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RENEWABLE ENERGY SOLUTIONS FOR BUILDING SERVICES

BUILT ENVIRONMENT SERVICES

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Abbreviations

I.	University of Wales Trinity Saint David: UWTSD
II.	Carbon Dioxide: CO₂
III.	United Kingdom: UK
IV.	Limited Company: LTD
V.	Photovoltaic: PV
VI.	Feed in Tariff: FiT
VII.	Standard Assessment Procedure: SAP
VIII.	Computer-aided Design: CAD
IX.	Alternating Current: AC
X.	Direct Current: DC
XI.	Building Research Establishment: BRE
XII.	Construction Industry Training Board: CITB
XIII.	Construction (Design & Management): CDM
XIV.	Building Research Establishment Environmental Assessment Method: BREEAM
XV.	Microgeneration Certification Scheme: MCS
XVI.	Return on Investment: ROI
XVII.	Health & Safety Executive: HSE
XVIII.	Low Carbon Commitment Implementation Plan: LCCIP



1.0 Introduction

Several renewable energy technologies can be successfully integrated into buildings and developments if they are considered in the early stages of the planning and design process.

1.0.1 Rationale

An open tender has been produced by the University of Wales Trinity Saint David (UWTSD) for renewable energy technology contractors to implement their technology into UWTSD's phase 2 development. A clear budget has also been defined by the university. Project Manager of the UWTSD SA1 development Mike Bessell said:

“The University continues to be committed to not only creating exemplar quality teaching and learning facilities, but also to ensuring the project contributes positively to environment and economic sustainability. The use of green technologies within the buildings reinforce this commitment, with the installation of the solar panels already complete.”

Phase 2 of the project includes the development of a single storey structure, 100m x 60m in perimeter with a total floor area of 6,000 m² which includes a swimming pool and gymnasium. The complex will operate from 7am to 10pm, 6 days a week and will see peak usage periods during term times when students are on campus.

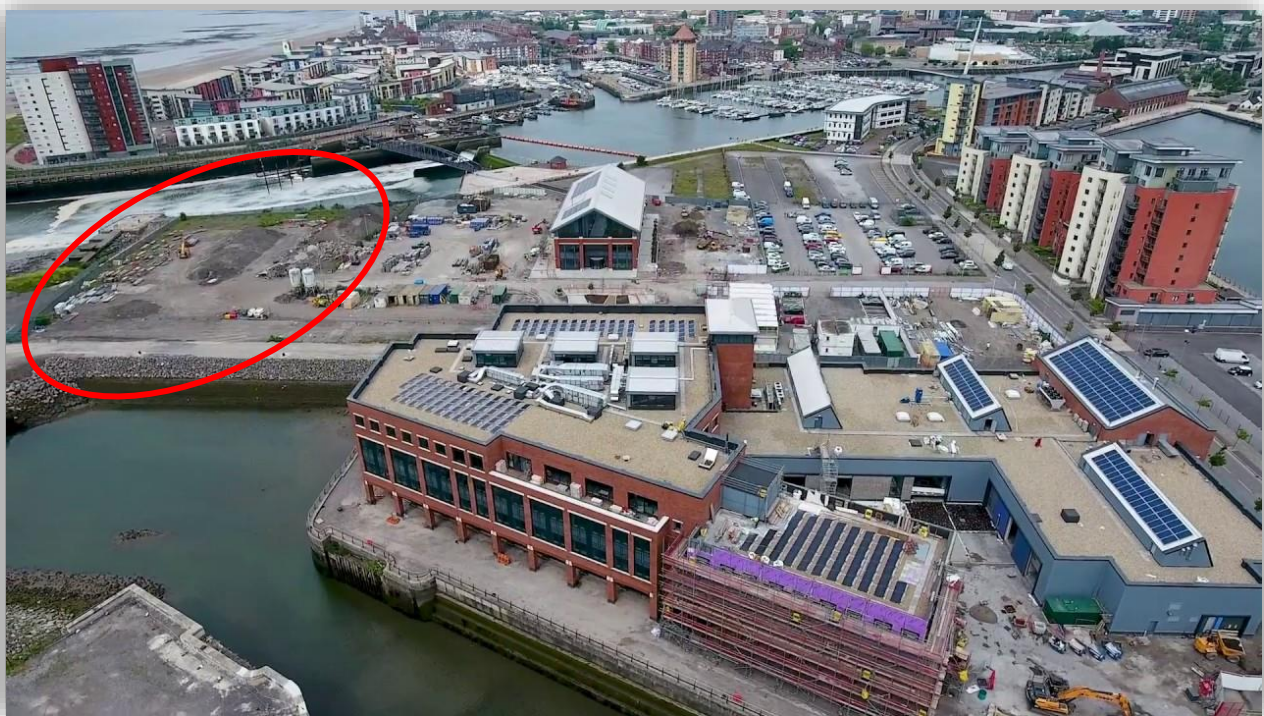


Figure 2: Proposed building plot (Solar Panels Swansea, 2018).

1.0.2 Contextual

The [Climate Change Act 2008](#) presents a target that at least a 34% decrease in greenhouse gas emissions should be achieved by 2020, and at least an 80% decrease by 2050 against the 1990 baseline. *“The UK’s sports sector buildings spend £700 million on energy every year, resulting in annual emissions of 10 million tonnes of CO₂. Sports facilities, such as swimming pools, can have high associated energy costs.”* (**Energy use in sports and recreation buildings, 2001**)



The introduction of energy-saving measures such as renewable technologies can therefore be very rewarding, both financially and in terms of user value.

1.0.3 Project Considerations

The main parameters that should be assessed by the client when selecting a successful tender for a renewable energy source for structure integration are presented below:

- Price,
- Building energy consumption,
- Payback time,
- Contractors relevant experience & understanding of the requirements,
- Resource availability,
- Proposed methodology (mobilisation plans, design proposals)
- Compliance with the regulations set out in the invitation to tender,
- Integration into design,
- Government incentives,
- Ease of maintenance and costs associated.

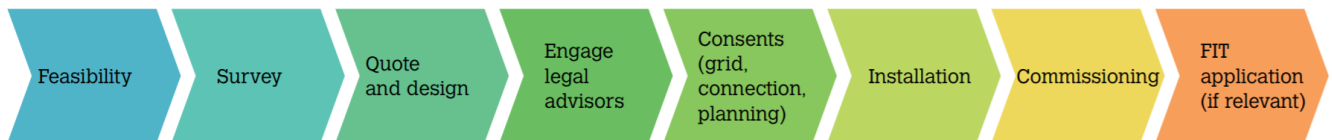


Figure 2: Renewable energy source implementation project process (Solar PV on commercial buildings - A guide for owners and developers, 2016)

1.1 The Successful Tender

The cover letter to the successful tender is shown on **Appendix A.1**. Photovoltaic array (PV) is the renewable technology chosen by the client UWTSD. A summary of the tender's contents is briefed in the following chapters.

1.1.1 Methodology

Firstly, the development area and orientation characteristics must be assessed to determine what technology would integrate most efficiently into the proposed structure. Considering the potential to construct the building South facing in orientation, it would be concluded that solar photovoltaic (PV) technology has huge potential and would be a perfect fit.

“Photovoltaics (PV) is the conversion of light into electricity using semiconducting materials that exhibit the photovoltaic effect, a phenomenon studied in physics, photochemistry, and electrochemistry. A photovoltaic system employs solar panels, each comprising several solar cells, which generate electrical power. PV installations may be ground-mounted, rooftop mounted, or wall mounted” (Components of Photovoltaic System, 2018).



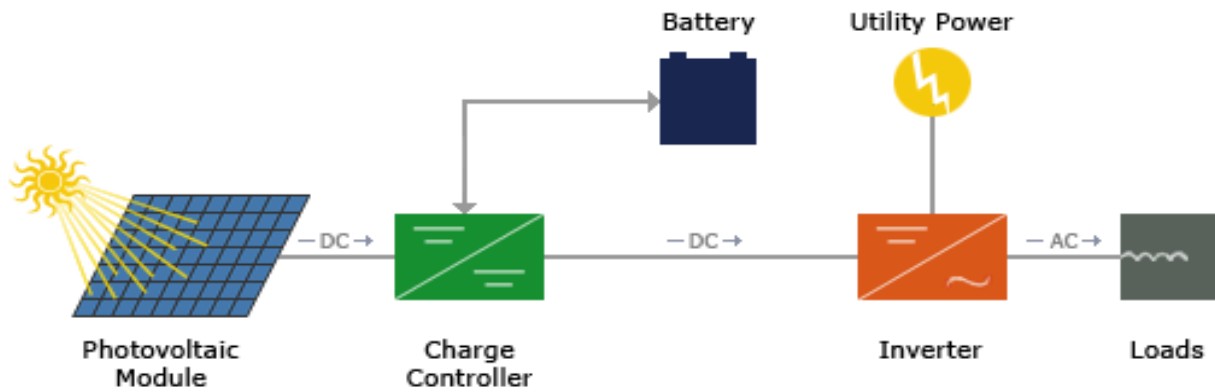


Figure 3: Typical solar PV working diagram (*Solar Photovoltaic Systems, 2018*).

1.1.2 Solar Radiation

To further assess their effectiveness in this role, solar radiation maps of South Wales can be consulted to determine how much energy they can expect to generate.

