The Norwich Solar System

Technical Report

Norwich
Business
Improvement
District

Norwich Solar System Feasibility Study

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Version 2

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Executive Summary

This report describes an approach and methodology which was developed to identify the optimal sites for generating electricity by rooftop photovoltaic systems across the Norwich Business Improvement District. Three hundred and seven sites were found to be optimal but would be subject to planning permission, structural integrity of the roofs to mount arrays and approval by UK Power Networks in order to be installed and connected. Other roofs, such as those with east-west aspect may also be suitable but were not considered in this initial analysis.

Key findings from this feasibility study include:

- If all of the identified sites were permitted, up to 146% of the annual electricity consumption from a Business Improvement District (BID) membership of 750 businesses could be generated.
- Some 25 thousand tonnes of carbon dioxide (equivalent) emissions could be avoided over a twenty year system lifespan, equivalent to removing the emissions from driving an average car over 145 million kilometres!
- Businesses vary widely in their annual energy consumption but by using Government figures for non-domestic electricity consumption we were able to estimate the range within which all installations could pay back their capital expenditure (capex). This was between 3.75 and 18 years across all sites. However some consumers could achieve this far quicker, especially if systems were sized to limit the amount of surplus energy requiring export and larger systems achieved an installed price of less than £1,300/kW_{peak} - which was used as the standard cost across the study.
- It was recognised that collaborative buying and installation contracts could also help to reduce capex.
- The concept of a *pico grid* was considered as a means to support a local energy market trading surplus energy from installations by businesses in Norwich city centre. Opportunities could exist both behind and in front of supply meters, subject to Supplier cooperation and extant metering arrangements.

The approach overall was recognised to have various potential errors which are discussed, but this study is only intended to offer an initial survey of what could be achieved and in its favour, the costs are probably over-estimated and the efficiencies of modules compared to new PV technology coming to market in the next few years, under-estimated.

Introduction

The total amount of solar energy that can potentially be collected on the land surface of the Earth is enormous. Allowing for energy reflected back to the sun, averaged over an entire year, approximately 342 Watts of solar energy fall upon every square meter of Earth. This is a tremendous amount of radiation—44 quadrillion (4.4 x 10^{16}) Watts of power or about 385 million TWh of energy over the course of a year.[1] This is equivalent to approximately 15,000 times the total global electricity consumption and about 2,300 times all primary energy consumed in 2021.[2,3] Of course, this figure represents the maximum amount of solar energy that could potentially be harvested under ideal conditions, assuming that all available land surface was covered with solar panels and that they were 100% efficient in converting solar radiation into electricity. In reality, the amount of solar energy that can be practically collected will depend on a range of factors, including the availability of suitable surfaces to mount collectors and PV modules, their energy conversion efficiency, and the cost of installation and maintenance.

Despite these limitations, solar energy is becoming an increasingly important source of clean electricity around the world, as the cost of solar panels continues to decline and as governments and businesses invest in renewable energy as part of efforts to reduce greenhouse gas emissions and combat climate change. The Levelised Cost of Electricity (LCOE) from photovoltaics (PV) is also likely to continue to decline based on the continuing improvements to PV module efficiency.[4]

Based on UK Government statistics for Norwich in 2021, the median non-domestic electricity consumption was 5,972 kWh per electricity meter.[5] The median non-domestic gas consumption was 163,919 kWh per meter in 2021.[6] Adding these figures together gives us 169.9 MWh/$year_{2021}$ as the median energy consumption value for a non-domestic customer, assuming there is only one electricity and one gas meter per customer premises. Not all businesses conform to the median consumption value however, and the average value for electricity consumption in 2021 by non-domestic premises in Norwich is reported to be 39,941.7 kWh (the mean value for gas consumption is also a lot higher at 660,928.4 kWh in 2021). As there are 750 businesses members of the Norwich BID, we could estimate their total median annual energy consumption, based on the above statistics, is 750 x 169.9 = 127 GWh in 2021, although not all businesses will have their own meter as many premises are shared. However, as the BID catchment has an estimated area of 293 ha (2,927,956m^2 measured in ArcGIS[7]) and an average solar insolation of 1000 kWh/m^2/year (the value for Norwich used in our estimates), the gross solar energy incident upon Norwich is about 2,928 GWh/yr. To put this in perspective, this is about 23 times more than the total median energy (electricity and gas in kWh) and about 5.6 times the *average* (or mean) value of energy consumed by businesses in the Norwich BID catchment. While we will never be able to collect and convert

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1 https://www.nasa.gov/pdf/135642main_balance_trifold21.pdf

2 https://www.statista.com/statistics/280704/world-power-consumption/#:~:text=Global%20electricity%20consumption%201980%2D2021&text=The%20world%27s%20electricity%20consumption%20has,increased%20by%20roughly%2075%20percent.

3 https://www.statista.com/statistics/265598/consumption-of-primary-energy-worldwide/

4 https://www.nrel.gov/pv/cell-efficiency.html

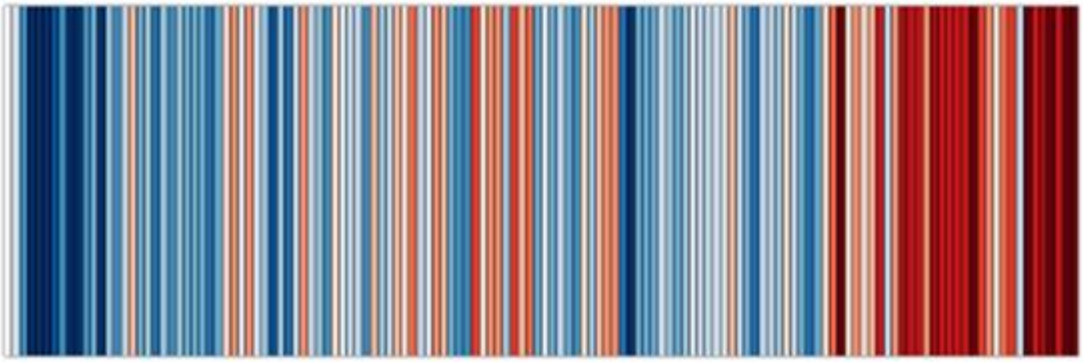
5 https://www.gov.uk/government/statistics/regional-and-local-authority-electricity-consumption-statistics

6 https://www.gov.uk/government/statistics/regional-and-local-authority-gas-consumption-statistics

7 https://www.esri.com/en-us/arcgis/about-arcgis/overview

all the solar energy incident on Norwich and put it to use powering and heating our businesses, this snapshot of the magnitude of solar energy gives a context to why trying to do so is worthwhile.

There is another reason as well that speaks for itself in the form of the 'Norwich Stripes' - an iconic depiction of the annual average air temperatures for the city since 1882. The effect of global warming is reflected in the concentration of darkening red stripes as we pass through time from left to right.



Norwich Annual Average Temperature 'Stripes' 1884 - 2022 courtesy of Tyndall centre for Climate Change Research, UEA

The Tyndall Centre for Climate Change Research has conducted an analysis of local authority carbon emissions budgets throughout the country in order to understand what targets should be set in order to be consistent with limiting global warming to 1.5°C by 2100 under the Paris Agreement of 2015. Based on their analysis, for Norwich to make its 'fair' contribution as part of the total UK commitment towards the Paris Climate Change Agreement, the following recommendations should be adopted:

1. Stay within a maximum cumulative carbon dioxide emissions budget of 3.4 million tonnes ($MtCO_2$) for the period of 2020 to 2100. At 2017 CO_2 emission levels, Norwich would use this entire budget within 7 years from 2020.
2. Initiate an immediate programme of CO_2 mitigation to deliver cuts in emissions averaging a minimum of -12.7% per year to deliver a Paris aligned carbon budget. These annual reductions in emissions require national and local action, and could be part of a wider collaboration with other local authorities.
3. Reach zero or near zero carbon no later than 2043. This report provides an indicative CO2 reduction pathway that stays within the recommended maximum carbon budget of 3.4 $MtCO_2$. In 2043, 5% of the budget remains. This represents very low levels of residual CO_2 emissions by this time, or the authority may opt to forgo these residual emissions and cut emissions to zero at this point. Earlier years for reaching zero CO_2 emissions are also within the recommended budget, provided that interim budgets with lower cumulative CO_2 emissions are also adopted.

This report describes the process to estimate how much solar energy we could generate from the commercial rooftops we have identified as optimal sites in the Norwich BID catchment area, which in turn will contribute to the mitigation of carbon emissions and support the city's carbon budget.

Background

With the recent energy price surge affecting businesses and a growing momentum to decarbonise, there is an urgent need to explore rooftops within Norwich City Centre for generating low-cost electricity. The *Norwich Solar System* (NSS) project is aimed at enabling organisations to exploit viable PV generation opportunities as well as break-down *siloed thinking.* Critically, it supplements established initiatives driving Net Zero in Norfolk, such as the Norfolk Climate Change Partnership (NCCP) and Norwich Climate Commission (NCC) as well as the success of the *Net Zero Expo*, held at the Norwich University of the Arts (NUA) in 2022.

Recognising Norwich as a place of existing networks a further aim is to draw people together geographically, rather than just by sector, providing significant insights as well as building capacity amongst SMEs to create and use knowledge among themselves through collaboration and synergy around knowledge exchange. As such, the NSS project offers potential to attract new sources of funding and capital investment in Norfolk, given that 20% of its GVA is derived from economic activity in Norwich. But beyond that, it also promotes Norwich as a place leading national innovation and supports a new campaign by the BID called *Work in Norwich.*[8]

The Norwich Solar System is a project delivered by the Norwich Business Improvement District funded through the Norfolk Investment Framework (NIF) under the thematic objectives laid out in that framework as follows:

Business Growth and Innovation
TO6: Support Norfolk's existing and emerging clusters to grow and expand in Norfolk;
TO6A: Establish Net Zero business clusters;
TO6B: Drive creation of new clusters, using Norfolk's assets;

Climate Change
TO7: Mitigate the constraints imposed on Norfolk's economy by climate change;
TO7A: Circular systems for water and energy re-use'
TO8: Reduce the costs and maximise the opportunities of the transition to Next Zero;
TO8A: Initiatives to help Norfolk to transition to Net Zero;
TO8B: Support to build Net Zero businesses.

The Norwich BID area membership comprises 750 businesses which are located within 8 subdistricts, or quarters, known as:

1. Cathedral Quarter
2. King Street Quarter
3. Riverside
4. Creative Quarter (Over the Water)
5. Castle and Market Place
6. Norwich Lanes
7. Chapelfield

[8] https://www.norwichbid.co.uk/what-we-do/voice-for-business/norwichs-inward-investment-campaign/

8. Business District

A collaborative approach to achieving the thematic objectives laid out above was taken, underpinned by *District Dialogues* at a hyper-local level within each of the quarters, usually hosted on the premises or making reference to, an established local user of rooftop Photovoltaic (PV) generated electricity within each subdistrict. Understanding of the potential for rapid transition towards a Net Zero economy through early stage business community consultations was seen as a highly desirable approach to developing vital partnerships that could then be followed by prioritisation of projects in workshops conducted by the Norwich Net Zero Business Network. In the initial phase these workshops would fully explore the potential and make preparations for future project delivery.

This document reports on the Norwich BID proposal known as the Norwich Solar System (NSS). Findings from the research and analysis gained in studying the rooftop potential for PV systems and the knowledge and key insights from the eight district dialogues are presented. It is hoped that its impact will:

- Provide support to SMEs struggling with the current crisis and promote more competitive businesses;
- Build business resilience by cross-fertilisation of ideas;
- Identify exciting projects that could have major impacts on climate change, but also the viability of High Streets;
- Help to combat the current energy crisis;
- Identify pathways to cutting carbon emissions & increasing energy sustainability and higher degrees of energy independence;
- Generate revenue from community energy business activity into community action supporting others;
- Provide energy to SMEs at best possible price;
- Improved flora diversity and resilience in the BID catchment area.

Vision for a rooftop solar farm

The Norwich Solar System is a *rooftop solar farm* proposed by Norwich BID to assist business resilience and energy affordability but also, in doing so, to help Norwich meet its net zero target date.

There are approximately 750 businesses within the Norwich BID membership, with many more in Norwich City and potentially large amounts of electricity could be generated from the best-suited rooftops of these non-domestic premises. It would therefore make sense for development of the NSS concept to integrate within a Local Area Energy Plan (LAEP) for Norwich which could be commissioned by the City Council to engage and motivate local energy stakeholders, including users, generators and network operators, in a coordinated programme of decarbonisation. As policy and legislation regarding the development of an entity like a rooftop solar farm is piecemeal, much of the development approval process will fall upon local authorities. Government offers general Low carbon Technology (LCT) planning advice for this purpose.[9] Ofgem have also concluded a recent consultation on arrangements affecting local government and energy with the results due to be published towards the end of 2023.[10] Their vision is for more local government facilitation to ensure effective participation between local actors in a *whole system* place-based energy transition.

