A Work Project, presented as part of the requirements for the Award of a Master's degree in Finance from the Nova School of Business and Economics

ECONOMIC ANALYSIS OF RESIDENTIAL GRID-CONNECTED PHOTOVOLTAIC SYSTEM IN LONDON

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17-12-2021

1. EXECUTIVE SUMMARY

Location: London, United Kingdom **Date of analysis**: Dec 2021

Recommendation*: install 6 solar panels (11.8 m^2), for a net present value of £2,979, with a payback of 16 years.*

Main economic results:

Financing	NPV (£)	Payback (years)	IRR (%/year)	LCOE (c/kWh)
75% debt	2,979	16	6.33	6.1
100% equity	3,227	15	5.95	10.7

Additional results:

A system of 6 400W panels, together with a battery of 3.3 kWh, requires an initial investment of £5,595, but provides an NPV of £3,789, with a payback of 17 years.

Main inputs and assumptions:

Household and Economics					
Electricity Consumption	3900	kWh/year	Inflation	2.6%	per year
Electricity price – buy	0.188	£/kWh	Bank loan interest rate	3.1%	per year
Electricity price – sell	0.0557	£/kWh	Bank loan maturity	5	years
			Equity cost of capital	0.85%	per year

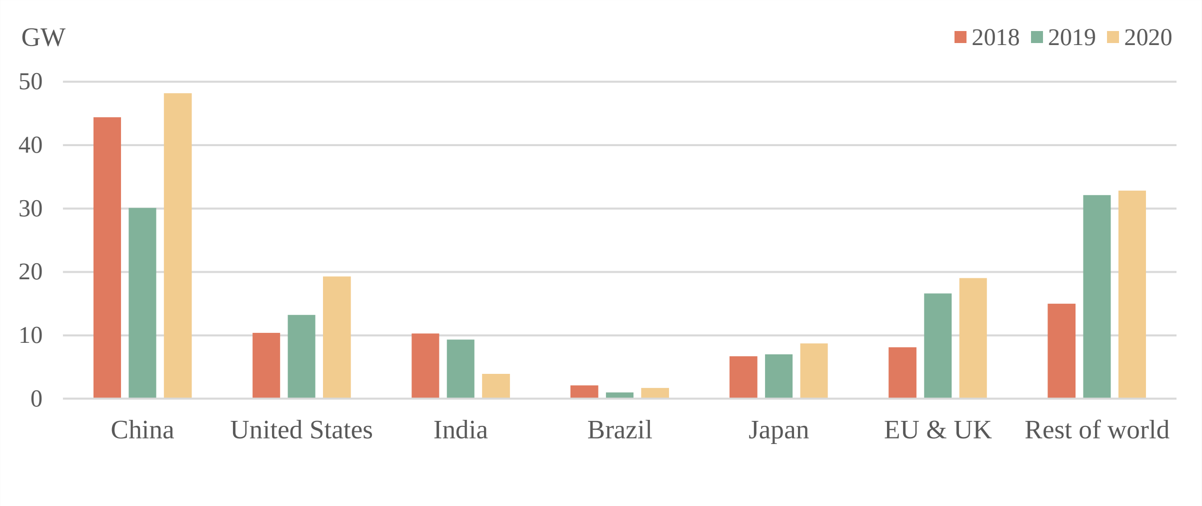
PV panels chosen					
Peak power	400	W/panel	System losses	14%	of output
Panel area	1.96	m^2/panel	Degradation with age	0.4%	Per year
Useful life	25	Years	Maintenance costs	19.9	£/kW
			Total cost of optimal installation size	2,400	£

1. INTRODUCTION

The global energy system is in the midst of a transformation. Decentralized renewable generating and smart, flexible system operations are replacing centralized fossil fuel power plants. Rapid technical advancements, commercial innovation, and the need to decarbonize the electricity supply to solve the climate issue are driving this transformation. The shift in how civilization is powered is expected to accelerate during this decade and one of the primary technologies driving this shift will be solar photovoltaics.

Despite the COVID-19 worldwide pandemic lasting longer than expected, the global demand for solar did not decrease at all. Instead, Solar PV output grew by 156 TWh (23%), reaching 821 TWh in 2020 (SolarPower Europe 2021). In 2020, it had the second-highest absolute generation increase of any renewable technology, after only wind but ahead of hydropower. Due to looming policy deadlines in China, the United States, and Vietnam, PV capacity increases reached an all-time high of 134 GW (International Energy Agency 2021). In most parts of the world, solar PV is becoming the most cost-effective choice for energy generation, which is projected to drive investment in the future years. While COVID-19 and a silicon raw material scarcity in 2021 have constrain the deployment volume, rising vaccination rates in major solar markets and new silicon factories coming online will result in annual additions of over 200 GW by end of 2022. Figure 1 shows the net solar PV capacity additions from 2018 till 2020. After a downturn in 2018-2019, solar PV capacity additions in China resumed in 2020. The United States, the European Union and Latin America continued the growth experienced in the previous years, while India's capacity expansion has stalled.

Figure 1. Solar PV capacity additions 2018-2020



PV's contribution to decarbonizing the energy mix is growing, with the technology saving up to 875 million tons of CO_2 equivalent (International Energy Agency 2021). However, more work has to be done to fully decarbonize, and PV deployment should grow by at least one order of magnitude to meet the Paris COP21 objectives.

The goal of this Field Lab is to perform an economic analysis of a residential grid-connected photovoltaic system for different cities around the world. The outputs for each location are the optimal number of panels that a landlord should install, the system size, costs involved and the potential financial gains. To obtain comparable results, a similar approach has been used across all territories. This report covers the analysis of a photovoltaic system in London, United Kingdom, highlighting the assumptions, methodology and recommendations in the following sections.

Looking ahead, the UK solar panel market has a promising future, thanks to the government's decarbonization drive in the public, commercial, and residential sectors. Subsidy-free, large-scale solar deployment and commercial installations are expected to fuel market expansion at first. Concerning the residential sector, favourable upcoming changes to the Building Regulations and the 2025 Future Homes Standard will most likely deliver substantial growth in the new build market while more enticing offers for clients in terms of financing and installation of solar-plus-storage systems, as well as a developing EV market, are projected to stimulate demand in the retrofit market (Preedy 2021).

To formalise the effort towards a greener economy, the UK has a legally binding commitment to achieve a net-zero economy by 2050. To do so, it will require to increase substantially the quantity of power it generates from renewable sources. As a result, clean electricity will be able to be utilized to power homes and businesses, as well as for new clean hear and transportation technologies, like electric heat pumps and electric cars.

