An assessment of the potential for solar PV electricity generation from rooftops in Northern Ireland

Final Report
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EXECUTIVE SUMMARY

1. Following the passing of The Climate Change Act 2008 (2050 Target Amendment) Order 2019, extensive electrification, supporting the major expansion of renewable power generation, has become a key priority to reach 'net-zero carbon' in the UK. In Northern Ireland (NI), The Climate Change Act (Northern Ireland) 2022 likewise sets a Net Zero target by 2050 and the Northern Ireland Executive's Draft Green Growth Strategy sets out the Executive's long-term vision, commitments, and recognition of the need for adaption and mitigation measures and new policies to facilitate the change required to reduce admissions. The strategy envisions, inter alia, the need to scale up low-carbon technologies and increase the volumes of renewable generation and energy improvements in buildings (N.I. Executive, 2021, p.37).

2. This report was commissioned by the Department for the Economy (DfE) as part of the 10X Economy An open call specifically for energy research proposals. This research relates to one 10X Economic pillars of Zero Carbon Technologies, by undertaking an assessment of the solar photovoltaic (PV) rooftop generating potential for Northern Ireland (NI) and the role of battery storage for linked to domestic PV systems generation. This aligns with two of the five Energy Strategy principles namely, principle 4; to replace fossil fuels with renewable energy, and principle 5; to create a flexible, resilient, and integrated energy system and under the research programme theme "Focus on Key Technologies and Priority Clusters".

3. The determination of the potential level of rooftop PV adoption is an important step in informing policy with an evidence base and for the transition to meeting the net-zero legislative requirements . Further, energy storage can support this transition by bringing flexibility to the grid but since it represents high capital investments, the right choices must be made in terms of the technology and the location point in the network. Most of the potential for storage is achieved when connected further from the load, and Battery Energy Storage Systems (BESS) are a strong candidate for behind-the-meter integration.

4. This research was commissioned to undertake;

(i) an assessment of roof top PV potential generation across all suitable* building types within NI applying to 1,414,135 buildings with a total rooftop area of **168,646,423**m^2. The research outputs provide estimates for generating potential for PV on the following building types, Residential, Commercial, Industrial and Residential General (Garages), Non Residential General Buildings together with All Other Building types which includes uses such as Education and Health buildings etc.

- Note suitable buildings are those extracted from the Fusion Data Building Polygons of area 10m^2 plus

(ii) an assessment of PV potential to be at varying spatial geographies, such as PV generation potential estimates for residential property typologies and commercial classifications at Local Government District (LGD) (Councils), and Census statistical output geographies such as Super Output Areas (SOA), Small Areas (SA) and Data Zones (DZ) and

Note, there are 3,780 Data Zones (DZ2021) across Northern Ireland, which nest within the 850 Super Data Zones (SDZ2021). These in turn nest within the 80 District Electoral Areas (DEA2014) and 11 Local Government Districts (LGD2014).

(i) assessing the potential impact of battery storage within the residential sector. Energy storage improves the efficiencies of PV generated electricity usage within residential households and limits the extent to which electricity is exported to the network, as the network was not designed to accommodate distributed energy generation, such as domestic PV.

(ii) This project also investigates the deployment of behind-the-meter batteries operating to maximise the renewable energy consumption rate of PV generated electricity from domestic roofs as they can increase financial benefits to homeowners and help further reduce carbon emissions. The benefits of domestic batteries can be expanded to the electricity network, where they can provide optimal and location-specific services (e.g. peak saving), increase the penetration of intermittent renewable sources (e.g. use of curtailed wind energy), and defer costly network upgrades. Additional tasks also undertaken in the research include,

- the provision of a tool/dashboard permitting further scenario and assumption testing and
- a presentation delivered to the Department and its interested partners.

Key Findings PV Installations and Potential PV Generation from Roof Tops

Current PV Installations

a) There were a total 29,342 PV installations as of the end of 2023 in Northern Ireland, (MCS March 2024)
b) There are 25,577 PV installations of 6.5kWp system size or less assumed to be domestic (MCS March 2024).
c) Approximately 3.35% of dwellings currently have PV installed.
d) Households with a typical 4kWp PV system average an annual generation of 3606 kWh.

e) Households with PV systems have on average 28% of their electricity demand met by PV generation.
f) The potential for roof top PV generation from a range of building categories with entire area (100%) of roof tops covered with PV displayed in Table 1 below.

Potential PV Generation

Table 1 Summary of Potential PV Generation by Building Category

Building Category	Number of Building Polygons	Total Roof Area (m2)	Total Peak Power (kWp)	Potential Total Rooftop Generation (MWh)	Potential Total Rooftop Generation (GWh)	Percentage Potential Generation (%)
Dwellings	787,625	83,476,108	18,258,006	13,251,203	13,251	49.0
Domestic Garages and Outbuildings	363,706	13,253,336	2,899,170	2,086,220	2,086	7.7
Industrial	8,986	7,328,263	1,603,071	1,194,840	1,195	4.4
Commercial	36,315	10,381,932	2,270,995	1,692,495	1,692	6.3
Non-Domestic General Buildings	189,778	44,299,424	9,691,336	7,186,540	7,187	26.6
All Other Buildings	27,725	9,907,360	2,167,238	1,615,872	1,616	6.0
Total	**1,414,135**	**168,646,423**	**36,889,816**	**27,027,170**	**27,027**	**100.0**

Building category details obtained from Fusion data, calculations by author.

g) If PV installations covered 50% of all rooftops in Northern Ireland, it is estimated they would generate 13,514 GWh of electricity annually. Information provided by the Department for the Economy and calculated by NIE Networks indicates that Northern Ireland's consumption of electricity in 2023 was 7,297 GWh[1], thus potential generation at 50% rooftop availability equates to 185% of demand.
h) PV generation is not distributed evenly throughout the year. There is insufficient daylight for PV generation to meet electricity demand for the months of November to January inclusive.

Key Findings from the Assessment of the Potential Impact of Domestic Battery Storage

[1] https://www.economy-ni.gov.uk/news/electricity-consumption-and-renewable-generation-northern-ireland-year-ending-december-2023#:~:text=In%20terms%20of%20the%20volume,of%20total%20electricity%20was%20consumed.

a) Under the right scenario in the domestic setting Solar PV + Storage can potentially achieve a total renewable energy consumption rate* of 96%, with the maximum consumption rate achieved from a Solar PV only system being 80%.

*Renewable energy consumption rate refers to the percentage of consumed electricity that originates from a renewable source. If 30% of a dwellings demand is met from Solar PV, the rate would be 30%.

b) The lowest consumption rates returned from the modelling were 70% and 55% for Solar PV + Storage, and Solar PV Only, respectively.

c) Across all modelling scenarios there was an approximate increase of 15% in the renewable energy consumption rate from generated Solar PV energy when battery energy storage was included.

d) Adding Solar PV with or without storage has significant potential to reduce net emissions, as nearly all scenarios achieved a net zero carbon footprint, with most of these also offsetting additional emissions (see modelling summaries in chapter 7 for specific results). Notably Low and Medium energy demand scenarios that incorporated battery energy storage were able to offset over 200% relative to their baseline CO_2 emissions.

e) Modelling highlighted that in all scenarios a Solar PV system with or without energy storage achieved cost savings when compared to the baseline of just using a grid connection.

f) Statistical analysis highlighted a strong relationship with increasing renewable energy generation, resulting in better project economics and emissions.

g) The modelling highlighted the relatively large upfront capital requirements associated with the system installations, with the initial capital requirements often being more than 50% the value of the total Net Present Cost over 25 years.

h) It was observed that a Grid connection was crucial for achieving such desirable economic and environmental results, as energy exports to the Grid made up a large part of system activity which generated net positive economic and environmental results for the system.

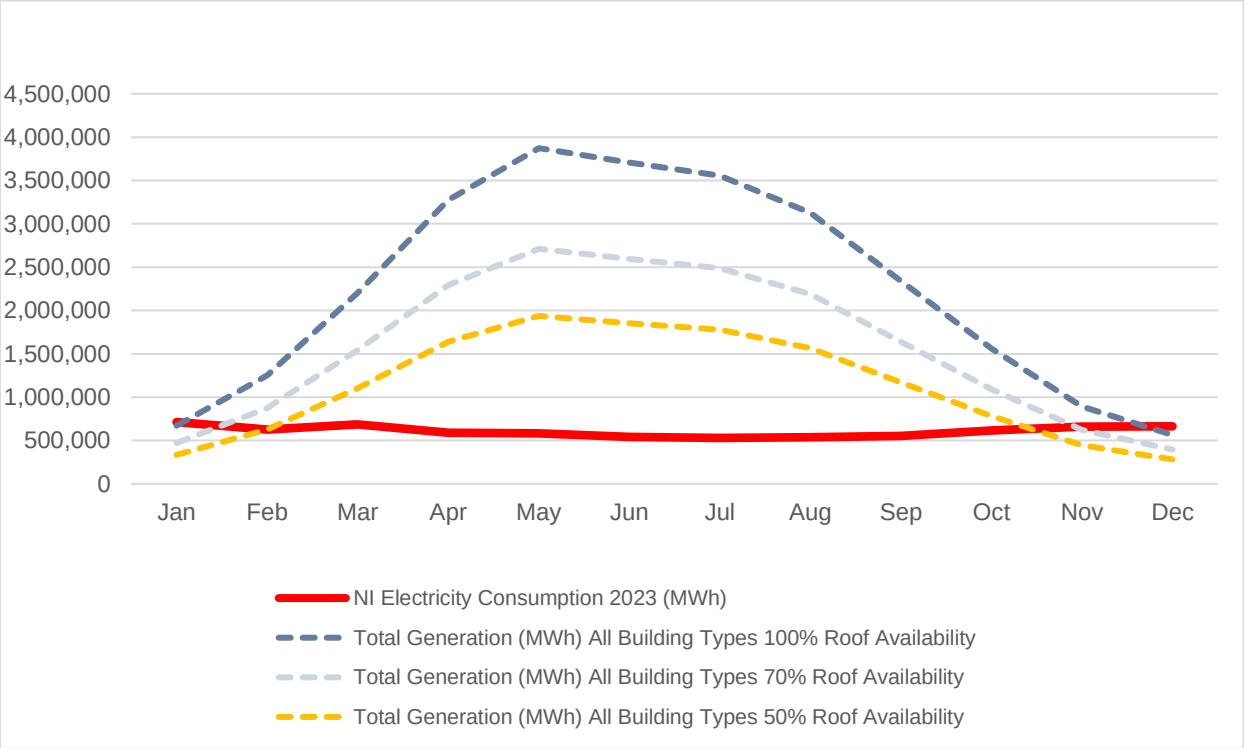
i) It should be noted that a significant decrease in the current export tariff of £0.1422/kWh may result in a less favourable economic performance, although emission reductions would remain the same.

j) It should also be noted that modelling allowed for full exports to the grid, whereas in some situations grid limits may apply. If exports of excess generation are curtailed to the grid this would have a negative impact on the results, reducing the economic benefits and grid level emission reductions. This highlights the importance of improving grid interactions with distributed energy generation, with an increase in export limits being desirable.

Key Conclusions

- Solar PV is a mature technology that can make a significant contribution to electricity generation in Northern Ireland.
- A typical 4kWp residential PV will meet on average 28% of household electricity demand, with this increasing as the solar PV system size (kWp) increases.
- The current Micro Generation Solar PV G98/NI registration process limit of 3.68 kWp (4kWp) for single phase installations has become the de facto residential PV system size.
- PV installation rates showed a rapid decline after the ending of the ROCs scheme in 2017, while there was a slight recovery in installation rates in 2022 and 2023. There is unlikely to be a substantial uptake of PV in the domestic sector without the introduction of a financial incentive scheme (in addition to the current export tariff payments) for households to meet some of the capital costs of installing the technology.
- The potential utility of PV can be significantly enhanced by the addition solar plus technologies such as PV water heating and battery storage. These technologies enable households to potentially consume 70% plus of their PV electricity generation.
- In magnitude, rooftop PV generation could on an annual basis exceed Northern Ireland's electricity demand, however significant mismatches occur between PV generation and demand especially during the months November through to January. See Graph 1 overleaf.

Graph 1 Potential PV Generation v NI Electricity Consumption 2023



KEY RECOMMENDATIONS

Recommendations are framed by the extent of the policy ambition for the roll out of Solar PV electricity generation, i.e. does the policy seek to maximise the potential of solar PV generation for Northern Ireland or is PV viewed as a niche renewable technology for those households that can afford the upfront installation costs?

The uptake of Solar PV impacts positively on legislation, policies and strategies such as The Climate Change Act (NI) 2022, Net Zero Carbon, the Renewables Electricity target and on levels of fuel poverty by reducing household electricity consumption from the grid. However, the level residential PV installation remains low at 3.4%, and this is likely to remain the case without the introduction of financial incentives and regulatory changes. The following recommendations are made on the basis that there is a policy imperative to substantially increase the uptake of Solar PV

- Consideration should be given to the introduction of a financial incentive scheme for installation of PV at existing households. Models for such schemes are already

in place in wider G.B., Scotland and Ireland, leaving Northern Ireland as an outlier with no financial assistance available to install Solar PV.

- Changes to the Buildings Regulations NI 2012, Part F (Conservation of Fuel and Power) requiring the installation of solar PV on all new buildings and those properties undergoing extensive renovation should be explored.

- Solar Plus technologies such as PV hot water diverters maximise the PV generation renewable energy consumption rate by households but require properties to have a hot water storage tank. Again, consideration should be given to amending the Buildings Regulations to require the fitting and/or retention of hot water storage/thermal tanks in new and existing dwellings[2] to facilitate these Solar Plus options.

- Under the current G99/NI[3] limit, battery storage and export limitation devices can be used to maximise household PV installed capacity and associated generation. The economics of those systems are directly linked to the electricity and hot water demand profiles of the household. Consideration should be given to encouraging the installation solar plus technologies (Battery Storage and PV Hot Water Diverters) as a standard component of PV systems (were warranted by household electricity demand), as this has the potential to facilitate double the household single phase installed capacity of PV systems to 7.36 kWp, without increasing generation exports to the electricity network.

- The potential for further streamlining of the G99/NI application process for larger (greater than 3.68 kWp) domestic PV installations should be assessed.

[2]Note hot water storage tanks are also an essential component of Heat Pump heating systems.

[3] The G99/NI (Grid Connection) Process allows 16 Amps per phase of generation to be connected …with an export limiting device that restricts the output to the network to 16 Amps per phase. (SONI and NIE, 2023 p. 6)

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1.0 Introduction

1.1 In 2019 the United Kingdom (UK) government introduced The Climate Change Act 2008 (2050 Target Amendment) Order 2019 which set a target, known as "net-zero carbon", for the net UK carbon account for the year 2050 to be 100 per cent lower than the 1990 baseline.

1.2 The UK has under 26 years to achieve this net zero objective, which amounts to an 87% reduction in CO_2 emissions compared to 2017 levels. Its attainment will necessitate societal, behavioural and technological changes, in the ways and extent to which we generate and consume energy. The Committee for Climate Change report, that in part prompted the adoption of the Net Zero target, foresees the "*extensive electrification, particularly of transport and heating, supported by a major expansion of renewable and other low-carbon power generation*" (Committee on Climate Change, 2019, p.23) to be key priorities for meeting the Paris accord agreements. The Paris Agreement is a legally binding international treaty on climate change, adopted by 196 Parties at the UN Climate Change Conference (COP21) in Paris in December 2015. Its overarching goal is to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels" and pursue efforts "to limit the temperature increase to 1.5°C above pre-industrial levels." United Nations Climate Change (The Paris Agreement | UNFCCC, Accessed 14/02/24).

1.3 This decarbonisation process will necessitate the increasing use of renewable energy sources as a means of achieving these targets. A component of this is the extension of renewable energy production away from largely centralised electricity generation and towards home energy production and consumption. Locally the Northern Ireland Executive in the Draft Green Growth Strategy (N.I. Executive, 2021, p.37) envisages that *"the 2020s will be focused on scaling up of low-carbon technologies and behaviours and building essential supply chains. As well as behavioural changes, this means deploying large volumes of renewable generation, energy improvements in buildings and electric vehicle roll-out"*.

1.4 In Northern Ireland, The Path to Net Zero Energy strategy has set a renewables target to "*Meet at least 70% of electricity consumption from a diverse mix of renewable sources by 2030"* (NI Executive 2021, p.7). This has subsequently been superseded by the Climate Change Act (Northern Ireland) 2022, which augments this target and states in section 15 section that "*the Department for the Economy must ensure that at least 80% of electricity consumption is from renewable sources by 2030"*. The Northern Ireland Executive's Draft Green Growth Strategy sets out the Executive's long-term vision, commitments and

recognition of the need for adaption and mitigation measures and new policies to facilitate the change required to reduce emissions. The strategy envisions, inter alia, the need to scale up low-carbon technologies and increase the volumes of renewable generation and energy improvements in buildings (N.I. Executive, 2021, p.37).

1.4.1 Solar Photovoltaic (PV) panels are a mature technology and their adoption increased dramatically in the province between 2012 and 2017 with the introduction of the Renewables Obligation Certificate (ROCs) scheme. In the last decade the price of domestic PV systems has halved with a PV 4 kWp system now typically costing £5,000, because of this and its comparative ease of installation, solar PV potentially has a core role in achieving the Net Zero target.

1.5 Solar PV panels operate by converting solar radiation into electricity. *"Photovoltaic systems contain cells that convert sunlight into electricity. Inside each cell there are layers of a semi-conducting material. Light falling on the cell creates an electric field across the layers, causing electricity to flow. The intensity of the light determines the amount of electrical power each cell generates"* (Tyagi et al., 2013, p.444). PV installations can be large scale "solar farms" producing megawatts of electricity, but the technology is also suitable for installation on domestic and non-domestic rooftops.

1.6 This clear policy context in relation to cutting carbon emissions requires the adoption and adaptation of renewable energy sources, particularly within the existing property stock, to reduce carbon emissions and help with affordable energy. Indeed, the current NI Energy Strategy highlights the role *of "phasing out fossil fuel heating oil for around 68% of homes and businesses"* to combat climate change. (N.I. Executive, 2021, p.36)

1.7 The Strategy also identifies that "*as traditional sources of energy supply are replaced by new renewable sources and demand becomes more dynamic, the energy system - particularly electricity - will be more complex to manage*", and that a resilient and secure electricity system is of critical importance. Thus, to transition to the low carbon pathway, this necessitates a range of integrated and flexible approaches, particularly in relation to low carbon technologies and energy storage solutions alongside renewable energy uptake in order to transition to a new energy system based around renewables.

1.8 This research examines existing levels of residential PV installations in Northern Ireland and also is specifically targeted to profile and understand the potential of rooftop PV generation at the Northern Ireland level for a range of property types. In addition, a detailed analysis by building classifications

across spatial geographies has also been undertaken consistent with the existing research commissioned by the DfE. The research has a dual focus: first, to profile both domestic and non- domestic buildings to determine their PV potential generation, and second, to investigate and assess the role of battery storage for enhancing a resilient and secure electricity system, the introduction of low carbon technologies and energy storage solutions alongside renewable energy.

1.9 The report is structured as follows: -

Section 2: provides a contextual outline of data the adoption and uptake of PV installations within Northern Ireland.

Section 3: sets out the project methodology and data sources used within the research for determining PV generation.

Section 4: details the project aims and objectives.

Section 5: provides an assessment of the potential PV for rooftop electricity generation by building type.

Section 6: contextualises Potential PV electricity generation and current electricity consumption in Northern Ireland

Section 7: provides analysis surrounding the assessment of battery storage solutions alongside PV generation.

Section 8: Research Findings

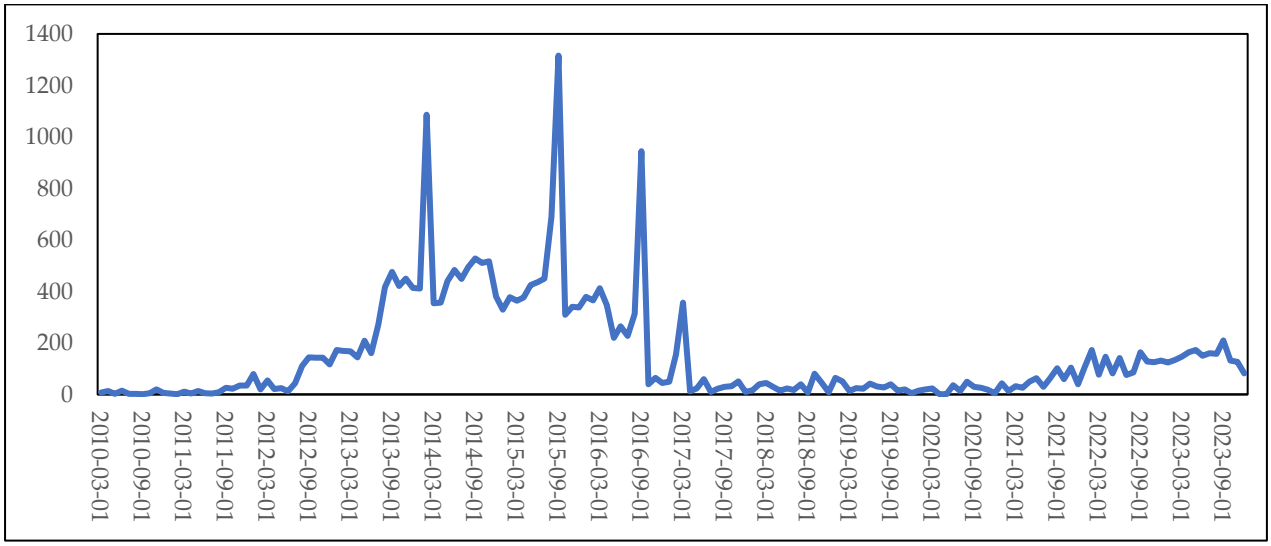
Section 9: Conclusions and Recommendations.

2.0 Current Adoption of PV systems in Northern Ireland and Impacts on Household Electricity Consumption

2.1 The number of PV residential installations in Northern Ireland is 25577 as of the end of 2023 (MCS, 2024). The number of installations increased steadily between 2013 and 2016 coinciding with the incentive provided by the Renewables Obligation Certificate (ROC) scheme for small scale renewable generation.

2.2 Each of the installation peaks illustrated in Figure 2.1 clearly coincides with a reduction in the payments by the ROC scheme, with applicants attempting to enter the scheme before the reductions were implemented. The ending of the ROCs schemes has reduced new PV installations to very small numbers annually.

Figure 2.1 Number of PV System Installations less than 6.5 kWp system size in NI



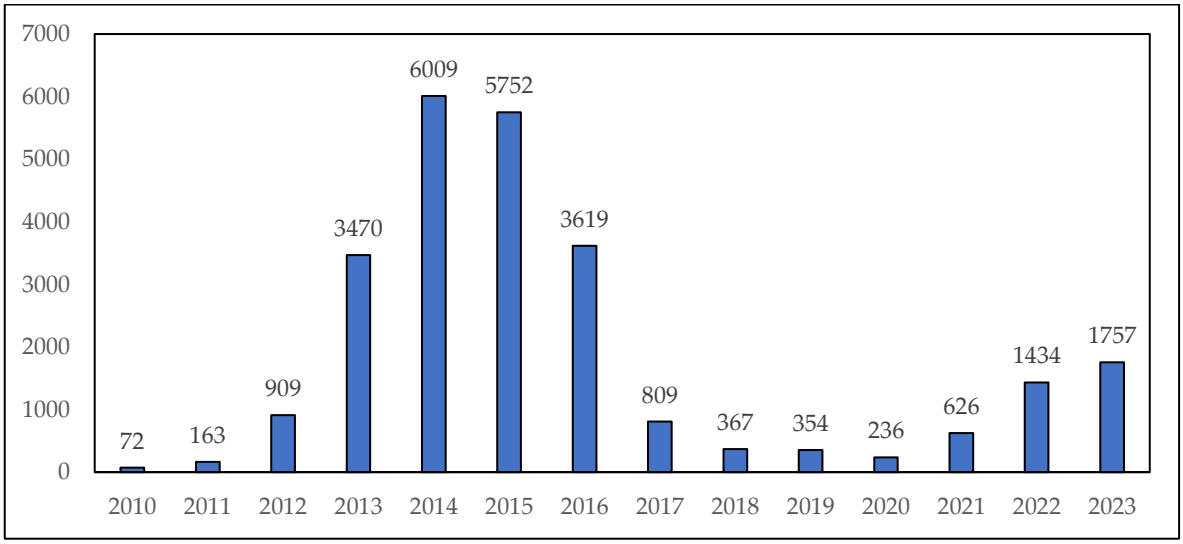
Source: MCS Data 2024

2.3 Analysis of the MCS data to produce a percentage of total PV system installations in the province by year produced the following results. As illustrated in Figure 4.2, in 2012, there were 909 PV installations, with 2013 observing 3,470 installations. In 2014, the number of installations increased to 6,009 and in 2020, there were 236 installations, equating to a 25-fold decline in PV uptake from peak levels observed in 2015.

2.4 Between 2013 and 2016, 74% of total PV installations occurred during this period, this was followed by a marked decline in the number of installations with the ending of ROC scheme incentives. There was an increase in 2023 to 1,757 PV

installations, in all probability prompted as a response to the increase in electricity prices in the spring of 2022. However, the number of installations declines in the second half of 2023 perhaps coinciding with a reduction in electricity prices from their peak.

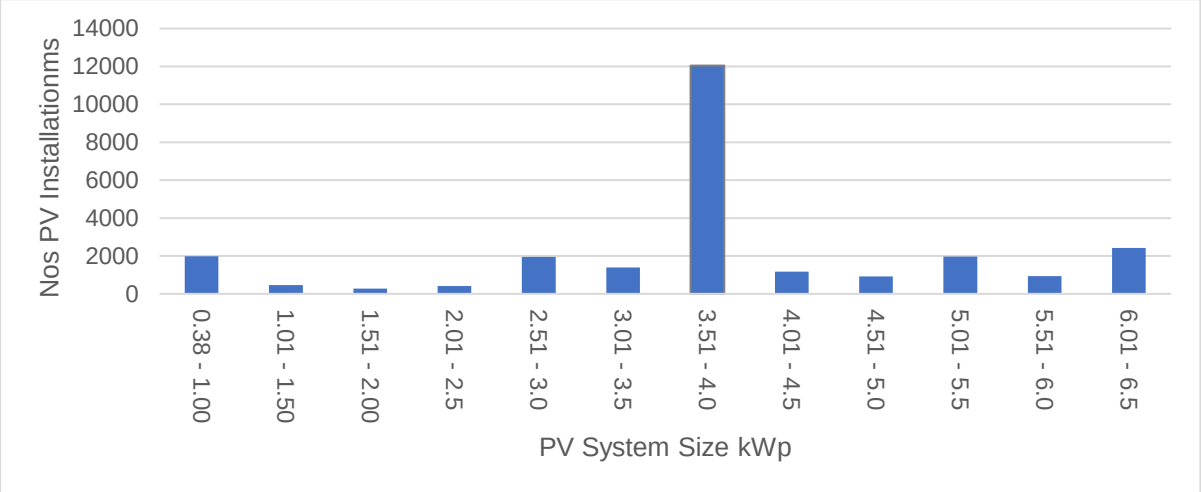
Figure 2.2 The number of Residential PV Installations less than 6.5 kWp Per Annum (2010-2023)



Source: MCS Data 2024

2.5 The average capacity of a PV system is 8.95 kWp. When the domestic PV systems (i.e. those of 6.5 kWp or less) are isolated, there are a total of 25,577 installations and the mean size is 3.96 kWp. The total peak power output of these installations is 102,909 kWp. The frequency of residential PV installations by kWp system sizes is illustrated in the graph figure 2.3 below.

Fig 2.3 Frequency of PV Installation by Size (kWp)



Source: MCS Data 2024

Incentives for Households to Install Solar PV

2.6 The graph Figure 2.2 illustrates the impact that the ending of the ROCs incentive scheme had on the uptake of solar PV in the residential sector. Northern Ireland is currently unique within a UK and Ireland context in that it offers no grants to households towards meeting the cost of installing PV.

- In Scotland a grant of £1250 plus an optional loan of £4750 is available for PV installations. Home Energy Scotland Grant and Loan: overview · Home Energy Scotland
- The ECO 4 grant scheme operates throughout G.B and includes the installation of Solar PV, households in receipt of specified benefits can receive between £7,000 – £20,000+ worth of ECO4 grant funding. Energy Company Obligation Grants - ECO4
- In Ireland a grant of a maximum of €2100 is available for 4kWp PV installations. Solar Electricity PV Grants | Home Energy Grants | SEAI

Location of Current Solar PV Installations

2.7 The location of PV installations, as can be observed in Figures 2.4 and 2.5 which illustrate the substantial variation in the spatial distribution of PV installations, with those LGDs around the Belfast Metropolitan Area broadly having fewer PV installations than more rural LGDs.