As many commercial buildings in Norwich are converted Victorian domestic properties, PV installations could be advised to conform with domestic Building Regulations Part A (Structural Safety)[11] and Part P (Electrical Safety).[12] Many standards exist covering electrical safety and materials for installing renewable energy systems of different capacities including PV generators, Battery Energy Storage Systems (BESS), solar thermal and small wind generators. To build a PV generator, or any associated equipment, that connects to the public electricity distribution network, the approval and collaboration of UKPN would be necessary from a regulatory point of view (regulations G98 and G99 apply).[13]

Considerations with respect to local planning

The Tyndall Centre for Climate Change Research have calculated that in order for Norwich to align with the conditions agreed by the UK government under the United Nations Paris Agreement, a 12.7% year on year reduction in the city's CO_2 emissions is required out to the end of this century. Failing to do so will spend the locally determined carbon budget of 3.4MtCO_2 for Norwich city within 7 years, from 2020![14]

Sometimes conflicts arise between those wanting to contribute to the decarbonisation of their activities and those that wish to preserve the built environment in the name of heritage. Examples of such cases where planning approval for rooftop PV has been denied are plentiful.[15,16] Norwich is heavily populated by listed buildings within a conservation area that will have standards set by the Council as to what is *permitted development*. Current circumstances involving climate change and the Council's declarations of net zero targets will possibly demand a reassessment of the planning standards behind cumulative impacts upon the look of the Norwich roofscape. Recognising the importance of PV in both rooftop and ground-mounted installations to help reach net zero, the government has recently implemented a *Solar Taskforce*.[17] It has committed to achieve a fivefold increase in solar PV deployment (up to 70GW) by 2035 and is working to publish the results of its recent consultation on Permitted Development Rights.[18]

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9 https://www.gov.uk/guidance/renewable-and-low-carbon-energy

10 https://www.ofgem.gov.uk/publications/consultation-future-local-energy-institutions-and-governance

11 https://www.gov.uk/government/publications/structure-approved-document-a

12 https://www.gov.uk/government/publications/electrical-safety-approved-document-p

13 https://www.ukpowernetworks.co.uk/electricity/distribution-energy-resources/installing-large-scale-distributed-generation

14 https://carbonbudget.manchester.ac.uk/reports/E07000148/

15 https://www.bbc.co.uk/news/uk-england-northamptonshire-65421487

16 https://www.bbc.co.uk/news/uk-england-essex-65780417

17 https://www.gov.uk/government/groups/solar-taskforce

18 https://www.gov.uk/government/consultations/permitted-development-rights-supporting-temporary-recreational-campsites-renewable-energy-and-film-making-consultation/permitted-development-rights-supporting-temporary-recreational-campsites-renewable-energy-and-film-making-consultation

If one of the biggest challenges to implementing a rooftop solar farm on commercial buildings in Norwich is the proximity of a large number of historic buildings and churches, then the BID, its members and Norwich City council should work closely together to agree the terms of sensitivity to the cumulative impacts upon a place from multiple *permitted developments.*[19] Normally a permitted development of rooftop PV would conform to the following criteria:

- Roof-mounted or wall-mounted commercial solar panels should project no more than 200mm from the wall surface or roof slope;
- With pitched roof and flat roof installations, the panels need to be situated at least 1m from the external edges of the roof, or the wall joint that they sit on;
- With flat roof installations only, the roof-mounted panels should protrude less than 1m from the roof surface, and they cannot be the highest part of the roof (excluding the chimney).

PV is already recognised as a relatively cheap retrofit intervention to decarbonise buildings, raising their Energy Performance Certificate (EPC) rating and also their value. Inevitably this addresses the *time value of carbon*, or to put it another way, if we have and deploy a solution that can make a credible reduction in our carbon emissions now, it has a greater value over time (the integral value) than delaying its deployment, as its impact accumulates. Businesses as a major source of carbon emissions have an important role to play alongside their local communities in achieving net zero targets. Some advice for orienting businesses towards lowering their carbon footprints and further detail about how employees can engage to support this change has been produced by Project Drawdown.[20]

Financial investment considerations

Investing in a solar PV generator system presents a capital expense proportional the scale of the installation. However, some of the options to consider that can help to make a positive case for any business, are described below:

- Currently, VAT on installing a solar generator can be fully recovered by VAT registered businesses. It reverts to 5% in 2027.
- PV generators are included within the scope of the Annual Investment Allowance (AIA) which means businesses can offset the cost of their investments in solar (and other renewable generation technologies) against their tax bills. A business can claim 100% of the capital expense for installing a solar generator up to £1 million in the year. If this limit has already been reached due to other eligible claims, then the business may be able to claim up to 50% of the capex under a First Year Allowance;
- The money saved by consuming self-generated electricity will be proportional to the contracted tariff, which recently has been as much as £0.60 per kWh. Higher tariffs bring forward the breakeven point of return on capex investment;

[19] https://www.planningportal.co.uk/permission/responsibilities/planning-permission/permitted-development-rights
[20] https://www.drawdown.org/sites/default/files/210920_Drawdown_AtWork_06.pdf

- The efficiency of PV modules continues to increase, meaning that systems can generate more electricity per square metre, which adds to the pace of capital recovery through self-consumption for the same roof area occupied;
- The export tariff for surplus solar energy has tripled since the Smart Export Guarantee (SEG) began at around £0.045 per kWh, to £0.15 per kWh currently paid by suppliers such as Octopus and Scottish Power;
- Depending on how the Norwich Solar System develops, collaboration in a Norwich City Centre-wide project could attract green investment finance and purchasing through a buyers collective for at scale discounts. Commercial finance with zero upfront payment for carbon reduction interventions such as PV are available from a wide range of organisations like Thrive Renewables[21] and Smart Ease;[22]
- There may also be an opportunity to have a system installed free of charge by a third party such as The Big Solar Coop, who are financed by community energy investors. Under this approach, the occupant pays for the clean energy they consume at a discount to their supplier tariff, but the expense of installation and maintenance falls to the installer who retains ownership of the system under a roof space lease contract.[23] An example of how this works from the investors' perspective would be the recently issued 'Brighton Energy Cooperative 5 year Solar Bond';[24]
- Installing rooftop solar is likely to increase the buildings' Energy Performance Certificate (EPC) rating which would improve its sale value.
- Bigger systems need more inverters and the lifespan of a typical inverter is around 10 years, compared to solar modules which are around 25 years;

Worked examples, modelled in OpenSolar, for the principal financial considerations when investing in a solar generator are presented in Table 0, below. Two different array capacities were modelled for the same roof pitched at 34.8˚ and an azimuth angle of 170.6˚ from north. A 7% increase in energy costs per year has been assumed for a 20 year life span of the modelled systems.

The results illustrate the economy, in terms of capex break-even point and return on investment, from sizing the array to limit the amount of surplus energy earning £0.15/kWh, while still satisfying a high proportion of the consumed energy worth £0.45/kWh (in this example). However, over the life of the system greater net savings accrue to bigger systems. In the case of the pico grid example (see below) export tariffs to neighbouring energy offtakers would be set under a *Power Purchase Agreement* (PPA) and are likely to be higher than the SEG price while still offering a discount to the offtaker's Supplier import price. In this case there would be added revenue benefit to the economy of an over-sized array as per System 1.

Table 0: Key financial metrics for PV systems of different sizes		
	System 1	System 2

[21] https://www.thriverenewables.co.uk/projects-seeking-investment/

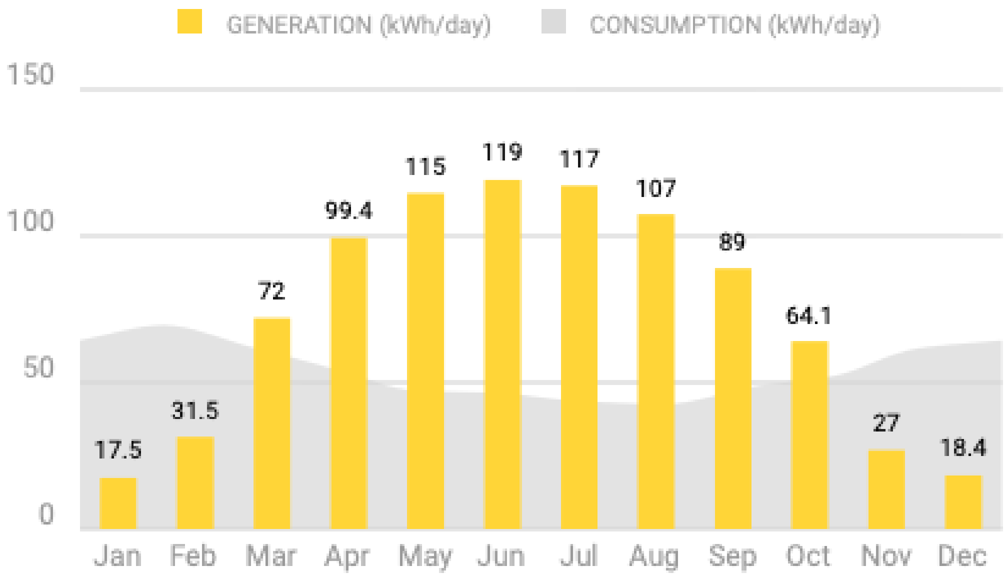
[22] https://smartease.uk/energy/

[23] https://bigsolar.coop/get_solar/

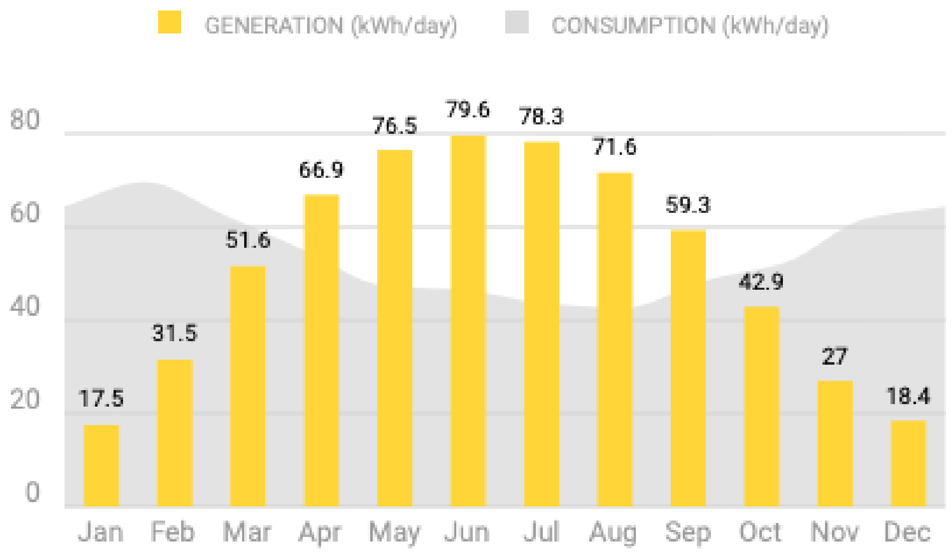
[24] https://www.brightonenergy.org.uk/2023/07/brighton-energy-launches-6-5-5-year-solar-bond-invest-now/

Assumed annual consumption by business	20,000 kWh	20,000 kWh
Import tariff	£ 0.45	£ 0.45
Export tariff	£ 0.15	£ 0.15
Standing charge	£ 0.40	£ 0.40
Annual bill	£ 9,146.00	£ 9,146.00
PV installation cost	£ 1,300 per kWp	£ 1,300 per kWp
Installed PV system	30.5 kWp (57 x 535W Canadian Solar panels)	20 kWp (38 x 535W Canadian Solar panels)
PV generator capex	£ 39,644	£26,429
Annual generation output	26,770 kWh	18,923 kWh
Generation/Consumption ratio	1.34	0.95
Payback period	6 years 2 months	4 years 11 months
Estimated net savings over 20 year lifetime	£ 148,000	£138,000
Return on Investment (savings/capex)	379%	531%

Figure 0 presents the energy generated (yellow) by each system in Table 0, against a typical annual consumption profile (grey). Surplus generated energy is assumed to be exported at the rate indicated in the Export tariff.



System 1



System 2

Figure 0: Graphs of daily energy generated against consumption over the period of a year.

