THE UNIVERSITY *of* EDINBURGH
School of Engineering

Solar Energy Group Report – GROUP 12

Comparative study of a residential and commercial PV System designs in the UK and the US

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Abstract: The variation of solar characteristics has led to the study of solar resources, national policies and solar photovoltaic (PV) development in PVsyst and thermal technologies in the United Kingdom (UK) and United States (US). The climate is a challenge in the UK, yet the encouraging incentives offered by the government have influenced residential rooftop solar PV system design and the vast sunlight penetration in the US has influenced to a solar car park installation at Santa Barbara Airport. Within the payback period, both small-scale and large-scale solar PV projects proved their feasibility and return of investment. Compared with local projects, the vast sunlight irradiation in the US retains widely installed both solar PV and thermal, gaining more interest in commercial sector. For the UK, due to its policy encouragement, residential sector is widely popularised. Exploiting natural resource, solar PV system has become an alternative to generating energy and are suitable for a greener environment. A solar thermal for water heating system at a hospital in Birmingham and a hybrid solar thermal on the gas-fired system in California are discussed to emphasise the natural resources and incentives towards the growing market.

Keywords: solar energy; solar resource; solar market; solar policy; PV system design; PVsyst; solar thermal;

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1. Introduction

With the aggravation of climate change and energy resources shortages, many governments put forward energy-saving policies and incentives. Among renewable energy technologies, solar photovoltaic (PV) is the most rapidly developing technology in recent years. Electricity generation through solar panels causes no pollution to the environment, which fits the trend of applying sustainable energy networks. Besides, the convenience and low cost of solar panels make photovoltaic power flexible for commercial and civilian applications.

In this study, two PV systems are proposed, a residential in Essex, UK, and a commercial electrical vehicle charging station in Santa Barbara, California, USA. Firstly, a detailed investigation of the solar energy resources in both places are presented. Subsequently, the paper analyses the aspects of the local solar energy markets and policies and performs simulation studies for both locations using PVsyst. Lastly, the report gives an overview of solar thermal applications in the two countries, including relevant markets, notable projects, and emerging technologies.

2. The Solar Resource in the UK and the USA

2.1. Solar Resource in the UK

The temperate climate in the United Kingdom might sparks some doubts about the feasibility of the solar photovoltaic (PV) technology in meeting the national energy demand. However, solar PV is a growing renewable energy sector that plays an important role in the electricity market. Since 2015, due to rapid expansion of government incentives, the technology has surpassed hydropower in terms of electricity generation from renewable sources [1].

Environmental and climatic factors, such as solar irradiance, average daily sun hours, ambient temperature and wind speed, have the most significant impact on efficient energy production of the solar PV system. As for the UK, its location on the off-north-western coast of Europe lies between the latitude of 49°N and 59°N and longitude from 8°W to 2°E, therefore, the Earth's rotation provides a significant difference between the winter and summer solstices. As shown in Figure 1, the annual irradiation ranges from as little as 850 kWh/m² in Scottish Highlands to over 1000 kWh/m² in the South East and West, where country's most PV installation are located. As the daylight duration in winter is up to 8h 49 min shorter than in the summer, solar irradiation and thus electricity generation are highly variable throughout the year. As opposed to the countries located near the equator where the factors of winter and summer solstices are not so severe.