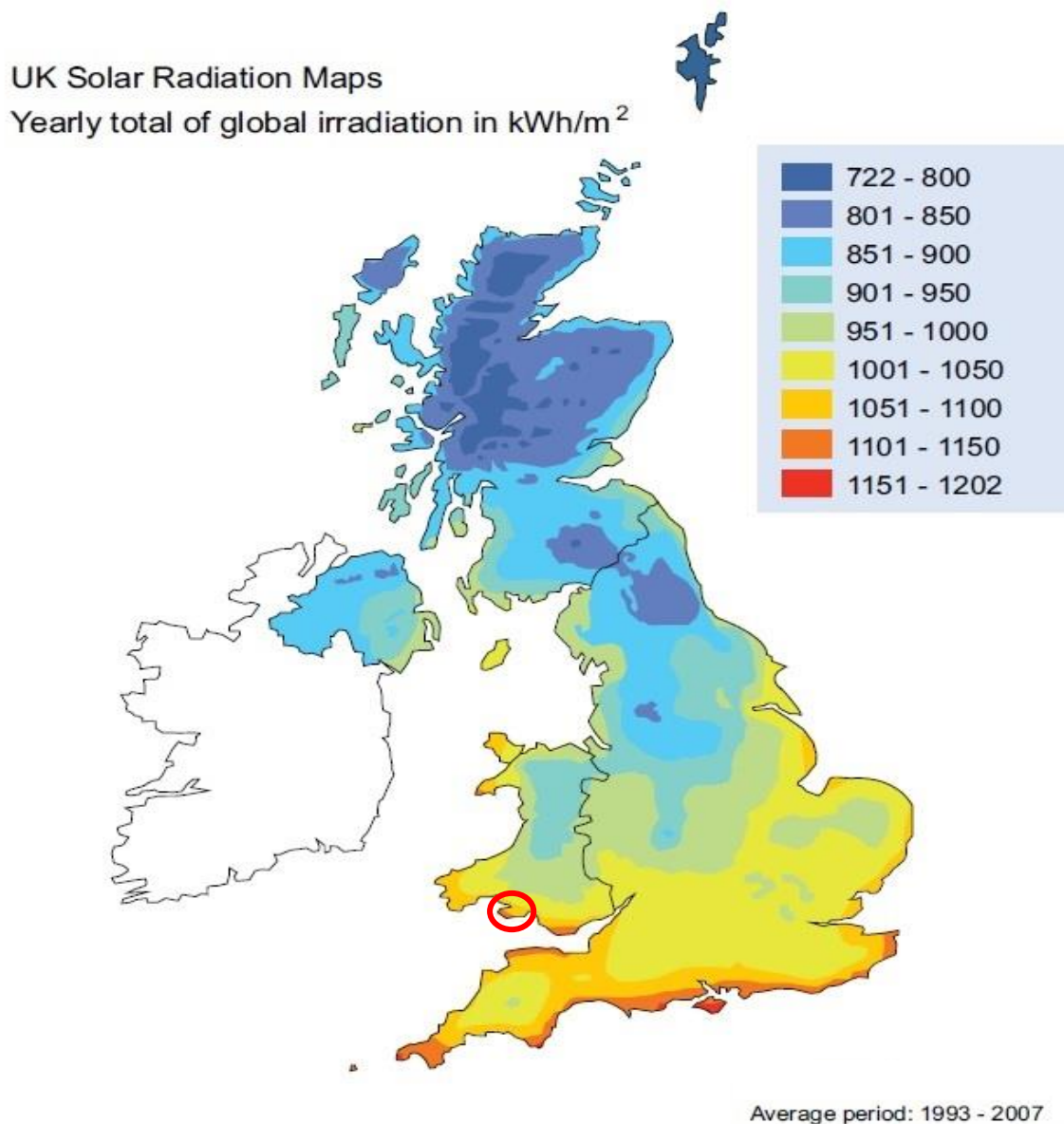


Figure 4: Solar radiation map of the UK. The South West is particularly well suited to solar PV and an unshaded installation can be expected to generate several thousand kWh per annum (*Greenleafinnovations, 2018*).



According to the solar radiation map, the SA1 development can expect to gain an average radiation of between 1051 – 1150kWh/m² annually. This is among the best areas in Wales for solar gains.

1.1.3 Solar Orientation

It is important that solar orientation is considered early during the design stage. SketchUp has built-in shading software that calculates building shade automatically given the structures orientation in the model. Alternatively, www.gaisma.com can be consulted to generate a sun path diagram (solar chart) for the anticipated building plot.

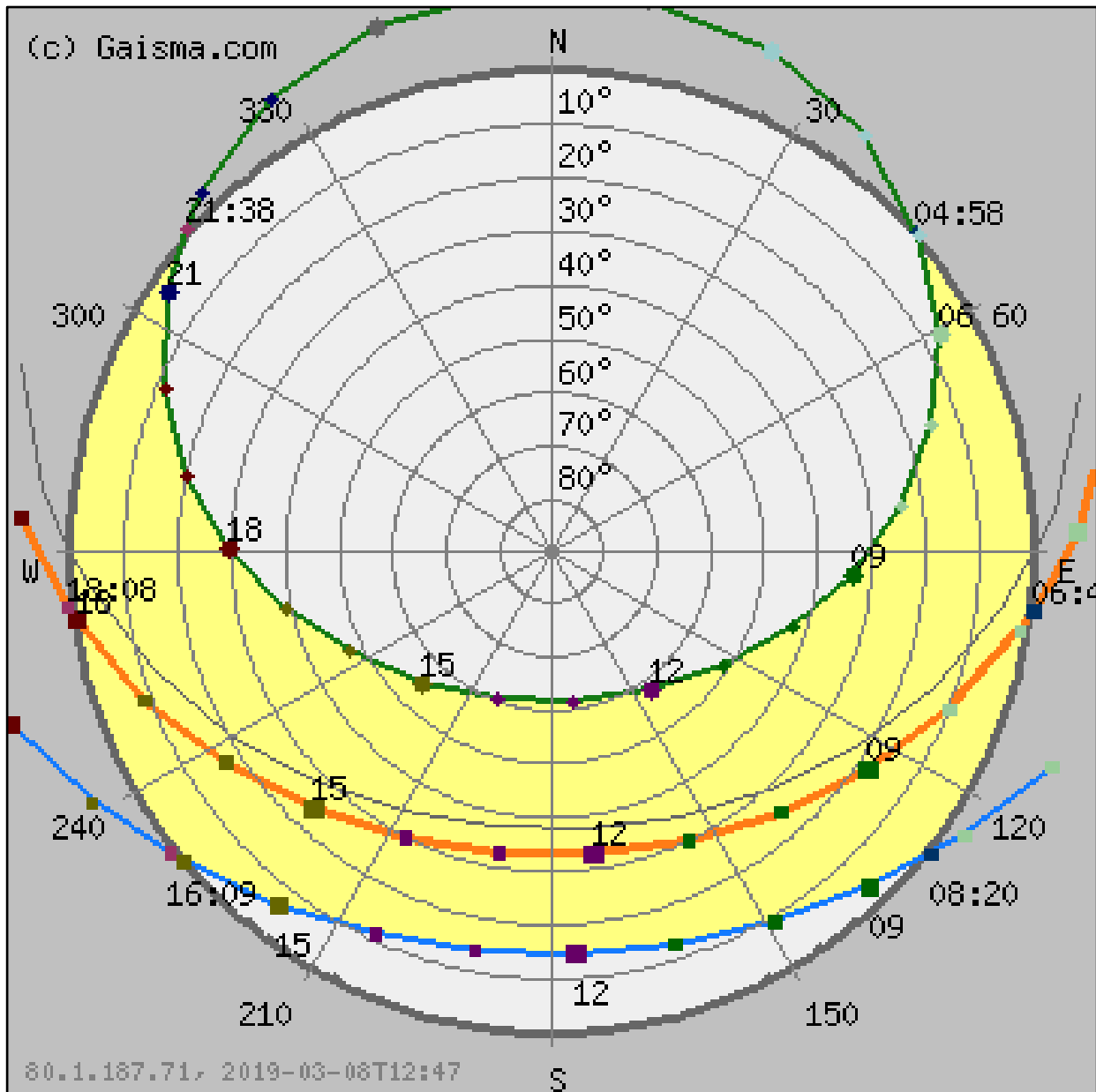


Figure 5: Sun path diagram for Swansea, UK. It shows the sun's path, where it rises and its angle of elevation all year around (Gaisma, 2018).

If the building is orientated incorrectly then the solar PV's will not be harnessing energy to full capacity. This will result in a longer payback time and a loss of energy and potential revenue. Sometimes it is not possible to obtain the desired building orientation due to external factors but there are little restrictions on this project.



1.1.4 Other Considerations

The City & County of Swansea's Renewable Energy Assessment 2015 is an important toolkit for the surveyor to exploit when assessing an areas adaptability to adopting renewable technologies.

Appendix A.2 assesses Swansea's built up areas and infrastructure solar constraints to further the structures potential to adopt solar PV's. As seen on **Appendix A.3**, environmental and heritage constraints were subsequently recorded as they would also have the potential to constrain the universities solar PV development. **Appendix A.4** illustrates the mapping of slopes above 15° slope using GIS layers. The 15° angle is specified by the guidance as a constraint for solar PV technology that results in shading. All agricultural land must be recorded to ensure that the implementation of solar PV's is not trespassing across bordering properties or adversely affecting land owners, evidence of this assessment is found on **Appendix A.5**.

1.1.5 Assessment Conclusion

It can be concluded that the proposed development area is free of constraints surveyed in 2015 **Appendix A.6** represents this fact in the final Swansea solar constraints map. However, there may be other restrictions and limitations so supplementary on-site investigation will be required to conform with planning and design framework. In addition, this survey was undertaken in 2015 and has not been revised meaning environmental and built changes have since been undertaken and therefore not considered.

1.2 Project Delivery

The preliminary assessments confirm that the implementation of solar PV technology into the building fabric of the new development is perfectly apt, meaning it can now be integrated into the design stage. Since the structure is single-storey and has an internal floor area of $6,000m^2$ there is the same area available for the implementation of renewable technology. But considering the need for services on the roof, the floor area will be more like $2,000m^2$.

After the surveyor consulted Cenwyn Jones of the UWTSO estates department, it was confirmed that 'Mitsubishi MJE-B Series (275W) PV-MJE275FB-B' solar PV modules are currently integrated in the SA1 IQ building. The PV modules manufacturers specification datasheet can be found at **Appendix 7**. It is worthwhile to use the same technology on the proposed development for uncomplicated maintenance. The modules are also currently amongst the most efficient currently available.

Module size:

$$1600mm \times 1000mm = 1.6m^2$$

It is proposed that 500 of these panels are integrated, this number will conform to the universities budget and will not use an excessive amount of roof space.

Total Installation:

$$1.6m^2 \times 500 \text{ panels} = 800m^2$$



1.2.1 Standard Assessment Procedure (SAP)

The Standard Assessment Procedure (SAP) is a Building Regulations requirement which measured the energy efficiency of a property. For SAP calculations PV are included within the assessment. The energy produced per year depends on the installed peak power (kWp) of the PV module. The procedure and full calculations for annual PV generation is found on **Appendix A.8**.

The calculation applies the average annual solar radiation for Swansea value found on **Figure 4**, shading values and values from the proposed solar PV manufactures product specification sheet the following formula has been solved:

$$\text{Annual Energy Produced (AEP)} = 0.8 \times \text{kWp} \times S \times \text{ZPVfar} \times \text{ZPVnear}$$

$$\text{AEPmin} = 0.8 \times 0.275\text{kWp} \times 1101\text{kWh}/\text{m}^2 \times 1 \times 1 = 242.222.$$

$$242.222 \times 500 \text{ panels} = \mathbf{121,110\text{kWh}}$$

$$\text{AEPmax} = 0.8 \times 0.275\text{kWp} \times 1150 \text{ kWh}/\text{m}^2 \times 1 \times 1 = 253.$$

$$253 \times 500 \text{ panels} = \mathbf{126,500\text{kWh}}$$

1.2.2 Design Integration

It would be advised that the building should be designed South in orientation for the solar PV cells to obtain maximum solar gains (**see Figure 5**). The building should also be designed to have a flat roof, this will allow more solar PV's to be implemented than that on pitched roofs. Adequate roof access should also be designed into the CAD model.