A note about waste

The Norwich BID is actively supporting a circular economy strategy for businesses and so it is appropriate to mention waste from PV modules. As they reach the end of their designed service life of a nominal 25 years, the question facing us is what to do with the materials that are intimately bonded in making up a PV module. This will become a very real and pressing issue going forward for which it would be advisable to develop a local recycling plan in conjunction with installers. Currently it is reported that while the UK government is aware of the issue, only one operational recycling plant for PV modules currently exists in Europe.[25]

The next two sections outline the approaches adopted and summarise the findings from the technical studies and business engagement events conducted for each sub district as well as reporting on the final summary conference.

[25] https://www.bbc.co.uk/news/science-environment-65602519

NSS Technical study

The technical study aimed to identify the best rooftop locations for collecting solar radiation and converting this into electricity using PV systems on commercial premises within each Norwich BID subdistrict. Case studies were then conducted on the most viable rooftops from each sample, and estimates of generation capacity and output were made. It is recognised that these are only approximations of what may be possible and that detailed studies by professional PV installers will be required to finalise any installation. Within these studies, critical criteria such as roof structural capacity to accommodate the extra weight of a solar array, the kind of fixings required to mount it according to the roofing material and the capacity of the UK Power Networks (UKPN is the owner-operator of the local public electricity network in Norfolk) electricity network to meet regulatory requirements will all need to be satisfied. The sizing of components in any proposed array will also take account of the host building electricity consumption (gross monthly or annual demand as well as instantaneous peaks) in order to be designed according to its intended purpose.

As discussed above, in the sizing of the generator, self-consumption of generated electricity could be prioritised over having surplus to export to make the economic case that justifies the capital expenditure against the returns on the investment and when the capex will be repaid. With some businesses facing economic hardship imposed by the rapid increase in electricity prices in 2022, the timing of electricity contract renewals and the changing of Government-backed support packages, has impacted heavily upon business continuity.[26] This issue is potentially of greater importance to SMEs currently than concerns about reducing the carbon emissions due to their energy use. But under the Environment, Sustainability and Governance (ESG) policies of larger companies, there is more concern. However the benefits for using self-generated, or hyper-locally generated electricity, would go some way to addressing both the cost and the carbon reduction issues. In making this initial analysis, we aimed to show how much PV electricity could be generated from harvesting incident solar radiation at particular locations, rather than the concerns of tailoring the array to the individual requirements.

If a rooftop installation is oversize compared with the host building demand (notwithstanding seasonal variations in generation and demand) and surplus electricity is available, it could be stored on site or in nearby battery energy storage systems (BESS) and reused at a time when there is no generation available from the PV modules (eg. at night). A further extension could be established to charge electric vehicles (EVs), or use in water heating as another form of energy storage. These options could prove more economically favourable over the lifetime of a system.

Pico grid concept

The concept of *pico grids* was discussed in a subsequent *meet the experts* surgery with UK Power Networks on the 5th April 2023 the Distribution System Operator (UKPN became a DSO at the start of April 2023). While it may be technically possible to physically connect adjacent buildings

[26] https://www.cornwall-insight.com/press/businesses-facing-up-to-133-electricity-bill-rise-for-fixing-at-market-peak/

through short *private wires*, it is likely to be challenged under current market rules set by Ofgem.[27] The reason for this is the design of the UK energy market which permits only one Supplier to each Meter Point Administration Number (MPAN) - the number that registers an electricity meter connected to the grid for measuring electrical imports to meet electrical demand and exports, the surplus energy, once internal demand is satisfied, that could be generated by a PV array.[28] An export and import meter on the same premises would require two MPANs, and open the possibilities for a different Supplier administering import and export.

The issue of management of surplus generated energy by a rooftop PV system was discussed and UKPN suggested that consideration could be given to creating interconnections via private wire(s) to adjoining buildings in order to utilise surplus energy exported from the generator host building. The term *pico grid* was coined to describe this kind of electrical architecture (Figure 1) which could potentially also serve to charge electric vehicles via an intermediary Battery Electric Storage System (BESS).

[27] A private wire enables electricity to pass between a source such as a renewable energy generator and an end user without the use of the public network. A generator owner may also consume some electricity on site and export any surplus to a neighbouring end user via the private wire.

[28] There was a proposal tabled to change the current limitation of Supplier monopoly over the MPAN, in order to enable innovation in local electricity supply and markets, however this was withdrawn on the basis of the cost of implementing the change.. See - P379 'Multiple Suppliers through Meter Splitting

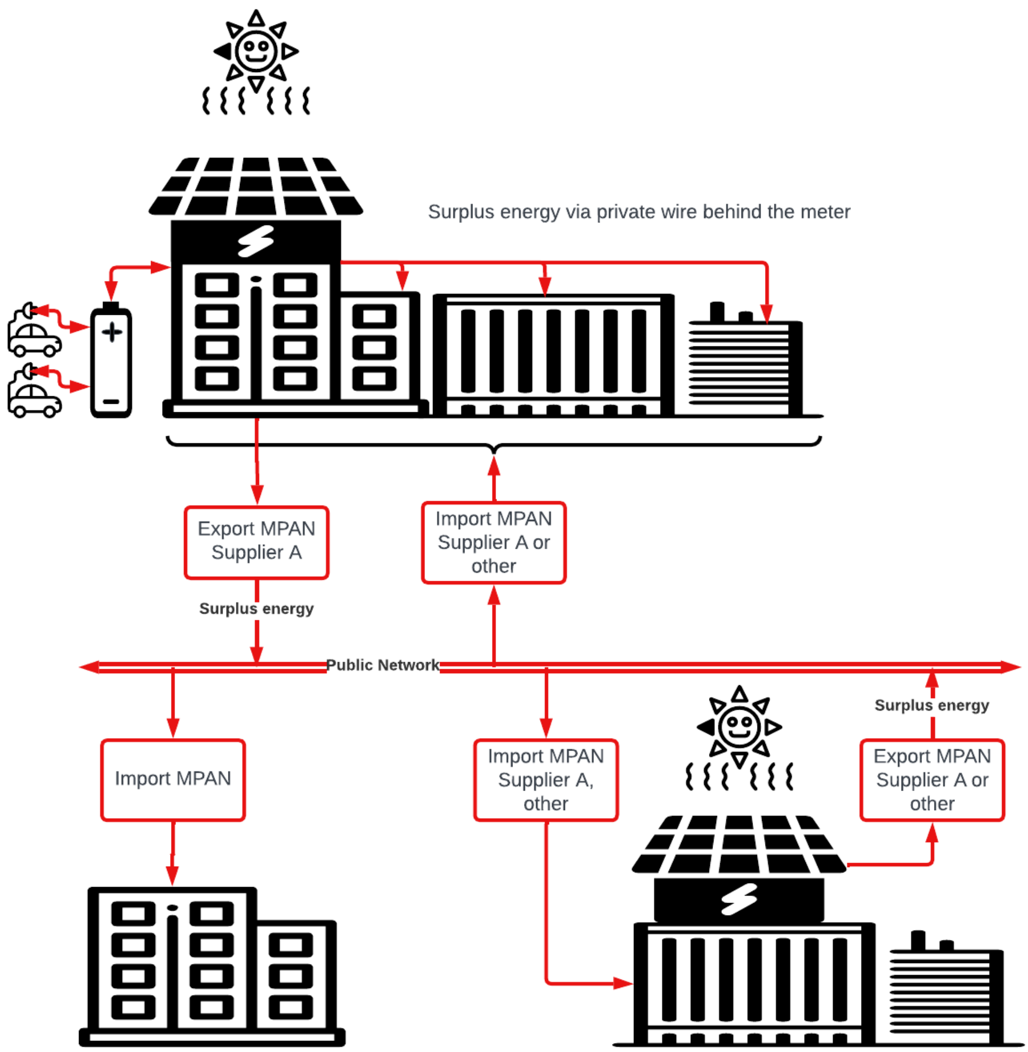


Figure 1: Pico grid utilising both private and public wires with EV charging station

For example, an owner of a large rooftop PV generator could choose to share surplus energy, after self-consumption requirements are satisfied, with local consumers either within the same building or adjacent to it. Allume's *SolShare* was designed for distributing energy to multi-tenanted blocks of flats but may offer an opportunity for use with commercial tenants in this scenario.[29] However, the energy can only be shared within the scope of the 'import MPAN' registered to the PV generator of the host building. This is what is known as a *behind the meter* setup and any large multi-tenanted prem ises may have more than one MPAN. If energy is to be shared in the domain of a different import MPAN, then the intervention of the Supplier registered to that MPAN is required as well as the use of the public network to transport the energy. The exported energy to another import MPAN is administered through an 'export MPAN'. Note, the export MPAN belonging to the PV generator can be registered to a different Supplier than the import MPAN of the building where the PV generator is located.

29 https://allumeenergy.com/uk/solshare/?gclid=CjwKCAjw3ueiBhBmEiwA4BhspLYTe0pe7lmdRvgh3VZPU9UsNIF5LCF7rLFT_RbAGOzWvfU8u4euwxoCPJ4QAvD_BwE

Exported energy travels through the wires of the public network, incurring Distribution Use of System (DUoS) and Transmission Use of System (TUoS) charges, which put additional cost to the buyer on each kWh purchased. Buying arrangements (sometimes called *sleeving arrangements*) under a Power Purchase Agreement (PPA) are agreed between the exporter and importer which set out terms for quantity, cost, timing and delivery of the energy. In the absence of a targeted export arrangement, (there are several other examples - such as selling energy on a *flexibility market*) the Supplier registered to the export MPAN purchases the exported energy, often at a lower cost per kWh than is achievable under a PPA.

These scenarios could, in the case of the Norwich Solar System, be replicated many times and form the components of a local electricity ecosystem, or *peer-to-peer* trading system which could manage the selling, buying and billing transactions by using an application such as UrbanChain.[30]

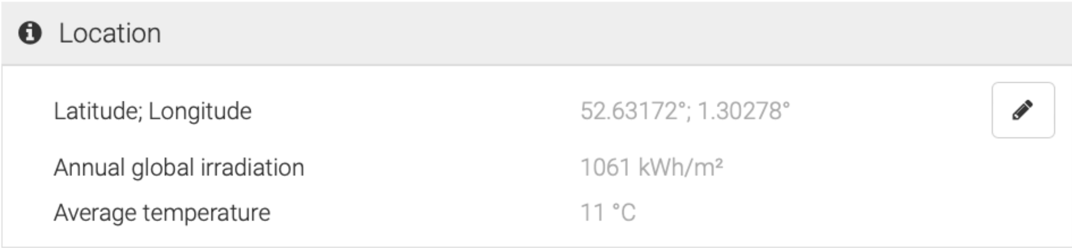
Approach and Methodology

We approached estimation of the potential to generate electricity from rooftop PV systems in the BID catchment area by firstly building a digital surface model (DSM) using ArcGIS, removing the residential buildings and then applying a solar radiation tool to identify the roofs that receive most solar radiation in accordance with a set of criteria imposed as filters upon the data. To select only optimised locations for rooftop PV, the coefficient values used in each filter were established from solar industry installation advice, such as for PV module azimuth and tilt angle ranges, as well as typical solar insolation values received at the latitude of Norwich (Figures 2 and 3).