Figure 2.4 Number of Residential PV Installations by LGD

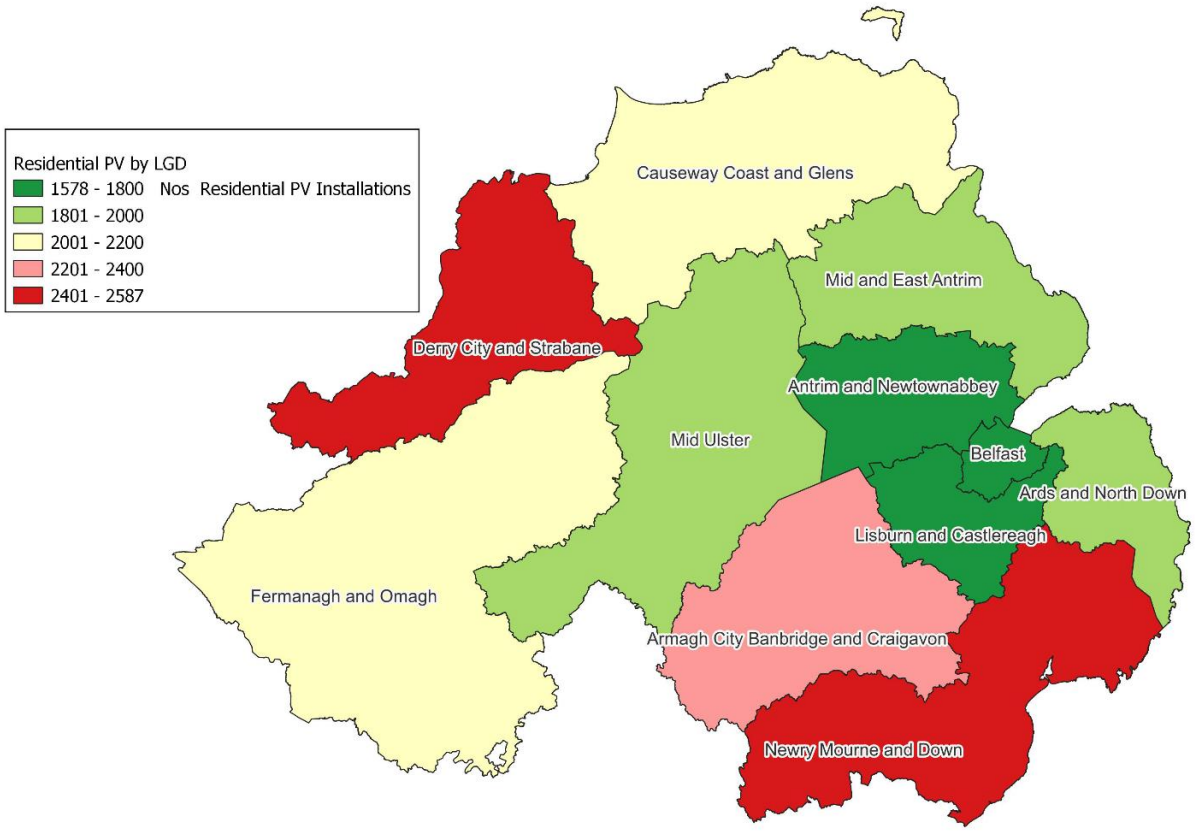
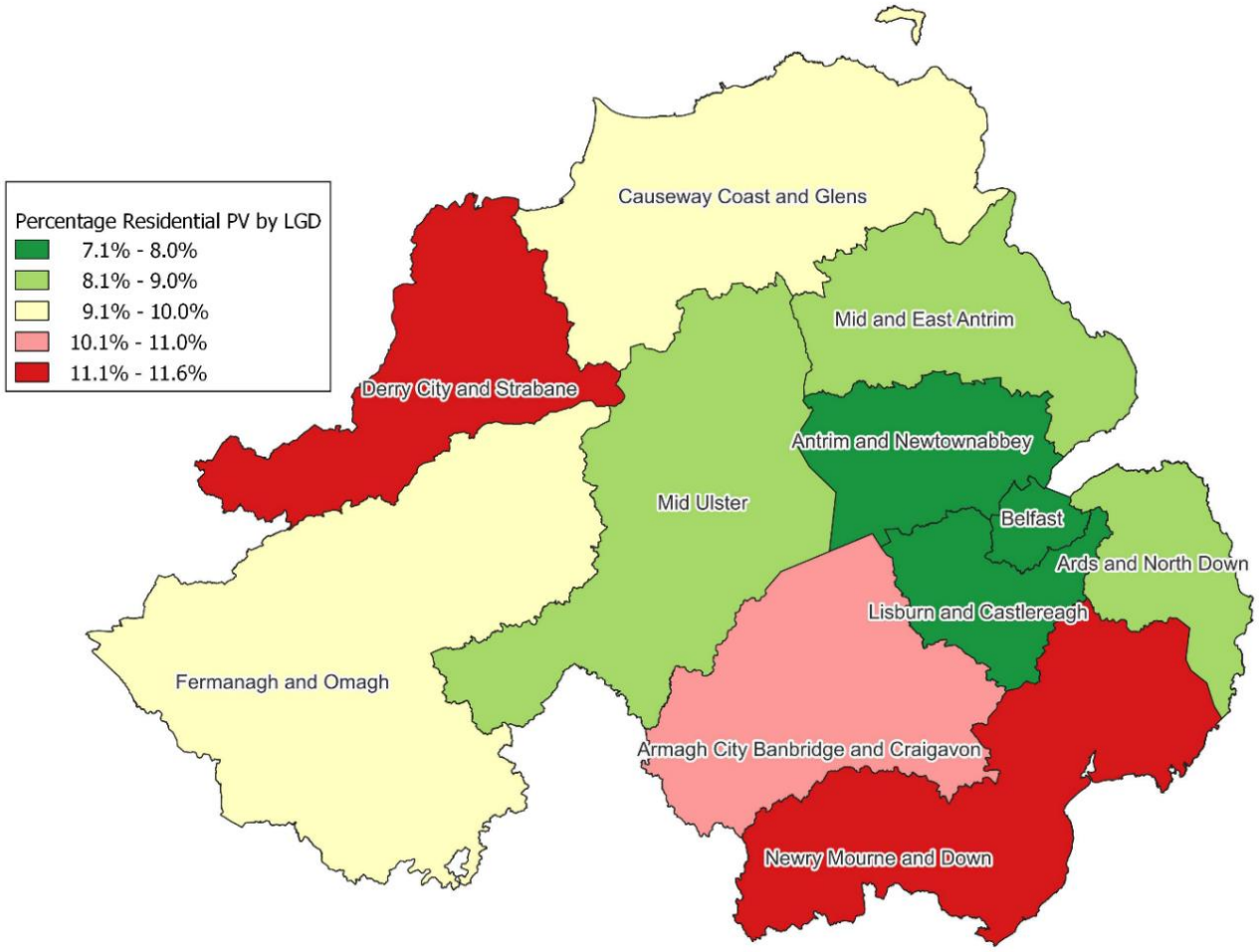


Figure 2.5 Percentage of Residential PV Installations by LGD



2.8 Examining the number and percentage of PV installations at postcode districts, provides some granular analysis of the spatial distribution of PV installations at a Northern Ireland scale.

As identified in Figure 2.6, the distribution of residential PV installations indicates a greater prevalence for the adoption of the technology in rural locations. The analysis of the percentage of PV installations by the number of dwellings in postcode districts is particularly revealing, indicating that rural areas of counties Tyrone (BT77) Londonderry (BT46) and Fermanagh (BT75) have the highest rate of uptake per number of dwellings, in a given postcode district (Table 2.1) of residential PV installations in Northern Ireland, albeit at a relatively modest level.

Table 2.1 Percentage of PV as Proportion of Number of Dwellings by Postcode District

Postcode District	Number Residential Properties	Number Residential PV Installations	Percentage of Residential PV Installations
BT77	600	64	10.7
BT46	4036	239	5.9
BT75	1627	94	5.8
BT69	1087	60	5.5
BT33	5673	308	5.4
BT31	3584	194	5.4
BT29	5040	269	5.3
BT24	7795	404	5.2
BT25	6671	345	5.2
BT78	12667	651	5.1

(Number of Properties Calculated by Researcher using LPS Pointer Data and Postcode District Boundaries)

Figure 2.6 Number of Residential PV Installations by Postcode District (2023)

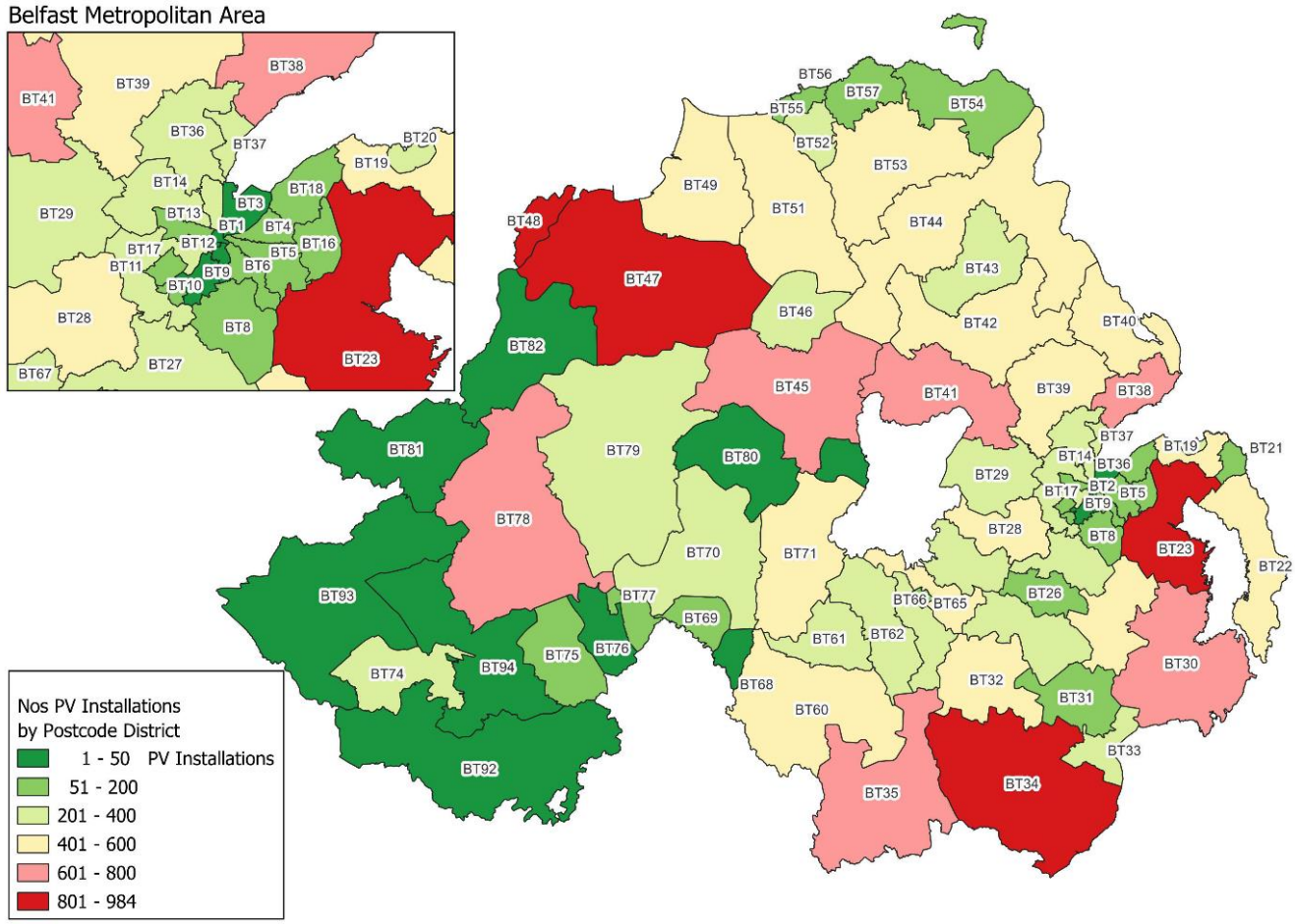
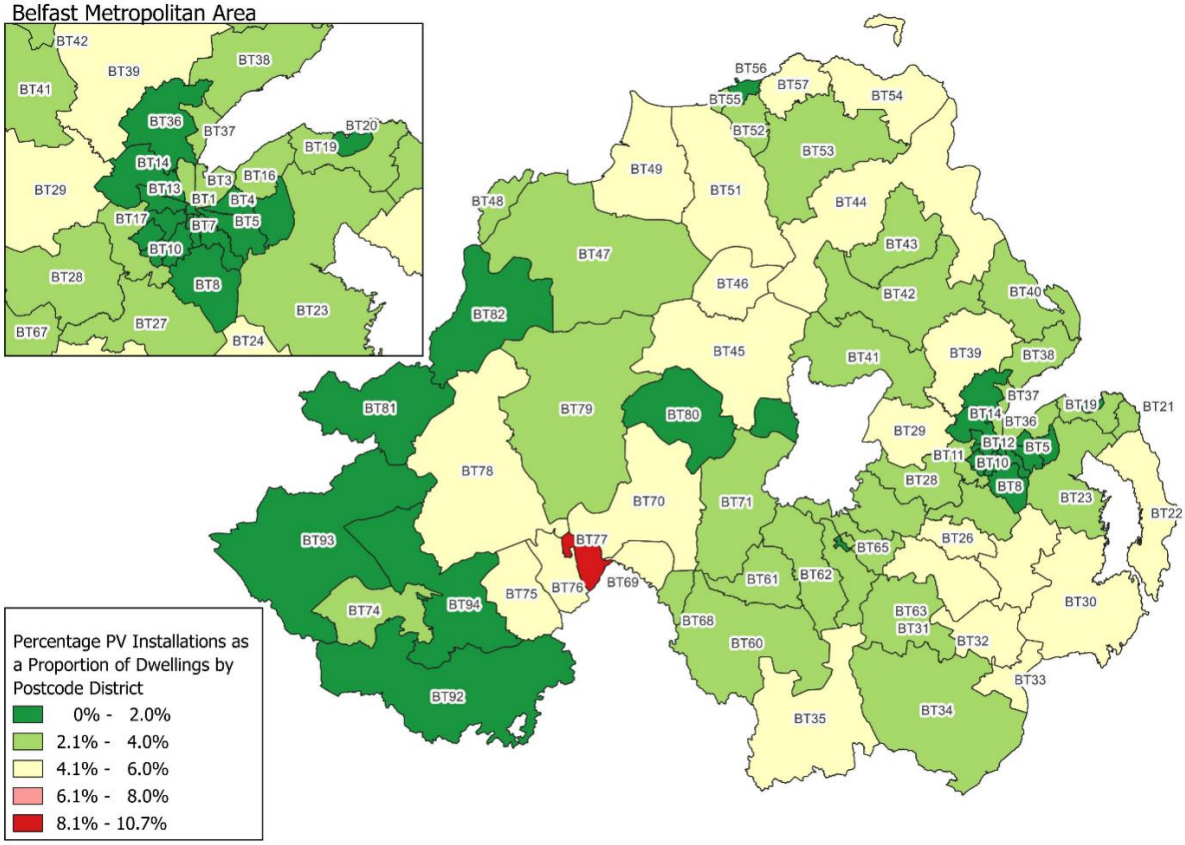


Figure 2.7 Percentage of PV as Proportion of Nos of Dwellings by Postcode District (2023)



2.9 Further detailed examination of the number and spatial distribution of PV installations reveals (Table 2.2), that while dwellings in the rural area account for 20% of the residential housing stock, these rural dwellings account for 43% of PV installations.

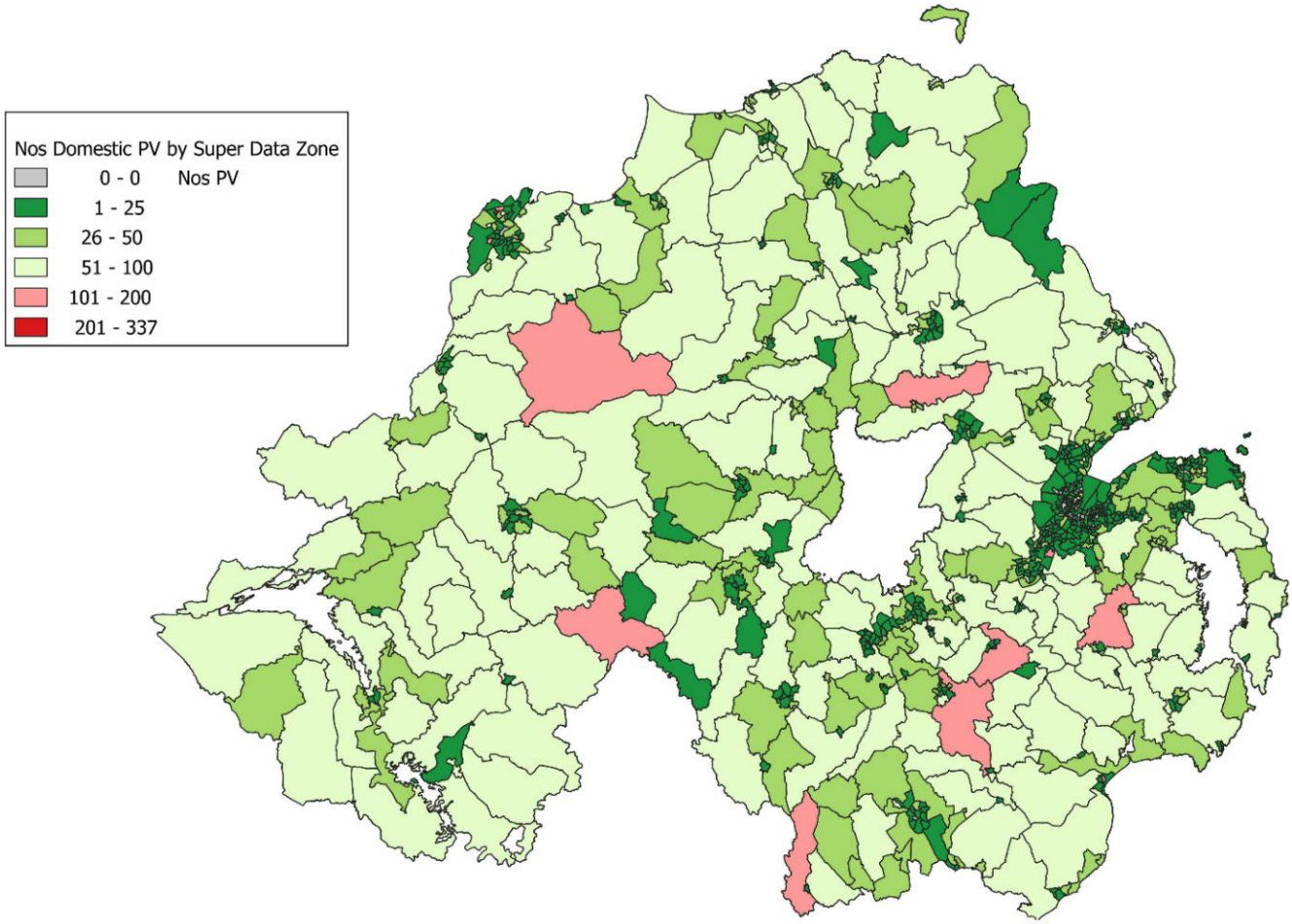
Table 2.2 PV installations by rural and urban classifications.

Settlement Band	Number of Dwellings (Fusion Database)	Percentage of Dwellings in Settlement Band	Number of PV Installations in Settlement Band	Percentage of PV Installations in Settlement Band	Potential Yearly Total Generation (MWh)
Rural Remainder	157,816	20	10,938	43	4,340,366
A	115,227	15	1,539	6	1,338,334
B	34,481	4	1,369	5	415,436
C	230,144	29	5,373	21	3,203,608
D	56,762	7	1,225	5	879,417
E	55,225	7	1,569	6	879,731
F	33,969	4	929	4	538,397
G	48,582	6	1,178	5	756,385
H	55,419	7	1,457	6	899,529
Total	787,625	100	25,577	100	13,251,203

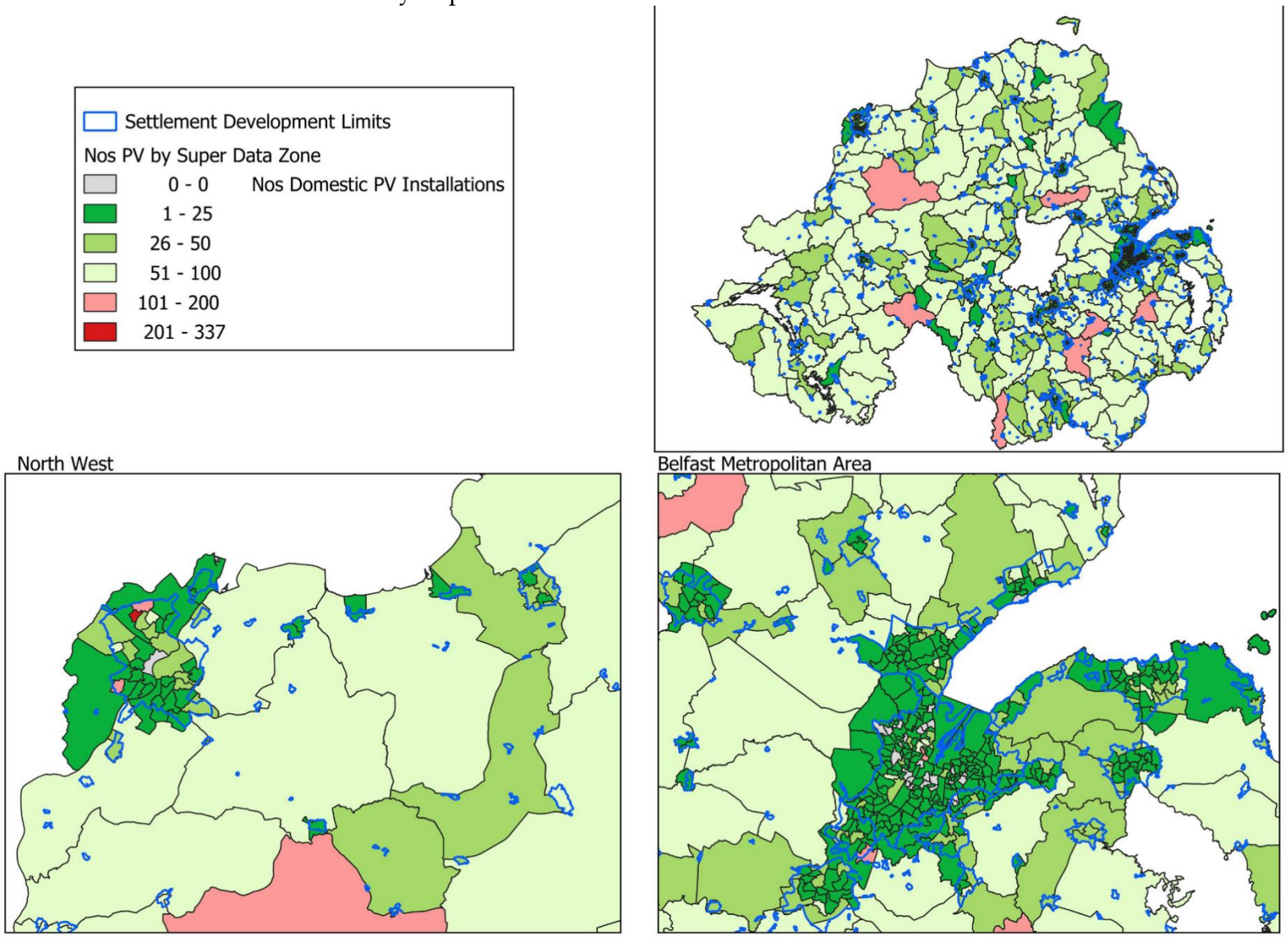
*Note: Settlement bands relate to the Settlement Development Limits (SDLs) which are a statistical classification and delineation of settlements in Northern Ireland produced by NISRA. Band "A" relates to Belfast, "B" Derry City and "C" Large Towns such as Bangor Craigavon etc. Rural remainder refers to dwellings outside the Settlement Development Limits

2.10 The number of PV installations by Super Data Zone (SDZ) is illustrated in Figures 2.8 and 2.9 below. The spatial distribution of PV installation at this level clearly shows that those SDZs with higher PV uptake are located within rural areas and conversely that the lower uptake of PV installations is in urban areas within the Settlement Development Limits. Indeed, of the twelve SDZs which have no domestic PV installations at all, eleven are located in Belfast and one located in Derry/Londonderry.

Figure 2.8 Domestic PV by Census Super Data Zone



Figures 2.9 The number of PV installations by Super Data Zones



The Impacts of PV Installations on Household Electricity Consumption.

2.11 Ongoing research at Ulster University has been monitoring the electricity generation and consumption patterns of households with PV systems installed. The aims of the research in gathering these case study observations is to;

a) quantify household PV generation,
b) determine the extent to which PV generated electricity is used by the households,
c) establish the percentage of household electricity consumption met by PV generation and
d) ascertain the percentage of PV electricity generation exported to the grid.

2.12 The study entails monitoring electricity generation and consumption from participating households. The data is gathered on a monthly basis, with participants returning the following meter readings from their properties at the end of each month,

e) PV Generation Meter Reading, kWh
f) Electricity Import Reading, kWh
g) Electricity Export Reading, kWh (and where installed)
h) Electricity diverted to PV water Heating, kWh and
i) Electricity diverted to Battery Storage kWh

2.13 The readings are taken directly from the installed meters rather than from monitoring software to ensure the accuracy of the data. In all 18 households have participated in the monitoring to date, with 49 years of monitoring data having been collected. The households were categorised into the following types of PV installations to differentiate between those with PV only and those with PV Plus set ups.

2.14 "PV Only" describes those households with PV systems installed but no electricity diversion or storage options. "PV and Hot Water Diversion" describes those households with additions to their PV such as iBoost or Eddi devices (typical cost £350) installed that automatically switch on the dwelling's immersion heater once PV generation exceeds household usage and diverts the excess electricity into heating water for the home. These hot water diversion devices are reliant on properties having a hot water storage tank in order them to work. "PV, Hot Water and Battery Diversion describes those households with battery storage installed in addition to PV and Hot water diversion.

2.15 Solar power diverters like the Eddi, and iBoost are compatible with solar batteries and the PV System can be configured in such a way, to prioritise;

a) household electricity usage, then
b) battery charging and then
c) excess generation bring diverted into hot water heating.
Table 2.3 below shows the breakdown of household PV installations by type.

Table 2.3 Overview of Case Study Household PV Installations.

PV System Type	Nos Installations	Number Year Long Observations
PV only	6	22
PV and Hot Water Diversion	11	26
PV, Hot Water and Battery Diversion	1	1

Case study Household PV Electricity Generation

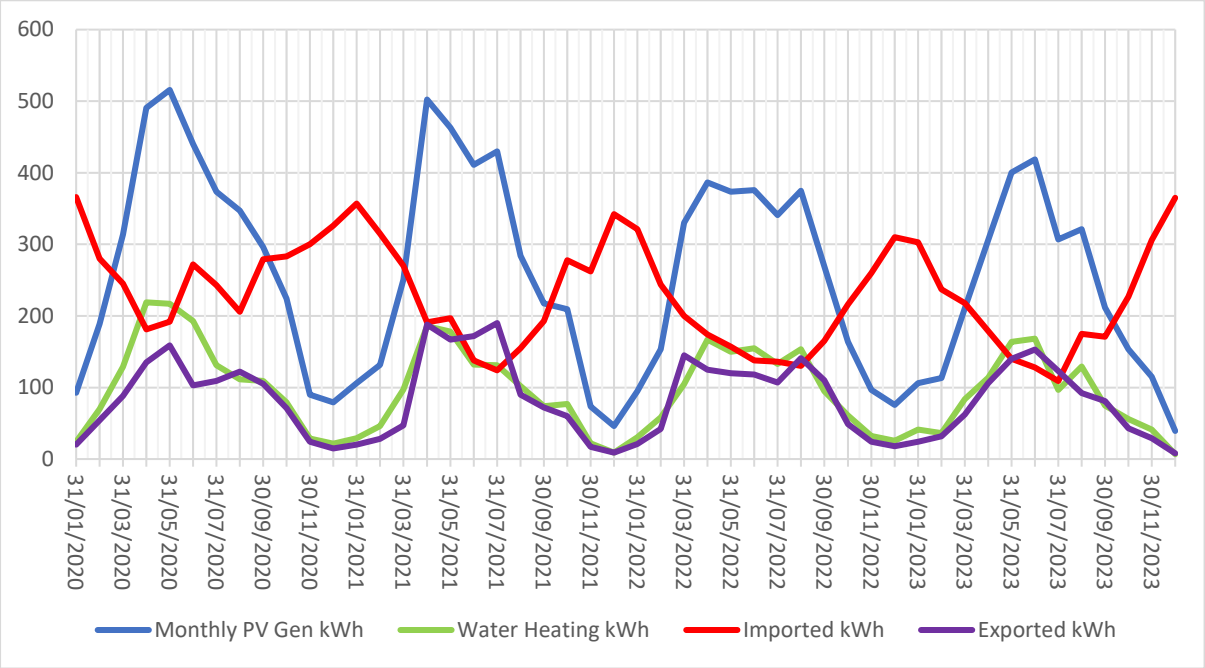
2.16 The case study household PV systems ranged in generating capacity from 2kWp to 6.5kWp with an average system size of 4kWp. The PV generation output ranged from 1759 kWh to 5813 kWh per annum with an average PV system annual generation of 3648kWh across all households.

2.17 The households with a typical 4kWp PV system averaged an annual generation of 3606kWh. The average PV system size of 4kWp results from the introduction of the Electricity Safety, Quality and Continuity Regulations (Northern Ireland) 2012. These regulations limited the size of single-phase connections to 3.68kW for the G98/NI registration process, however taking into consideration the operating rating of the PV inverter a 3.98kWp PV installation is accepted by NIE. (NIE Networks, Customer FAQs - NIE Networks | Northern Ireland Electricity Networks, accessed 09/01/24).

2.18 It should be noted that the *"G99/NI Fast Track Process allows 16 Amps per phase of generation to be connected ….. with an export limiting device that restricts the output to the network to 16 Amps per phase"*. (SONI and NIE, 2023 p.6) This requires the addition of battery storage but increases the PV system size to 7.36 kWp.

2.19 The graph overleaf illustrates the typical seasonal variation in PV generation from a 4kWp household installation. Short winter days and the sun being low on the horizon limits the potential of PV generation, meaning that electricity generation in December and January is approximately only 15% of electricity generation in May or June.

Figure 2.10 PV Typical Case Study Household PV Generation



Current Typical Household Consumption Values of Electricity in GB

2.20 The most recent figures from OFGEM (the Office of Gas and Electricity Markets) indicate the following annual consumption electricity rates for households, in GB.

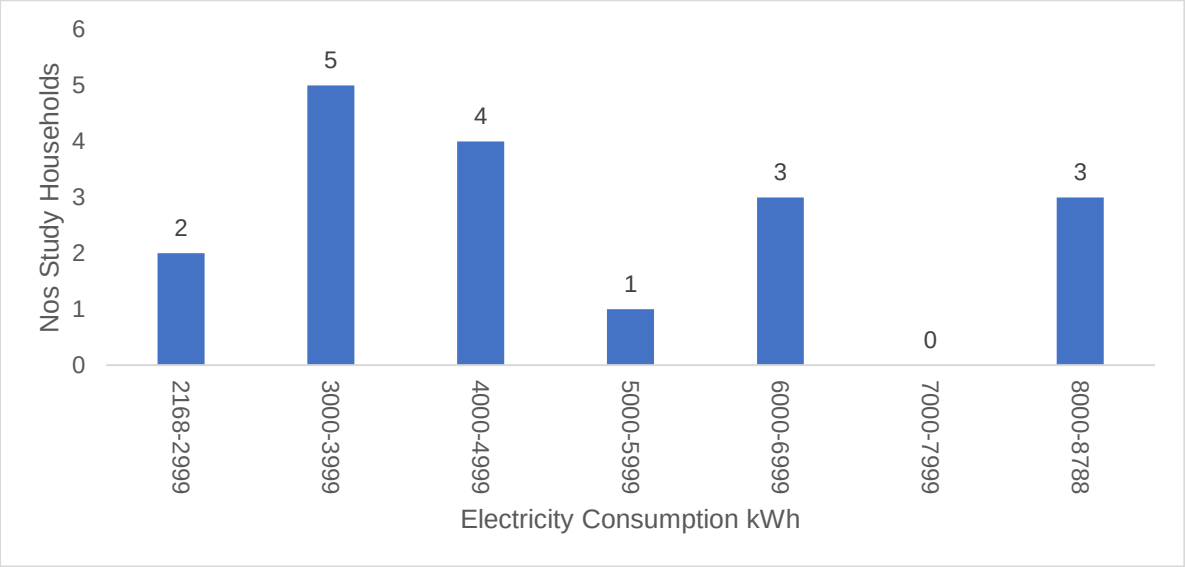
Table 2.4 OFGEM Electricity Consumption Profiles

User Electricity Profile Class	User level	Current Typical Domestic Consumption Values (kWh)
Electricity: Profile Class 1	Low	1,800
	Medium	2,900
	High	4,300
Electricity: Profile Class 2 (e.g. Economy 7)	Low	2,200
	Medium	3,900
	High	6,700

OFGEM 25/05/2023 OFGEM Average gas and electricity usage | OFGEM

2.21 Electricity consumption in the case study households ranged from 2168 kWh to 8788 kWh per annum with an average household consumption of 5032 kWh. As can be seen from Table 2.4 these consumption values are considerably higher than the OFGEM Current Typical Domestic Consumption Values. The graph below Figure 4.7 shows the electricity consumption values for the case study households.

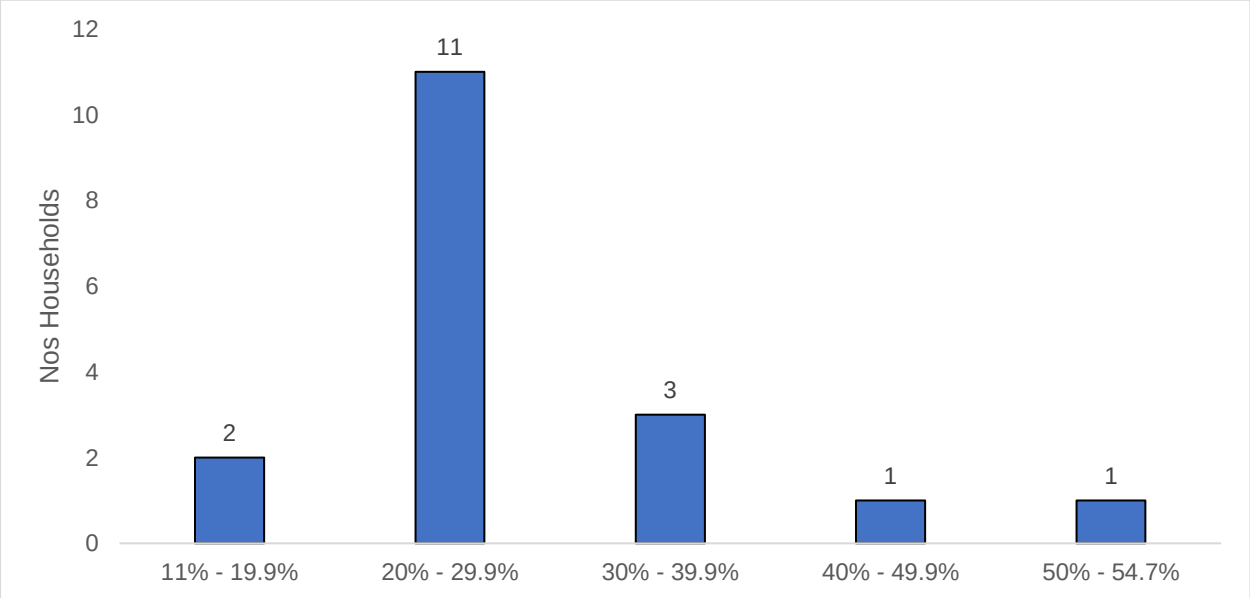
Figure 2.11 Case Study Households Annual Electricity Consumption



How Much of Household Electricity Consumption is Met by PV Generation?