Positive progress has been made in decarbonising the electrical supply provided by the national grid. However, onsite home solar power may and must provide a considerable percentage of clean electricity. According to Solar Energy UK (2021), 4.4 million smart solar homes - houses with a solar system on the roof, an energy storage system (such as a battery), and a smart meter - would be a significant contribution to the UK's climate change goals and ambitions. Currently, more than 1 million homes have solar panels installed in the UK.

These solar systems have a combined generation capacity of 2.8GW, which is equivalent to the capacity of numerous gas or coal-fired power plants.

As a result, many more solar houses are required, and while the energy benefit of solar is generally established, its financial worth is not. The fact that a million houses have already installed solar equipment demonstrates that homeowners and renters alike recognize the advantages of self-generating homes. However, according to a government study conducted in spring 2021, the perceived upfront cost of rooftop solar systems is a barrier to customer adoption. This is even though, according to the same study, solar panel costs have dropped by 60% since 2010. Indeed, according to Solar Energy UK (2021), a typical household solar system currently costs less than £4,000, which is similar to many other home improvements.

The fact that many current solar installations get payments through the government Feed-in Tariff (FIT) plan (closed to new applications on March 2019), which effectively launched the market for residential and small commercial solar power projects in the UK, may contribute to the perceived cost of solar. However, even without a subsidy, installing a solar energy system, is a worthwhile investment that minimizes a home's carbon footprint while also saving money.

This is critical, given the need for a significant increase in solar deployment, both new build and retrofit home installations: the UK's residential building stock accounts for 15% of the country's total carbon emissions, and the majority of homes that will be in use in 2050 – the country's net-zero target year – have already been built.

The basic principle behind solar photovoltaic systems is simple: thy transform sunlight into electricity. A typical 3-4 kW system will include 10-14 solar panels connected directly to the home's electrical supply. Any energy that isn't utilized by the home's appliances may be transmitted to the national grid, which will help to power other houses. Homeowners may be compensated for this by their energy provider. Alternatively, many contemporary PV systems now include a battery, allowing extra electricity to be stored and utilised at a later time. In the UK's energy grid, battery storage is becoming increasingly significant.

The mayor of London, Sadiq Khan, aspires to make London a zero-carbon city, as stated in his Environment Strategy. London will need to be supplied with a variety of efficient and sustainable energy sources for this to happen. Solar-generated energy will be included in this mix, with London aiming for two gigawatts of installed solar energy capacity by 2050 (Greater London Authority 2018). To meet this target, London will need to develop much more solar energy capacity

A thriving and increasing solar energy sector is required to realize London's solar energy potential. Solar energy technologies will become more cost-competitive with fossil fuel-based generation and other low-carbon energy sources shortly as a result of this. When solar energy-producing technologies are combined with energy storage technology (such as batteries), onsite heat or electricity may be used to satisfy demand at any time of day. As technological prices continue to plummet, London must maximize the potential for solar energy storage.

London's objective is to have 1 GW of installed capacity by 2030, ten times what it has now, and 2 GW by 2050. This cannot be accomplished only through the mayor's leadership and programs. It will require national government policy that is robust and supportive, as well as backing from local governments, the commercial sector, charities, and people. To do his bit, the mayor has set a goal for his programs to nearly quadruple London's existing installed capacity by 2030, adding 100 megawatts (MW).

Solar PV and solar thermal technologies have a lot of potential space in London. Greater London is around 1,600 km^2 in size, with building roofs accounting for about a third of that. However, roofs aren't the only place where solar technology may be used. Installing renewable technology on unoccupied land and open space, building facades, and besides thousands of kilometres of highways and railway sidings is a potentially large, but unquantified, opportunity in London. London, on the other hand, has a lower economic potential for solar. As part of its zero-carbon pathways modelling for the London Environment Strategy, the GLA analysed the economic possibilities for solar PV and solar thermal technologies on buildings. This takes into consideration the financial limits imposed by current government policies, particularly the reduction in FiTs, as well as patterns in deployment from 2010 to 2017. According to this assessment, solar PV installations might reach roughly 550 MW capacity by 2025, 850 MW capacity by 2030, and 2 GW capacity by

2050 in an aggressive scenario17. By 2030, solar thermal might provide the equivalent of an additional 100 MW of power.

If there is a broad knowledge of the technology, its accompanying business models, and the logistics of battery installation and administration, London will be best positioned to take advantage of this market trend.

This analysis represents a typical case of the financial gains which could be achieved by installing a solar PV system on a typical home in London, to show that, even with the typical British weather, solar panels can be a profitable investment and provide landlords attractive returns.

2. DATA AND ASSUMPTIONS

The general goal of this project is to integrate current data sources to generate new evidence on the financial benefit of solar panels, which included the creation of a bespoke financial model. The model examines the operating cost reductions offered by households that use solar panels and allows alteration of input variables - number of panels, financing and type of solar system (with or without battery). Given some assumptions, the outputs of the model include a range of system outputs, such as the expected yearly electricity generation, and how these relate to its capital and operational expenses. As a result, the model generates a set of standard indicators for evaluating the solar system's financial profitability. The system's NPV, payback period, and IRR are among the indicators. The model also gives detailed information on the value of grid-imported power displaced by the existence of a solar system, as well as the value of payments received from exporting electricity back to the grid. These results are meant to assist the user in understanding the overall economic performance of the system, which includes all parts that generate a financial cost or gain. The following section describes in more detail the underlying assumptions and input parameters of the model.

3.1 Property characteristics

Table 1 presents the assumptions used for the property and its household. They are non-flexible, implying that the economic analysis applies only to properties that follow these parameters. For example, a different location in the UK (for example, Birmingham) will be characterised by a distinct annual irradiation level, leading to lower or higher electricity generation from the solar system. The type of house, heating fuel, occupancy level and corresponding electricity consumption were selected from the UK Department for Business, Energy & Infrastructure (2021) based on their frequency in London i.e. to make the model applicable to a large number of properties in London, the house attributes that are most frequent, were selected. This approach leads to the annual electricity consumption of 3,900kWh, the median value obtained from a sample of 8,980 semi-detached houses in London. The size of the suitable roof area for the panels was obtained through Energy Saving Trust (2015) and it will be a fundamental determinant in assessing how many and what sizes of solar panels can be installed on the roof. It is assumed the absence of nearby obstacles, such as trees and buildings, that could cause overshading and thus reduce the amount of solar energy that reaches the solar panels. The rooftop is facing south and has a 35° inclination, which are optimal characteristics for the UK. Optimal slope and azimuth (2°) were obtained from the EU Science Hub (2021). The household is composed of four members, two adults and two children, that are away from home in the 9am-6pm timeframe. This assumption has effects on the amount of energy used and how much of it is covered by any onsite solar system, which has an impact on the system's overall financial performance. Occupancy patterns are especially important in light of the COVID-19 pandemic and its impact on the labour force. As remote access to systems and technology make remote working more possible, home occupancy levels may rise, resulting in increased electricity consumption and, as a result, an influence on the costs and advantages of a solar and storage system for the house.

