# Greater Brighton Energy Plan

## Solar Roadmap

**043916**

15 January 2020

Revision 00

This report was commissioned by Greater Brighton and funded by the Interreg EU SOLARISE project, Greater Brighton and Brighton & Hove City Council.

| Revision | Description | Issued by | Date | Checked |
|---|---|---|---|---|
| 00 | Solar Roadmap for Greater Brighton – extracted from the Greater Brighton Energy Plan final report | AC | 15/01/2020 | PP |

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# Acknowledgements

We would like to take the opportunity to acknowledge the many different people and groups who contributed to this work. Firstly, thank you to those who filled in questionnaires and provided very useful additional material and meetings: Dan Hyttner, Marco Picco, James Higgins, Abigail Dombey, Kayla Ente, Damian Tow, Matthew Bird, Ralitsa Hiteva, Tim Foxon and Francesca Iliffe; apologise if I have missed anybody out. Thank you to all those who attended the workshops – your input was vital in shaping this project. Thanks also to all those who presented at the three workshops: James Higgins, Alex Fox, Colin Barden, Rachel Thompson, Chris Rowland, the Electric Blue team, Matt Brown and Peter Turner; these provided many useful insights, as did the discussions they triggered. Finally, we would like to thank Ollie Pendered (of Community Energy South) for facilitating the vital interaction with community energy groups, and sharing his vast local knowledge, and John Taylor of the South East Energy Hub – for giving so much time to the project and for providing highly instructive presentations at all the workshops.

We would also like to take the opportunity to acknowledge the contribution of the EU Interreg SOLARISE project in part funding this work.

# 1 Introduction

The Greater Brighton region covers seven different Local Authority (LA) areas in south east England and is home to over 900,000 people, 400,000 jobs and 40,000 businesses. The extent of the region and the Local Authorities are displayed in Figure 1—1.

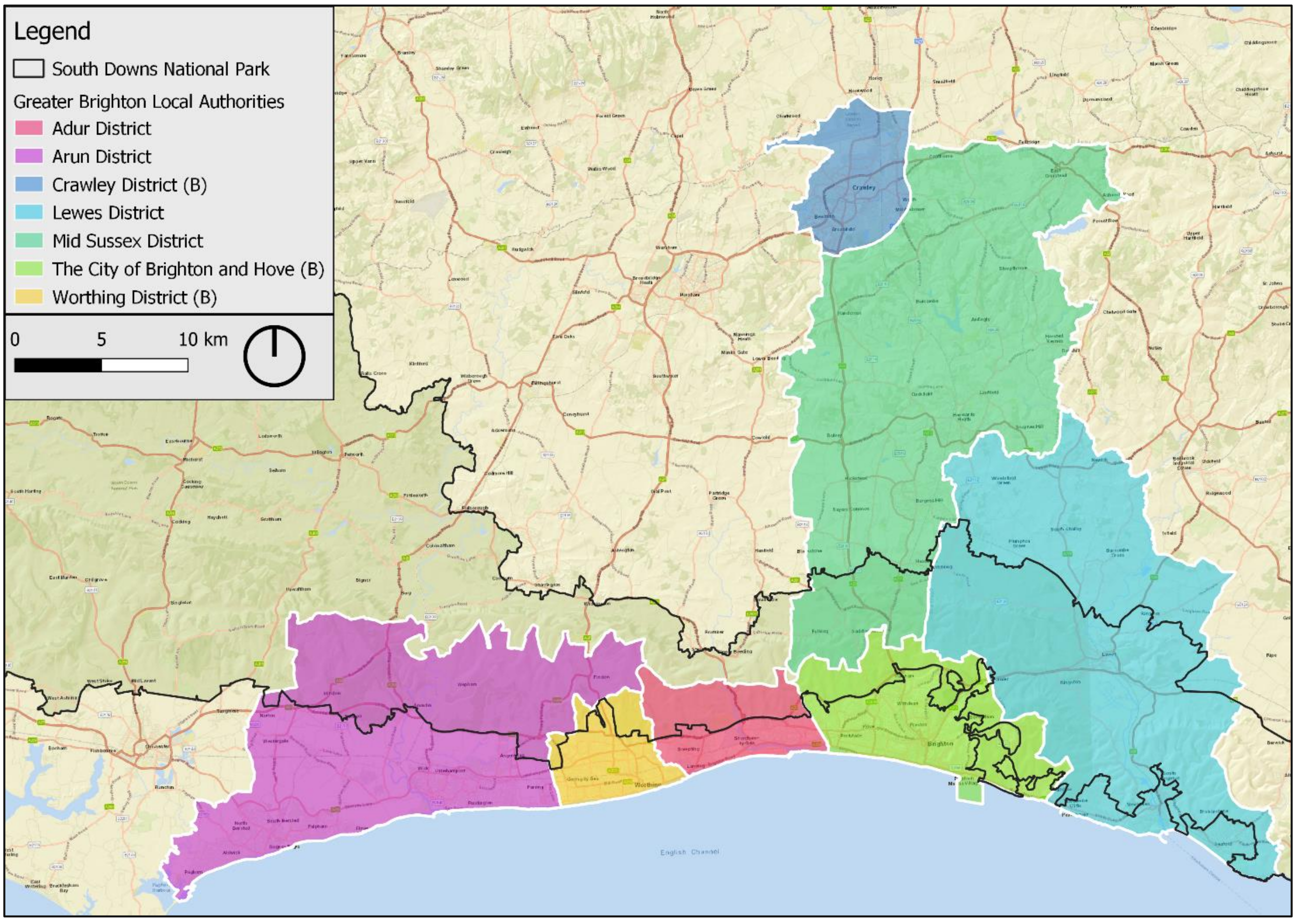


**Figure 1—1 The Greater Brighton area. The background map is the ESRI standard baselayer.**

As the map indicates there is a substantial variation in geography of Greater Brighton; containing urban areas, notably Crawley in addition to Brighton and Hove, as well as rural areas – predominantly in Mid Sussex and Lewes. The area, as shown in Figure 1—1has the South Downs National Park running through it. The impact of this is discussed more in the planning section below but essentially large scale renewable projects within the National Park are less likely to pass through the planning system. However, there is a strong political will in the area to make carbon reductions, with many of the LAs declaring climates change emergencies – aiming for 'net-zero'[1] wherever possible by 2030. This is more ambitious than the 2019 central UK target of 'net-zero' by 2050, which again marked an increase from the previous 80% carbon reduction by 2050. A review of the historic Greater Brighton Carbon emissions is presented in Figure 1—2.

[1] 'Net-zero' refers to an overall balance of zero carbon emissions, so in addition to switching to low carbon energy and materials carbon be offset through carbon sequesting environments and projects – such as tree planting.

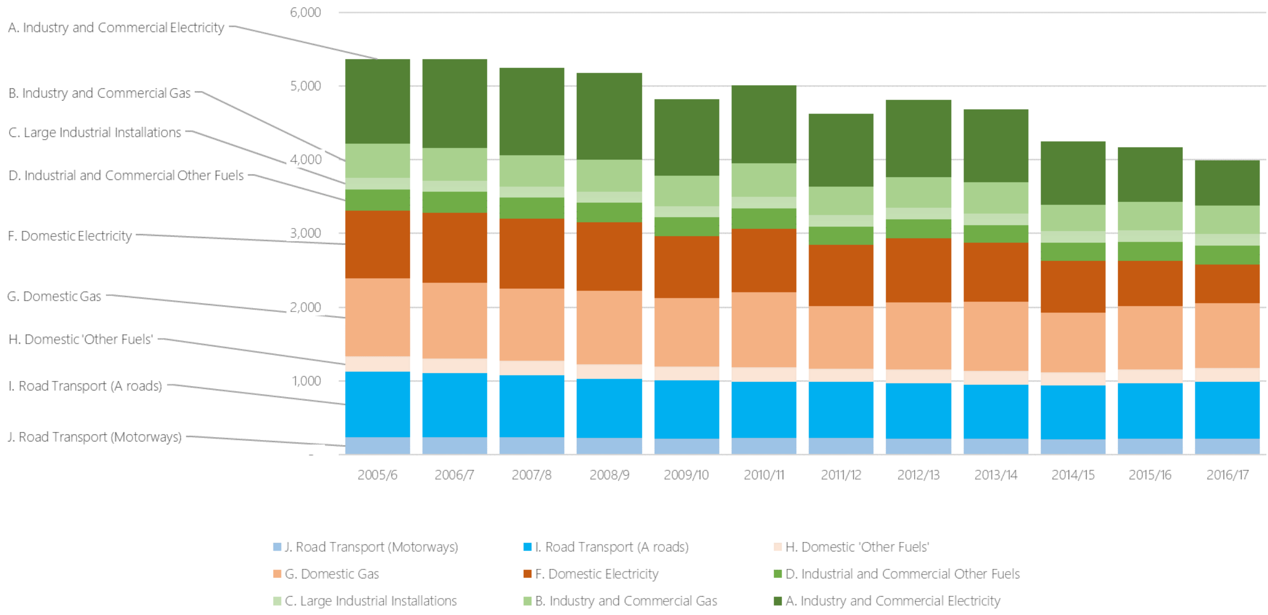


**Figure 1—2 Greater Brighton historic carbon emission. Values for emissions are provided in $ktCO_2$**

There is a strong desire to use locally generated renewable electricity, primarily solar, as a first step to bring about these carbon reductions. However, as shown in Figure 1—2 there is a large reduction in the carbon emissions from electricity between 2005/2006 and 2016/2017; making it the smallest share of Greater Brighton's carbon emissions from the three energy vectors of electricity, heat and transport. This is due to the decarbonisation of the UK's national grid, with 46GW of renewable capacity - the largest shares coming from onshore wind (~14GW), solar (~13.5GW) and offshore wind (~9GW)[2]. This grid decarbonisation means that any solar capacity added in the region which is fed into the grid will have a relatively low impact on the area's carbon targets, with benefits instead being captured at the national level. Furthermore, historic trends show that the electricity sector is rapidly decarbonising in the UK, so to be of most value solar projects should assist with the transition to low carbon technologies in the heat and transport sectors. Thus particular attention is given in this road map to solar applications which assist with these aspects of the energy system.

Despite solar making up a nearly equal portion of installed capacity in the UK to onshore wind it has a lower capacity factor meaning onshore wind generates more electricity, e.g. during a relatively optimal quarter (April-June 2019) for solar and sub optimal for wind in the UK onshore wind produced 6.1TWh compared to 4.9TWh from solar. Despite a lower capacity factor solar power can still be competitive with onshore wind due to lower local environmental and visual impacts, easier planning permission, efficient small scale devices, greater number of suitable sites, and easier power to utilise on site[3]. Solar is also seen as an empowering technology where individuals, communities, businesses and local government can easily engage. There has, however, recently been some changes in the UK support framework for solar power.

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[2] BEIS, 2019: UK renewables April-Rune 2019. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/835114/Renewables_September_2019.pdf

[3] Wind power from a single small scale wind turbine has a 'lumpy' generation profile, this rapid variability leads to problems with among things frequency control.

# 2 Technology review

This section provides a brief review of major solar technologies, the overall UK position on them and an indication of costs.

## 2.1 Crystalline Silicon Photovoltaics

Crystalline silicon (c-Si) is the most mature and widely used PV technology and represents 85-90% of the global market (IEA). c-Si continues to dominate the domestic market in the UK with around 90% of the market share, this is split between mono-crystalline (mc-Si) and polycrystalline materials (pc-Si). Crystalline modules are reliable and have relatively high efficiencies (mc-Si ~15-18%, pc-Si ~12-16%).

The manufacture of the silicon wafers is a very energy intensive process and there are now alternative manufacturing techniques which require less energy but would not benefit from the economies of scale that the more mature manufacturing processes have earned. Silicon is an abundant resource and its supply will not limit the projected further growth.

**UK position:**

There is currently no manufacturing base for silicon PV cells in the UK, although reclamation manufacturing occurs at Pure Wafer in Swansea, Sharp in Wrexham and Romag in the North East of England. The UK is also actively involved in research into silicon cell manufacture at Loughborough University as well as the National Renewable Energy Centre (NaREC). There is also a micro-electronics facility specialising in PV at Southampton University.

**UK costs:**

Being the market leader technology, crystalline silicon module types are assumed when quoting benchmark solar PV module prices. These benchmarks fell quite rapidly between 2010 and 2013, and average module prices in the different gigawatt-scale national markets continued falling, with a 35% decline in the UK between 2013 and 2018. In absolute British sterling values, this corresponds to module prices firmly below 0.40 GBP per Wp, depending on the specific module design as observed in Table 2—1.

**Table 2—1 October 2019 crystalline module price index (Source: pvxchange.com)**

| Module class | Avg module price (2019 GBP per Wp) | Nominal power (Wp) | Design Notes |
|---|---|---|---|
| **Bifacial** | 0.34 | N/A | Both sides of bifacial modules harness solar radiation |
| **High efficiency** | 0.29 | >295 | Advanced module design (PERC, HJT, n-type, back-contact cells) |
| **All black** | 0.31 | 200-330 | Black back sheet and frames |
| **Mainstream** | 0.22 | 270-290 | Standard modules, typically with 60 multicrystalline cells, aluminium frame, white backsheet |

## 2.2 Thin Film Photovoltaics

Thin film solar cells consist of one or more thin layers of photovoltaic material on a supporting material such as glass or plastic. Thin films account for ~10-15% of global PV sales. The material and manufacturing costs of this technology are normally lower than other technologies but the efficiency of the modules is lower which therefore requires larger installations. Thin film PV exhibits good low light performance such as diffuse irradiance from cloudy skies. Research suggests that thin films may also perform better at sub-optimal solar angles, these are two issues that the UK faces. Another advantage of thin film PV is an improved temperature coefficient compared to crystalline silicon (0.25% per ºC rise in thin film compared to 0.5% per ºC rise in c-Si).