Understanding the additional solar PV weight is the best way to be certain that the roof can support a full installation. Each panel will weigh a maximum of 20kg meaning the maximum additional load on the roof structure will be:

$$20\text{kg} \times 500 \text{ panels} = \mathbf{10,000\text{kg (10 tonnes)}}$$

A structural engineer should be consulted during the design stage to assess additional weight and to make recommendations on how it can be counteracted. This can be through:

- Steel beam resizing,
- Beam direction and beam span adjustments.



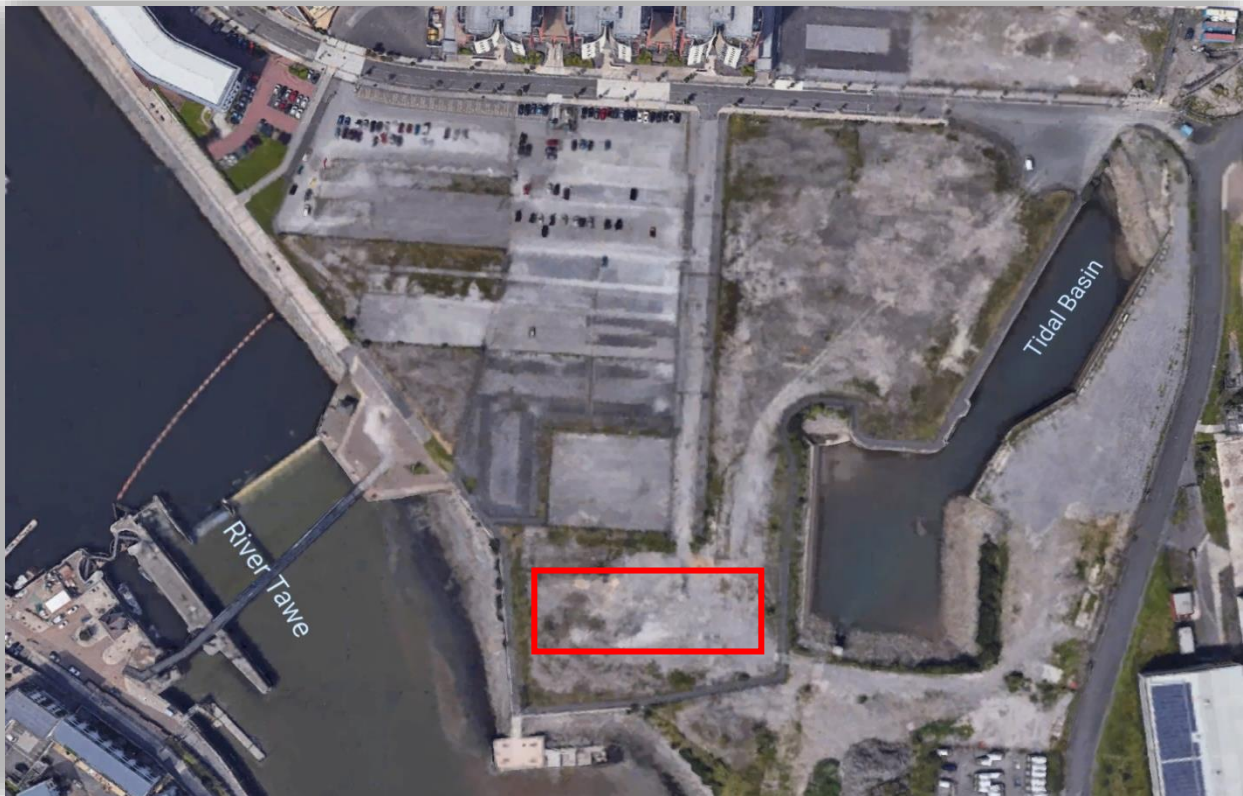


Figure 6: The area outlined in **RED** is the proposed location of the development, it is south facing and has and is 100m x 60m in perimeter (**GoogleMaps.com, 2019**).

The best way to install solar PV's onto flat roofs is to provide a frame which will raise the panels to a suitable inclination for greater harnessing of energy (**see Figure 7**). Designing the elevation to be above 12° from horizontal means that the solar PV's will be able to self-clean, resultantly output is not reduced. In addition to this, the additional wind loading upon the panels must be calculated, the SA1 development is situated within zone 4 where wind speeds are at an average of 22-24m/s (**see Appendix A.9**).



Figure 7: Solar PV currently implemented onto the IQ building in UWTSd's SA1 Campus (**Davies, 2017**).

An example roof layout for the structure is illustrated on **Appendix A.10**.

1.2.3 Cost & Payback Time

The payback period is the length of time required to recover the cost of an investment, it is a useful and effective measure of investment risk to the client. The payback period of a given investment is an important determinant of whether to client goes forward with the proposal, as longer payback periods are typically less desirable for investment positions.

Figure 8: Total System Cost

System Component	Cost (£)	Number Required (n)	Total (£)
'Mitsubishi MJE-B Series (275W) PV-MJE275FB-B' Solar PV modules.	£250	500	£125,000
"Solar power mounting kit; certified inverter, DC and AC isolation switches and connection to the grid and certification" (SPON's Architects and Builders Price Book, 2018).	£7,000 to £9,300	-	£7,000 to £9,300
Tesla Powerwall 2.0 battery (See Appendix A.13)	£5,000	1	£5,000
Design fees, planning fees, labour costs and other services.	£5,000	-	£5,000
After installation the modules should undergo servicing every 6 months.	£1,000	2/year	£2,000/year
Total:	£125,000 + £5,000 + £5,000 £7,000 to £9,300 = £142,000 to £144,300		

What Funding Schemes are Available?

It is desirable that the client signs up to the Feed in Tariff (FiT) scheme. "The FiT scheme is a government programme designed to promote the uptake of renewable and low-carbon electricity generation technologies." (**Feed-In Tariff (FiT) rates, 2019**) The scheme is due to expire on the 31st March 2019 so the development of solar PVs on site will need registered imminently.

The FiT benefits include:

- A generation tariff payment, which is based on the total electricity generated,
- An export tariff payment, which is for any energy exports made,
- Lower bills from your supplier for imported electricity.

Project Feasibility

To calculate the financial feasibility of installing solar PV into the structure, a solar business model spreadsheet has been consulted by Cymru Solar. By inputting data already calculated and obtained, annual savings can be accurately calculated. This data includes:

- System size (kW)
- System cost (£)
- Estimated annual output (kWh/kWp)
- Total system output (kWh)
- Export tariff (£/kWh)
- Maintenance cost (£)



Figure 9 shows the imputed data listed above, spreadsheet functions then automatically calculated savings associated with the solar PV installation on this proposed construction development.

Input data			
Cells in yellow can be edited to change the assumptions used. Cells in grey use a formula so should not be changed. Assumptions are then used to update the LCOE and PPA models in the two tabs.			
System Size (kW)	135.5		
System cost (£/kWp)	£ 1,011		
System cost (£)	£ 136,091		
Annual output (kWh/kWp)	1211		
Total system output Yr 1 (kWh)	164090.5		For an estimate look at http://www.microgenerationcertification.org/images/PV20Book20ELECTRONIC.pdf
FIT rate (£/kWh)	£ 0.0963		the latest FIT and Export tariffs can be found here: https://www.ofgem.gov.uk/environmental-programmes/feed-tariff-fit-scheme/tariff-tables
Export Tariff (£/kWh)	£ 0.0485		
Base electricity unit cost (£/kWh)	£ 0.06		
Red Duo5 rate (£/kWh)	£ 0.12	20%	% solar, consumed during red Duo5
Amber Duo5 rate (£/kWh)	£ 0.06	40%	% solar, consumed during amber Duo5
Green Duo5 rate (£/kWh)	£ 0.02	40%	% solar, consumed during green Duo5
Real Benefit of PV (£/kWh)	£ 0.1160		For LCOE model
Percentage self consumption	80%		This cell is relevant for PPA calculations only
% PV generated Exported	20%		
RPI	1.40%		https://www.ons.gov.uk/economy/inflationandpriceindices/timeseries/cbbh
Energy inflation	2.40%		
Degradation of PV/yr	0.50%		
Borrowing interest rate %	3.00%		
Maintenance £/kWp/yr	£12.00		
Inverter % of total cost	15%		
Inverter replacement cost	£ 20,549		In year 12 inverters are predicted to require replacement
Greenhouse Gas Conversion Factor (KgCO2/kWh)	0.410		Source https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2016

Figure 9: Solar PV business model input data.

It can be concluded from **figure 10** that the implementation of solar PV in the structure will have a long-term financial benefit. The savings calculated by the spreadsheet model are:

- Year 5: £22,586.88
- Year 10: £51,228.78
- Year 25: £182,202.98

The model calculates an estimated payback time of 17 years. It also calculates that after 25 years there will be £40,202.98 profit:

Profit: Year 25 savings - £142,000 system cost = **£40,202.98.**

Cash Flow Projections using a PPA							
Assumptions							
RPI (FIT & Export rate)		1.40%					
Energy Inflation		2.60%					
Degradation of PV /yr		0.5%					
Average cost of electricity	£	0.11600					
PPA base price	£	0.08500					
System Size kW		136					
Annual output (kWh/kWp)		1211					
Self consumption of PV		80%					
Power Purchase Agreement							
		Investment	PV Yield (kWh)	PV Consumption (kWh)	Electricity Tariff	PPA Tariff	Energy Savings
Year 1			164,091	131,272	0.116	0.085	4,069
Year 2			163,270	130,616	0.119	0.086	4,288
Year 3			162,454	129,963	0.122	0.087	4,512
Year 4			161,641	129,313	0.125	0.089	4,741
Year 5			160,833	128,667	0.129	0.090	4,977
Year 6			160,029	128,023	0.132	0.091	5,219
Year 7			159,229	127,383	0.135	0.092	5,467
Year 8			158,433	126,746	0.139	0.094	5,722
Year 9			157,641	126,112	0.142	0.095	5,983
Year 10			156,852	125,482	0.146	0.096	6,251
							Accrued Savings
							4,069
							8,357
							12,869
							17,610
							22,587
							27,806
							33,273
							38,995
							44,978
							51,229

Figure 10: Solar PV business model savings.



1.2.4 Building Energy Usage

Figure 11 shows the typical monthly solar generation of solar PV array installations in the UK. The graph can be used as a basis as to what electricity the PV's should expect to generate throughout the year. During the summer months the development should expect to be generating more electricity than consuming, that associates the need for requirement for UWTSD to install battery storage components.