2.22 The extent to which PV generation can meet household electricity annual needs was also assessed. The results from the 18 case study households ranged from 11% to 55% of household annual electricity consumption being met from their PV generation. The average figure is 28% of household electricity needs being met from their PV generation with a mode of 11 out of the 18 households falling within the 20% to 29.9% band. (See Fig 2.12 below).

Figure 2.12 Percentage of Household Electricity Consumption met from PV Generation

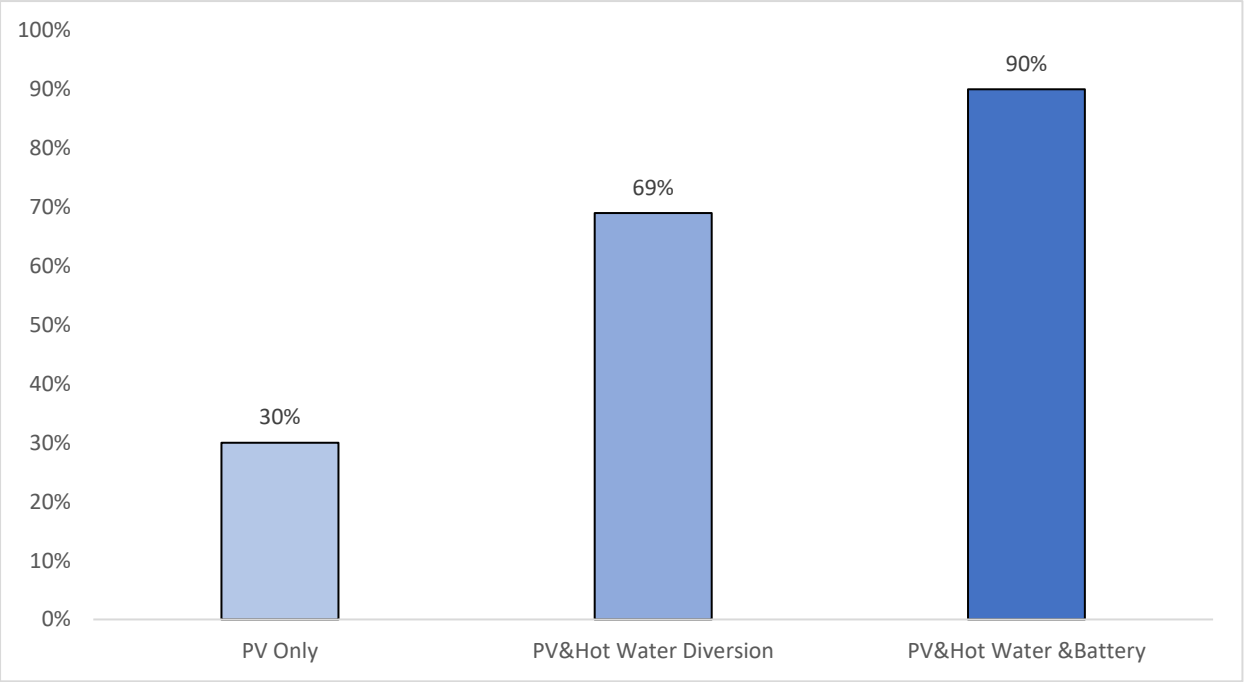


PV Generation Renewable Energy Consumption Rate by Households

2.23 The proportion of PV generation consumed by the households varied in accordance with the PV system set up, i.e. PV only, PV and Hot Water Diversion or PV, Hot Water and Battery Diversion.

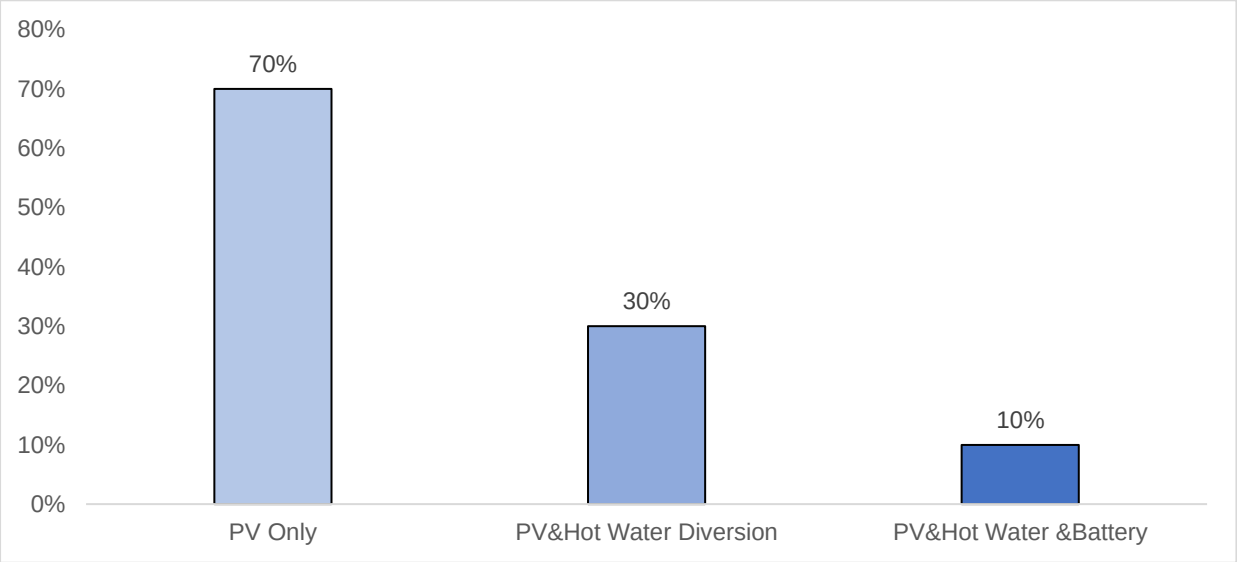
The graph below Figure 2.13 indicates that averaged across the case study households, PV only systems consumed on average 30% of their generation, this figure rose to 69% for the renewable energy consumption rate in those households with "Solar PV Plus" in the form of PV plus Hot Water Diversion and for one case study household with PV, Hot Water Diversion and Battery Storage, the renewable energy consumption rate figure was 90%. (Note from a small sample size)

Fig 2.13 Percentage of PV Renewable Energy Consumed by Households



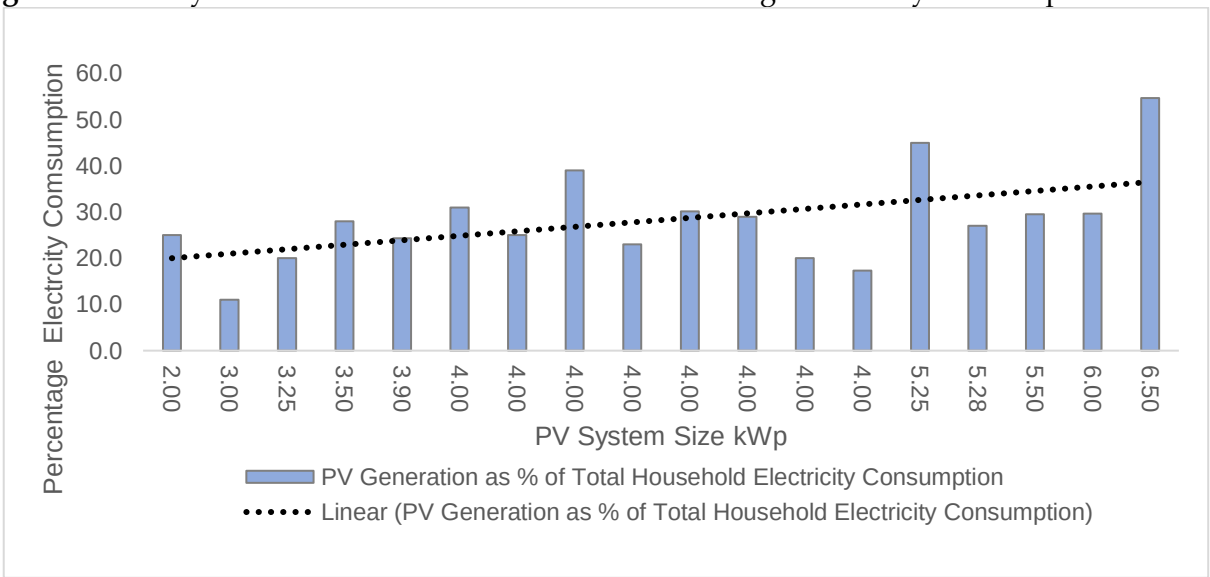
2.24 The degree of household renewable energy consumption also relates directly to the amount of electricity from PV generation exported to the electricity network. The graph (Figure 2.14) indicates the impact of solar plus technologies on the electricity exports with the figures being virtually a mirror image of the renewable energy consumption rate results.

Figure 2.14 Percentage of PV Generation Exported to the Grid



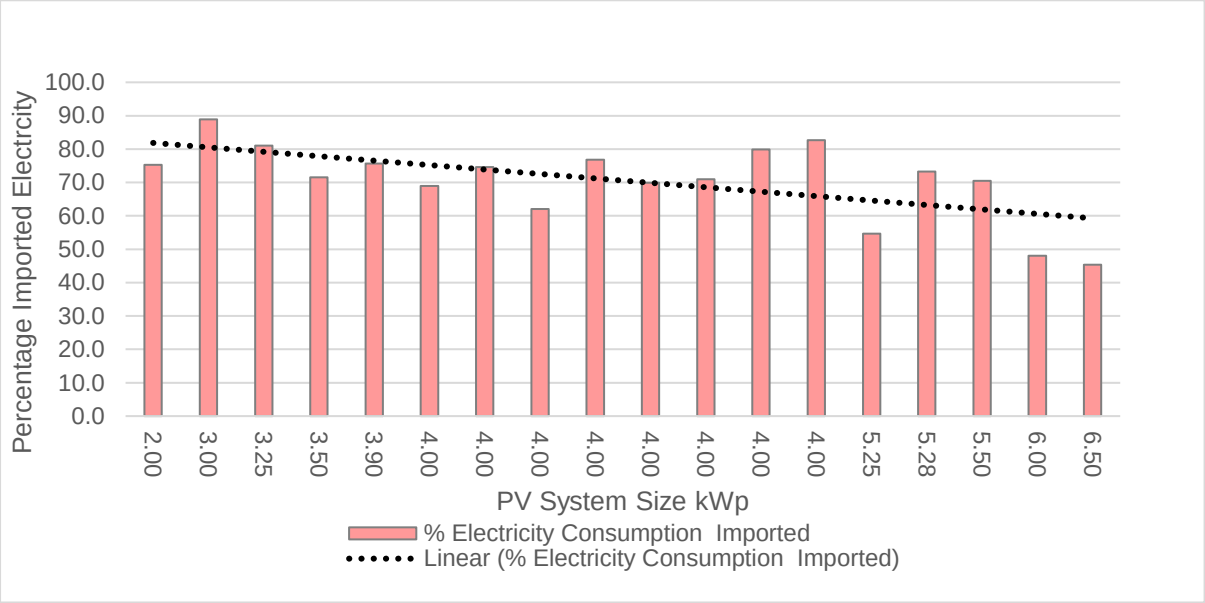
2.25 The size of PV system installed in dwellings also impacts on the proportion of household electricity consumption that can be met from PV generation. The graph below Fig 2.15 illustrates the percentage of household electricity consumption met by PV generation. As the trend line shows the larger the kWp of the PV system the greater the percentage of household electricity needs that are met from PV generation.

Figure 2.15 PV System Size and PV Generation as a Percentage Electricity Consumption



2.26 The converse situation is also illustrated in Figure 2.16 which shows the percentage of household electricity consumption imported from the grid versus PV system size in kWp. The trend line shows the impact PV system size has on the percentage of electricity consumption imported, the larger the PV system the lower the percentage import.

Figure 2.16 PV System Size and Percentage of Household Electricity Imported



Conclusions from Household Case Study Analysis

2.27 The G98/NI PV registration process has created a de facto standard PV system size of 4KWp. This impacts on the potential PV generation from households.

Electricity consumption in the case study households is predominantly in the high usage band.

On average PV generation met 28% of household electricity needs, in the one household in the study that had battery storage installed the generation and storage enabled 56% of household annual demand to be met.

The use of solar plus technologies, (Hot Water Diversion and Battery Storage) reduces the percentage of electricity exported to the grid;

- 70% of generation exported with PV only,
- 30% of generation exported with PV and Hot Water,
- 10% of generation with Hot Water Diversion and Battery storage.

The provision of hot water tanks in dwellings is essential to make use of water heating solar plus technologies.

Summary of Key findings from Case Study current number of Residential PV installations Analysis.

The analysis of the current number of installed PV systems in NI shows five key findings:

a) As of 31st December 2023 there were 25,577 PV installations of 6.5kWp system size of less, assumed to be domestic in Northern Ireland. (MCS March 2024).
b) These 25,577 PV installations equate to approximately 3.4% of dwellings in Northern Ireland having PV systems installed.
c) Households with a typical 4kWp PV system average an annual generation of 3606 kWh.
d) The addition of solar plus technologies (Diversion to Water Heating and Battery Storage) to household PV systems increases the percentage of PV renewable energy consumed from 30% to 70% plus and reduces PV generation exports to the electricity network from 70 to 30% or less.
e) The typical PV systems size of 4KWp does not maximise the potential PV generation for households.

3.0 Research Aims and Objectives

3.1 This research seeks to build on previous exploratory research commissioned by DfE and undertaken and completed by GIA (2022) which examined the potential for PV electricity generation in Belfast. In view of this, this research seeks to undertake further market intelligence and analysis to assist DfE in further profiling and understanding PV potential for electricity generation. Thus, the aim of this project is to model the potential PV generation for all domestic garages and outbuildings and non-domestic buildings and in Northern Ireland and undertake an assessment of the potential battery storage within the domestic (residential) sector.

3.2 To meet the overall aim of the research, the primary research objectives are to:

- Undertake an assessment of rooftop PV potential across all suitable building types within NI. This will provide estimates for domestic (Residential) PV potential; and non-domestic (Commercial and Industrial) PV potential as classified by the Ordinance Survey NI (OSNI) Fusion Data Type Code. A spatial database containing details of all buildings in NI.

- Undertake an assessment of rooftop PV potential at varying spatial geographies (such as Local Government District (LGD), Small Area (SA) and Data Zone (DZ) levels) for domestic (residential) and non-domestic (Commercial and Industrial) property typologies.

- Assess the potential impact of battery storage within the residential sector, to model the improvement and efficiency of energy storage solutions with PV generated electricity usage within residential households and the extent to which electricity is exported to the network.

- Provide an evidence base and interactive Tool/Dashboard for DfE which will inform the delivery strategy for informing at scale climate change policies and renewable energy strategies.

3.4 Given the specific need to determine the potential PV rooftop generation in Northern Ireland and to assess the impact of battery storage with PV solar panels in the residential sector, the research has the following key objectives:

- Determine the total footprint (area in m^2) of Dwellings and Domestic Garages in NI by utilising the OSNI Fusion database of buildings.

- The total footprint (area in m^2) of Commercial and Industrial units in NI and by classification using Fusion building polygon data type code classifications.

- The total footprint (area in m^2) of dwellings and garages by LGD and at SA and DZ levels.

- The total footprint (area in m^2) of Commercial and Industrial units by LGD and at SA and DZ levels.

- Determination of electricity use relative to occupancy rates[4] modelled and electricity demand profile generation.

- Techno-economic analysis of solar PV and battery installations, and extrapolation of modelled results to assess potential impacts across council areas.

- Establish the extent of existing Solar PV installations in Northern Ireland.

[4] Occupancy rates refer to the estimated energy consumption that was based on current domestic energy profiles and estimated dwelling sizes. For scenario modelling a range of sizes were used, across five categories, with larger dwellings being afforded a larger energy consumption.

4.0 Research Methodology

4.1 The research methodology applies a quantitative approach and specifically the application of secondary analysis of quantitative datasets alongside Geographic Information Systems (GIS) software packages, Ordinance Survey Northen Ireland (OSNI) Fusion and Basemap and assumptions agreed with DfE before commencement of the research.

Identification of Existing Residential PV Installations

4.2 PV panels and systems have been installed in both domestic and non-domestic buildings in NI since the early 2000s. These installations are certified by the Microgeneration Certification Scheme (MCS). MCS is a standards organisation which "certifies low-carbon products and installations used to produce electricity and heat from renewable sources".[5]

4.3 This research utilises a data set of PV installations in Northern Ireland provided by MCS installer clients, it comprises details of 29,342 PV systems installed between 2010 and end of 2023. The MCS data provides details of each installation's full postcode, the system size in kWp, expressed as the declared net capacity, (the maximum output of the PV systems inverter, multiplied by the efficiency of the inverter) and date of commissioning.

Assessment Components and Applied Assumptions

4.4 The following assumptions were agreed with DfE prior to the commencement of the research:

a) The roof pitch of residential properties was assumed to be 35 degrees.
b) The pitch of non-domestic rooftops was assumed to be 0 degrees.
c) PV panels for the purpose of the analysis were assumed to have panel size of 1.6m2 X 1.0m2 panel and an output of 350 kWp.
d) The minimum useful size of a rooftop to accommodate a PV installation was assumed to be $10m^{2.}$
e) The generation potential is calculated at 100% of rooftop availability, with lower percentage rooftop availabilities also determined.
f) Panel efficiency is 22%.

4.5 A summary of the parameters and assumptions applied within the research can be observed in Table 4.1 overleaf page 32.

[5] (Mcscertified.com: Accessed 30/01/24).

Methodology for Determining Rooftop Potential PV Generation

4.6 The analysis of the data is carried out using Geographical Information Software (GIS), with three different programs used: QGIS 3.28.2, ArcGIS 10.4.1. and ArcGIS Pro. The different programs are applied as each has a slightly different range of functions. This also facilitates comparisons to be made enabling the checking of results between the software packages.

4.7 In order to undertake the spatial analysis to determine the potential generation output from Rooftop PV the Fusion building polygon database from OSNI was utilised. This database provides geographical vector information on all 1,480,191 domestic and non-domestic buildings in NI including a classification of the building type (Fusion Type Code), residential, industrial, etc. and the area of each building polygon in square metres.

4.8 The Fusion data was cleaned to remove any information that was not required for the analysis. For residential buildings (categorised in the Fusion Data as detached, semi-detached, terrace, dwelling, apartment, mixed and other), the Fusion Data polygons with a calculated roof area of less than $10m^2$ (17,433 in total) were removed for this analysis leaving a total of 787,625 dwellings with a calculated roof area of greater than $10m^2$.

4.9 Similarly for domestic garages and outbuildings, classed as "General" in the Fusion Type Code, those with a calculated rooftop area of less than $10m^2$ were removed as being too small to accommodate a PV system. In addition to domestic garages, this "General" category also includes agricultural buildings, large sheds and outhouses. Therefore, a size limit had to be determined that would include domestic garages but would exclude these large non-domestic buildings. An examination of residential areas with garages was undertaken using GIS and it was determined that having an upper limit area of $80m^2$ would capture almost all domestic garages but would exclude the non-domestic sheds. On this basis, any non-domestic polygons with a calculated rooftop of greater than $80m^2$ were excluded as being unlikely to be for domestic use[6]. In relation to non-domestic buildings, they were assumed to have a flat roof therefore the area of the Fusion Data building footprint was used in the methodology. As the domestic "general" polygons were assumed to have a pitched roof they were assessed on a calculated rooftop area. The $80m^2$ calculated rooftop limit is equivalent to a polygon area of $66.7m^2$ which was used as the lower size limit for "general" non-domestic flat roofed buildings. This

[6] We apply an assumption (based by visually looking at a sample of polygons) that any "general" garages and outbuildings greater than $80m^2$ are likely to be non-domestic. Those "general" buildings above $80m^2$ were included within the non-domestic analysis.

ensured that all the Fusion "general" polygons with a calculated roof area of greater that 10m^2 were included in the analysis with no duplication between the delineation of Building Type Codes.

4.10 In the UK, a roof pitch between 25 degrees and 47.5 degrees would be considered conventional[7]. For the purpose of this study, a roof pitch of 35 degrees is deemed as typical and is used as the working assumption. As the area of a pitched roof is greater than the area of the footprint of the building, a calculation of Cosine angle 35 degrees is applied to each dwelling and residential garage polygon. This produces a multiplication factor of 1.2 for the building footprint area to roof area. Consequently, the dwelling and garage polygon areas were multiplied by 1.2 to take account of this in the methodology. The area of the rooftops was then divided into two, to facilitate the determination of the generation output from the orientations of each of the two halves of the roofs. A similar methodology was applied to determining the potential generation from domestic garage rooftops. For non-domestic dwellings an assumption was agreed that the pitch of the roof would be 0 degrees, thus no multiplication factor was necessary.

4.11 The Fusion data was imported into QGIS GIS software and the orientation of each building polygon determined. This analysis was undertaken using the Oriented Minimum Bounding Box (OMBB) tool which assigns an orientation to each polygon with - 90° being East, 0° being South and 90° being West. These orientations were applied to one half of the residential and garage roofs with the remaining half of the roofs assigned an orientation of the primary half angle minus 180°.

4.12 A range of spatial geographies (shapefiles) were appended to the Fusion database, including Local Government District (LGD), Small Areas, Super Output Areas, Super Data Zones and Data Zones together with District Electoral Areas and Postcode Districts. The addition of these spatial geographies will facilitate future socio-economic analysis of the results.

[7] See: https://dwbgroup.co.uk/how-to-measure-the-pitch-angle-of-your-roof/

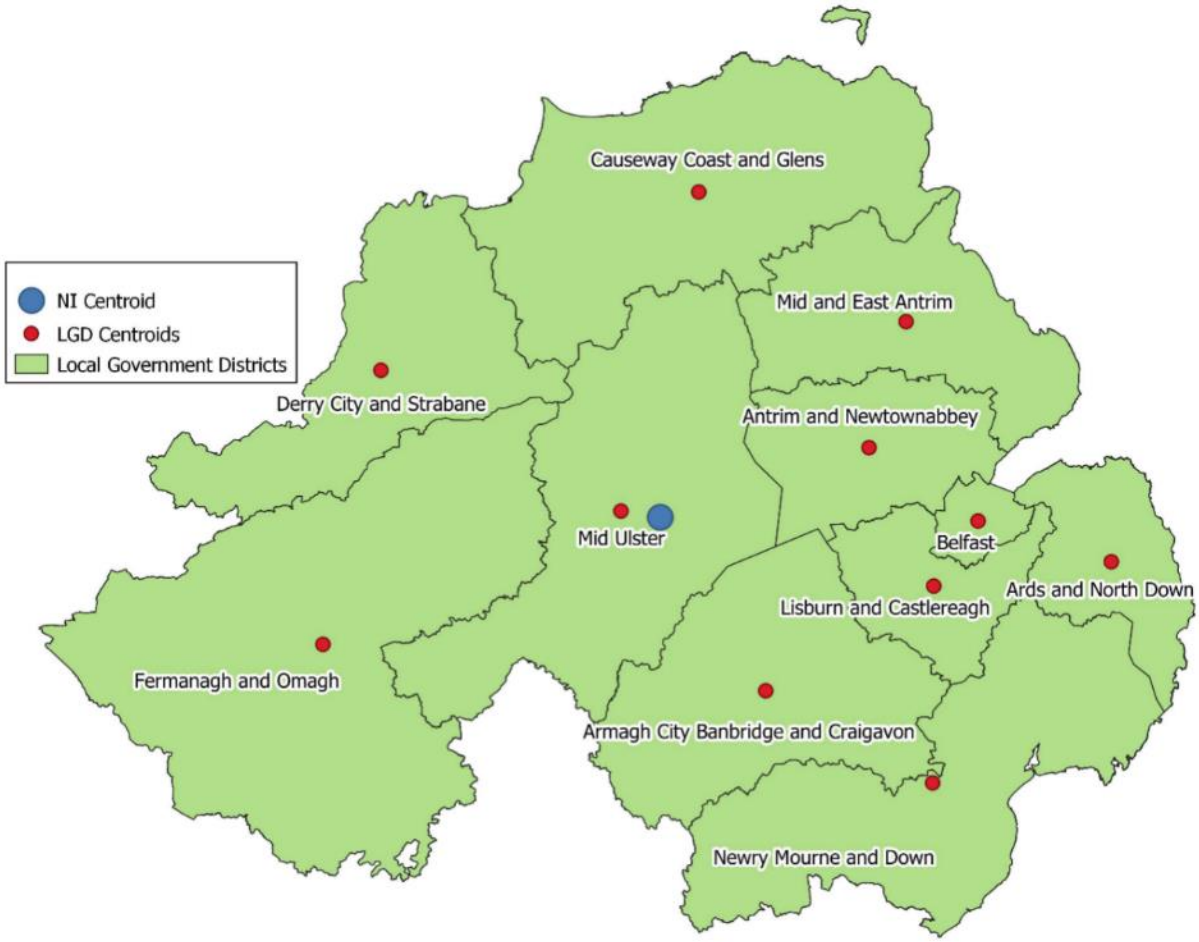
Table 4.1 Parameters and assumptions applied within the research

Parameter/ Specification	Assumption	Source (where required)
Flat Roofs (inclination)	0 degrees.	
Pitched Roofs (inclination)	35 degrees.	
Panel Dimensions	1.6m x 1.0m (L x W)	Solar Together. Green Match.
Panel Wattage (Wp)	350Wp.	
Panel Efficiency	22%.	Hybrid Energy Systems Models. Solar Learning Centre.
Panel Cell Technology	Monocrystalline.	
Installation Cost Per kWp	£1,016.12 - includes cost of generating equipment (panels, mounting kit, inverter, meters etc,) and labour.	Department for Energy Security and Net Zero (DESNZ).
Electricity Price (£/kWh) - Commercial	£0.189 / kWh.	Power NI.
Electricity Price (£/kWh) – Domestic	£0.36398 / kWh.	Consumer Council.
Export Price (£/kWh) – Commercial	£0.0495 / kwh	Power NI. The Eco-Experts.
Generation Incentive Scheme Tariff (£/kWh)	£0/kWh	
Grid Carbon Intensity (2021)	0.371 kgCO2e/kWh.	The Department for Agriculture, Environment and Rural Affairs (DAERA).
Carbon Cost of Production and Installation of PV	41 gCO2e/kWh.	Intergovernmental Panel on Climate Change (IPCC).
Scenarios Modelled for renewable energy consumption at generation levels	100% 75% 50% s, Residential PV Only 34%, PV and Hot Water Hot 70%, PV HW and Battery 90%	
Panel Viability Parameter Applied	No Minimum generation rate/year	

Location and Solar Radiation

4.13 The amount of solar radiation received varies by location on the earth's surface. To account for this variation within NI, the centroid[8] locations (central point) for each of the eleven LGDs in the province were determine from the LGD boundaries using GIS and the Latitude and Longitude entered into the EU PV GIS modelling web application[9] (Figure 4.2).

Figure 4.2 Northern Ireland LGD Centroid Locations



4.14 The variation of yearly energy production, from pitched roofs at 35 degrees angle, for the eleven locations across the province and at a range of building orientation angles was then modelled using the EU PV GIS web tool[10]. The modelling was based on a 4 kWp PV system typical of dwellings and domestic garages and outbuildings.

[8] The centroid is the mean position of all the points in all of the coordinate direction

[9] European Commission, PV GIS Performance of Grid Connected Yearly PV energy production web tool: JRC Photovoltaic Geographical Information System (PVGIS) - European Commission (europa.eu)

[10] European Commission, PV GIS Performance of Grid Connected Yearly PV energy production web tool: JRC Photovoltaic Geographical Information System (PVGIS) - European Commission (europa.eu)

The percentage output from each location and building orientation was calculated for the range of building orientations and LGD centroid locations below (Tables 4.2 and 4.3).

4.15 In relation to non-domestic buildings a similar process was undertaken but with an assumed zero-degree pitch of the roof. Working on this assumption means that the orientation of the building has no significant impact on the energy output with the main variable being the solar irradiation at that location. Again the solar irradiation level at LGD centroid points was used and the percentage output from each location was modelled using the EU PV GIS web tool.

Table 4.2 Pitched Roof 35 Degrees Angle Percentage Efficiency in Power Output by LGD Centroid Location and Roof Orientation

Local Government District	NW 135	W 90	West 45- 89	SW 44	South 0	SE - 44	East- 45 - 89	E -90	NE -135	North -180
Antrim and Newtownabbey	54.8	68.7	80.8	85.6	85.6	85.6	80.8	68.7	54.9	48.4
Ards and North Down	56.6	72.5	86.9	92.6	92.6	92.6	86.8	72.4	56.8	49.4
Armagh City Banbridge & Craigavon	55.5	69.9	83	88.5	88.5	88.5	83.6	70.7	56	49
Belfast	55.5	70.3	83.6	89.1	89.1	89.1	83.9	70.8	55.9	49
Causeway Coast and Glens	53	66.2	77.8	82.4	82.4	82.4	77.8	66.3	53.1	46.8
Derry City and Strabane	52.2	64.3	75	79.2	79.2	79.2	75.1	64.7	52.8	46.8
Fermanagh and Omagh	53.6	66.5	77.9	82.5	82.5	82.5	78.1	67	54.1	47.8
Lisburn and Castlereagh	55	69.3	82.2	87.6	87.6	87.6	82.7	70.1	55.5	48.7
Mid and East Antrim	54.8	68.6	80.3	84.5	84.5	84.5	79.5	67.6	54.3	48.2
Mid Ulster	54.6	68.4	80.9	86.1	86.1	86.1	81.5	69.3	55.3	48.5
Newry Mourne and Down	55.3	68.8	80.3	84.8	84.8	84.8	80.2	68.7	55.3	49

Source: Author's calculation using EU PV GIS webtool

4.16 The impact of PV panel orientation and location on generation output can be seen in Table 4.4 (p.38 overleaf) which indicates how the output of a typical 4kWp domestic system is influenced by the variation in these factors. For instance, a PV installation in Ards and North Down facing due south, operates at a 92% efficiency compared to a similar installation in Derry Strabane which operates at 79.2% efficiency. On a typical 4kWp PV installation this equates to a difference of 537kWh of generation per year between the two locations. PV installations on north

facing roofs operate at a range between 46.8% and 49.4% efficiency across the province.

Table 4.3 Flat Roof 0 Degrees Angle Percentage Efficiency in Power Output

Local Government District	Flat Roof (0 degrees) Irradiance Factor Percentage
Antrim and Newtownabbey	74.36%
Ards and North Down	77.86%
Armagh City Banbridge and Craigavon	76.18%
Belfast	75.71%
Causeway Coast and Glens	71.79%
Derry City and Strabane	70.05%
Fermanagh and Omagh	72.53%
Lisburn and Castlereagh	75.35%
Mid and East Antrim	74.34%
Mid Ulster	74.94%
Newry Mourne and Down	75.23%

Source: Author's calculations

4.17 The PV output radiance percentages were integrated into the dwelling, garage and outbuildings polygon data using the interval angles illustrated in Table 4.4 by multiplying the roof area potential generation kWp figure for each building roof by the modelled output reduction percentage for each LGD centroid derived from the PV GIS webtool tool.

4.18 The installed peak power output was calculated for each half (kWp) of dwelling, garage and outbuilding roofs and the total kWp for each rooftop was determined by adding the output for each half together. This total kWp figure was then multiplied by the percentage efficiency in power output at the particular LGD centroid and orientation for each roof to give the output in MWh.