	Orientation from North						
	W			S			E
Tilt	270°	240°	210°	180°	150°	120°	90°
0°	84	84	84	84	84	84	84
10°	84	87	90	91	90	87	84
20°	82	89	94	96	94	89	82
30°	81	90	97	100	97	90	81
40°	78	89	97	100	97	89	78
50°	74	87	95	98	95	87	74
60°	69	82	92	95	92	82	69
70°	64	77	86	89	86	77	64
80°	57	69	78	81	78	69	57
90°	50	61	68	71	68	61	50

Figure 2: Tilt and Azimuth range values were adopted for the ranges offering 94-100% solar gain

30 https://www.urbanchain.co.uk/



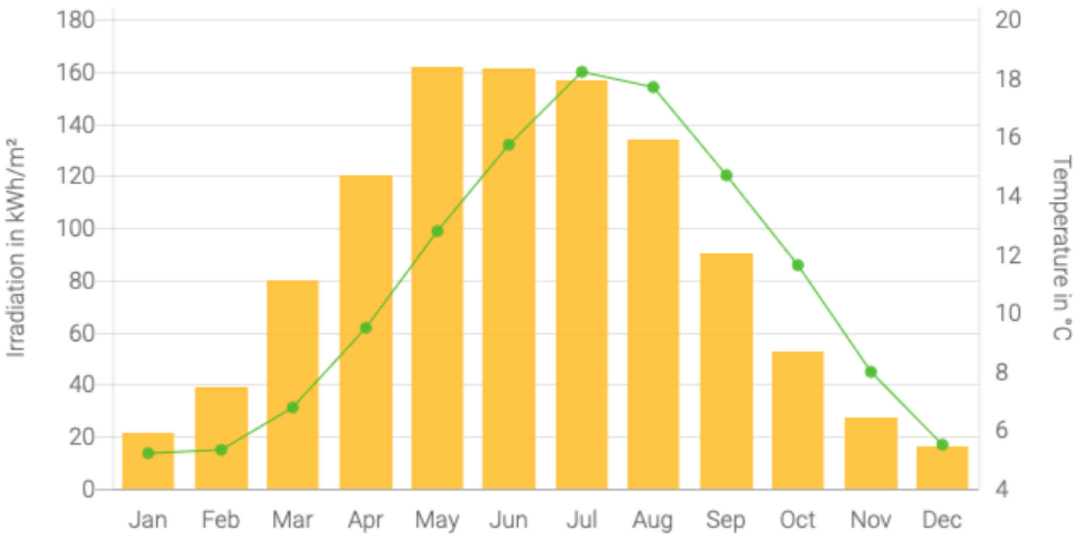


Figure 3: Typical mean annual solar irradiation and temperature for Norwich

The ArcGIS tool found rooftop areas according to the criteria set and mean annual solar radiation values which were then treated with further filters to derive estimates of potential annual electrical energy generation from the sample of roofs identified. Models of solar arrays on a sample of these roofs were then built in the OpenSolar tool[31] to compare with the theoretical values for annual generation derived in ArcGIS. An iterative sensitivity analysis to derive filter coefficients followed, to calibrate the generation values derived from each tool to within ±10% of each other in most cases. Some variation on this was necessary because of the way the DSM identified buildings. Different treatments of pitched and flat roofs were necessary for building an inclusive understanding of the solar potential. This approach broadly followed the methodology reported in work by Koch et al.[32], and Guillén-Lambea et al.[33] and is summarised in Figure 4, below.

Once the approach was calibrated to achieve a reasonable level of alignment in results between the two tools, it was possible to derive energy metrics for each Norwich BID Quarter as well as represent the abated carbon emissions with various analogues, including avoided car kms and long-haul flights as well as the equivalent carbon sequestration by Sitka Spruce trees planted and managed in a recognised manner, over a 20 year system lifetime. Assumptions behind these analogues are explained below.

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[31] https://www.opensolar.com/

[32] https://www.mdpi.com/1996-1073/15/19/6991

[33] https://www.sciencedirect.com/science/article/pii/S0048969723016960

It must be emphasised that this approach, being only desk based, can not guarantee the viability of any rooftop identified in the study for a PV system and that it would be necessary for a professionally certified installer to carry out the appropriate checks before a PV generator could be commissioned. This would normally include a roof structural survey as well as approval of the installation by UKPN as it is to be connected to the public electricity network. Various other considerations are identified concerning the estimation of generating capacity in the following discussion.

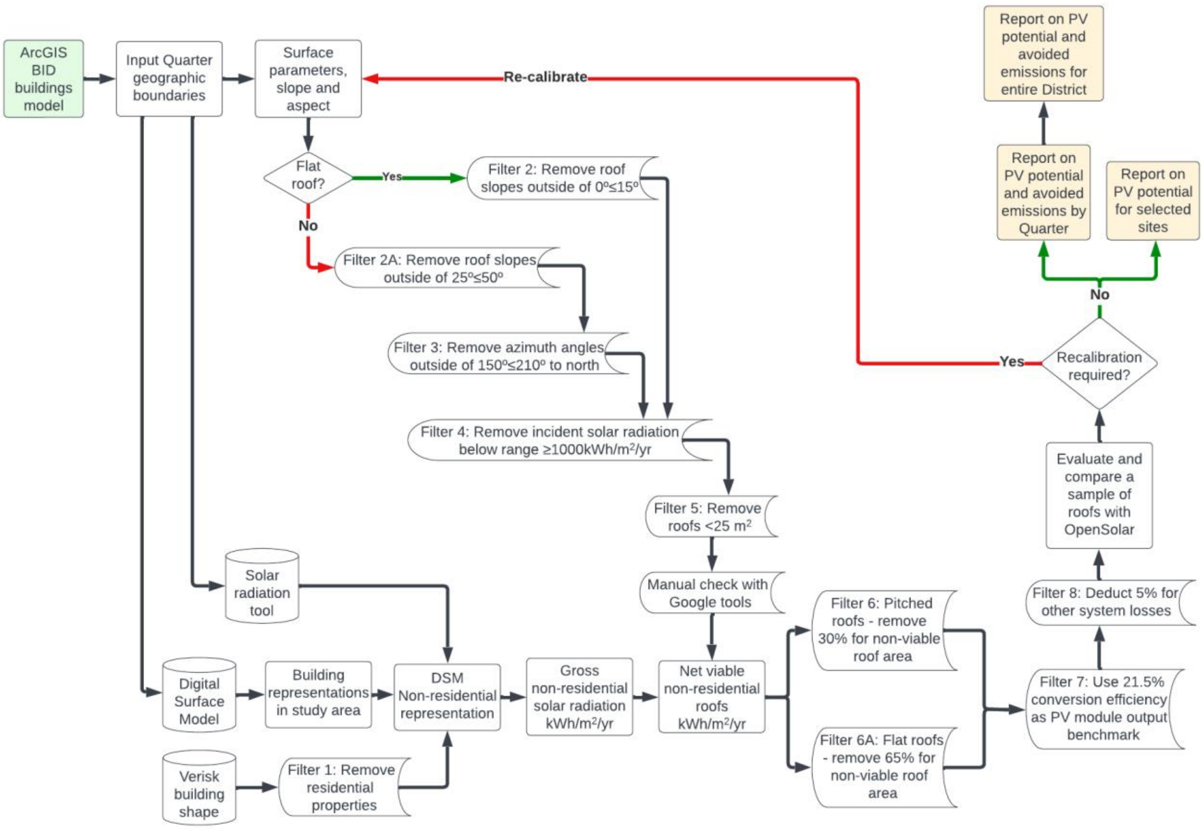

Figure 4: Summary of approach used to derive estimates of PV generation capacity for Norwich BID

Explanation of GIS criteria and filters

ArcGIS is an industry standard Geographic Information System platform that is capable of spatial 3D analysis and mapping of the earth's surface in data layers (Figure 5), including the built environment.[34] We used it to model and then analyse the rooftops of the Norwich BID area according to data for solar insolation, removing those buildings known to be residential only (Filter 1). A separate Digital Surface Model (DSM) was used to input data to the GIS tool describing the elevation topology of buildings across Norwich City Centre, and a solar tool applied the data for the insolation incident upon Norwich. Sky diffusivity of 40% and transmissivity of 50% were set to represent the sky above Norwich. Insolation values were then assessed in intervals of 3 hours to allow for a more accurate profile of the annual

[34] https://www.esriuk.com/en-gb/arcgis/about-arcgis/overview

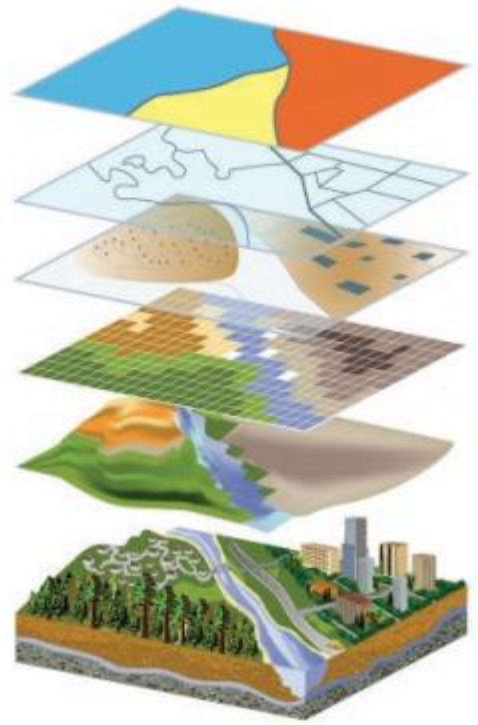

Figure 5: ArcGIS data layers used to represent details of the earth's surface.

solar energy received. Thirty-two solar azimuth and zenith measurement points were taken to estimate the solar radiation received by each rooftop 'solar cell' identified after ArcGIS had applied the values specified in our filters. The solar cells showing the insolation within the limits we set in ArcGIS were then overlaid upon the rooftops of the DEM.

Filter 2 and 2A in Figure 4, distinguish treatments of flat and pitched roofs. It was necessary to set these parameters in order to limit the number of roofs that ArcGIS would otherwise identify, reducing the amount of data to be processed while selecting the optimal roof spaces for PV arrays from a radiation received perspective.

To capture the most viable flat roofs, we set Filter 2 to exclude roof slopes outside of the range 0° and 15°, following industry best practice (Figure 6). We limited the roof slope to 15° to distinguish flat roofs from pitched, and hence the mounting considerations of an array (Figure 7). As flat roofs offer flexibility in terms of array azimuth angle, PV arrays could be aligned to face south, so azimuth angle was not placed as constraint in filtering of flat roofs.

Output data for London

Degrees from south	10° output/m² (kWh/yr)	30° output/m² (kWh/yr)	Increased output at 10°
0	84.3	55.3	52%
10	84.2	55.1	53%
20	83.9	54.7	54%
30	83.5	53.9	55%
40	82.8	53.0	56%
50	82.0	51.7	58%
60	80.9	50.3	61%
70	79.9	48.6	64%
80	78.7	46.9	68%
90	77.4	45.0	72%

Figure 6: Flat roof tilt and azimuth.

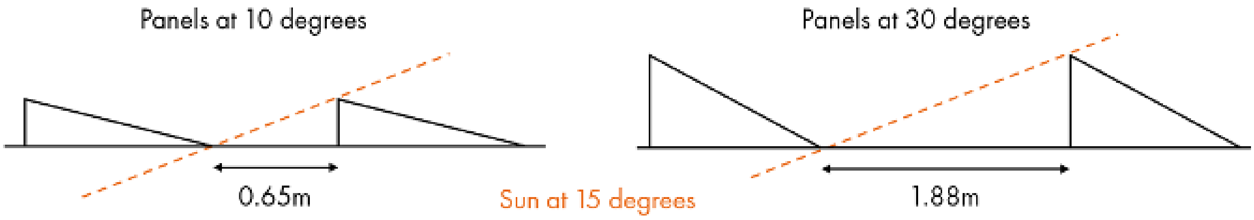

Figure 7: Panels set on flat roofs at different angles require differing spacing between rows to avoid shading.

Filter 2A however, imposed a range of roof slope angles between 25° and 50° to capture the optimum pitched roofs. Solar industry advice recommends an optimum tilt of 35° for London. We wanted to not exclude some roofs that were outside of this value, so we imposed a range in accordance with optimised values reported in Figure 2. Roofs outside of this pitch angle may still be viable for PV however, but if included in a modelling range down to 15° say, we would have also captured many more roofs most of which would not have been optimal candidates for a PV array.

Filter 3 then imposed an azimuth range of 150° to 210° on pitched roofs, to be able to identify those receiving most sunlight from a unidirectional (as opposed to a bidirectional East-West) perspective. It is possible that a solar array could be set up on a suitable roof with an east-west (90°- 270°) perspective, but this was not considered in our study due to the complexity of filtering suitable sites from Norwich's varied roofscape. We were aware that by introducing these constraints in the filtering of data, we may exclude some viable solar sites - for example roofs with an east-west orientation and those falling between 15° and 25° pitch.

In accordance with the data reported in Figure 3, Filter 4 then set a minimum acceptable value of 1000kWh/m²/year insolation for both flat and pitched roofs to exclude those receiving less optimal radiation. Filter 5 removed roof areas of less than 25m² that had passed previous filters. This was to ensure if a PV array were to be considered, it would be able to accommodate the area required by at least 8 typically sized 500W modules.

We then manually inspected each site using Google Earth to deselect candidate sites that had passed the filters yet were not suitable - such as demolished buildings and derelicts, roofs heavily shaded by trees or historic sites unlikely to achieve planning approval. Following the above approach would identify some buildings deemed out of scope for PV - such as Norwich Cathedral - but not the roof over the Cathedral refectory for example. We now had an approximation of the non-domestic roofs offering district solar potential by identifying the optimum non-residential roof spaces most applicable to siting of a PV array, subject to the usual pre-installation survey which would include:

- Assessment of shading from objects like trees, unidentified by our GIS survey;
- The building status and whether it has planning constraints upon it;
- A roof structural survey, including assessment of the capacity of its material make-up to support and secure a PV array without risk of damage, failure or leaks.