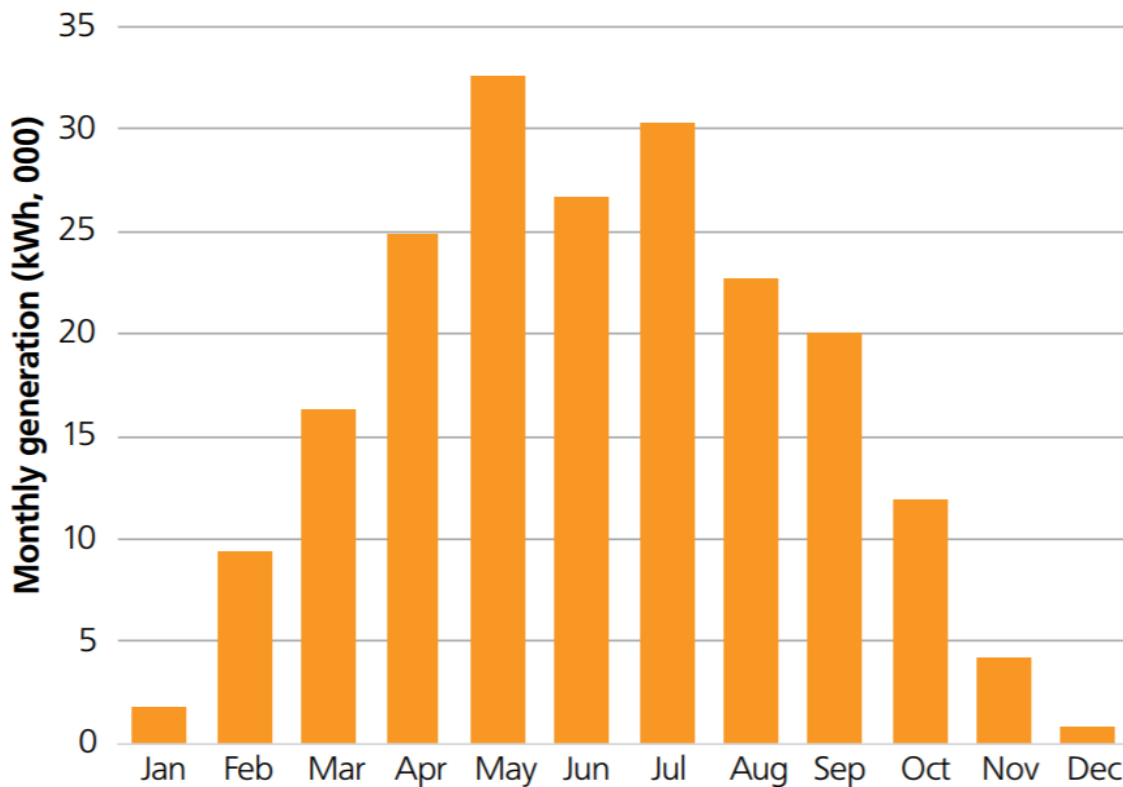


Figure 11: Typical monthly solar electricity generation (*SolarEdge.com, 2018*).

Figure 12 illustrates how energy prices can change throughout the day. During times of high usage, the tariff can be up to 6p more expensive than at off peak times. This imposes the need for the client to be self-generating electricity rather than importing.



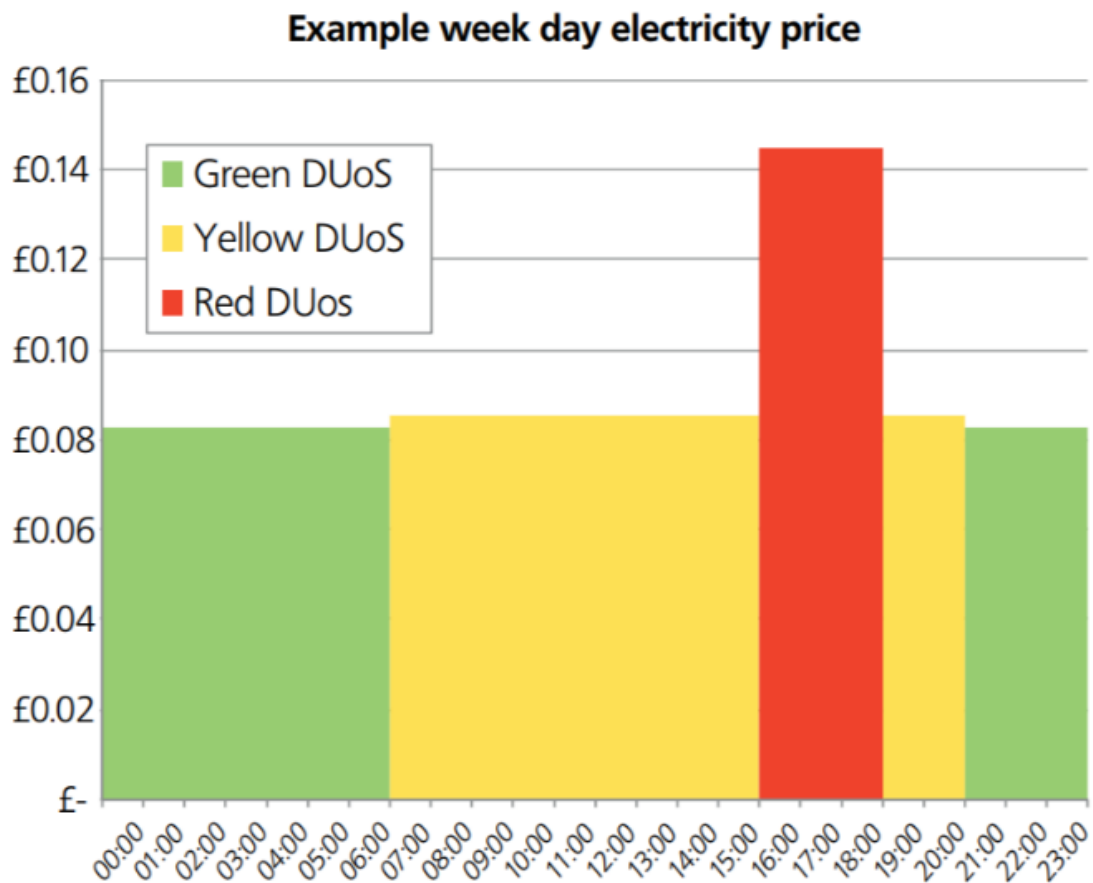


Figure 12: Example of daily energy price fluctuations (BRE, 2013).

Figure 13 gives a guide as to how the erected structure will generate and consume electricity throughout the day. The trend identifiable is that most energy will be consumed during speak times from 15:00 to 18:00 which interlinks with **Figure 12** in that electricity prices will peak during this time.

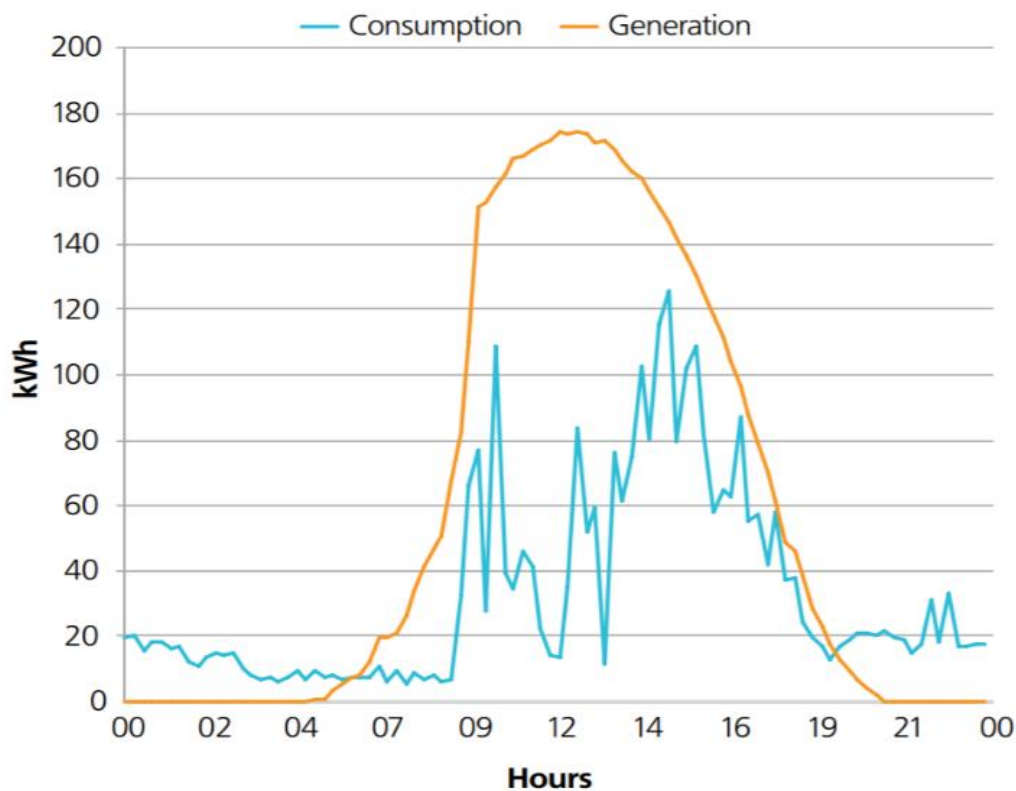


Figure 13: Electricity consumption and solar PV generation comparison (BRE, 2015).



1.3 Installation & Construction Methodology

The integration of solar PV into the structure is regulated by the [*Construction, Design and Management \(CDM\) Regulations 2015*](#) which aims to improve health and safety in the industry by helping to sensibly plan the work, so the risks involved are managed from start to finish.

Cymru Solar strictly adhere to professional work practices and use certified bodies only to adapt their construction methods to. Therefore, the document '*Solar Panel Installation*' by the CITB (see [*Appendix A.12*](#)) will epitomise the process for this project.

