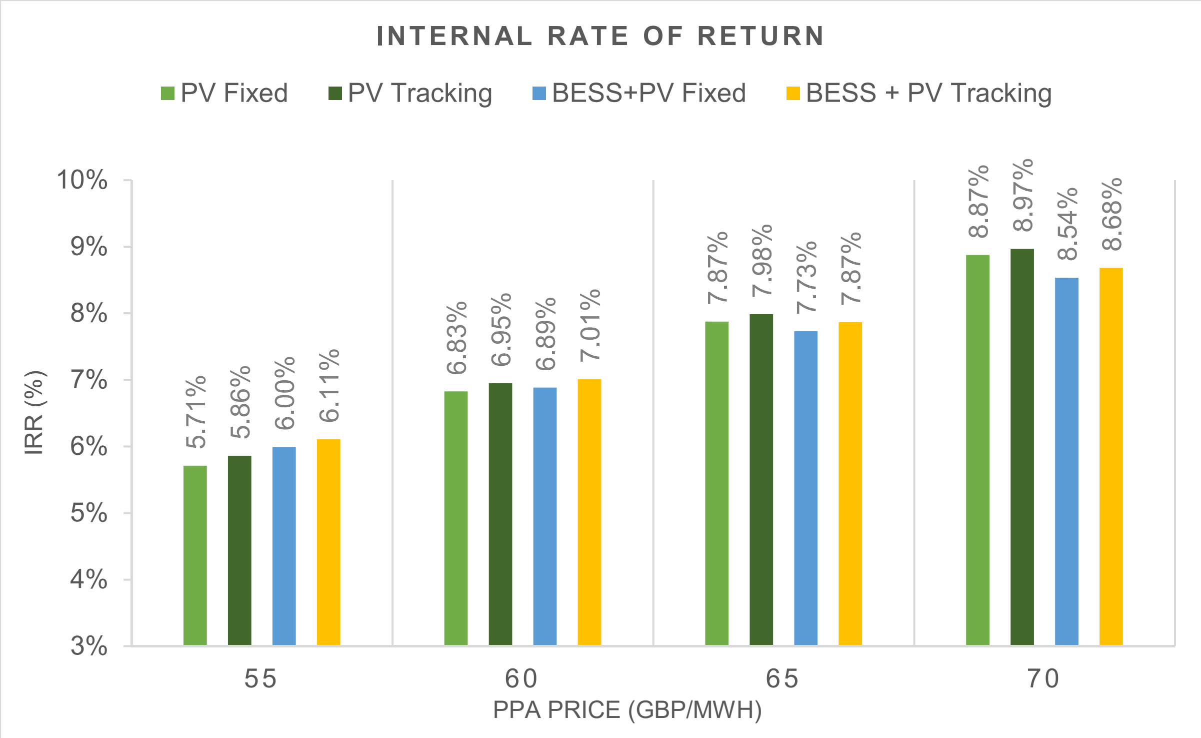


Figure 57. *Sensitivity of IRR for different PPA Prices. Source: IC 2023 Team*

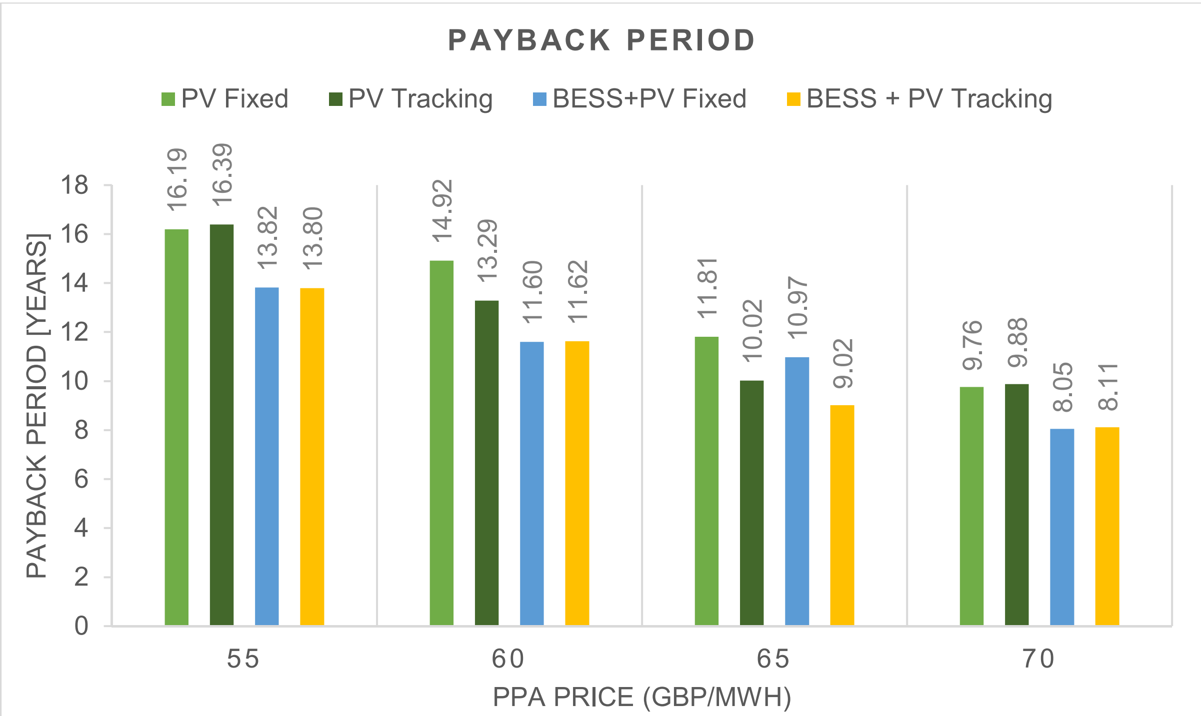


Figure *58* shows the comparison of the payback period for the four scenarios for different PPP prices. This payback period is calculated under the conditions of an interest rate of 3%, a loan maturity of 15 years, and an inflation rate of 2.7%.

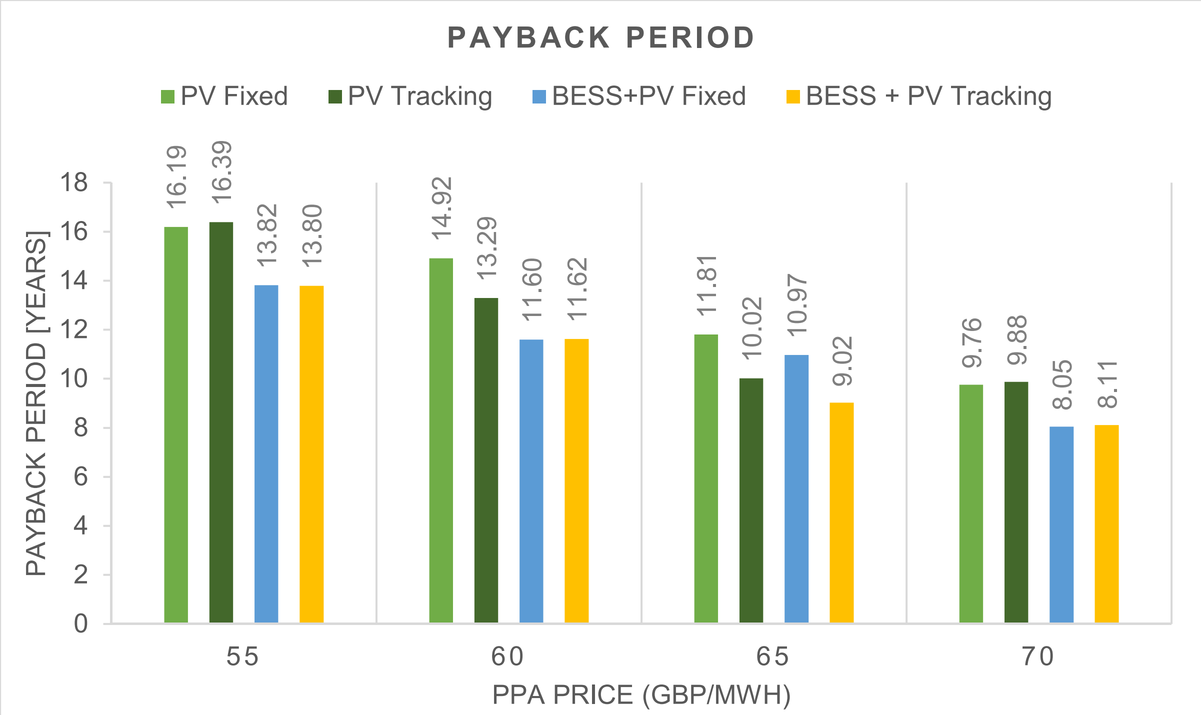


Figure 58. *Sensitivity of Payback Period for different PPA Prices. Source: IC 2023 Team*

11.5.4. Comparison of total investment and IRR at PPA Price

Table 22 shows the IRR and Payback period for each scenario assuming a PPA Price of 60£/MWh. This information is presented in graphical form in Figure 59.

Table 22. *Payback period and IRR at PPA Price of 60 £/MWh. Source: IC 2023 Team*

Scenario	PPA Price (£/MWh)	Equity (£ million)	Payback Period (years)	IRR (%)	NPV (£ million)
PV Fix 35°	60	4.42	14.92	6.83%	3.58
PV Tracking	60	4.96	13.29	6.95%	4.41
BESS+PV fix 35°	60	7.10	11.60	6.89%	3.91
BESS+PV tracking	60	7.72	11.62	7.01%	4.71

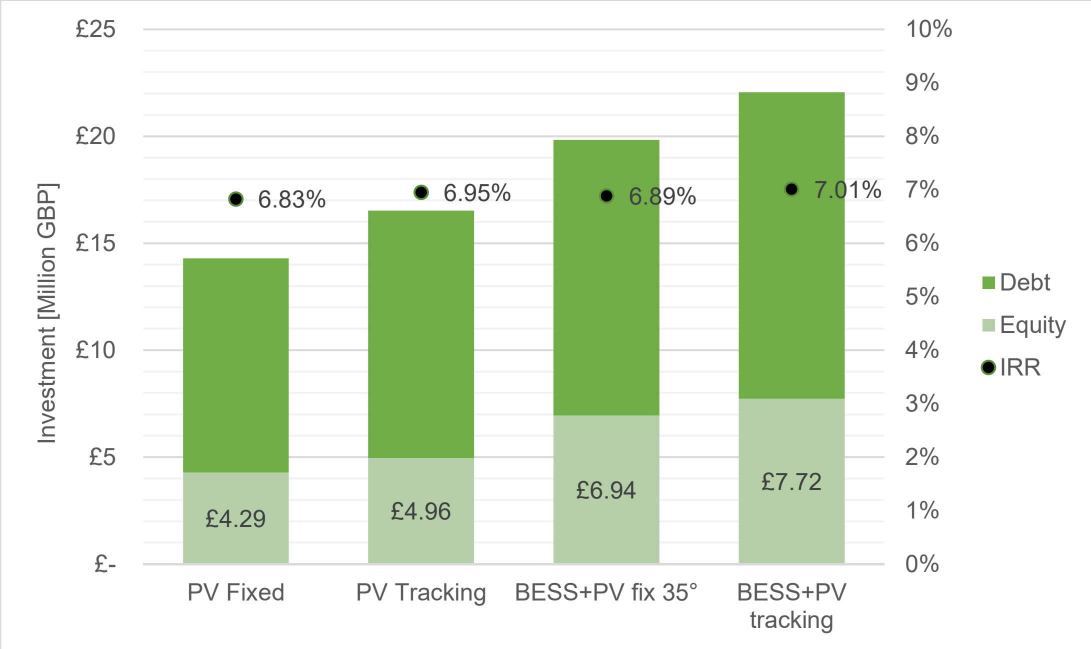


Figure 59. *Comparison of Required investment and IRR at PPA price of 60 GBP/MWh. Source: IC 2023 Team*

11.6. Conclusion of financial analysis

After conducting an in-depth analysis of the UK energy market and performing a detailed financial assessment of a Solar PV project, it can be concluded that such a project may produce favourable returns for its shareholders. Based on the findings of our analysis, a fixed Power Purchase Agreement (PPA) at a rate of £60/MWh has the potential to generate an Internal Rate of Return (IRR) of 6.83% for the project and provide stable cash flows for shareholders. Our research indicates that the implementation of PV with a tracker may marginally enhance the project's IRR from 6.83% to 6.95%, but would necessitate a larger investment and perhaps a higher operational risk as tracking systems are not well proven in the local climate.

The overall environment for investing in renewable energy is conducive in the UK. The government has demonstrated its commitment to supporting renewable energy through Contracts for Difference (CFDs) and Capacity Market, while corporate power purchase agreements are also becoming increasingly popular as companies seek to protect themselves from rising electricity costs and increase their renewable energy portfolios.

Our price forecasting analysis suggests that the average cost of electricity is projected to decline in the future due to the growing share of renewable energy. This implies that the capture rate of solar and wind power would decrease because renewable energy plants tend to generate electricity at the same time, thereby reducing profitability of new generation, a phenomenon known as "self-cannibalisation effect." For example, Solar plants produce electricity at the same time during the day when sun is shining, thereby creating surplus electricity at certain hours. Therefore higher share of solar in the system will decrease capture price for new solar plants. However, the daily price spread is expected to expand, providing revenue opportunities for Battery Energy Storage Systems (BESS) through energy arbitrage. Combining BESS revenues from energy arbitrage and capacity market would supplement the income generated by the Solar PV plant. However, BESS revenues are more volatile and would necessitate a higher percentage of equity from shareholders. The decision to invest in BESS would be contingent on the risk tolerance and risk profile of shareholders. The 20 MW Solar PV and 15 MW/15 MWh BESS could generate decent IRR, if the required equity is attainable and shareholders risk profile allows.

Furthermore, certain risks are associated with the overall economic conditions of the country. Elevated interest rates and inflation may inflate the financing and capital costs of the project. At an interest rate of 5%, the IRR would still be higher than the Weighted Average Cost of Capital (WACC) but may not be particularly appealing to shareholders. But as a community-owned project, the initiative may contribute to the overall well-being of the local community by creating job opportunities and also reducing construction and Operation and Maintenance (O&M) expenses.

12. Community Engagement

12.1. Stakeholders

Stakeholder analysis is a crucial tool for understanding the various stakeholders involved in a particular project, program, or organization. It helps to identify the key stakeholders, their behaviour, intentions, interrelations, agendas, interests, and their level of involvement in the project. The information can then be used by decision-makers in developing strategies to manage these stakeholders (Brugha & Varvasovszky, 2000).

12.1.1. Stakeholder identification

For the first step of stakeholder analysis, we identify existing stakeholders based on their roles and positions in the project. The stakeholder identification departs from the perspective of a community benefit society that will operate the solar PV farm and manage the benefit from the operation. However, there is some exception to this analysis. The stakeholders that will be involved during the construction of the solar PV farm are not included in this analysis, only the external stakeholders will be identified. The internal stakeholders will be explained in the subsequent chapter (organization structure).

The stakeholders are grouped according to their type of organisation/activity. We identified 2 stakeholders in government, 5 stakeholders in companies, and 5 stakeholders in the community.

12.1.2. Stakeholder mapping

The identified stakeholders are moved to the stakeholder map. This is a technique involving a grid or matrix that can assist in visualizing the project's various stakeholders, their level of interest in the project, and their potential influence on project outcomes (Murray-Webster & Simon, 2006). This map is needed to help the company in deciding how to approach and deal with the stakeholders.