The next task was to convert the capacity of roofs with optimal solar insolation into estimates of electrical energy that could be generated annually from a PV array. The results from ArcGIS effectively gave gross estimates of this from multiplying viable area by annual solar insolation:

Area (m^2) x Solar insolation ($kWh/m^2/year$) $\rightarrow$ Energy (kWh/year)

As ArcGIS presents its viable roof area in terms of aggregate solar cells that pass our filter criteria, a fraction of the roof area identified would not be amenable to mounting a PV array in practice because not all of these solar cells aggregate in one place. A sensitivity analysis was therefore necessary to compare a sample of roofs identified by ArcGIS against arrays modelled in the OpenSolar tool. From this it was possible to derive the coefficients in Filter 6 and 6A with which we calibrated the outputs from ArcGIS into closer alignment with possibilities modelled in OpenSolar to mount PV arrays. We aimed for an error range between the two sets of results of ±10%. The sensitivity analysis for the Cathedral Quarter, our first survey district, resulted in a -2.69% divergence between ArcGIS derived and OpenSolar estimates for flat roofs, and -8% for pitched roofs which suggests our results to be underestimates of potential to generate electricity.

For the PV array modelling, we chose a 535 W Canadian Solar PV module as the standard module used to build all the arrays modelled (see Figure 7 for module specification.) It is rated as having a peak efficiency of 21.5%, which was the value used in Filter 7. Most high performance PV modules currently have a peak efficiency of at least 22% which will be surpassed in future with the launch of modules coated with a Perovskite layer, and be capable of over 30% conversion efficiency.[35] However, when these will be commercially available for use in rooftop applications (the highest performance modules are often targeted at ground arrays in large solar farms) will depend on market forces. All PV modules also decline in efficiency over time and may be only 85% productive at the end of their design life, normally after 25 years. Our estimates are based on first year, peak performance, generation outputs.

[35] https://www.cleanenergyreviews.info/blog/most-efficient-solar-panels

CS6W-535MS
Datasheet

Manufacturer :	Canadian Solar
Technology :	Mono-c-Si
SKU :	
Rated output power :	535 W
Width :	1.134 m
Height :	2.261 m
Thickness :	30 mm
Weight :	27.6 kg
V_{mp} :	41.1 V
V_{oc} :	49 V
I_{mp} :	13.02 A
I_{sc} :	13.85 A

Figure 7: The specifications of the Canadian Solar PV module used in OpenSolar to model the PV arrays.

Filter 8 deducted a further 5% of the total generation estimate to account for system losses such as from resistance in inverters and cables, dirt on the modules and temperature gradients. This may be considered low in comparison to the other approaches cited (with losses up to 20%), but we felt that the criteria set in Filters 6 and 6A compensated for this by squeezing the available solar insolation into an acceptable error band of ±10% after calibration.

From here it was possible to:

- Identify the optimal rooftops from a solar insolation perspective;
- Estimate the energy that could be generated from these roofs, subject to to detailed survey;
- Estimate the energy that could be generated by the roofs identified across the whole Quarter;
- Present the findings alongside a number of analogue measures for illustration purposes.

How analogue values were derived

Analogues were based on the annual electrical energy estimates over a 20 year system lifespan (this is also a conservative value compared to a typical service life of 25 years for PV modules). Conversion of the avoided emissions from electricity generation referenced the *UK Government Conversion Factors for Company Reporting* from the total kg of CO_2e per kWh generated in 2022.[36] Equivalents of avoided car and flight km reference the same conversion factors. A long haul flight from the UK was considered as being at least 4,000km. The value for Sitka Spruce trees, which are a fast growing species whose biomass could remove atmospheric CO_2 at a relatively rapid rate during the 200 year lifetime of the tree, was derived from Forestry Commission tables. Table 1 presents the values used in deriving analogues.

36 https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2022

Table 1: Conversion factors used in deriving analogue quantities		
Analogue	Conversion factor	Unit
Electrical energy (UK)	0.19338	$kgCO_2e$/kWh
Executive diesel car	0.174684	$kgCO_2e$/km
Long haul flight average passenger	0.19309	$kgCO_2e$/passenger km
Sitka Spruce tree	35.7231	$kgCO_2e$/tree/average year[37]

Outputs

Each Quarter studied resulted in a report that detailed the following criteria:

- Maps of the Quarter identifying optimal flat and pitched roof sites for the Quarter;
- Statistics for identified sites in terms of usage of the premises;
- Estimated annual generation output from optimal sites;
- Histogram of estimated site generation capacity over a year;
- Total estimated generation from viable rooftop sites by Quarter;
- Detailed models of two flat and two pitched roof optimal sites;
- Avoided emissions over a 20 year period of system operation;
- Equivalent representations (analogues) of the avoided emissions;
- A high level financial model scaled from an exemplar site within the Quarter. This was based on Government statistics for non-domestic median and mean annual electricity consumption for Norwich.[38] In each case, the amount of self-generated electricity used on site was deemed to be 50% at a tariff of £0.35/kWh, with the other 50% deemed to be exported, earning £0.15/kWh. No standing or network charges were included in the evaluation;
- All PV installations were costed at £1,300/kW_{peak} which is a conservative estimate as several larger arrays could achieve a cheaper cost/kW_{peak} installed, improving the payback time on capex;
- Some of the optimal sites identified already have a rooftop PV array installed, but our estimates were included to reflect the potential total solar energy that could be derived from a given Quarter. Our estimate may differ from the size of the array already installed.

Reports for each Quarter are contained in the accompanying Appendices based on its respective presentation.

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37 Sitka Spruce data for biomass over a 200 year lifespan, planted at 2m spacing, yield class 14, no-thin management. Ref: https://www.woodlandcarboncode.org.uk/standard-and-guidance/3-carbon-sequestration/3-3-project-carbon-sequestration

38 www.gov.uk/government/statistics/regional-and-local-authority-electricity-consumption-statistics

Error considerations

The task of estimating the scale of PV generation potential across any city is prone to error in a number of ways. Some of the most obvious are listed below and should be considered alongside the results of this study:

- ArcGIS data analysis is fundamental to up-to-date assessments and can be out-dated by digital surveys which are not accurate to the latest developments in the built environment, as was the case with our DSM, which in a few cases showed buildings recently demolished and omitted some recently constructed;
- Building use status changes faster than the data about it. For example, some office buildings are converted into apartments and religious buildings converted for recreation;
- Green infrastructure (such as trees) may not appear in the calculations for solar insolation modelling. Thus we can be unaware of the possibility of shading upon a rooftop. Checks were made to catch these possibilities in most cases;
- Rooftop furniture from building services may not be obvious from digital models and as these present obstacles to setting up PV arrays, their impact can only be verified with on-site visits. We believe this is a justification for heavily constraining the reported potential from flat roofs;
- ArcGIS can confuse viable roofs for unviable ones by selecting roofs with inappropriate roof materials, especially glass. We filtered some examples of this through doing manual surveys using Google Earth and Google Maps;
- Flat roof spaces allow for orientating the modules to the optimum azimuth but can lose usable roof space in doing so. Shading by a row of solar modules of others set up behind can occur if the tilt angle is set too high, which impacts on the available roof space to build rows of modules in an array (see Figure 7);
- Knowledge of the district would be very helpful in order to deselect some candidate buildings due to their listed status preventing inclusion in the Quarter to avoid over-estimation of the generating potential. We did this for Norwich Cathedral but the previously mentioned issue of cumulative visual impacts, especially in the Cathedral Quarter, may influence permitted development rights;
- We chose a single PV module type and manufacturer to model all our arrays in OpenSolar, but there are a large number of other types, manufacturers, efficiencies and dimensions to select for a particular application, which may offer a better solution. These are usually selected by the installer;
- PV outputs are estimated for peak module efficiency in the first year of operation. PV modules display an incremental decline in their efficiency over time;
- There is a wide spectrum from median to mean energy usage in non-domestic premises in Norwich and not every business will have its own independent electricity meter. Because of this the high level financial model only offers *bookend* estimates of the time for system capex payback within each Quarter. However several businesses may consume electricity outside of this range with larger consumers in six-figure amounts each year. This would dramatically improve payback time on capex to install an array;
- Each Quarter selects a different exemplar site to perform the financial analysis resulting in non-uniform financial basis across the different Quarters;

- Sites with curved roofs may accommodate flexible solar panels such as those made by Solivus[39], to offer advantages over standard flat panels. Where this is the case these roofs have not been included in this modelling;
- As previously mentioned, any array that would be commissioned for a specific site would require a more detailed study before commissioning.

[39] https://www.solivus.com/

Findings by Norwich BID Quarter

The results from the desktop studies were presented at seven face to face and one online BID Breakfast meetings spread over the summer of 2023. A further summary conference is to be held in September 2023. Time was allowed for stakeholders representing businesses located in the Quarter to ask questions and workshop collaborative solutions to developing their elements of the NSS.

Key findings of the technical study are reported in the following sections. Sites with a PV array already installed are highlighted in green. Some sites appear in both Flat and Pitched roof tables because these were identified to have both roof profiles. Details of the Quarter and site reports are contained in accompanying documents.

Cathedral quarter

See Cathedral Quarter report. Summary generation statistics are presented in the tables below. Due to the high concentration of historic religious buildings in this Quarter some sites may not be viable propositions. The financial model was scaled from the results from 20 Prince of Wales Road, which was modelled with a 30 PV panel array.

Table 2: Cathedral Quarter summary findings	
Net total number of roofs surveyed	45
Total estimated annual generation output	468,542 kWh/year
Estimated capex at £1,300/kWp installed all sites	£661,041
Break even time based on mean non-domestic annual consumption	1.89 years
Break even time based on median non-domestic annual consumption	8.04 years

Table 3: Summary of generation capacity estimates by site – Flat Roofs

Address	Coordinates	Generation capacity kWh/year ±10%
71A The Cl, Norwich NR1 4DD	52.631972N 1.305126E	2,706
Tombland, Norwich NR3 1HF	52.631693N 1.29851E	2,024
Norwich Magistrates Court Bishopgate, Norwich NR3 1UP	52.634186N 1.301154E	2,810
7-9 Queen St, Norwich NR2 4SG	52.630513N 1.297727E	6,522
Norwich NR3 1RW	52.632812N 1.30033E	5,577
King Street House, Upper King St, Norwich NR3 1RB	52.630051N 1.299428E	5,738
116-118 Prince of Wales Rd, Norwich NR1 1NS	52.628781N 1.304792E	33,064
6 Queen St, Norwich NR2 4TL	52.630256N 1.298215E	2,045
20 Tombland, Norwich NR3 1LB	52.632289N 1.298688E	9,353

Princes of Wales P H, 8-14 Prince of Wales Rd, Norwich NR1 1LB	52.629659N 1.299225E	5,302
48 St Faiths Ln, Norwich NR1 1NN	52.630198N 1.303203E	25,103
Norwich NR3 1RF	52.631075N 1.299425E	2,947
71A The Cl, Norwich NR1 4DD	52.632564N 1.299911E	6,644
De Vere House, 90 St Faiths Ln, Norwich NR1 1NE	52.629868N 1.30135E	8,596
24-26 Prince of Wales Rd, Norwich NR1 1LG	52.629804N 1.300143E	2,219
Centenary House, 19 Palace St, Norwich NR3 1RT	52.632355N 1.299521E	3,552
Bishopgate, Norwich NR1 4EL	52.633485N 1.3056E	3,994
Palace St, Norwich	52.632952N 1.299699E	28,234
Stuart Court, Recorder Rd, Norwich NR1 1NP	52.62987N 1.305341E	1,868
15 St Martin-At-Palace Plain, Norwich NR3 1RW	52.633726N 1.301053E	1,923
60 St Faiths Ln, Norwich NR1 1NN	52.629904N 1.3021E	12,450
16 St Faiths Ln, Norwich NR1 1NN	52.629208N 1.303436E	7,197
102 Prince of Wales Rd, Norwich NR1	52.628759N 1.303816E	7,479
7 Upper King St, Norwich NR3 1FA	52.630216N 1.29936E	22,050
20 Tombland, Norwich NR3 1LB	52.632102N 1.298714E	2,646
Daynes Sports Centre, St Faiths Ln, Norwich NR1 4DL	52.630072N 1.300738E	24,498
Total		233,834