Table 1. Characteristics of the property and its household

Variable	Assumption
Location	London
House type	Semi-detached
Heating fuel	Electric
Household members	4
Occupancy	In half the day
Roof Size (m2)	29.5
Roof Slope	38°
Shading	None
Roof Direction	South
Annual Electricity Consumption (kWh)	3,900

3.2 Solar System characteristics

Table 2 includes the attributes of the solar system. The number of panels and the peak power of a panel determines the system size (kWh).

Table 2. Characteristics of solar system

Item	Value	Unit
# of Panels	10	panels
Peak Panel Power	400	W
Panel Size	1.96	m2

The selection of solar panels was done via primary research, whereby 50 local installers have been contacted for quotes. Out of 50, 5 provided a comprehensive quote for installation and the model of the panel. From the model, it was possible to detract information about its peak power, efficiency and size. The selection of the preferred installer was done after comparison of factors such as panel pricing per kWh, efficiency and quality of panels and warranty length. Appendix 1 shows the quotes provided by the selected party, for different system sizes, given the same 400W panel model. Given the size of each panel and the roof, the maximum number of panels that could fit is 15. Then linear interpolation has been used to create a synthetic quote for solar systems that are composed of 2 to 15 panels. Appendices 2 and 3 show, respectively, the graph with the relationship between the number of solar panels and cost (linear relationship), and the summary table with all the quotes (organic and synthetic). The aim of following this approach, is to obtain the optimal number of panels a landlord should install to maximise its financial benefits from installing solar panels.

3.3 Net Inflow (Electricity and Financial)

3.3.1 Electricity Production

The electricity generated by the system is estimated using PVWatts (2021), a system that uses the most recent data from NREL international to provide information about solar radiation (W/m^2) and PV performance (W). The main inputs for the calculations are latitude and longitude of the location, type of sun-tracking technology and peak power (1kWh). The output that will be used in the analysis is the hourly AC system production for one year (8760 values).

3.3.2 Electricity Consumption

As mentioned previously, it is assumed that the annual electricity consumption of the household is 3,900 kWh. To obtain an accurate estimation of electricity inflow and outflow (from house to grid and vice versa) it is necessary to find out the yearly consumption on an hourly basis. To do so a top-down approach is used, meaning that a consumption profile is used to allocate the total annual consumption to each hour of the calendar year (8760 values). A load profile is a collection of coefficients that report the pattern of electricity usage over a year. As each of these factors is stated as a percentage of yearly consumption, they will add up to 1. Load profile data was created by Elexon (2021), which provides pattern of consumption for different profile classes. Based on the household attributes mentioned before, data from Profile Class 1 (domestic unrestricted customer) was selected.

3.3.3 Hourly and Yearly Electricity Net Inflow

Given the hourly consumption and production data for a calendar year, it is possible to calculate the hourly:

- Amount of system generated electricity used at home (inflow to home)
- Amount of system generated electricity sold to the grid (outflow to grid)
- Amount of electricity used from the grid (inflow from grid)

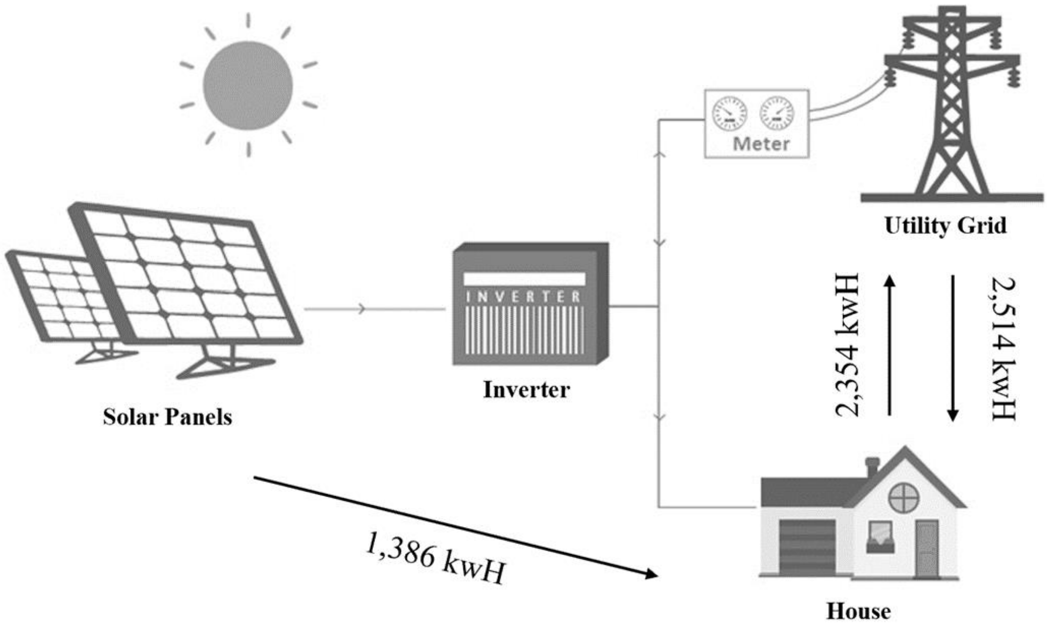
The production data can be adjusted to account different system sizes. Assuming a 4kWh system, Table 3 shows the annual electricity inflow and outflow from the hourly data.

Table 3. Annual Electricity Net Inflow

Item	Value	Unit
Consumption	3,900	kWh
Production	3,739	kWh
Inflow to home	1,386	kWh
Outflow to grid	2,354	kWh
Inflow from grid	2,514	kWh

Figure 1 portrays the general logic underlying the calculation and illustrates the electricity exchange process with three parties involved (solar panels, utility grid and home).

Figure 1. Electricity flow of grid-connected solar system



3.3.4 Hourly and Yearly Financial Net Inflow

The flow of electricity described above corresponds to a financial benefit/cost. Table 4 includes the price paid for the electricity and the price at which it is possible to sell to the grid.