Thin film technology has a unique design advantage as they are flexible and can be curved, partially transparent and bonded to a variety of materials. The lightweight nature of thin film PV allows for novel design ideas as well as improved aesthetics in buildings that might see traditional panel designs as a barrier for adoption. The most common thin film PV material has been amorphous silicon (a-Si) which has an efficiency of 5-8%, however, the performance of a-Si modules degrades during the first few weeks of operation before stabilising. In recent years a more stable variant that uses micromorph silicon tandem cells has been introduced which is capable of efficiencies up to 10% (UKsolarroadmap).

**UK position:**

The UK has a strong R&D community in thin film PV. There are already significant supply chain businesses such as Pilkington who specialise in glass optimised to suit a variety of thin-film photovoltaics. The Solar tower in Manchester uses 7,244 80W modules to clad the entire surface of the tower which demonstrates how a large-scale solar installation can be aesthetically designed (UKsolarroadmap).

There is significant UK expertise across all aspects of thin film PV, of particular note is SUPERGEN which involves nine of the UK's top universities and has established a network for PV R&D across academia, industry and finance. SUPERGEN is the UK's only accredited body for the measurement and analysis of PV cells and modules, highlighting their significance to the UK industry.

**UK costs:**

As a result of the more favourable manufacturing process of thin film PV technologies, average European module prices per Wp have historically been below those of crystalline technologies, despite the lower nominal efficiencies. However, in 2018, it seems high efficiency silicon module prices have become competitive against thin film a-Si modules on a per Wp basis.

## 2.3 Concentrated Solar Power (CSP)

CSP systems generate solar power by using mirrors or lenses to concentrate a large area of solar energy input onto a small area. Electricity is generated when the concentrated light is converted to heat, which drives a heat engine turbine. Heat can be stored in molten-salt storage and used overnight reducing power storage issues for continuous overnight supply. They are generally very large facilities, in the tens to hundreds of MW range.

**UK position:**

For CSP to function effectively it needs high levels of direct solar radiation. This coupled with cloud cover having a very large impact on performance, relative to PV, means current technology is not currently suited to the UK. The lack of suitability in a Greater Brighton context is enhanced by the scale normally associated with CSP not being suitable for the region.

**UK costs:**

Average installation costs have fallen from 4,600 – 10,000 £/kW in 2010 down to 2,400 – 5,600 £/kW in 2018. This is still several times higher than PV but includes storage and has a higher capacity factor. This has resulted in CSP being on at least cost parity per Wh with PV in optimal conditions (e.g. Saudi Arabia), however, this would not be achieved in the UK with current technology.

## 2.4 Concentrator PV

Concentrator PV uses an optical concentration system which focuses the suns energy onto small, high-efficiency cells. The technology uses high-quality epitaxial multi-layer structures and is much more complex than thin film or silicon panels as it involves solar tracking (the cells do not generate electricity when the sky is cloudy or the sunlight is not direct) and optical concentration.

**UK position:**

This is an area that the UK already has strength from an established satellite industry with companies such as Surrey Satellite Technology and IQE Ltd in Cardiff. IQE Ltd is the leading UK manufacturer of high performance multi-junction epitaxial structures. There are UK industry strengths in the sectors required by this technology and the UK has a history of world leading manufacture of III-V semiconductors.

**UK costs:**

There are currently no concentrator PV installations in the UK yet and deployment is still limited world-wide compared to traditional PV and CSP. CPV costs are currently at ~1800 £/kW.

## 2.5 Solar Thermal

Solar thermal systems can contribute to decarbonising heat, by harnessing the sun's energy through a collector and using it to provide domestic hot water and space heating in the serviced building. Both diffuse and direct solar radiation are exploited by the system. Due to the seasonality of the solar resource and the majority of the space heating demand peaking in winter, such systems would greatly reduce the energy production and therefore fuel costs of existing conventional boiler systems in summer, but only partially do so in winter. Two main design types of the solar collector exist:

1. Glazed flat plate collectors – this is the most widespread and economic design in Europe. They are easily integrated on roofs and are characterised by insulation on their back and sides to minimise heat loss.
2. Evacuated tube collectors – they are more efficient than the previous, but also more expensive and cannot be integrated on roofs as they use glass tubes surrounded by a vacuum to minimise heat loss.

Solar thermal systems are usually coupled with some degree of existing or new water storage solution (cylinders or tanks) as peak heating in domestic buildings is necessary in the mornings and evenings while solar thermal energy production peaks in the middle of the day. As a result, retrofits based on this technology are more compatible with old dwellings serviced by conventional boiler systems already integrated with tanks and/or cylinders. On the other side, more recent properties are serviced by a combi boiler type, which provides almost instantaneously space heating or hot water on demand without the need of storage. Lastly, solar thermal systems can also be coupled with thermal absorption chillers in order to provide cooling during summer periods.

Solar thermal systems in the UK have a peak quoted thermal efficiency of around 70% (from estimation of nominal capacity over area). However, as a result of the UK solar resource seasonality and orientation of the collector, glazed flat plate collectors will collect around 350 kWh $m^{-2}$ per year while evacuated tube collectors will collect around 450-550 kWh $m^{-2}$ per year, which would correspond to annual plate efficiencies between 30 and 55%.

**UK position:**

Solar thermal systems are far less developed in the UK than solar PV installations, with only around 580 MWth total capacity in operation as of 2017. In this respect, the UK is behind other major European economies such as France and Italy, which have around 1,933MWth and 3,202MWth of installed capacity. There is also small progress in new installations, as only 8.5MWth were installed in 2017.

The UK does, however, benefit from a strong manufacturing base, with companies such as Kingspan, Viridian and AES quite active in the global solar thermal market.

**UK costs:**

Individual solar thermal installations are usually in the size range of less than 5-6 $m^2$, particularly when installed on the roofs of residential buildings. For smaller solar water heating systems (2-4 $m^2$), installation costs lie in the range GBP 1,000 – 1,500 per $m^2$; as the system size increases, installation costs can potentially drop down to GBP 800-900 per $m^2$. These estimations have to be treated as indicative because depending on the integration of the solar thermal panels with the existing heating system, additional costs can be incurred.

## 2.6 Emerging Technologies

This section briefly presents some of the more novel solar technologies. These are still generally at the research and development stage, so are important to include to give an overall view of the solar sector but not significant in terms of actual projects in the ground for a solar roadmap.

### 2.6.1 Organic Photovoltaics

Organic photovoltaics (OPV) is another advanced technology which has the potential to reduce costs in manufacturing and materials by using a polymer blend. The highest efficiencies of OPV is currently at ~9%. This technology has some interesting novel applications with potential for OPV use in indoor lighting and in clothing.

**UK position:**

There has been significant investment in Eight19, based in Cambridge and Molecular Solar, based in Warwick. There is also research taking place at Leeds University and Imperial College.

### 2.6.2 Dye-sensitised solar cells

Dye-sensitised solar cells (DSC) is an advanced technology that uses a photoactive dye on a semiconductor support to adsorb light. DSC can be deposited on metal, glass and plastic which offers a potentially low-cost high-volume manufacturing route such as roll to roll coating. As this technology is still new its reliability has not been proven over time. The target market for this technology is mainly point consumers that do not require heavy electricity demands.

**UK position:**

There has been a recent advance at Oxford university that showed that using Perovskite as the absorber layer as a solid state approach.

### 2.6.3 Photovoltaic-Thermal Systems (PVT)

PVT systems combine photovoltaic and thermal solar energy conversion in a single collector, as the solar radiation not converted to electricity is then harvested to be converted to useful heat. PVT designs are mostly of the air collector type (the heat transfer fluid is air due to low capital cost), relatively few designs use a different approach with an uncovered water collector - despite this being the dominating PVT-technology. This indicates a lack of technological maturity despite multiple installations across the globe.

Overall, higher energy yields per area can then be achieved, as up to 70% of the incident solar resource is exploited. Nominal thermal power yields of 400 – 600 Wth/m$^{-2}$ (40-60%) and nominal PV power yields of 100 - 200 (10-20%) are quoted by 26 PVT collector manufacturers surveyed by IEA SHC through a comprehensive international market survey (just one manufacturer is from the UK). The major obstacle represented by this technology is the increased upfront cost required. However, the overall levelised cost of energy of these systems can be 30-40% lower than that of equivalent PV-only systems. Current UK installation capacity is virtually non-existent (only 192 kWth and 62 kWpeak).

### 2.6.4 Cost summary for key solar technologies

An up-to-date average installation cost of the key solar PV project types specific to the UK market is provided in Table 2—2.

**Table 2—2 Cost summary for different solar PV schemes.**

| PV setup | Small scale (0-4 kW) | Small scale (4-10 kW) | Small scale (10-50 kW) | Utility scale | Solar carports |
|---|---|---|---|---|---|
| **Average installation cost (2019 GBP per kWp)** | 1816 | 1498 | 1139 | 1042 | ~1400 |

The small-scale project cost data have been gathered by BEIS from the Microgeneration Certification Scheme (MCS) database and mostly refer to roof-mounted, domestic systems installed in the period between January 2018 up and March 2019. Utility-scale projects are most often deployed in a ground-mounted arrangement; their average total installed costs have fallen an outstanding 77% since 2010 in the UK and benefit to a higher extent from economies of scale with respect to smaller scale installations. Finally, UK solar carports are still a novel concept and costs more than conventional commercial installations, as a result of the increased complexity of integrating the solar modules with the canopy roofs. However, they are also able to unlock more niche revenue streams given their strategic location and future integration potential with EVs in public parking spaces.

# 3 Context for solar development

This section outlines the financial support mechanisms in place for solar generation. It also gives a brief summary of planning considerations and the current status of solar in the area.

## 3.1 Economic support frameworks

The UK's solar legislation has changed considerably over time, most recently there was a Feed in Tariff (FIT) scheme, however, this was closed to new entrants on 31st of March 2019. The closure followed consultations in 2015 and 2018, to reduce the costs to consumers as the price of installing solar panels came down, the cost of residential solar installations has come down by 50% since 2011 according to the UK government. A review of the UK legislative framework applicable to solar energy is provided below, this is focused on subsidised generation of solar power.

The **Renewable Obligation (RO)** was one of the main support mechanisms for large-scale renewable electricity projects in the UK. The RO came into effect in 2002 in England, Wales and Scotland and 2005 in Northern Ireland. It places an obligation on UK electricity suppliers to source an increased proportion of their electricity from renewable sources. Renewable Obligation Certificates (ROCs) were issued to accredited renewable operators and the certificates were used by suppliers to demonstrate that they had met their obligation. The scheme closed in March 2017, to be replaced by Contracts for Difference (which are discussed later).

**Contracts for Difference (CfD)** has replaced the RO as the UK government's main mechanism for supporting low-carbon electricity generation. This is done by incentivising renewable electricity by providing developers with high upfront costs and long lifetimes with direct protection from volatile wholesale prices through an agreed strike price. This also protect consumers from paying increased support costs when the price of electricity is high.

Renewable generators can apply for a CfD and there can be a range of renewable technologies competing directly against each other for a contract, in auction process. Successful developers of renewable projects enter into a private law contract with the Low Carbon Contracts Company (LCCC). With the developers being paid a flat rate for the electricity they produce over a 15 year period, agreed during the auction process.

Solar projects are not generally supported through this scheme – with none appearing in the latest round of funding. The majority of the CfD auction went to offshore wind projects, at ~40£/MWh. This makes a useful comparison point for solar power in the UK if it is going to compete with large scale renewable grid decarbonisation.

The UK **Feed-In Tariff (FIT)** was designed to engage small scale renewable electricity production, such as at the household level. This gave payments (generally quarterly) for the electricity generated and exported to the grid. The focus of this was on small scale projects, below 5MW, with projects of a smaller size achieving a higher price per unit of electricity. Payments are made based on the meter reading that generators submit to their electricity supplier. The scheme was introduced in April 2010 and led to a massive increase in uptake in solar PV in the UK, ~840,000 solar installations since the start of the scheme, this is explored further in a Greater Brighton context in Section 4.

The FIT support has now been removed in the UK (ending 1st April 2019) which along with the competitive nature of the CfD means in the UK solar power is generally having to compete with other forms of generation without market support, although it is being replaced to an extent by the smart export guarantee, discussed below.

The FIT has to an extent served its duel purposes of increasing solar installations and bring down costs. Whilst the costs have come down (estimated total install cost including equipment in a domestic environment to have dropped from ~5000£/kW in 2010 to ~1700£/kW at the start of 2019), with no FIT market commentators consider a 17 year payback is the best that can be expected through export [1].