Table 4: Summary of generation capacity estimates by site - Pitched Roofs		
Address	Coordinates	Generation capacity kWh/year ±10%
5 Recorder Rd, Norwich NR1 1NR	52.628816N 1.305262E	6,459
The Great Hospital, Calthorpe Lodge, Norwich NR1 4EL	52.633065N 1.304661E	5,543
Boardman House, Norwich	52.630879N 1.297127E	6,446
3 Princes St, Norwich NR3 1AZ	52.63071N 1.296207E	4,463
15 Palace St, Norwich NR3 1RT	52.631836N 1.299202E	7,281
24-26 Prince of Wales Rd, Norwich NR1 1LG	52.629678N 1.3E	4,297
71A The Cl, Norwich NR1 4DD	52.631972N 1.305126E	31,114
Centenary House, 19 Palace St, Norwich NR3 1RT	52.632189N 1.299375E	3,893
60-62 Prince of Wales Rd, Norwich NR1 1LT	52.629381N 1.302207E	4,544
Bank of Scotland, 3 Queen St, Norwich NR2 4SG	52.630212N 1.297731E	3,825
3 The Cl, Norwich NR1 4DH	52.630165N 1.300024E	4,291
ST Michael at Plea, Redwell St, Norwich	52.630543N 1.297222E	4,755
The Great Hospital, Calthorpe Lodge, Norwich NR1 4EL	52.632827N 1.304736E	27,211
Norwich Lower School, 71A The Cl, Norwich NR1 4DD	52.63201N 1.305502E	6,543
74 The Cl, Norwich NR1 4DR	52.630871N 1.299436E	4,679
10 Tombland, Norwich NR3 1HF	52.631377N 1.299381E	4,551
Norwich Cathedral refectory, Norwich NR1 4EH	52.631966N 1.301254E	41,010
5 Tombland, Norwich NR3 1HE	52.630809N 1.298484E	5,543
Greyfriars House, 20 Prince of Wales Rd, Norwich NR1, UK	52.629634N 1.299824E	13,879

82 Prince of Wales Rd, Norwich NR1 1NJ	52.629171N 1.303019E	3,959
6 Queen St, Norwich NR2 4TL	52.630256N 1.298215E	5,372
Norwich NR1 4EH	52.632485N 1.300706E	3,881
19 Princes St, Norwich NR3 1AF	52.63133N 1.298429E	6,897
7-9 Queen St, Norwich NR2 4SG	52.630374N 1.297463E	9,473
St Faiths Ln, Norwich NR1 4DL	52.630072N 1.300738E	17,084
27 28 Tombland, Norwich NR3 1RE	52.630456N 1.299191E	4,174
Total		234,709

Kings Street Quarter

See Kings Street Quarter report. Summary generation statistics are presented in the tables below. Due to the high concentration of historic and religious buildings in this Quarter some sites may not be viable propositions.

The financial model was scaled from the results from Gerald Giles, 16-20 Ber Street, which was modelled with a 32 PV panel array.

Table 5: Kings Street Quarter summary findings	
Net total number of roofs surveyed	33
Total estimated annual generation output	462,550 kWh/year
Estimated capex at £1,300/kWp installed all sites	£655,785
Break even time based on mean non-domestic annual consumption	2.47 years
Break even time based on median non-domestic annual consumption	9.48 years

Table 6: Summary of generation capacity estimates by site - Flat Roofs		
Address	Coordinates	Generation capacity kWh/year ±10%
23 Cattle Market St, Norwich NR1 3DY	52.626849N 1.298162E	11,441
24 Ber St, Norwich NR1 3EJ	52.62525N 1.297206E	12,657
St. Vedast house, 5-7 St Vedast St, Norwich NR1 1BT	52.62882N 1.302165E	2,201
Communications Centre, 33 King St, Norwich NR1 1PL	52.628286N 1.299637E	11,263
20 Rouen Rd, Norwich NR1 1QQ	52.625503N 1.299736E	11,358
Garden St, Norwich NR1 1QU	52.624467N 1.299023E	1,903
Normans Buildings, Rouen Rd, Norwich NR1 1QZ	52.626295N 1.299406E	14,795
119 Prince of Wales Rd, Norwich NR1 1DU	52.627823N 1.305267E	40,853
Nelson Hotel, Prince of Wales Rd, Norwich NR1 1DX	52.627413N 1.304419E	19,329
61-65 Rose Ln, Norwich NR1 1BY	52.628412N 1.302251E	16,472
Norfolk, 60-64 Ber St, Norwich NR1 3EW	52.624121N 1.29807E	6,429
135 /137 King St, Norwich NR1 1QH	52.624806N 1.302203E	5,588
Mountergate, Norwich NR1 1QB	52.62703N 1.302357E	30,179
12 Garden St, Norwich NR1 1QU	52.624335N 1.299043E	3,434
Kings Centre, Norwich NR1 1PH	52.627311N 1.300183E	3,741
8-12 St Vedast St, Norwich NR1 1BT	52.628789N 1.301719E	13,765
Ber St, Norwich NR1 3ES	52.622946N 1.29926E	18,381
Rouen House, Rouen Rd, Norwich NR1 1RB	52.626374N 1.298886E	12,115
Prospect House, Rouen Rd, Norwich NR1 1RE	52.626035N 1.297594E	39,490
70-72 Rose Ln, Norwich NR1 1PT	52.628791N 1.302677E	5,142

2 Rose Ln, Norwich NR1 1PL	52.628137N 1.300128E	4,434
Total		**273,529**

Table 7: Summary of generation capacity estimates by site – Pitched Roofs

Address	Coordinates	Generation capacity kWh/year ±10%
70-72 Rose Ln, Norwich NR1 1PT	52.628791N 1.302677E	11,646
The Waterfront Studios, 139-141 King St, Norwich NR1 1QH	52.62471N 1.302869E	28,306
Rose Ln, Norwich NR1 1PL	52.627909N 1.300169E	5,657
Boulton St, Norwich NR1 1PJ	52.628049N 1.300472E	4,610
Norwich NR1 1PH	52.627311N 1.300183E	9,211
Norwich NR1 1PH	52.627068N 1.299989E	4,385
Gerald Giles, 16-20 Ber St, Norwich NR1 3EJ	52.625391N 1.296895E	15,528
169 King St, Norwich NR1 1QW	52.624252N 1.303006E	31,306
Norwich NR1 1PH	52.627171N 1.299343E	11,405
Wensum Lodge, 169 King St, Norwich NR1 1QW	52.624031N 1.303094E	5,244
Wensum Lodge, 169 King St, Norwich NR1 1QW	52.623924N 1.303497E	15,188
Domino's Pizza, 5-6 Eastbourne Pl, Norwich NR1 1DH	52.628624N 1.303318E	7,323
17 Prince of Wales Rd, Norwich NR1 1BD	52.629349N 1.300243E	4,658
Hardwick House, King St, Norwich NR1 1DB	52.628946N 1.298402E	24,251
21 Prince of Wales Rd, Norwich NR1 1BG	52.629392N 1.30048E	5,176
Total		**189,021**

Riverside Quarter

See Riverside Quarter report. Summary generation statistics are presented in the tables below. Due to the high concentration of retail warehouse buildings in this Quarter some sites may not be viable propositions from a roof loading point of view.

The financial model was scaled from the results from Morrison's supermarket, 4 Albion Way, which was modelled with a 592 PV panel array.

Table 8: Riverside Quarter summary findings	
Net total number of roofs surveyed	20
Total estimated annual generation output	1,479,309 kWh/year
Estimated capex at £1,300/kWp installed all sites	£2,388,416
Break even time based on mean non-domestic annual consumption	9.53 years
Break even time based on median non-domestic annual consumption	18.11 years

Table 9: Summary of generation capacity estimates by site – Flat Roofs

Address	Coordinates	Generation capacity kWh/year ±10%
22 Lower Clarence Rd, Norwich NR1 1HA	52.625393N 1.310656E	3,335
Morrisons, 4 Albion Way, Norwich NR1 1WU	52.623374N 1.307723E	7,307
Retail Warehouse, 7, Norwich NR1 1XA	52.625159N 1.306788E	79,831
Riverside, Norwich	52.625941N 1.309614E	5,032
1 Wherry Rd, Norwich NR1 1WS	52.625849N 1.304592E	61,279
Broadland Court, 12 Wherry Rd, Riverside, Norwich NR1 1UN	52.625068N 1.305155E	134,553
6b, Norwich NR1 1WR	52.624693N 1.305854E	290,060
Riverside Retail Park, Norwich NR1 1WR	52.622808N 1.306485E	243,734
47A Wherry Rd, Norwich NR1 1WS	52.625303N 1.304245E	30,482
Broadland Court, 12 Wherry Rd, Riverside, Norwich NR1 1UN	52.625075N 1.304581E	25,943
Riverside Retail Park, 8B Albion Way, Norwich NR1 1WR	52.625045N 1.307512E	2,684
Morrisons Supermarket, Albion Way, Norwich NR1 1WU	52.62405N 1.308903E	253,492
Carrow Rd, Norwich NR1 1JE	52.621712N 1.309728E	200,783
Riverside Leisure Park, Wherry Rd, Norwich NR1 1WX	52.62194N 1.306457E	57,057
Riverside Entertainment, Norwich	52.626144N 1.305399E	45,423
Carrow Rd, Norwich NR1 1HU	52.622245N 1.31068E	15,712
Total		1,453,370

Table 10: Summary of generation capacity estimates by site – Pitched Roofs		
Address	Coordinates	Generation capacity kWh/year ±10%
Riverside Leisure Park, Norwich NR1 1WX	52.625842N 1.303807E	11,795
Norwich Railway Station, Station Approach, Norwich NR1 1EF	52.626636N 1.3072E	7,288
Wherry Rd, Norwich	52.625073N 1.30383E	13,683
Carrow Rd, Norwich NR1 1JE	52.621712N 1.309728E	4,968
Total		25,939

Creative Quarter

See Creative Quarter report. Summary generation statistics are presented in the tables below. Due to the high concentration of retail warehouse buildings in this Quarter some sites may not be viable propositions from a roof loading point of view.

The financial model was scaled from the results for Kingfisher House, 1-2 Gilders Way, which was modelled with a 115 PV panel array.

Table 11: Creative Quarter summary findings	
Net total number of roofs surveyed	70
Total estimated annual generation output	1,305,930 kWh/year
Estimated capex at £1,300/kWp installed all sites	£2,177,215
Break even time based on mean non-domestic annual consumption	3.71 years
Break even time based on median non-domestic annual consumption	12.72 years

Table 12: Summary of generation capacity estimates by site – Flat Roofs

Address	Coordinates	Generation capacity kWh/year ±10%
7 St Crispins Rd, Norwich NR3 1SN	52.63558N 1.298784E	38,296
Barrack St, Norwich NR3 1TS	52.634859N 1.307071E	62,322
St Crispins Rd, Norwich NR3 1BS	52.634945N 1.294722E	4,827
Duke St, Norwich NR3 3AP	52.633816N 1.291762E	3,634
Magdalen St, Norwich NR3 1JE	52.635209N 1.296216E	2,360
8/10 Magdalen St, Norwich NR3 1HU	52.633822N 1.296556E	4,636
St Mary's House, Duke St, Norwich NR3 1QA	52.635093N 1.291891E	30,778
Magdalen St, Norwich	52.634295N 1.297247E	11,591
Carmelite House, 2 St James Ct, Norwich NR3 1SL	52.635331N 1.301078E	12,162
8 Blackfriars St, Norwich NR3 1SF	52.635024N 1.29963E	106,720
51 Colegate, Norwich NR3 1DD	52.634585N 1.291317E	6,187
St Marys Works, 24 St Marys Plain, Norwich	52.634166N 1.290592E	7,035
St Andrews & Blackfriars Hall, St Andrews Hall Plain, Norwich NR3 1AU	52.631141N 1.295728E	3,944
Muspole St, Norwich NR3 1DJ	52.633958N 1.292839E	5,086
2 Duke St, Norwich NR3 3AP	52.632444N 1.293032E	20,593
8/10 Magdalen St, Norwich NR3 1HU	52.63394N 1.296608E	2,970
Oak St, Norwich NR3 3AE	52.632733N 1.290699E	19,513
92-98 Westwick St, Norwich NR2 4SZ	52.633141N 1.287901E	6,097
51 Colegate, Norwich NR3 1DD	52.634621N 1.291698E	2,157
Oak St, Norwich NR3 3AE	52.632989N 1.29147E	2,520