Table 4. Retail Billing Details

Item	Value	Unit
Credit value for reduced inflows	0.188	£/kWh
Credit value for outflows	0.056	£/kWh

The credit value for outflows is paid by the electricity supplier, under the Smart Export Guarantee (SEG). The SEG is a government-backed initiative introduced on 1 January 2020 and require electricity suppliers to pay small-scale generators for low-carbon electricity which they export back to the grid (Ofgem 2021). Solar Energy UK (2021) provides a list of the suppliers and the corresponding rates they offer. Based on this, the supplier that offers the highest tariff rate, without the need of purchasing additional products, is Bulb Energy (however it must be the supplier of the import tariff as well). Taking this condition in consideration, the credit value for reduced inflow is given by Bulb Energy (2021) and indicates the variable unit price of retail electricity. Table 5 shows the annual financial costs, revenue and savings from installing a 4kWh solar system.

Table 5. Annual Financial Net Flow

Item	Value	Unit
Cost w/o PV system	733	£
Revenue	131	£
Cost w/ system	473	£
Savings	260	£

3.4 Operational & Maintenance Costs

Solar systems don't require a high level of maintenance, thanks to the lack of moving parts. In the UK, panels that are inclined at 15° or more benefit from being rainwater cleaning, which helps to guarantee optimal performance of the system.

However, occasional cleaning and preventive maintenance are still necessary to avoid reduction in the effectiveness of the panels over time. The panels should last 25+ years, but the inverter will most likely need to be replaced at some point during that time. Therefore, the cost of replacing the inverter needs to be factored in the model. The yearly operational and maintenance costs were calculated using the model developed by SunSpec Alliance and the National Renewable Energy Laboratory (2020), which incorporates factors such as cleaning, inspection and preventive maintenance. The string inverter, that converts the direct current (DC) into alternating current (AC), has typically a 10-year lifetime (Sangwongwanich et al.

2018). Wood Mackenzie and SEIA (2020) estimate the inverter cost to be 8% of the initial installation cost of the photovoltaic system, however, to account for the developments of inverters in terms of components' quality and topology a 3% annual cost reduction is assumed (Burger, Kranzer and Stalter 2008).

Table 6. O&M Costs

Item	Value	Unit
PV O&M costs	19.93	£/kW
Inverter as % of installed cost	8%	%
Inverter life	10	years
Inverter cost reduction	3%	%/year

3.5 Financing

To reduce the initial capital investment and spread the cost of the solar system, financing options are available in the market. In this analysis two scenarios are going to be presented: no financing and partial financing (75% of initial cost). The term of the loan is assumed to be 5 years. The loan provider was selected after reviewing interest rates and conditions from 15 different entities. A good credit score and healthy financial situation of the landlord was assumed. Appendix 4 provides the full list of lenders contacted and the corresponding interest rates offered. The lowest rate available is 3.1% on a 5-year term schedule. Based on the terms and conditions, a 3% origination fee applies, which is paid up front and not added to the original loan amount.

Table 7. Financing

Item	Value	Unit
Financing	Yes	Yes/No
% Financed	75%	%
Term	5	years
Rate	3.1%	%
Loan origination costs	3.0%	%
Lump origination into loan?	No	Yes/No

3.6 Economic Variables

Table 8 shows the economic variables used in the model as an input to obtain projected O&M costs, electricity costs and financial metrices.

Table 8. Economic Variables

Item	Value	Unit
O+M cost escalator	2.60%	%/year
Electricity cost escalator	4.10%	%/year
Equity (household) cost of capital	0.86%	%

The annual cost escalator for O&M was obtained from the historical consumer price inflation time series, while the annual escalator of electricity price from the historical electricity price inflation time series (Office of National Statistics, 2021). The proxy for the equity cost of capital used is the 10-year GBP LIBOR Swap, which will be an input to calculate NPV and LCOE.

3.8 Battery Storage

In general, battery storage is widely regarded as a viable option for lowering the intermittency of electricity generated by solar systems. However, it is presently uncertain when and under what circumstances battery storage may be used profitably in residential PV systems without government incentives and financial support.

When solar panels and storage are combined, there are additional financial considerations that need to be analysed. Battery energy storage can help to overcome technical barriers created by PV grid integration and expand the market for solar systems. Storage can increase the value propositions that residential solar projects can access and improve the value of the system, but it can also raise overall costs and add complexity, which can outweigh the advantages. Shifting when PV generation is used has a variety of potential benefits, including savings on time-of-use and demand charge reductions; avoiding net metering where technical constraints or utility policy prevent it; increasing facility resilience by keeping systems energized during grid outages; and potentially monetizing other grid benefits such as power factor correction, frequency regulation, and voltage support (Pena-Bello et al. 2017). This study will compare the financial performance of a PV system with and without a battery, to establish if the initial increase in capital expenditure is worthwhile. Table 9 shows the technical characteristics of the battery storage.

Table 9. Battery Storage Characteristics

Item	Value	Unit
Battery Storage	Yes	Yes/No
Storage useful life	10	years
Max. Loading capacity	3.3	kWh
Initial State of Charge	1.0	kWh
Usable Capacity	3.0	kW
Max Charging Power	2.0	kW
Max discharge depth	93%	%
Losses	0.05%	%
Battery cost reduction	8.27%	%/year

The same solar panels installer has provided a quote for a 3.3kwH battery. The lifetime of the battery is assumed to be 10 years (reference), this implies that after this period, it will require replacement and involve additional costs. According to the International Renewable Energy Agency (2017), between 2014 and 2017, small-scale Li-ion battery system have experienced a 60% reduction in pricing. This was mainly driven by the strong growth in scale of Li-ion battery manufacturing for EVs. By 2030, the cost of stationary applications might drop by another 54-61%. The lower bound of the estimate was used to calculate the CAGR of battery cost (8.27%). It is also assumed that the battery is DC connected, such that the battery power output is inverted to AC using the same inverter as the solar system. Based on these assumptions, Table 10 displays the annual flow of electricity between grid, battery, solar panels and household.

Table 10. Yearly Electricity Net Inflow (with battery)

Item	Value	Unit
Production	3,739	kWh
Consumption	3,900	kWh
Direct self-consumption	1,386	kWh
Self-consumption from battery	806	kWh
Mains Supply	1,708	kWh
Grid feed-in	1,544	kWh
Battery losses	5	kWh

The self-consumption ratio, or the percentage of power generated by the PV system that is used by the home, is computed first as the foundation for the financial calculations. The calculation's general logic is depicted in Figure 2. It is assumed that whenever the electricity consumption throughout the day can be met by the simultaneous electricity production of the solar system, the household consumes its own electricity (4). If residential usage exceeds power output, excess electricity is either stored for later use (2) or sold to the grid if the storage is full (3). The self-consumption ratio is the proportion of power used directly (4) or subsequently taken from storage (5) to the total electricity generated by the solar system (sum of 2,3,4). This ratio is directly proportional to the size of the solar system and the size of the battery storage for a given power usage.