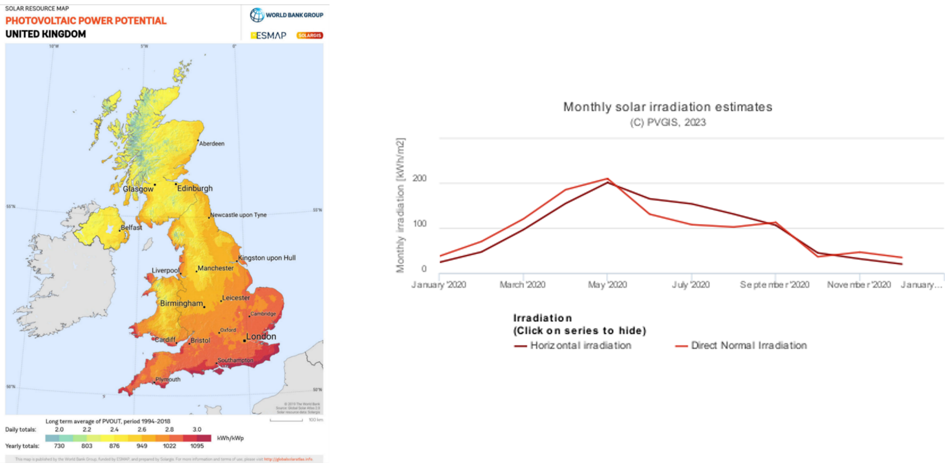


Figure 1. UK Annual Average Solar Radiation [2] (left) & Horizontal and direct normal irradiation over a year in Essex [3] (right).

Generally, the whole country experiences multiple rainy and cloudy days, with Essex average annual sunshine hours accounting to 1615.59h/yr and approximately 102 rainy days per year [4].

With limited sunlight, only 4.4h per day on average, and low average annual ambient temperature ranging from 7.54°C to 14.65°C, Essex experiences less direct irradiation [4]. However, solar PV can also utilise the diffuse irradiation reflected from the clouds, sky, and surroundings. The changing weather conditions are difficult to predict, thus the power generation curve is subject to multiple variations throughout the day.

Although the location of the UK correlates with the weather stands for a technological challenge, an optimised generation is achievable. With encouraging incentives and policies, more solar PV can generate profit and are increasingly deploys in both public and private sectors.

2.2. Solar Resource in the USA

The annual total solar radiation in the United States, varies depending on factors such as location, season, and weather, as shown in Figure 2. According to data from the National Renewable Energy Laboratory (NREL), the average total solar radiation in the United States is around 43MJ/m²/yr (118kWh/m²/day).

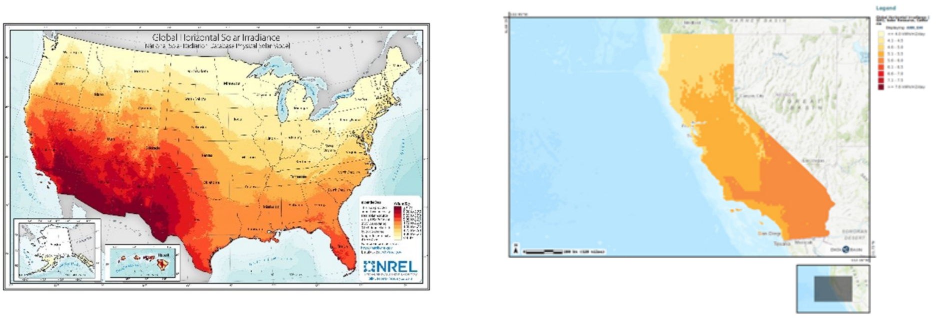


Figure 2. US Annual Solar GHI (left) & California Annual Solar DHI (right) [5].

Generally, the southern and western regions of the United States receive higher total solar radiation than the northern and eastern regions, as shown in Table 1. In addition, the total solar radiation is typically higher in summer and lower in winter [6].

Table 1. Average Annual Solar Radiation in kWh/m² according to U.S. regions.

Regions	Average Annual Solar Radiation in kilowatt-hours per square meter
Northeast	3,600 - 4,200 kWh/m²
Midwest	4,200 - 5,000 kWh/m²
Southeast	4,500 - 6,000 kWh/m²
Southwest	5,000 - 7,000 kWh/m²
Northwest	3,000 - 4,500 kWh/m²
Alaska	1,200 - 2,400 kWh/m²
Hawaii	5,000 - 6,500 kWh/m²

2.2.1. The solar resources in California and Santa Barbara

The southeastern deserts of California characterise of one of the best solar resources in the US, where a broad portfolio of large-scale solar PV and solar thermal plants can be found. As of December 2021, California owned more utility-scale solar power capacity (15,500 MW) than any other state, whereas the small-scale facilities accounted for almost 28,000MW of total solar power [7].