National Grid Connection

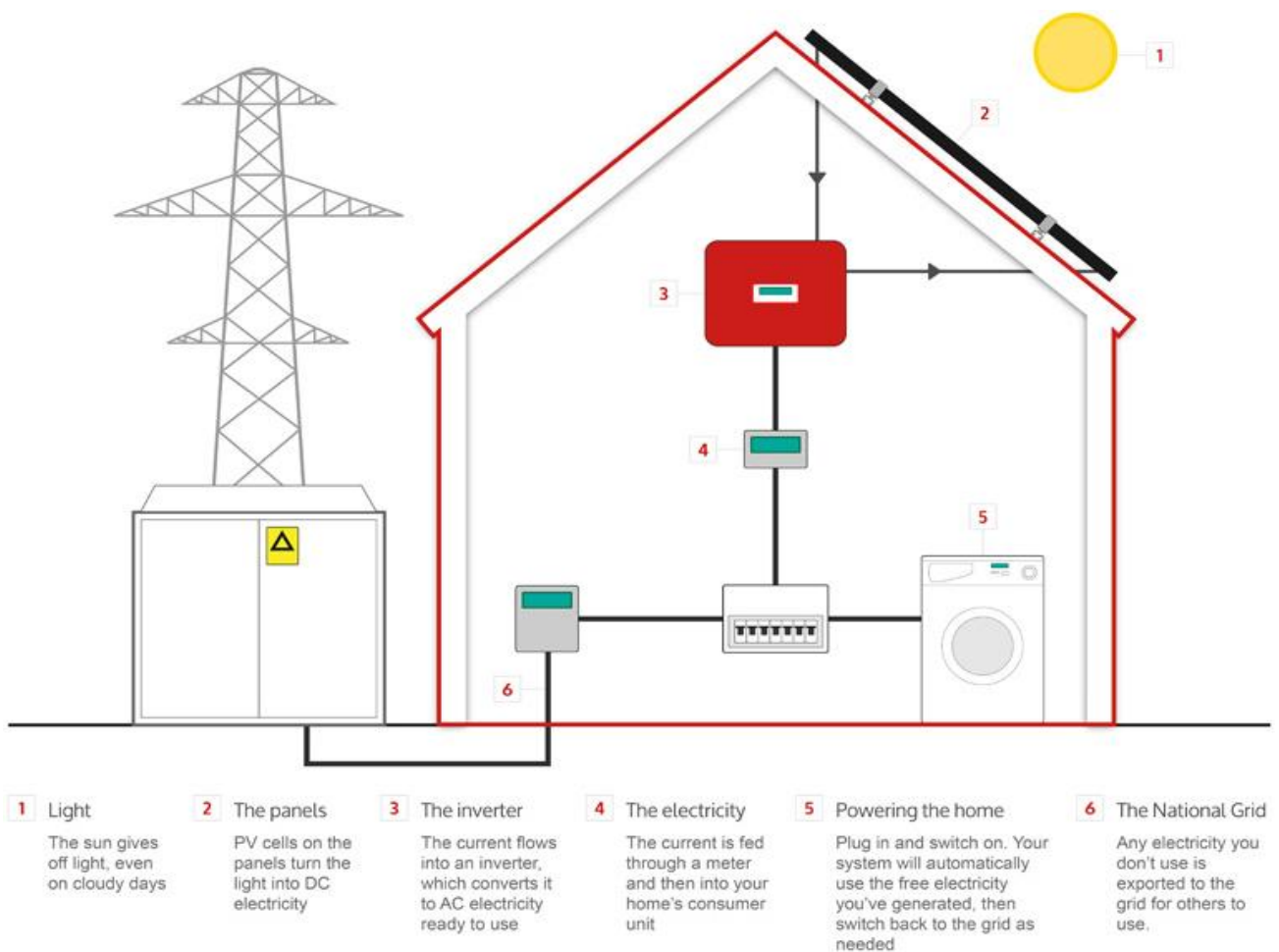


Figure 14: Diagram showing how surplus electricity gets fed back in to the National Grid (*How Solar Panels Work, 2017*).

1.3.1 Regulations & Legislation

The Building Regulations

Solar PV installations must adhere to the following parts of the building regulations and should be addressed early at the system design stage:



Figure 15: Constructors considerations for solar PV to conform with the building regulations.

Approved Document	Criteria Considerations
<u>Approved Document A - Structure</u>	▪ Strength of roof (increased weight loading) ▪ Effect of wind lift on solar PV panels & roof supports, ▪ Depth of wall chases, ▪ Sizes of holes and notches used for cables, ▪ Use of certified and correctly applied materials and equipment.
<u>Approved Document B - Fire Safety</u>	▪ PV installations in relation to fire risk (short circuits, overloaded cables) ▪ Fire resistance of roof coverings, ▪ Cable penetrations through walls, ceilings and floors must not assist the spread of fire, ▪ Adequate ventilation of heat producing equipment (inverters, PV modules and PV cables) ▪ Use of certified and correctly applied materials.
<u>Approved Document C - Moisture</u>	▪ Cable penetrations through external walls and prevention of moisture ingress, ▪ Moisture ingress through roof coverings, ▪ Correct choice, use and application of moisture prevention (roof flashings, waterproofing)
<u>Approved Document E - Sound</u>	▪ Sound passage through cable penetrations should be minimised.
<u>Approved Document F - Ventilation</u>	▪ Correct positioning and ventilation of heat emitting equipment such as inverters, solar PV and cables.
<u>Approved Document K - Protection from Falling</u>	▪ Safe installation of solar PV systems at height, ▪ Safe maintenance of solar PV systems at height, ▪ Correct selection, construction and use of access equipment such as scaffolding.
<u>Approved Document M - Access & Use of Buildings</u>	▪ Accessible placement of equipment (inverters, monitors, fuse boxes, isolators) ▪ Suitable access to roof
<u>Approved Document P - Electrical Safety</u>	▪ Correct usage, sizing and positioning of cables,



	▪ Labelling and warning signs, ▪ Adequate earthing and bonding, ▪ Protection from damage, dust, water of electrical equipment and cables, ▪ Test certificates, manuals and safety instructions, ▪ Isolation arrangements (how to disconnect parts or all the system) ▪ Correct selection and use of protective devices such as RCDs, fuses and isolators.
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Source: Solar PV: Safety and The Building Regulations, 2018.

Design and construction approaches must also adhere to the following regulations and guidance otherwise prosecution by the HSE may be undertaken:

- HSE Health & Safety in Roof Work,
- HSE Working on Roofs,
- HSE Using Electrical Storage Batteries Safely,
- Electrical Regulations 1989.

Some key British Standard relating to the quality of the system include:

- BS EN 7671 - Requirements for electrical installations. (Part 7-12 – Solar PV)
- BS EN 62446 - Grid connected photovoltaic systems - Minimum requirements for system documentation, commissioning tests and inspection.
- BS EN 7375 – Electrical equipment installation & maintenance.

1.3.2 Certifications

Certifications provide independent verification of a certain level of quality and are highly important to proving safety, merit and efficiency.

BREEAM

Under the Welsh Governments Sustainable Building Standards initiative, every new structure with over 2001m² of floor space must achieve a BREEAM 'Excellent' certification.

BREEAM is a method which is used to assess the environmental performance of both new buildings. It is widely regarded as a measure of best practice in environmental design and management, featuring renewable technologies such as solar PV will gain credits in the 'energy' category of the certification.

Microgeneration Certification Scheme (MCS)

Microgeneration Certification Scheme (MCS) is a nationally recognised quality assurance scheme supported by the Government that is fundamental requirement for solar PV developments. *"MCS certifies technologies used to produce electricity from renewable sources such as solar PV achieve BS and protect the end-user, guarantee safety and product aging criteria. Achieving the certification is also an eligibility requirement for the Government's financial incentives"* (MCS, 2019)





The Microgeneration Certification Scheme

Figure 16: MCS Logo (MCS, 2019)

1.4 Case Study: University of Exeter

A 140.5kW solar PV system installed by SunGift LTD located at the University of Exeter is effectively identical to that proposed for the UWTSD development. *“Completed in October 2018, the array comprises more than 500 panels and covers 800 square metres of the university’s sports hall roof. It’s expected to generate just shy of 125,000kWh of power each year” (UoE, 2019).* In comparison, the surveyor for the UWTSD development has calculated a minimum power generation of 121,110kWh and a maximum of 126,500kWh annually.

The project manager for the development, Gareth Walton elucidated that *“the campus is served by a single MPAN. This means that only a single PV installation can claim the feed-in tariff, with one such system having already been installed. Another main driver for the installation had been that PV prices have dropped to such an extent that the system made sense economically without subsidy support.”*

The installation was financed directly by the university and falls under its new Low Carbon Commitment Implementation Plan (LCCIP), under which the organisation has committed to reduce its carbon emissions by 50% by 2026. *‘As part of the LCCIP, the university are estimated to save £3.2 million on utilities and 4,628 tonnes of carbon – equivalent to the typical annual carbon emissions of approximately 600 UK households’ (O’Beirne, 2018).*

Key facts:

- Cost: £150,000,
- 140.5kW solar PV system,
- 125,000kWh of power generated annually,
- £3.2 million on utilities and 4,628 tonnes of carbon saved by 2026,
- £4,713.69 Projected first year income and savings assuming 90% of electricity used on site,
- 18.8% Projected first year return on capital invested,
- 15 years - System payback before finance, tax and electrical upgrades,
- £187,674.39 - Total projected income and savings over 25 years,
- 3.5p/kWh - Equivalent forward purchase price of 5.4 million units of electricity over 25 years plus FiT income on top.





Figure 17: University of Exeter alumni showcasing the 500-panel solar PV array (Stoker, 2018).

1.5 Conclusion

It would be concluded that the implementation of solar PV into the development would outperform other technologies given the areas typology, orientation, budget and available space. In addition, this technology would allow profits to be made during holiday seasons where surplus energy can be transferred to the National Grid.

When comparing the project to the case study at the University of Exeter which is the exact same array size, square meterage, orientation and solar radiation zone that that at SA1, it can be deduced that:

- The system has a proven track record,
- The cost of the project is constant with that elsewhere,
- Shorter payback times than ever before attract investors.

1.5.1 Advantages & Limitations

Advantages:

- Solar PV systems can be designed for a variety of applications and operational requirements, and can, therefore, be adapted to your own personal situation.
- PV systems require minimal maintenance.
- Solar PV systems don't create any noise or pollution.
- Since PV systems are modular, it is easy to expand them and transport them.
- The Government's Feed-in Tariff (FiT) which pays a set rate per kWh of electricity generated and an additional rate for any exported back to the national grid.
- PV also generate power on cloudy days.
- Installation and maintenance expertise are easily accessible nationwide.



Limitations:

- PV's should not be shadowed by structures post-construction (future proofing). A large area of unshaded S, SW or SE facing roof is required to maximise payback.
- Panels degrade over time by approximately 20% over 25 years, this is considered in manufacturers performance calculations.
- It may be advantageous to replace the systems inverter after 10 years to enhance power generation.
- Additional insurance costs are important to safeguard a PV investment.
- The initial cost of purchasing a solar system and solar energy storage is considerably high.

Rendering investigation within the research proposal '***Solar Together***' by ***Colin McCormick and David Sandalow (2016) of Columbia University*** there is thought to be much potential for solar PV to advance further through greater funding, recycled panels and components. The research proposal can be found on ***Appendix A.13***.

1.5.2 Why Choose Solar PV Over Alternative Technologies?

Alternatively, it is possible that wind turbine technology could also be installed into the development. During the surveyor's assessment of the SA1 area, several were recorded within a mile of the site. The City & County of Swansea Renewable Energy Assessment 2015 rejects this hypothesis although by illustrating various constraints to the technology on site. ***Appendix A.14*** shows a map of all Swansea wind turbine constraints combined. In addition, this alternative would also surpass the cost of the PV installation and statistically generate less electricity. In addition:

- The technology depends heavily on wind speed, meaning on calm days little power is generated.
- Wind turbines can be extremely noisy, this would disrupt UWTSD students in quiet learning environments.
- Wind turbines require their own floor area whereas the PV installation is to be integrated onto the roof.
- Wind turbines require more frequent maintenance and are therefore expensive to maintain.