4.19 Having obtained the generation potential for each roof top the generating potential at LGD level was determined by undertaking a spatial dissolve of the data using ArcMap GIS software, (See table 4.5 for methodological details of process). The output of this spatial dissolve of 787,625 dwellings produced the total potential generating output at the LGD geography level.

Table 4.5 overleaf, illustrates the stages in the methodology for calculating the potential generation from roof tops by way of an example for a dwelling roof situated in Antrim Newtownabbey LGD.

Table 4.4 Pitched Roof 35 Degrees Angle Yearly Output from a 4 kWp PV System

Local Government District	Nw135	W 90	SW 45	South 0	SE - 45	East - 90	NE - 135	North - 180
Antrim and Newtownabbey (kWh)	2191.3	2746.9	3233.8	3424.2	3231.7	2748.6	2195.9	1935.1
PV GIS % Output of 4kWp System	54.8	68.7	80.8	85.6	80.8	68.7	54.9	48.4
Ards and North Down (kWh)	2263.0	2903.1	3476.8	3705.7	3472.5	2897.7	2270.0	1975.2
PV GIS % Output of 4kWp System	56.6	72.6	86.9	92.6	86.8	72.4	56.8	49.4
Armagh City Banbridge and Craigavon (kWh)	2218.9	2796.1	3321.4	3540.9	3344.8	2828.8	2239.3	1960.8
PV GIS % Output of 4kWp System	55.5	69.9	83.0	88.5	83.6	70.7	56.0	49.0
Belfast (kWh)	2221.8	2811.4	3344.1	3562.5	3357.1	2832.5	2237.0	1958.6
PV GIS % Output of 4kWp System	55.5	70.3	83.6	89.1	83.9	70.8	55.9	49.0
Causeway Coast and Glens (kWh)	2119.7	2648.4	3110.4	3294.3	3113.1	2654.0	2124.6	1872.0
PV GIS % Output of 4kWp System	53.0	66.2	77.8	82.4	77.8	66.3	53.1	46.8
Derry City and Strabane (kWh)	2088.4	2570.9	2999.6	3169.7	3004.5	2588.9	2110.8	1871.0
PV GIS % Output of 4kWp System	52.2	64.3	75.0	79.2	75.1	64.7	52.8	46.8
Fermanagh and Omagh (kWh)	2145.2	2658.6	3114.1	3300.4	3125.2	2678.7	2164.8	1913.3
PV GIS % Output of 4kWp System	53.6	66.5	77.9	82.5	78.1	67.0	54.1	47.8
Lisburn and Castlereagh (kWh)	2201.7	2773.2	3287.7	3502.4	3309.9	2803.2	2221.2	1946.5
PV GIS % Output of 4kWp System	55.0	69.3	82.2	87.6	82.7	70.1	55.5	48.7
Mid and East Antrim (kWh)	2192.2	2745.2	3213.2	3380.5	3178.5	2705.8	2172.0	1927.1
PV GIS % Output of 4kWp System	54.8	68.6	80.3	84.5	79.5	67.6	54.3	48.2
Mid Ulster (kWh)	2184.5	2737.4	3236.8	3445.9	3259.1	2771.9	2211.7	1940.6
PV GIS % Output of 4kWp System	54.6	68.4	80.9	86.1	81.5	69.3	55.3	48.5
Newry Mourne and Down (kWh)	2212.3	2750.9	3213.2	3393.4	3208.1	2746.3	2210	1958.3
PV GIS % Output of 4kWp System	55.3	68.8	80.3	84.8	80.2	68.7	55.3	49.0

Source: Author's calculation using EU PV GIS webtool. Note if the PV panels output was at 100% of potential then the maximum generation cited in the above table would be 4000kWh

Table 4.5 Methodology Stages for calculating the potential generation from roof tops

Building	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**	**Stage 5**
Residential Type	Building Footprint Area m2	Rooftop Area Total m2 COS 35 @1.2	Roof Area m2 Primary Orientation	Roof Area m2 Secondary Orientation	Nos Panels Primary 1.6m2
Dwelling	8.30	10.00	5.00	5.00	3.00
Stage 6	**Stage 7**	**Stage 8**	**Stage 9**	**Stage 10**	**Stage 11**
Nos Panels Secondary 1.6m2	Primary kWp Max .350	Secondary kWp Max .350	Total kWp Max (Primary and Secondary)	QGIS_Primary Angle South_= zero	QGIS Secondary Angle
3.00	0	1.05	2.10	9.00	-171.00
LGD 2014	**Stage 12**	**Stage 13**	**Stage 14**	**Stage 15**	**Stage 16**
Antrim and Newtownabbey	Primary LGD Orientation Factor %	Secondary LGD Orientation Factor %	MWh Primary Energy Output	MWh Secondary Energy Output	Annual MWh Total Rooftop Generation
	0.86	0.55	0.903	0.58	1.48

Source: Author's calculation

Assessing the Potential Impacts on Domestic Households from Incorporating Battery Storage with Rooftop PV Generation

4.20 The assessment is carried out by generating electricity consumption and load profiles for domestic households and measuring the impacts from adding energy storage to baseline solar PV generation, and extrapolating results to measure impacts across NI and LGDs.

4.21 To determine values for the annual electricity consumption across different household occupancy rates, annual consumption figures were used from OFGEM with three categories of energy consumption profiles modelled (Low, Medium, and High).

Table 4.6 Typical Annual Energy Use for UK households relative to occupancy

Energy use	Home type & number of residents	Typical annual gas use (kWh)	Typical annual electricity use (kWh)
Low	Flat or 1 bed house; 1-2 people	8,000	1,800
Medium	2-3 bed house; 2-3 people	12,000	2,900
High	4+ bed house; 4-5 people	17,000	4,300

Source: (OFGEM, 2023)

4.22 These values were selected as they are currently used to inform policy decision in this area and are currently the values used by OFGEM when calculating the energy price cap (OFGEM,2023). Although the energy price cap has not been implemented in Northern Ireland, as instead a tariff review process is conducted by the Utility Regulator, these figures still serve as a useful baseline that have a precedent for use within policy making decisions. It should also be highlighted that these figures are in line with expectations for NI consumption, as a prior report conducted by the DfE in 2020 estimated from council meter readings an annual domestic electricity consumption of 3600kWh (DfE, 2020). For the purposes of the modelling being conducted, only annual electricity consumption values are required and applied.

4.23 Case study analysis from 18 households (comprising 49 years of data)[11] is also examined to assist with this profiling of household energy consumption and PV generation to triangulate the estimations.

[11] The case study data is taken from a sample of domestic households based on ongoing research by Ulster University.

4.24 To generate electricity load profiles, the annual consumption values from OFGEM were combined with the reported domestic load profiles produced by Elexon[12]. Elexon as an institution are responsible for managing the Balancing and Settlement Code (BSC), and as part of their remit report on average consumption profiles for different categories of households. This data was gathered from smart meters put in a large sample of consumers homes, and as such is an accurate representation of the average household demand profile across Great Britain[13].

4.25 Combining these profiles with the OFGEM benchmarks will enable the generation of load profiles that more accurately represent when the demand will occur, and not just the net value over the year.

Solar PV & Battery Sizing for Modelled Scenarios

4.26 To model the impacts of solar PV with and without battery energy storage, we apply assumptions in relation to about the size of solar PV and energy storage being considered. For each category of consumption that was modelled different values are considered to reflect the availability of roof area, and the varying requirements due to different consumption levels.

4.27 Part of the modelling process includes an optimisation stage to explore the most ideal scenarios within a given range.

Modelling Process and Main Variables Identified to Measure Impact of Storage.

4.28 Homer Pro modelling software is used to model the impacts from adding Solar PV with/without energy storage on a (domestic) household level[14]. This enables the simulation of system performance over an extended period.

4.29 PV performance, battery lifetime capacity, equipment costs, etc. are obtained from performance specifications of equipment that is available on the UK market today. This is to ensure that any modelled performance can be achieved with available

[12] Elexon load profile notes & guidance - https://bscdocs.elexon.co.uk/guidance-notes/load-profiles-and-their-use-in-electricity-settlement

[13] Similar data was not available for NI specifically, and lack of smart meter data also reduces chance of getting enough specific data to extrapolate with confidence.

[14] This is an industry standard software that is used when optimising energy systems using a range of renewable technologies.

technology that can be procured locally in NI through available markets. These are in line with specifications and assumptions used elsewhere in this report.

4.30 The system lifespan modelled is 25 years to match the expected lifespan of the Solar PV modules, as this is generally considered the length of time before performance will drop below 80% of the rated performance and replacements are required. This is shown in various studies including a case study investigating the degradation of Solar PV across sites in the UK & Ireland which found an average degradation of -0.74% each year (Dhimish, 2020). Extrapolating these figures out we can see that a performance drop of -18.4% would be expected across the lifespan of the modelled scenarios. Other components in the system that have a rated lifespan lower than this will be replaced in the simulation as and when they are required, as Homers simulation process accounts for this.

4.31 Utilising modelling software generates a range of valuable information about the lifetime system performance. This determines the utilisation of generated power from solar PV with and without energy storage, provides an estimate of the potential use of adding energy storage and the impacts this has on the wider system.

4.32 We measure the corresponding change in emissions as a result of the addition of solar PV, and the corresponding changes when energy storage is added. This along with utilisation results informs the optimal scenario in terms of reducing emissions, as the expectation would be that as utilisation of solar PV goes up, emissions come down.

4.33 We further examine the economic performance of a household's energy bill when adding solar PV with/without energy storage. This step is undertaken to help inform the viability of making such changes in today's landscape and may help further inform future policy decisions regarding economic support in this area.

Extrapolation of Modelled Results to Assess Potential Impacts across LGDs.

4.34 Using the model results from adding solar PV with/out energy storage, we extrapolate the potential impacts across LGDs. 2021 Census data was used to obtain the total number of households across each LGD in which the dataset is applied. This is also triangulated with Pointer to ensure accurate estimation of the number of properties and more accurate estimations within each LGD.

4.35 Using the modelled values, estimations for the total financial impact on households are determined, as well as suggesting potential payback periods and emission reduction estimations.

5.0 Assessing the Generation Potential of Rooftop PV in Northern Ireland

5.1 Existing research on solar PV within NI has identified that further profiling of the potential of PV generation is required to inform Energy Strategy policy development. Accordingly, there is a need to gather further evidence relating to potential PV estimation/generation for buildings at an NI level. This section presents the findings from the assessment exercise undertaken using a combination of open source and publicly available data within GIS analysis, PV GIS system generation locational capacity information, PV panel sizes and assumptions on roof availability and pitch (angle) and OSNI Fusion polygon which provides information on the area (m^2) and use class of buildings. The following broad classes of buildings were included within the analysis, dwellings, domestic garages and outbuildings, industrial, commercial, government (Fusion Type Code buildings only), non-domestic general buildings and all other buildings.

PV Generation Potential from Dwellings

5.2 The analysis was undertaken as described in the methodology (Section Four) and the following results obtained. Table 5.1 details the area of rooftops by LGD and the potential installed peak power (kWp) is derived from the number of 350 watt panels that can be accommodated on rooftop areas[15]. The total (MWh) is the potential generation form those same panels per annum

5.3 Potential annual energy output in MWh by LGD was derived using the Fusion data and the efficiency output at the relevant LGD centroid locations derived from the EU PV GIS webtool. This webtool calculates the yearly PV energy production taking account of a range of factors including Latitude/Longitude, slope angle, irradiation levels and year-to-year variability, produced by choosing, for each month the most "typical" month out of the time period 2005-2020. The results from the analysis are contained in Tables 5.1 Dwellings.

5.4 The research further extrapolates the potential annual energy output for a range of percentage rooftop area availability. Research undertaken by (Wiginton et al., 2010:352) examined the fraction of available roof area for PV installation across a range of determination methods and countries. Their results indicated that the fraction of roofs available for PV ranges from 22% to 95% with an average of 47%. Taking this into consideration, the 50% availability potential annual energy output is the most likely attainable generation estimate, see Table 5.2.

[15] It is assumed at that 100% of the rooftop area is available for PV installation.

Table 5.1 Dwelling PV Generation Potential (MWh)

Local Government District	Number of Dwelling Polygons Greater than 10m2	Total Roof Area (m2)	Total Peak Power (kWp)	Total Annual Generation (MWh)
Antrim and Newtownabbey	60,190	6,043,019	1,321,758	958,276
Ards and North Down	71,507	7,563,668	1,653,978	1,274,447
Armagh City Banbridge and Craigavon	89,102	9,912,951	2,168,078	1,610,346
Belfast	136,242	9,810,677	2,146,314	1,600,231
Causeway Coast and Glens	64,945	7,832,284	1,713,454	1,195,039
Derry City and Strabane	61,928	6,056,164	1,324,496	897,461
Fermanagh and Omagh	51,239	6,681,199	1,461,294	1,026,365
Lisburn and Castlereagh	61,111	6,425,649	1,405,306	1,035,246
Mid and East Antrim	60,010	6,376,950	1,394,628	999,331
Mid Ulster	58,432	7,603,737	1,662,964	1,207,744
Newry Mourne and Down	72,919	9,169,810	2,005,736	1,446,717
Total	**787,625**	**83,476,108**	**18,258,006**	**13,251,203**

*Note applying 100% Rooftop Availability Building details obtained from Fusion data, calculations by author.

Table 5.2 Dwelling PV Generation Potential MWh (Roof Availability Ranging 100%-50%)

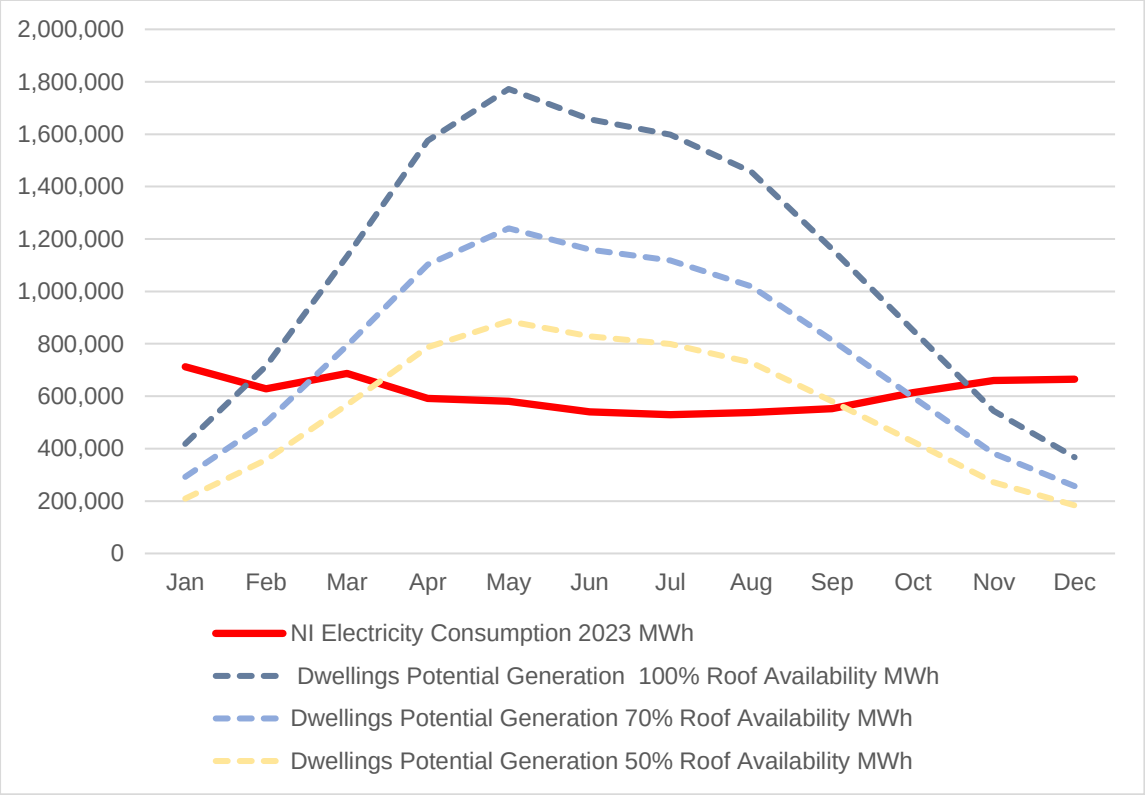
Local Government District	Dwellings Potential Annual Energy Generation Output (MWh)			
	Roof Availability 100%	Roof Availability 90%	Roof Availability 70%	Roof Availability 50%
Antrim and Newtownabbey	958,276	862,448	670,793	479,138
Ards and North Down	1,274,447	1,147,002	892,113	637,224
Armagh City Banbridge and Craigavon	1,610,346	1,449,311	1,127,242	805,173
Belfast	1,600,231	1,440,208	1,120,162	800,116
Causeway Coast and Glens	1,195,039	1,075,535	836,527	597,520
Derry City and Strabane	897,461	807,715	628,223	448,731
Fermanagh and Omagh	1,026,365	923,729	718,456	513,183
Lisburn and Castlereagh	1,035,246	931,721	724,672	517,623
Mid and East Antrim	999,331	899,398	699,532	499,666
Mid Ulster	1,207,744	1,086,970	845,421	603,872
Newry Mourne and Down	1,446,717	1,302,045	1,012,702	723,359
Total	**13,251,203**	**11,926,083**	**9,275,842**	**6,625,602**

Building details obtained from Fusion data, calculations by author.

5.5 The graph below contextualises the generating potential from dwellings at a range of percentage rooftop availabilities and compares these to the actual electricity

consumption in Northern Ireland in 2023. As is illustrated in Figure 5.1 below on a monthly basis, dwelling rooftop PV with 50% of the area of each rooftop covered is capable of meeting the electricity consumption rate of 2023 between the months of March and September. (Note this does not take into account daily, daytime nighttime PV generating cycles).

Figure 5.1 Northern Ireland Dwellings Monthly Potential PV Generation by Percentage Rooftop Availability and NI Electricity actual Consumption **2023**



Potential Rooftop Generation from Domestic Garages and Outbuildings

5.6 In relation to domestic garages and outbuildings the research further extrapolates the potential annual energy output for a range of percentage rooftop area availabilities.

In relation to these "general" outbuildings and garages, the percentage roof availability for solar panels is likely to be higher than that of dwellings, as there is a lower likelihood of chimneys, dormer windows and skylights etc. being present on these types of buildings.

Table 5.3 Domestic Garages and Outbuildings PV Generation Potential (MWh)

Local Government District	Nos General Polygons with Roof Calculated Area between 10m2 and 80m2	Total Roof Area (m2)	Total Peak Power (kWp)	Potential Total Annual Generation(MWh)
Antrim and Newtownabbey	23,634	797,532	174,460	126,314
Ards and North Down	26,978	851,087	186,183	134,800
Armagh City, Banbridge and Craigavon	46,565	1,727,662	377,919	281,098
Belfast	28,895	699,684	153,060	114,197
Causeway Coast and Glens	35,840	1,366,950	299,028	208,692
Derry City and Strabane	22,292	798,029	174,566	118,224
Fermanagh and Omagh	41,065	1,724,154	377,157	264,652
Lisburn and Castlereagh	25,932	870,801	190,485	140,188
Mid and East Antrim	29,773	1,095,938	239,734	171,906
Mid Ulster	38,356	1,603,150	350,688	254,756
Newry, Mourne and Down	44,376	1,718,351	375,892	271,393
Total	**363,706**	**13,253,336**	**2,899,170**	**2,086,220**

Building details obtained from Fusion data, calculations by author applying 100% Rooftop Availability

Table 5.4 below indicates the PV generating potential of garages and outbuildings at a range of roof availability percentages.

Table 5.4 Garages and Outbuildings PV Generation Potential MWh Roof Availability 100%-50%

Local Government District	Garages and Outbuildings Potential Annual Generation Energy Output (MWh)			
	Roof Availability 100%	Roof Availability 90%	Roof Availability 70%	Roof Availability 50%
Antrim and Newtownabbey	126,314	113,683	88,420	63,157
Ards and North Down	134,800	121,320	94,360	67,400
Armagh City Banbridge and Craigavon	281,098	252,988	196,769	140,549
Belfast	114,197	102,778	79,939	57,099
Causeway Coast and Glens	208,692	187,823	146,084	104,346
Derry City and Strabane	118,224	106,402	82,757	59,112
Fermanagh and Omagh	264,652	238,187	185,256	132,326
Lisburn and Castlereagh	140,188	126,169	98,132	70,094
Mid and East Antrim	171,906	154,715	120,334	85,953
Mid Ulster	254,756	229,280	178,329	127,378
Newry Mourne and Down	271,393	244,254	189,975	135,697
Total	**2,086,220**	**1,877,599**	**1,460,355**	**1,043,111**

Building details obtained from Fusion data, calculations by author.

5.7 The mapping of the dwelling analysis below (Figure 5.2-5.4), displays the calculated potential dwelling rooftop areas in squared metres (m^2) by LGD, the associated potential PV Generation in MWh, assuming 100% rooftop availability by LGD, by postcode district and Super Data Zone. The analysis indicates that potential PV rooftop generation is most pronounced within both the Belfast and Armagh City, Banbridge and Craigavon LGDs, followed by the Newry, Mourne and Down LGD.

Figure 5.2 Dwelling Rooftop Area (m^2) by LGD

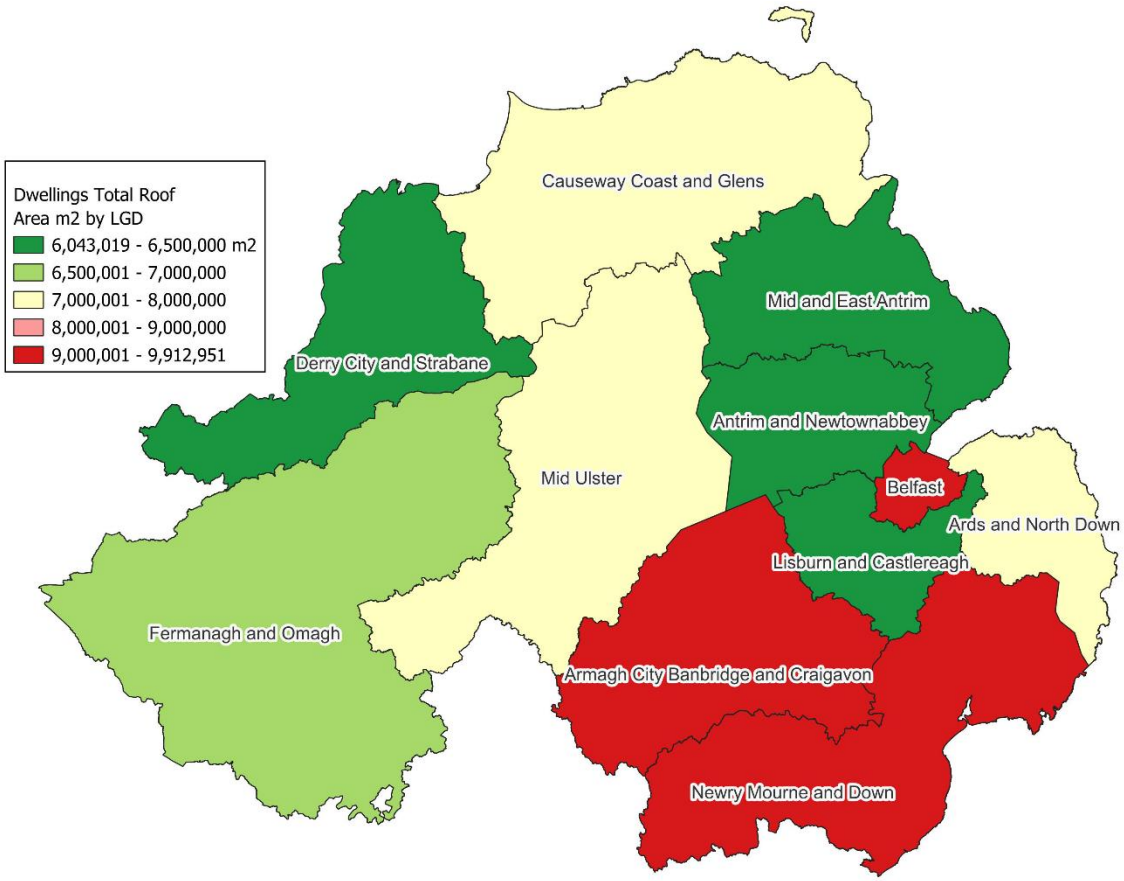


Figure 5.3 Dwelling Rooftop Potential Generation MWh by LGD

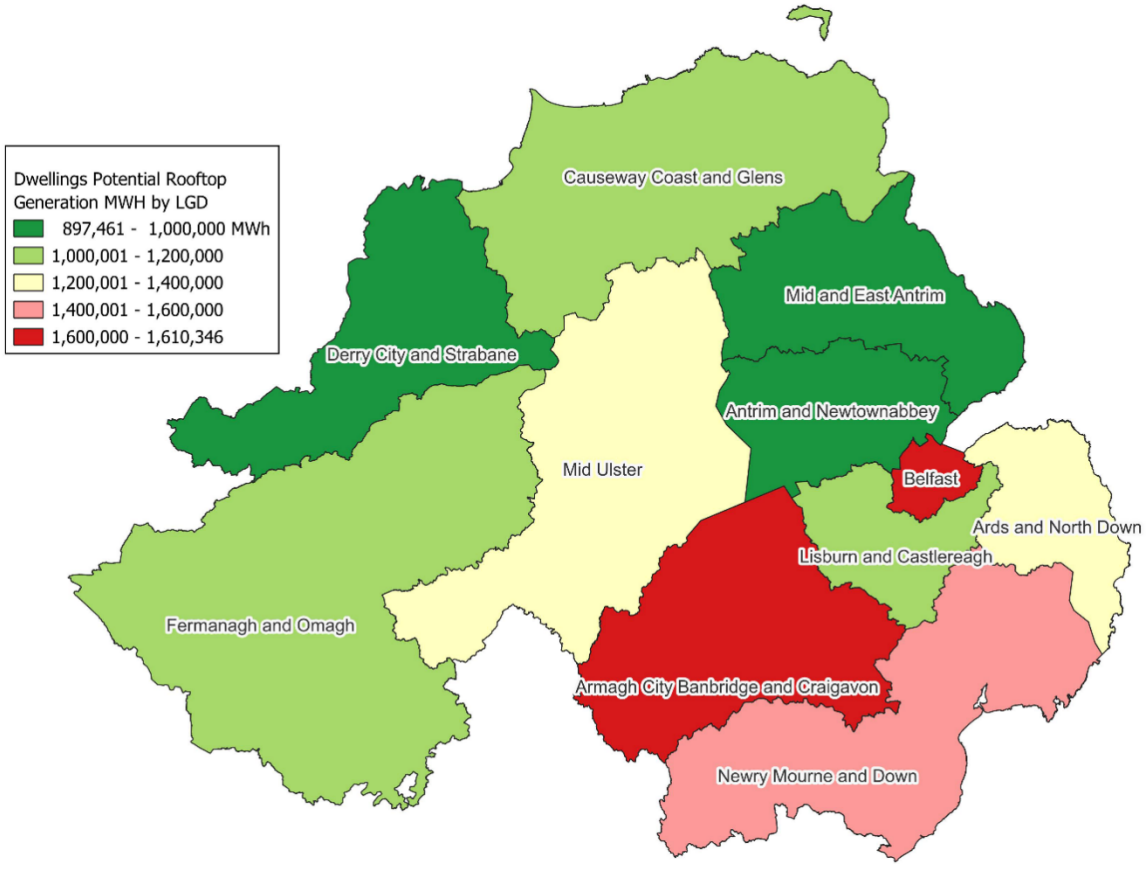


Figure 5.4 Dwelling Rooftop Potential Generation MWh by Census Super Data Zone

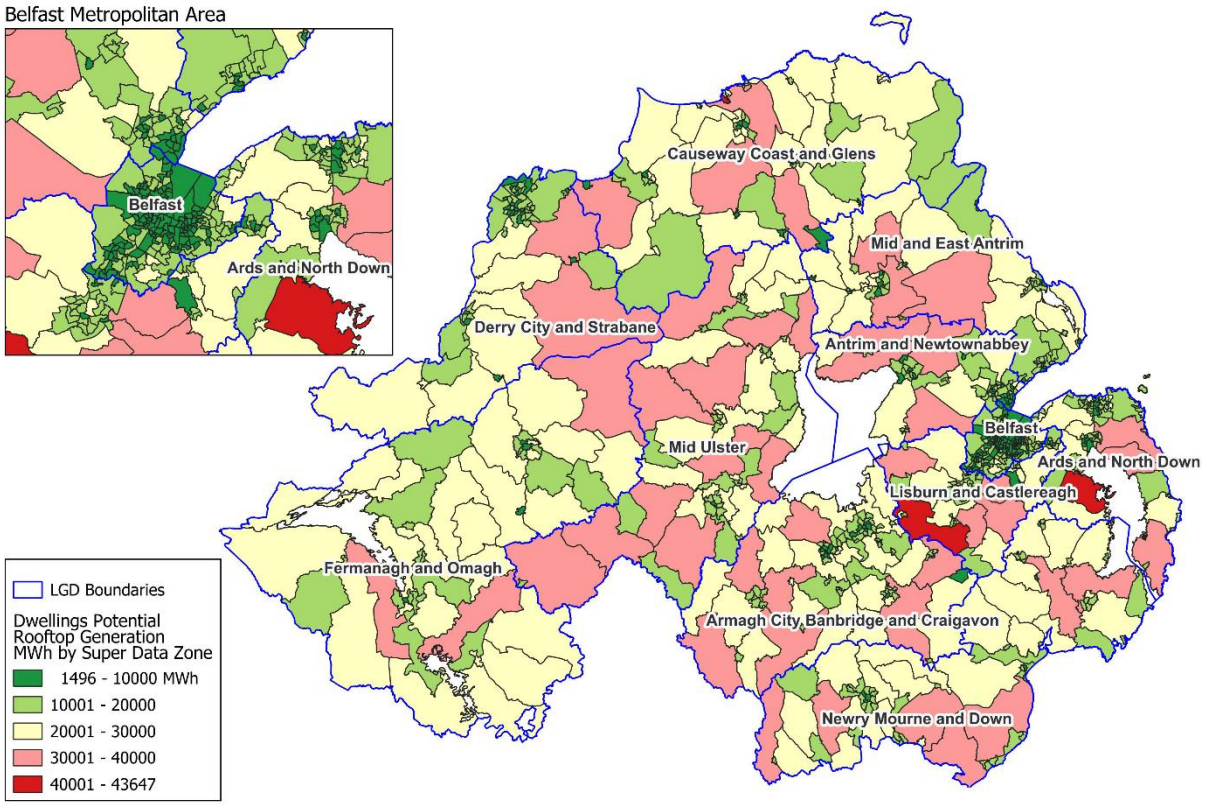
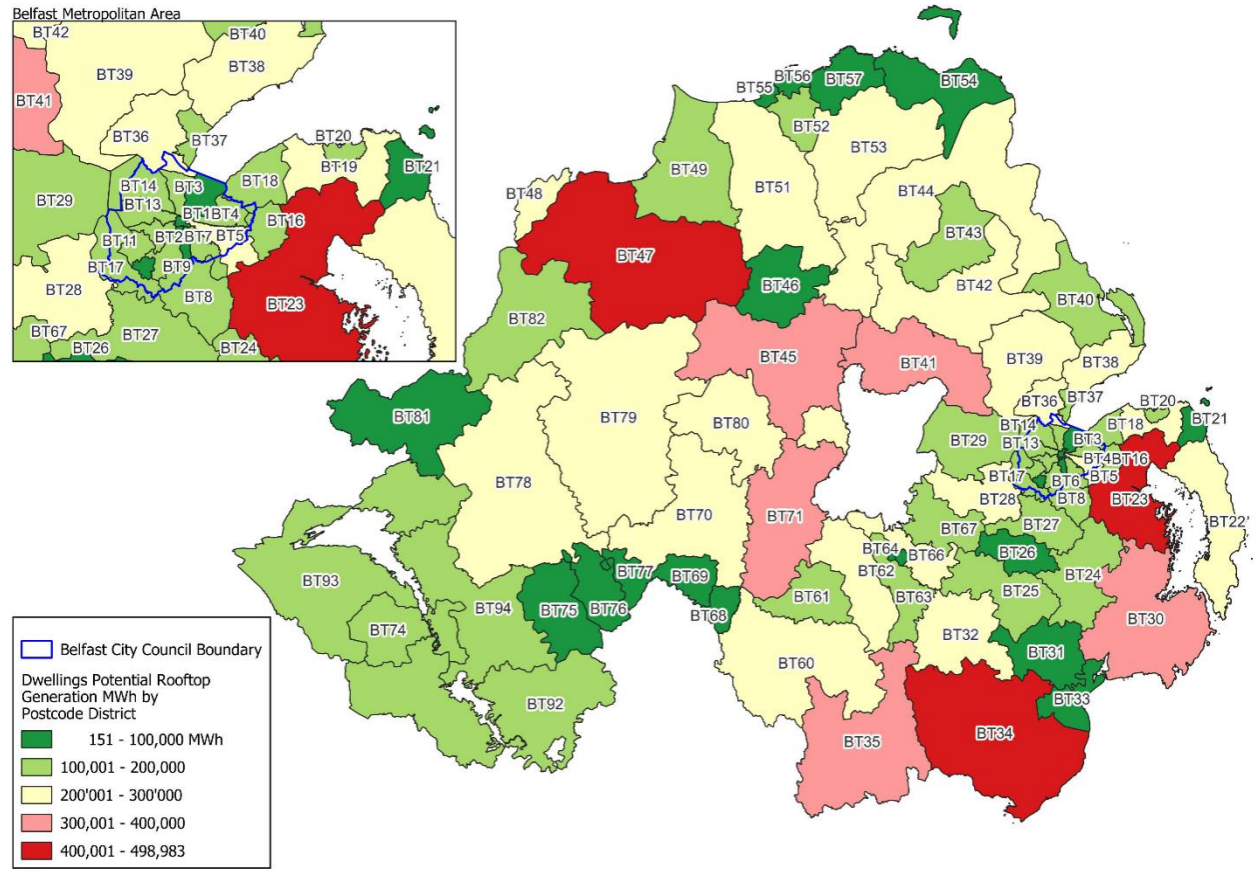


Figure 5.5 Dwelling Rooftop Potential Generation MWh by Postcode District



Potential Rooftop Generation by Fusion Domestic Type Code

5.8 Estimating the potential rooftop generation by domestic classifications identifies the detached sector of the market as having the largest PV generation capacity of 7,207,674 MWh or equating to 54% of the total generating potential, despite representing only 36% of the housing stock. Semi-detached dwellings account for a peak power of 2,545,276 MWh and represent 26% of the housing stock, while terrace housing has a potential peak power of 2,202,510 MWh for and accounts for 29% of housing. Apartment buildings reveal a PV peak power of 399,391 MWh or 3.0% of the generating potential. See Table 5.5 for details.