The **Climate-Change Levy (CCL)** is an environmental tax charged on the energy used by businesses and has been designed to encourage businesses to be more energy efficient in order to reduce greenhouse gas emissions. The tax was first introduced in April 2001 and was forecast to cut annual emissions by 2.5 million tonnes by 2010. The CCL applies to businesses in the industrial, public services, commercial and agricultural sectors. Originally the electricity generated from renewables and approved cogeneration schemes was not taxed but this exemption was removed in the July 2015 budget.

The **Renewable Heat Incentive (RHI)** is a government financial scheme to promote the use of renewable heat and contribute towards the 2020 ambition of 12% of heating coming from renewable sources. BEIS develops the scheme policy and rules and Ofgem implements and administers the scheme. From a solar perspective the significant element is a 21.09p/kWh currently being given for solar thermal projects. Meaning in terms of subsidy solar thermal technology is the only technology currently strongly supported by the UK government, in a generation context.

The UK Government are replacing the FIT scheme **Smart Export Guarantee (SEG)**, new laws guarantee payment for small-scale generation that provides excess electricity to the grid – as with the FiT small scale generation is considered to be <5MW. Part of the scheme is that it will not be paid for by fees added to consumer bills, aligning with a central Government aim that renewables, although seemingly not nuclear, will part of a UK transition to a 'subsidy-free, cleaner and greener energy system'. The inclusion of a support mechanism for small scale renewables is promising for solar. The SEG only recently finished its consultation period so the exact extent of the support is yet to be made clear. The efficiency of the scheme is going to be aided by tracking the generation using smart meters. The combination of distributed generation, smart meters and battery storage, SEG is aimed to help bridge the gap to a smarter and more efficient energy system. For this to be successful SEG users will need to be able to participate more actively in the electricity, taking advantage of different tariff structures.

Whilst the SEG shows some promising for solar power the UK Green Finance Strategy, an 80-page document launched in July 2019, makes little mention of solar PV. Nuclear power and offshore wind both focus areas, whilst solar PV is only discussed in passing and as a sector to be tackled in other countries. Thus in the most part solar has limited support in the UK.

## 3.2 Planning

Historically planning permission has been relatively easy to obtain planning permission for both roof and ground mounted systems. For roof mounted systems solar panels are generally a permitted development right – which means they do not need to acquire planning permission. However, there are still guidelines to be met. Permitted development rights are more restricted on listed buildings and in Conservation Areas, National Parks and Areas of Outstanding Natural Beauty – which impacts large areas of Greater Brighton. Whilst these are unlikely to limit rooftop PV listed buildings are more likely to be a barrier for some developments but should not significantly impact the area's rooftop PV potential.

Ground mounted solar systems face larger hurdles. The South Downs National Park authority states that installations must comply with other relevant policies will be encouraged providing that:

- The siting, scale, design and appearance will not have an adverse impact upon landscape character, including cultural heritage, and wildlife;
- adjoining uses, residential amenity and relative tranquillity are not adversely impacted in terms of noise and disturbance, vibration, stroboscopic effect, or electromagnetic interference;
- existing public access is not impeded;
- and the installation does not result in the loss in use of Grade 1 or 2 agricultural land.

The final point is true for all areas in terms of agricultural land, with Grade 3 also requiring further justification than Grades 4 and 5 (which are preferable). A useful summary of planning legislation for solar power is provided by the BRE [2], however Figure 3 Figure 3—1provides a rough summary of areas which should be excluded from ground mounted PV due to land use. In terms of landuse this is taken to be any area which is Grades 1-2 agricultural land urban areas, non-agricultural areas and wooded/forested locations should also be considered constraint areas and Grade 3 suboptimal.

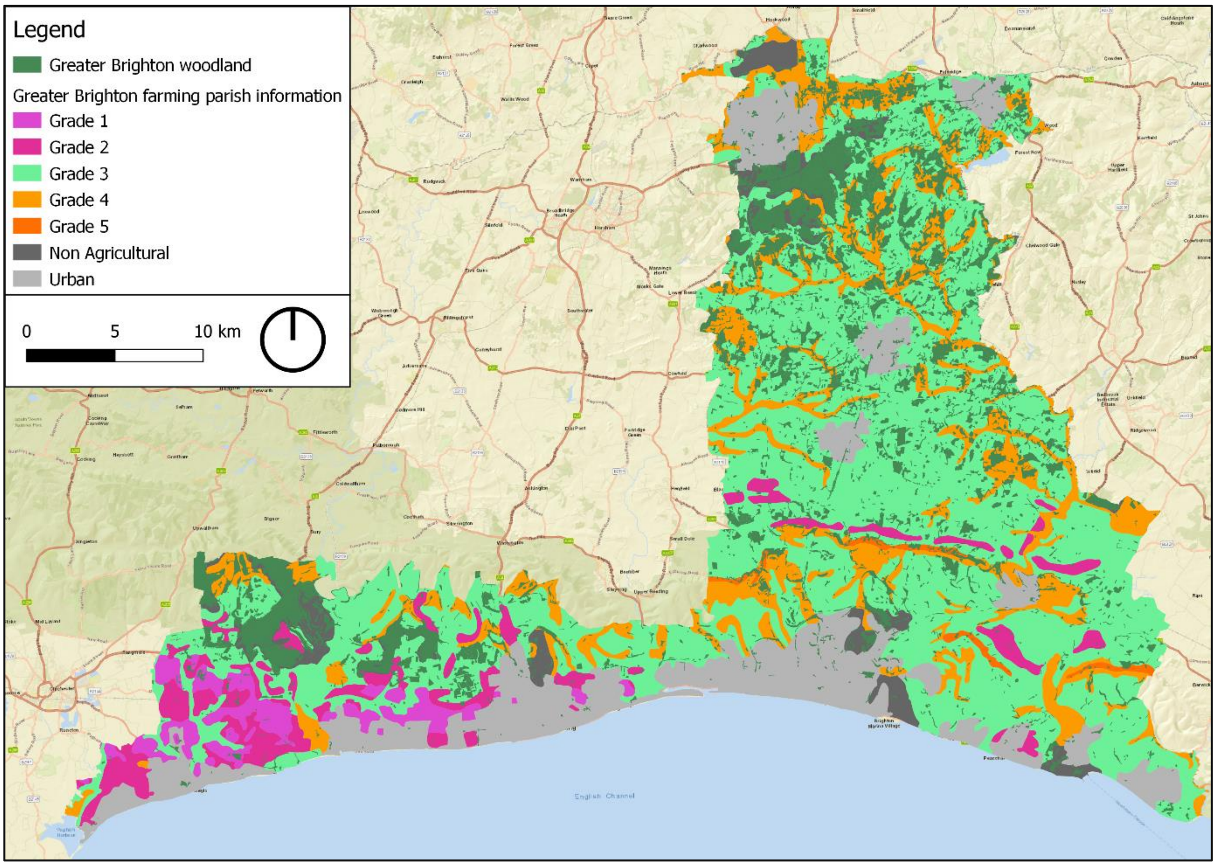


**Figure 3—1 Summary of land classification constraints areas for solar farms in the Greater Brighton area. The map is compiled using the UK Government agricultural land classification data and forestry commission woodland data.**

There are several large areas of constraint for large scale ground mounted solar generation, the most notable being the extensive urban conurbation along the coastal region. Figure 3—1also shows that low grade agricultural land (Grades 3-4) makes up a relatively small portion of the land take, with Grade 3 dominating. However, if large scale ground mounted solar was deemed desirable this allows rapid identification of priority areas. It should be noted that due to the visual impact large tens of megawatts scale projects are unlikely to be tenable in the national park area of Greater Brighton, regardless of land use.

### 3.3 Current status of solar in Greater Brighton

Combining two UK Government datasets (feed-in tariff data and UK renewable power plant data) a total of 177MW of solar capacity has been identified in the region, this makes up ~1.3% of the UK total. However, behind the meter and schemes may not be captured and some of the more recent developments may not be captured at a local level. Despite this the relatively small percentage share given that the area represents one of the best solar resource areas in the UK (see Figure 3—2). This is likely in part due to the high land value and constraints illustrated in Figure 3—1.

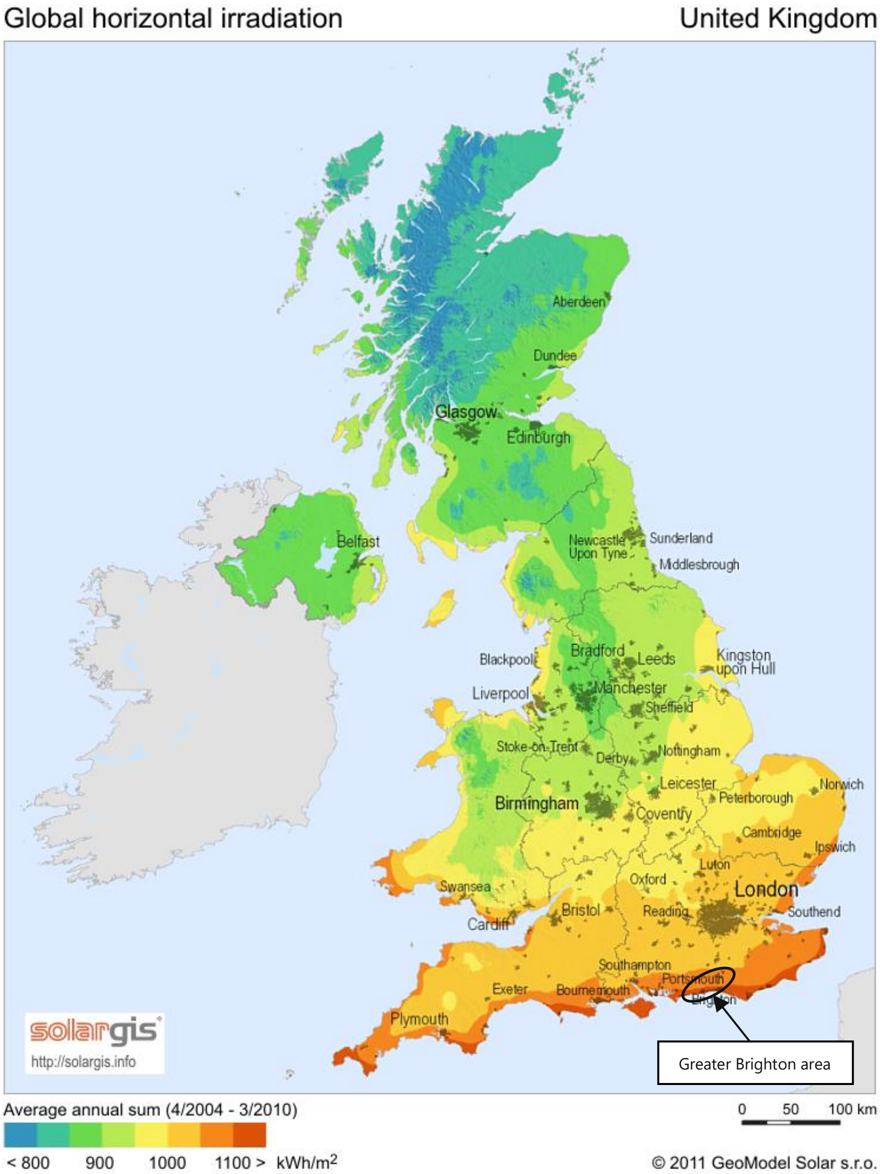


**Figure 3—2 UK solar resource with approximate location of the Greater Brighton marked. Background image from Solar GIS.**

A detailed geographic breakdown of solar capacity in Greater Brighton is provided below in Figure 3—3; this includes both larger PV farms (with data drawn from a BEIS data set giving precise coordinates of solar farms) and the FiT presenting data presenting installed small scale connections. The FiT data is presented at Lower Layer Super Output Area (LSOA) level, LSOAs are distinct geographic areas used for breaking down census statistics covering about 1500 people.