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<https://www.bre.co.uk/filelibrary/nsc/Documents%20Library/NSC%20Publications/123160-NSC-Solar-Roofs-Good-Practice-Guide-WEB.pdf> (Accessed: 22nd March 2019)

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https://www.solarpowerportal.co.uk/news/sungift_completes_140kw_subsidy_free_solar_install_for_university_of_exeter (Accessed: 28th March 2019)

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http://www.exeter.ac.uk/sustainability/newsandevents/archive/title_707943_en.html (Accessed: 27th March 2019)

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Appendices

A.1: Successful tender cover letter.

Kier Construction LTD,
St Mellons Business Park,
Fortran Road,
St. Mellons,
Cardiff,
CF3 0EY



Tender Proposal Cover Letter

To: Mike Bessel (*Kier*)
From: Adam Meyrick (*Cymru Solar*)
CC: Kier Construction LTD
Date: 23rd August 2018

Tender Notice **No. SE/BCPRES/A/2018/030**. Dated: 23.06.2018. Due: 23.08.2018.

Cymru Solar are pleased to present our proposal for your review against Tender Notice **No. SE/BCPRES/A/2018/030**. Dated: 23.06.2018. Due: 23.08.2018.

We have studied the invitation to tender and now have a full understanding of the construction projects requirements.

In the last ten years, we have incorporated solar photovoltaic (PV) technology into several high-profile construction projects and achieved great success. As one of the leading contracting firms in Wales, Cymru Solar has been at the forefront in execution of a wide array of construction projects for domestic, government, and private corporations.

The five separate envelopes enclosed consist of:

Part 'A' Technical Bid Proposal

Part 'E' Compliance with Regulations

Part 'B' Methodology

Part 'C' Project Assessment

Part 'D' Case Study

Thank you for the opportunity to participate in this tender. If you have any questions, please don't hesitate to get in contact with me directly.

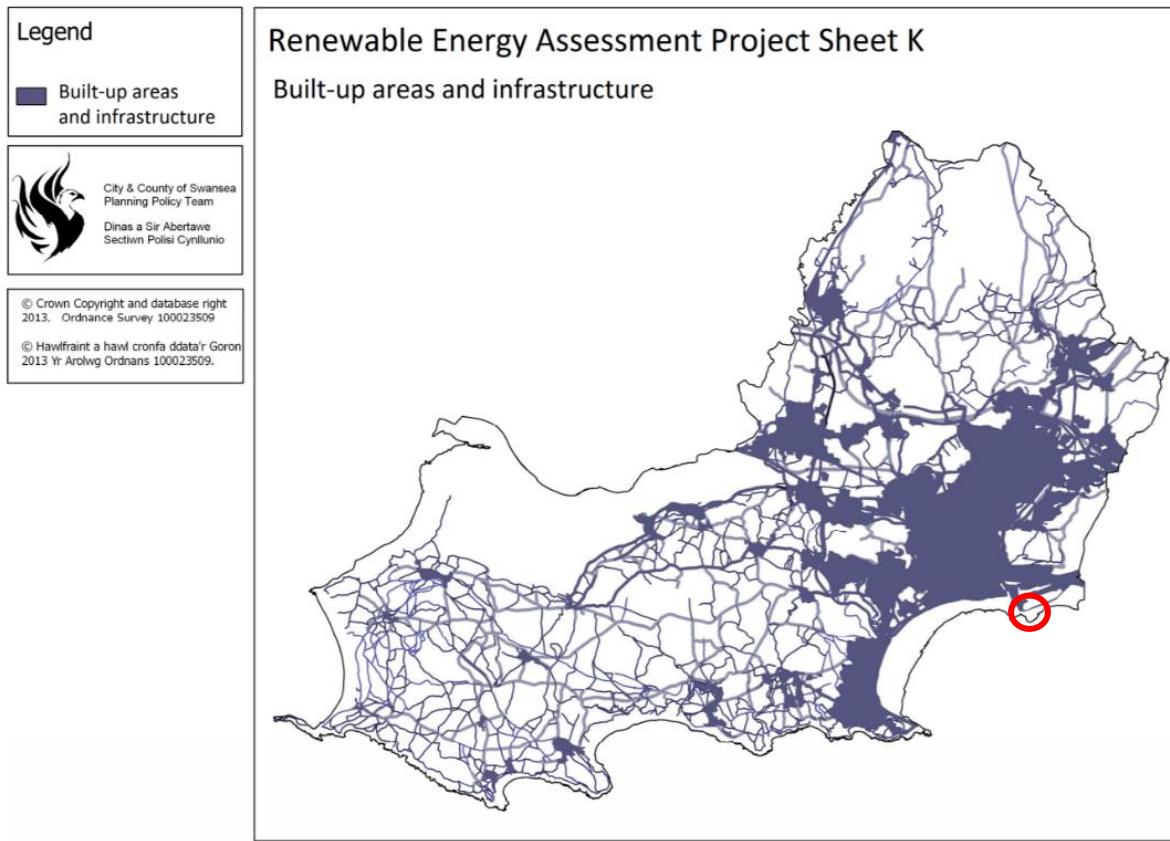
Sincerely,

Adam Meyrick (*Director, Cymru Solar*)

A.2: Swansea built up areas and infrastructure solar constraints.

URL: <https://swansea.jdi-consult.net/.../Renewable%20Energy%20Assessment%202015.pdf>

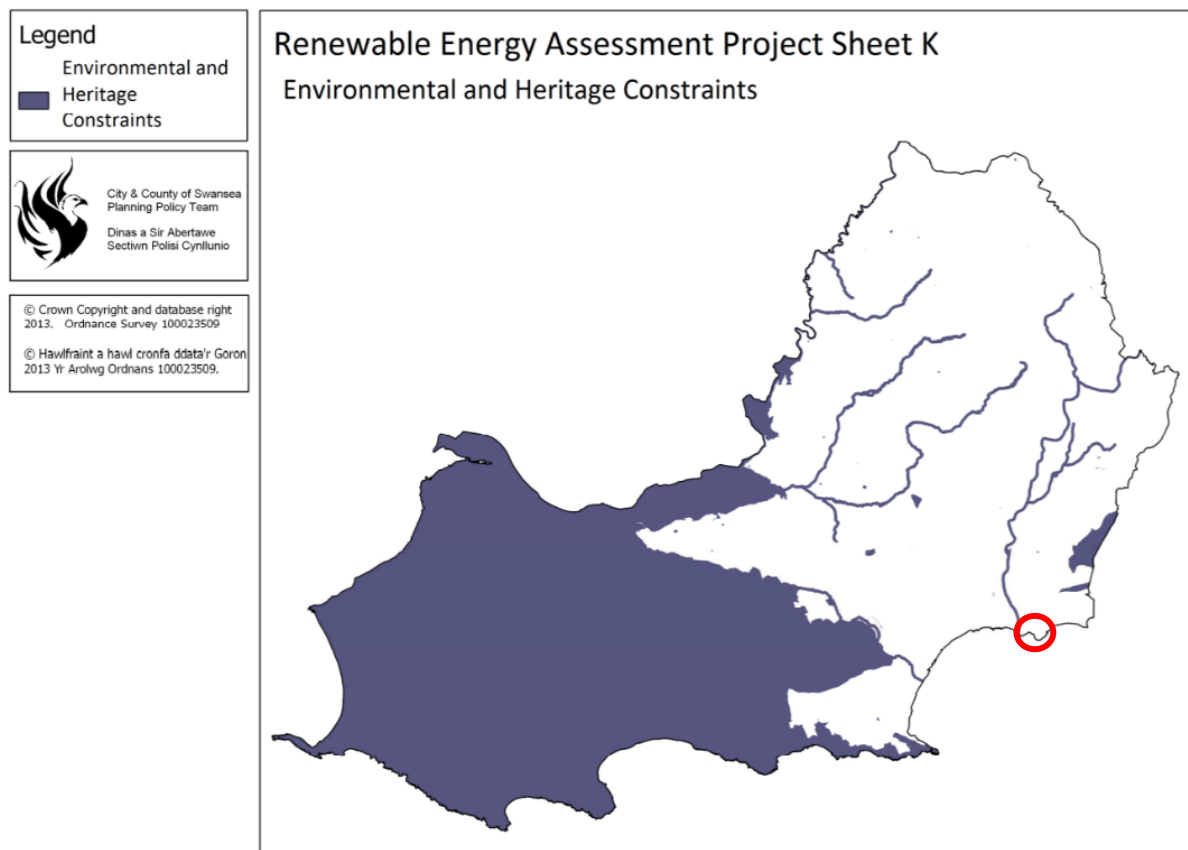
Accessed: 03/03/2019



A.3: Swansea environmental and heritage solar constraints.

URL: <https://swansea.jdi-consult.net/.../Renewable%20Energy%20Assessment%202015.pdf>

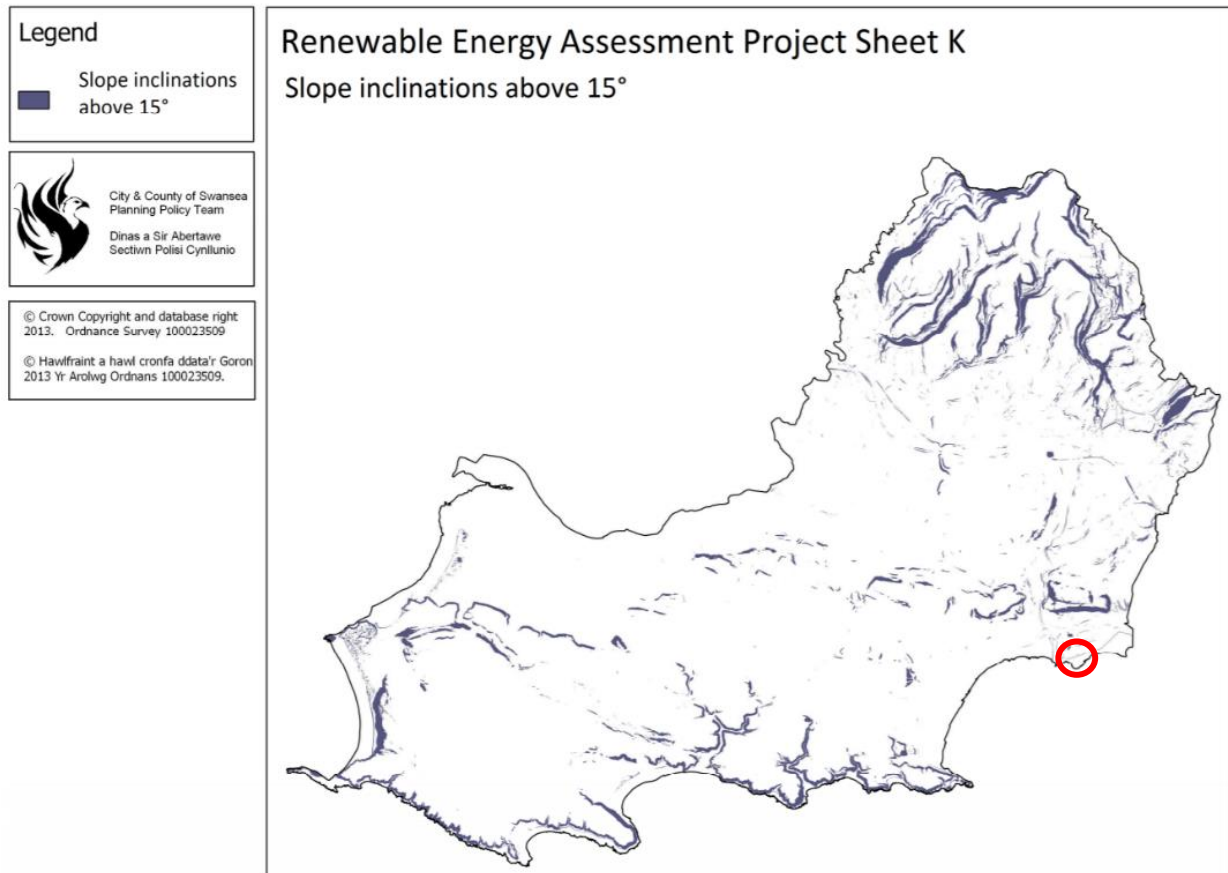
Accessed: 03/03/2019



A.4: Swansea slope inclinations above 15°.