Norwich NR3 1JU	52.634975N 1.295925E	17,314
2 St Andrews St, Norwich NR2, UK	52.630875N 1.293517E	6,019
Oak St, Norwich NR3 3AQ	52.634843N 1.290202E	3,068
Kingfisher House, 1 Gilders Way, Norwich NR3 1UB	52.634765N 1.305078E	31,813
64-66 Westwick St, Norwich NR2 4SZ	52.632516N 1.288819E	9,561
3 St James Ct, Norwich NR3 1RJ	52.635509N 1.300332E	45,713
1 St James Ct, Norwich NR3 1RU	52.635013N 1.301288E	1,950
Oak St, Norwich NR3 3AQ	52.635105N 1.289672E	21,194
8 Blackfriars St, Norwich NR3 1SF	52.635054N 1.29878E	199,822
Dukes Palace Wharf, 2 Duke St, Norwich NR3 3AT	52.631373N 1.293884E	58,681
Colegate, Norwich	52.632723N 1.293708E	2,987
St Andrews St, Norwich NR2 4TP	52.630919N 1.295038E	7,930
Saint James Mill, Whitefriars, Norwich NR3 1SH	52.634922N 1.300487E	39,973
St Martins House, Westwick St, Norwich NR2 4SZ	52.63308N 1.288158E	5,467
Barrack St, Norwich NR3 1TY	52.635567N 1.30258E	7,614
2 Gilders Way, Norwich NR3 1UB	52.63495N 1.304543E	16,682
Total		790,921

Table 13: Summary of generation capacity estimates by site – Pitched Roofs

Address	Coordinates	Generation capacity kWh/year ±10%
47 Colegate, Norwich NR3 1DB	52.633383N 1.292887E	49,051
Old Meeting House Yd, Colegate, Norwich NR3 1BW	52.633645N 1.295825E	4,063
51 Colegate, Norwich NR3 1DD	52.634585N 1.291317E	5,881
53-57 St Martins Ln, Norwich NR3 3SA	52.635074N 1.290181E	7,470
Cavell House & Austin House Stannard Place, St Crispins Rd, Norwich NR3 1YE	52.634959N 1.294082E	46,789
St Marys Works, 24 St Marys Plain, Norwich	52.634166N 1.290592E	56,299
20 Magdalen St, Norwich NR3 1HU	52.634008N 1.29646E	4,260
St Marys Works, 24 St Marys Plain, Norwich	52.634906N 1.290886E	48,302
St Andrews & Blackfriars Hall, St Andrews Hall Plain, Norwich NR3 1AU	52.631141N 1.295728E	33,083
Norwich NR3 1JU	52.63518N 1.296922E	5,167
Golden Dog Ln, Norwich NR3 1AR	52.634621N 1.294621E	4,393
10 Golden Dog Ln, Norwich NR3 1BP	52.634377N 1.295029E	6,412
34-44 Calvert St, Norwich	52.634945N 1.294722E	7,336
8 Blackfriars St, Norwich NR3 1SF	52.635024N 1.29963E	10,194
Norwich University of the Arts, 31 Ancnsr St, St Georges St, Norwich NR3 1BB	52.631808N 1.295613E	24,072
Colegate, Norwich	52.632723N 1.293708E	25,538
45 Magdalen St, Norwich NR3 1LQ	52.634919N 1.296787E	4,083
Colegate, Norwich NR3 1BW	52.633858N 1.295569E	11,338

Sherwyn House, 63 St Georges St, Norwich NR3 1BL	52.634546N 1.293979E	5,913
21 Colegate, Norwich NR3 1BN	52.633554N 1.295196E	5,883
Oak St, Norwich NR3 3AE	52.632989N 1.29147E	15,728
Oak St, Norwich NR3 3AQ	52.634843N 1.290202E	11,303
100 St Georges St, Norwich NR3 1BX	52.634042N 1.293783E	5,125
3 Colegate, Norwich NR3 1BN	52.633546N 1.296559E	5,627
2 St Andrews St, Norwich NR2, UK	52.630875N 1.293517E	17,135
3 Coslany St, Norwich NR3 3PS	52.631574N 1.290727E	10,346
8 Blackfriars St, Norwich NR3 1SF	52.635054N 1.29878E	8,016
Muspole St, Norwich NR3 1DJ	52.633958N 1.292839E	35,977
Duke St, Norwich	52.632563N 1.292328E	4,159
70-76 St Georges St, Norwich NR3 1AB	52.632635N 1.294223E	27,343
Britons Arms Coffee House, 8 Elm Hill, Norwich NR3 1HN	52.63121N 1.296338E	15,154
Norwich University of the Arts, 31 Ancnsr St, St Georges St, Norwich NR3 1BB	52.631677N 1.295237E	13,499
Anchor House, 22 Anchor Quay, Norwich NR3 3XP	52.631312N 1.290545E	19,064
12 St Clements Alley, Norwich NR3 1LJ	52.633274N 1.296601E	10,058
Total		515,009

Castle and Marketplace Quarter

See Castle and Marketplace Quarter report. Summary generation statistics are presented in the tables below. Due to the high concentration of retail warehouse buildings in this Quarter some sites may not be viable propositions from a roof loading point of view.

The financial model was scaled from the results for John Lewis, All Saints Green which was modelled with a 220 PV panel array.

Table 14: Castle and Marketplace Quarter summary findings	
Net total number of roofs surveyed	57
Total estimated annual generation output	1,086,241 kWh/year
Estimated capex at £1,300/kWp installed all sites	£1,567,978
Break even time based on mean non-domestic annual consumption	3.27 years
Break even time based on median non-domestic annual consumption	11.12 years

Table 15: Summary of generation capacity estimates by site – Flat Roofs

Address	Coordinates	Generation capacity kWh/year ±10%
9 All Saints Grn, Norwich NR1 3LX	52.625024N 1.295957E	105,540
Norwich NR1 3DD	52.626783N 1.296027E	90,464
2-6 Opie St, Norwich	52.629618N 1.296083E	5,720
Castle House, Norwich	52.628217N 1.294875E	3,128
10 London St, Norwich NR2 1LH	52.629028N 1.293744E	6,234
Millennium Library the Forum, 2 Millennium Plain, Norwich NR2 1TF	52.627722N 1.291183E	127,286
Ber St, Norwich NR1 3AD	52.624286N 1.297184E	6,441
1 Market Pl, Norwich NR2 1ND	52.628565N 1.292859E	4,861
27 Castle Mdw, Norwich NR2 1PN	52.629606N 1.296536E	3,400
3-4 Haymarket, Norwich NR2 1QD	52.627719N 1.293707E	8,807
7-9 Haymarket, Norwich NR2 1QD	52.627317N 1.293955E	30,059
Norwich Castle, Norwich NR1 3JU	52.628456N 1.296886E	3,497
City Hall, Norwich	52.628508N 1.291633E	39,208
57 Bethel St, Norwich NR2 1NR	52.628557N 1.288533E	31,472
The garage, 14 Chapel Field N, Norwich NR2 1NY	52.628132N 1.288701E	10,302
The Old Fire Station, 30 Bethel St, Norwich NR2 1NR	52.628353N 1.29018E	5,092
Castle House, Norwich	52.628364N 1.294816E	5,753
7-9 Haymarket, Norwich NR2 1QD	52.627253N 1.293528E	3,888
Orford Pl, Norwich NR1 3RZ	52.626611N 1.293667E	25,632
12-14 Brigg St, Norwich NR2 1QN	52.626929N 1.292862E	40,049
1 Theatre St, Norwich NR2 1RG	52.62737N 1.292258E	63,393
20 Bank Plain, Norwich	52.629517N 1.297327E	39,898
18 London St, Norwich NR2 1LG	52.629N 1.294293E	7,768
60 Bethel St, Norwich NR2 1NR	52.629014N 1.288767E	5,584
10A Castle Mdw, Norwich NR1 3DE	52.628745N 1.294924E	7,786
Total		**681,263**

Table 16: Summary of generation capacity estimates by site – Pitched Roofs		
Address	Coordinates	Generation capacity kWh/year ±10%
Millennium Library the Forum, 2 Millennium Plain, Norwich NR2 1TF	52.627722N 1.291183E	14,357
Norwich Castle, Norwich NR1 3JU	52.62844N 1.29601E	19,942
Shirehall, Market Ave, Norwich NR1 3JQ	52.628412N 1.297369E	6,541
9 All Saints Grn, Norwich NR1 3LX	52.625024N 1.295957E	21,496
12-14 Brigg St, Norwich NR2 1QN	52.626929N 1.292862E	5,569
4 The Royal Arcade, Norwich NR2 1NQ	52.628445N 1.294321E	6,603
St Giles St, Norwich NR2 1LW	52.629334N 1.288421E	5,136
7-9 Haymarket, Norwich NR2 1QD	52.627317N 1.293955E	5,017
36 St Giles St, Norwich NR2 1LL	52.629152N 1.289729E	9,188
42 St Giles St, Norwich NR2 1LW	52.629238N 1.289255E	14,311
St Giles St, Norwich NR2 1LL	52.629125N 1.290267E	5,643
3a, Norwich	52.627863N 1.294882E	4,109
45-31 Timber Hill, Norwich NR1 3LA	52.625901N 1.295945E	4,214
Norwich NR1 3DD	52.626783N 1.296027E	30,652
Old Post Office Ct, Norwich	52.62859N 1.294362E	6,805
21 The Royal Arcade, Norwich NR2 1PN	52.628027N 1.294103E	6,224
21 The Royal Arcade, Norwich NR2 1PN	52.6281N 1.294068E	16,852
St Giles Nursery School, Norwich	52.628909N 1.289921E	10,566
Norwich NR1 3QB	52.627246N 1.295138E	4,361
3-4 Haymarket, Norwich NR2 1QD	52.627719N 1.293707E	9,880
Old Post Office Ct, Norwich	52.628644N 1.293976E	13,867
28 St Giles St, Norwich NR2 1LL	52.629081N 1.290504E	8,309
34-36 Bethel St, Norwich NR2 1NR	52.628658N 1.289722E	40,060
6-9 White Lion St, Norwich	52.628002N 1.293646E	7,299
Royal Arcade, The Royal Arcade, Norwich NR2 1NQ	52.628208N 1.294083E	11,554
White Lion St, Norwich NR2 1QA	52.627689N 1.294057E	7,416
St Peter Mancroft, St. Mary's House, The Chantry, Norwich NR2 1QZ	52.627853N 1.292615E	21,319
City Hall, Norwich	52.628508N 1.291633E	24,346
Norwich Castle, Norwich NR1 3JU	52.628813N 1.296617E	6,507
20 Bank Plain, Norwich	52.629517N 1.297327E	20,356
1 Market Pl, Norwich NR2 1ND	52.628565N 1.292859E	32,221
2-6 Opie St, Norwich	52.629618N 1.296083E	4,255
Total		404,977

The Lanes Quarter

See The Lanes Quarter report. Summary generation statistics are presented in the tables below. Due to the high concentration of retail warehouse buildings in this Quarter some sites may not be viable propositions from a roof loading point of view.

The financial model was scaled from the results for Kiln House, Pottergate, which was modelled with a 123 PV panel array.

Table 17: The Lanes Quarter summary findings

Net total number of roofs surveyed	50
Total estimated annual generation output	693,162 kWh/year
Estimated capex at £1,300/kWp installed all sites	£987,628
Break even time based on mean non-domestic annual consumption	2.46 years
Break even time based on median non-domestic annual consumption	9.47 years

Table 18: Summary of generation capacity estimates by site – Flat Roofs

Address	Coordinates	Generation capacity kWh/year ±10%
Upper St Giles St, Norwich	52.629182N 1.286505E	5,794
Norwich Quaker Meeting House, Upper Goat Ln, Norwich NR2 1EW	52.629944N 1.290857E	6,039
Wild Man, 25 Bedford St, Norwich NR2 1AG	52.62993N 1.295414E	2,909
The Guildhall, Gaol Hill, Norwich NR2 1JS	52.629034N 1.292432E	7,019
City Centre, St Andrews St, Norwich NR2 4AD	52.630281N 1.296273E	13,873
5 St Andrews Hill, Norwich NR2 1AD	52.63015N 1.295962E	7,799
Kiln House, Pottergate, Norwich NR2 1BZ	52.630316N 1.290536E	60,030
23-23A, St Giles St, Norwich NR2 1JL	52.629301N 1.29068E	6,437
23-23A, St Giles St, Norwich NR2 1JL	52.629279N 1.290862E	5,503
Norfolk House, St John Maddermarket, Norwich	52.630111N 1.293265E	6,956
unit c, Cathedral Retail Park, Westwick St, Norwich NR2 4SZ	52.632503N 1.286946E	218,561
Russell House, St Andrews St, Norwich NR2 4AE	52.630252N 1.294506E	10,541
25b St Giles St, Norwich NR2 1JN	52.629328N 1.290508E	5,656
Lower Goat Ln, Norwich NR2 1EL	52.629736N 1.291511E	4,280
St. Andrew's Church, Norwich	52.630365N 1.295433E	8,799
Stable Loft, 23 Fishers Ln, Norwich NR2 1ET	52.629905N 1.28945E	14,468
11 London St, Norwich NR2 1JF	52.629342N 1.293804E	34,522
Norwich University of the Arts, Francis House, 3-7 Redwell St, Norwich NR2 4SN	52.630295N 1.296689E	7,238
6-8 Little London St, Norwich NR2 1EA	52.629431N 1.294517E	35,099
Norwich Enterprise Centre, Norwich	52.629432N 1.292801E	3,934
Total		**465,457**