The GHI distribution in CA is shown in Figure 2, showing this state has abundant solar resources compared to other states in US, which is a suitable position to build PV system. Santa Barbara is located in one of the most grid-vulnerable regions in California, the Goleta Load Pocket (GLP). The area gets most of its power from just one set of transmission lines that are hung on the same transmission towers and routed through 40 miles of mountainous terrain — making the GLP highly vulnerable. With its abundant solar resources, shown in Figure 3, the city develops distributed solar plants to meet the energy demand.

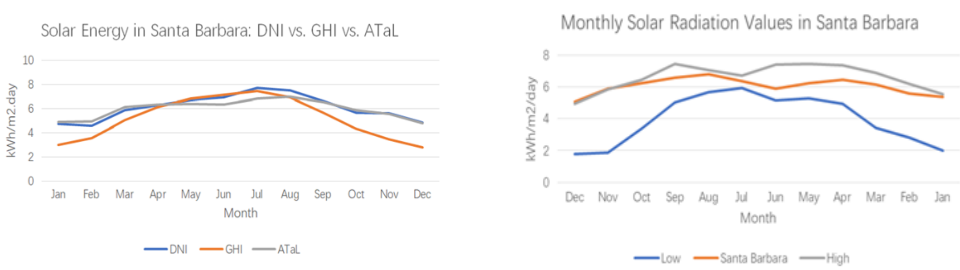


Figure 3. Solar Energy in Santa Barbara.

3. The Solar Market and Policies in the UK and California, USA

3.1. Solar Market and Policies in the UK

The electricity demand in the UK is expected to continue growing as electrification of more sectors is bound to occur. Unfortunately, the electricity generated from renewable sources decreases as a result of less favourable weather conditions, which causes fossil fuel to return to meet the demand [8]. Despite that, the renewable generation grew by 18% of total electricity generation by 2022 even enhanced by the summer heatwave in 2022 by 20% [9].

Considering the rise in electricity demand grievously affecting the electricity prices, the government has played a major role in promoting solar PV as an alternative for energy generation and reduction of carbon emissions. As seen in Figure 4, government incentives and declining solar technology costs have encouraged solar PV adoption in residential and commercial sectors [10,11].

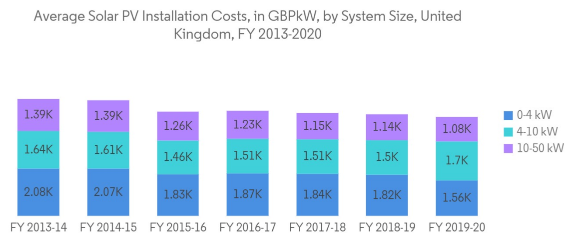


Figure 4. Average installations costs for solar PV in the UK.

Policies and incentives introduced by the governemnt over the last decade have encouraged solar PV system utilisation to reach 40 GW capacity by 2030 and contribute to the net-zero goal in 2050 [10]. Throughout 2010 until 2019, the feed-in tariffs (FiT) allowed homeowners to sell the surplus energy to the grid. The scheme coupled with decreasing solar panel market prices, greatly contributed to popularisation of solar energy in the UK [11].

In order to sustain the pace of the market growth and mitigate the impact of FiT removal, the government commenced the Smart Export Guarantee (SEG) scheme on 1 January 2020. The scheme enables small-scale low-carbon electricity generators to receive payment for selling surplus energy to energy suppliers. All licensed suppliers with over 150,000 customers are bound to offer an export tariff to the customers [12]. Customers can browse for different SEG licenses for the best tariff which encourages healthy competition between suppliers, while also benefiting the customers in generating profit.

The UK government introduced a 5-year zero rate VAT to reduce the costs of installation and energy-saving materials (ESM) in domestic properties, which also covers solar PV. Beginning from April 2022 until March 2027, the new tax scheme, referring to the Value Added Tax Act 1994 (VATA) ('Group 2'), permits the businesses that install EMS to no longer deal with social policy conditions to determine the qualification of installation or the ESM cost not exceeding 60% of total value supply [13]. This measure passes the VAT saving to the customers, lowering the prices charged by the installer and thus encouraging more ESMs installation.