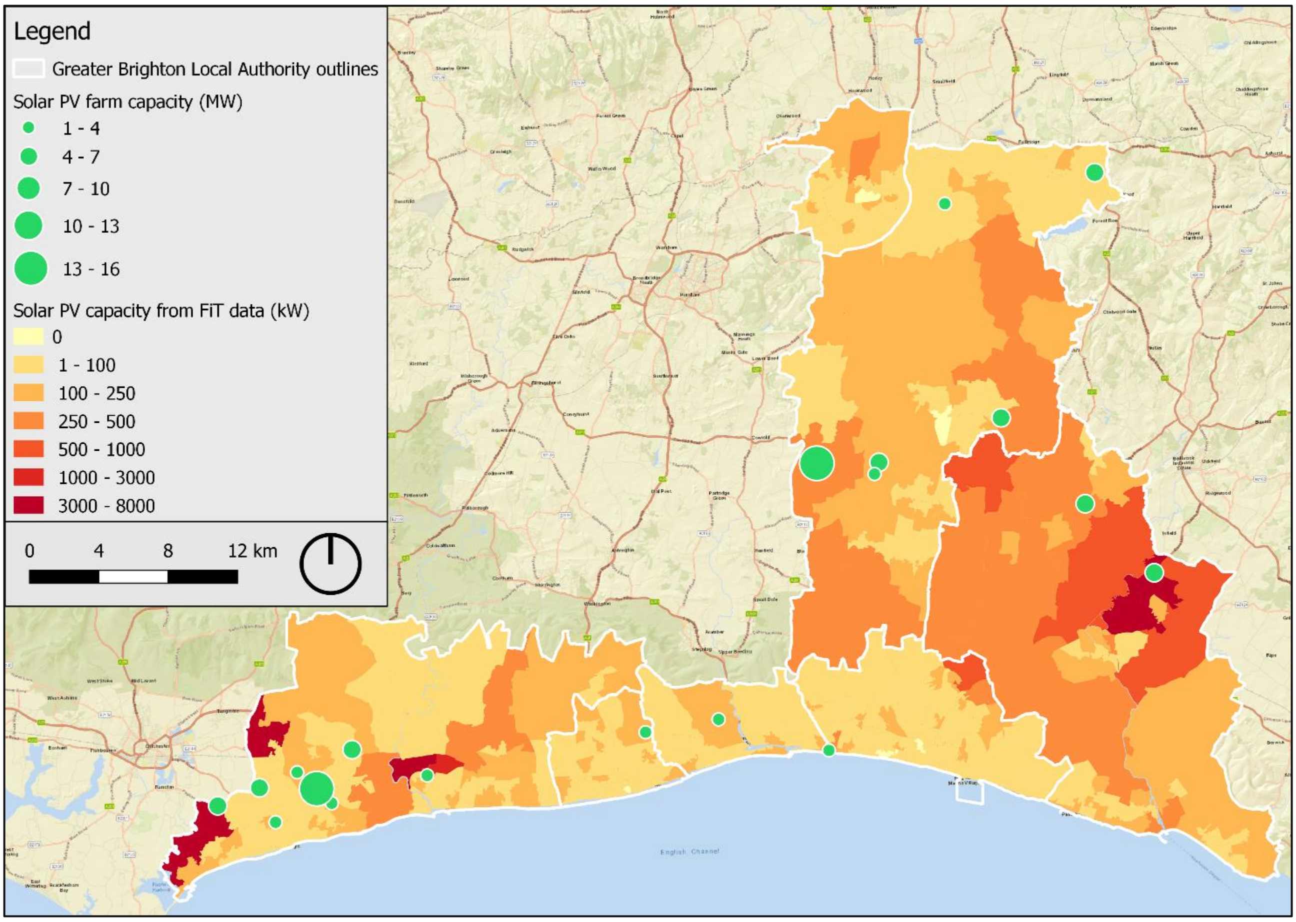


**Figure 3—3 Current solar installations in Greater Brighton.**

The distribution of large scale solar generation matches well with the constraints map, it also highlights that Arun is leading the way in solar development in the Greater Brighton area for these types of developments with Mid Sussex being the next highest in terms of capacity. In terms of small scale FiT capacity Arun again performs well in terms of installed capacity per LSOA along with Lewes. It should be noted Figure 3—3 does not include the boundaries of the LSOAs, so if adjoining LSOAs fall into the same capacity banding they will merge (this is due to in urban areas LSOAs being spatial small - so differentiating would hinder interpretation). The FiT capacity breakdown for the different LAs is:

- Adur 2,694kW
- Arun 23,399kW
- Brighton and Hove 8,004kW
- Crawley 4,484kW
- Lewes 13,012kW

- Mid Sussex 8,520kW
- Worthing 3,395kW

The FiT data for Greater Brighton is illustrated with temporal detail in Figure 3—4, it should be noted in 2012 and 2016 there were particularly large cuts to the FiT.

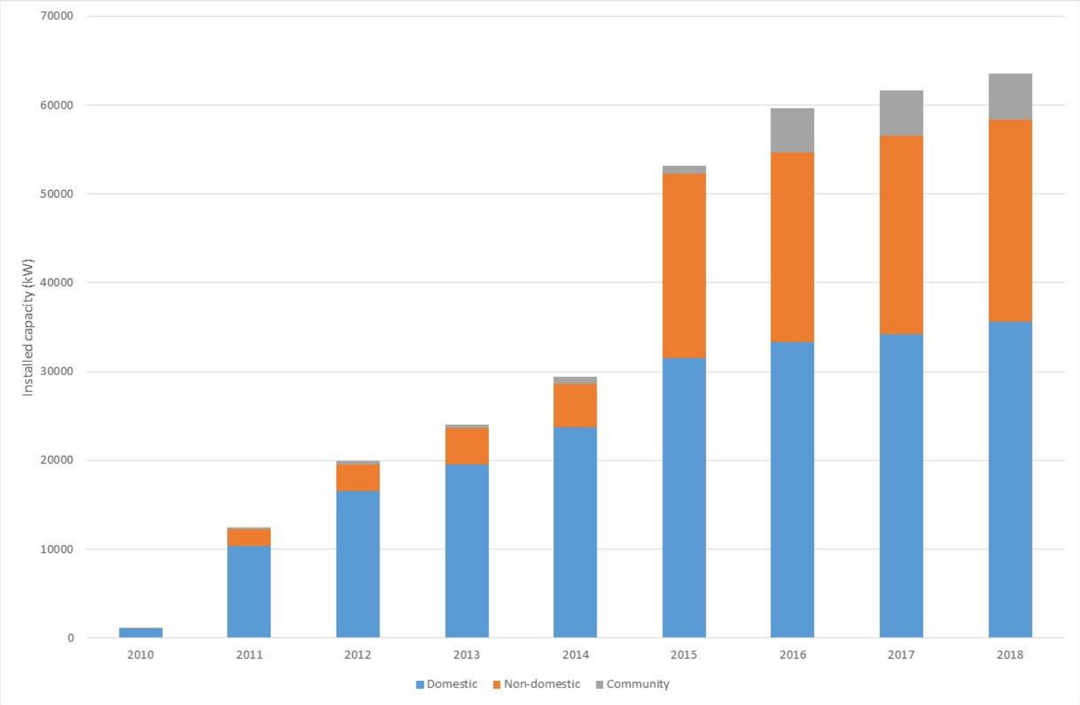


**Figure 3—4 FiT registered solar projects in Greater Brighton, split by project type.**

The growth in solar capacity is markedly faster between 2010 and 2012 than 2012 and 2014. This is due to the first review in FiT rates happening in 2012 and resulting in fewer people investing in PV. The market then recovered with percentage growth in uptake of the FiT peaking in 2015, however, once the impact of the rate cut (65% in 2016) filtered through the market stagnated - with a dramatic decrease in percentage growth in 2016 and beyond.

This market uncertainty had large impacts on the solar industry and supply chain. A notable example in Greater Brighton being the loss of the company Southern Solar in 2015, which had been operating since 2002, and been heavily involved in promoting the growth of community owned solar projects in the Greater Brighton area.

Community owned projects and community energy companies are a key theme that came out of the stakeholder engagement part of the project and is an area that Greater Brighton continues to be a leader in at a national and global level.

# 4 Solar projects in Greater Brighton

As shown in Figure 3—4 the solar market has generally stagnated in the area, due to the cuts in FiT. However, one sector which has managed to buck this trend is the community generations sector (this is slightly hidden in the data for Figure 3—4, possibly due to the presence of PPAs for the electricity produced). This is in part due to an extension of the FiT for community projects of one year, which resulted in a very high level of interest in 2019.

## 4.1 Solar schools

A model frequently used by community energy groups in the area is that of solar schools, where the community energy group will gather shareholders to invest in the scheme, construct solar PV on the roof space and sell generated electricity to the school through a PPA at a lower price than it could purchaser electricity through a standard supplier. Brighton Energy Cooperative, OVESCO and BHESCo are all active community groups in Greater Brighton promoting solar schools. Well over £2million of funding has been raised by these groups for solar school projects. As solar schools have a business model which is proven (discussion with community energy groups suggests this is the case even without the FiT – although it does mean payback rates have fallen) it seems an excellent opportunity for a solution to be rolled out across the region. A regional energy investment company would be an excellent vehicle to achieve this, allowing for an increase in scale and deployment rate. If the energy investment company was to be Greater Brighton based it would likely be happy to accept a slightly lower rate of return than private companies, ensuring rapid project uptake. The scale of deployment could be significant, with the area containing several hundred schools and projects generally ranging from a few tens of kW for primary schools to several hundred for large secondary schools and colleges. Assuming an average install of 60kW across 250 schools this would equate to 15MW of capacity but the potential could be more than double this.

Community energy groups in the areas should be heavily engaged with activity in this area due to their experience and expertise and engagement with the supply chain. It should be noted that there are signs the supply chain is not currently geared towards rapid deployment of applications like this; the extension of the FiT for community projects meant that so many projects were put forward in some areas that they could not be deployed in the required timescale (although there are none in Brighton and Hove which seem to have suffered from this issue).

## 4.2 Solar landfill sites

In the Tri-LEP study the utilisation of old land fill sites for solar power is flagged as a key opportunity for large scale solar deployment. In the initial instance this is because the sites generally have little productive value and require many years of remediation before they are suitable for regular development. Large sites are also frequently owned by the LA and thus are an area where the Greater Brighton Authority will be able to focus.

The tri-LEP study also flags that many landfill sites are already linked to the electricity grid – in order to feed in electricity generated from gas turbines run on the methane produced on site. As the gas diminishes additional capacity could be freed for solar generation and the gas could be managed to not generate during daylight (this would also help maximise value from the gas). However, as not all landfill have gas turbines since this will not always be suitable.

Historic and active land fill sites were examined and validated initially in GIS, rejecting some due to constraints (such as use as playing fields or very high visual impact due to location in the National Park) and a size of 40,000m$^2$ to ensure high level installed capacity (4MW and over) – to optimise economics. This left 20 landfill sites that were considered suitable for consideration for solar PV in the region (seven of which are still active).

### 4.3 Solar car parks

Solar car parks utilise solar power to feed into electric vehicle charging points. The PV itself can be land based next to the car park, rooftop based or utilising purpose built canopies. Brighton Energy Cooperative are currently examining solar carparks and Brighton & Hove carried out an exercise to identify suitable locations (analysis of this latter data only flagged one site – on Rottingdean seafront). Big Lemon buses can probably be considered the pioneer of this technology application the Greater Brighton with solar panels on their depot site being used to charge electric buses (it was the first with this kind of application in the UK).

Solar car parks are considered to have extra value beyond feeding directly into the grid, from a Greater Brighton carbon perspective as they help to directly displace transport emissions.

A developed case study for PV car parks is provided in Section 6.1 for a multi-storey car park in Haywards Heath. This site is next to a train station which we identify as an important focus for such charging hubs due to the length of stay and the wider mobility model work this meshes into – which will be required for successful decarbonisation of transport.

### 4.4 Solar thermal

Currently solar thermal is considered for rooftop installs, for utilisation within the same building. To reach full decarbonisation of the energy system heat presents a greater challenge than electricity, so in some instances solar thermal on a roof may be of more value than PV. However, the technology is not as widely considered by the public. To address this local schemes above the central UK Government RHI seem to be required to increase uptake. Additionally, LA owned assets would be useful place to start increasing installs – providing a guaranteed base to help grow the supply as well increase public familiarity with the technology.

BEIS are potentially looking to develop a work stream examining solar thermal heat networks. If these are shown to be practicable there may be several opportunities within the Greater Brighton region which would suit this approach. Opportunities should be monitored and if funding is available try to promote a pilot scheme in the region. Which would be well suited to this technology application due to the high solar resource (for the UK) and areas with large population densities. Thus it is suggested opportunities in this area are monitored.

### 4.5 Large scale rural community solar

The Greater Brighton region is one of the leaders in large scale renewable community solar projects. An exemplar project model is that of Riding Sunbeams – where direct supply of solar power to rail traction systems. Projects will be funded by offering shares to communities and commuters, allowing local people to own and benefit from the low carbon electricity powering their trains. Being community projects they are able to leverage additional funding through the Rural Community Energy Fund, with multiple communities biding in a combined manner to pool funding. This is necessary given the scale of the projects, with one Riding Sunbeams proposed site in the Greater Brighton area being 11MW. A full project breakdown is provided in Section 6.2.

Rural communities are suited to large scale solar projects due to substantial land assets, however, they are often on the extremity of the grid making connection difficult. In a pre-development project identified in the questionnaires a 4.2MW combined solar and battery installation was identified in the rural community of Firle. Having a battery integrated into the development helps reduce the impact of grid constraints in the area as the power can be more easily utilised and managed within the local area, helping to reduce pressure on the grid.

At Barcombe (another rural village) there is also discussion of a community solar farm, with the proposed funding mechanism for this including a community bond. Barcombe is currently pursuing major funding form the Network Innovation Competition, to help determine how issues such as grid constraint for decarbonisation can be overcome through innovative approaches.

If novel solutions can be found to grid constraint issues there is seen to be significant potential for community solar farms in the rural areas of Greater Brighton. The National Park Authority seeming to present relatively little deviation from national policy in terms of suitability of sites for deployment. As shown in Figure 3—1 there are large tracts of suitable land, particularly grade 3 agricultural areas. As grade 3 is not preferred but not a hard constraint having a community ownership aspect is seen as a positive factor for deployment in these areas. It should be noted there is likely to be a limit to the level of solar which will be considered acceptable, due to the cumulative impact of multiple installations to the area's character. Consequently, particularly in the National Park there will be a limit to the number of solar farms that will be considered acceptable.

## 4.6 Encouraging large scale solar deployment for high energy users

It is suggested that the largest emitters are the best to initially target for solar power to displace onsite carbon emissions, these are illustrated in Figure 4—1.