Table 19: Summary of generation capacity estimates by site – Pitched Roofs

Address	Coordinates	Generation capacity kWh/year ±10%

Norwich Enterprise Centre, Norwich	52.629432N 1.292801E	6,101
Woburn Court, Norwich	52.629235N 1.293254E	5,582
92 Pottergate, Norwich NR2 1DZ	52.630447N 1.287398E	5,877
2 Charing Cross, Norwich NR2 4AL	52.630597N 1.29265E	14,496
60 Pottergate, Norwich NR2 1DY	52.630266N 1.288706E	6,566
93 Upper St Giles St, Norwich NR2 1AB	52.629469N 1.285645E	7,660
Shibleys Court, Fishers Ln, Norwich NR2 1EE	52.62961N 1.290199E	5,774
The temple, 47 St Giles St, Norwich NR2 1JR	52.629755N 1.289017E	11,967
8 Swan Ln, Norwich NR2 1HZ	52.629572N 1.294603E	9,698
St Benedicts St, Norwich NR2 4AB	52.631432N 1.286738E	5,747
87 Upper St Giles St, Norwich NR2 1AB	52.629452N 1.286039E	5,123
St. Giles on the Hill,75 Upper St Giles St, Norwich NR2 1AB	52.629506N 1.287318E	11,968
The Gateway, Norwich	52.630511N 1.288128E	4,956
Cow Hill, Norwich NR2 1EZ	52.629416N 1.286532E	6,710
3-15 Dove St, Norwich	52.62967N 1.293067E	9,208
45 St Benedicts St, Norwich NR2 4PG	52.631384N 1.288065E	13,592
Lower Goat Ln, Norwich NR2 1EL	52.629736N 1.291511E	9,469
11 London St, Norwich NR2 1JF	52.629342N 1.293804E	3,933
unit c, Cathedral Retail Park, Westwick St, Norwich NR2 4SZ	52.632503N 1.286946E	4,366
2 St Gregorys Alley, Norwich NR2 1ER	52.630446N 1.291482E	9,896
84 St Benedicts St, Norwich	52.631268N 1.287221E	8,146
Turners Court, St Benedicts St, Norwich NR2 4AQ	52.630619N 1.289449E	5,616
Brettingham House, 98, Pottergate, Norwich NR2 1EQ	52.630297N 1.28657E	5,457
St Swithins Ter, Norwich	52.631563N 1.287234E	5,992
2 Pottergate, Norwich NR2 1DS	52.629798N 1.292471E	7,910
St Benedicts St, Norwich NR2 4PF	52.631134N 1.289212E	6,948
Norwich Quaker Meeting House, Upper Goat Ln, Norwich NR2 1EW	52.629944N 1.290857E	9,802
Maude Gray Court, St Benedicts St, Norwich NR2 4PA	52.631079N 1.289593E	4,241
6-8 Little London St, Norwich NR2 1EA	52.629431N 1.294517E	7,456
Wild Man, 25 Bedford St, Norwich NR2 1AG	52.62993N 1.295414E	7,449
Total		227,705

Chapelfield Quarter

See Chapelfield Quarter report. Summary generation statistics are presented in the tables below. Due to the high concentration of retail warehouse buildings in this Quarter some sites may not be viable propositions from a roof loading point of view.

The financial model was scaled from the results for The Assembly House, Theatre Street, which was modelled with a 41 PV panel array.

Table 20: Chapelfield Quarter summary findings	
Net total number of roofs surveyed	15
Total estimated annual generation output	630,358 kWh/year
Estimated capex at £1,300/kWp installed all sites	£837,053
Break even time based on mean non-domestic annual consumption	5.5 years
Break even time based on median non-domestic annual consumption	13.3 years

Table 21: Summary of generation capacity estimates by site - Flat Roofs

Address	Coordinates	Generation capacity kWh/year ±10%
Theatre St, Norwich NR2	52.627342N 1.290008E	10,200
40-46 St Stephens St, Norwich NR1 3SH	52.625954N 1.291523E	6,499
Chantry Place, Norwich NR2 1SH	52.625825N 1.289603E	262,971
1 Rampant Horse St, Norwich NR2 1QR	52.626329N 1.293194E	64,047
Noverre House, 14 Theatre St, Norwich NR2 1RG	52.627227N 1.2905E	3,953
St Stephens St, Norwich NR1 3SH	52.624802N 1.290802E	122,410
4 Theatre St, Norwich NR2 1QY	52.626928N 1.29193E	4,237
Theatre St, Norwich NR2 1RL	52.627456N 1.289558E	31,371
Chapel Field E, Norwich NR2 1SZ	52.62621N 1.291083E	24,105
Norwich NR1 3SA	52.625679N 1.292662E	18,287
Total		548,079

Table 22: Summary of generation capacity estimates by site - Pitched Roofs

Address	Coordinates	Generation capacity kWh/year ±10%
1 Rampant Horse St, Norwich NR2 1QR	52.626329N 1.293194E	5,302
2 Rampant Horse St, Norwich NR2, UK	52.626637N 1.292342E	13,821
The Assembly House, Norwich NR2 1RF	52.626743N 1.290714E	21,576
Theatre St, Norwich NR2	52.627342N 1.290008E	19,266
Chantry Place, Norwich NR2 1SH	52.625825N 1.289603E	22,314
Total		82,278

The Business Quarter

See the Business report. Summary generation statistics are presented in the tables below. Due to the high concentration of retail warehouse buildings in this Quarter some sites may not be viable propositions from a roof loading point of view.

The financial model was scaled from the results for Victoria House, Queens Road, which was modelled with a 180 PV panel array.

Table 23: The Business Quarter summary findings	
Net total number of roofs surveyed	17
Total estimated annual generation output	429,044 kWh/year
Estimated capex at £1,300/kWp installed all sites	£616,777
Break even time based on mean non-domestic annual consumption	4.08 years
Break even time based on median non-domestic annual consumption	12.35 years

Table 24: Summary of generation capacity estimates by site – Flat Roofs

Address	Coordinates	Generation capacity kWh/year ±10%
8 Surrey St, Norwich NR1 3NS	52.624454N 1.294631E	12,165
Victoria House, Queens Rd, Norwich NR1 3QQ	52.623328N 1.291202E	86,550
135-137, 139 Ber St, Norwich NR1 3EY	52.622816N 1.298662E	31,651
Norfolk Tower, 48 Surrey St, Norwich NR1 3PA	52.623614N 1.29602E	12,572
9-11 St Stephens St, Norwich NR1 3QN	52.625108N 1.292509E	51,221
76 Surrey St, Norwich NR1 3NT	52.623002N 1.294632E	3,365
11 Mariners Ln, Norwich NR1 3AF	52.62192N 1.299512E	52,757
9, 13 St Stephens St, Norwich NR1 3QN	52.625472N 1.29311E	3,359
Ber St, Norwich	52.623309N 1.298135E	12,222
125 Ber St, Norwich	52.623096N 1.298457E	4,281
Queens Rd, Norwich	52.624338N 1.292886E	34,210
Chapel Loke, Norwich NR1 3PA	52.623303N 1.296349E	4,201
8 Surrey St, Norwich NR1 3NX	52.625208N 1.294054E	59,365
45 St Stephens St, Norwich NR1 3QR	52.624801N 1.291847E	41,852
Total		**409,772**

Table 25: Summary of generation capacity estimates by site – Pitched Roofs

Address	Coordinates	Generation capacity kWh/year ±10%

76 Surrey St, Norwich NR1 3NT	52.623002N 1.294632E	5,447
177 Ber St, Norwich NR1 3HB	52.621652N 1.300009E	6,124
Queens Rd, Norwich	52.624338N 1.292886E	7,701
Total		19,271

Technical Study Conclusions

A summary of the findings from the solar energy assessments made for each Quarter is presented in Table 26.

Table 26: Summary findings across all Quarters		
Gross total number of roofs identified by ArcGIS		365
Net total number of roofs evaluated		307
Total estimated generation capacity		7,609 kW_{peak}
Total estimated annual generation output		6,555,135 kWh/year
Total estimated capex installed @£1,300/kW_{peak}		£9,891,892
Break even time based on mean non-domestic annual consumption		3.75 years
Break even time based on median non-domestic annual consumption		12.17 years
Proportion of BID business membership total annual electricity demand (mean)		22%
Proportion of BID business membership total annual electricity demand (median)		146%
Proportion of BID business membership total annual energy demand (mean)		1.25%
Proportion of BID business membership total annual energy demand (median)		5.14%
Carbon dioxide emissions avoided over a 20 year system lifespan		25,353 tCO_2e
Equivalents to CO_2e avoided over 20 years system lifespan	Avoided car kms	145,134,249 km
	Avoided long haul flights of 4000 km	32,825 flights
	Number of Sitka Spruce trees planted under management[40]	709,699 trees

The break even time is based on the same approach as used in each Quarter, whereby 50% of the generated energy is deemed to be exported at £0.15/kWh and the other 50% of energy consumed is self-generated, which displaces imports at a cost of £0.35/kWh.

The values for mean and medium consumption are based on Government statistics for non-commercial business in Norwich (see p4), however several consumers in the sample are anticipated to consume energy outside of these levels. While the mean value of consumption is

40

kgCO2e/average year/Sitka Spruce biomass over lifetime of 200 yrs at 2m spacing, yield class 14, no thin management.
Ref: https://www.woodlandcarboncode.org.uk/standard-and-guidance/3-carbon-sequestration/3-3-project-carbon-sequestration

39,941kWh/year, some large retail sites, leisure centres and multi-tenanted premises could consume six figure quantities of kilowatt hours, making the capex payback time far shorter than estimated.

This study demonstrates that a coordinated rollout of rooftop solar across the 307 optimal sites identified could in theory generate 22% or 146% respectively, of the total annual electricity consumption for a Norwich BID membership of 750 businesses using the values given in Government statistics for mean and median non-domestic electricity consumption in Norwich.

If we add the statistics for gas use then the Norwich Solar System contributes 1.25% or 5.14% of the total annual energy (electricity and heat) for a sample of 750 businesses, if they all consumed the mean and median values of energy given in Government statistics.

Future opportunities

The findings from this report clearly identify the potential for businesses across Norwich City Centre to make substantial financial savings by offsetting a large amount of imported energy through self-consumption of rooftop solar-generated energy, while at the same time enhancing local energy security. In addition, the capex for implementing these systems could present favourable tax circumstances to individual businesses making the investment and, if a wider system were to be established, offer other benefits from the creation of a local energy market. Savings could be enhanced by a 'collective buying scheme' for the required equipment for example. A substantial carbon saving would be associated with development of the Norwich Solar System as well, which would support the process of achieving the Net Zero target set by the City Council. For individual businesses this would contribute to their Environmental, Sustainability and Governance (ESG) plans.

Enablement of the Norwich Solar System vision is perhaps less a technical challenge than one requiring collaboration between the Norwich BID, City Council Planners, legal actors including landlords and tenants as well as the DSO. However this complexity goes with the territory of decarbonising society and requires innovation and commitment with regard to the wider challenges from mitigation of, and adaptation to, anthropogenic global warming. Without this, the future for business continuity anywhere will be in jeopardy. However, there are ample opportunities, subject to the approval of the above actors and cooperation between businesses, to demonstrate the principles of the Norwich Solar System in a scalable manner.

Recommendations for next steps

This feasibility report offers a starting point for two important next steps to initiate action towards the Norwich Solar System:

1. A rallying call to the relevant actors to set out a collective aim to implement a pilot in a designated part of Norwich City Centre that demonstrates the principles and measures the benefits from implementation of rooftop solar generators and Power Purchase Agreements (PPAs) for surplus energy to be traded between participants. This pilot could

take the form of a *solar zone* perhaps formed around a cluster of businesses identified from the feasibility study in a given street. As noted in this report the buildings identified to be optimal sites should not limit others from inclusion, but will ultimately be determined by site models provided by installers of the equipment.

2. To progress on the above it will be necessary for understanding and cooperation to be built between the key enablers identified. So a parallel stream of *policy developmen*t should be considered as a next step that will align the aims of any pilot to the vision of key decision makers.

Appendices

Eight appendices to this report are delivered separately. Each one presents findings for an individual Quarter with some examples of modelled PV arrays on buildings with flat and pitched roofs within the Quarter concerned.

To find out more please get in touch

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