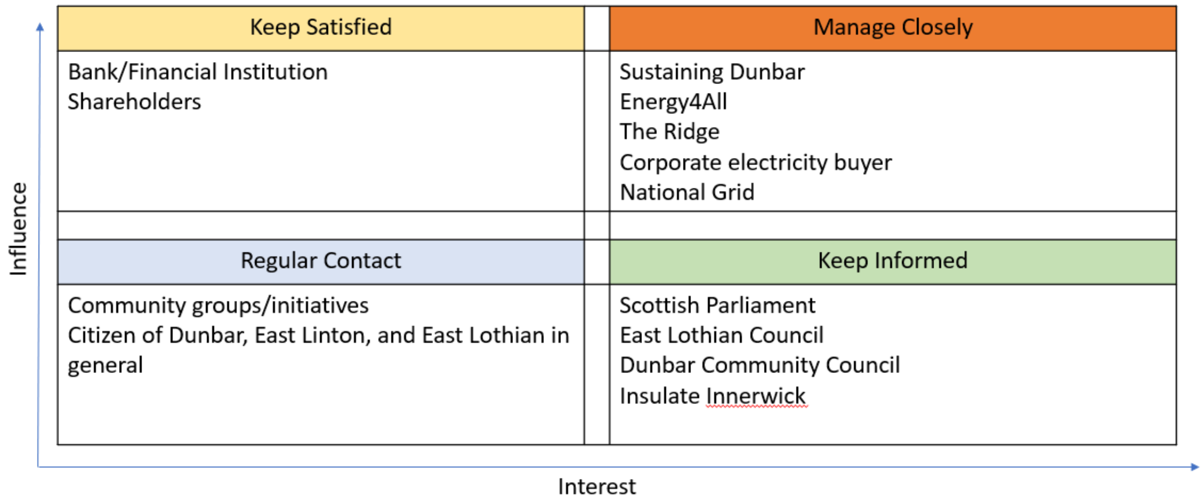


Figure 60. *Matrix of stakeholders of the community-owned solar PV farm in Dunbar. Source: IC2023 team*

The stakeholders are classified into four quadrants on a matrix based on their level of interest and influence in the project, as shown in Figure 60. The upper right quadrant is occupied by those with high interest and high influence, who are directly related to the project and possess the power to impact it significantly, and therefore require close management. The lower right quadrant contains stakeholders with high interest but low influence, who only need to be informed about the project's progress. The upper left quadrant includes stakeholders with high influence but low interest, who need to be kept satisfied and are typically parties with financial or authoritative power that can affect the project's success. Finally, the lower left quadrant is comprised of stakeholders with low interest and low influence, who only require regular communication and maintenance.

This stakeholder map is a preliminary analysis from IC 2023 Team's perspective. Given that stakeholders can change over time, it will need to be periodically reviewed and updated to reflect changes in social, economic, environmental, and other factors within society.

12.2. Stakeholder Engagement

The Benefit Community Society (Bencom) will generate revenues that will strategically be made available for community development. Engaging with members of the community and obtaining information will help comprehend the problems and identify issues that need to be handled.

To collect such knowledge, active members of the community were interviewed. These people are volunteers or leaders of different organizations whose objectives are to increase the wellbeing of the community in different ways related to mental health, food security, and environmental issues. Visits were also paid to where these organizations carry out their activities, in an attempt to better understand their motivations, issues, and goals. A survey was prepared to get to know awareness and attitudes towards solar farms and a Community benefit society (Bencom). Lastly, two workshops were performed, the first one to inform about the project and the second to gather the information that can help to create projects to invest in, for the wellbeing of the community.

12.2.1. 1st Workshop: Creating a Wellbeing Economy

The first workshop was held on Tuesday, 31st January 2023 at Dunbar Church Parish Hall. The event was held by Sustaining Dunbar to promote community action towards wellbeing economy, where Katherine Trebeck and Iain Black were invited as guest speakers. There were around 90 participants who attended the event with the majority being inhabitants of Dunbar and East Linton. A few others came from neighbouring villages outside Dunbar. At the beginning of the event, an introduction to this community-owned solar energy project was presented. It was stated that the project will examine solar farm design, energy market opportunities, and wellbeing economy implementation by reinvesting the revenues from the electricity sales for energy efficiency projects and other community projects. In general, the reception from the participating community members was good and they were enthusiastic about the project.

12.2.2. 2nd Workshop: Community Workshop and City Portrait

The second workshop was held on Monday, 20th February 2023 at Dunbar Townhouse with two main points on the agenda. The first is to raise awareness of fuel poverty and community-owned solar farms. The second part consisted of building “city portraits”s for Dunbar and East Linton using the Doughnut economy DEAL tool. The event was attended by 20 members of the community who showed a keen interest in the topics and engaged actively in the workshop.

The workshop started with a presentation on fuel poverty and community-owned solar farms, which provided examples of successful community-owned projects. This presentation was followed by a Q&A and brainstorming session where the attendees were encouraged to share their views and experiences about the topics. The participants shared their personal stories and highlighted the challenges they faced regarding fuel poverty and access to renewable energy sources. The brainstorming session that followed was the highlight of the event, with the attendees divided into groups of five and were given pertinent questions to brainstorm on. The participants enthusiastically shared their ideas and suggestions on three topics related to the involvement of the society in a community-owned solar energy project.

Table 23. *Results of Workshop Discussion. Source: IC2023 Team*

TOPIC	DISCUSSION
Fuel poverty	• Most participants associated fuel poverty with cold temperatures, physical and mental health concerns, as well as the high prices of fuel. • More than half of them agreed that a community could collaborate to address fuel poverty.
Information needs to be shared with the public	• Several approaches can be taken. Open meetings can be held in-person meetings, or sitting in an open café. It is also encouraged to regularly the updated website, which avoids consultation fatigue and does not require speaking from everyone. • Make the information tangible, which can be done through the use of visuals, such as short videos • Transparency in sharing information, and it should be ensured from the beginning of any initiative. • To consider what kind and what level of information to share, as some people prefer details while others only need the basics. • Targeted information, such as project flow charts outlining the steps can be helpful
Community members have access to jobs provided by the project	• A commitment to training local individuals with the necessary skills for jobs in areas such as surveying, construction, maintenance, and service agreement is needed. • Allocate a minimum portion of jobs to local individuals. The project can provide jobs related to the solar array, including development, construction, operation, and maintenance, as well as training and supply chain roles.

	• Active roles in the Bencom organization structure can also be available.
Community members to be part owners of the project.	• Determining the minimum and maximum share proportion or cost, which may involve a comparison to overheads. • The process of becoming a part owner could involve engaging shareholders or community council representation. • The amount of community ownership will depend on various factors, and the community should be defined accordingly, considering the ability to raise funds. • Overall, the aim is to ensure that community members have the opportunity to have a stake in the project and contribute to its success. • One group created a scheme of possible sources of funding by priorities as shown in Figure 61 where the local community is the main priority of shareholders, while banks and other sources of capital as the least priority.

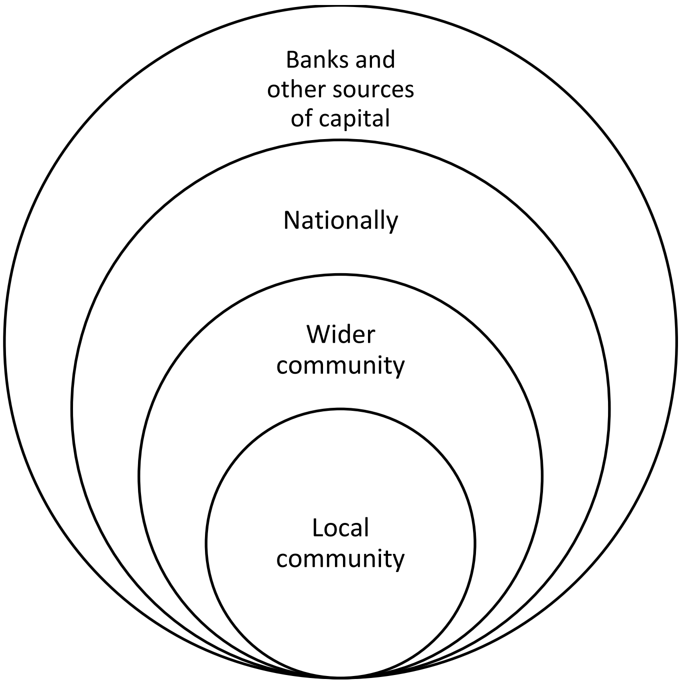


Figure 61*. A potential source of funding for a community-owned solar PV farm. Source: IC2023 Team*

The last activity was to create a "city portrait canvas". This is a tool used to develop a project and good practices that are mindful of a thriving economy theory. This tool was taken from the Doughnut Economics Action Lab (DEAL). The tool is used "to foster big-picture thinking on how a particular city strategy may impact the world in which it is embedded, socially and ecologically, locally and globally. The Canvas is designed for strategic policy development and analysis in workshop settings" (DEAL, 2022).

The intention is that we use this tool to help our stakeholders visualize the project with a holistic perspective considering, local, global, social, and ecological aspects. The city portrait is divided into 4 categories or "lenses" as named by the DEAL, shown in Figure 62.

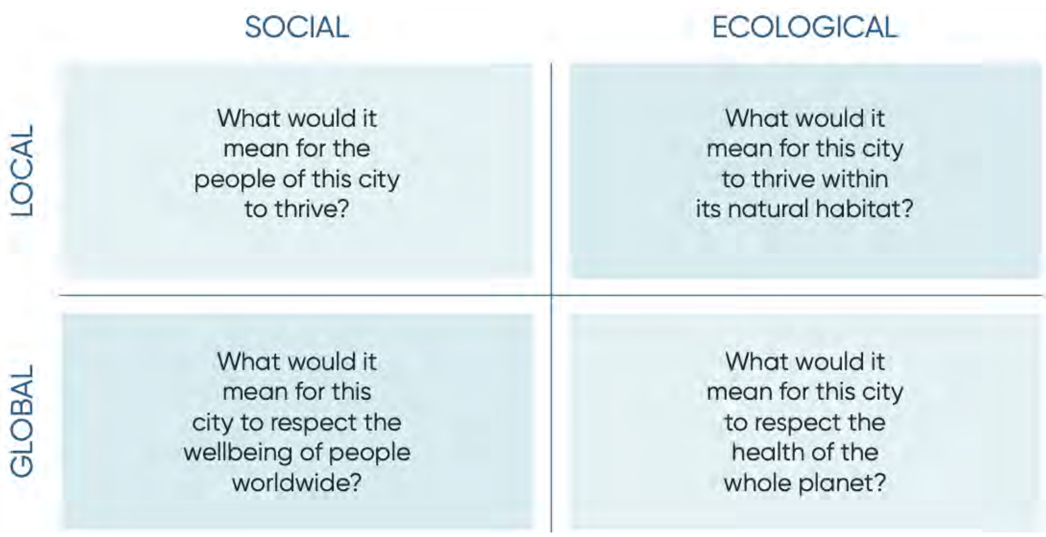


Figure 62*. Lenses of the city portrait. Source: (DEAL, 2022)*

By using this tool, the benefits of the solar farm can be directed in a more effective way that brings the most impactful results.

After processing the city portrait, we can conclude the following:

- The local-social lens is more relevant to the community than the others. This category had 55 topic inputs, followed by local-ecological with 29. Global social only had two inputs and global ecological 1.
- Each lens has categories that help describe its characteristics. The most addressed category was "empowerment", followed by the category "health" and lastly the category named "connected". Connected refers to having a community that is involved and participates collaboratively.
- The most frequent topics found in the city portrait were mobility, food, voice, and infrastructure. The participants have expressed that they see deficiencies in these matters and would like to see community action to improve them. Voice is referring to

the representation of the population in the government, it is mentioned that the voice of representation is very poor.

The information obtained from this tool is not very specific due to the lack of statistical data and specific targets, but it is a good start because we now know that people are willing to create a baseline for projects that support their mutual wellbeing. In the future, this activity can be repeated to bring it to its completion. For more detailed information about the results of this activity please refer to Annex 6.

12.2.3. Interviews with Community Key persons

Considering that Dunbar and East Linton have many community-owned organisations and projects. Interview sessions were conducted with these organisations. These organisations/projects considered are mentioned in the background above. The purpose and a summary of the results of these interviews are presented in this section.

These organisations/projects are heavily involved with many aspects of the community and work for the betterment of the community as a whole. For this reason, it was important to understand their activities and the major problems they are facing. This could be the perfect point of departure for building a well-being economy in Dunbar and East Linton. Secondly, they interact with the inhabitants on a day-to-day basis and can give useful insights about the members of the society and what to expect from them. Thirdly they are owned and run by the community. Their experiences will provide knowledge on how to manage a community-owned organization in Dunbar and East Linton. Lastly, the community-owned project will need partners for the project to be successfully implemented. It was there important to see the willingness and level of engagement these organisations/projects could have with the project being developed.

The interviews were very informative and revealed a lot about the different community organisations in the area. Here are some key takeaways:

- It was understood that most of these organizations/projects are working towards creating a sustainable and wellbeing community, raising awareness on major societal and climatic issues.
- The involvement of the community in the projects shows their willingness and engagement in community activities that can better their wellbeing.
- It was also observed that there are key members in the community with experience and leadership skills that could be very useful for the running of a community project.

- The organizations also have visions that benefit the community in the long and short term. They are willing to collaborate with the Community Benefit Society toward the realization of these visions for the wellbeing of the community.
- Energy for All was of particular interest as their role is to help communities set up community-owned companies. They have the right experience needed and are open to guiding and assisting in the creation and running of this project.

Overall, the interviews were a success and provided valuable insights into the potential for collaboration and engagement with local organizations. Table 24 below gives a summary of the main subjects that are supported, opposed, promoted, and ignored by the interviewed stakeholders. The full interviews are provided in the annex 5.

Table 24. *Summary of Interviews. Source: IC 2023 Team*

Summary	Characteristics	Description
Building a wellbeing economy	Support	The organizations are supportive of the company working for the wellbeing of the community.
Community Engaging	Promote	The organizations want this company to promote community engagement
Collaboration between organisations	Support	Supportive collaboration between organisations
Building a Solar Farm.	Support	Supportive of having a solar farm in the area
Local Job Creation	Promote	They believe that the company should promote job opportunities
Skill development	Promote	They believe that the company should promote skill development
Funding and assisting Local projects	Support	They believe that the company should use the benefits to support local projects

13. Community Benefit Society

A Community Benefit Society, also referred to as Bencom, is a legally recognized corporate structure designed for the benefit of a specific community or group of people. It is a type of cooperative enterprise in which all members have an equal voice in determining how the business is run and earnings are shared with the local area (Co-operative UK, 2017). Bencoms can be created for a variety of reasons, including to solve social or environmental issues or to provide local services and amenities. They must provide evidence that their actions serve the interests of the community, and they are monitored by the community to make sure they stay true to their original goals. In recent years, Bencoms have gained popularity as a means for communities to reclaim ownership of resources and assets and develop lasting, equitable solutions that meet the needs of their constituents. For the community-owned solar project in Dunbar which will be run by an organization, a Community Benefit society is the recommended legal registration structure. This legal structure will ensure the fair implication of the members of the community and will ensure the benefits from the project are placed at the service of the community. This organization will be responsible for the day-to-day run of the project and ensure the engagement of the community.

13.1. Specific design for the solar farm in Dunbar

The success of any community-owned project depends on a clear and effective legal structure that provides the necessary framework for decision-making, accountability, and financial management. In the case of this community-owned solar project in Dunbar, there are several crucial derivable that have to be accomplished while establishing the organization. Some of these derivable are proposed by the Co-operative and Community Benefit Society Act 2014. They include a well-drafted constitution, registration at the appropriate regulatory body, putting place a managerial and organizational structure, and a possible funding mechanism (The Houses of Parliament, 2014). These derivable are covered in detail in the following section.

Constitution

A constitution, also known as organizational rules, is a set of fundamental principles and rules that guide the operation and management of a Bencom (Co-operative UK, 2017). It defines the purposes, activities, membership structure, governance, decision-making process, and other key aspects of the society's operations. The constitution usually includes the following sections:

a. Name and purpose of the society

In addition to having the organization's name, the constitution should specify Bencom's goals and objectives in detail. This should include a concise description of the community benefit that the initiative aims to deliver, such as lowering fuel poverty and enhancing community wellbeing. The items should also list the tasks that the Bencom is allowed to carry out, like owning and operating solar power plant assets and supplying electricity to the national grid (The Houses of Parliament, 2014).

b. Membership eligibility and structure

The constitution needs to specify the requirements for membership as well as the procedure for applying. Members should have equal rights and a voice in decision-making, and the membership structure should be transparent and democratic. The members' obligations, such as attending meetings and abiding by society's rules, should be outlined in the constitution (The Houses of Parliament, 2014).

c. Management and governance structure

The CBS's administration and governance structure should be described in the constitution. This covers the duties and obligations of the directors or committee members, their election or appointment processes, and their decision-making processes. The constitution should also contain clauses that allow for the replacement of any departing directors or committee members (The Houses of Parliament, 2014). Figure 63 below provides a proposed organizational and managerial structure that can be used to run the organization.