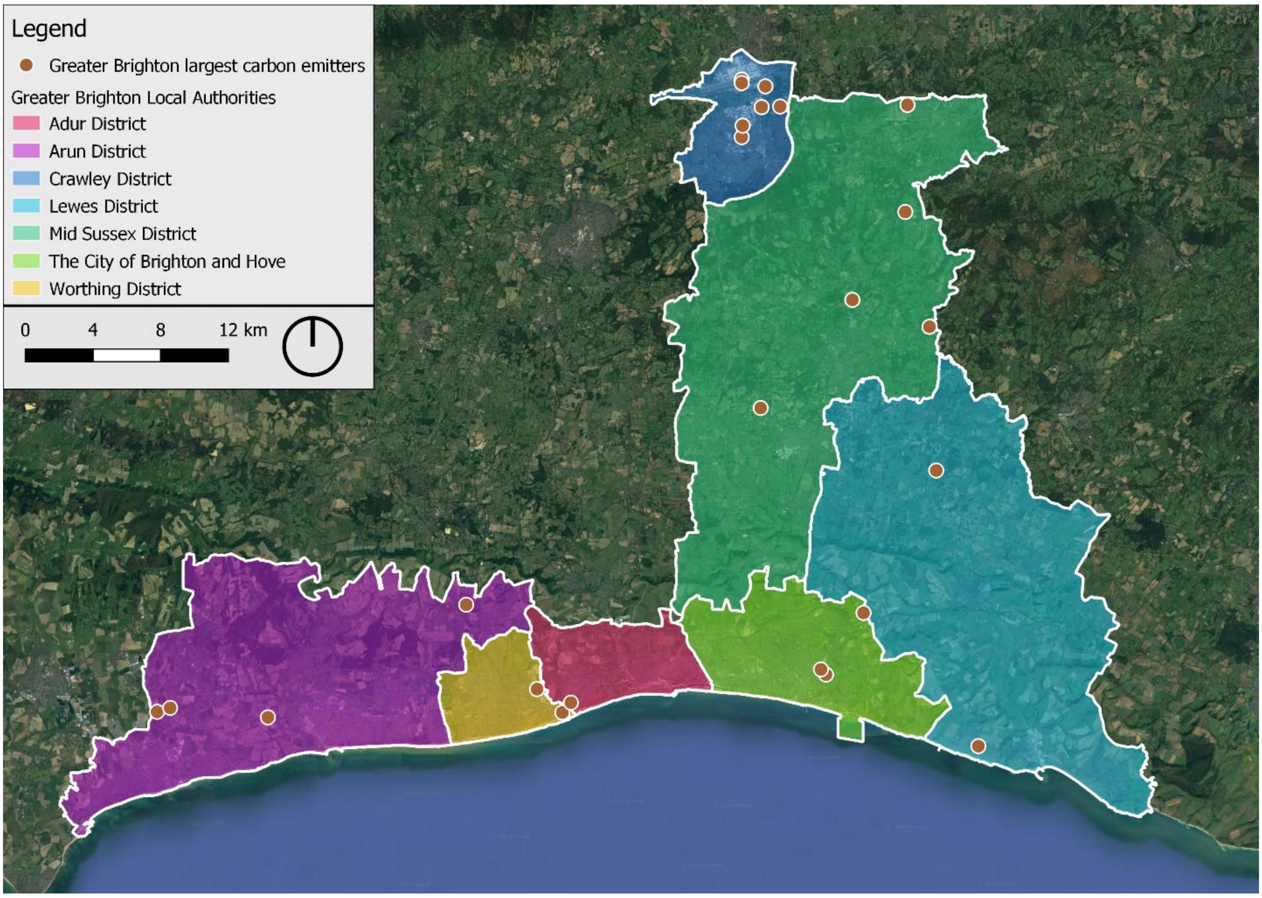


**Figure 4—1 Largest single carbon emitters in the Greater Brighton area[4].**

The map highlights the density of high emitters in Crawley, Gatwick Airport and the Manor Royal business park are responsible for most of these. Gatwick has its own advanced energy strategy and Manor Royal is progressing with measures to enable large scale PV uptake. At Manor Royal this is being assisted through the BISEPS scheme (funded through INTERREG), where multiple applications of solar technology are being explored.

The universities in Greater Brighton are also flagged in the carbon analysis as large emitters in the GIS analysis. Both the University of Sussex and the University of Brighton are using solar to address this issue, with Sussex University's rooftop solar project in 2017 being the largest install at a University in the UK at the time.

Shoreham Port is another large emitter in the area and is pioneering the way to reduce emissions through multi-vector and technology applications. This includes large scale rooftop deployment of solar panels, a technology to which the building typology of industrial sites like this is well suited (e.g. warehouse rooftops).

The water provider in the area, Southern Water, is highlighted as one of the largest single emitters in the Greater Brighton region. Southern Water provided details of all sites that are being considered for solar generation, with only two sites appearing in the Greater Brighton area (Arun was a late inclusion in the project area and was not included in this part of the analysis). However, there were many areas considered outside the Greater Brighton area, showing that is an issue with suitable assets rather than lack of commitment to solar power.

[4] Emissions data taken from the NAEI (https://naei.beis.gov.uk/emissionsapp/), data was filtered to exclude power plants which should be considered separately (notably the energy from waste facility at Newhaven and Shoreham Power Plant).

Floating solar PV on water reservoirs is becoming an increasingly established technology a GIS scan of the region was carried out to try and locate any suitable sites – however none were identified. The largest reservoir is at Ardingly in Mid Sussex but this is heavily used for activities, including sailing, and so considered unsuitable for development.

# 5 SWOT analysis of solar projects

A succinct SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis now follows, split into the different typologies of projects identified: domestic rooftop PV, non-domestic rooftop PV, solar farms, solar thermal and solar carports. The relative solar resource abundance in the Greater Brighton area with respect to the rest of the UK represents a significant strength for all types of solar installations analysed next.

## 5.1 Domestic rooftop PV

Domestic rooftop PV installations are largely constrained by the roof space availability of residential buildings. Average peak capacities are around 2.5 – 4 kW, occupying roof areas of 20-30 $m^2$. The proliferation of these systems in the early 2010s was mainly a result of the introduction of generous FITs in the domestic sector.

*Key to this is removal of feed-in tariff and slow down of install*

| STRENGTHS | WEAKNESSES |
|---|---|
| • A familiar solution which is now an every day sight<br>• The discontinuation of domestic FITs is to be followed by the introduction of the SEG in January 2020, demonstrating the commitment of the government to support the specific domestic PV market.<br>• The SEG will promote competition between energy suppliers with 150,000 or more customers to offer an appropriate export tariff to remunerate domestic PV owners.<br>• Initial SEG tariffs are expected to be relatively close to the export tariff in the final quarter of the FITs scheme (Energy Saving Trust).<br>• When coupled with heat pump solutions they can provide very efficient low carbon heat (due to COP of heat pump technology). | • PV installations in the UK residential sector have fallen dramatically from a peak rate of 55,000 installed units per month in 2011 to just 2,000 – 3,000 per month in early 2017 due to reductions of government subsidies in the sector.<br>• The government has gradually reduced tariffs of domestic FITs (in particular the generation rate), in conjunction with capital cost reductions of installations, eventually closing the scheme in March 2019 and creating uncertainty in the market.<br>• SEGs do not have a set or minimum export rate (just that it shall be greater than zero).<br>• Coupling solar PV with domestic batteries is currently expensive and even more costly if residents wish to use the system for resilience<br>• Still very low uptake despite having had incentives, demonstrating lack of buy in for adoption<br>• Lack of incentive for private landlords to fit on to rental properties<br>• Payback can currently be many years which is not attractive unless residents plan to stay for the period<br>• Typical installations are very susceptible to shadowing which limits scope and yield |
| **OPPORTUNITIES** | **THREATS** |
| • Great integration opportunity with domestic ASHPs and GSHPs and EV charging providing for loads during the middle hours of the day can greatly reduce peak evening loads ( continuous heating mode over two times a day mode).<br>• Lower export PV tariffs than import grid electricity tariffs promote self-consumption (up to 45%) and more conscious energy usage (https://doi.org/10.1016/j.enpol.2018.04.006).<br>• Directly supports a (visual) strategy for decarbonisation in the region, raising awareness.<br>• With the right financial support mechanisms can help to mitigate fuel poverty by reducing bills | • Supply chain could reduce significantly following FiT unless market uptake is maintained<br>• Electricity network capacity could provide a barrier to update due to local constraints if not managed properly<br>• Participation to the SEG is dependent on the presence of a smart meter, which only has a 30% penetration rate in domestic metered households and even lower for domestic PV arrays (BEIS "Smart Meter statistics in Great Britain: quarterly report to end June 2019). |

## 5.2 Non-domestic rooftop PV

Non-domestic rooftop PV installations tend to be greater in size with respect to non-domestic installations and characterise both commercial and public sector buildings, such as car parks and schools.

*To include projects such as co-location with EV charging/car parks and solar schools*

| STRENGTHS | WEAKNESSES |
|---|---|
| • No planning complications for public sector buildings.<br>• Public sector rooftop PV installations can become "quick wins" for attracting private renewable energy investment and further public funding.<br>• Rooftop PV farms on schools promotes social responsibility in classes.<br>• Proven engagement and crowd funding success in the region.<br>• Direct route and quick installation to support decarbonisation strategy<br>• Large roofs can give good yield to support local power consumption | • Reduced power load requirements of commercial and public sector buildings in weekends and holidays that therefore do not match PV profiles.<br>• Odd roof arrangements and physical obstacles of non-domestic rooftops might limit PV installation capacities. |
| **OPPORTUNITIES** | **THREATS** |
| • Large untapped energy potential represented by car parks (with integrated EV charging and batteries) and school roofs.<br>• Can create alternative revenue streams for LA to promote inclusive growth or further energy investment.<br>• Can promote the take-up of EVs with car parks PV installations.<br>• Opportunity to develop local expertise and engineering resources.<br>• Demonstrable visual driver to show decarbonisation is being taken seriously<br>• Can be used to provide cheap energy to consumers through PPA arrangements | • Might require specific expertise in the local authority resources or partnering with more capable private companies.<br>• Relatively long payback periods might put off private investment contributions.<br>• Supply chain could reduce significantly following FiT unless market uptake is maintained |

## 5.3 Solar farms

Solar farms primarily comprise large-scale, ground mounted installations, usually connected to the grid for the sale of PV electricity in the wholesale market or through private PPAs. As a result, they require large extensions of lands.

*Primarily large scale ground mounted solar, e.g. Riding Sunbeams and solar landfill sites*

| STRENGTHS | WEAKNESSES |
|---|---|
| • Solar farm businesses are sometimes owned by community schemes, benefitting the local community and promoting inclusive growth. | • The feasibility of solar farm installations is limited by the available distribution network capacity. |

| | |
|---|---|
| • Solar farms are relatively large-scale and therefore their significantly large energy output can be traded through PPAs, minimising the investment risk.<br>• Solar farms can benefit from economies of scale and represent more viable business cases.<br>• Recent technological advances in solar PV designs can overcome stability issues of uneven land.<br>• Established models for deployment<br>• Can often be deployed on low value land | • There is currently no incentive from the central government for DNOs to increase connection capacity/ points. (https://doi.org/10.1016/j.renene.2018.08.109.)<br>• Visual impact may be of concern to nearby residents<br>• Lack of subsides means revenue schemes need to be carefully considered |
| **OPPORTUNITIES** | **THREATS** |
| • Possibility to exploit a large number of former landfill sites with no other productivity potential, unfit for other economic activities and characterised by existing grid connections.<br>• High concentration of Network Rail load hotspots (traction and non-traction electricity demand) that can be directly connected to the solar farms, bypassing the grid.<br>• Significant job creation potential.<br>• PPA agreements with large consumers can reduce energy costs and decarbonise whilst providing long term revenue<br>• Revenue stacking potential to support business case<br>• Coupled with storage can provide multiple energy services and mitigate network reinforcement | • Risk of congesting the local distribution network if solar farms are connected to the grid and not to significantly large load hotspots.<br>• Natural obstacles can pose major structural risks to solar farm installations and cause project delays and costs increases.<br>• Public resistance due to visual impact<br>• Short term revenue contracts for flexibility services may diminish |

## 5.4 Solar thermal

Solar thermal in the UK has lagged behind PV since the FiT was introduced but as the focus shifts to decarbonisation of heat it is seen to potentially have an important role to play.

| STRENGTHS | WEAKNESSES |
|---|---|
| • Heat decarbonisation solution which would not put additional stress to the grid network and does not depend on the presence of infrastructure.<br>• Can establish great synergies with domestic and commercial heating systems with existing water storage (more likely to be older boiler systems) and with district heating projects.<br>• Can be combined on the same collector with solar PV technology to harness the wasted solar resource, although at an additional capital cost.<br>• Useful solar thermal energy densities are higher than useful solar PV energy densities (350-600 kWhth $m^{-2}$ vs. 230 – 140 kWhe $m^{-2}$ in Greater Brighton)<br>• Benefits from the most generous domestic RHI tariff (extended until 2021), helping to reduce payback periods.<br>• Market model is simple, consumer saves energy. Not associated with multiple metering or tariffs. | • Solar thermal collectors performance is greatly dependent on the outside ambient temperature, the heat transfer fluid inlet temperature and the minimisation of heat loss to the environment, requiring specific design work and control strategies (https://doi.org/10.1016/j.solener.2018.01.013).<br>• Most common thermal collector designs are of the glazed flat type, the most inefficient type.<br>• Requires a hot water tank<br>• Not a familiar technology to many in the UK<br>• Payback is often over very long period of many years<br>• No market incentive to bulk deliver due to lack of revenue streams e,g, through PPA or roof rent. |
| **OPPORTUNITIES** | **THREATS** |
| • Great integration potential with cooling technologies (absorption chillers) particularly in commercial applications. | • Less established supply chain and in particular installer base than solar PV. |

| | |
|---|---|
| • Heat decarbonisation can be achieved without increasing peak electrical demand, which could be the case with electrification solutions.<br>• Opportunity for proving its decarbonisation potential, given that it is much less visible than solar PVs in the UK.<br>• Make people aware of RHI | • More complicated installed system and more capital intensive projects with respect to solar PVs might put off investors and project owners.<br>• Unclear subsidy system after RHI |