URL: <https://swansea.jdi-consult.net/.../Renewable%20Energy%20Assessment%202015.pdf>

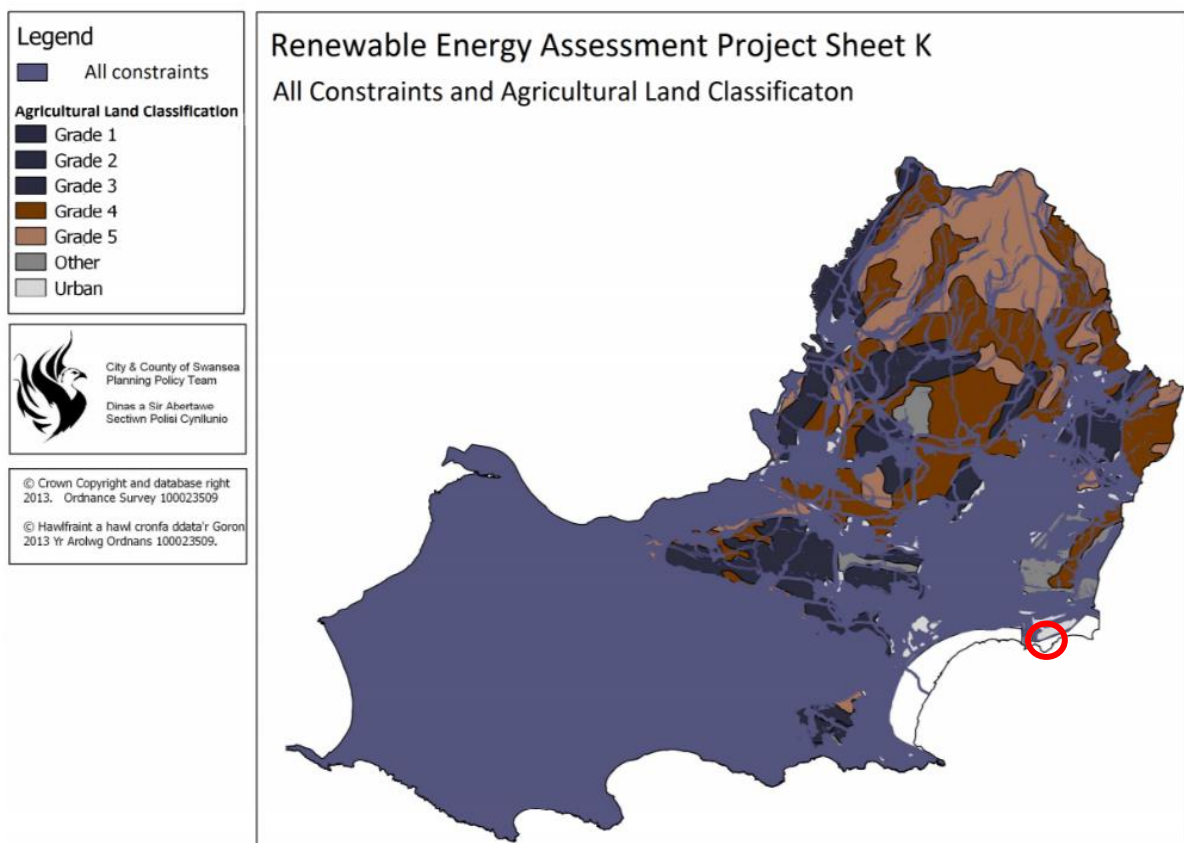
Accessed: 03/03/2019



A.5: All agricultural land constraints overlaid with all previous constraints.

URL: <https://swansea.jdi-consult.net/.../Renewable%20Energy%20Assessment%202015.pdf>

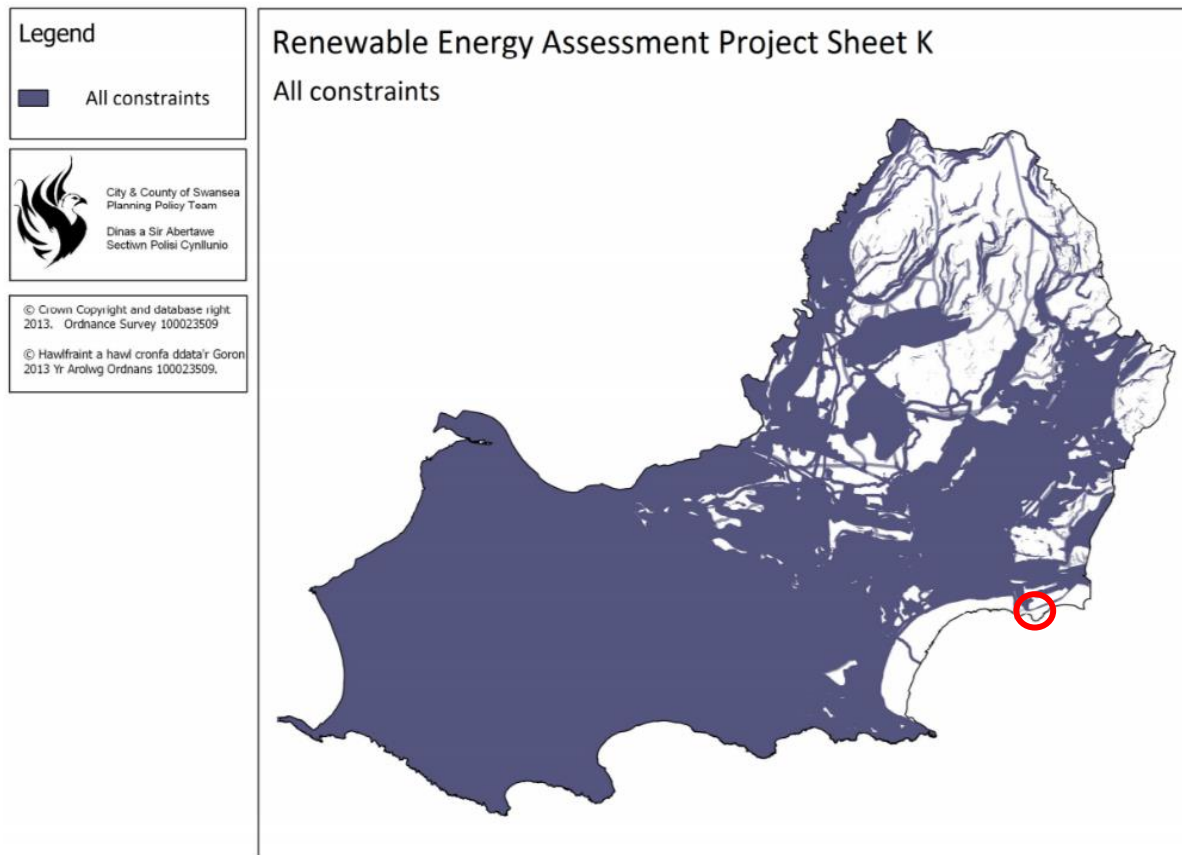
Accessed: 03/03/2019



A.6: Final Swansea solar constraints map.

URL: <https://swansea.jdi-consult.net/.../Renewable%20Energy%20Assessment%202015.pdf>

Accessed: 03/03/2019



A.7: 'Mitsubishi MJE-B Series (275W) PV-MJE275FB-B' Solar PV manufactures product specification sheet.

URL: https://www.mitsubishielectricsolar.com/images/uploads/documents/specs/MJEB_275.pdf

Accessed: 16/03/2019

Module Specifications

Model name	PV-MJE275FB
Cell type	Monocrystalline Silicon, 156 mm x 156 mm
Number of cells	60 cells
Maximum power rating (Pmax)	275 W
Warranted minimum Pmax	275 W
PV USA test condition rating (PTC)	247.6 Wp
Open circuit voltage (Voc)	38.3V
Short circuit current (Isc)	9.36A
Maximum power voltage (Vmp)	31.3V
Maximum power current (Imp)	8.79A
Module efficiency	16.7%
Aperture efficiency	18.8%
Tolerance of maximum power rating	-0/+5%
Weight Static load test passed	5,400 Pa
Number of bus bars per cell	4 Bus bars

Normal operating cell temperature (NOCT)	46.0°C
Maximum system voltage, DC	600V & 1000V (UL), 1000V (IEC)
Fuse rating	15A
Dimensions	65.2 x 39.1 x 1.81 inch (1657 x 994 x 46 mm)
Weight	41.8 lbs (19 kg)
Number of modules per pallet	22
Number of modules per container (40 ft. container)	616
Output terminal	SMK (PV-03) connector
Output cable, (+) & (-)	46.3 inches (1175 mm)
Certifications	UL 1703, IEC 61215 2nd Edition, IEC 61730
Fire rating	Type 2, 5, 8
Country of Origin	Made in Japan

A.8: SAP Calculations

URL: <https://www.bre.co.uk/filelibrary/SAP/2016/SAP-2016-10.00--July-2016CONSULTATION-VERSION-14-07-2016.pdf>

Accessed: 17/03/2019



The energy produced per year depends on the installed peak power (kWp) of the PV module, the procedure for PV energy calculations is as follows:

- 1) Establish the installed peak power of the PV unit (kWp).
- 2) The electricity produced by the PV module, EPV (kWh/year), is as follows:
 - a. If an MCS certificate for the installation is available:

$$EPV = 0.8 \times kWp \times S \times SF$$

- b. In no MCS certificate is available:

$$EPV = 0.8 \times kWp \times S \times ZPVfar \times ZPVnear$$

Where,

S is the annual solar radiation (kWh/m²) from **Figure 4**.

SF is the shading factor from the MCS certificate and *ZPVnear* and *ZPVfar* are over shading factors from **Tables M1 & M2**. Apply equation to each solar PV and sum all together to achieve the cumulative annual electricity generation for the array.