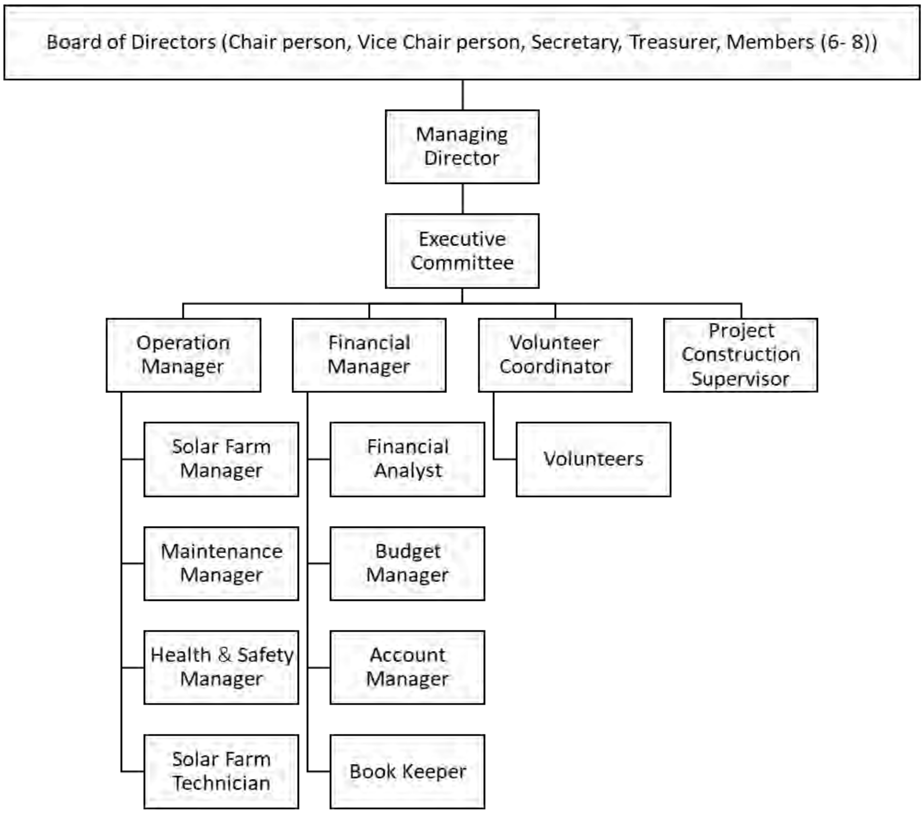


Figure 63. *Proposed management and organizational structure. Source: ICTeam 2023*

d. Voting and decision-making procedures

The voting and decision-making processes should be spelled out in the constitution. This covers the procedures for making decisions, the number of votes needed to pass a motion, and summoning general meetings. The use of electronic voting and proxies should likewise be included in the constitution (The Houses of Parliament, 2014).

e. Financial management and reporting

The management and reporting of Bencom's finances should be covered under the constitution. This comprises the methods used to raise, manage, and disperse finances. The constitution should also specify how financial reports are prepared and submitted (The Houses of Parliament, 2014).

f. Asset Lock

The asset lock is a contractual agreement that ensures that any assets controlled by the Bencoms are safeguarded and used only for the good of the community, not sold or given to another company or person (Community Shares Scotland, 2018). Members and stakeholders are further reassured that the Bencom is committed to upholding its status as a community-owned organization that puts the needs of the community first by the inclusion of an asset lock in the constitution. Organizations seeking to be registered as Community Benefit Societies in Scotland must include an asset lock. This is so that any potential conflicts of interest or attempts to sell off Bencom's assets can be prevented thanks to the asset lock (The Houses of Parliament, 2014).

g. Dissolution and distribution of assets

The procedure for dissolving the Bencom and distributing its assets should be outlined in the constitution. This comprises the procedure for choosing a liquidator or trustee, the method for disposing of assets, and the method for distributing any leftover assets to family members or the neighbourhood (The Houses of Parliament, 2014).

The establishment of a Community Benefit Society is a critical step in the successful implementation of our community-owned solar project in Dunbar. By incorporating the key elements outlined in this report into the constitution and rules of the CBS, Sustainable Dunbar can ensure that the project is well-governed, financially sustainable, and aligned with the principles of community ownership and benefit. This, in turn, will help to ensure that the project achieves its objectives and contributes to the well-being of the community. A sample constitution will be provided for guidance.

Registration

To register a Community Benefit Society (Bencom) in the UK, a step-by-step process is needed. This involves several stakeholders, including the Financial Conduct Authority (FCA). The process includes choosing a suitable name for your Bencom, preparing the required documents, and submitting them to the FCA for registration. Once registered, an annual report will need to be filed and other ongoing compliance requirements will need to be met. The step-by-step process for registering a Bencom in the UK can be found on the FCA's website (FCA, 2019), which provides detailed guidance on the process and the requirements involved. This guidance includes information on the necessary documents, fees, and timelines, as well as links to useful resources and forms.

The registration of a Community Benefit Society in Scotland is a straightforward process that can be completed in a few weeks. By following the steps outlined on the website, the registration of a Bencom for a community-owned solar project in Dunbar can be accomplished smoothly and efficiently. This will ensure that the project is well-governed, financially sustainable, and aligned with the principles of community ownership and benefit.

Funding

Funding is a critical aspect of any energy project, and the solar project in Dunbar is no exception. Solar projects require significant upfront capital investment to purchase equipment, hire contractors, and conduct feasibility studies. This report explores the possible funding mechanisms for a community-owned solar project, including grants, loans, crowdfunding, and other innovative funding models.

a. Share offer (Equity)

Community Benefit Societies (Bencoms) in Scotland frequently raise money by selling some of the organization’s equity as shares to members and investors. In this concept, members or investors buy Bencom shares in exchange for the possibility of monthly dividend payments or other financial advantages. It is very common for community-owned companies to offer share sales to members to encourage community engagement and encourage a sense of belonging. External purchase of shares is not discouraged but the target community should be prioritized. This could be achieved by offering a slightly higher interest on the shares bought. It is important to note this will require consultation with the right experts to be implemented and it must meet all legal requirements.

The minimum and maximum share price for community-owned enterprises in Scotland might change based on the organization and the particular project. The Financial Conduct Authority's community share rules state that there is no set minimum or maximum share value for community share offers; instead, this is often decided by the organization itself based on the project's requirements and the community's capacity to contribute (FCA, 2021). However, the Organisation Energy4All advises a £100 minimum and a £100,000 maximum investment for community shares. Usually, the maximum amount is set at £30,000. This is an attempt to avoid an individual owning a large portion of the shares. To promote broad community engagement and ownership in the project, it is also critical that the share offer be affordable and accessible to all citizens.

Overall, offering shares or equity can be an effective way to finance a community-owned renewable energy project and this project should consider offering shares and seek professional advice to ensure that the project is structured appropriately and complies with relevant regulations and laws. Energy for All is an organization that can assist CBSs in raising money by helping and direction when selling shares to the public and investors. Community Shares Scotland, Social Investment Scotland, and the Community Shares Unit are additional organizations that can offer comparable support and direction.

b. Grants

Grants are a common form of funding for renewable energy projects in Scotland. Grants are typically provided by the Scottish government or its agencies, such as Scottish Enterprise or the Scottish Environment Protection Agency (SEPA). Some possible examples of grants that can fund renewable energy projects in Scotland include:

- The Low Carbon Infrastructure Transition Programme (LCITP)

The Low Carbon Infrastructure Transition Programme (LCITP) in Scotland aimed to facilitate the development of private, public, and community low-carbon projects through expert advice and financial support. The program's focus was to assist in developing investment-grade business cases to secure public and private finance for innovative low-carbon technologies, which could be replicated across Scotland to attract commercial investment. The program aimed to contribute towards Scotland's greenhouse gas emissions reduction while creating conditions to attract commercial investment in the low-carbon sector (Scottish Government, 2015).

- The Community and Renewable Energy Scheme (CARES)

The Scottish government offers a subsidy program called the Community and Renewable Energy Scheme (CARES) to assist locally operated renewable energy projects. The program provides funding and technical help for the creation, setup, and operation of renewable energy projects, such as those utilizing wind, solar, and hydropower. With the help of funding from CARES, communities may take control of their local energy supply, empowering them to cut carbon emissions and build resilient, sustainable communities. The CARES grant also aids with associated projects like energy efficiency measures (Community Energy Scotland, 2020).

- SPEN's Green Economic Fund

The Green Economy Fund of SP Energy Networks (SPEN) is a funding program designed to aid in the execution of low-carbon energy projects in Scotland. The fund contributes money to initiatives that support renewable energy, lower carbon emissions, and foster economic development. It is open to a wide range of applicants, including neighbourhood associations, private companies, and government agencies. Project design, feasibility analyses, and installation charges are just a few examples of the many uses for the award. The fund aims to promote renewable energy investment, foster employment creation, and economic development, and help Scotland reach its goal of net-zero emissions by 2045 (SP Energy Network, 2021).

- The National lottery community Fund

In the UK, community-based organizations and initiatives can get financing from the National Lottery Community Fund. Grants are given to a variety of organizations, including charities, volunteer groups, social entrepreneurs, and community interest companies. The fund is funded by National Lottery winnings. The fund provides financing for a range of programs and projects, including those focused-on sustainability and renewable energy. The fund's purpose is to encourage people to act to better their lives and their communities while also assisting in the development of stronger local communities (Community Fund, 2019).

c. Loans

Loans are another form of funding for renewable energy projects. Loans can be obtained from banks, credit unions, or other financial institutions. Some possible examples of loans that can fund renewable energy projects in Scotland include:

- The Energy Investment Fund (EIF)

A fund funded by the Scottish Government called the Energy Investment Fund (EIF) was created to assist Scottish firms in accelerating the adoption of cutting-edge low-carbon energy solutions. The EIF offers firms adaptable financial support for the creation, testing, and commercialization of low-carbon energy technology as well as the building and maintenance of low-carbon energy infrastructure. Through raising investment in low-carbon energy projects, lowering greenhouse gas emissions, and helping to promote a more circular economy, the fund aims to make Scotland's energy future more sustainable (FVA, 2021).

- The Bank of Scotland

Under the Bank of Scotland's Clean Growth Finance Program, which aspires to be the most inclusive offering in the UK market, discounted loans for green initiatives can be obtained. A wide range of initiatives in sustainable business can be financed by the Bank of Scotland, from modest reductions in environmental effects to extensive renewable energy infrastructure such as Solar panels, wind turbines, electric vehicles, and other equipment covered by the Enhanced Capital Allowance Scheme. They have partnered up with top sustainability consultants to create a list of acceptable green goals for our Clean Growth Funding Program (Bank of Scotland, 2021).

d. Crowdfunding

Crowdfunding is an innovative form of funding that has become increasingly popular in recent years. Crowdfunding allows individuals to contribute small amounts of money to a project in exchange for rewards or equity. Some possible examples of crowdfunding platforms that can fund renewable energy projects in Scotland include:

- Crowdfunder

Crowdfunder is a web platform that enables people and organizations to raise funds through various crowdfunding methods such as equity, donation, and reward-based. More information about the Crowdfunder can be found on the website (Crowdfunder, 2011).

- Indiegogo

Indiegogo is a crowdfunding website that allows users to raise funds for various purposes, including projects across various industries, including technology, community, and creative fields. More information can be found on the website (Indiegogo, 2008).

There are several possible funding mechanisms for the solar project in Dunbar, including grants, loans, crowdfunding, and other innovative models. Each funding mechanism has its advantages and disadvantages which are presented in Table 25 below. The choice of funding mechanism also depends on the specific needs and circumstances of the project. It must be noted that funding a large solar project usually happens in two stages. In the first stages, funds are required for leasing the land, paying for grid connection, and completing other preliminary activities. This fund can be obtained in the form of a Grant such as the Community and Renewable Energy Scheme (CARES) enabler grant. This is because grants are usually not very high to cover the entire cost of the project but can be very helpful for the first stages of the project development. In the second stage of funding shares are offered to the community and general public or a loan offer can be requested.

By exploring and leveraging these different funding options, the solar project in Dunbar may not be fully funded and supported only by offering shares to the community and general public, it will be advisable to include a loan as a funding option. The loan could be a low-interest loan that will run throughout the life of the project.

Table 25. *Summary of various funding mechanisms. Source: IC2023 Team*

Funding Options	Example	Advantages	Disadvantages
Equity	- Share offers to the community - Share offers to the general public.	- Enables a CBS to generate money from a wider range of investors and community people. - develops a sense of ownership and dedication for shareowners	- It might be harder to sell shares in a community-owned initiative or to draw investors, for smaller projects. - For the bigger project, it is usually very unlike for all the investment capital to be raised from shares alone. - There can be legal and regulatory constraints on how shares can be sold or transferred
Grants	- The Low Carbon Infrastructure Transition Programme. - The Community and Renewable Energy Scheme - SPEN's Green Economic Fund - The National lottery community Fund	- They do not require repayment. - Grants can also be used to leverage other sources of funding	- Grants are highly competitive and there is no guarantee of success. - The purpose is often defined by the funding body
Loans	- The Energy Investment Fund.	- Loans can also be used to build a credit history for the project,	- They require repayment with interest, which can

	- The Bank of Scotland.	which can be useful in securing future funding. - They provide a source of capital that can be used to finance the project.	add to the financial risk of the project
Crowdfunding	- Crowdfunder - Indiegogo	- It allows the community to become directly involved in the project and can build a sense of ownership and support	- It requires a significant amount of effort to launch and manage a successful campaign

13.2. Revenue distribution

13.2.1. Mechanism

In the spirit of implementing the wellbeing economy, the profit from electricity generation is reinvested in the community to foster a healthy community and a sustainable environment. A just, transparent, and well-targeted mechanism is required to ensure the fair distribution of benefits to the community. The following are some mechanisms that can be implemented:

Loan

This scheme offers a no-interest loan program that is specifically designed to fund energy efficiency projects to reduce fuel poverty. The energy efficiency loan program provides borrowers with a no-interest loan to fully or partially fund their energy efficiency projects such as building retrofitting and heat pump installation. The program is designed to help individuals and organizations reduce their energy consumption, lower their energy costs, and promote sustainable practices. The loan offers competitive interest rates and flexible repayment terms to make it more accessible to borrowers.

Shareholder Option

Borrowers who are also shareholders of the company will be given the option to use the interest earned on their shares to make repayments through a direct-debit scheme. This feature allows shareholders to contribute to the solar PV project while also benefiting from the returns on their investment in the form of an energy efficiency project. This has the potential to provide shareholders with a double benefit while also having a double impact on the environment.

Assistance for Borrowers

The loan program also offers guidance and assistance to borrowers to help them identify and access other funding sources to ensure they have the necessary funds to complete their projects. Understandably, energy efficiency projects can be expensive and complex, therefore, the Bencom shall commit to helping borrowers navigate the process of securing additional funding such as Warmer Homes Scotland and Home Energy Scotland Grant and Loan that are provided by the Government (Energy Saving Trust, 2023).

Grant

A lump sum fund will be granted for existing or potential community projects or initiatives in the Dunbar and East Linton area that seek to create or promote energy efficiency or the reduction of CO2 emissions, or that support community sustainability. To apply for grants that can range from 500 GBP to 5000 GBP, the organisation must apply to the Bencom, which will then be reviewed by a committee based on certain criteria. This scheme has been successfully implemented in many community energy projects such as REPOWERBalcombe (REPOWERBalcombe, 2022) and Westmill Solar Cooperative (Westmill Solar, 2023).

13.2.2. Benefits for the community

Retrofit

Retrofitting the housing stock is a measure that needs to be implemented if households aspire to reduce fuel poverty and if the country is to achieve its emission reduction targets.

The SIMD study of 2020 provides a deprivation ranking according to different indicators such as central heating, income, and employment, which are presented per data zones. Dunbar and East Linton have 18 zones of interest delimited by yellow lines on a map. As an example, Figure 64 is showing the Ward's most populated area with 12 of the 18 data zones; to view further data zones please refer to the SIMD interactive online map. The ranks are shown in a colour scale that is calculated from an overall score (SIMD, 2020).

In Dunbar and East Linton, most people have central heating systems. On average only 1.8% of people don't have it. Nevertheless, three zones exist with many more houses without central heating than others. These are S01008277 located between North Berwick and Dunbar, S01008282 East of Dunbar city centre, and S01008289 by the Battery.