Figure 2. Battery Storage Rationale

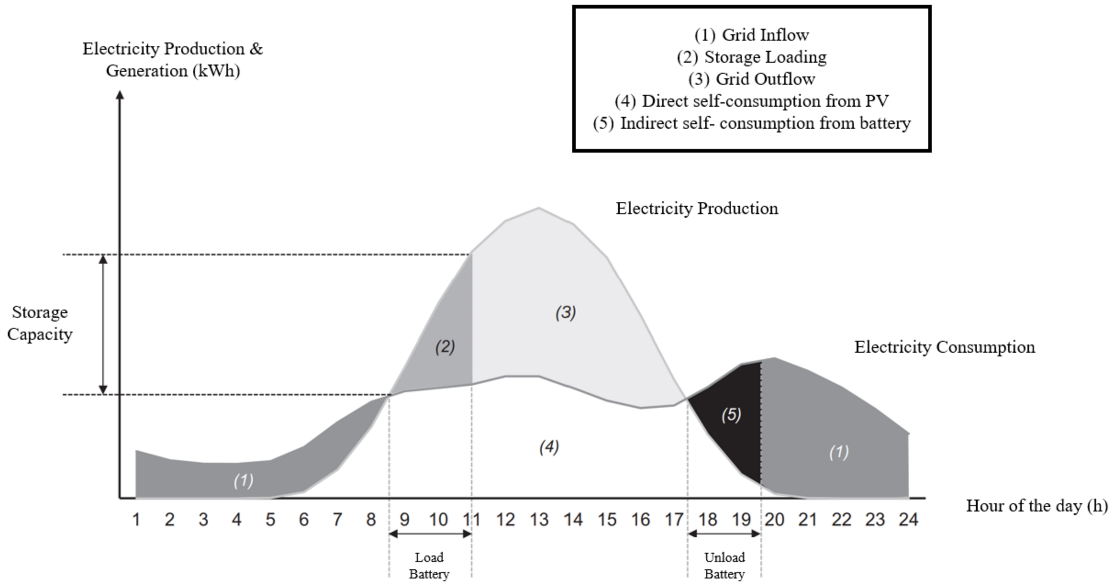


Table 11 reports the corresponding annual cost, benefits and savings from a 4kWh solar system and a 3.3kWh battery.

Table 11. Annual Financial Net Flow (with battery)

Item	Value	Unit
Cost w/o PV system	733	£
Revenue	86	£
Cost w/ system	321	£
Savings	412	£

The savings obtained correspond to £412, a 36.9% increase if compared to the savings obtained from the same solar system, without the battery. This, however, does not consider the initial capital outlay on the battery and the future expenditures to replace it.

3. ECONOMIC ANALYSIS

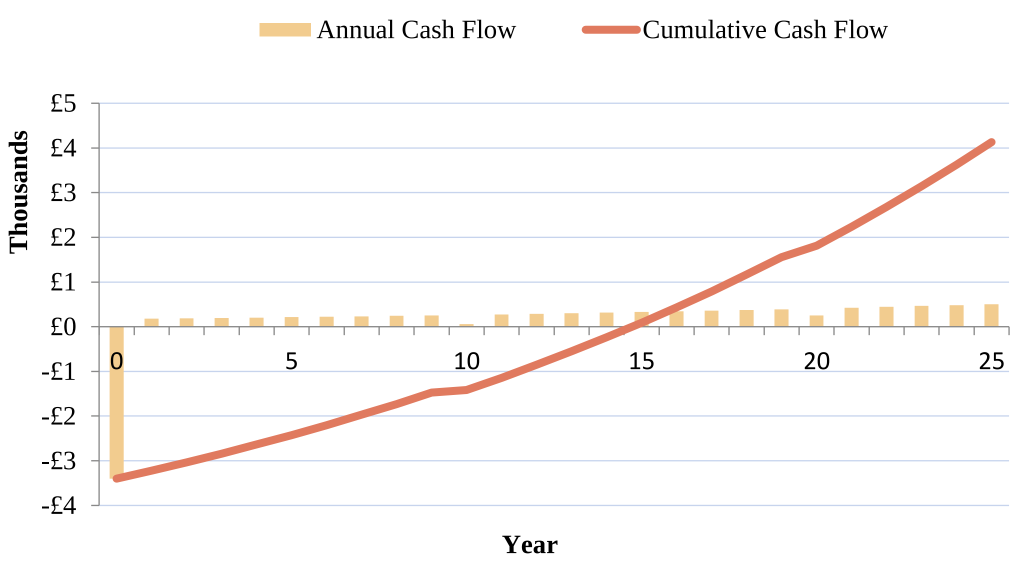
In this section, the model outcomes are described, i.e. the financial benefits and costs of investing in solar systems and the optimal number of panels that the landlord should install. First, assuming no battery and 75% financing of the initial investment, Table 12 presents the financial performance for different numbers of panels installed (2-15).

Table 12. Financial performance of solar system with different number of panels

# of panels	NPV (£)	IRR (%)	Payback (years)	LCOE (c/kWh)	BCR
2	£1,352	4.32%	18	10.08	2.9
3	£2,290	6.04%	16	8.10	4.0
4	£2,800	6.67%	16	7.10	4.4
5	£2,970	6.63%	16	6.51	4.4
6	£2,979	6.33%	16	6.11	4.2
7	£2,903	5.93%	17	5.83	4.0
8	£2,764	5.48%	17	5.61	3.7
9	£2,576	4.99%	18	5.45	3.4
10	£2,346	4.49%	18	5.32	3.0
11	£2,083	3.98%	19	5.21	2.7
12	£1,792	3.46%	20+	5.12	2.4
13	£1,481	2.95%	20+	5.04	2.1
14	£1,151	2.44%	20+	4.98	1.8
15	£806	1.94%	20+	4.92	1.6

From the results, it is possible conclude that 6 is the optimal number. Therefore, to maximize the NPV, the landlord should invest in 6 400W solar panels, leading to a 2.4kWh solar system. Figure 3 shows the annual cash flows and cumulative cash flows of the optimal investment.

Figure 3. Cash Flows optimal investment



Once the optimal number of panels has been suggested, this study presents detailed cash flow projections for four different scenarios:

(a) No battery storage and 75% financing of initial investment

(b) No battery and self-funded investment

(c) 3.3kwH battery and 75% financing of initial investment

(d) 3.3kwH battery and self-funded investment

Appendix 5 (a, b, c, d) shows the 25-year projections, which all include initial capital outlay, value of energy, O&M costs, inverter replacement costs. To compare the potential financial benefits of each scenario, various metrices are employed (Table 13). A more detailed description of decision criteria is presented in the next section.