5.9 Detached properties therefore demonstrate a potential generation uplift of 2.83 times than that of the semi-detached sector, and a 3.27 times uplift compared to the terrace segment of the market.

Table 5.5 PV Potential Rooftop by Fusion Data Dwelling Type

Dwelling Type	Number of Dwellings Polygons by Type	Percentage of Dwellings	Potential Generation (MWh)	Percentage of Potential Generation
Detached	280,888	36	7,207,674	54
Terrace	225,528	29	2,202,510	17
Semi-Detached	205,963	26	2,545,276	19
Dwelling	55,052	7	862,788	7
Apartment	18,927	2	399,391	3
Mixed	1,006	0.13	28,924	0.22
Other	261	0.03	4,639	0.04
Total	**787,625**	**100**	**13,251,203**	**100**

Building category details obtained from Fusion data, calculations by author.

***Note: Mixed is defined as buildings with both residential and other uses e.g. commercial**

***Note applying 100% Rooftop Availability, potential generation calculated by author**

5.10 The monthly generation potential for dwelling rooftop PV installations across a range of rooftop availabilities is displayed in Figures 5.1. and Table 5.6. The analysis shows that total potential PV generation for;

- 100% rooftop availability annual potential generation is 13,251,203 MWh
- 70% rooftop availability annual potential generation is 9,275,842 MWh and at
- 50% rooftop availability annual potential generation is 6,625,602 MWh

5.11 To place this potential generation in context the total electricity consumption for Northern Ireland in 2023 was 7,297,000 MWh. Potential generation and electricity consumption is discussed in more detail in section 6.0.

Table 5.6 Dwellings Potential Electricity Generation by roof availability and NI Electricity Consumption.

	NI Electricity Consumption 2023 (MWh)	Dwellings Potential Generation 100% Roof Availability (MWh)	Dwellings Potential Generation 70% Roof Availability (MWh)	Dwellings Potential Generation 50% Roof Availability (MWh)
Jan	712,348	418,480	292,936	209,240
Feb	627,859	714,484	500,139	357,242
Mar	686,787	1,133,733	793,613	566,868
Apr	591,205	1,574,765	1,102,335	787,382
May	580,470	1,772,461	1,240,723	886,230
Jun	540,408	1,656,940	1,159,858	828,470
Jul	529,527	1,598,054	1,118,638	799,027
Aug	537,553	1,456,180	1,019,326	728,090
Sep	552,461	1,162,329	813,630	581,165
Oct	613,634	852,277	596,594	426,139
Nov	659,739	544,383	381,068	272,191
Dec	665,066	367,116	256,981	183,558
Annual Total MWh	**7,297,057**	**13,251,203**	**9,275,842**	**6,625,602**
Total GWh	**7,297**	**13,251**	**9,276**	**6,626**

Source NI Electricity Consumption figures provide by DfE, calculated by NIE Networks, potential generation calculated by author.

Potential Rooftop Generation from Industrial Buildings

5.12 The OSNI Fusion database provides details of a range of non-domestic building categories (Type Codes). In relation to industrial uses the Fusion data has three relevant categories namely, ND Industry, ND Industry Other and Industry. In total there are 8,986 building polygons included within these three Type Codes. These Industrial categories were extracted from the Fusion database and the methodology as described in paragraph (3.15) was applied to the analysis. The results from the analysis are contained in Tables 5.6

Table 5.7 Industrial Building PV Annual Generation Potential MWh

Local Government District	Number of Industry Polygons Greater than 10m2	Total Roof Area (m2)	Total Peak Power (kWp)	Potential Total Annual Generation (MWh)
Antrim and Newtownabbey	710	637,283	139,406	103,667
Ards and North Down	336	252,424	55,217	42,985
Armagh City Banbridge and Craigavon	1,223	995,644	217,799	165,939
Belfast	994	799,986	174,998	132,482
Causeway Coast and Glens	612	451,554	98,778	70,922
Derry City and Strabane	699	488,476	106,856	74,847
Fermanagh and Omagh	855	551,489	120,641	87,495
Lisburn and Castlereagh	597	567,884	124,226	93,607
Mid and East Antrim	647	757,662	165,742	123,215
Mid Ulster	1,521	1,270,308	277,880	208,261
Newry Mourne and Down	792	555,553	121,528	91,420
Total	**8,986**	**7,328,263**	**1,603,071**	**1,194,840**

Building category details obtained from Fusion data applying 100% Rooftop Availability, potential generation calculated by author

5.13 Figures 5.6, 5.7 and 5.8 overleaf illustrate industrial buildings roof area ($m^{2)}$ by LGD and annual potential generation (MWh) by LGD and postcode district geographies. As can be seen from the maps, Mid Ulster and Armagh City Banbridge and Craigavon LGDs have the highest total industrial building roof areas and related potential PV generation. BT71 is highlighted as the postcode district with the highest industrial rooftop PV generating potential in Northern Ireland.

Figure 5.6 Industrial Buildings Rooftop Area (m^2) by LGD

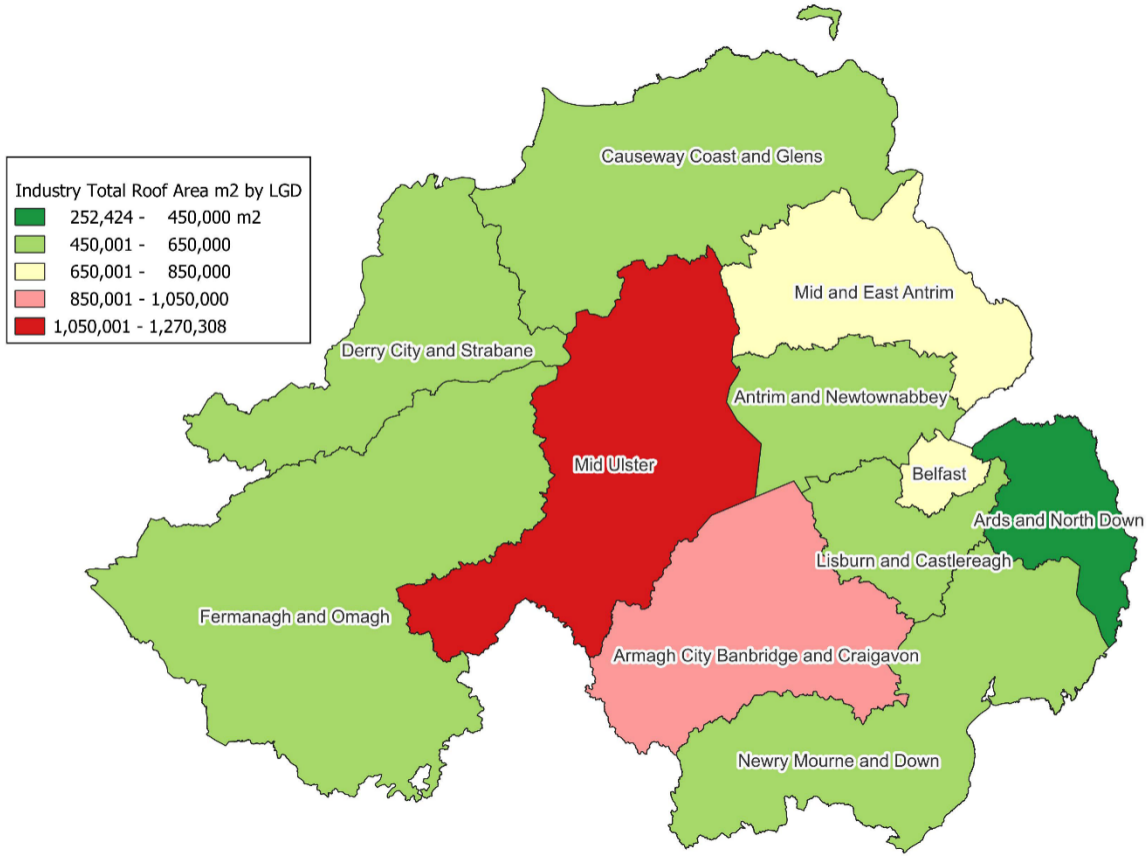


Figure 5.7 Industrial Buildings Rooftop Potential Annual Generation MWh by LGD

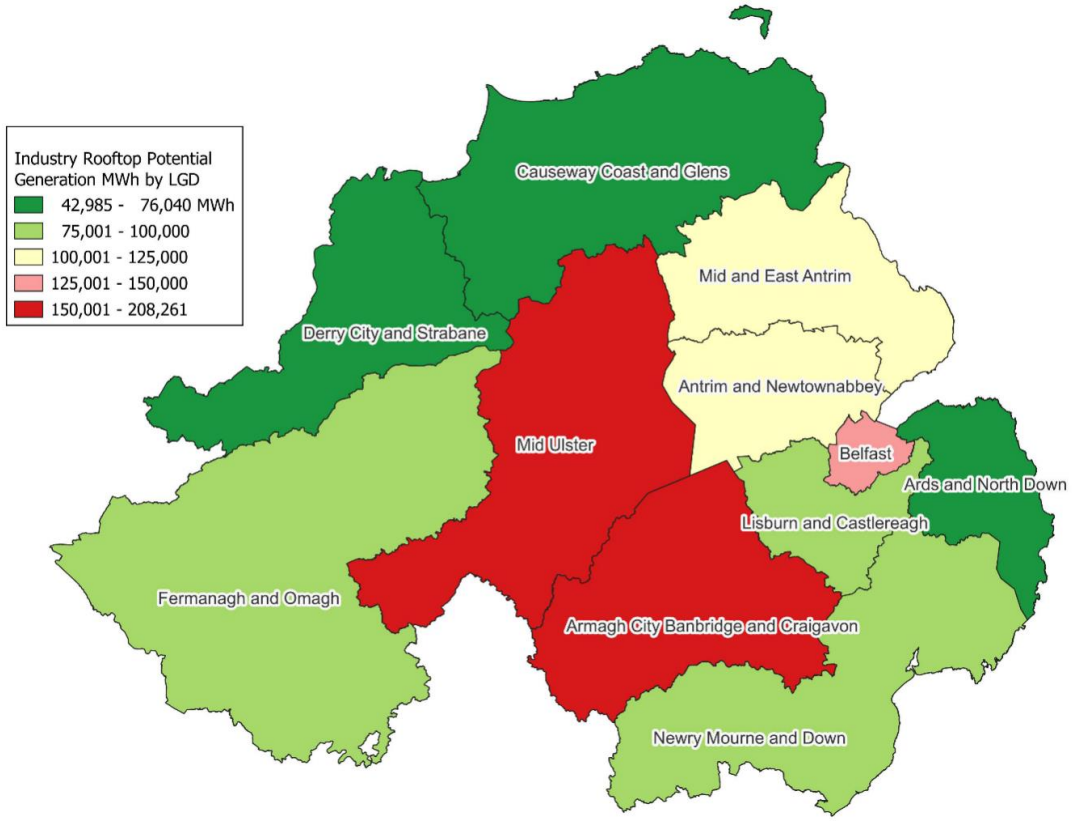
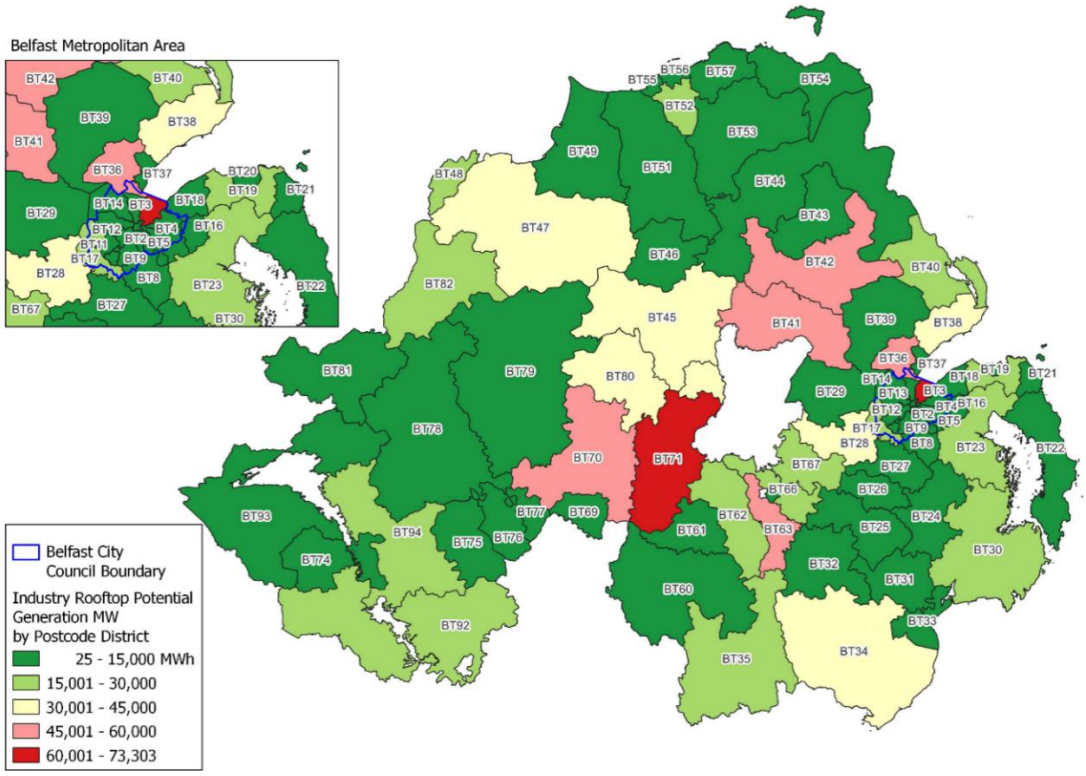


Figure 5.8 Industrial Buildings Rooftop Potential Annual Generation MWh by Postcode District



Potential PV Rooftop Generation from Non-Domestic: Commercial Buildings

5.14 In relation to commercial building uses, the Fusion data has six relevant Type Code categories namely, Commercial, ND Commercial, ND Hospitality, ND Office, ND Retail and Mixed. The OSNI Basemap set of building polygons (a precursor of the Fusion data set) in relation to the Fusion "Mixed" category was a source of additional detail by describing 2,050 of these "Mixed" building polygons as "Commerce General Buildings", so these were included within the commercial category for the analysis. In total there are 36,315 building polygons included within these commercial Type Code categories, details of which are provided in the Table 5.7 below.

Table 5.8 Number of Fusion Commercial Type Code Categories

Fusion Type Code (Category)	Number of Properties	Total Potential Annual Generation (MWh)
Commercial	16,737	748,114
Mixed	2,050	57,976
ND_Comm_Other	2,969	266,377
ND_Hospitality	1,688	90,494
ND_Office	4,241	196,898
ND_Retail	8,630	332,637
Total	**36,315**	**1,692,495**

Building category details obtained from Fusion data, calculations by author applying 100% Rooftop Availability, potential generation calculated by author

5.15 These Commercial categories were extracted from the Fusion database and the methodology as described in paragraph (3.15) was applied to the analysis. The results from the analysis are contained in Table 5.8

Table 5.9 Commercial Buildings Potential PV Annual Generation (MWh)

Local Government District	Number of Commercial Building Polygons Greater than 10m2	Total Roof Area (m2)	Total Peak Power (kWp)	Potential Total Annual Generation (MWh)
Antrim and Newtownabbey	2,191	1,057,846	231,389	172,076
Ards and North Down	2,400	580,082	126,878	98,794
Armagh City, Banbridge and Craigavon	4,275	1,081,477	236,570	180,229
Belfast	6,414	2,083,574	455,748	345,063
Causeway Coast and Glens	3,462	840,217	183,774	131,947
Derry City and Strabane	2,780	820,677	179,516	125,748
Fermanagh and Omagh	3,026	739,715	161,800	117,358
Lisburn and Castlereagh	1,924	682,218	149,258	112,449
Mid and East Antrim	2,738	730,650	159,822	118,817
Mid Ulster	3,214	834,670	182,601	136,830
Newry, Mourne and Down	3,891	930,806	203,639	153,184
Total	**36,315**	**10,381,932**	**2,270,995**	**1,692,495**

*Note applying 100% Rooftop Availability, potential generation calculated by author

Potential PV Rooftop Generation from Non-Domestic: General Building Greater than 66.7m2

5.16 The Fusion "General" type code in addition to domestic garages and outbuildings also contains data on larger non-domestic buildings, to differentiate these buildings from those classed as domestic a calculated roof size of 80m² or a polygon area of 66.7m² was used as the delineation point between the domestic and non-domestic general buildings. As the non-domestic buildings are assumed to have a flat roof the polygon size is the same as the roof area. (See paragraph 4.9 and Table 4.1)

5.17 To place this in context a standard double garage has a recommended minimum size of 36m². (FAQ Garage Plans accessed 11/03/24) . The analysis revealed that there are 189,778 Fusion "general" polygons with a size greater than 66.7m². The results of the generation potential from the non-domestic "general" Buildings is contained in table 5.9.

Table 5.10 General Non Domestic Buildings PV Potential Annual Generation MWh

Local Government District	Number of General (Non-Domestic) Building Polygons with Roof Area Greater than 66.7m2	Total Roof Area (m2)	Total Peak Power (kWp)	Potential Total Annual Generation (MWh)
Antrim and Newtownabbey	9,179	2,484,306	543,430	404,102
Ards and North Down	7,525	1,891,797	413,820	322,231
Armagh City Banbridge and Craigavon	26,172	6,100,307	1,334,592	1,016,715
Belfast	701	133,868	29,293	22,181
Causeway Coast and Glens	21,390	5,409,082	1,183,336	849,530
Derry City and Strabane	11,632	2,829,242	618,982	433,442
Fermanagh and Omagh	30,952	6,590,108	1,441,719	1,045,753
Lisburn and Castlereagh	9,516	2,227,257	487,272	367,189
Mid and East Antrim	15,213	3,580,360	783,248	582,288
Mid Ulster	32,806	7,828,703	1,712,720	1,283,304
Newry Mourne and Down	24,692	5,224,396	1,142,924	859,805
Total	**189,778**	**44,299,424**	**9,691,336**	**7,186,540**

Building details obtained from Fusion data applying 100% Rooftop Availability, potential generation calculated by author

Potential Rooftop Generation from Remaining Building Polygons

5.18 Once the analysis of the previous building categories was complete a range of other Non-Domestic Building Types remained totalling 27,725 in number. The breakdown of these remaining All Other Buildings by Fusion Type code is listed overleaf Table 5.13 page 59. These buildings have a total roof area of 9,882,884m^2 and a generation potential of 1,615,872 MWh at a 100% roof availability. There are some categories amongst these buildings such as "glass" which are probably not be suitable rooftops for PV installations.

5.19 The generating potential of these All Other Building types is provided in Table 5.13 overleaf, which indicates that buildings used for Education account for 34.8% of the PV generation potential followed by Health at 13.5%. Table 5.11 provides details of the generating potential of All Other Building types by LGD. Belfast has the highest PV generating potential of the LGDs with a generating potential of 313GWh per annum. Table 5.12 provides a summary of PV generation by Building Category, dwellings account for 49% of the generating potential with Non-Domestic General Buildings being the next highest category with 26.6% of generating potential.

Table 5.11 Number of All Other Buildings by LGD

Local Government District	Number of Building Polygons	Total Roof Area (m2)	Total Peak Power (kWp)	Potential Total Rooftop Generation (MWh)	Potential Total Rooftop Generation (GWh)
Antrim and Newtownabbey	1,916	720,579	157,626	117,213	117
Ards and North Down	2,125	652,527	142,740	111,006	111
Armagh City, Banbridge and Craigavon	3,261	1,121,948	245,425	186,971	187
Belfast	4,754	1,911,906	418,234	316,623	316.6
Causeway Coast and Glens	2,312	768,922	168,203	120,756	121
Derry City and Strabane	2,013	807,979	176,744	123,807	124
Fermanagh and Omagh	2,274	705,155	154,255	111,856	112
Lisburn and Castlereagh	1,905	718,078	157,078	118,358	118
Mid and East Antrim	2,075	817,687	178,868	132,870	133
Mid Ulster	2,343	773,227	169,144	126,760	127
Newry, Mourne and Down	2,747	909,352	198,921	149,652	150
Total	27,725	9,907,360	2,167,238	1,615,872	1,616

*Note applying 100% Rooftop Availability Building details from Fusion data, calculations by author.

Table 5.12 Summary of Potential PV Generation by Building Category

Building Category	Number of Building Polygons	Total Roof Area (m2)	Total Peak Power (kWp)	Total Rooftop Generation (MWh)	Total Rooftop Generation (GWh)	Percentage Potential Generation
Dwellings	787,625	83,476,108	18,258,006	13,251,203	13,251	49.0
Domestic Garages and Outbuildings	363,706	13,253,336	2,899,170	2,086,220	2,086	7.7
Industrial	8,986	7,328,263	1,603,071	1,194,840	1,195	4.4
Commercial	36,315	10,381,932	2,270,995	1,692,495	1,692	6.3
Non-Domestic General Buildings	189,778	44,299,424	9,691,336	7,186,540	7,187	26.6
All Other Buildings	27,725	9,907,360	2,167,238	1,615,872	1,616	6.0
Total	1,414,135	168,646,423	36,889,816	27,027,170	27,027	100.0

*Note applying 100% Rooftop Availability Building category details from Fusion data, calculations by author.

Table 5.13 All Other Buildings by Fusion Type Code

Fusion Type Code	Number of Buildings	Rooftop Area (m2)	Total Peak Power (kWp)	Potential Generation (MWh)	Percentage of Potential Generation
ND_Education	1,348	1,745,306	381,793	283,502	17.5
Education	5,589	1,699,826	371,839	277,764	17.2
Health	1,782	714,854	156,368	116,582	7.2
ND_Religious	1,965	698,744	152,847	113,829	7.0
ND_Health	924	620,359	135,704	101,303	6.3
Services	4,359	599,519	131,144	97,310	6.0
Religious	1,890	553,002	120,969	90,532	5.6
Communal	2,263	518,346	113,388	84,635	5.2
ND_Mixed	381	488,512	106,862	79,527	4.9
ND_Sporting	633	424,576	92,877	69,237	4.3
Recreation	1,745	408,338	89,324	66,650	4.1
Glass	2,365	341,931	74,799	56,438	3.5
ND_Entertainment	1,218	285,956	62,552	46,693	2.9
ND_Comm_Other	319	232,334	50,823	37,808	2.3
ND_Ents_Other	348	162,273	35,498	26,373	1.6
Mixed	190	161,814	35,397	26,366	1.6
ND_Other	162	92,367	20,206	15,117	0.9
ND_Legal	66	71,558	15,653	11,682	0.7
ND_Culture	43	30,427	6,656	5,075	0.3
Law Administrative	43	14,155	3,097	2,349	0.1
Multi Storey Car Park	4	14,067	3,077	2,299	0.1
ND_Culture_Other	6	4,276	935	714	0.0
ND_Agriculture	2	306	67	50	0.0
Government	80	24,514	5,363	4,037	0.2
Total	27,725	9,907,360	2,167,238	1,615,872	100

*Note applying 100% Rooftop Availability, potential generation calculated by author

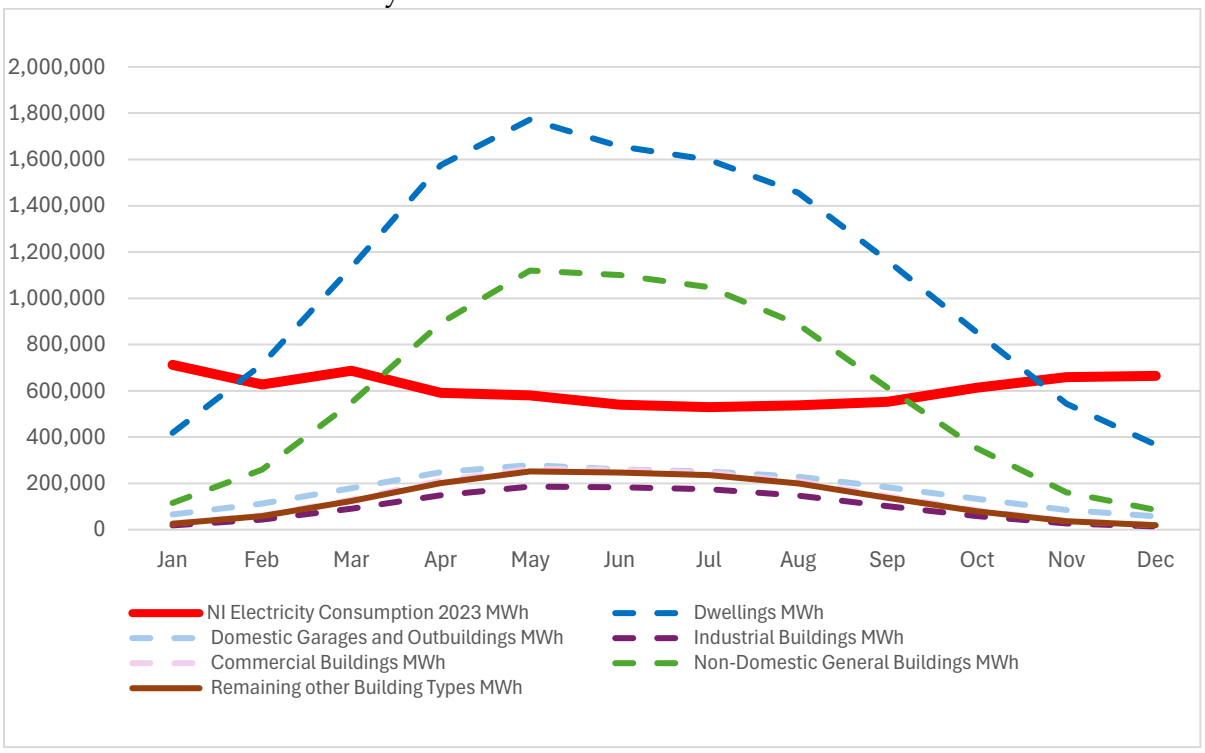
6.0 Contextualising the generation potential of rooftop PV generation in NI

6.1 This analysis has determined the potential for electricity generation from rooftops in Northern Ireland, taking into consideration the class of building, Dwellings, Domestic Garages, Industrial Commercial and Non-Domestic etc. The result of the analysis indicates that with 100% rooftop availability the potential annual generation is 27,027,170 MWhs.

6.2 Data provided by DfE (Statistics Information, Analysis & Research, Department for the Economy) on the consumption of electricity (calculated by NIE Networks from data on actual and estimated meter readings across both domestic and non-domestic sectors) indicates that in 2023 NI consumed a total of 7,297,057 MWh of electricity. This equates to 27% of the rooftop generating potential figure in paragraph 6.1. However a note of caution needs to be added to this comparison. Firstly, a figure of 100% rooftop availability is unrealistic and as mentioned previously a figure of 50% or perhaps 70% roof availability is more likely. Secondly while the annual generation total exceeds consumption this does not take into account, either seasonal or daily variation in generation.

6.3 Figure 6.1 below illustrates the difference between generation in the summer months and during the winter.

Figure 6.1 NI Electricity Consumption in 2023 and Potential PV Generation (MWh) with 100% Roof Availability



6.4 It should be noted though that even at a roof availability level of 50%, PV generating potential exceeds consumption from March through to October (See Table 6.1). Unfortunately, from November through to January, Northern Irelands' latitude of 55 degrees north means that the days are too short and the sun too low in the horizon for PV generation to meet electricity demand.

Summary of Key findings from assessing the potential rooftop generation of PV

a) Northern Ireland, despite its 55 degrees north latitude, receives sufficient solar energy to generate enough electricity from PV to meet demand for 9 months of the year, at 2023 consumption levels.
b) If 70% of rooftops in Northern Ireland were fitted with Solar PV it would generate, on an annual basis 2.6 times the electricity demand of 2023.
c) If 50% of rooftops in Northern Ireland were fitted with Solar PV it would generate, on an annual basis 1.8 times the electricity demand of 2023.
d) With 70% rooftop PV coverage there would be sufficient generation to meet electricity demand at 2023 levels for the months February to October inclusive.
e) With 50% rooftop PV coverage there would be sufficient generation to meet electricity demand at 2023 levels for the months March to October inclusive.
f) There is insufficient daylight in the months of December and January to meet electricity demand from PV generation alone, even with 100% of rooftops being fitted with PV.
g) While overall PV would generate sufficient electricity, on a monthly basis, to meet demand between February/March and October, in order to address variability (daytime/nighttime) in daily generation cycles, battery storage would be an essential component of PV installations.