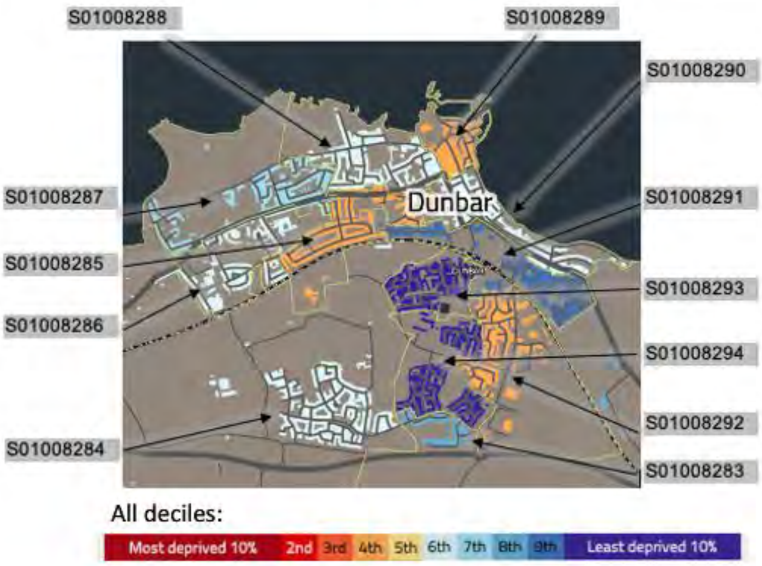


Figure 64. *Data zones in Dunbar. Source: (SIMD, 2020)*

With a review of the local EPC certificates available in the region and considering the fuel poverty background presented earlier in the report, it is possible to determine the zones that have fewer opportunities to leave fuel poverty. In this way, a targeted audience can be identified for strategic purposes including marketing strategies, prioritization of benefit distribution, and surveys. The following paragraph has been prepared to present the ideal target audience of the most vulnerable population within Dunbar and East Linton Ward.

Both EPC certificates and SIMD statistics share data zones making it possible to relate their statistics. The total count of EPCs available is 3,374. When selecting dwellings with the highest levels of employment and income deprivation, three data zones have almost double the average of East Linton and Dunbar. There are therefore of higher priority. Out of this initial count, 979 have been catalogued as not retrofittable due to their current characteristics.

A point system was established to determine the priority which can be used as an eligibility criterion. This point system ranks the highest priority as number 1 and the lowest at 39. Each energy efficiency band transition, for example, G to B or C to B has a different priority. The lowest bands get fewer points because they have the highest potential for energy demand reduction. Employment and income deprivation highest rates have the highest priority, therefore, fewer points. In total there are three categories to add to a total point ranking which then serves to set the order of retrofitting.

Considering the scenario where the solar farm produces the least revenue, 19.1 million GBP, it can be possible to retrofit 346 dwellings from 2026 to 2040, an average of 22 per year. This will be funded by an average yearly revenue of 320,000 GBP while the loan is being paid out till 2040. After 2040, the revenue available is significantly higher, with an average of 1.4

million GBP per year until 2050. This means that much more retrofits could be done. This could cause the exceed of the labour force capacity. For practical purposes, an average of 30 retrofits per year was selected after the year 2040. A higher count of retrofits would not pose an issue in terms of financing, due to the very high budget available. Contrary, some issues will arise in terms of resource allocation. These issues should be aligned with the priorities of the Bencom. All in all, a total of 616 dwellings will be retrofitted over 25 years, which is an average of 25 per year. For a more detailed review please refer to Annex 6.

Skill Development

The revenues should also be used to support training opportunities that create a larger labour force pool to be able to make dwelling renovations and perform EPC certifications. The target audience should be people that are unemployed or have any other challenge that might be overcome by such training.

The Ridge, a charity company in Dunbar, trains young people and employs them to renovate buildings in the town. The youths are trained locally and sent to college as well. There is also the possibility of a sponsorship for certification at the Passiv Haus Institute. Costs for certificates are around £2,000 depending on the type of certificate. If such sponsorship is offered by the Bencom, it should include a clause that elaborates how the skills gained can be later implemented for the wellbeing of the community over some time. An example could be to perform energy audits and retrofitting services in Dunbar for a period equivalent to their salary and the cost of certification (Passive House Institute, 2022) (PassivHausTrust, 2022).

The Bencom can approach The Ridge and fund projects to increase the organization's capacity to train and certificate people or establish a similar concept that offers this type of benefit.

14. Energy efficiency measure

Dunbar and East Linton, like many other communities, face a significant challenge in reducing its energy cost and emissions. Buildings account for a significant portion of energy use and emissions, which is why implementing retrofitting measures is an essential component of the energy efficiency solution. By retrofitting buildings, it is possible to improve their energy performance, reduce energy bills, and decrease their carbon footprint.

In this report, we will provide top-down approach to estimate the cost of improving buildings' energy performance and potential energy savings. This report includes geospatial analysis, available resources for the status of buildings like EPC certificate, low carbon heating technologies, TABULA, and recommendations for further improvement of the analysis.

14.1. Methodology

This section describes the steps that were taken to propose solutions for new technologies, calculations of investment costs and energy savings, and provides information for the project to prioritize those dwellings that need a retrofit in the area of study. The results were obtained using our methodology, which consists of a combination of computer-based software like ArcGIS and MS Excel, site visits to a village, Google Maps, on-site data collection using a smartphone, databases from the Scottish Government, and discussions with influencing members of the community.

The aim was to combine the existing data with a modelling approach because there are approximately 7,000 dwellings in Dunbar and East Linton and elaborating energy audits for many homes seems to be an impossible task for 4 members of the Energy Efficiency Group. It was then decided to use Innerwick as a pilot because we had good access to information from its community leaders which allowed for the proposed combination.

14.2. Case study: Innerwick, Dunbar and East Linton

Innerwick is a village that lies in the east of East Lothian, it is located 8 km (5 miles) from Dunbar. This project is looking for solutions to improve energy efficiency in the village. Some efforts have been made, for example, a preliminary list of dwellings of the village. The project has been driven by the increasing energy crisis and raising awareness of climate change.

Innerwick has social housing and privately owned houses. According to the first conversations with Dr. Elisabeth Wilson, a resident of the village and project leader of “Insulate Innerwick”, this village has houses built in different years and sizes and have different levels of insulation (Wilson, 2023). After our conversations with Dr. Elisabeth Wilson, we decided to create a methodology to approach the problem of lack of building data to identify energy efficiency improvements and reduce energy costs. The methodology uses existing databases from the European Union, the Scottish Government, and other sources.

The geographical extent and nature of the exercise necessitates the use of GIS. Since the project involves a geographical space that can be expanded to other areas, it was decided to use ArcGIS as a starting point (Geospatial World, 2022).

The free, community-maintained data produced by the OpenStreetMap project was used for general mapping purposes. OpenStreetMap (OSM) was founded in the United Kingdom and aims to create a free, worldwide geographic data set. It focuses on transport infrastructure and collects a multitude of points of interest, including buildings, natural features, land use, coastline, and administrative boundaries, obtained by (Geofabrik, 2022). From this layer, the information on the polygons that are equivalent to building footprints was extracted. The name of it is “osmBuildingDunbarEL”. To focus on the area of study of Dunbar and East Linton, it was necessary to add a layer from the Global Administrative Areas (GADM) (GADM, 2023).

By compiling information from OSM, Google Street View, and a site visit to Innerwick, it was possible to add the type of houses, approximate year of construction, number of dwellings, and number of floors to each polygon (equivalent to building). This was useful to calculate energy consumption, energy savings, and cost of investment for each one using an Excel Model. This will be explained in the next chapters. Applying Excel and ArcGIS helps to explain the obtained results more visually, so the stakeholders can understand easier our results better.

This methodology is useful as a starting point for a project like this and can be applied to other villages. The reason to do it like this is that there is no country-wide catalogue or register of buildings and energy-related properties. A general methodology for Dunbar and East Linton.

The scope of the present project requires the expansion of the findings of the Innerwick case to the rest of the Ward.

It was decided to rely on existing databases from the Scottish Government, specifically the database of EPCs (Energy Performance Certificate). An EPC provides information on how energy efficient a building is and how it can be improved (Scottish Government , 2023). For our study, it contains per dwelling important information like energy consumption per year, type of building, year of construction, area, energy efficiency rating, and heating source. An EPC is prepared when a new building is constructed and when is to be sold or rented to a new tenant.

The EPC is linked to a UPRN (Unique Property Reference Number). It is a number that refers to an individual address, each dwelling has a unique number (Scottish Government , 2023).

From the “Ordnance Survey Data Hub Open Data” (Ordnance Survey Data Hub, 2023) a shapefile was downloaded containing all the UPRNs with geolocation of Scotland (Scottish Government , 2023). Then, the geographical points in Dunbar were linked with the EPC on a Map in ArcGIS. Figure 65 explains how the GIS model works.

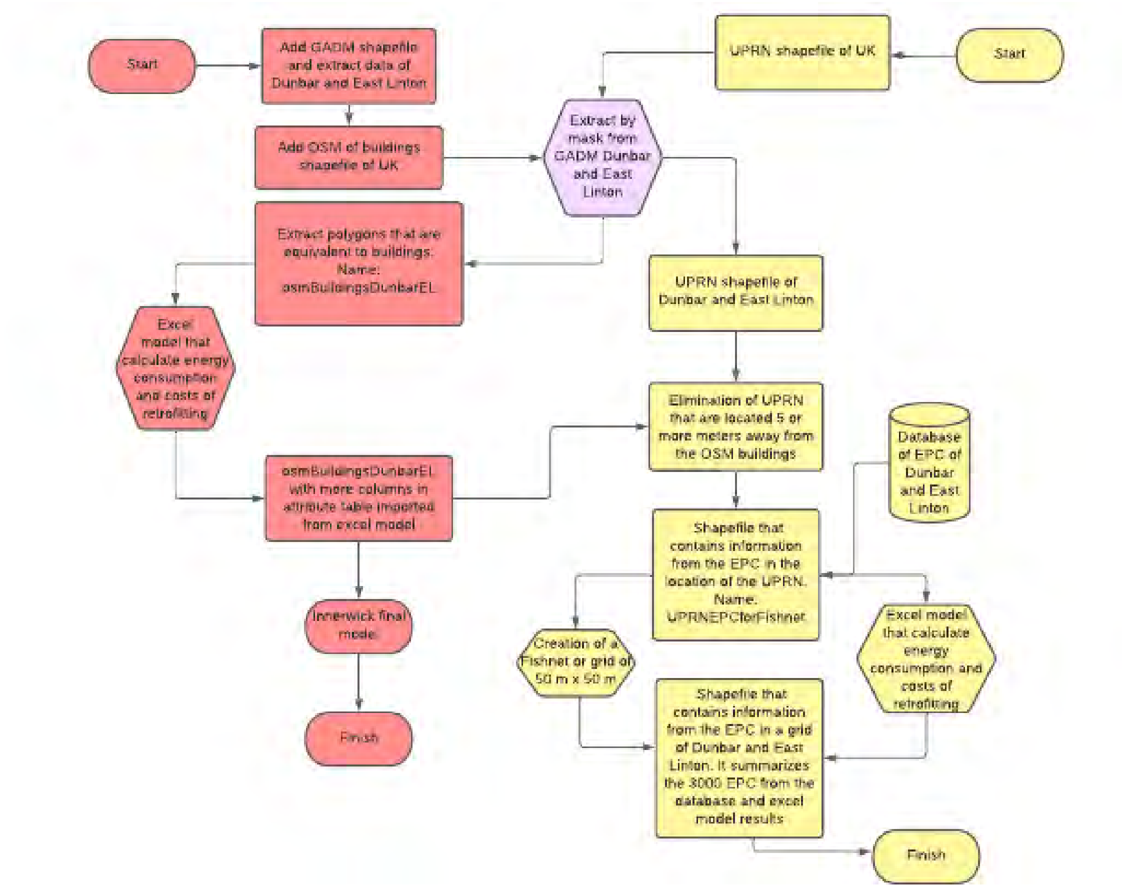


Figure 65. *Flow chart that explains the steps taken to build the models in GIS. Source: IC2023 Team*

Since not every dwelling has an EPC, some assumptions have been made to extrapolate our results to all buildings in the Ward. There are around 9,000 UPRN in Dunbar and East Linton, but not all UPRN belong to buildings or dwellings. Some belong to public telephones or other public infrastructure. A filter was applied to the UPRNs based on their proximity to polygons from the OSM database. It was assumed that any UPRN located more than 5 meters away from an OSM polygon is not associated with a building. As a result of this filter, 6,768 UPRNs and 3,374 EPCs were identified.

Due to this fact, we decided to create a grid of 50 meters by 50 meters (50x50m) that can generalize (count, sum, calculate mean depending on the necessity) the EPRN/EPC data inside each square and obtain with this method more general results for an area of 2,500 sqm per square. The results of this procedure will be explained further in this report.

The results from this methodology helped the general project to create a retrofit strategy to reduce fuel poverty and energy demand in Dunbar and East Linton. One of the limitations of this model is that if there is no UPRN with a linked EPC within a cell of the grid, it cannot calculate any result because there are no values inside the cell.

14.3. Investigation of available resources for building energy performance in Scotland

14.3.1. TABULA, Building Typology Approach

This section describes the building typology approach which was taken to improve the building's energy efficiency. Typology Approach for Building Stock Energy Assessment (TABULA) is a European research project that developed a standardized methodology for assessing the energy performance of buildings. The TABULA methodology includes a building typology that groups buildings based on their function, form, and construction period. The TABULA building typology is used primarily in Europe, and more specifically, in the countries that participated in the TABULA project. It was implemented in this project because it's a specific building energy performance typology, on which time could be saved for a building assessment in Innerwick, (TABULA, 2014)

The resulting TABULA building typology is a classification system that uses various building characteristics to assess the energy performance of buildings, such as construction period, building type, insulation level, heating system, and air tightness (TABULA, 2014). To assess energy saving potentials and costs of retrofitting, an energy performance assessment for dwellings was conducted, following the TABULA approach. This allowed for the development of targeted strategies to improve the energy performance of buildings, such as insulation upgrades, heating system retrofits, and air sealing measures.

Table 26 below shows the age and types of houses which were considered to calculate energy demand and energy savings in (MWh/a) after standard and ambitious refurbishment in the village of Innerwick.

Table 26. *Considered age and type 68 buildings for the analysis in this case study. Source: (TABULA, 2014)*

S.No.	Age of House	Type of House
1	1919-1944	Terrace / Detached house
2	1945-1964	Terrace / Detached house
3	1965-1980	Terrace / Detached house
4	1981-1990	Terrace / Detached house
5	1991-2003	Terrace / Detached house
6	2004-2009	Terrace / Detached house
7	2010	Terrace / Detached house

The difference between standard and ambitious refurbishment is the level of change and innovation involved in the renovation process. While standard refurbishment involves mainly upgrading the existing building systems, ambitious refurbishment involves significant modifications to the building's inner spaces and the use of innovative technologies and materials to achieve a much higher level of energy efficiency and sustainability.

In this study, we only considered energy saving with standard refurbishment for retrofitting houses. TABULA project identifies standard refurbishment as a set of retrofit measures that were economically feasible for each dwelling type and energy efficiency class for standard renovation to improve the inner spaces and functionality of the spaces including wall insulation, roof insulation and windows glazing.

From TABULA, a reference value of energy needed for heating in kWh/m²a on yearly basis for each type and age of dwelling was taken. In addition, the energy needed for heating value was according to the age of the dwelling which directly affects the thermal performance of the dwelling elements. Therefore, some measures which include improvements to the building envelope through insulation, and replacement of windows and doors were considered in this case study.

To calculate the current energy demand for heating each type of dwelling, the energy needed for heating (kWh/m²a) as built was taken from TABULA. Building footprints & floor area of the dwelling were defined by using OSM building polygons which are mentioned in the methodology section, as input in ArcGIS software. The construction year concerning the type of dwelling located in Innerwick was noted by a conversation with influential members of the community during the site visit.

14.3.2. Energy Efficiency Rating of dwelling (EPCs Database)

In Scotland, as in other parts of the UK and the European Union, buildings are required to have an Energy Performance Certificate (EPC) which provides information about the energy efficiency of the property. In this case study, the EPC database was taken from energy saving trust (Trust, 2019) and was considered to retrieve the current energy performance of those buildings that have EPCs in Dunbar and East Linton.