Table 13. Direct Financial Metrics

Financial Metric	(a)	(b)	(c)	(d)
NPV (£)	£2,979	£3,227	£3,380	£3,789
IRR (%)	6.33%	5.95%	4.75%	4.65%
Simple Payback Years	16	15	18	17
LCOE (c/kWh)	6.11	10.74	10.76	18.38
Benefit/Cost Ratio	4.2	1.9	3.2	1.7

3.1 Net Present Value (NPV)

For a given investment in year t, the NPV of landlord's investment is computed as the sum of the discounted cash in- and outflows over the 25-year lifetime of the solar system (Hoppmann, Huenteler and Girod 2014). Cash outflows include investment expenditure in the solar system (and battery), as well as O&M, as shown previously in Appendix 5. For the cash inflow, it is assumed that when the household consumes power from its own solar system, it is substituting electricity that it would otherwise have to purchase at retail prices from the electricity provider. Excess electricity is sold at wholesale prices, under the SEG programme, if it is not consumed or stored. The household's revenues are then calculated as the sum of self-consumed multiplied by the retail electricity price and electricity sold to the grid. The discount rate used is the equity (household) cost of capital. Based on the results, scenario (d) provides the highest value for NPV (£3,789), therefore the landlord should invest in the solar system with battery without using a loan (if financial conditions permit). As the cost of debt is higher than the cost of equity, the NPV of the project with 100% equity is higher than the one with 75% debt.

3.1 Internal Rate of Return (IRR)

For an investment with a series of future cash flows, the IRR is the rate that makes the NPV of the cash flows equal to zero. The IRR analysis enables for a wide range of investment activity to be compared. When analysing projects that require more investment after return, however, IRR is not suggested since downstream investments are erroneously discounted, resulting in numerous positive PRR values. IRR is a popular tool for accepting or rejecting offers since it allows for a rapid comparison to a minimum acceptable rate of return. Because the values of different investment amounts are not taken into account, IRR should not be used when choosing between mutually exclusive options. In this case, scenario (a) presents the highest (6.33%) rate because it requires the smallest capital outlay.

3.2 Simple Payback Period

Simple payback is the number of years necessary to recover the initial capital expenditure of an investment. For example, a £1,000 investment which provides £500 in annual returns would have a payback period of two years. Following this, the investment will have paid for itself. In the analysis, scenario (b) offers the lowest payback period, 15 years. In other words, considering the £3,400 project cost and the cashflows presented in 5 (b), it will take 12 years to cover the initial financial outlay. Simple payback is useful for quick assessments, but it ignores time value of money.

3.3 Levelized Cost of Energy (LCOE)

The LCOE allows alternative technologies to be compared when different scales of operation, different investment and operating time periods, or both exist. For example, it allows the comparison between the cost of energy produced with fossil fuel with that one from a renewable source. The formula to calculate LCOE is:

$$\text{LCOE}=\frac{\text{Total Lifetime Cost}}{\text{Total Lifetime Output}} \quad \text{or} \quad \text{LCOE}=\frac{\sum_{t=1}^{n}\frac{I_t+M_t}{(1+r)^t}}{\sum_{t=1}^{n}\frac{E_t}{(1+r)^t}}$$

Where:

I_t = Investment and costs for the year t

M_t = O&M for the year t

E_t = Electrical output for the year t

r = Discount rate

n = The (expected) lifetime of the power system

The denominator is equal for all the cases, while the numerator. As expected, case (a) has the lower LCOE due to the lower lifetime cost.

3.4 Benefit/Cost Ratio (BCR)

BCR analysis is performed to establish whether and to what degree the benefits of a particular project exceed its costs. If the BCR of a project is larger than 1.0, the project is expected to generate a positive NPV for the investor. The opposite is true if BCR is smaller than 1.0. In all the cases, the BCR exceeds 1.0.

4. FINAL RECOMMENDATION

This report highlights the operational financial benefits of installing a solar system in London, which could be more than £220 per year without a battery and more than £330 with a battery. The savings are driven by electricity bill reduction and revenue from selling surplus power to the grid. One factor that could lead to further financial benefits that were not included in this analysis is the increase of the overall property value from installing a solar system. Solar Energy UK (2021) has shown that a typical property in the UK could increase its sales price by at least £1,800. Beyond the financial benefits, the solar system will also have a substantial environmental impact as it will reduce carbon emissions and improve the environmental performance of the property. It also ensures a clean, cheap source of energy for new green technologies such as electric vehicles.

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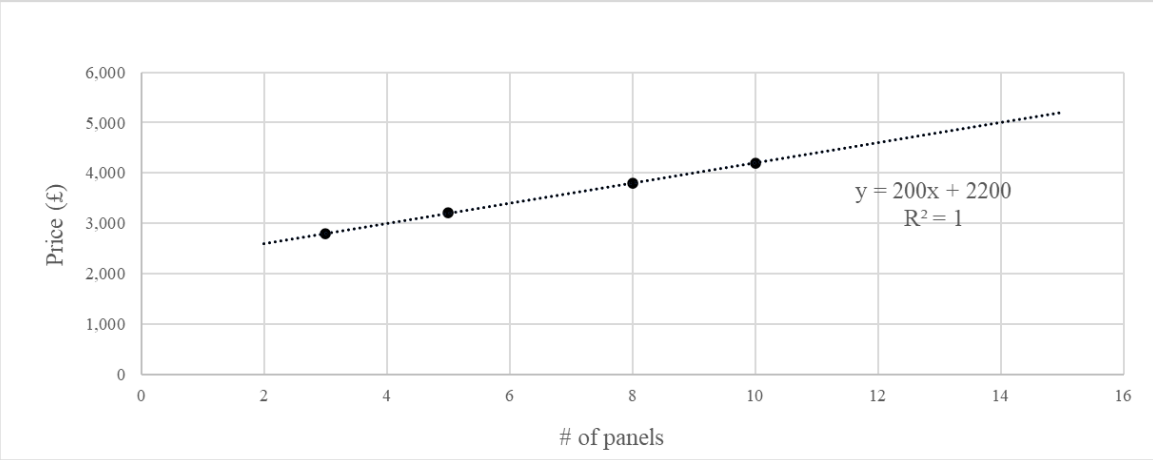
6. APPENDIX

Appendix 1. Solar panels installer quotes (Hyundai Solar HiE-S400VG)

Panel Size (W)	Efficiency (%)	Space (m2)	Quantity	Total Space (m2)	System Size (kWp)	Cost (£)	Price per Kwh
400	20.9%	1.96	3	5.9	1.20	£2,800	£2,333
			5	9.8	2.00	£3,200	£1,600
			8	15.7	3.20	£3,800	£1,188
			10	19.6	4.00	£4,200	£1,050