Table 6.1 PV Potential generation by building type across roof availability scenarios

		PV Generation by Building Type MWh 100% Roof Availability							70% Roof Availability	50% Roof Availability
	NI Electricity Consumption 2023 MWh	Dwellings MWh	Domestic Garages and Outbuildings MWh	Industrial Buildings MWh	Commercial Buildings MWh	Non-Domestic General Buildings MWh	Remaining other Building Types MWh	Total Monthly Generation All Buildings MWh	Total Monthly Generation All Buildings MWh	Total Monthly Generation All Buildings MWh
Jan	712,348	418,480	65,884	19,191	27,185	115,430	25,954	672,124	470,487	336,062
Feb	627,859	714,484	112,486	43,221	61,223	259,962	58,452	1,249,829	874,880	624,915
Mar	686,787	1,133,733	178,491	91,163	129,133	548,314	123,287	2,204,121	1,542,885	1,102,061
Apr	591,205	1,574,765	247,925	148,588	210,475	893,701	200,946	3,276,401	2,293,480	1,638,200
May	580,470	1,772,461	279,050	186,204	263,758	1,119,950	251,818	3,873,240	2,711,268	1,936,620
Jun	540,408	1,656,941	260,862	182,999	259,219	1,100,674	247,481	3,708,175	2,595,723	1,854,088
Jul	529,527	1,598,054	251,592	174,355	246,974	1,048,682	235,793	3,555,449	2,488,814	1,777,725
Aug	537,553	1,456,180	229,255	147,561	209,020	887,524	199,557	3,129,097	2,190,368	1,564,549
Sep	552,461	1,162,329	182,993	101,908	144,353	612,940	137,818	2,342,340	1,639,638	1,171,170
Oct	613,634	852,277	134,179	58,617	83,032	352,563	79,273	1,559,941	1,091,959	779,971
Nov	659,739	544,383	85,706	26,802	37,965	161,205	36,247	892,308	624,616	446,154
Dec	665,066	367,116	57,797	14,231	20,158	85,595	19,246	564,145	394,902	282,073
Total	7,297,057	13,251,203	2,086,220	1,194,840	1,692,495	7,186,540	1,615,872	27,027,170	18,919,018	13,513,585
2023 Total Electricity NI Consumption 7,297,057 MWh		**100% Roof Availability Total Annual PV Generation 27,027,170 MWh**							**70% Roof Availability 18,919,018 MWh**	**50% Roof Availability 13,513,585 MWh**

7.0 Assessment of the potential impact of battery storage and PV generation for dwellings

Modelling Assumptions

7.1 When assessing the Solar PV and battery storage potential a range of scenarios and system configurations were considered for modelling. The system configurations modelled included a Grid connection, a Solar PV system, and a LiFePO4 battery.

7.2 A range of sizes for the equipment were modelled across a range of scenarios, which were broken down into five different load profile categories**. Different orientations for the Solar PV system were also modelled to reflect the different orientations found across domestic households, with 0˚, 45˚ & 90˚ West of South being modelled. The "West of South" standard is used to as the optimum orientation for solar panels is to face the equator, which for the northern hemisphere is facing South (Chinchilla et al., 2022). As such South is set to 0° with any deviations from the optimum being described in degrees relative to South.

7.3 The system specifications for each model were informed by the agreed assumptions described previously in this report, with the addition of load profiles being generated to model consumption rate across scenarios. These scenarios are described in the tables below:

Table 7.1 - Table showing load profile categories, parameters chosen, and range of Solar PV and battery sizes modelled.

Profile Category	Annual Consumption (kWh)	Daily Consumption (kWh)	Estimated Footprint (m2)	Modelled PV Sizes (kWp)			Modelled Battery Capacity (kWh)		
Low	1800	4.93	0 - 50	3	4	5	3	5	8
Medium	2900	7.95	50 - 100	5	6	7	5	8	11
High	4300	11.78	100 - 150	7	8	9	5	8	11
V. High*	5600	15.34	150+	8	10	12	5	8	11
V. High + Heat Pump***	7156	19.61	150+	10	12	14	8	11	15

*Note: V. High is calculated from using anecdotal data observed in real life scenarios, can update value later to reflect collected household data. **A Load Profile is a timeseries set of data that represents the electricity consumption over fixed increments of time. ***V. High + Heat Pump is calculated from using heat + electricity demand from 2017 house with EPC rating A, assuming a heat pump COP of 4.

7.4 The annual consumption values used were informed by recent figures from OFGEM, as well as using a mixture of measured and calculated data. The annual consumption values for the first three profiles (Low, medium, and high) were taken directly from OFGEM, and represent the average consumption expected across different household sizes. These values are a good indicator of expected usage in a "normal" scenario when looking at the entirety of the grid.

7.5 These values however lack the ability to capture the performance of a renewable/hybrid system in a more modern, power demanding environment. This is what led to the addition of two extra load profiles (V. High and V. High +Heat Pump), which try to account for the increasing electrification of energy demand in a domestic setting.

7.6 The V. High load profile is based on measured data from households that contain an EV and represents the additional load we can expect if the electrification of transport is to occur[16]. The V. High + Heat Pump is a load profile with the same electricity demand, that also estimates additional demand that could occur from utilising a heat pump with a COP of 4.

Table 7.2 - Table showing benchmarked energy consumption / m2 for households in the UK across different EPC ratings (BEIS, 2019).

EPC rating	First year of consumption	Average energy consumption per square meter (kWh/m2)	Average electricity consumption per square meter (kWh/m2)	Average gas consumption per square meter (kWh/m2)	Number of properties
A	2015	117	34	83	1,225
A	2016	113	32	81	1,710
A	2017	113	29	84	1,453
B	2015	127	35	92	69,066
B	2016	124	33	91	89,915
B	2017	122	31	90	98,584
C	2015	132	46	85	17,747
C	2016	124	49	75	14,430
C	2017	121	53	68	11,589
D	2015	117	88	29	1,067
D	2016	117	104	13	1,019
D	2017	114	102	12	1,155

[16] The V. High + Heat Pump profile assumes that household heat demand will be supplied by a heat pump with a coefficient of performance (COP) rating of 4, with the demand values being calculated from the recent energy performance certificate (EPC) values. See Figure 6.1. The annual demand was calculated using 2017 EPC values for a house with rating A and a building footprint of 125m^2.

Modelling Process

7.7 To model the performance of each scenario and system configuration a program called HOMER Pro was used. HOMER Pro is a software package specifically designed for the modelling of hybrid renewable energy systems and provides the ability to accurately model performance across 1hr timesteps. This enabled an accurate assessment of the Solar PV and battery performance, to determine an accurate representation of the expected real-world performance for each system.

For this section of the modelling only domestic dwellings were considered, with no considerations given specifically to a utilisation % of the roof used. Instead Solar PV sizes were estimated using a range of appropriate sizes relative to the m2 area of the dwelling. This approach is agnostic regarding the building type and instead scales system component size and load profile demands with the range of sizes seen in domestic dwellings (see Table 7.1).

This was done to isolate the impacts that adding energy storage had to a range of Solar PV system sizes, rather than to investigate the range of Solar PV sizes that are possible.

7.8 When modelling the performance of each system several assumptions had to be made to include the battery storage elements. These assumptions are outlined below:

Battery Assumptions:

a. Battery lifespan of 12.5 years with 5000 cycles (5000kWh/kWh installed)
b. Battery costs of £300 / kWh which is based on LiFePO4 rack batteries available on the market today* with a 50% addition to cost to account for variation in pricing.
c. Installation costs already associated with solar PV and as such not added to battery costs.
d. Voltage and other operational limiting factors are ignored for ease of modelling, as impacts on results would be negligible.

7.9 When selecting a battery chemistry to use there are many to choose from. For the purpose of this study, we chose to model Lithium Iron Phosphate (LiFePO4) batteries, as these have several distinct advantages over other battery chemistries. The ones of most importance to this study were the relatively long-life cycle, and the relative safety of the batteries when compared to other battery chemistries (Wang et al., 2020).

7.10 When considering the costs for installing the battery, the main cost associated was the purchase cost of the battery, with batteries of a comparative size being available for purchase off the shelf today at approximately £200/kWh (Fogstar, 2024B). To account for any variations that may arise due to project specific requirements, an additional cost of 50% was added when modelling.

7.11 Generally, when installing a domestic solar PV system with storage the installation costs are for the whole system. As such the additional 50% added to the base price plus the installation costs already associated with the solar PV model price should account for any additional installation or equipment costs that may arise.

*Current market pricing was used from Fogstar LTD which is a major supplier of LiFePO4 batteries in the UK, current pricing can be found at https://www.fogstar.co.uk/collections/server-rack-batteries

Modelling Results

7.12 The results from the modelling process can be found in the results tables and include data for every load profile and system configuration modelled. A baseline model for each load profile was completed and can be found as the top row in each table of results. This baseline model consists of only a grid connection to supply electricity and represents the status quo if no Solar PV & Battery system was installed. Within the results table, the most optimal result for each column has been highlighted in green text, with the least optimal result being shown in red text, for each system orientation that was modelled.

The outputs from the models found in the table are described below:

a) °W of S – The degrees west of south the panels were facing. A value of 0° represents facing south, with 90° representing West.
b) PV (kWp) – The maximum rated power output of the installed solar PV.
c) Battery (kWh) – The useable storage capacity of the battery in kWh.
d) NPC (£) – The total lifetime cost of the project factoring in all costs & savings.
e) LCOE (£/kWh) – The levelised cost of electricity over the project lifetime.
f) CAPEX (£) – The initial capital expenditure required to finance the project.
g) Ren Frac (%) – The % of power consumed on site that came from renewables.

h) CO_2 (kg/yr) – The amount of CO_2 emissions generated yearly by each system[17]. This value only accounts for displaced emissions from conventional grid usage, and does not account for embodied emissions of the technologies modelled.
i) PV Out (kWh/yr) -The total electrical output from the solar PV each year.
j) Grid Bought (kWh) – The amount of electricity bought from the grid each year.
k) Grid Sold (kWh) - The amount of electricity sold to the grid each year.
l) Net Savings (£) – The total lifetime savings from the project when compared to the baseline of just using the grid when factoring in all project costs.

[17] Based on Grid intensity values for NI.

Figure 7.1 Modelling Result Tables – PV Only

Model Results: Low Demand - Daily use @ 4.93 kWh - 1800 kWh annually - Solar PV Only										
ºW off S	PV (kWp)	NPC (£)	LCOE (£/kWh)	CAPEX (£)	Ren Frac (%)	CO2 (kg/yr)*	PV Out (kWh/yr)	Grid Bought (kWh)	Grid Sold (kWh)	Net Savings (£)
Baseline		£9,435	£0.30	£0	0	750	0	1800	0	0
0	3	£4,658	£0.07	£3,150	68	-298	2891	1202	1917	£4,777
	4	£3,273	£0.04	£4,200	75	-677	3855	1141	2765	£6,162
	5	*£1,978*	*£0.02*	£5,250	*80*	*-1051*	*4818*	*1104*	*3625*	*£7,457*
-45	3	£5,129	£0.08	£3,150	66	-236	2737	1237	1803	£4,306
	4	£3,851	£0.05	£4,200	73	-595	3649	1174	2602	£5,584
	5	£2,683	£0.03	£5,250	78	-949	4562	1138	3413	£6,752
-90	3	*£6,211*	*£0.11*	£3,150	*61*	*-72*	*2328*	*1273*	*1446*	*£3,224*
	4	£5,225	£0.08	£4,200	69	-380	3104	1204	2116	£4,210
	5	£4,355	£0.05	£5,250	75	-682	3880	1164	2798	£5,080

*CO_2 column reflects the net reduction in grid level emissions from the system and does not include embodied emissions for Solar PV. Current literature suggests that a value of 615 $kgCO_2$/kWp (Louwen et al., 2016) of Solar PV installed is appropriate, which would mean that a 4 kWp solar system has embodied emissions of around 2460 $kgCO_2$.

Using the modelling results above as an example, in the second row with solar we can see that the system with 4 kWp of Solar PV had net reductions of -677 $kgCO_2$ / Year. This means that the entire system will be entirely net zero in 3.63 years (2460 $kgCO_2$ / 677 $kgCO_2$). So, using the same row as an example we can say that the proposed system has a grid level reduction in emissions of -677 $kgCO_2$ / year, which is a net reduction in 1427 $kgCO_2$ / year when compared to the baseline of 750 $kgCO_2$ when using the grid alone. This system will be carbon neutral in 3.6 years using an embodied emission value of 615 $kgCO_2$/kWp.

Model Results: Medium Demand - Daily use @ 7.95 kWh - 2900 kWh annually - Solar PV Only										
ºW off S	PV (kWp)	NPC (£)	LCOE (£/kWh)	CAPEX (£)	Ren Frac (%)	CO2 (kg/yr)	PV Out (kWh/yr)	Grid Bought (kWh)	Grid Sold (kWh)	Net Savings (£)
Baseline		£15,215	£0.30	£0	0	1210	0	2900	0	0
0	**5**	£7,274	£0.07	£5,250	69	-543	4818	1925	3227	£7,941
	6	£5,877	£0.05	£6,300	73	-922	5782	1862	4073	£9,338
	7	***£4,569***	***£0.03***	£7,350	***77***	***-1296***	***6746***	***1820***	***4929***	***£10,646***
-45	**5**	£8,050	£0.08	£5,250	67	-440	4562	1982	3036	£7,165
	6	£6,778	£0.06	£6,300	72	-798	5474	1919	3833	£8,437
	7	£5,574	£0.04	£7,350	75	-1153	6386	1874	4640	£9,641
-90	**5**	*£9,836*	*£0.10*	£5,250	*62*	*-167*	*3880*	*2038*	*2439*	*£5,379*
	6	£8,863	£0.08	£6,300	67	-474	4656	1971	3107	£6,352
	7	£7,950	£0.07	£7,350	71	-778	5432	1919	3785	£7,265

Model Results: High Demand - Daily use @ 11.78 kWh - 4300 kWh annually - Solar PV + Battery										
ºW off S	PV (kWp)	NPC (£)	LCOE (£/kWh)	CAPEX (£)	Ren Frac (%)	CO2 (kg/yr)	PV Out (kWh/yr)	Grid Bought (kWh)	Grid Sold (kWh)	Net Savings (£)
Baseline		£22,546	£0.30	£0	0	1793	0	4300	0	0
0	**7**	£11,387	£0.07	£7,350	67	-647	6746	2887	4439	£11,159
	8	£9,963	£0.06	£8,400	71	-1027	7709	2816	5280	£12,583
	9	***£8,563***	***£0.05***	£9,450	***74***	***-1408***	***8673***	***2754***	***6129***	***£13,983***
-45	**7**	£12,494	£0.08	£7,350	65	-502	6386	2972	4176	£10,052
	8	£11,151	£0.07	£8,400	69	-865	7299	2893	4968	£11,395
	9	£9,918	£0.06	£9,450	72	-1221	8211	2840	5768	£12,628
-90	**7**	*£15,019*	*£0.11*	£7,350	*60*	*-120*	*5432*	*3058*	*3346*	*£7,527*
	8	£13,943	£0.10	£8,400	64	-433	6208	2968	4007	£8,603
	9	£13,039	£0.08	£9,450	68	-735	6984	2915	4678	£9,507

Model Results: V. High Demand - Daily use @ 15.34 kWh - 5600 kWh annually - Solar PV Only										
ºW off S	PV (kWp)	NPC (£)	LCOE (£/kWh)	CAPEX (£)	Ren Frac (%)	CO2 (kg/yr)	PV Out (kWh/yr)	Grid Bought (kWh)	Grid Sold (kWh)	Net Savings (£)
Baseline		£29,359	£0.30	£0	0	2335	0	5600	0	0
0	8	£16,498	£0.09	£8,400	63	-415	7709	3859	4853	£12,861
	10	£13,551	£0.06	£10,500	70	-1180	9636	3692	6523	£15,808
	12	*£10,774*	*£0.04*	£12,600	*74*	*-1939*	*11564*	*3572*	*8221*	*£18,585*
-45	8	£17,797	£0.10	£8,400	61	-249	7299	3970	4567	£11,562
	10	£15,075	£0.07	£10,500	68	-975	9123	3799	6137	£14,284
	12	£12,560	£0.05	£12,600	72	-1691	10948	3681	7736	£16,799
-90	8	*£20,749*	*£0.13*	£8,400	*56*	*190*	*6208*	*4087*	*3633*	*£8,610*
	10	£18,611	£0.10	£10,500	63	-433	7760	3903	4940	£10,748
	12	£16,700	£0.08	£12,600	68	-1044	9312	3777	6281	£12,659

Model Results: V. High + Heat Pump - Daily use @ 19.61 kWh - 7156 kWh annually - Solar PV Only										
ºW off S	PV (kWp)	NPC (£)	LCOE (£/kWh)	CAPEX (£)	Ren Frac (%)	CO2 (kg/yr)	PV Out (kWh/yr)	Grid Bought (kWh)	Grid Sold (kWh)	Net Savings (£)
Baseline		£37,531	£0.30	£0	0	2985	0	7156	0	0
0	10	£21,420	£0.09	£10,500	62	-444	9636	4952	6017	£16,111
	12	£18,431	£0.07	£12,600	68	-1212	11564	4774	7679	£19,100
	14	*£15,594*	*£0.05*	£14,700	*72*	*-1972*	*13491*	*4637*	*9367*	*£21,937*
-45	10	£23,041	£0.10	£10,500	60	-238	9123	5092	5663	£14,490
	12	£20,277	£0.08	£12,600	66	-965	10948	4909	7224	£17,254
	14	£17,747	£0.06	£14,700	70	-1680	12773	4784	8814	£19,784
-90	10	*£26,773*	*£0.13*	£10,500	*55*	*313*	*7760*	*5248*	*4498*	*£10,758*
	12	£24,606	£0.11	£12,600	61	-310	9312	5054	5797	£12,925
	14	£22,594	£0.09	£14,700	66	-927	10864	4904	7127	£14,937

Figure 7.2 Modelling Result Tables – PV + Storage

Model Results: Low Demand - Daily use @ 4.93 kWh - 1800 kWh annually - Solar PV + Battery											
ºW off S	PV (kWp)	Battery (kWh)	NPC (£)	LCOE (£/kWh)	CAPEX (£)	Ren Frac (%)	CO2 (kg/yr)	PV Out (kWh/yr)	Grid Bought (kWh)	Grid Sold (kWh)	Net Savings (£)
Baseline			*£9,435*	*£0.30*	*£0*	*0*	*750*	*0*	*1800*	*0*	*£0*
0	3	3	£4,548	£0.08	***£4,050***	*84*	-332	2891	*486*	1283	£4,887
		5	£5,672	£0.11	£4,650	87	-329	2891	389	1177	£3,764
		8	*£7,541*	*£0.15*	£5,550	89	*-327*	2891	317	*1101*	*£1,894*
	4	3	£3,167	£0.05	£5,100	90	-700	3855	404	2083	£6,268
		5	£4,294	£0.06	£5,700	92	-697	3855	308	1979	£5,142
		8	£6,171	£0.09	£6,600	94	-695	3855	238	1905	£3,265
	5	3	***£1,858***	***£0.02***	£6,150	93	***-1069***	4818	350	***2913***	***£7,577***
		5	£2,986	£0.04	£6,750	94	-1065	4818	254	2809	£6,449
		8	£4,873	£0.06	*£7,650*	***96***	-1064	4818	***189***	2740	£4,562
45	3	3	£5,007	£0.10	***£4,050***	*82*	-274	2737	*525*	1182	£4,428
		5	£6,136	£0.12	£4,650	85	-270	2737	430	1079	£3,299
		8	*£8,035*	*£0.16*	£5,550	87	*-269*	2737	370	*1015*	*£1,400*
	4	3	£3,730	£0.06	£5,100	88	-622	3649	438	1929	£5,705
		5	£4,865	£0.08	£5,700	90	-618	3649	345	1828	£4,570
		8	£6,759	£0.11	£6,600	92	-617	3649	283	1762	£2,677
	5	3	***£2,529***	***£0.03***	£6,150	92	***-970***	4562	380	***2707***	***£6,906***
		5	£3,667	£0.05	£6,750	93	-967	4562	288	2608	£5,768
		8	£5,552	£0.07	*£7,650*	***95***	-966	4562	***222***	2537	£3,884
90	3	3	£6,131	£0.13	***£4,050***	*78*	-119	2328	597	883	£3,304
		5	£7,341	£0.16	£4,650	80	*-117*	2328	535	816	£2,094
		8	*£9,304*	*£0.21*	£5,550	81	*-117*	2328	500	*781*	*£131*
	4	3	£5,129	£0.09	£5,100	85	-414	3104	*495*	1488	£4,307
		5	£6,337	£0.11	£5,700	87	-412	3104	431	1420	£3,099
		8	£8,300	£0.15	£6,600	88	-412	3104	397	1385	£1,135
	5	3	***£4,214***	***£0.06***	£6,150	89	***-711***	3880	426	***2130***	***£5,222***
		5	£5,410	£0.08	£6,750	91	-708	3880	357	2056	£4,026
		8	£7,362	£0.11	*£7,650*	***92***	-708	3880	***318***	2016	£2,073

Model Results: Medium Demand - Daily use @ 7.95 kWh - 2900 kWh annually - Solar PV + Battery											
°W off S	PV (kWp)	Battery (kWh)	NPC (£)	LCOE (£/kWh)	CAPEX (£)	Ren Frac (%)	CO2 (kg/yr)	PV Out (kWh/yr)	Grid Bought (kWh)	Grid Sold (kWh)	Net Savings (£)
Baseline			*£15,215*	*£0.30*	*£0*	*0*	*1210*	*0*	*2900*	*0*	*£0*
0	5	5	£7,181	£0.08	***£6,750***	*85.15*	-595	4818	*755*	2181	£8,034
		8	£8,874	£0.10	£7,650	87.59	-590	4818	611	2026	£6,342
		11	*£10,720*	*£0.13*	£8,550	89.05	*-588*	4818	530	*1939*	*£4,495*
	6	5	£5,799	£0.06	£7,800	88.57	-963	5782	672	2981	£9,417
		8	£7,492	£0.07	£8,700	90.76	-958	5782	529	2826	£7,723
		11	£9,353	£0.09	£9,600	91.97	-956	5782	454	2746	£5,862
	7	5	***£4,452***	***£0.04***	£8,850	90.99	***-1331***	6746	604	***3795***	***£10,764***
		8	£6,159	£0.05	£9,750	92.89	-1326	6746	466	3646	£9,057
		11	£8,027	£0.07	*£10,650*	***93.93***	-1324	6746	***393***	3569	£7,188
45	5	5	£7,936	£0.09	***£6,750***	*83.37*	-497	4562	*817*	2009	£7,279
		8	£9,640	£0.12	£7,650	85.77	-492	4562	677	1858	£5,576
		11	*£11,510*	*£0.14*	£8,550	87.07	*-490*	4562	606	*1782*	*£3,706*
	6	5	£6,659	£0.07	£7,800	87.11	-845	5474	729	2756	£8,556
		8	£8,364	£0.09	£8,700	89.27	-840	5474	591	2606	£6,851
		11	£10,240	£0.11	£9,600	90.41	-839	5474	521	2532	£4,975
	7	5	***£5,421***	***£0.05***	£8,850	89.77	***-1194***	6386	657	***3519***	***£9,794***
		8	£7,140	£0.06	£9,750	91.66	-1189	6386	524	3375	£8,075
		11	£9,021	£0.08	*£10,650*	***92.65***	-1187	6386	***456***	3303	£6,195
90	5	5	£9,804	£0.13	***£6,750***	*78.82*	-240	3880	934	1509	£5,412
		8	£11,621	£0.15	£7,650	80.48	-237	3880	841	1409	£3,594
		11	*£13,569*	*£0.18*	£8,550	81.25	*-236*	3880	800	*1367*	*£1,646*
	6	5	£8,797	£0.10	£7,800	83.45	-535	4656	*830*	2112	£6,418
		8	£10,616	£0.12	£8,700	85	-532	4656	737	2013	£4,599
		11	£12,559	£0.15	£9,600	85.74	-531	4656	695	1969	£2,656
	7	5	***£7,842***	***£0.08***	£8,850	86.78	***-831***	5432	745	***2737***	***£7,374***
		8	£9,658	£0.10	£9,750	88.23	-828	5432	652	2636	£5,557
		11	£11,605	£0.12	*£10,650*	***88.89***	-827	5432	***610***	2593	£3,610

Model Results: High Demand - Daily use @ 11.78 kWh - 4300 kWh annually - Solar PV + Battery											
°W off S	PV (kWp)	Battery (kWh)	NPC (£)	LCOE (£/kWh)	CAPEX (£)	Ren Frac (%)	CO2 (kg/yr)	PV Out (kWh/yr)	Grid Bought (kWh)	Grid Sold (kWh)	Net Savings (£)
Baseline			*£22,546*	*£0.30*	*£0*	*0*	*1793*	*0*	*4300*	*0*	*£0*
0	7	5	£10,250	£0.08	***£8,850***	*80.96*	-742	6746	*1430*	3209	£12,295
		8	£11,537	£0.09	£9,750	84.35	-730	6746	1123	2873	£11,008
		11	*£13,235*	*£0.11*	£10,650	86.02	*-725*	6746	981	*2720*	*£9,310*
	8	5	£8,845	£0.06	£9,900	83.87	-1110	7709	1339	4001	£13,700
		8	£10,122	£0.07	£10,800	87.09	-1097	7709	1027	3659	£12,424
		11	£11,807	£0.09	£11,700	88.7	-1092	7709	881	3501	£10,738
	9	5	***£7,492***	***£0.05***	£10,950	86.08	***-1478***	8673	1268	***4813***	***£15,053***
		8	£8,743	£0.06	£11,850	89.2	-1465	8673	946	4459	£13,803
		11	£10,435	£0.07	*£12,750*	***90.67***	-1460	8673	***803***	4304	£12,111
45	7	5	£11,309	£0.09	***£8,850***	*79.13*	-605	6386	*1517*	2968	£11,236
		8	£12,616	£0.10	£9,750	82.46	-593	6386	1218	2640	£9,929
		11	*£14,330*	*£0.12*	£10,650	84.06	*-589*	6386	1083	*2494*	*£8,215*
	8	5	£10,010	£0.07	£9,900	82.25	-953	7299	1421	3707	£12,536
		8	£11,302	£0.08	£10,800	85.46	-941	7299	1116	3372	£11,244
		11	£13,008	£0.10	£11,700	87	-936	7299	978	3222	£9,538
	9	5	***£8,761***	***£0.06***	£10,950	84.66	***-1302***	8211	1345	***4467***	***£13,785***
		8	£10,034	£0.07	£11,850	87.75	-1289	8211	1032	4123	£12,512
		11	£11,742	£0.08	*£12,750*	***89.19***	-1284	8211	***894***	3974	£10,804
90	7	5	£13,826	£0.12	***£8,850***	*74.83*	-242	5432	1642	2223	£8,719
		8	£15,292	£0.14	£9,750	77.55	-233	5432	1406	1966	£7,254
		11	*£17,132*	*£0.16*	£10,650	78.59	*-231*	5432	1323	*1876*	*£5,414*
	8	5	£12,815	£0.10	£9,900	78.44	-538	6208	*1536*	2827	£9,731
		8	£14,255	£0.12	£10,800	81.18	-529	6208	1291	2558	£8,291
		11	£16,076	£0.14	£11,700	82.26	-526	6208	1199	2460	£6,469
	9	5	***£11,851***	***£0.09***	£10,950	81.3	***-834***	6984	1449	***3449***	***£10,694***
		8	£13,261	£0.10	£11,850	84.05	-824	6984	1191	3166	£9,285
		11	£15,084	£0.12	*£12,750*	***85.07***	-821	6984	***1100***	3069	£7,461

Model Results: V. High Demand - Daily use @ 15.34 kWh - 5600 kWh annually - Solar PV + Battery											
°W off S	PV (kWp)	Battery (kWh)	NPC (£)	LCOE (£/kWh)	CAPEX (£)	Ren Frac (%)	CO2 (kg/yr)	PV Out (kWh/yr)	Grid Bought (kWh)	Grid Sold (kWh)	Net Savings (£)
Baseline			*£29,359*	*£0.30*	*£0*	*0*	*2335*	*0*	*5600*	*0*	*£0*
0	8	5	£14,577	£0.09	***£9,900***	*76*	-567	7709	*2242*	3601	£14,782
		8	£15,497	£0.10	£10,800	79	-548	7709	1787	3101	£13,862
		11	*£17,008*	*£0.11*	£11,700	81	*-540*	7709	1570	*2865*	*£12,351*
	10	5	£11,761	£0.06	£12,000	81	-1303	9636	2060	5186	£17,598
		8	£12,616	£0.07	£12,900	85	-1283	9636	1577	4654	£16,743
		11	£14,074	£0.08	£13,800	87	-1274	9636	1339	4395	£15,285
	12	5	***£9,077***	***£0.04***	£14,100	84	***-2041***	11564	1928	***6822***	***£20,282***
		8	£9,867	£0.05	£15,000	88	-2019	11564	1419	6261	£19,492
		11	£11,310	£0.06	*£15,900*	***90***	-2010	11564	***1175***	5994	£18,049
45	8	5	£15,829	£0.10	***£9,900***	*74*	-411	7299	*2357*	3342	£13,530
		8	£16,774	£0.11	£10,800	77	-392	7299	1911	2851	£12,585
		11	*£18,290*	*£0.13*	£11,700	79	*-384*	7299	1696	*2617*	*£11,069*
	10	5	£13,215	£0.07	£12,000	79	-1108	9123	2162	4818	£16,144
		8	£14,109	£0.08	£12,900	83	-1088	9123	1695	4304	£15,250
		11	£15,580	£0.09	£13,800	85	-1079	9123	1462	4049	£13,779
	12	5	***£10,755***	***£0.05***	£14,100	83	***-1806***	10948	2025	***6355***	***£18,604***
		8	£11,575	£0.06	£15,000	87	-1784	10948	1528	5807	£17,784
		11	£13,034	£0.07	*£15,900*	***88***	-1775	10948	***1290***	5546	£16,325
90	8	5	£18,727	£0.13	***£9,900***	*69*	4	6208	2507	2497	£10,632
		8	£19,845	£0.15	£10,800	72	20	6208	2131	2084	£9,514
		11	*£21,529*	*£0.16*	£11,700	74	*25*	6208	1984	*1924*	*£7,830*
	10	5	£16,673	£0.10	£12,000	75	-588	7760	*2286*	3696	£12,686
		8	£17,717	£0.11	£12,900	79	-571	7760	1879	3247	£11,642
		11	£19,331	£0.13	£13,800	80	-564	7760	1704	3057	£10,028
	12	5	***£14,779***	***£0.08***	£14,100	80	***-1180***	9312	2125	***4955***	***£14,580***
		8	£15,747	£0.09	£15,000	83	-1162	9312	1687	4473	£13,612
		11	£17,340	£0.10	*£15,900*	***85***	-1155	9312	***1503***	4272	£12,019

Model Results: V. High + Heat Pump Demand - Daily use @ 19.61 kWh - 7156 kWh annually - Solar PV + Battery											
°W off S	PV (kWp)	Battery (kWh)	NPC (£)	LCOE (£/kWh)	CAPEX (£)	Ren Frac (%)	CO2 (kg/yr)	PV Out (kWh/yr)	Grid Bought (kWh)	Grid Sold (kWh)	Net Savings (£)
Baseline			*£37,531*	*£0.30*	*£0*	*0*	*2985*	*0*	*7156*	*0*	*£0*
0	10	8	£19,366	£0.10	***£12,900***	*77*	-629	9636	*2609*	4118	£18,165
		11	£20,502	£0.11	£13,800	79	-614	9636	2241	3713	£17,029
		15	*£22,601*	*£0.12*	£15,000	81	*-605*	9636	1987	*3438*	*£14,930*
	12	8	£16,472	£0.07	£15,000	81	-1365	11564	2396	5669	£21,060
		11	£17,559	£0.08	£15,900	84	-1349	11564	2008	5242	£19,972
		15	£19,635	£0.09	£17,100	86	-1339	11564	1743	4954	£17,897
	14	8	***£13,692***	***£0.05***	£17,100	85	***-2101***	13491	2226	***7265***	***£23,839***
		11	£14,765	£0.06	£18,000	87	-2085	13491	1833	6832	£22,767
		15	£16,803	£0.07	*£19,200*	*89*	-2074	13491	***1553***	6527	£20,728
45	10	8	£20,941	£0.11	***£12,900***	*75*	-434	9123	*2757*	3798	£16,590
		11	£22,107	£0.12	£13,800	77	-420	9123	2400	3406	£15,425
		15	*£24,220*	*£0.13*	£15,000	79	*-410*	9123	2151	*3135*	*£13,311*
	12	8	£18,266	£0.08	£15,000	80	-1130	10948	2538	5249	£19,265
		11	£19,397	£0.09	£15,900	82	-1115	10948	2166	4840	£18,134
		15	£21,473	£0.10	£17,100	84	-1105	10948	1902	4552	£16,058
	14	8	***£15,715***	***£0.06***	£17,100	83	***-1827***	12773	2365	***6746***	***£21,817***
		11	£16,817	£0.07	£18,000	85	-1811	12773	1982	6324	£20,714
		15	£18,864	£0.08	*£19,200*	***87***	-1800	12773	***1706***	6023	£18,667
90	10	8	£24,685	£0.14	***£12,900***	*70*	82.4	7760	2992	2794	£12,847
		11	£26,028	£0.15	£13,800	72	93.9	7760	2707	2482	£11,503
		15	*£28,357*	*£0.17*	£15,000	73	*99*	7760	2546	*2308*	*£9,174*
	12	8	£22,550	£0.12	£15,000	75	-508	9312	*2738*	3956	£14,981
		11	£23,835	£0.13	£15,900	77	-495	9312	2430	3618	£13,696
		15	£26,084	£0.14	£17,100	79	-489	9312	2236	3409	£11,447
	14	8	*£20,557*	***£0.09***	£17,100	79	***-1100***	10864	2540	*5177*	***£16,975***
		11	£21,798	£0.10	£18,000	82	-1086	10864	2213	4818	£15,733
		15	£24,044	£0.12	*£19,200*	***83***	-1079	10864	***2018***	4606	£13,488

Solar PV and Storage Modelling Results - Summaries

Solar PV Output VS Installed PV Capacity:

7.13 Figure 7.3 shows the range of Solar PV sizes and their annual electricity generation by daily demand. This chart shows the range of sizes that was modelled for each demand scenario, as well as the annual generation modelled. Boxplots have been used to highlight where the range of values observed from the dataset, and where the 2nd and 3rd quartiles occur, with the horizontal line indicating the median value.