In addition to this, the EPC database was considered for Dunbar and East Linton which provides access to a wide range of information on individual buildings in Scotland. The information provided in the EPC database includes energy efficiency ratings, energy consumption, CO_2 emissions, heating system, insulation, other energy-related features and the types of improvements and energy-saving effects that are recommended to improve energy efficiency (Trust, 2019). The energy savings and retrofitting cost calculations made for Innerwick and Dunbar are compared and briefly described in Table 27.

Table 27. Comparison of calculation made for Innerwick and Dunbar. Source: IC2023 Team

Calculation for Innerwick from TABULA	Calculation for Dunbar from EPCs
The approach and data from TABULA were used for Innerwick	EPCs database was used energy performance analysis for Dunbar and East Linton.
Considered standard value of energy needed for heating kWh/(m²a) for calculation from TABULA	EPCs database contains type of building, year of construction, area, energy efficiency rating, and heating source
Calculated energy demand and energy savings for houses using standard refurbishment	Property UPRN was joined with OSM building polygons using GIS software. was used to calculate energy savings and average cost of retrofitting.
Cost curve for retrofitting was developed	Energy savings, average cost of retrofitting and average cost of heat pump was calculated and visualized on maps.

14.3.3. Current status of Innerwick and Dunbar using TABULA and EPCs

The energy demand of the dwelling depends upon the age, typology, and total area (m²) and to calculate energy demand and cost of retrofitting for the heating purpose an Excel model was developed. Energy savings in (MWh/a) were also calculated after standard refurbishment of each type of dwelling. Figure 66 illustrates the total current energy demand for heating and resulting energy demand after standard and ambitious refurbishment in (MWh/a) with respect to the types and construction years of the dwelling.

Furthermore, the total energy demand for heating was noted as 4,457 (MWh/a) and approximately 1,279 (MWh/a) would be the resulting energy demand if the buildings are retrofitted according to standard refurbishment. In this case study, we only calculated energy savings and energy cost for the standard refurbishment, and from Figure 66 the resulting energy demand of 1880 (MWh/a) is remaining after the standard refurbishment of dwellings.

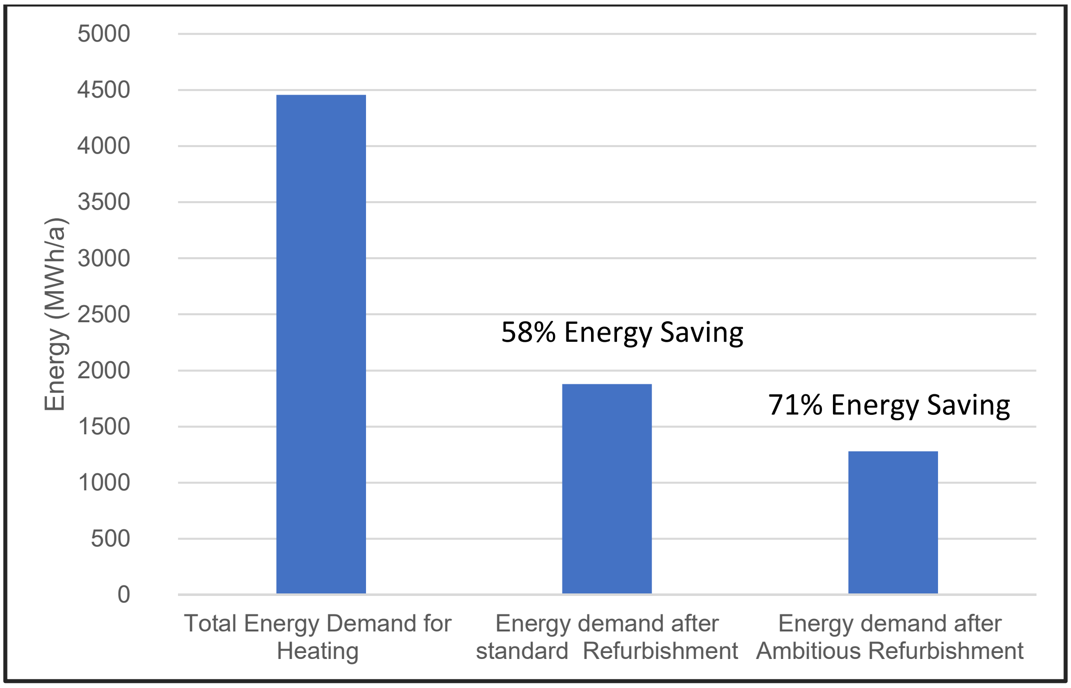


***Figure 66**. Comparison of Current Energy Demand and Energy Saving Potential after Standard and Ambitious Refurbishment in Innerwick (MWh/a). Source: IC2023 Team, (TABULA, 2014)*

Figure 67 illustrates the percentage of energy savings and the average cost of retrofitting for all the Ward. It is evident that there is no such significant potential for energy savings through retrofitting methods based on the analysis of the energy efficiency potential in Dunbar. Further, it can be noticed from the map in Figure 67 that, there are some locations near Dunbar city centre and in the suburbs where the percentage of energy potential exists up to 87%. This suggests that focused retrofitting measures in these areas can result in significant reductions in energy consumption and associated costs.

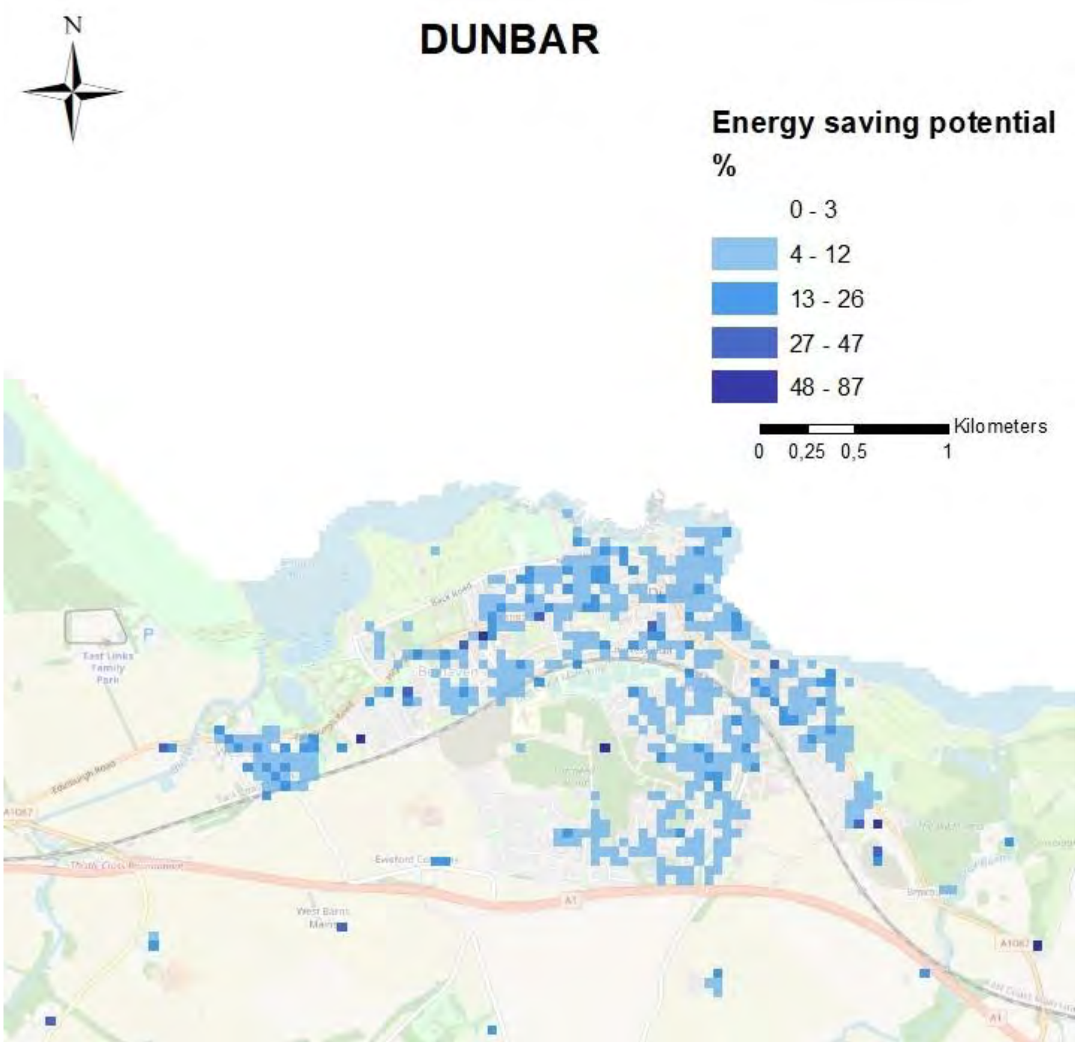


Figure 67. *Map for the percentage of energy-saving potential in Dunbar. Source: IC2023 Team*

Moreover, according to the database of EPCs, published by the Energy Saving Trust (Trust, 2019), the current energy efficiency status for 3,374 dwellings can be analysed. Table 28 represents the current energy efficiency rating and energy cost potential future savings in Dunbar and East Linton. According to the EPCs database, the average energy efficiency rating was noted as 69 and can be improved to 84 after performing the recommendations provided by the Energy Saving Trust (Trust, 2019).

Table 28. *Overview of EPCs data for Dunbar. Source: IC2023 Team*

EPCs database from Scottish Govt.	Calculated Average
Current Energy Efficiency Rating	69
Potential Energy Efficiency Rating	84
Potential future savings over 3 years	£ 741.16

The energy efficiency rating map shown in Figure 68 was created by joining the property UPRNs from the EPCs database and polygon geometry (area and perimeters). The map provides a comprehensive overview of the current energy efficiency performance of different locations in Dunbar. The number 1 to 8 shows the buildings that have less energy efficiency ratings and the range 61 to 137 presents the buildings that have high energy efficiency ratings. Furthermore, from the map below it can be noted that the dwellings which have high energy efficiency ratings are located on the outskirts of Dunbar. Noticeable numbers of dwellings with low energy efficiency ratings are located near the city centre of Dunbar.

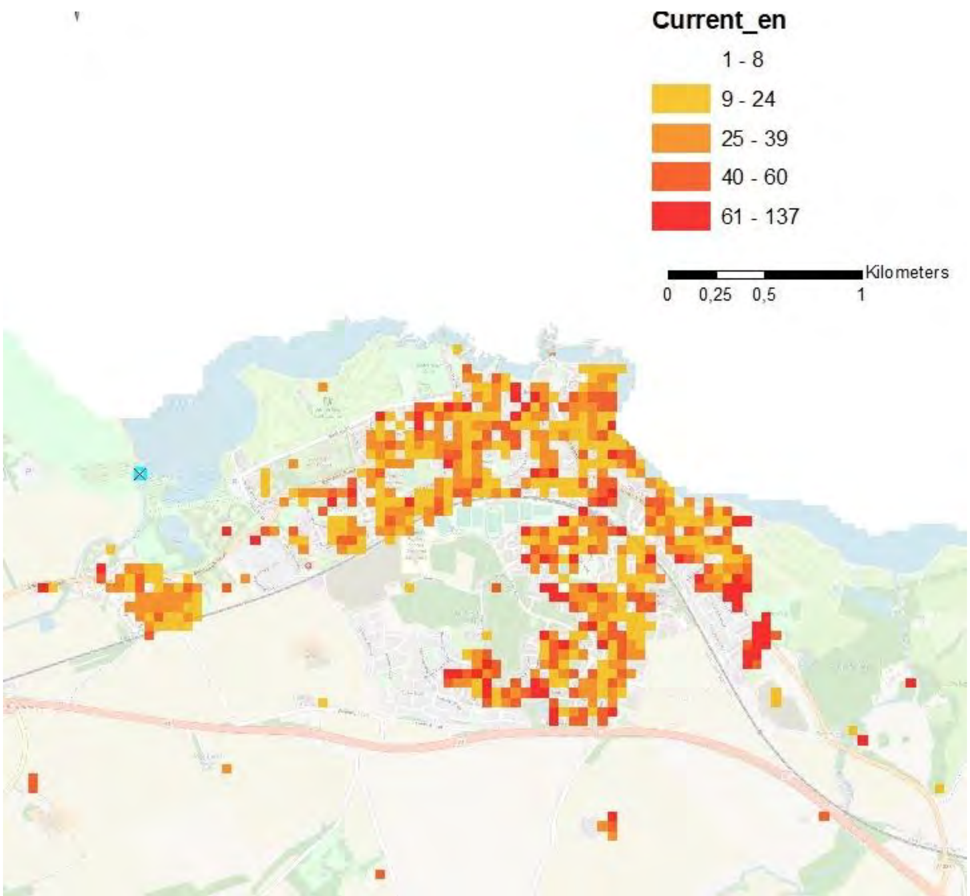


Figure 68. Map for energy efficiency rating in Dunbar Scotland. Source: IC2023 Team

15. Heating Technologies

In May 2018, the Scottish Government launched an energy-efficient program that outlines several measures to encourage low-carbon heating systems in buildings (SG, 2020). Most homes currently use gas for heating (ET, 2021). Households in Scotland will need to modify their heating systems to achieve the established goals. Heat pumps, electric combi boilers, biomass boilers, solar water heating, and other low-carbon heating options can all be implemented.

By 2030, Scotland's heat-in-buildings strategy aims to install one million low-carbon heating systems in one million homes and double the annual number of heat pump installations. The Scottish government has devised a strategy and is collaborating with businesses to reduce the purchase price of heat pumps compared to that of boilers powered by fossil fuels. In addition, the Government has established a £60 million innovation fund to train 40,000 installers annually to make clean heat systems easier to install (GOV.UK, 2022).

The Innerwick community consists of a large variety of building stocks and there is no main gas for heating contrary to most other populated areas of Scotland. It resulted in higher-than-average carbon emissions and was relevant to advancing our study on the suitability of heat pumps for heating.

There are many factors that impact which type of heat pump is most suitable, including the type of building construction, the level of energy efficiency, the installation cost, the current heating technology and heat distribution system, as well as limitations related to internal and external space, among others.

15.1. Brief description of heat pumps as a low-carbon solution

Heat pumps are a viable alternative for energy-efficient heating for residential and commercial buildings because they can absorb heat from air or ground and transfer it into the interior area. The refrigerant enters the evaporator as a low-temperature liquid, absorbs heat from the heat source through evaporation at low pressure, and exits as a low-temperature vapour. The evaporator serves as a low-temperature heat exchanger. After that, the low pressure of the low-temperature refrigerant rises to a pressure corresponding to the compressor's condenser's desired condensing temperature. The refrigerant enters the condenser as a high-temperature vapour, rejects heat to the heat sink through condensation, and exits as a high-temperature liquid. The condenser serves as a high-temperature heat exchanger. As a throttling device, the expansion valve lowers the temperature and pressure of hot liquids so that they can return to the evaporator for the cycle to repeat (Bhatia A. , 2018). Reverse valves can also be used in the cooling mode of heat pumps that are designed for both heating and cooling. Figure 69 gives a schematic diagram of the operation of heat pumps.

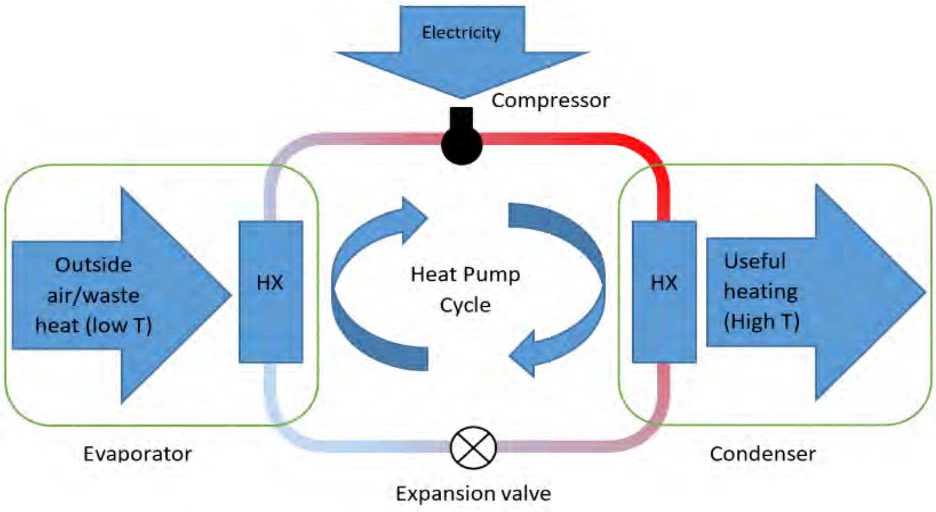


Figure 69. *The heat pump cycle. Source:* (Automatic heating, 2018)

The heat transferred using a heat pump is greater than the energy needed to drive the cycle. The heat pump's efficiency is measured by its Coefficient of Performance (COP). The COP is the ratio of the heat produced per unit of electrical energy consumed when pumping the heat. The efficiency performance tends to reduce during periods of severe cold.