Appendix 2. Relationship between number of panels and cost



Appendix 3. Organic and Synthetic quotes

Quantity	Total Space (m2)	System Size (kWp)	Cost (£)
2	3.9	800	£2,600
3	5.9	1,200	£2,800
4	7.8	1,600	£3,000
5	9.8	2,000	£3,200
6	11.8	2,400	£3,400
7	13.7	2,800	£3,600
8	15.7	3,200	£3,800
9	17.6	3,600	£4,000
10	19.6	4,000	£4,200
11	21.6	4,400	£4,400
12	23.5	4,800	£4,600
13	25.5	5,200	£4,800
14	27.4	5,600	£5,000
15	29.4	6,000	£5,200

Appendix 4. Loan Providers and Rates (5-year term)

Provider	Rate
AA	8.1%
Tesco Bank	8.1%
Cahoot	9.4%
Shawbrook Bank	11.9%
Paragon	3.7%
Post Office	8.3%
Masthaven	4.3%
Admiral	3.1%
M&S Bank	2.9%
Precise Mortgages	4.4%
Creditplus	19.9%
Believe Loans	9.4%
Pegasus	7.8%
Forever Green Energy	9.9%
Hitachi Capital (UK)	7.7%

Appendix 5. (a) Cash Flows Project – No battery & 75% Financing

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
PV Energy Production		2,244	2,236	2,227	2,219	2,211	2,204	2,196	2,188	2,180	2,172	2,164	2,156	2,149	2,141	2,133	2,125	2,118	2,110	2,103	2,095	2,087	2,080	2,072	2,065	2,058
SYSTEM COSTS	-£3,400																									
FINANCING COSTS																										
Loan Origination Costs	-£77																									
Less Loan Proceeds	£2,550																									
NET CAPITAL COSTS	**-£927**																									
BENEFITS/INCOME																										
PV Energy Value		£226	£235	£245	£255	£266	£276	£288	£300	£312	£325	£338	£352	£366	£381	£397	£413	£430	£448	£466	£485	£505	£526	£547	£570	£593
OPERATING COSTS																										
- Annual scheduled O+M		£48	£49	£50	£52	£53	£54	£56	£57	£59	£60	£62	£63	£65	£67	£69	£70	£72	£74	£76	£78	£80	£82	£84	£86	£89
- Interest pymts		£79	£64	£49	£33	£17	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0
- Inverter replacement		£0	£0	£0	£0	£0	£0	£0	£0	£0	£207	£0	£0	£0	£0	£0	£0	£0	£0	£0	£152	£0	£0	£0	£0	£0
- Battery replacement		£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0
TOTAL OPERATING COSTS		**-£127**	**-£113**	**-£99**	**-£85**	**-£70**	**-£54**	**-£56**	**-£57**	**-£59**	**-£267**	**-£62**	**-£63**	**-£65**	**-£67**	**-£69**	**-£70**	**-£72**	**-£74**	**-£76**	**-£230**	**-£80**	**-£82**	**-£84**	**-£86**	**-£89**
NET INCOME		**£99**	**£122**	**£146**	**£170**	**£196**	**£222**	**£232**	**£242**	**£253**	**£58**	**£276**	**£288**	**£301**	**£314**	**£328**	**£343**	**£358**	**£374**	**£390**	**£255**	**£425**	**£444**	**£463**	**£483**	**£505**
- Principal pymts		-£479	-£494	-£510	-£525	-£542	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0
Annual Cash Flow	**-£927**	**-£380**	**-£372**	**-£364**	**-£355**	**-£346**	**£222**	**£232**	**£242**	**£253**	**£58**	**£276**	**£288**	**£301**	**£314**	**£328**	**£343**	**£358**	**£374**	**£390**	**£255**	**£425**	**£444**	**£463**	**£483**	**£505**
Cumulative Cash Flow	-£927	-£1,307	-£1,679	-£2,042	-£2,397	-£2,743	-£2,521	-£2,289	-£2,047	-£1,794	-£1,736	-£1,460	-£1,172	-£871	-£556	-£228	£115	£473	£847	£1,237	£1,492	£1,917	£2,360	£2,824	£3,307	£3,812

Appendix 5. (b) Cash Flows Project – No battery & Self-funded

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
PV Energy Production		2,244	2,236	2,227	2,219	2,211	2,204	2,196	2,188	2,180	2,172	2,164	2,156	2,149	2,141	2,133	2,125	2,118	2,110	2,103	2,095	2,087	2,080	2,072	2,065	2,058
SYSTEM COSTS	-£3,400																									
FINANCING COSTS																										
Loan Origination Costs	£0																									
Less Loan Proceeds	£0																									
NET CAPITAL COSTS	**-£3,400**																									
BENEFITS/INCOME																										
PV Energy Value		£226	£235	£245	£255	£266	£276	£288	£300	£312	£325	£338	£352	£366	£381	£397	£413	£430	£448	£466	£485	£505	£526	£547	£570	£593
OPERATING COSTS																										
- Annual scheduled O+M		£48	£49	£50	£52	£53	£54	£56	£57	£59	£60	£62	£63	£65	£67	£69	£70	£72	£74	£76	£78	£80	£82	£84	£86	£89
- Interest pymts		£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0
- Inverter replacement		£0	£0	£0	£0	£0	£0	£0	£0	£0	£207	£0	£0	£0	£0	£0	£0	£0	£0	£0	£152	£0	£0	£0	£0	£0
- Battery replacement		£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0
TOTAL OPERATING COSTS		**-£48**	**-£49**	**-£50**	**-£52**	**-£53**	**-£54**	**-£56**	**-£57**	**-£59**	**-£267**	**-£62**	**-£63**	**-£65**	**-£67**	**-£69**	**-£70**	**-£72**	**-£74**	**-£76**	**-£230**	**-£80**	**-£82**	**-£84**	**-£86**	**-£89**
NET INCOME		**£178**	**£186**	**£195**	**£203**	**£213**	**£222**	**£232**	**£242**	**£253**	**£58**	**£276**	**£288**	**£301**	**£314**	**£328**	**£343**	**£358**	**£374**	**£390**	**£255**	**£425**	**£444**	**£463**	**£483**	**£505**
- Principal pymts		£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0
Annual Cash Flow	**-£3,400**	**£178**	**£186**	**£195**	**£203**	**£213**	**£222**	**£232**	**£242**	**£253**	**£58**	**£276**	**£288**	**£301**	**£314**	**£328**	**£343**	**£358**	**£374**	**£390**	**£255**	**£425**	**£444**	**£463**	**£483**	**£505**
Cumulative Cash Flow	-£3,400	-£3,222	-£3,035	-£2,841	-£2,637	-£2,425	-£2,203	-£1,971	-£1,728	-£1,475	-£1,418	-£1,142	-£853	-£552	-£238	£91	£433	£791	£1,165	£1,555	£1,810	£2,235	£2,679	£3,142	£3,626	£4,130