7.14 Figure 7.4 below shows the annual electricity generation across a range of system sizes and Solar PV orientations. As seen from the charts, the most optimal angle is facing south which in this case is shown as 0 degrees ºW off S. As expected, there is a constant linear increase in electricity generation as the Solar PV system size increases.

Figure 7.3 Annual electricity generation from Solar PV system for range of PV capacities modelled for each demand scenario.

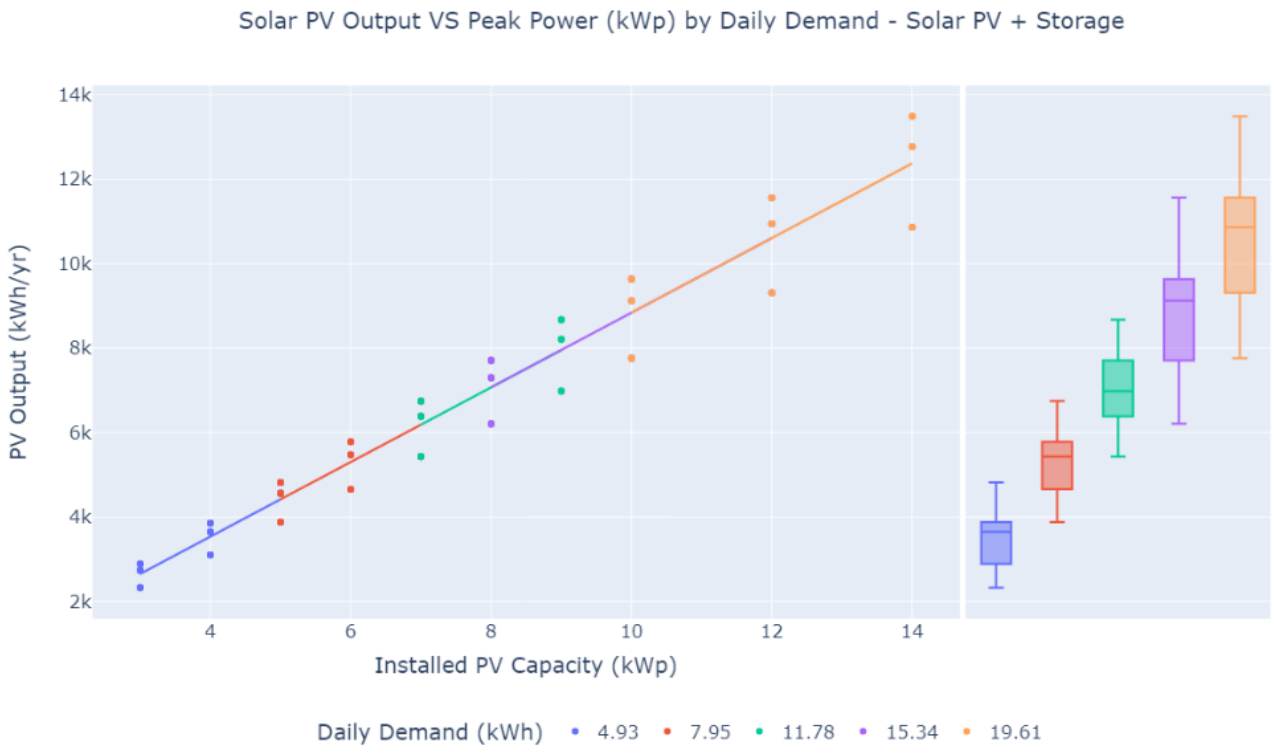
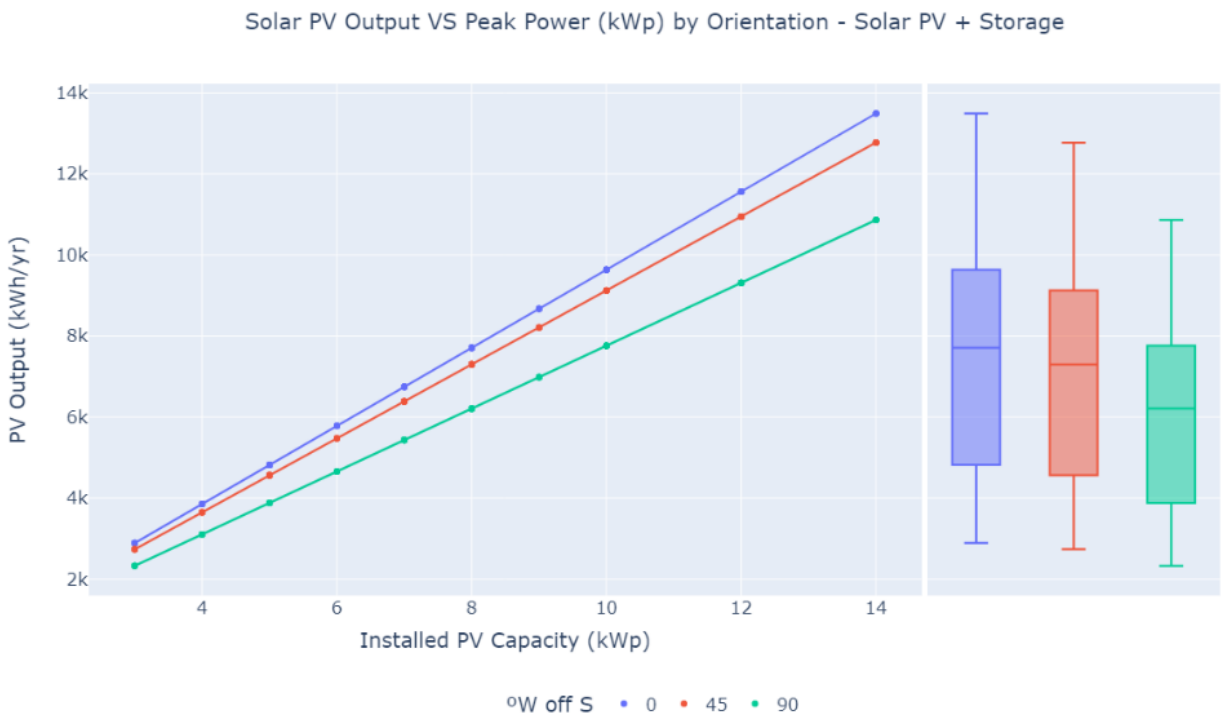


Figure 7.4 Annual electricity generation from Solar PV system depending on PV capacity and system orientation.



Renewable Fraction VS Installed PV Capacity:

7.15 Figures 7.5 and 7.6 show the achieved renewable fraction relative to Solar PV capacity for both the PV Only and the PV + Storage systems respectively. As can be observed, the Solar PV + Storage system was able to achieve a higher renewable fraction across all systems. The maximum renewable fraction achieved for Solar PV + Storage was 96%, with Solar PV Only models achieving a maximum renewable fraction of 80%.

7.16 The modelling results for both systems also showed a clear trend with renewable fraction of total energy increasing as Solar PV capacity increased, which was noticeable in all models. It should also be noted that the higher the daily demand, the lower the average renewable fraction achieved was. This was due to lower generation from Solar PV during the winter months, which was more impactful in models with higher demands relative to others.

Figure 7.5 PV Capacity VS Renewable Fraction achieved for Solar PV Only.

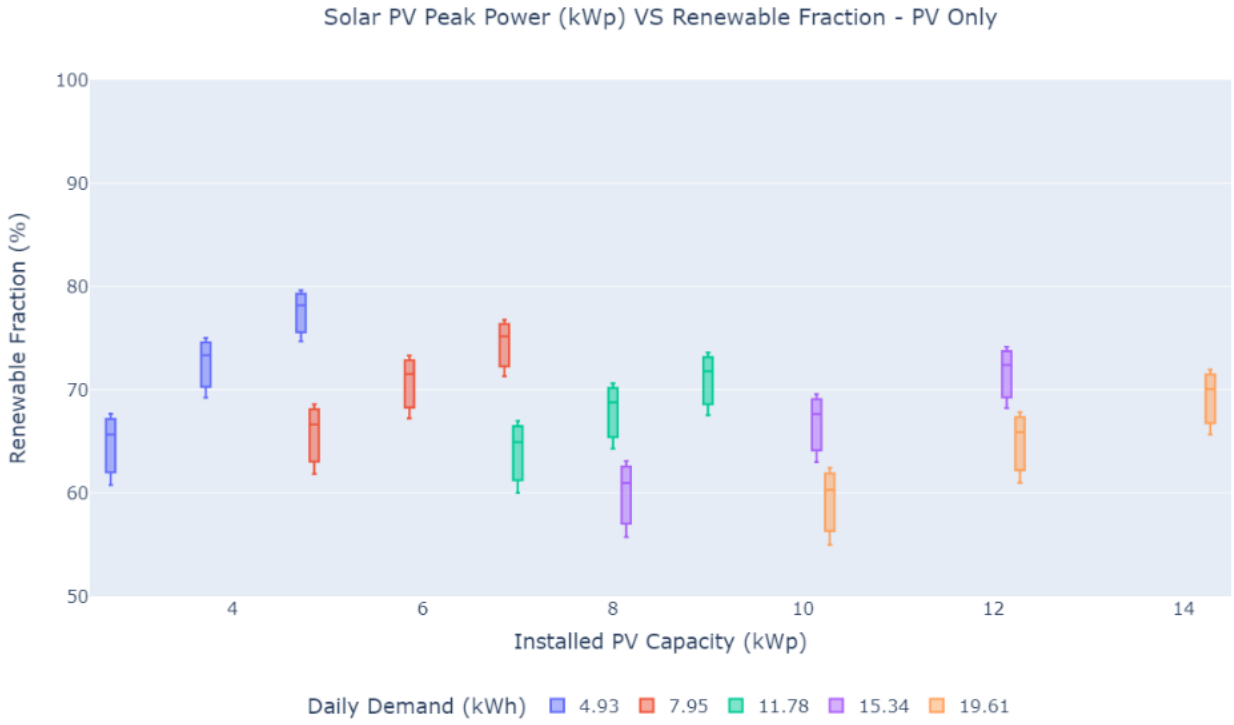
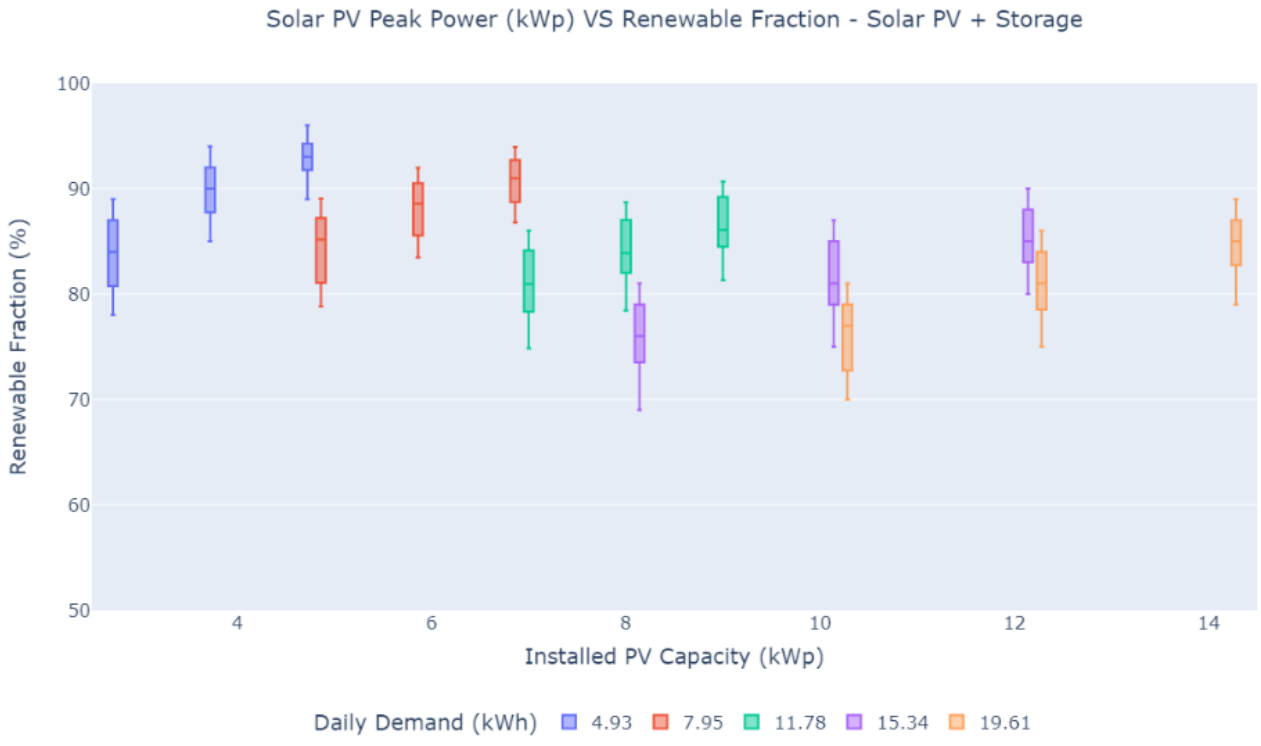


Figure 7.6 PV Capacity VS Renewable Fraction achieved for Solar PV + Storage.



CO_2 Emissions VS Installed PV Capacity

7.17 Figures 7.7 and 7.8 show the Net Change in CO_2 Emissions relative to Solar PV capacity for both PV Only, and PV + Storage, with an indicator line marking the point where a model has a Net Zero carbon footprint. As can be seen from the charts the majority of Solar PV systems achieved a net zero carbon footprint and contributed significantly to reducing the overall carbon emissions on the wider network.

7.18 This was due to grid exports being provided when energy demand was lower than generation, and there was insufficient room to charge the battery. In these instances, electricity from the Solar PV systems was exported to the wider grid, which displaced energy that otherwise would have been procured elsewhere on the network. A trend can be seen where emission reductions were greater when Solar PV capacity was increased.

Figure 7.7 PV Capacity VS Net CO_2 Emissions for Solar PV Only.

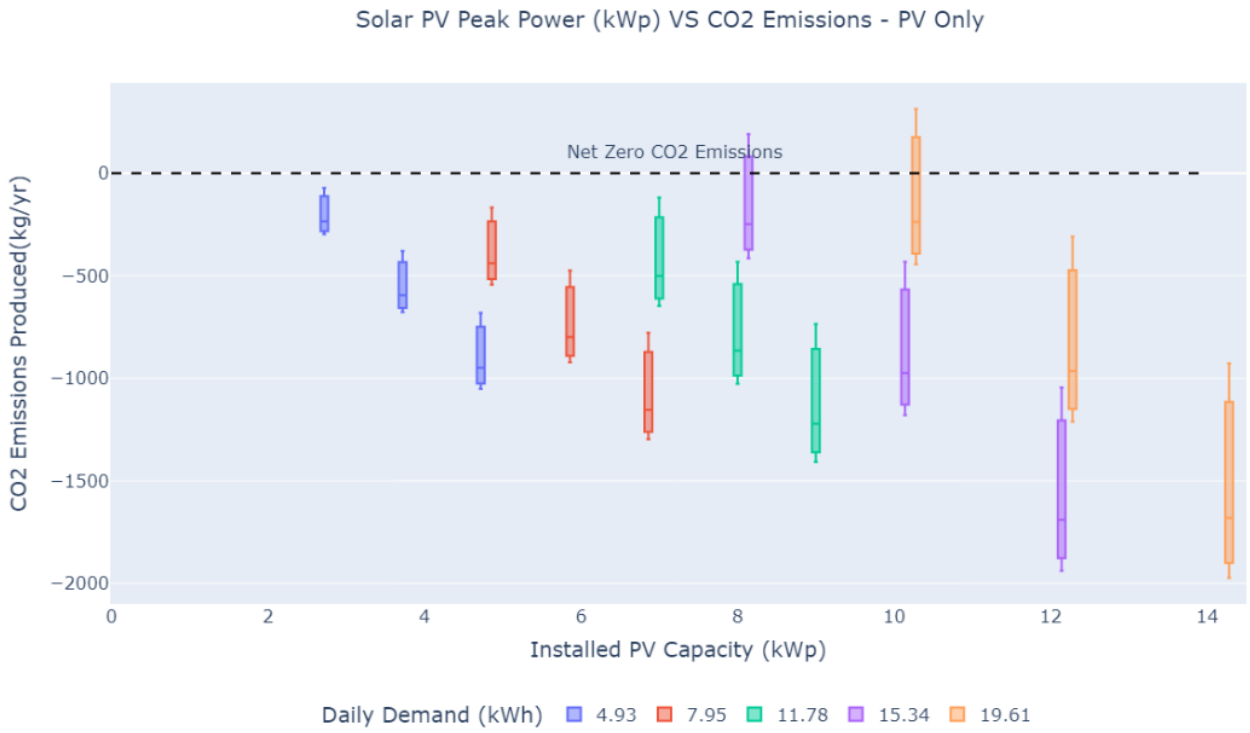
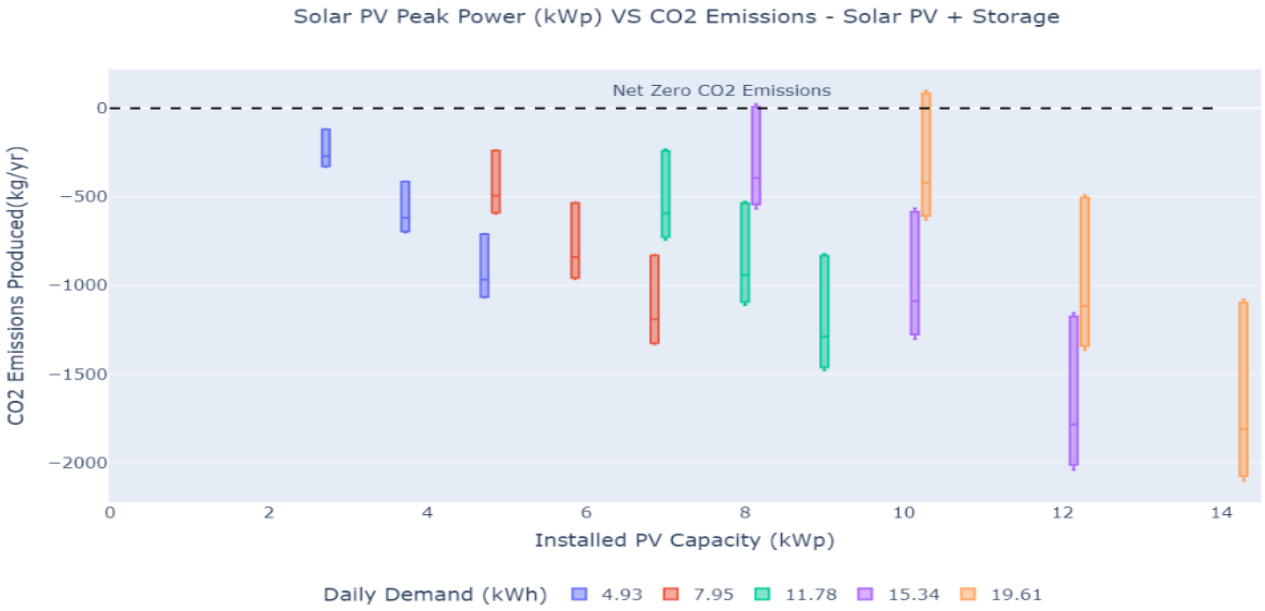


Figure 7.8 PV Capacity VS Net CO_2 Emissions for Solar PV + Storage.



Initial Capital Expenditure VS Renewable Fraction Achieved

7.19 Figures 7.9 & 7.10 show the Renewable Fraction achieved relative to the initial Capital Expenditure for both PV Only, and PV + Storage. The findings reveal that a higher Renewable Fraction was achieved when Capital Expenditure was increased. This reflects the larger initial upfront costs associated with building any renewable energy system.

Figure 7.9 Initial Capital Expenditure VS Renewable Fraction achieved for Solar PV Only.

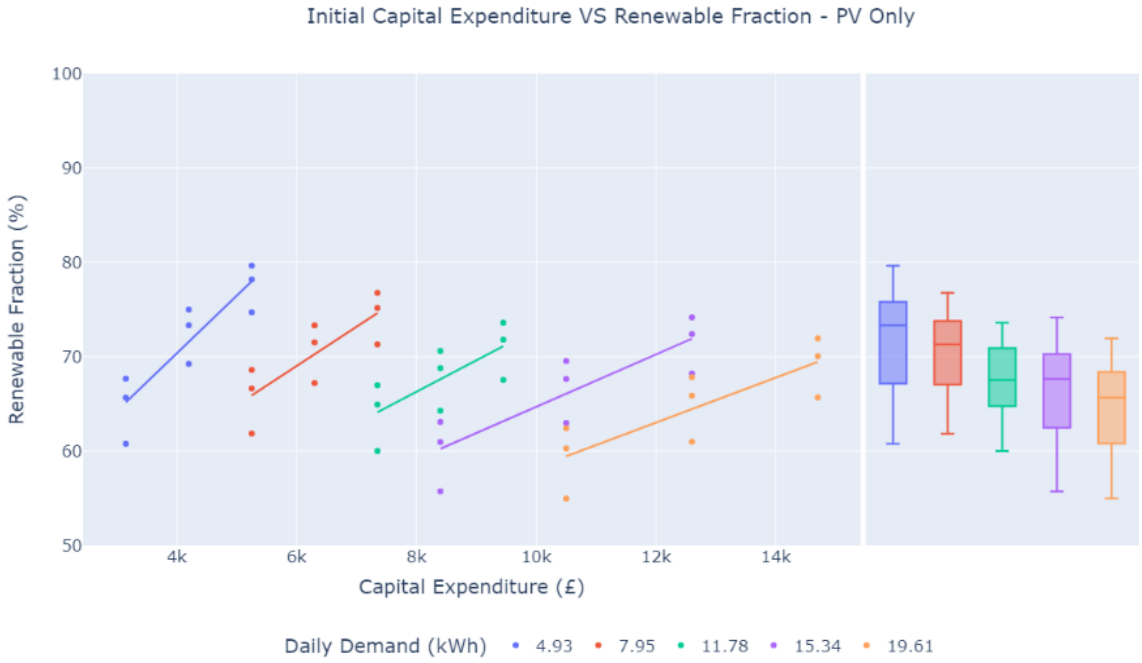
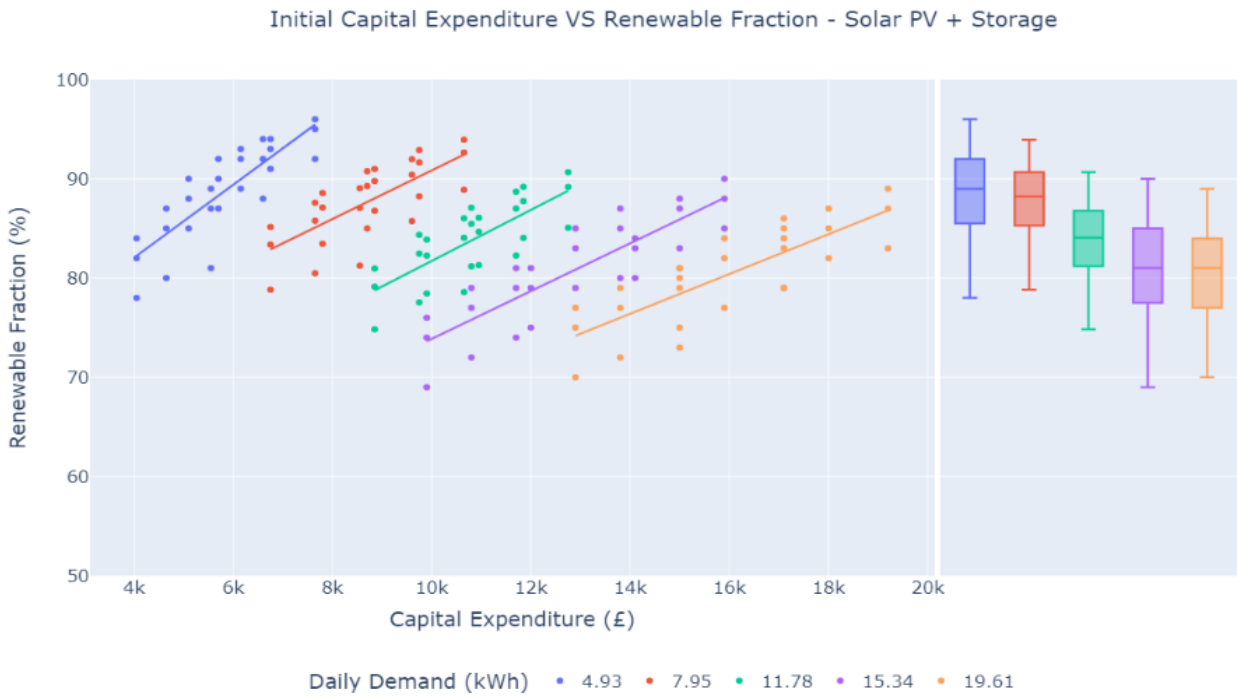


Figure 7.10 Initial Capital Expenditure VS Renewable Fraction achieved for Solar PV and Storage.



Project Net Present Cost VS Renewable Fraction Achieved

7.20 Figures 7.11 and 7.12 reveal the Renewable Fraction achieved relative to the project total Net Present Cost for both PV Only, and PV + Storage. The findings show that a higher Renewable Fraction was achieved as the lifetime project cost decreased. This highlights that the more renewable energy is being generated within a system, the lower the overall cost over the project lifetime will be. The modelling showed that this is true across all scenarios and Solar PV capacities, with the trend being observed in all modelled scenarios. This is of importance as it suggests that despite the higher initial capital expenditure requirements, the net project costs are lower for systems with renewable generation.

Figure 7.11 Projected Net Present Cost VS Renewable Fraction achieved for Solar PV Only.

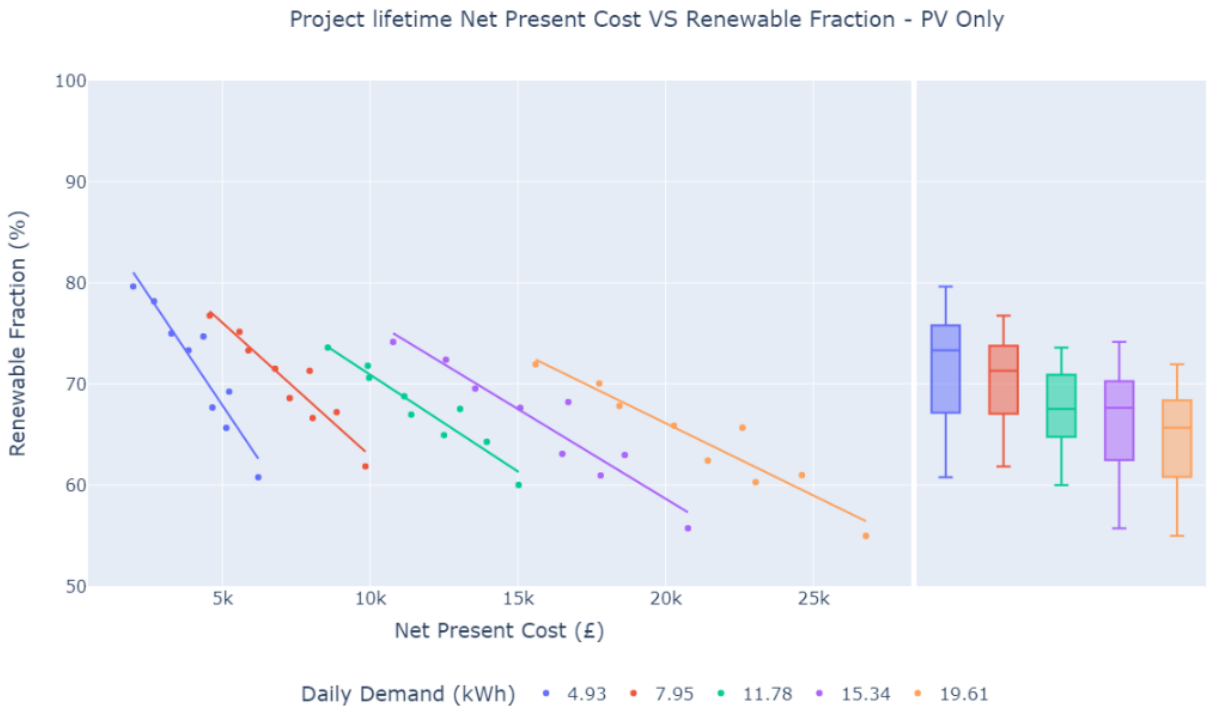
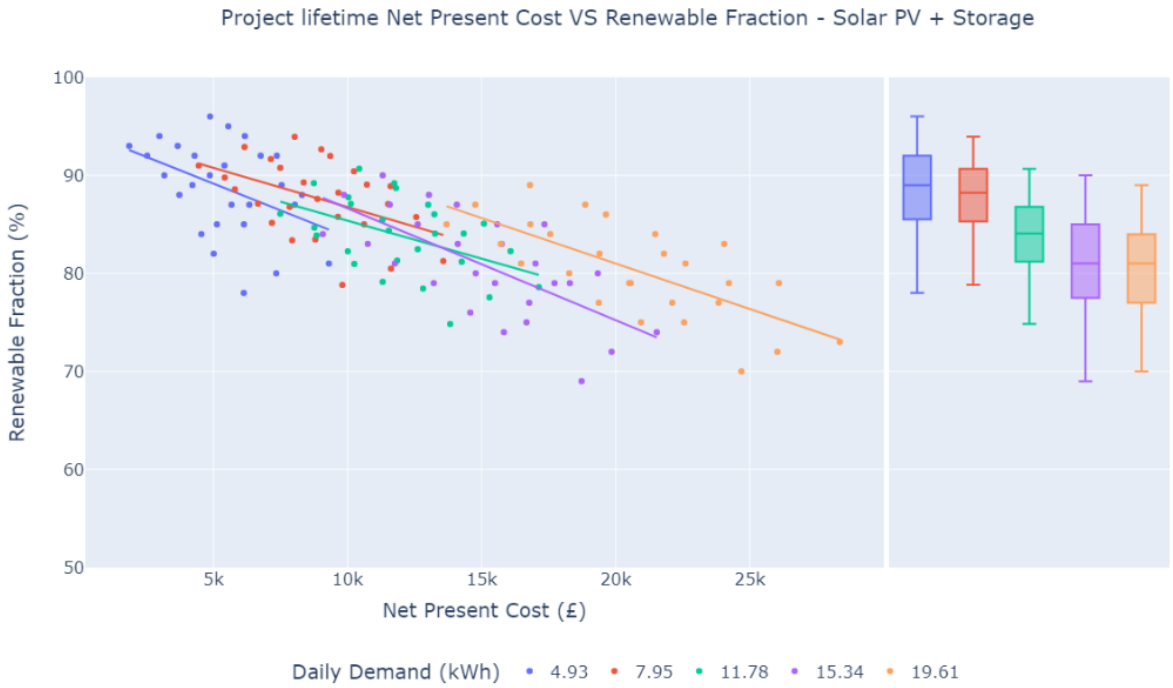


Figure 7.12 Projected Net Present Cost VS Renewable Fraction achieved for Solar PV and Storage.