In moderate climate conditions, electrically driven air source heat pumps used for space heating applications usually have a COP of at least 3·5 (Bhatia A. , 2018). This means that 3.5 kWh of heat output for every 1 kWh of electricity is used to run the pump. The primary factors that affect the efficiency of heat pumps are outdoor temperature, indoor temperature, insulation of the building and sizing of the pump.

15.2. Types of heat pumps

15.2.1. Air to Air heat pumps (AAHP)

AAHP can provide both heating and cooling functionalities. They use air heat to warm the indoor environment in the heating mode. Tubing and a transfer medium connect the indoor and outdoor units (refrigerant). The interior unit performs condensation and circulates hot air into the space while the outdoor unit acts as an evaporator to collect heat from the air. The heat pump does the opposite regarding summer cooling, expelling the heat from the interior air outside.

15.2.2. Air to Water heat pumps (AWHP)

Heat is transferred from the outside air to water through air-to-water heat pumps, which can then be used for space heating, hot water for faucets, showers, and other household tasks. Two components comprise the system: an inside unit and an outdoor unit. The indoor unit is connected to a third part, a hot water storage tank. To provide direct hot water to taps for home purposes or to channel heated water across a low-temperature central heating network, or radiators, heated water up to around 55°C may be used (Bhatia A. , 2018).

15.2.3. Ground Source heat pumps (GSHP)

These heat pumps generate heating and cooling using the earth's comparatively warm surface. A fluid-filled underground conduit passes through long lengths of underground pipework. The fluid in the pipework absorbs heat from the ground and transfers it to the buildings. Because no external energy is needed to heat or cool the loop water, the heat transfer from and to the piping is passive. The fluid can be circulated in a closed loop with just a tiny circulation pump.

15.2.4. Water Source heat pumps (WSHP)

Heat is extracted from groundwater or surface water using water source heat pumps. They operate effectively in the heating mode and deliver cooling with excellent efficiency. Two wells must be drilled in WSHPs that use groundwater. Water is drawn from one well, sent to the heat pump, and then returned to the ground. When surface water is used, it is taken out and then put back in again using a closed loop system (seai, 2020).The diagrams in Figure 70 below gives a pictorial view of the operations of the different types of heat pumps.

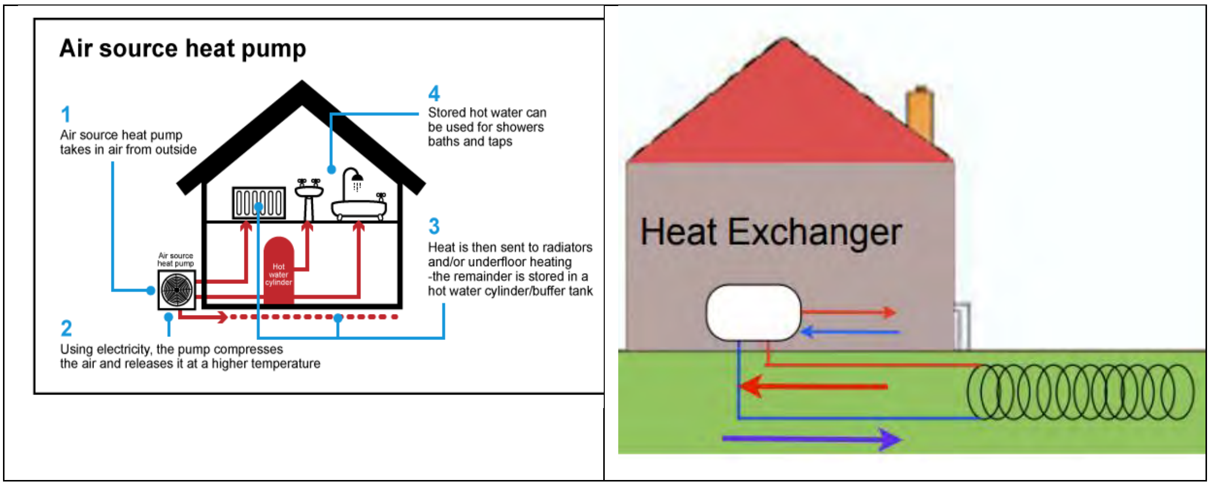


Figure 70. ASHP and GSHP. Source: (CL, 2019) (Countryside, 2011)

15.3. Technical Feasibility of heat pumps

Ground Source heat Pumps (GSHP): The deployment of GSHPs was not considered in the analysis because these pumps require excavation works and laying pipes can raise complexities due to space constraints.

Water Source heat Pumps: Similar to the GSHPs, it also requires drilling and was not considered as a feasible solution in the analysis.

Air to Air heat Pumps: The majority of houses in the UK utilise central heating with radiators as their primary heat source, according to the English housing survey from 2020. Adopting ASHPs will therefore be a workable solution. In contrast to other heat pumps, AAHPs need higher insulation levels and bigger radiator sizes to transfer heat at lower forward temperatures.

Air to Water heat Pumps: They do not need air ducts because they are made to connect quickly to existing radiators. Also, they do not require as much work during installation as other heating systems that call for drilling. Moreover, unlike GSHP, fluid is not pumped around pipework using energy.

Based on these reasons, the deployment of AWHP is considered to be more feasible solution in the analysis.

15.4. Sizing and cost parameters of AWHPs

The sizing of a heat pump for an application depends on several factors including heat load calculation, temperature range, energy efficiency and many more.

According to (Nesta, 2022), UK household's typical nominal heat pump capacity ranges from 5KW to 16KW. We divided the buildings into three categories (small, medium, and large heat demands) based on the BEIS research report code and verified with the National Energy Efficiency data framework gas consumption figures in order to choose the right size of heat pumps that could be installed to provide heating solutions. For the small, medium, and large buildings, the yearly heat demand was 9,500, 14,500, and 22,000 KWh, respectively (Nesta, 2022).

Additionally, the team also had a conversation with the consultant working on the ridge insulation project in the community and he provided us with a formula that was also utilized to verify the size ranges of heat pumps.

In modelling the cost of installing the heat pumps in various houses, we assumed that only houses which have boiler or heating systems with "poor", "very poor" or "average" energy efficiency will require heat pumps. Table 29 gives a breakdown of the heat pump sizes and cost that is used in the model.

Table 29. *Cost and size parameters of heat pumps based on building category.*
Source: (Nesta, 2022)

Property type	Heat pump size (kW)	Upfront Cost (£)
Smaller home	5	9,100
Medium home	10	10,100
Large home	16	13,100

It was calculated that the total cost of installing heat pumps as low-carbon heating solutions for Innerwick will be around £689,800 and the cost for Dunbar and East Linton based on houses with EPC information will be around £31,015,400. The estimated cost to retrofit houses in Dunbar with poor or average boilers is around £6,575,800.

16. Calculation of retrofitting cost and energy-saving potential

In this report, the cost of retrofitting and energy saving potential of Innerwick as a specific case, and Dunbar & East Linton as a general case are estimated with different approaches.

To calculate the cost of upgrading the energy performance of buildings we used TABULA (for realizing retrofitting requirements) and a report named "Updating the Cost Assumptions for BEIS's Energy Efficiency Modelling" prepared by Cambridge Architectural Research and published by UK Department of Energy & Climate Change (DECC). In the DECC report cost data is collected by interviewing organisations carrying out energy-saving retrofitting (Jason Palmer, 2017).

The cost of 18 measures that are applicable for improving the energy efficiency of a building are reported in three ranges: lowest, mean, and highest cost. Moreover, costs are reported for a range of house types and two sizes that are summarized in Table 30.

Table 30. *Classification of House types for cost calculation. Source:* (Jason Palmer, 2017)

House type	Floor Area (m^2)
Small flat	<54m^2
Large flat	>54m^2
Small mid-terrace house	< 76m^2
Large mid-terrace house	> 76m^2
Small semi-detached / end-terrace	< 80m^2
Large semi-detached / end-terrace	> 80m^2
Small detached house	< 117m^2
Large detached house	> 117m^2
Bungalow	Approx. 117m^2

16.1. Calculation model for Innerwick

In terms of comprehensiveness, EPC data gives us better information for calculating cost and energy saving, but an insufficient number of EPC certificates for Innerwick obstructed us to use this source. Therefore, we used the TABULA report as a source for typology, energy demand, energy saving potential, and requirements for retrofitting.

For calculating the total cost of retrofitting in Innerwick village, we applied two approaches:

- **Approach A**: Using the mean costs of retrofitting for each type of house (Table 31). In this approach, buildings are classified into small and large based on the floor area, which is extracted from the footprint of polygons in OpenStreetMap.
- **Approach B**: Using the cost of retrofitting per unit (Table 32). In this approach used for calculating wall insulation cost, the area of exterior walls for each building block is required. To calculate the area, we extracted the perimeter of buildings from OpenStreetMap in ArcGIS and assumed 2.7 metres as the standard wall height.

Since there are no flats in Innerwick and the number of Bungalows is very limited, we removed these categories for cost calculation in this model and only considered Terrace houses and Detached houses.

It is worth noting that in Table 31 there are internal, external and cavity wall insulation alternatives, although cavity wall insulation can be complementary to solid wall insulation. In addition, the cost of glazing was only reported for uPVC windows and not considered changing frames. The costs for aluminium or timber frames might be up to double the cost of uPVC (Jason Palmer, 2017).

Table 31. *List of different retrofitting measures cost per houses type (1st approach)*
Source: (Jason Palmer, 2017)

House types	Mean cost per houses type (£)				
	Internal Wall Insulation	External Wall Insulation	Cavity Wall Insulation	Loft Insulation	Glazing
Small mid-terrace house (<76m²)	3,700	6,800	460	350	3,900
Large mid-terrace house (>76m²)	4,000	7,500	505	420	5,000
Small semi-detached or end-of-terrace (<80m²)	6,800	7,800	529	360	5,500
Large semi-detached or end terrace (>80m²)	7,000	8,400	660	470	6,400
Small detached house (<117m²)	7,200	10,200	680	510	5,900

House types	Mean cost per houses type (£)				
	Internal Wall Insulation	External Wall Insulation	Cavity Wall Insulation	Loft Insulation	Glazing
Large detached house (>117m²)	9,400	11,500	950	600	8,300

Table 32. *List of different retrofitting measures cost per unit (2nd approach)*
Source: (Jason Palmer, 2017)

Cost per unit (£)	Internal Wall Insulation	External Wall Insulation	Cavity Wall Insulation	Loft Insulation	Glazing
Cost per m² wall area (materials + labour)	95	116	6		
Cost per m² roof area (materials + labour)				10	
Cost per window (materials + labour)					530

Additionally, in the second approach, to calculate the cost of glazing we used an average number of windows for each type of house in UK which is reported in Table 33.

Table 33*. Average number of windows for each type of houses.*
Source: (Britannia Windows, 2022)

Type of house	Average number of windows
Flat/apartment	3
Mid- terrace	6
Semi-detached	7
Detached	9

Since each building has different energy performance and requirements for retrofitting, the estimation of the exact cost of retrofitting for all houses in an area is a relatively long process that needs a considerable amount of time. Time constraints in this project hindered us to examine every house in Innerwick village. So, retrofitting requirements for each house were extracted from "TABULA" project report. Since TABULA does not contain floor insulation for standard retrofitting, we did not consider floor insulation for standard refurbishment in

Innerwick. Table 34 shows requirements for standard retrofitting based on typology and construction year. Figure 71 shows an overview of the calculation steps for Innerwick.

Based on the necessity of each retrofitting measure (Table 34), the Excel model calculates the cost of retrofitting for different measures. Since three types of wall insulation are available for improving the energy performance of walls, we selected only cavity and internal wall insulation for estimation of the total cost. Both internal and external wall insulation are not required for a house. Besides, internal wall insulation is more cost-effective and for semi-detached or terrace houses is more applicable if only one house wants to install it. Although external wall insulation has its own advantages, we dismissed it in total cost.

According to TABULA, buildings built after 1945 have cavity walls and those built after 2004 have cavity wall insulation. TABULA recommends solid wall insulation for buildings built between 1945 and 1990 and cavity wall insulation for houses built between 1991-2003 for standard retrofitting (TABULA, 2014).

Table 34. *Standard retrofitting requirements based on TABULA project.*
Source: (TABULA, 2014)

Year of construction	Wall insulation	Cavity wall insulation	Loft Insulation	Glazing
pre-1918	✓	X	✓	✓
1919-1944	✓	X	✓	✓
1945-1964	✓	X	✓	✓
1965-1980	✓	X	✓	X
1981-1990	✓	X	✓	X
1991-2003	X	✓	X	X
2004-2009	X	X	X	X
2010-	X	X	X	X

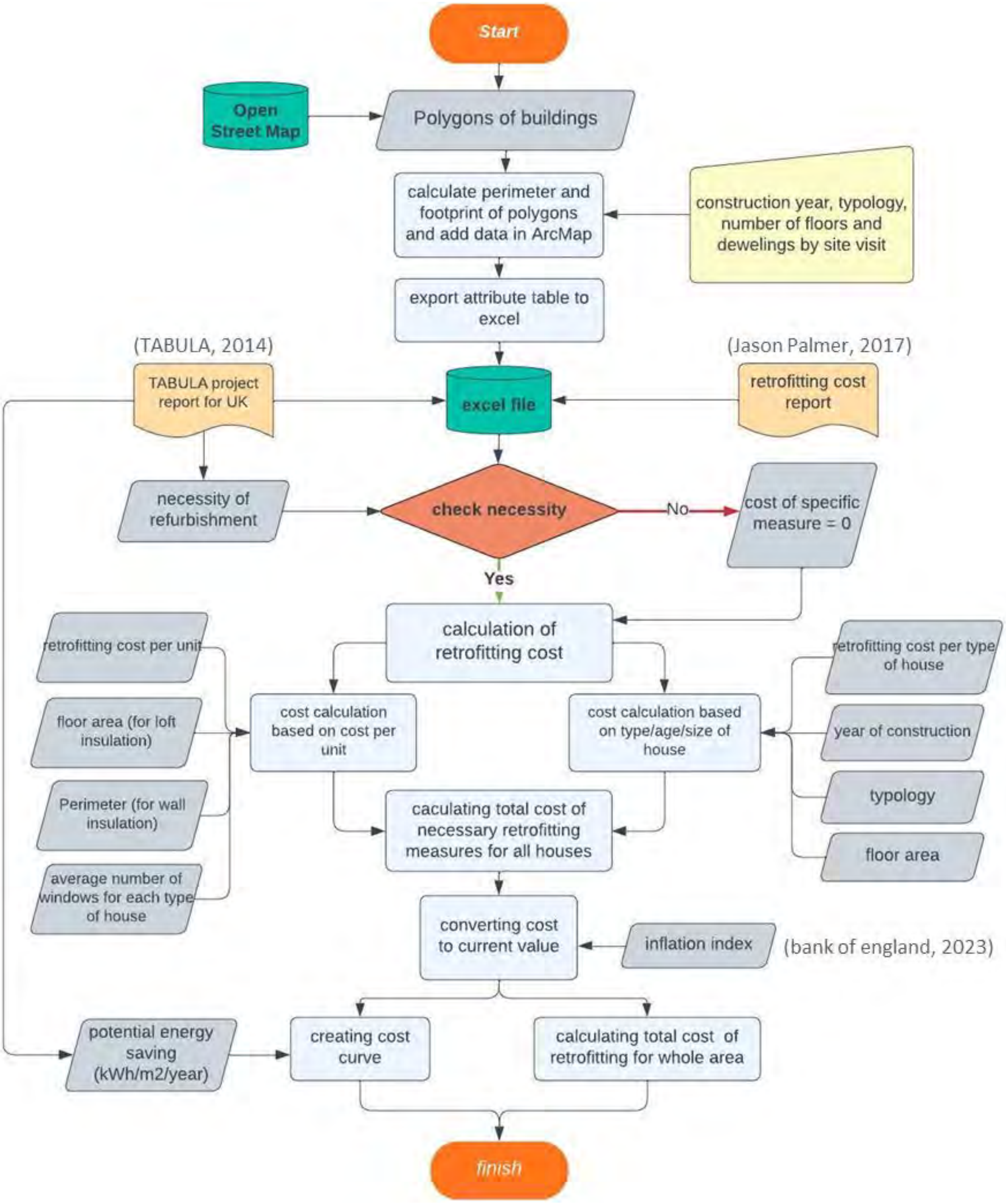


***Figure 71**. Flowchart of calculation model for Innerwick*

Since our reference for the cost of retrofitting in the UK was for 2015-16, we considered the inflation index to convert cost to the current value. According to the Bank of England, the value of 1£ in 2015 is equal to 1.22£ in 2022 (Bank of england, 2023).