Appendix 5. (c) Cash Flows Project – Battery & 75% Financing

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
PV Energy Production		2,244	2,236	2,227	2,219	2,211	2,204	2,196	2,188	2,180	2,172	2,164	2,156	2,149	2,141	2,133	2,125	2,118	2,110	2,103	2,095	2,087	2,080	2,072	2,065	2,058
SYSTEM COSTS	-£5,595																									
FINANCING COSTS																										
Loan Origination Costs	-£126																									
Less Loan Proceeds	£4,196																									
NET CAPITAL COSTS	**-£1,525**																									
BENEFITS/INCOME																										
PV Energy Value		£340	£354	£369	£384	£400	£416	£433	£451	£469	£489	£509	£529	£551	£574	£597	£622	£647	£674	£701	£730	£760	£791	£824	£857	£893
OPERATING COSTS																										
- Annual scheduled O+M		£48	£49	£50	£52	£53	£54	£56	£57	£59	£60	£62	£63	£65	£67	£69	£70	£72	£74	£76	£78	£80	£82	£84	£86	£89
- Interest pymts		£130	£106	£80	£54	£28	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0
- Inverter replacement		£0	£0	£0	£0	£0	£0	£0	£0	£0	£340	£0	£0	£0	£0	£0	£0	£0	£0	£0	£251	£0	£0	£0	£0	£0
- Battery replacement		£0	£0	£0	£0	£0	£0	£0	£0	£0	£1,009	£0	£0	£0	£0	£0	£0	£0	£0	£0	£426	£0	£0	£0	£0	£0
TOTAL OPERATING COSTS		**-£178**	**-£155**	**-£131**	**-£106**	**-£81**	**-£54**	**-£56**	**-£57**	**-£59**	**-£1,410**	**-£62**	**-£63**	**-£65**	**-£67**	**-£69**	**-£70**	**-£72**	**-£74**	**-£76**	**-£755**	**-£80**	**-£82**	**-£84**	**-£86**	**-£89**
NET INCOME		**£162**	**£200**	**£238**	**£278**	**£319**	**£362**	**£377**	**£394**	**£411**	**-£921**	**£447**	**£466**	**£486**	**£507**	**£529**	**£551**	**£575**	**£600**	**£625**	**-£24**	**£680**	**£709**	**£740**	**£771**	**£804**
- Principal pymts		-£789	-£813	-£838	-£864	-£891	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0
Annual Cash Flow	**-£1,525**	**-£626**	**-£614**	**-£600**	**-£587**	**-£572**	**£362**	**£377**	**£394**	**£411**	**-£921**	**£447**	**£466**	**£486**	**£507**	**£529**	**£551**	**£575**	**£600**	**£625**	**-£24**	**£680**	**£709**	**£740**	**£771**	**£804**
Cumulative Cash Flow	-£1,525	-£2,151	-£2,765	-£3,365	-£3,952	-£4,524	-£4,163	-£3,785	-£3,392	-£2,981	-£3,902	-£3,456	-£2,990	-£2,504	-£1,997	-£1,468	-£917	-£341	£258	£884	£859	£1,540	£2,249	£2,988	£3,760	£4,564

Appendix 5. (d) Cash Flows Project – Battery & Self-funded

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
PV Energy Production		2,244	2,236	2,227	2,219	2,211	2,204	2,196	2,188	2,180	2,172	2,164	2,156	2,149	2,141	2,133	2,125	2,118	2,110	2,103	2,095	2,087	2,080	2,072	2,065	2,058
SYSTEM COSTS	-£5,595																									
FINANCING COSTS																										
Loan Origination Costs	£0																									
Less Loan Proceeds	£0																									
NET CAPITAL COSTS	**-£5,595**																									
BENEFITS/INCOME																										
PV Energy Value		£340	£354	£369	£384	£400	£416	£433	£451	£469	£489	£509	£529	£551	£574	£597	£622	£647	£674	£701	£730	£760	£791	£824	£857	£893
OPERATING COSTS																										
- Annual scheduled O+M		£48	£49	£50	£52	£53	£54	£56	£57	£59	£60	£62	£63	£65	£67	£69	£70	£72	£74	£76	£78	£80	£82	£84	£86	£89
- Interest pymts		£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0
- Inverter replacement		£0	£0	£0	£0	£0	£0	£0	£0	£0	£340	£0	£0	£0	£0	£0	£0	£0	£0	£0	£251	£0	£0	£0	£0	£0
- Battery replacement		£0	£0	£0	£0	£0	£0	£0	£0	£0	£1,009	£0	£0	£0	£0	£0	£0	£0	£0	£0	£426	£0	£0	£0	£0	£0
TOTAL OPERATING COSTS		**-£48**	**-£49**	**-£50**	**-£52**	**-£53**	**-£54**	**-£56**	**-£57**	**-£59**	**-£1,410**	**-£62**	**-£63**	**-£65**	**-£67**	**-£69**	**-£70**	**-£72**	**-£74**	**-£76**	**-£755**	**-£80**	**-£82**	**-£84**	**-£86**	**-£89**
NET INCOME		**£292**	**£305**	**£318**	**£332**	**£347**	**£362**	**£377**	**£394**	**£411**	**-£921**	**£447**	**£466**	**£486**	**£507**	**£529**	**£551**	**£575**	**£600**	**£625**	**-£24**	**£680**	**£709**	**£740**	**£771**	**£804**
- Principal pymts		£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0	£0
Annual Cash Flow	**-£5,595**	**£292**	**£305**	**£318**	**£332**	**£347**	**£362**	**£377**	**£394**	**£411**	**-£921**	**£447**	**£466**	**£486**	**£507**	**£529**	**£551**	**£575**	**£600**	**£625**	**-£24**	**£680**	**£709**	**£740**	**£771**	**£804**
Cumulative Cash Flow	-£5,595	-£5,303	-£4,997	-£4,679	-£4,347	-£4,000	-£3,638	-£3,261	-£2,868	-£2,457	-£3,378	-£2,932	-£2,466	-£1,980	-£1,473	-£944	-£392	£183	£782	£1,408	£1,383	£2,064	£2,773	£3,512	£4,284	£5,088