Table M1: Over shading from distant obstruction ≥ 10m away		
Description	% of Southern sky blocked by obstruction ≥ 10m away	ZPVfar
Heavy	> 80%	0.2
Significant	> 60% - 80%	0.35
Modest	20% - 60%	0.5
None or very little	< 20%	1

Table M2: Over shading from distant obstruction ≤ 10m away	
Description	ZPVnear
None	1
Tall obstruction to South or passing through array	0.2
Tall obstruction to SE/SW	0.45
Tall obstruction to E/W	0.65
Short obstruction to South of passing through array	0.75
Short obstruction to SE/SW	0.75
Short obstruction to E/W	0.85

Full calculation:

Mitsubishi MJE-B Series (275W) PV-MJE275FB-B peak installed power = 275W

Convert 275W to kWp = 0.275kWp

Establish,

- 1) *ZPVfar* and *ZPVnear* as 1 (none or very little shading)
- 2) SA1 annual solar radiation (kWh/m²) from Figure 1.D as between 1101kWh/m² and 1150kWh/m²



Finally, apply values to the formula,

$$\text{Annual Energy Produced (AEP)} = 0.8 \times \text{kWp} \times S \times \text{ZPVfar} \times \text{ZPVnear}$$

$$\text{AEP}_{\text{min}} = 0.8 \times 0.275\text{kWp} \times 1101\text{kWh/m}^2 \times 1 \times 1 = 242.222.$$

$$242.222 \times 500 \text{ panels} = \mathbf{121,110\text{kWh}}$$

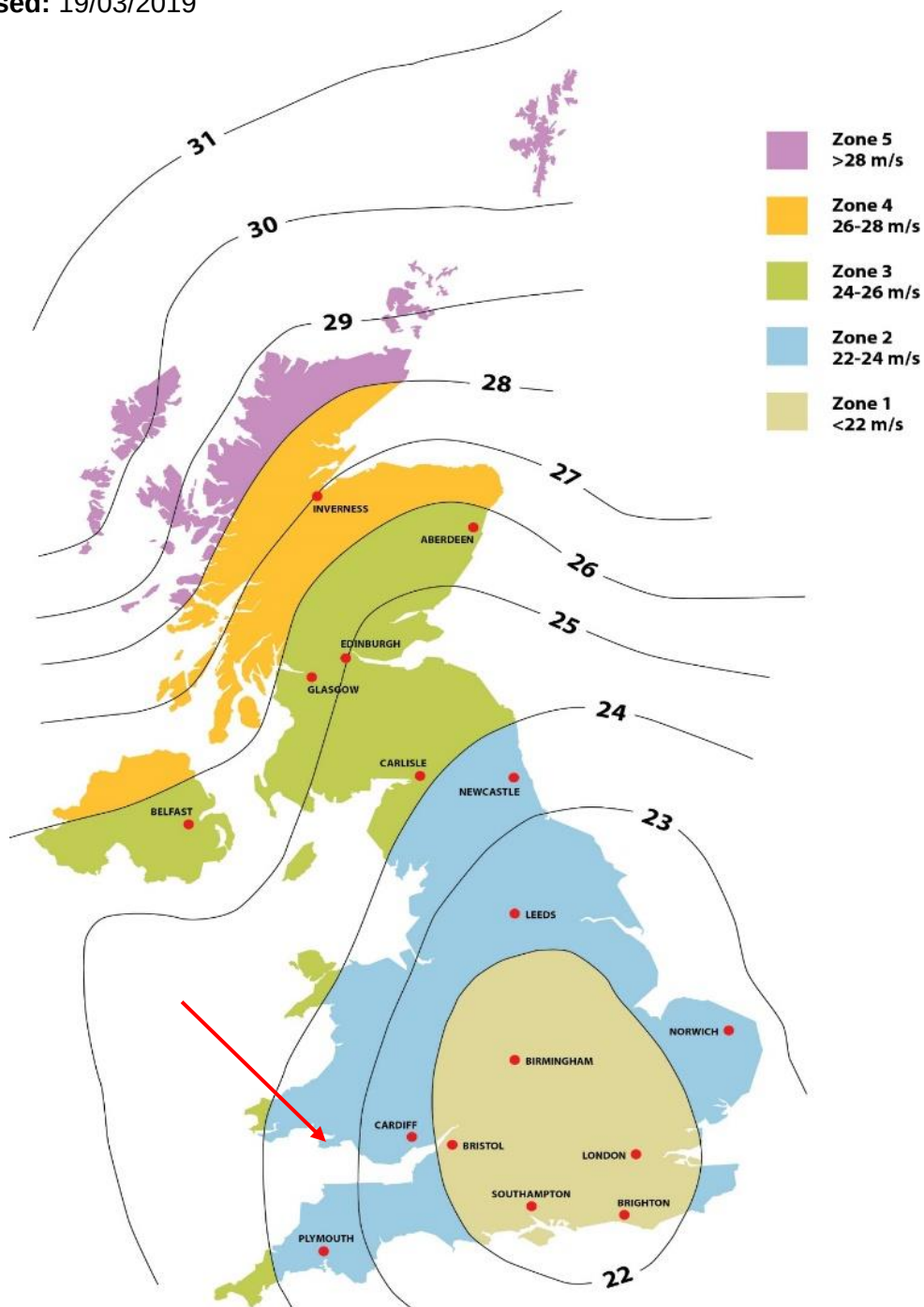
$$\text{AEP}_{\text{max}} = 0.8 \times 0.275\text{kWp} \times 1150 \text{ kWh/m}^2 \times 1 \times 1 = 253.$$

$$253 \times 500 \text{ panels} = \mathbf{126,500\text{kWh}}$$

A.9: Map of UK wind speed zones for determining additional wind loading of solar PV.

URL: <http://www.singleply.co.uk/the-effects-of-wind-uplift-on-roofs/>

Accessed: 19/03/2019



URL: <https://www.sepisolar.com/solar-pv-system-design/utility-medium-voltage-solar-design-energy-storage-lp/>

Accessed: 12/03/2019



A.11: Tesla Powerwall 2.0 solar PV battery.

URL: <https://www.solarguide.co.uk/tesla-energy/powerwall-2/>

Accessed: 03/03/2019

Tesla Powerwall 2.0 Specifications:

Usable Capacity	13.5 kWh
Depth of Discharge	100%
Efficiency	90%
Power	7kW peak / 5kW continuous
Warranty	10 years
Scalable	Up to 10 Powerwalls
Operating Temperature	-4° to 122°F / -20°C to 50°C
Dimensions	L x W x D: 44" x 29" x 5.5" (1150mm x 755mm x 155mm)
Weight	264.4 lb / 120 kg
Installation	Floor or wall mounted Indoor or outdoor



A.12: Approved CITB 'Solar PV Installation Method'.

URL: <https://www.citb.co.uk/documents/csk-gs001-solar-infomaster.pdf>

Accessed: 04/03/2019

The document covers:

- Planning,
- Protecting others,
- Working at height,
- Lifting,
- Electrical safety,
- Commissioning,
- Future maintenance and access.

A.13: The research proposal 'Solar Together' by Colin McCormick and David Sandalow (2016) of Columbia University.

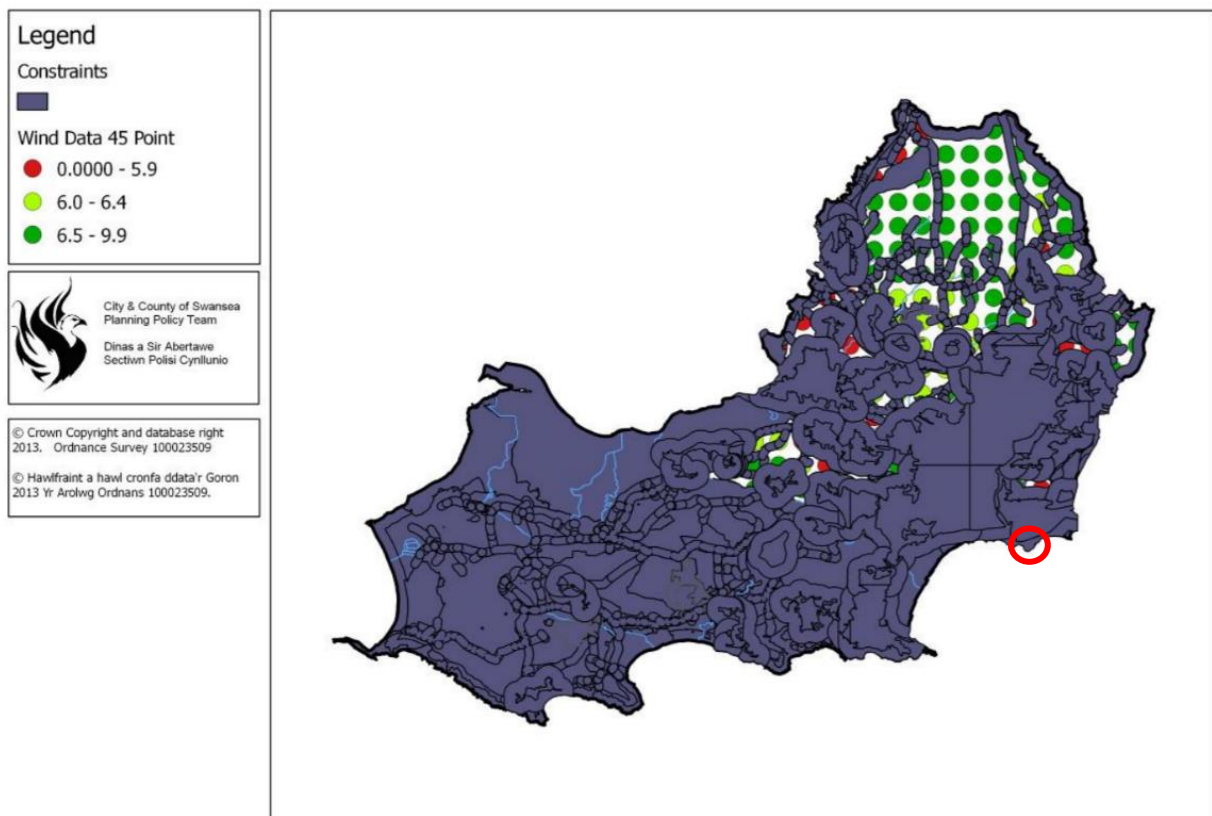
URL: https://energypolicy.columbia.edu/sites/default/files/Center%20On%20Global%20Energy%20Policy_Solar%20Together_April%202016.pdf

Accessed: 28/03/2019

A.14: All wind power constraints in Swansea, including wind average speeds (m/s) (**City & County of Swansea Renewable Energy Assessment 2015**).

URL: <https://swansea.jdi-consult.net/.../Renewable%20Energy%20Assessment%202015.pdf>

Accessed: 03/03/2019



The UWTSD SA1 site has been broadly assessed as unsuitable for wind turbine implementation by surveyors at Swansea City Council.