Thanks to TABULA project, we could assign current energy demand for heating and potential energy demand for heating after standard refurbishment (or energy saving potential). Based on these data we calculated the cost of energy saving by retrofitting per kWh and drew a cost curve. Figure 72 shows the marginal costs of energy saving by standard retrofitting for all houses in Innerwick. Each dot on the curve represents a building block in Innerwick. With

0.5 £/kWh about 23% of energy saving can be achieved and the marginal cost of improving efficiency by 50% is around 1 £/kWh.

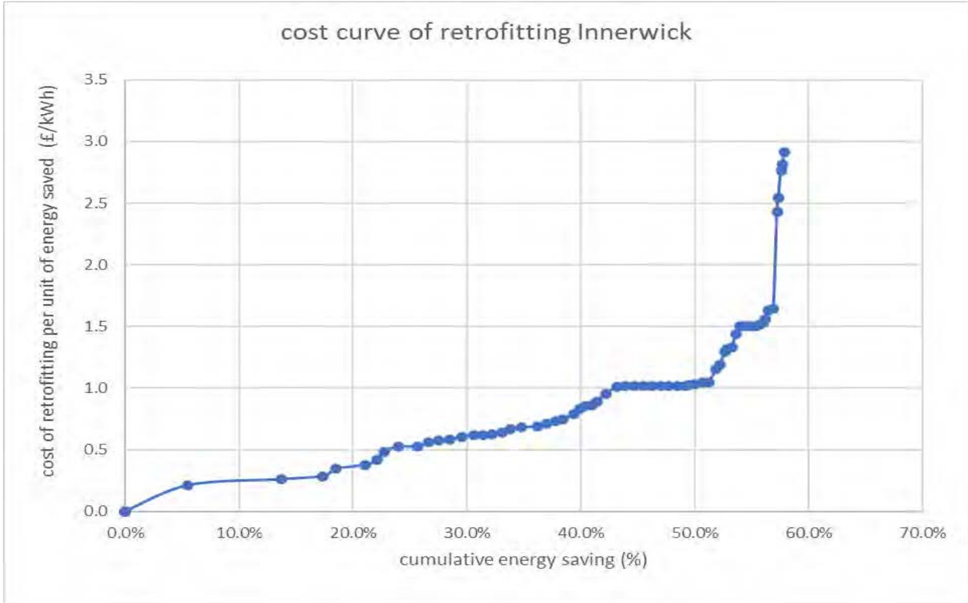


Figure 72. *Cost curve of improving energy performance of buildings in Innerwick (per building block). Source: IC2023 Team*

Table 35 shows a comparison of the cost of standard refurbishment of the current buildings based on the two mentioned approaches. In most cases, the cost calculated by cost per unit is higher in approach B than in approach A except for glazing, because the floor area of buildings in Innerwick is normally larger than the average area considered in the report.

Table 35. *Total cost of different measures based on cost per unit or cost per type of house. Source: IC2023 Team*

Parameters	Number of candidate houses	Approach A	Approach B
Total cost of loft insulation (£)	61	45,457	143,448
Total cost of cavity insulation (£)	2	1,610	2,788
Total cost of glazing windows (£)	40	450,546	365,329
Total cost of external wall insulation (£)	63	876,692	1,508,251
Total cost of internal wall insulation (£)		684,542	1,235,206
Sum of total cost with internal wall	63	1,182,156	1,746,770
Sum of total cost with external wall		1,374,306	2,019,816
Total cost of heat pump (£)	68	689,800	

16.2. Calculation model for Dunbar based on EPC

The method applied for cost calculation in Innerwick cannot be applied for a larger area because it needs a site visit to identify the type of building, age, number of floors, and number of dwellings. So, for estimating the cost of retrofitting in Dunbar and East Linton we used data from EPC certificates. As mentioned before, not all houses in the Ward have an EPC certificate.

In each EPC certificate, there is a breakdown of each element of a house including walls, roof, floor, windows, main heating, main heating controls, secondary heating, hot water, and lighting. In this breakdown, each element has a description and a current rating. This rating attributes a class from very poor to very good to each element (five classes).

To calculate the cost of retrofitting for those houses with EPC certificate, first, the efficiency rating of each element of a house is checked and if its efficiency is not classified as "good", the cost of retrofitting will be calculated based on the given cost in the report mentioned before. Figure 73 depicts the steps of cost calculation with EPC data and visualization on the map.

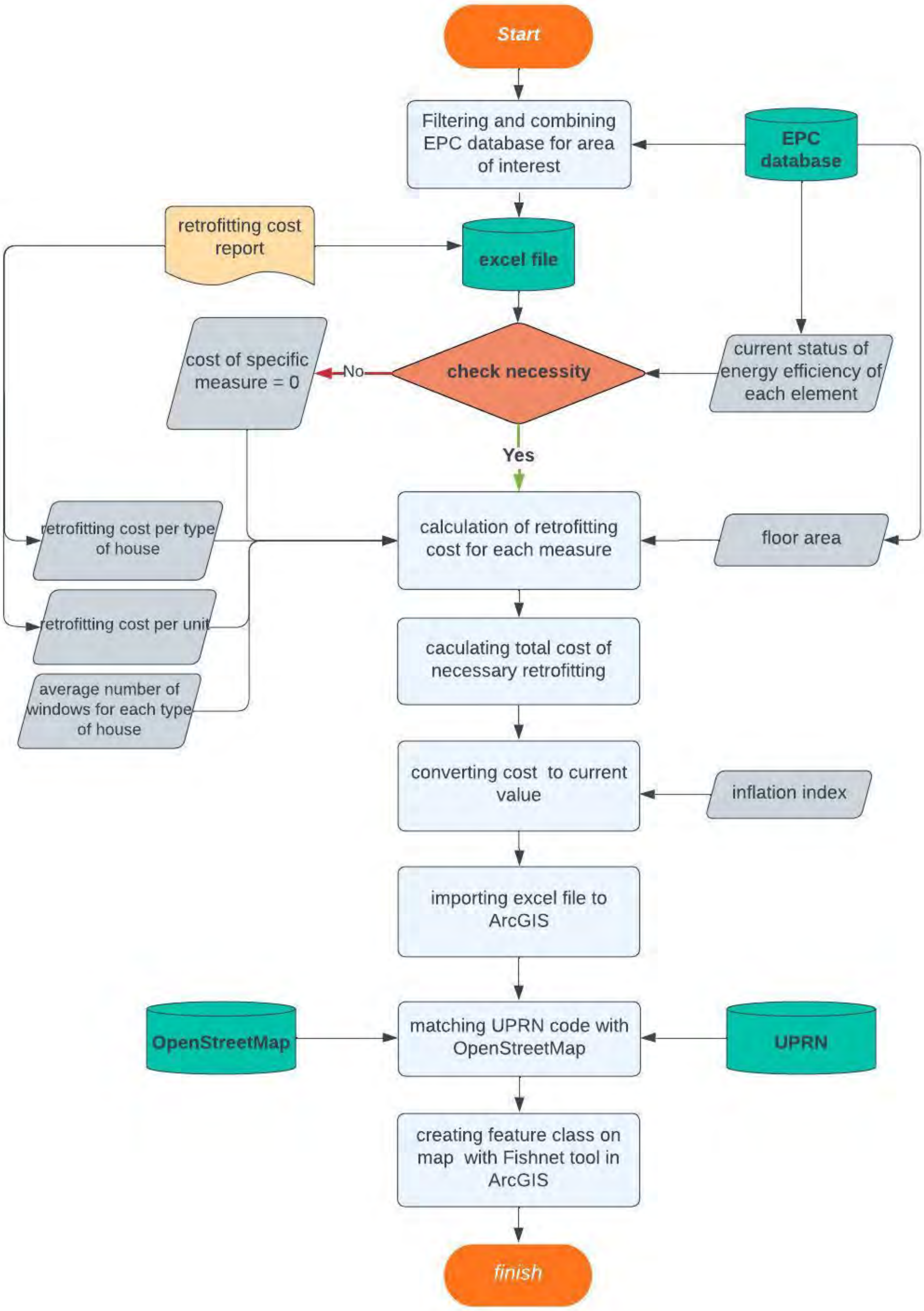


***Figure 73**. Flowchart of calculation model of retrofitting cost based on EPC. Source: IC2023 Team*

In this model, a combination of the two approaches in the first model is applied. For wall insulation, the average cost of retrofitting per type of house is taken as a reference since calculating the area of the exterior wall for each house was challenging for some properties in ArcGIS. But the cost per unit is used for calculating loft insulation and glazing cost. Regarding heat pump cost, we assumed only houses which have boiler or heating systems with "poor", “Very poor” or “average” energy efficiency require heat pumps. After calculating the cost of retrofitting, results were shown on a map with 50×50 m^2 grid.

Table 36 shows a summary of cost calculation for all houses with EPC certificates in Dunbar for two levels of retrofitting. The basic column shows numbers for those houses with urgent need of retrofitting, which means the energy efficiency of at least one main component of the energy system is poor. The medium column illustrates values for those houses in which the energy efficiency of at least one element is average or poor. Figure 74 also shows the average cost of retrofitting in a 50×50 m^2 grid in Dunbar considering houses which have any elements with poor energy performance.

Table 36. *Result of cost calculation for buildings with EPC certificate. Source: IC2023 Team*

Parameter	Basic	Medium
Average cost of retrofitting (£)	9,618	11,922
Share of houses needs retrofitting	34%	61%
Total cost of retrofitting (£)	11,060,648	24,416,012

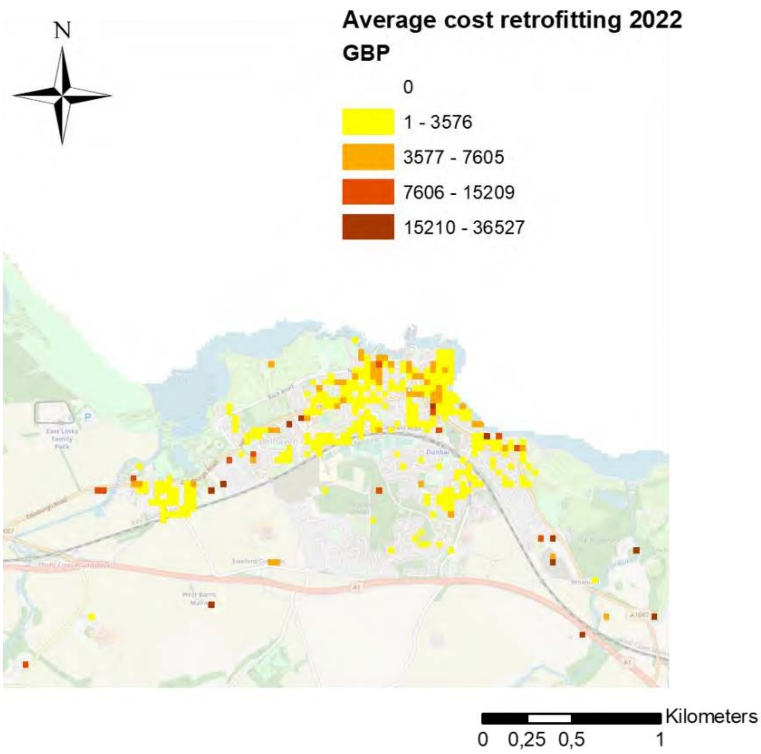


Figure 74. *Average cost of basic retrofitting in Dunbar. Source: IC2023 Team*

16.3. Recommendations to improve the calculation model

Because of certain limitations like time constraints, data access issues, and insufficient knowledge about the local architecture, a few assumptions had to be made during the calculation process:

- One cost of retrofitting for each type of house or one cost per unit for every house is applied and requirement intensity is not considered.
- Existing older retrofitting measures could not be identified.
- The area of a building was identified by means of the typical size of buildings/dwellings.
- Some construction years in Innerwick guessed.
- In the Innerwick model, the cost was calculated for building blocks (polygons) not individual dwellings. So, the cost on the map represents a cumulative cost of retrofitting for terrace or semi-detached houses.
- Floor insulation, Energy efficient lighting, and insulating hot water cylinder were eliminated.
- The total floor area of the building was assumed equal to the gross external area which includes the area of the external wall.

Regarding these assumptions, various opportunities exist for improving this model and estimating more precise costs that are listed below:

- Revision and completion of EPC records for all buildings.
- Revision of typology of houses by an architecture expert for Innerwick.
- Customize requirements of retrofitting for each house for Innerwick.
- Preparing a list of retrofitted houses in Innerwick.
- Evaluation of energy saving in retrofitted houses.
- Preparing more customized cost reference that reflects the level of improvement.
- Preparing more precise data about the construction year for Innerwick.
- Updating the cost of retrofitting and adding additional costs such as feasibility study, VAT, and transportation costs.
- Considering the complexity of the built form.

17. Impact Assessment

17.1. Fuel poverty reduction

The fuel poverty level in East Lothian is at 24% (SCHS Local, 2019). This statistic is from the pre-crisis period, thus it can be higher nowadays. A projection of Dunbar and East Linton dwellings is at 7,709 dwellings, using the 24% fuel poverty level, 1,850 dwellings will be considered fuel-poor at that stage. To achieve Scotland's target to reduce fuel poverty levels to 5% by 2040, starting in the year 2026, would imply that 1,850 dwellings need to be retrofitted at an average rate of 9 dwellings per month and 105 per year, for 14 years.

From the 3,374 available EPC certificates, only 2,394 are catalogued, as per their EPC certificate, with the possibility to upgrade energy efficiency bands. This is according to their construction and finishes. With this in mind, it is possible to reduce fuel poverty to 16% after retrofitting 616 dwellings as shown in Figure 75. That implies a reduction of 8% if the dwellings in fuel poverty are considered, the possible reduction is 33%. The cost per year of doing so is shown in Table 37.

Furthermore, it is important to expand the EPC database to have a more complete database that will help strategize where the benefits would tackle better fuel poverty. For more detailed information about the results please refer to Annex 6.