## 5.5 Solar carports

Solar carports are a relatively new business model disrupting the UK solar PV market only in 2015, with the first two 150 kW installations built on top of multi-story car parks in Exeter. The system integrates a PV-equipped roof with traditional parking canopies, with additional battery storage in some instances. Given the strategic location of these structures in public parking locations, projects have started including the procurement of a number of EV charge points in the parking spaces, supporting the transition of the mobility industry to electrification.

| STRENGTHS | WEAKNESSES |
|---|---|
| • Synergistic integration of established (solar PV) and emerging (battery storage and EV charging) technologies.<br>• Supports EV uptake in the area.<br>• Additional revenue potential for project owners (whether private or public)<br>• Modular designs of this product already available.<br>• Visual appeal and enhanced service offering of the carpark.<br>• Ideal PV arrangement in sites where roof space is restricted.<br>• Can offer lower cost energy to consumers | • Lower ROI than other PV project types?<br>• Relatively low commercial maturity of battery storage, particularly in the EV context.<br>• Requires new commercial models and digital platforms to retail<br>• Current EV uptake may not support investment |
| **OPPORTUNITIES** | **THREATS** |
| • Opportunity to reinforce a relatively unknown business model (tested already in the UK) and make it more visible.<br>• Possibility to provide building and mobility carbon reduction savings simultaneously.<br>• EV grid frequency response demonstration opportunity.<br>• Could accelerate EV uptake if done as part of a mobilisation strategy | • Threat of unjustified investment for commercial estates with respect to other estate refurbishments??<br>• Low maturity level of current EV market.<br>• Benefits might not be reaped immediately as a result of the slow EV uptake.<br>• Technical challenge of specific PV application.<br>• Mobility models may change in the future leaving stranded assets |

## 5.6 Priorities and Recommendations for increasing uptake

Combined purchasing power of Local Authorities is seen as key to bring down cost for solar power and replace some of the shortfall seen due to the removal of the FiT. A Greater Brighton Energy Investment Bank is seen as another key mechanism, this could take forward projects which are economically viable but would not stand up to the rates of return required by traditional private investment. Multiple projects which are directly replicable would be suited to an Energy Investment Company approach, such as solar schools and PV car parks. In the case of the former this is seen as an immediate priority, which through Local Authorities and One Public Estate Greater Brighton is well placed to accelerate. Even without an Energy Investment Company these bodies could help bring projects to community energy groups (by creating a day event for head teachers and school governors, for example). The trust, expertise and existing supply chain links of community energy groups are seen as key, certainly in the near-term, for enabling increased solar development in Greater Brighton.

**Projects identified across the Greater Brighton region indicate in the order of 300 MW of additional installed PV capacity is seen as tenable. This should focus on onsite utilisation and will be of particular use, from a carbon perspective, when coupled with heat and transport technologies.**

# 6 Case studies

This section presents two case studies for the application of solar technology. The first is for coupling solar PV and electric vehicle charging in a large commuter car park, examining optimal sizing and payback rates. The second details a world leading project - feeding community owned solar directly into the rail network to provide power for tractions, for which there are several sites in Greater Brighton identified. Both case studies examine linking solar power directly with other low carbon technology (in these instances both being transport based). This is significant in achieving maximum benefit from solar power in the UK. Due to cuts in support mechanisms making selling directly to the grid less economically attractive. Also, from a carbon perspective the UK electricity is seeing significant decarbonisation as a result of large scale centralised renewable generation (such as offshore wind), making heat and transport more important targets than feeding low carbon solar power into the national grid.

## 6.1 Haywards Heath train station – solar car parks

This section examines a solar car park/EV charging hub in the context of a busy commuter train station. It assesses stand alone PV and battery integration, and different tariff rates; arriving at some initial optimal savings and payback rates (a detailed feasibility study is required for full assessment).

### 6.1.1 Introduction

The Action Plan provided by the three LEPs identifies car parks as ideal locations for renewable energy generation projects. They provide a great opportunity for the innovative integration of solar PV in the form of solar carports, battery storage and electric vehicle charge-points. In this way, the electric mobility transition can be supported with clean energy generated in a decentralised fashion and through a highly visible carbon reduction initiative. The financial viability of this project is now explored through a pre-feasibility study of a solar carport in the Haywards Heath Station Car Park. As observed in Figure 6—1, there is extensive roof space available on the train station (~1200 $m^2$) and the possibility to cover the top floor of the new multi-storey car park (~5600 $m^2$) with a solar carport, which justify investment in a PV rooftop installation.

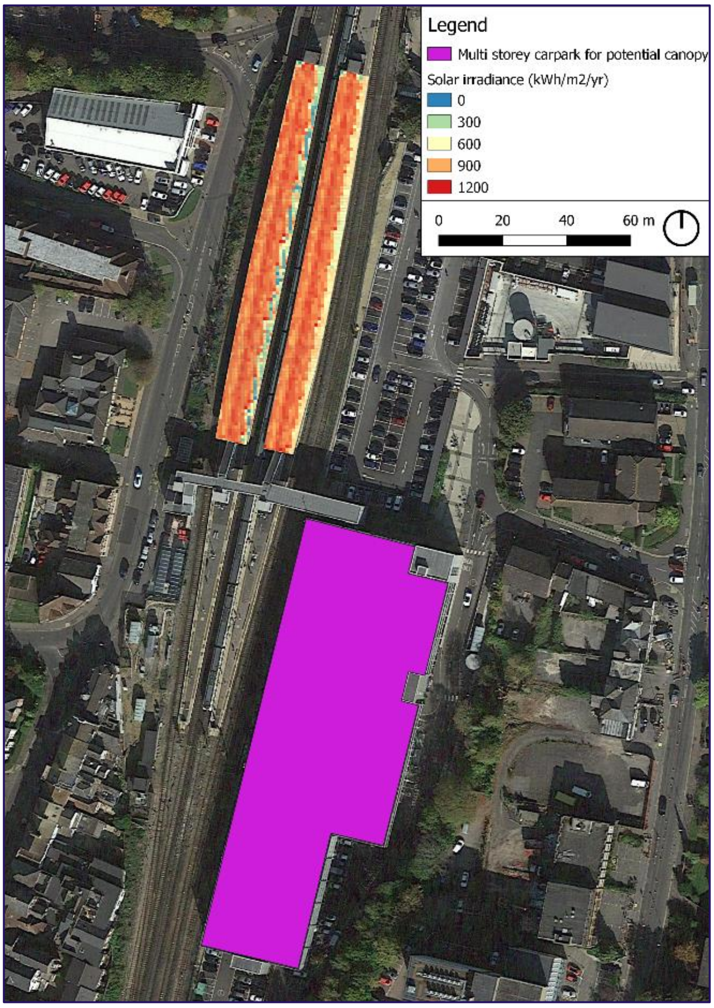


**Figure 6—1 Map of Haywards Heath train station car park and rooftop solar modelling for the train station.**

This is assessed in a near-future (2025) context of significant EV uptake trends, dictated by the UK government's objective of 50 to 70% EV share of new car sales by 2030 (Department of Transport, 2018). This justifies the installation of dedicated charge-points in part of the car park's parking spaces. Centralised battery storage is also considered for the energy management of the intermittent generation of PV electricity and the maximisation of its value for EV charging demands. An extent of energy arbitrage is also assumed, mainly to provide cheap electricity for EV charging when the generation of the PV modules is not sufficient.

### 6.1.2 Project Details and Assumptions

Given the uncertainty regarding future EV charging demands and the potential revenues available to commercial batteries as a result of regulatory uncertainty in the market of behind-the-meter installations, very general assumptions are made to produce a simplified techno-economic model of the solar carport energy system, which however is still able to provide useful insights into its economic performance.

The daily parking availability throughout the week is obtained from data gathered by the car park operator Saba (Saba Parking, 2019). An example of the average hourly trend on Tuesdays is shown in Figure 6—2. During the week, the data shows that the car park essentially fills up by 8-9 am there are virtually no free parking spaces until 4-5 pm.

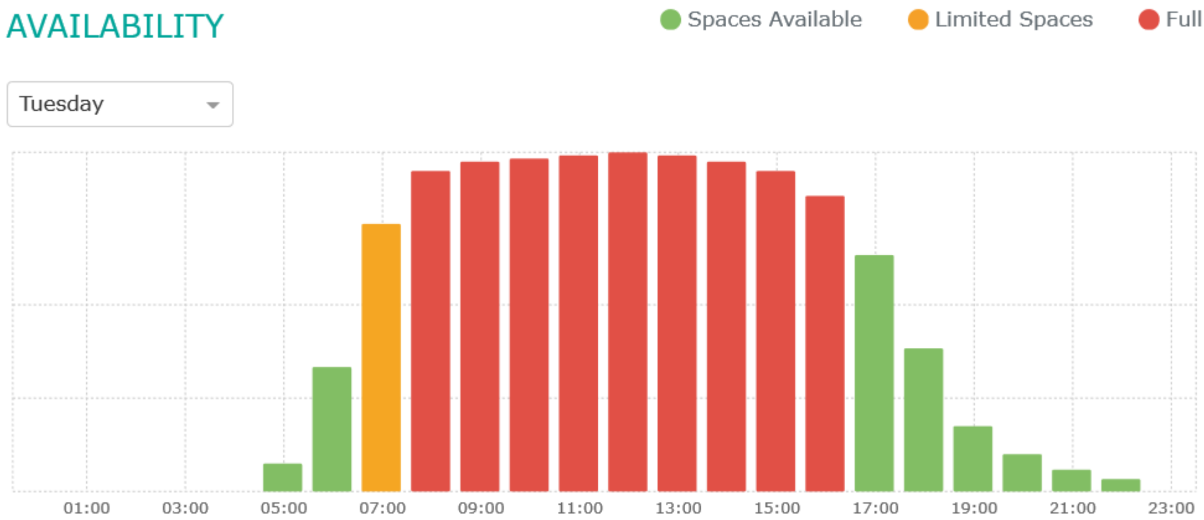


**Figure 6—2 Hourly parking availability on Tuesdays in the Haywards Heath Station Car Park** (Saba Parking, 2019)

On Fridays, Saturdays and Sundays the trend shown in Figure 6—2 is gradually less prominent, with more than 80% of spaces available throughout the day on Sundays. Two major utilisation patterns of the car park are noticeable:

1. The majority of the car park customers park for a good proportion of the day and take the train to a distant location, most probably in the London area where the congestion zone charge and limited parking space would not encourage them to drive there.
2. A proportion of the spaces are leased to local businesses. These would be similarly occupied by one vehicle for the majority of the day.

Since most of the customers remain parked for the majority of the working day (9 -17 h), it can be largely assumed that in the case that a parking space is occupied in a given day, the vehicle remains parked for the rest of the day. The average occupancy factor throughout each day of the week is then taken from the maximum occupancy peak observed in the monitoring data. This results in the average number of parked cars shown in Table 6—1.

**Table 6—1 Average number of parked cars in the Haywards Heath Station Car Park by day of the week**

| | **Monday to Thursday** | **Friday** | **Saturday** | **Sunday** |
|---|---|---|---|---|
| **Average number of parked cars** | 826 | 628 | 231 | 83 |

Table 6—2 below summarises the major assumptions regarding the formulation of the techno-economic model, subdivided by the part of the system to which they refer: the EV charging infrastructure, the solar PV modules or the centralised battery storage.