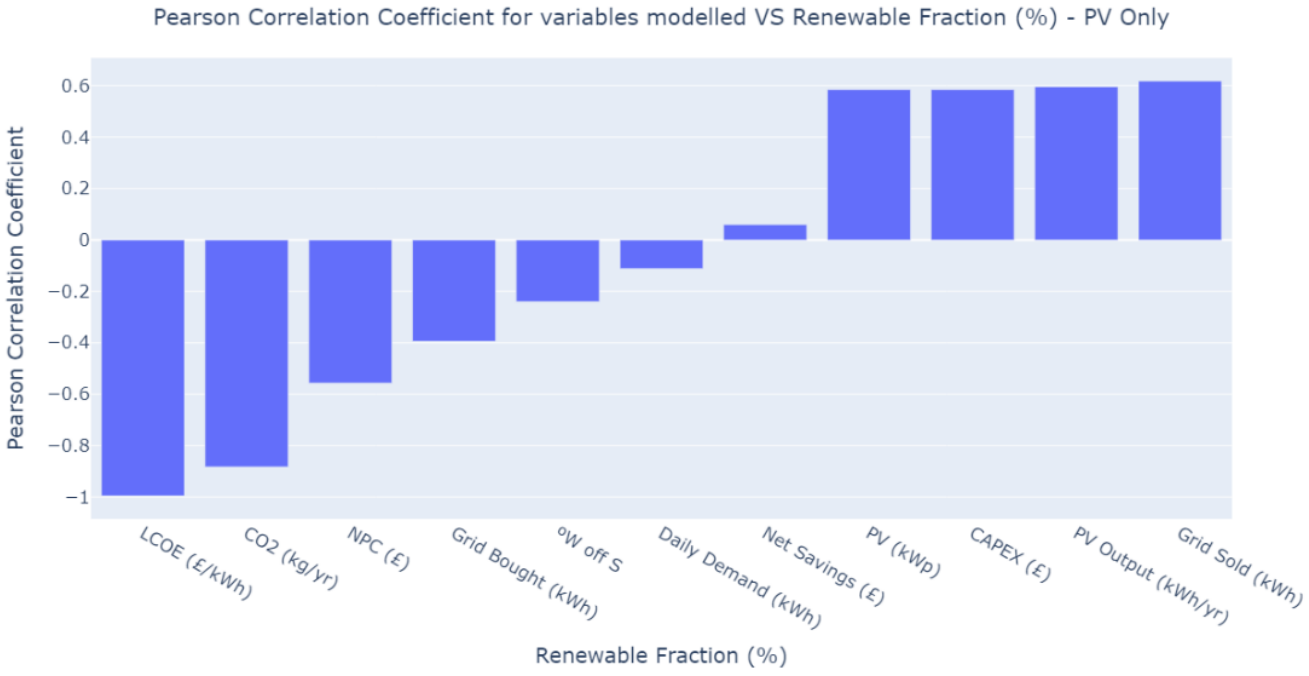
Pearson Correlation Coefficients – Renewable Fraction with other metrics

7.21 Figures 7.13 and 7.14 display the Pearson correlation coefficients* across a range of values relative to the achieved Renewable Fraction for both Solar PV Only, and Solar PV + Storage models respectively. A Pearson correlation coefficient is a measure of linear correlation from -1 to 1, which represents the strength and direction of a relationship between two variables.

Positive values indicate that values move in the same direction, so if one increases so does the other. Negative values indicate that values move in the opposite direction, if one increases the other will decrease. A value of 0 would indicate that there is no correlation or relationship between the values and that they are independent from each other.

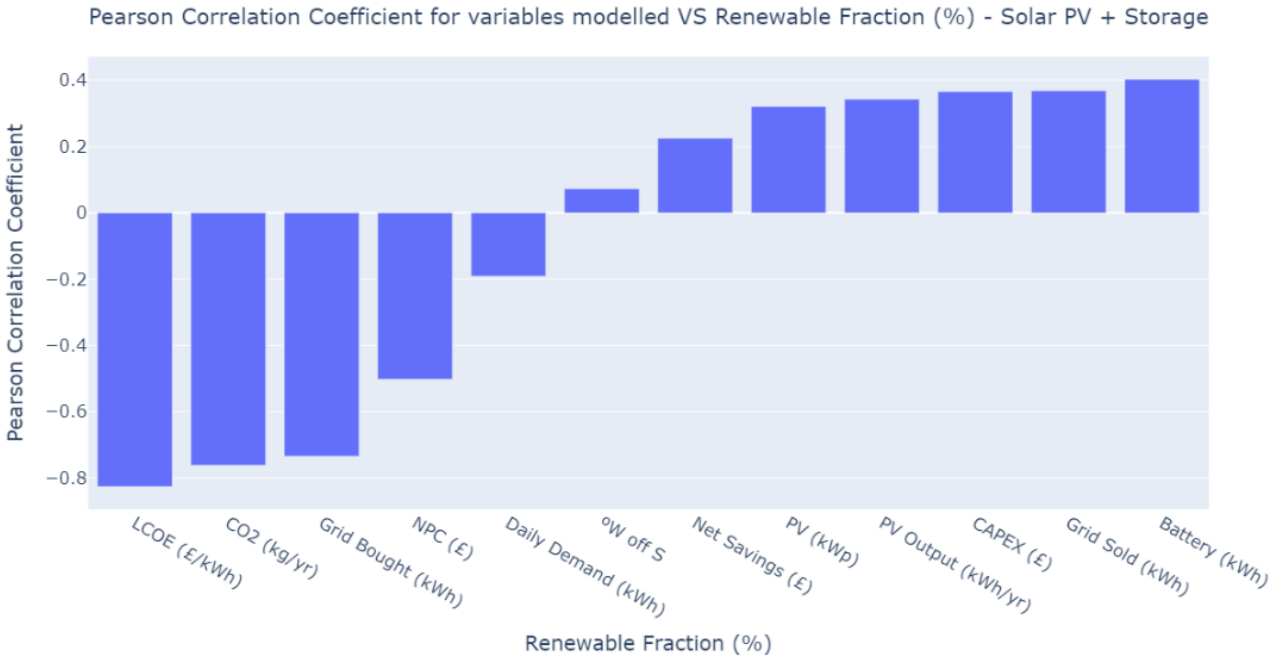
7.22 For both scenarios, there was a strong negative correlation between Renewable Fraction achieved and LCOE and CO_2 emissions produced. There was also a relatively strong negative correlation between the NPC and the Renewable Fraction achieved. This means that as the amount of renewable generation increases, these values decreased in a linear fashion. These results highlight not only the environmental benefits from increasing renewable generation, but the economic ones as well.

Figure 7.13 Pearson Correlation Coefficient for all variables VS Renewable Fraction achieved for Solar PV Only.



*More information on Person Correlation Coefficients can be found here:
https://www.investopedia.com/terms/p/pearsoncoefficient.asp

Figure 7.14 Pearson Correlation Coefficient for all variables VS Renewable Fraction achieved for Solar PV + Storage.



Pearson Correlation Coefficients – Levelised Cost of Electricity with other metrics

7.23 Figures 7.15 and 7.16 show the Pearson correlation coefficients across a range of values relative to the Levelised Cost of Electricity for both Solar PV Only, and Solar PV + Storage models respectively. The findings indicate for both scenarios, that there was a strong negative correlation between the LCOE, and the Renewable Fraction achieved. There was also a moderately strong negative correlation between the LCOE, and the amount of energy sold to the grid. This further highlights the strong relationship between an increase in renewable generation and a decrease in lifetime energy costs. What should be noted here is the high positive correlation with energy being sold to the grid, which tells us that large volumes of grid exports are an important factor in achieving favourable economic results.

These two metrics were chosen for comparing Correlation Coefficients as they best represent the factors that are considered when selecting a system, with concerns given to both emissions and economics. All other metrics are directly proportional to these, and as such the correlations look very similar. Thus, these two metrics/graphs where chosen to highlight the main correlations, whilst minimizing the number of graphs and space required.

Figure 7.15 Pearson Correlation Coefficient for all variables VS LCOE for Solar PV Only.

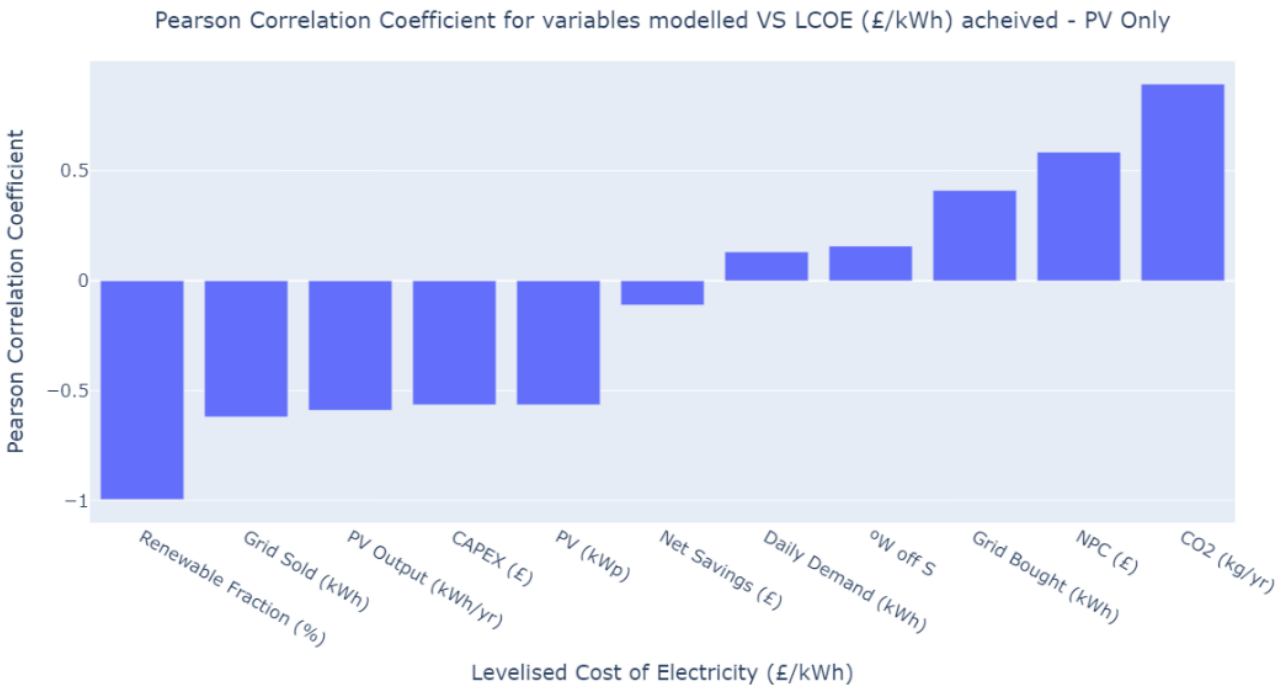
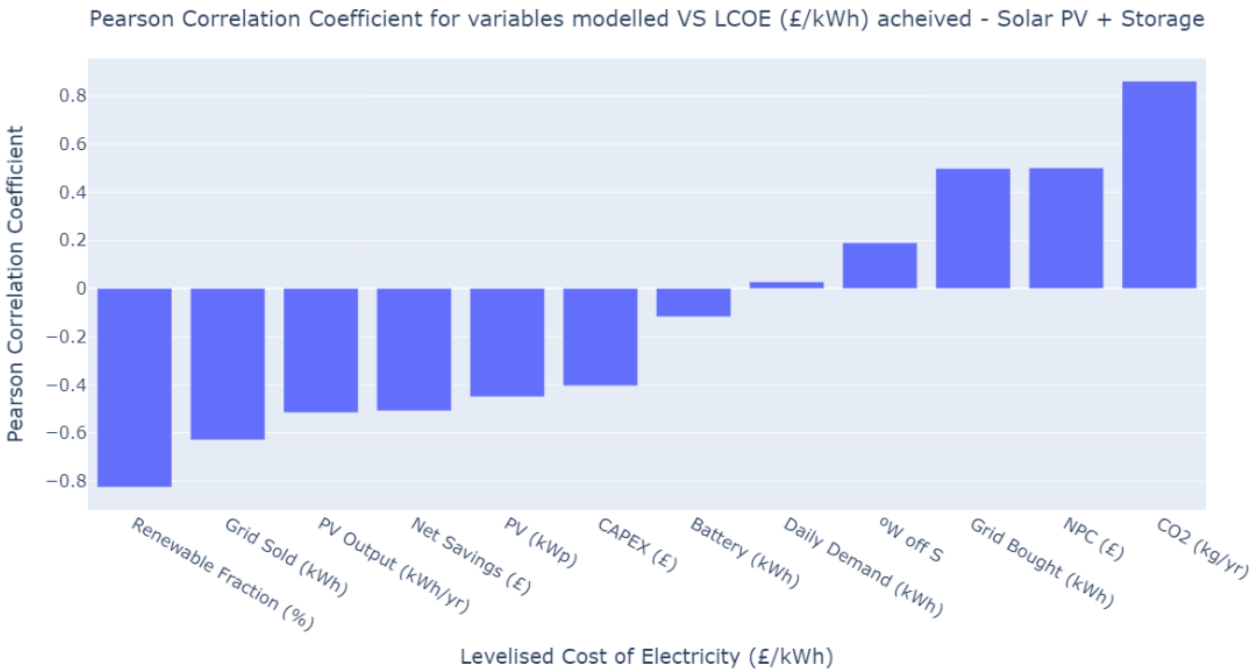


Figure 7.16 Pearson Correlation Coefficient for all variables VS LCOE for Solar PV + Storage.



Summary of Solar PV + Storage Modelling Results

7.24 The modelling results for all scenarios showed benefits both economically and environmentally from incorporating renewable energy generation. Across all models there were positive improvements to LCOE and the lifetime Net Present Cost, which would represent potential financial savings for consumers who adopted such systems. It should be noted however that all systems, both with and without energy storage, required significant upfront capital costs that may be a barrier for adoption when considering domestic uptake.

7.25 The modelling results also showed a significant amount of interaction with the local electricity network, being dependant on imports in times of low PV generation. Conversely, the model economics appear to be favourable in large part due to the relatively large electricity exports going to the wider grid. If the current export price of £0.1422/kWh was to lower significantly, the model economics may not be so favourable.

7.26 That being said, the environmental benefits from including a grid import and export connection cannot be ignored. In some Low and Medium demand scenarios that included Solar PV + Storage, the net CO_2 emission reductions were often greater than the original baseline emissions by more than 200%. This means that including a Solar PV + Storage system not only achieved a net zero carbon footprint for itself at the point of consumption, but it also reduced enough emissions through grid exports to offset a comparable dwelling. It should be noted that emissions results reflect a net change in the grid level emissions and do not include embodied emissions of the system components. This would reduce the economic favourability of the results somewhat, however all technologies included in the modelling have net reductions in emissions over their lifetime, so it is unlikely that including embodied emissions would have a significant impact on the emission reductions achieved. This was in part due to the availability of grid exports, but also due to the increased renewable fraction achieved when incorporating energy storage.

7.27 When comparing Solar PV Only models to those with storage, there was approximately a 15% difference in the renewable fraction of total energy consumed, with Solar PV + Storage having a more positive result. In the most optimal models Solar PV + Storage achieved a Renewable Fraction of 96%, with the most optimal Solar PV Only model achieving 80%.

7.28 In summary, the benefits from incorporating Solar PV with or without energy storage could be seen across most metrics. The large upfront capital requirements could however be a barrier to entry for some consumers, and as such consideration should be given to addressing this challenge going forward.

8.0 Research findings and discussion for potential PV generation

Research Findings PV Installations and Potential PV Rooftop Generation

8.1 There were a total 29,342 PV installations as of the end of 2023 in Northern Ireland. 25,577 PV installations of 6.5kWp system size or less are assumed to be domestic (MCS March 2024). Approximately 3.35% of dwellings currently have PV installed. A typical 4kWp household PV system averages an annual generation of 3606 kWh. Households with PV systems have on average 28% of their electricity demand met by PV generation.

8.2 The potential for roof top PV generation from a range of building categories and roof top percentage availability is displayed in Table 8.1 and Building category by LGD in table 8.2. below. The largest potential for rooftop generation is from dwellings which account for 49% of the calculated output. Detached dwellings constitute 54% of the potential roof top generation for dwellings or 26.5% of the total roof top generating potential.

Table 8.1 Summary of Potential PV Generation by Building Category

Building Category	Number of Building Polygons	Total Roof Area (m2)	Total Peak Power (kWp)	Potential Total Rooftop Generation (MWh)	Potential Total Rooftop Generation (GWh)	Percentage Potential Generation (%)
Dwellings	787,625	83,476,108	18,258,006	13,251,203	13,251	49.0
Domestic Garages and Outbuildings	363,706	13,253,336	2,899,170	2,086,220	2,086	7.7
Industrial	8,986	7,328,263	1,603,071	1,194,840	1,195	4.4
Commercial	36,315	10,381,932	2,270,995	1,692,495	1,692	6.3
Non-Domestic General Buildings	189,778	44,299,424	9,691,336	7,186,540	7,187	26.6
All Other Buildings	27,725	9,907,360	2,167,238	1,615,872	1,616	6.0
Total	**1,414,135**	**168,646,423**	**36,889,816**	**27,027,170**	**27,027**	**100.0**

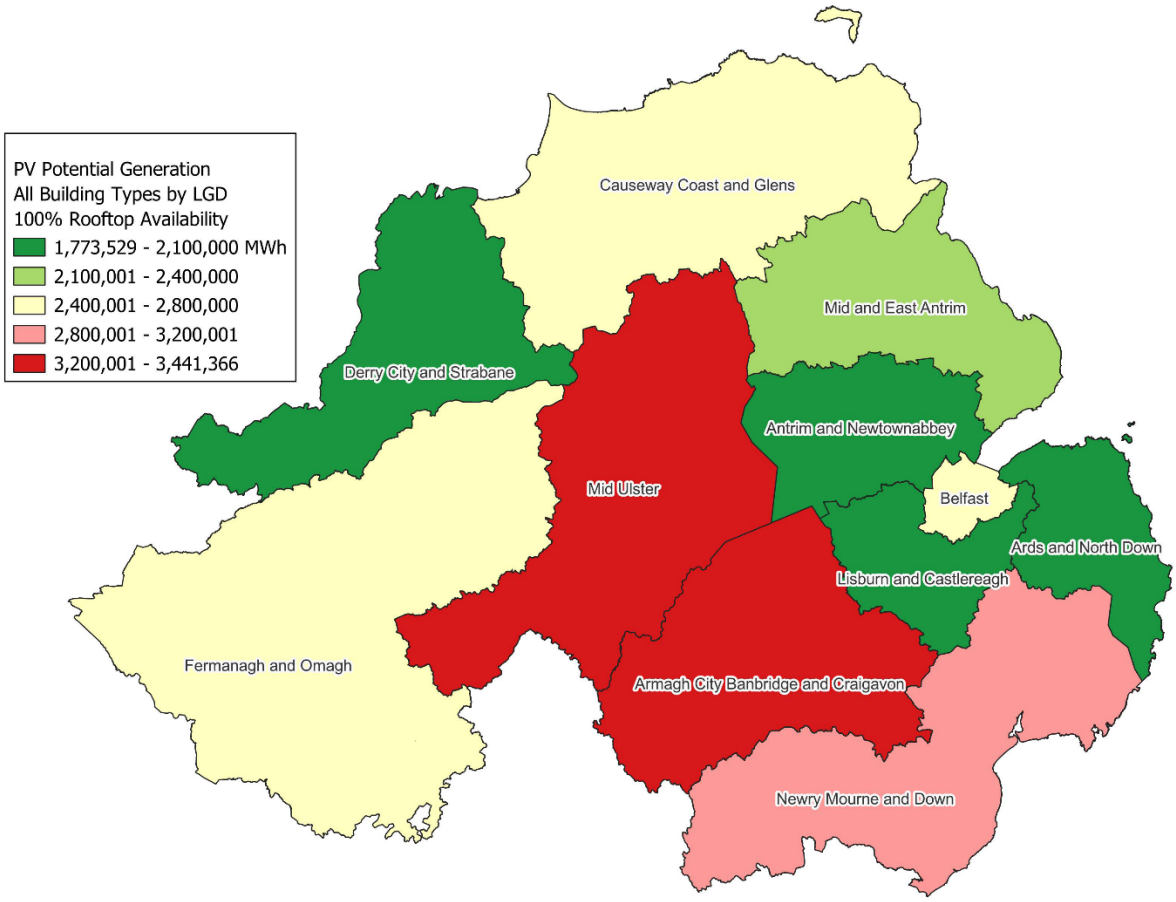
Building category details obtained from Fusion data, calculations by author.

Table 8.2 Summary of Potential PV Generation by Building Category and LGD

Local Government District	Dwellings Potential Annual Energy Output (MWh)	Garages and Outbuildings Potential Annual Energy Output (MWh)	Industrial Buildings Total Annual (MWh)	Commercial Buildings Total Annual (MWh)	General (Non-Domestic) Total Annual (MWh)	All Other Buildings Total Rooftop Generation (MWh)	Total Potential PV Generation by LGD 100% Roof Availability (MWh)
Antrim and Newtownabbey	958,276	126,314	103,667	172,076	404,102	117,213	1,881,648
Ards and North Down	1,274,447	134,800	42,985	98,794	322,231	111,006	1,984,263
Armagh City Banbridge and Craigavon	1,610,346	281,098	165,939	180,229	1,016,715	186,971	3,441,298
Belfast	1,600,231	114,197	132,482	345,063	22,182	316,623	2,530,778
Causeway Coast and Glens	1,195,039	208,692	70,922	131,947	849,530	120,756	2,576,885
Derry City and Strabane	897,461	118,224	74,847	125,748	433,442	123,807	1,773,529
Fermanagh and Omagh	1,026,365	264,652	87,495	117,358	1,045,753	111,856	2,653,479
Lisburn and Castlereagh	1,035,246	140,188	93,607	112,449	367,189	118,358	1,867,037
Mid and East Antrim	999,331	171,906	123,215	118,817	582,288	132,870	2,128,427
Mid Ulster	1,207,744	254,756	208,261	136,830	1,283,304	126,760	3,217,655
Newry Mourne and Down	1,446,717	271,393	91,420	153,184	859,805	149,652	2,972,171
Total	**13,251,203**	**2,086,220**	**1,194,840**	**1,692,495**	**7,186,540**	**1,615,872**	**27,027,170**

Building category details obtained from Fusion data, calculations by author.

Figure 8.1 Summary of PV Potential Generation (MWh) by LGD with 100% Roof Availability



8.3 If PV installations covered 50% of all rooftops in Northern Ireland, they could potentially generate 13,514 GWh of electricity annually. Northern Ireland's consumption of electricity in 2023 was 7,297 GWh[18], thus potential generation at 50% rooftop availability is 185% of demand. However, PV generation is not distributed evenly throughout the year, with there being insufficient sunlight to meet electricity demand from the months of November to January inclusive.

Research Findings from the Assessment of the Potential Impact of Domestic Battery Storage

8.4 In the right scenarios Solar PV + Storage can achieve a total renewable energy consumption rate of 96%, with the maximum achieved by Solar PV only being 80%. The lowest consumption rates returned from the modelling results was 70% and 55% respectively. Across all modelling scenarios there was an

[18] https://www.economy-ni.gov.uk/news/electricity-consumption-and-renewable-generation-northern-ireland-year-ending-december-2023#:~:text=In%20terms%20of%20the%20volume,of%20total%20electricity%20was%20consumed.

approximate increase of 15% in consumption from self-generated Solar PV energy when energy storage was included.

8.5 Solar PV with or without storage has significant potential to reduce net emissions, as nearly all scenarios achieved a net zero carbon footprint, with most of these also offsetting additional emissions. Low and Medium demand scenarios with energy storage were able to offset over 200% relative to their baseline CO_2 emissions.

8.6 Modelling highlighted that in all scenarios a Solar PV system with or without energy storage had a positive Net Present Cost when compared to the baseline of just using a grid connection. Statistical analysis using Pearson correlation coefficients highlighted a strong relationship between increasing renewable energy generation resulting in lower project costs and emissions.

8.7 The modelling also highlighted the relatively large upfront capital requirements associated with the system installations, with the initial capital requirements often being more than 50% the value of the total Net Present Cost. It was observed that a Grid connection was crucial for achieving such desirable economic and environmental results in the modelling as Grid exports made up a large part of the system activity that generated net positives for the system. It should be noted that a significant decrease in the current export tariff of £0.1422/kWh may result in a less favourable economic performance.

9.0 Conclusions

9.1 Solar PV is a mature technology that can make a significant contribution to electricity demand in Northern Ireland. A typical 4 kWp residential PV will meet on average 28% of household electricity demand. PV systems larger than 4 kWp generate more electricity and meet a higher percentage of household demand. The current Micro Generation Solar PV G98/NI registration process limit of 3.68 kWp (4kWp) for single phase installations, has become the de facto residential PV system size, with 46% of all residential installations being 4 kWp.

9.2 PV installation rates showed a rapid decline after the ending of the ROCs scheme in 2017, while there was a slight recovery in installation rates in 2022 and 2023, there is unlikely to be a substantial uptake of PV in the domestic sector, without some form of financial incentive for households to at least partly meet the capital costs of installing the technology.

9.3 Case study analysis of domestic dwellings shows that the potential utility of PV can be significantly enhanced by the addition solar plus technologies such as PV water heating and battery storage. These technologies enable households to consume 70% plus of their PV electricity generation. In households without these solar PV plus technologies only 30% of PV generation goes towards household electricity consumption.

9.4 If 50% of all rooftops in Northern Ireland had PV installed, generation could on an annual basis meet Northern Ireland's electricity requirements, but there is insufficient sunlight to meet electricity demand for the months November through to January.

Recommendations

9.5 Recommendations are impacted by the extent of the policy ambition for the roll out of Solar PV electricity generation, i.e. does the policy seek to maximise the potential of solar PV generation for Northern Ireland or is PV viewed as a niche renewable technology for those households that can afford the upfront installation costs?

9.6 The uptake of Solar PV impacts positively on targets set out in legislation, policy and strategy such as the Climate Change Act (Northern Ireland) 2022 (Act), which sets a target of an at least 100% reduction in net zero greenhouse gas (GHG) emissions by 2050 compared to the 1990 baseline, along with interim targets including an at least 48% reduction in net emissions by 2030, Net Zero

Carbon[15], Net Zero Carbon Strategy 2024 (publishing.service.gov.uk), the Renewables Electricity target Renewable electricity | Department for the Economy (economy-ni.gov.uk) and on levels of fuel poverty by reducing household electricity consumption from the grid.

Note 15 Net Zero Carbon is the balance between the amount of greenhouse gas (GHG) that's produced and the amount that's removed from the atmosphere

However, the level of residential PV installation remains low at 3.4% and this is likely to remain the case without the introduction of financial incentives and regulatory changes. On the basis that there is a policy imperative to substantially increase the uptake of Solar PV:

- Consideration should be given to the introduction of a financial incentive scheme for installation of PV at existing households. Models for such schemes are already in place in Scotland, G.B. and Ireland, leaving Northern Ireland's current situation where currently no financial assistance is available to install Solar PV as an outlier.

- Changes to the Buildings Regulations NI 2012, Part F(Conservation of Fuel and Power) requiring the installation of solar PV on all new buildings and those properties undergoing extensive renovation should be investigated.

- Solar PV Plus technologies such as PV hot water diverters maximise the renewable energy consumption rate by households but require properties to have a hot water storage tank. Again, consideration should be given to amending the Buildings Regulations to require the fitting and/or retention of hot water storage/thermal tanks in in new and existing dwellings[19].

- Under the current G99/NI limit, battery storage and export limitation devices can be utilised to maximise household PV installed capacity and associated generation. The economics of those systems are directly linked to the electricity and hot water demand profiles of the household. Consideration should be given to encouraging the installation solar plus technologies (Battery Storage and PV Hot Water Diverters) as a standard component of PV systems (were warranted by household electricity demand), as this has the potential to enable double the household single

[19] Note hot water storage tanks are also an essential component of Heat Pump heating systems.

phase installed capacity of PV systems to 7.36 kWp, without increasing generation exports to the electricity network.

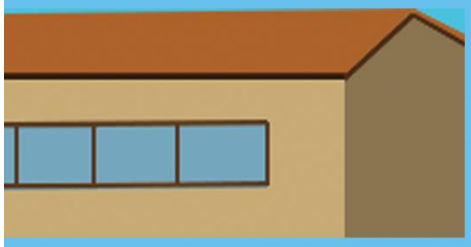
- The potential for further streamlining of the G99/NI application process for larger (greater than 3.68 kWp) domestic PV installations should be assessed.

Appendix 1 Infographic Solar PV and Household Electricity Savings

SOLAR PV PANELS

HOUSEHOLD ELECTRICITY SAVINGS

Northern Ireland (NI)



NI Home Average Yearly Electricity Bill £1029

Based on Electricity Consumption of 3465 kWh
At 29.7p per kWh



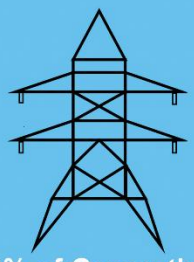
NI Home with Solar Panels Electricity Annual Bill £623

PV System (4kWp) Generates 3600 kWh Electricity



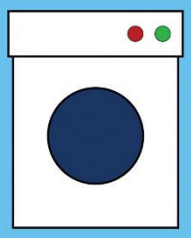
32% of Generation Provides Hot Water
(1152kWh)

Saves £62
Based on 56p per litre of oil
(10.35kwh per litre of oil)



30% of Generation Exported to Grid
(1080kWh)

£154 Paid to Householder
for Exported Electricity
Based on 14.22p per kWh



38% of Generation Used in Home
(1368kWh)

Saves £406
Based on 29.7p per kWh

Household Savings per Year

£622

Solar Panel PV System Lasts 25 Years Costs £4500

Pay Back Time 7.2 years

Graphic Design Anna MacIntyre

Information derived from Research at Ulster University June 2024
Sean MacIntyre, Michael McCord, Peadar Davis, Aggelos Zacharopoulos

Ulster University

Appendix 2: Sources of Research Data

1. MCS (Microgeneration Certification Scheme) Solar PV postcode dataset
2. OSNI LPS Fusion Database
3. OSNI NISRA, Census Spatial Geographies, Administrative Boundaries and Postcode Database
4. Photovoltaic Geographical Information System (PVGIS)
5. HOMER Grid
6. Ulster University, Households with PV Installations case study data on electricity generation and consumption.

Appendix 3 Table Indicating Fusion Type Codes included within Buildings Categories used in Analysis

Building Category	Fusion Type Code
Dwellings	"DO Apt", "DO Detached", "DO Mixed", "DO Other", "DO Semi", "DO Terrace"
Domestic Garages and Outbuildings	“General” while considering roof size - 10m2 to 80m2
Industrial	“ND Industry”, “ND Industry Other” and “Industry”
Commercial	“Commercial”; “Mixed”’ “ND_Comm_Other”; “ND_Hospitality”; “ND_Office”; “ND_Retail”
Non-Domestic General Buildings	“General” while considering roof size – over 80m2
All Other Buildings	"ND_Education"; "Education"; "Health"; "ND_Religious"; "ND_Health" ; "Services"; "Religious"; "Communal"; "ND_Mixed"; "ND_Sporting"; "Recreation"; "Glass"; "ND_Entertainment"; "ND_Comm_Other"; "ND_Ents_Other"; "Mixed"; "ND_Other"; "ND_Lega"l; "ND_Culture"; "Law Administrative"; "Multi Storey Car Park"; "ND_Culture_Other"; "ND_Agriculture"; "Government Office"

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