Table 37. *Investment in retrofits per year. Source: IC2023 Team*

Year	Cost of retrofits
2026	£ 169,622
2027	£ 187,354
2028	£ 197,084
2029	£ 238,434
2030	£ 259,360
2031	£ 281,022
2032	£ 294,828
2033	£ 311,536
2034	£ 326,640
2035	£ 314,202
2036	£ 361,983
2037	£ 384,638
2038	£ 390,255
2039	£ 438,658
2040	£ 446,099
2041	£ 299,242
2042	£ 615,648
2043	£ 689,309
2044	£ 266,689

Year	Cost of retrofits
2045	£ 417,333
2046	£ 603,011
2047	£ 560,765
2048	£ 351,990
2049	£ 533,150
2050	£ 745,325

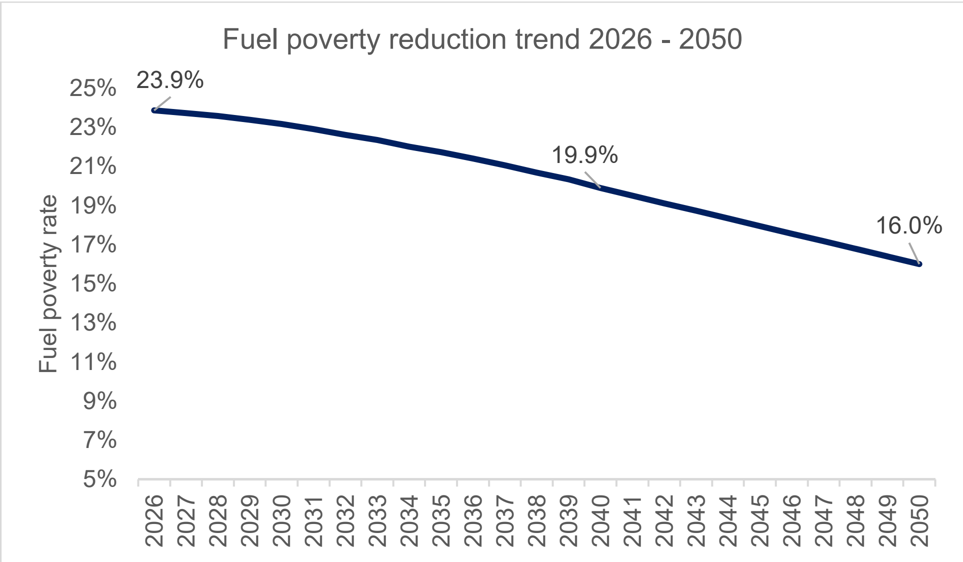


Figure 75. *Fuel poverty reduction potential. Source: IC2023 Team*

17.2. CO2 emission reduction

The United Kingdom (UK) has a net-zero plan to be achieved by 2050. Scotland's Climate Change act of 2009 is very ambitious, setting a net-zero target by 2045 (Gov UK, 2009). The solar PV farm has the potential to contribute to the achievement of this target by reducing Scotland's greenhouse gas (GHG) emissions in two ways. First, by the input of renewable energy-sourced electricity to the grid and second, from the reduction of energy demand because of retrofitting.

Electricity Grid Emission Reduction

From a more local perspective, the East Lothian Council has a climate change strategy plan for 2025. It states that it "will work with communities towards making East Lothian a carbon-neutral county". Part of the key priority areas of this plan includes (but is not limited to) opportunities for sustainable energy, thriving towns, and energy-efficient homes and buildings (East Lothian council, 2020).

The United Kingdom (UK) has a plan to decarbonize electricity production by 2035 (The Climate Change Committee, 2023). Therefore, the potential to participate in the emissions reduction of the electricity grid was calculated until that year.

The total emissions avoided thanks to the solar PV farm were calculated using the total electricity produced by the tilt design. An emission factor of 0.432 tCO2/MWh in 2021 from the current non-renewable sources that are used to produce electricity was used in the calculations (DUKES, 2022). The emissions saved are 94,766 tonnes of dioxide (tCO2). The production of the solar PV system generated 39,803 tCO2, therefore it needs to be offset. Finally, the solar PV system pays for its emissions during its 4th year of operations and can help avoid 54,962 tCO2 of CO2 emissions. Figure 76 below presents the year-by-year progress.

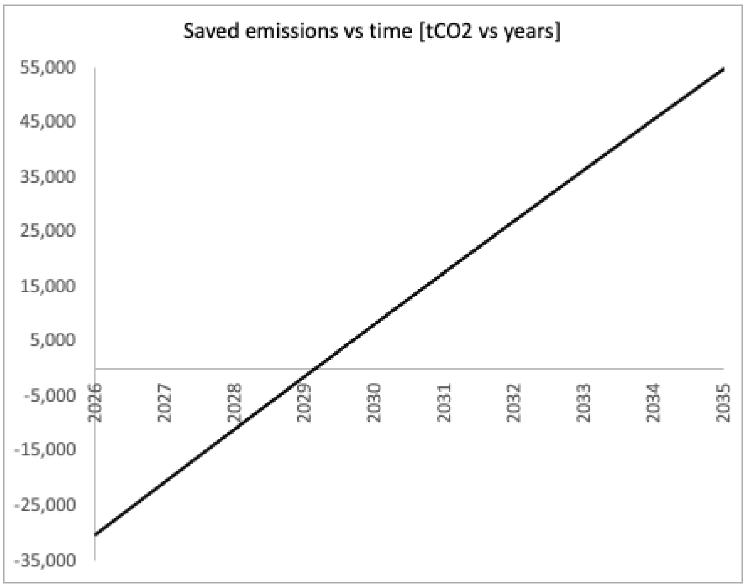


Figure 76. *CO2 emission reduction vs. years. Source: IC2023 Team*

Emission Reduction from Retrofitting

The Department for Business, Energy, and Industrial Strategy (BEIS) published the 2020 emissions of East Lothian as seen in Table 38 below. It is expected that between 2020 and 2040 the total national emissions will decrease by 18% in general for all sectors. From historical data on domestic emissions between 2005 and 2020 (BEIS, 2022) the changing trend was calculated. This trend decreases by -2.9% per year on average.

Table 38. Emissions from all sectors, East Lothian.Source: (BEIS, 2022)

Sector emissions 2020	tCO2e
Industry	493,340
Commercial	20,556
Public sector	23,385
Domestic	163,462
Transport	173,480
Agriculture	110,938
Waste	30,366

After retrofitting 616 dwellings, at the end of the programme, the total potential of emission reduction is expected to be 2,484 tCO2. The total emission is a result of adding all the individual potentials from the prescribed renovations on the EPC certificates. Not all dwellings have the same potential, the lowest potential, of, 0.1 tCO2, comes from renovating dwellings from energy efficiency bands D to C, and the highest, of 31 tCO2, comes from upgrading from F to D.

As can be shown in Figure 77, emission reduction benefits are not necessarily always increasing when investing more. 93% of the proposed retrofitting cost under 25,000 GBP and have the potential of reducing emissions of up to 10 tCO2.

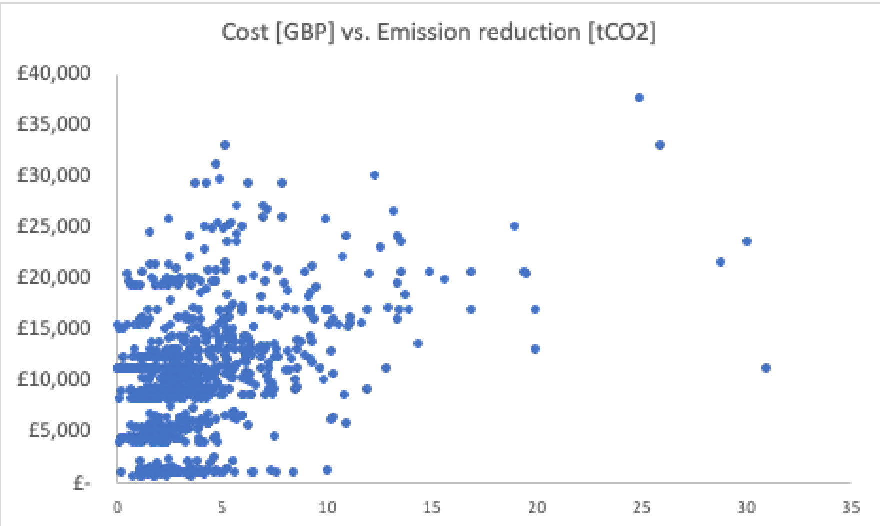


Figure 77. Emission reduction and retrofitting cost. Source: IC2023 Team

If the average historical trend of -2.9% continues, the net zero targets will not be achieved as the domestic sector emissions forecasted in 2050 are 68,044 tCO_2. Efforts of retrofitting from projects like this are relevant to increase the chances of net zero by 2050. Relating the total costs calculated for retrofitting the dwellings with EPC certificates and the total emission reduction potential, it was established that the cost of reducing 1 tCO_2 is 2,632

GBP. This implies implementing solely retrofitting measures for missing emission cover will cost 179 million GBP to attend net zero in the domestic sector.

In summary, this analysis reveals a total retrofit count of 616, which will cost a total of 9.7 million GBP throughout the life of the project. Looking at the initial (current) level of Fuel poverty, 24%, the implementation of this project could reduce it to 16% if all dwellings are considered. This is an 8% reduction. The reduction percentage can go up to 33% if only fuel poverty-affected homes are considered. Furthermore, the project can have a considerable impact on CO_2 emission reduction. 54,962 tCO_2 of CO_2 emissions can be saved by the solar farm by the end of the project. The implementation of retrofit to the households can help reduce 2,484 tCO_2 by the end of the project. In addition, the skill development program can help reduce unemployment and increase the labour force. For more detailed information about the results please refer to Annex 6.

17.3. Job creation

Job creation is among the outcomes anticipated from this project. Potential employment opportunities could arise from the solar PV farm, community benefits society establishment, and retrofitting projects.

In Scotland, even though solar PV capacity is much lower than onshore and offshore wind, which dominate renewable energy generation in the energy mix (Scottish Government, 2020), the number of full-time equivalent (FTE) jobs that can be created by solar PV development is quite high. According to a Fraser of Allander Institute (FAI) study, solar PV can generate 1,070 jobs (direct, indirect, and induced jobs combined) in 2019. The solar industry requires employees with diverse skill sets and experience. There are various direct job roles available in the sector, including surveyors, system designers, construction and trades roles, design and other engineers, and operations and maintenance specialists. The industry has a particularly high demand for construction and trades roles, and engineers involved in creating the distribution and transmission systems. Operations and maintenance specialists monitor the solar systems' performance and carry out maintenance, fault identification, and rectification using energy production data. Moreover, it require jobs on the non-technical aspects of the project such as business, strategic, management, and the whole suppy chain from manufacturing to logistics and transportation (Fraser of Allander Institute, 2021).

The creation of Bencom will result in employment opportunities for individuals working as board members, managers, and staff within the organization. It can also absorb more employment when it has internship program.

Furthermore by utilising the profits from solar PV for retrofitting projects, more jobs can be created. This is mainly due to the labour-intensive nature of the work. The IEA report states that approximately 60% of retrofitting expenditure can go toward labour (IEA, 2020). Retrofitting can generate both direct and indirect employment opportunities. Initially, a construction contractor will need to hire workers for the implementation and installation of energy-efficient measures, which are direct jobs resulting from the investment. Furthermore, the construction work will necessitate the use of materials that can be sourced from either local or imported manufacturers and service providers (ACEEE, 2021).

17.4. Land use conversion

Building a solar farm on grazing pasture may have both beneficial and detrimental consequences on the local ecosystem and biodiversity. Soil erosion, climatic changes, habitat loss, and fragmentation are among the possible negative impacts. But, solar farms can also offer advantages including habitat development and restoration, greater biodiversity, and decreased greenhouse gas emissions with good planning and management (Solar Energy UK, 2022).

The "State of Nature Report" reveals a 60% decline in 1,064 farmland species in the UK, with agricultural intensification being a key contributor (StateOfNature, 2019). However, research shows that effective land management can increase wildlife populations on agricultural land. According to the BRE National Solar Centre, Solar farms can also support biodiversity with proper land management and can result in large increases in biodiversity (BRE , 2014). Each solar farm on agricultural land will require a site-specific plan for preserving biodiversity. Solar farms should strive to maximize benefits for animals whenever possible. The parameters of a solar farm agreement should ideally contain a grazing plan that guarantees the farmer's continued access to the land, ideally in a format that allows the farmer to claim Basic Payment System agricultural support (BRE, 2014).

According to the BRE National Solar Centre, a biodiversity management plan (BMP) is required for each solar farm and outlines the specific objectives and methods for achieving biodiversity conservation, upgrades, management, and monitoring. Developers should consider all BMP components when financing a project, including weed management and site decommissioning (BRE , 2014). The BMP should:

1. Identify the most important components of the site's biodiversity, such as legally protected species, highly endangered species, designated areas nearby the proposed site, and species and habitats mentioned under Section 41 of the NERC Act 2006.
2. Determine any potential effects of the site's development and provide mitigation measures to mitigate them.
3. Describe the site's precise goals for enhancing biodiversity and the planned habitat improvements to meet those goals.
4. Increase connectivity between existing habitats to increase biodiversity in the local ecological network and the larger landscape.
5. choose appropriate sources for seeds and plants, as well as the species to plant.
6. Think about broader improvements like nesting and roosting boxes.
7. Summarise the habitat management plan throughout the site's full existence.
8. A plan for monitoring the site and for management adaptation in response to the monitoring's results.
9. Describe the process for decommissioning the location.

In addition, The BRE National Solar Centre Biodiversity guidance for solar development report plan provides the Best practices in solar farm development that aim to maximize biodiversity improvements, although there are significant limitations, such as legal or planning factors (BRE , 2014). The report provides the following 10 key points:

1. The site should be assessed for its ecological value and potential impacts on biodiversity.
2. There should be early engagement with stakeholders and communities to understand their concerns and incorporate feedback.
3. The solar farm design should prioritize the protection of existing habitats and minimize the loss of biodiversity.
4. The design should incorporate green infrastructure elements, such as hedgerows and wildflower meadows, to enhance biodiversity.
5. The design should also consider the opportunities for habitat creation and restoration, such as planting native trees and creating wetland habitats.
6. The solar farm's operation and maintenance should minimize risks to biodiversity, such as avoiding chemical treatments and reducing lighting.
7. The solar farm's design and management should be regularly monitored and adapted to improve biodiversity outcomes.
8. A management plan should be developed and implemented to ensure the long-term management of the site.

9. Opportunities for community engagement in biodiversity monitoring and management should be identified.
10. Reporting and sharing of monitoring data and outcomes with stakeholders should be undertaken to demonstrate the positive impact of the project on biodiversity.

By following this guidance, solar farms can be developed and managed to minimize their impact on biodiversity and contribute to enhancing local ecological value.

17.5. Conclusions

To reduce fuel poverty, a high level of investment is required regarding economic and human resources. Companies like this Bencom could contribute to achieving the fuel poverty reduction targets of 5% by 2040. Moreover, with the effective use of public funds for social housing fuel poverty can be kept at lower levels. As has been initially stated in the report, the main driver of fuel poverty is income therefore projects that produce job opportunities and projects for education should be developed.

An additional challenge is brought by the urgency of transitioning to a more resilient energy system that should meet the heating and other energy-related needs of the households without greatly harming their family economy while meeting net-zero targets. It is not similar to focusing on retrofits to decrease fuel poverty as it is to focus on decreasing energy demand. This is because not all high energy-demand dwellings suffer from fuel poverty, but all fuel-poverty households can benefit from energy demand reduction.

The Bencom must establish its priorities with clear and relevant goals and activities. This will help its achieve success by attracting investment and by its acceptance and growth in the community.

18. Recommendations

It is recommended that the company invests in outreach communication materials because it is possible that not every household who needs retrofitting will now that they can benefit from this company. A strong marketing strategy is recommended to reach out to a larger audience of potential shareholders in all of East Lothian.

It is important to note that only dwellings with an EPC have been considered for the retrofitting and fuel poverty analysis. It is then recommended that the EPC certificate count is increased to create a larger data base on which priorities can be established and actions can be implemented.

Based on the findings of the study, several recommendations are made to enhance the financial viability and operational efficiency of the proposed 20 MW Solar PV project co-located with a BESS.

Firstly, it is recommended to update the financial and investment model with the latest figures before commencing the project to ensure that the financial parameters are current and accurate. Additionally, while the price forecasting model provides useful insights for negotiating PPA prices and gaining insights into the future renewable-based electricity system, it should be supplemented with the latest PPA price deals in the UK to ensure more accurate pricing estimates.

Secondly, while the revenue optimization model provides a simplified picture of future revenues from energy arbitrage, it could be enhanced by utilizing the latest electricity prices to estimate revenues. Furthermore, the study did not analyse revenues from frequency response services, and as such, there is a scope for further analysis to optimize battery operations by including revenues from the frequency response services market.

Thirdly, most BESS assets are managed by utility or trading companies with specialized expertise in the field, and therefore, it is recommended to utilize the results from the revenue optimization modelling to negotiate better revenue deals from BESS optimizers. Additionally, investing in a state-of-the-art Asset Performance Management system to track battery health in real-time could improve operational efficiency and help BESS optimizers make informed decisions.

Finally, after 15 years of battery life, it is recommended to analyse the battery conditions, and if necessary, replace battery cells at a relatively lower cost after reaching maximum degradation levels. This would help enhance the life of the BESS and ensure optimal performance throughout its lifespan.

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