**Table 6—2 Details of key assumptions used in modelling**

| **Detail** | **Assumption** | **Justification** |
|---|---|---|
| | | **EVs charging** |
| **EV average daily mileage** | 36 km | The Department of Transport uses a corresponding average annual mileage of 13,200 km for EV policy design (Dodson & Slater, 2019) |
| **EV charge points allocation (2025)** | 20% of total parking spaces | In the most recent EV charging policy consultation, the UK government has proposed to allocate one in five parking spaces to be converted into an EV chargepoint by 2025 (Department of Transport, 2019). |

| | | |
|---|---|---|
| **EV average charge** | 4 kWh | It is assumed the average EV user would have charged up their vehicle overnight. Therefore, when he/she parks in the car park, the EV battery has been discharged for half of the average daily vehicle commute (18-20 km), which corresponds to 4 kWh. |
| **EV chargepoint type & cost** | Fast charger (7 kW) - £2,000 – £2,500 | This type of charging power is suitable for the relatively long stays of the customers. The EV average charge can be provided in a little more than half an hour. |
| **Solar PV** | | |
| **Average summer / winter capacity factor** | 18.4% / 6.54% | These values are specifically produced for the Haywards Heath location through simulations of the hourly power output of comparable solar PV installations (10% system losses) from renewables.ninja.com |
| **PV module power density** | 0.15 kWp/m$^2$ | (Lazard, 2019a) |
| **Solar carport CAPEX** | 1400 £/kW | https://www.energymanagermagazine.co.uk/nottingham-taking-the-lead-in-solar-carports/ |
| **Solar carport OPEX** | 16 £/kW-yr | (Tjengdrawira, Richter, & Theologitis, 2016) |
| **PV lifetime** | 25 years | (Lazard, 2019a) |
| **Centralised battery storage** | | |
| **Battery CAPEX** | 350 £/kWh | (Lazard, 2019b) – also taking into account 2025 battery pack cost reductions predicted by (Curry, 2017). |
| **Battery OPEX** | 11 £/kWh | (Lazard, 2019b) |
| **Battery lifetime** | 20 years | (Lazard, 2019b) |
| **Round trip efficiency** | 90% | (Mariaud, Acha, Ekins-Daukes, Shah, & Markides, 2017) |
| **Min/ max SOC** | 15%/ 90% | (Mariaud et al., 2017) |

The techno-economic analysis assumes electricity balances on a daily timeframe, with a differentiation between the summer and winter PV production loads. The entire daily PV electricity production is assumed to be available for EV charging regardless of the hourly resolution of the supply and demand trends because EV loads are deferrable, given the relatively long parking time of the vehicles as described earlier. In this way, solar PV utilisation can be maximised through an assumed smart charging protocol of the charge-points. The daily EV charging demands are derived with the following equation:

$$\begin{aligned} &Daily\ EV\ charging\ demand \\ &\quad = EV\ average\ charge\ \times EV\ chargepoint\ share\ of\ parking\ spaces\ \times daily\ number\ of\ parked\ cars \end{aligned}$$

This corresponds to an average charge point utilisation of one car per day when the car park is full, which could be considered a conservative assumption. A 1.05 factor is applied to the winter EV loads as the performance of the batteries worsens in colder temperatures.

### 6.1.3 Business Model & Revenue Streams

Two business models based on the solar carport infrastructure with and without centralised battery storage are analysed. The principal revenue stream of solar carports is understandably the sale of electricity to the parked EV users. Even though several businesses with public car parks, such as supermarkets currently offer free fast charging. This is based on the need to attract/support early EV adopters. In 2025, this is unlikely to be viable/necessary and therefore a charge per kWh purchased is assumed, with no connection charge. A low and a high price, both in the range between standard home charging tariffs and rapid charging tariffs are assumed for the analysis. A potential business model would entail the establishment of EV clubs, which enable discounted or exclusive use of EVCPs through a monthly or yearly membership subscription. This could be a possibility if EV customer charging trends for the specific site lead to a reasonable average cost per kWh of EV charging.

In the absence of battery storage, any daily excess of solar PV is sold instantaneously to the grid through the Smart Export Guarantee (SEG) at a particularly low tariff given the off-peak timing (current estimates are at £0.04 – £0.05 per kWh). On the other hand, if the daily EV demand is greater than the daily PV production, electricity is purchased at a standard midday tariff price to be used instantaneously for the EV charging demand. With centralised battery storage, the sale of excess PV electricity and the purchase of grid electricity can be time-shifted in order to obtain the most convenient rates, which correspond respectively to the peak evening period (16:30 to 18:30) and the overnight off-peak period (00:30 to 4:30). In order to maximise the revenue potential of the battery, it is assumed that every night it is charged to its maximum SOC, allowing for capacity of excess PV generation the next day. This is then discharged to its minimum SOC through EV demand balance and the sale of remaining capacity at peak time either to a third party through a PPA or to the grid, assuming greater access for behind-the-meter small-scale storage in 2025. Energy arbitrage strategies are dependent on the real-time grid electricity price predictions, unique to each different day. For the purpose of this simplified case study, constant average tariffs are assumed for the relevant periods of the day and the same strategy of selling all surplus electricity after balancing all EV loads is then proposed.

As the focus of the case study is the maximisation of the value of the solar resource in car park locations, the centralised battery is sized according to this objective and therefore the energy arbitrage service is secondary:

- For relatively small PV installations that mostly require the import of grid electricity to satisfy the EV loads, particularly in winter as a result of the reduced solar resource, the battery is sized to provide this deficit from cheap overnight grid electricity.
- For larger PV installations that mostly balance the EV loads with the locally produced electricity, the battery is sized to store this excess and sell it during the peak system time.

Historic data of Octopus Energy agile tariff are used as a reference for the determination of the peak sale and overnight purchase electricity tariffs. A high and low value is assumed for each, in order to understand the effect of the spread of these tariffs on the financial viability of the solar PV and battery storage business case. All the electricity tariff rates are indicated in Table 6—3.

**Table 6—3 Average summer and winter electricity tariff rates used for the techno-economic model** (Octopus Energy, 2019; pod Point, 2019)

| Electricity tariffs | Range | Average summer rate (£ per kWh) | Average winter rate (£ per kWh) |
|---|---|---|---|
| EV charging | Low | 0.14 | 0.14 |
| | High | 0.18 | 0.18 |
| PV day (8 -16 h) sale | Standard | 0.04 | 0.04 |
| Day (8 -16 h) purchase | Standard | 0.13 | 0.14 |

| | | | |
|---|---|---|---|
| Peak (16:30 – 18:30) sale | Low | 0.12 | 0.13 |
| | High | 0.16 | 0.18 |
| Overnight (00:30 – 4:30) purchase | Low | 0.08 | 0.08 |
| | High | 0.10 | 0.10 |

### 6.1.4 Financial Viability

Figure 6—3, Figure 6—4 and Figure 6—5 illustrate the annual cashflows (including annualised capital costs) resulting from investments in a PV-only solar carport and a solar carport coupled with centralised battery storage for the different ranges of PV deployment in the car park. Project payback periods to recoup the capital investments are also indicated, assuming the annual cashflow for this specific year of activity remains constant throughout the project lifetime. The investment necessary for the installation of fast chargers in 20% of the parking spaces (between £330,000 and £420,000) is omitted from the cashflow calculation as it is assumed it is covered by the infrastructure group or government's Charging Infrastructure Investment Fund.

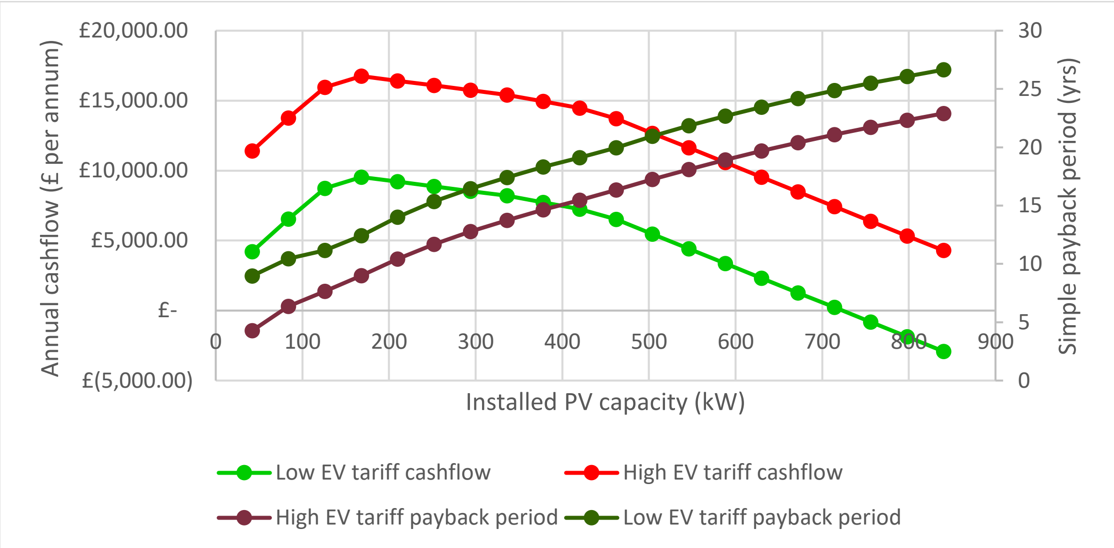


**Figure 6—3 Annual cashflow and payback period comparison of PV-only solar carport systems at different installed capacities.**

Figure 6—3 illustrates the trade-off between the size of the PV solar carport system and the financial viability of such project. At both low and high EV tariff charged, maximum cashflows between £9,700 and £16,900 are reached at installed capacities of 149 kWp in both scenarios. Past this solar PV capacity it is less cost-effective to balance residual EV loads with additional PV capacity than purchasing the required demand directly from the grid at the midday tariff assumed. The additional investment required does not justify the additional revenue from the EV charging sales. In addition, during the days with lower EV demand, any surplus PV electricity is exported at the SEG tariff, which has relatively low value. At the optimal PV size of 149 kW, the investments require relatively long payback periods between 8.3 and 11.6 years, attesting to the capital-intensive nature of the investment.

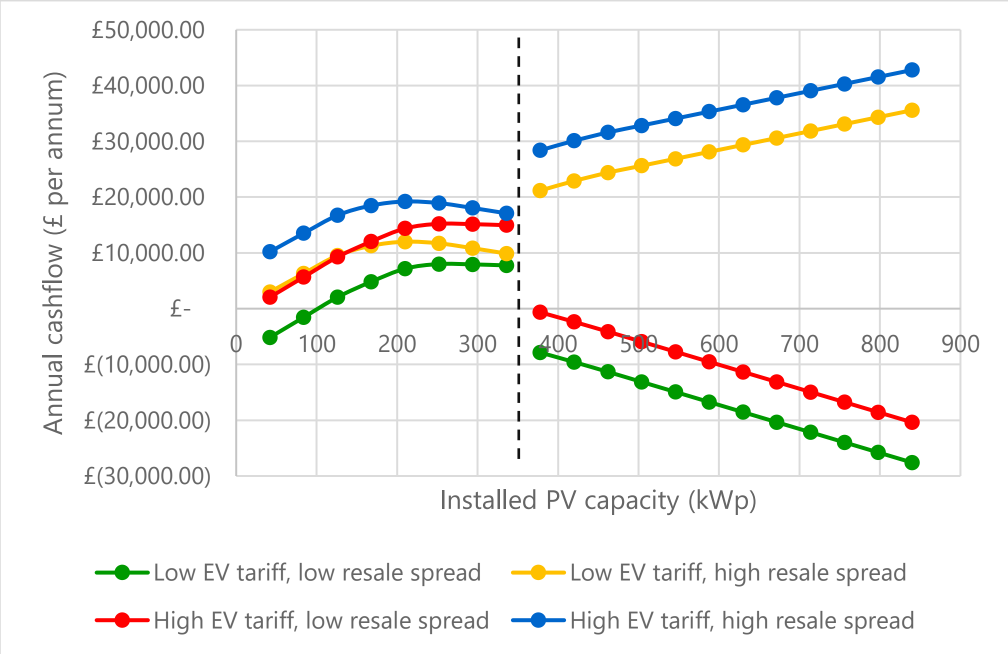


**Figure 6—4 Annual cashflow of solar carport system with centralised battery storage at different installed PV capacities**

For the cashflow and payback analysis of the PV-battery hybrid system in Figure 6—4 and Figure 6—5 respectively, four different tariff scenarios are presented using the tariff data from Table 6—3:

1. Low EV tariff, low resale spread – a low EV charging tariff is applied, along with an unfavourable electricity resale spread as it is assumed overnight electricity is purchased at an average high rate and surplus electricity is sold at an average low rate. Given these unfavourable revenue characteristics, the project payback periods are extremely long (mostly over 20 years) and the annual cashflow is positive only for solar PV systems that need a relatively small capacity battery system to balance the energy deficit for the required EV demand. When compared to the project economics of the PV-only carport, the hybrid battery-PV carport performs poorly and the investment in a battery system is not justified.
2. High EV tariff, low resale spread – this scenario differs from the previous one only in the EV tariff charged, which is in the high range. Despite this, the annual cashflow and payback period trends are similar to those of the prior EV tariff scenario; the main difference is that the payback period is reduced significantly for each solar PV size given the additional inflow of EV charging revenue. However, this scenario still performs worse than the corresponding PV-only, high EV tariff scenario.
3. Low EV tariff, high resale spread – the high resale spread reflects a low overnight electricity purchase rate and a high peak sale rate, hypothetically achieved with a more effective energy arbitrage strategy. This increases massively the annual cashflow values in Figure 6—4, outperforming the solar-only carport systems. Payback periods of all hybrid systems are also reduced below 18 years.
4. High EV tariff, high resale spread – this scenario is identical to the previous one, the only difference being that high EV tariffs are charged, therefore securing a higher total revenue. As a result, project payback periods are additionally reduced and annual cashflows receive a boost.

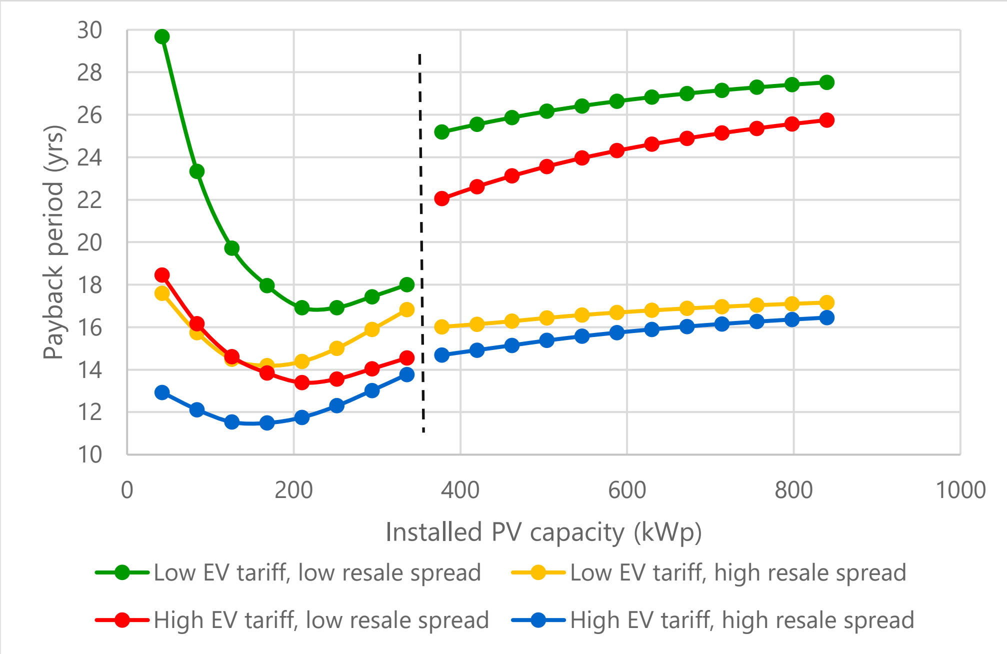


**Figure 6—5 Payback period solar carport system with centralised battery storage at different installed PV capacities.**

### 6.1.5 Scalability

The financial viability analysis demonstrates that the additional revenue that a battery system can potentially attract with successful energy arbitrage measures in a PV-battery hybrid solar carport system is able to make the additional investment worthwhile. The main drawback is that high electricity tariff spreads would most likely come with high risk profiles. In the scenarios where grid electricity arbitrage does not bring about significant revenue, it is mostly the case that investment into a battery system is not rapidly recouped solely based on the additional revenue from the arbitrage of the electricity produced from the solar carport. In conclusion, at the predicted 20% EV market share in 2025, solar carport projects represent an attractive decarbonisation initiative with the potential to bring value to an extensive commuter base; however, centralised storage implementation should be accurately assessed and additional arbitrage or demand-side management revenue opportunities should be explored. To this end, the future value stream of distribution network referral that batteries can bring about could play a role.

There are multiple locations which could incorporate similar strategies to Haywards Heath, some examples being Lewes, Worthing, Three Bridges and Burgess Hill. Although the scale of projects will vary the same principles apply. The sites suggested are for train stations, but the findings are analogous to other car park applications, so long as there are not resource issues due to factors like shading.

## 6.2 Riding Sunbeams

Riding Sunbeams is a company which is developing solar farms to feed directly into the rail traction system. This section explores the technical detail behind the project, business models and projects in Greater Brighton.

### 6.2.1 Introduction

The Tri-LEP Action Plan identifies solar PV installations for Network Rail, a major regional energy consumer, as a key renewable energy generation project model. With the heavily congested Sussex and Wessex dc rail network routes, the Greater Brighton region provides unique integration opportunities for solar farms, due to relatively high solar irradiance levels compared to the rest of the UK and highly congested electricity distribution networks. Following a high level audit of land use constraints from Community Energy South around the electrified rail infrastructure in the Southern Region area, around three quarters of the traction power substations should be able to accommodate an intermittent supply of around 1MWp solar array in lineside developments (South East Local Enterprise Partnerships, Coast to Capital, & Enterprise M3, n.d.). As a result, the local distribution networks would not bear any of the extra renewable energy generation capacity, while Network Rail would be able to source increasing proportions of electricity from renewable sources at a competitive price, to feed directly into the third rail for traction power.

### 6.2.2 Technical Details

The social enterprise Riding Sunbeams is a joint venture between the charity 10:10 Climate Action and the organisation Community Energy South that has made significant progress into delivering these types of projects. In 2017, they carried out a technical feasibility study along with researchers from Energy Futures Lab at Imperial College London and electrical engineering specialists Turbo Power Systems to assess if solar PV integration into third rail direct current is commercially viable. Following consultations with Network Rail engineers to refine the technical solution, the main outcomes are the following:

- The connection of solar PV arrays can be economically established through the conventional AC feeder systems that carry grid electricity to the substations, by using conventional DC-to-AC converters and ancillaries (Murray & Pendered, 2019).
- One of the major technical challenges is balancing the intermittency of both solar PV generation and the trains' traction power demand. However, since each grid supply point (GSP) supplies around ten to fifteen substations at an average 2-8 km apart, the DC traction power supplied by the hypothetical solar array would be shared across all of these and consequently all the electrified trains through the route, reducing significantly the intermittency component at the supply end (Murray & Pendered, 2019). This connection setup would prevent additional investment into storage assets, which could compromise the financial viability of the project given its low competitiveness in a strictly energy management model.
- The connection setup does not cause operational risks around possible dc voltage range exceedances on the tracks nor power quality issues on the DC supplies (Murray & Pendered, 2019).

### 6.2.3 Business model

The Riding Sunbeams consortium started thinking about this disruptive project model when developing a community owned solar farm in Balcombe, Sussex which unfortunately could not be connected to the distribution network without an expensive upgrade. In the absence of any other potential purchasers, they approached National Rail, which have explicitly targeted direct supply of renewable traction power as a priority for Control Period 6 (2019-2024) (Murray & Bottrell, 2017). Community-owned solar PV purchased through a "private wire" PPA remains the most viable business model. Table 6—4 illustrates some key financial indicators of this type of business model, based on actual cost data from the current project pipeline and estimated price and volumes of energy purchased from Riding Sunbeams' progress reports. These show potential advantages over the current business-as-usual National Rail grid power contracts:

- Solar arrays above a minimum peak power capacity of 1MWp would be able to offer unsubsidized LCOE prices competitive with the current grid electricity costs paid by National Rail, as observed in Table 6—4. Future cost trends demonstrate that this gap is expected to widen in the future. In addition, the significant array size would justify the capital raising process necessary for fixed development and connection costs of the project (Murray & Bottrell, 2017).
- Traction power makes up around 10% of the National Rail operational costs and therefore pursuing these "green" energy PPAs would help them reduce rail operating costs and carbon emissions, as their electricity traction costs would effectively be frozen in the long-term (Murray & Bottrell, 2017).
- Even though profit margins for this community-owned solar traction farm portfolio are relatively modest (see Table 6—4), they are sufficient to underwrite crowdfunded investment, and to generate surplus for community benefit funds (Murray & Pendered, 2019). This could in turn be used for further renewable energy or energy efficiency projects, feeding into a sustainable cycle.

**Table 6—4 Key financial indicators of community-owned, utility-scale solar PV projects with a "private wire" PPA in place with National Rail (Assumptions: capacity factor of 12-14%, 55 – 85% of annual PV production sold through the PPA to NR at competitive per-kWh-prices, remaining is sold to third parties or grid through SEG scheme at reduced per-kWh-price)** (Lazard, 2019; Murray & Bottrell, 2017; Murray & Pendered, 2019)

| Grid electricity LCOE (£ $kWh^{-1}$) | Utility-scale solar PV LCOE (£ $kWh^{-1}$) | Utility-scale solar PV CAPEX (£ $kWp^{-1}$) | Utility-scale solar PV OPEX (£ $kWp^{-1}$ $yr^{-1}$) | Profit margin (£ $kWp^{-1}$ $yr^{-1}$) | Simple payback period (yrs) |
|---|---|---|---|---|---|
| 0.070 – 0.090 | 0.050 – 0.116 | £1,000 - £1,200 | £9 - £13 | £5 - £55 | 10 - 30 |

Riding Sunbeams's intentions are to exploit the social involvement component of this business development model even further, by inviting commuters and railway workers to get actively involved with lineside communities in these crowdfunding-style projects.

### 6.2.4 Project Pipeline

From Riding Sunbeams feasibility study and the prior business case considerations, the project model is feasible from the technical point of view and viable from the commercial point of view. At the beginning of 2018, Riding Sunbeams identified the first solar traction farm project opportunities in the south of England by engaging with established community energy groups and National Rail and submitted a portfolio bid to the government's Rural Community Energy Fund. Having won it, they could fund full, site-specific feasibility studies for six pilot projects, of which three are in the Greater Brighton region (Murray & Pendered, 2019). The relevant project details are indicated in Table 6—5.

**Table 6—5 Pilot solar traction farm projects in the Greater Brighton region** (Murray & Pendered, 2019)**. The bracketed solar array and capital investment required values are from questionnaire feedback rather than the Riding Sunbeams Before Dawn report.**

| Project location | Solar array size (MW) | Capital Investment required (£ million) | Funding community energy group | Predicted carbon savings (tonnes $CO_2$ $yr^{-1}$) |
|---|---|---|---|---|
| Balcombe | 11 (10) | N/A (£10) | Repower Balcombe | 3214 |
| Hassocks | 3.8 (1) | N/A (£1) | HKD Energy | 321 |
| Brighton and Hove | 3.6 | N/A | Brighton and Hove Energy Services Coop | 1157 |

The locations of the three Greater Brighton Riding Sunbeams projects are displayed below in Figure 6—6.

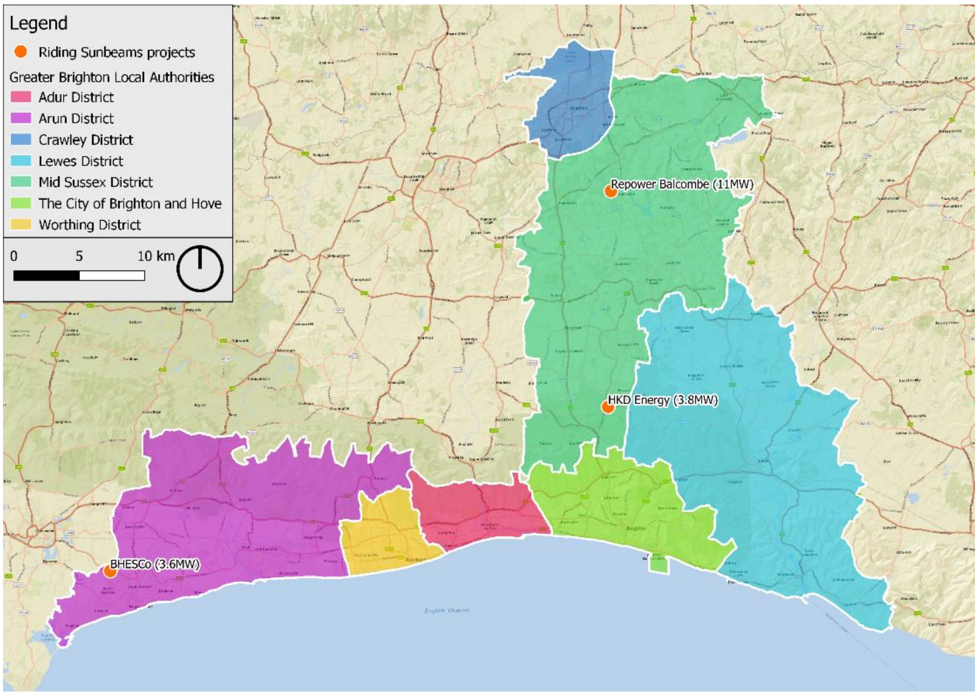


**Figure 6—6 Riding Sunbeams projects in Greater Brighton.**

Before progressing with the six full-scale projects, a demonstrator trial is being implemented since August 2019 along the railway line between London and Weymouth, at the Aldershot substation. With funding from the Department for Transport and Innovate UK, 135 solar PV panels with a total peak power capacity of 37 kWp were designed, installed and connected to the substation to an ancillary transformer on the traction system to supply power to lights and signalling equipment (Wordsworth, 2019). By monitoring demand loads, generation capacity and the quality of supply, the modelling and commercial delivery models used in the feasibility studies will be validated and tested for the much larger volumes of solar power planned for the pilot solar farms. At the current progress, the first community solar traction farms could connect to UK railways in 2020 (Murray & Pendered, 2019).

### 6.2.5 Scalability

According to the South East Local Enterprise Partnerships, Network Rail are the single biggest unregulated consumer of electricity in the UK, procuring around 3.2TWh per year . They have detailed in their corporate strategy ambitions to source increasing proportions of their traction and non-traction power demand from renewable energy sources and they can do so at competitive prices from these community-owned solar projects. Deployment at scale could plausibly shave around 4% off the Southern Region’s traction electricity bill - and 13% off the associated carbon emissions (Murray & Pendered, 2019). For community energy groups in the Greater Brighton region, this represents an attractive market between £0.6m and £2m per year, which corresponds to roughly 0.8 - 2% of the Southern Region’s total traction electricity demand. Once the first solar traction farms pipeline is delivered within the next five years and their financial viability demonstrated on a full-scale, the successive phase rollout will benefit from economies of scale and a greater understanding of the technical requirements of renewable energy grid connection to the third rail for traction power.

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