ECO4 was introduced by the government based on a £4 billion budget for years 2022-2026. This policy gives a chance for UK homeowners to reduce bills and carbon from housing stocks, improving the energy efficiency of UK households. The coverage by the government on solar panels and heat pumps installation has obliged the energy suppliers alongside the installation companies to provide services such as insulation, solar PV installation, boilers maintenance and greener heating system installation for low-income UK homeowners, under the new Energy Performance Certificate (EPC) requirements [14].

3.2. Solar Market and Policies in California, USA

In the first nine months of 2022, solar PV was the largest source of new power generation in the US, making up 45% of the total. The country added 4.6 GW of solar PV capacity in Q3 2022, reaching a cumulative capacity of 135.7 GW that can power up to

24 million homes. The residential sector had its best quarter ever with 1.57 GW installed, while the utility-scale sector faced a 36% drop from last year's Q3 due to supply chain and trade issues. However, the outlook for solar presents in bright colours due to the Inflation Reduction Act (IRA), which is expected to boost the average annual growth rate to 21% from 2023 to 2027 [15].

California is the leading state in the US for solar energy, as shown in Figure 5, with 38,145 MW of installed capacity that can power over 10 million homes and provide 27.3% of the state's electricity. California has a vibrant solar industry with more than 2,300 companies and 75,000 jobs. Over the last decade, solar prices have dropped by half and the state has invested $85 billion in solar projects. The state plans to add another 27,000 MW of solar in the next five years to meet its climate and energy goals [16].

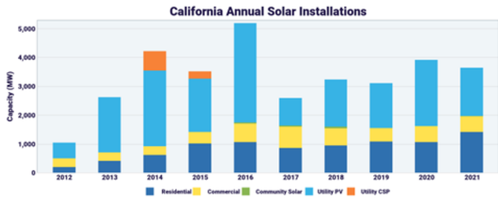


Figure 5. California Annual Solar Installations.

In order to achieve these impressive statistics, California implemented several policies to encourage the adoption of solar energy.

California's Renewable Portfolio Standard (RPS) is a vital program that promotes the adoption of renewable energy. The program mandates that load-serving entities in California meet ever-increasing procurement targets for renewable energy. To comply with the RPS, electricity generation must be sourced from facilities certified under the program. By 2030, electric utilities must source 60% of their electricity from renewable sources. As a result, the program has been instrumental in driving substantial investment in solar energy projects throughout the state [17].

Based on California's solar energy resource policy, Santa Barbara has also introduced solar energy resource policies for its residents to better protect the rights of local residents. The Santa Barbara Home Power Program is one of the examples. The program is officially supported by the City of Santa Barbara and Santa Barbara Clean Energy ensuring that the solar installation and battery storage system is state-of-the-art and customized for one's home. The program covers the costs of the system equipment, installation, and maintenance. There is no credit check, no financing, and no lien on residents' property [18].These policies provide financial incentives, regulatory requirements, and educational resources to encourage property owners to adopt solar energy and other sustainable practices.

4. Domestic Solar Panels Design in Essex, UK

4.1. Location Analysis

The first design proposes a domestic solar PV application for a single household, as shown in Figure 6, located in Essex, UK, with latitude of 51.859 N and longitude of 0.548 E, for which the horizon was taken. Essex has an annual irradiance of over 1000 kWh/m^2 which is one of the highest in the UK. Due to the government plans to introduce more renewable generation, homeowners are eligible to apply for tax reduction (0% VAT) for PV panels and installation which makes domestic PV design more economically attractive.

Figure 6. Chosen location (Google Earth Pro).

4.2. Design Methodology

4.2.1. Solar PV Panels Selection

UK market offers a vast selection of PV panels manufacturers, ones of the most popular being Panasonic, Sun Power, REC, and Trina Solar. For the proposed design, the solar panels used were Trina Solar 425 W, 36V mono-crystalline (TSM-DE0R-08W-425wp), manufactured since 2023. Trina solar is a reputable leading solar panel producer with a good track record and numerous patents. Their novel Vertex S panels characterise in great efficiency of up to 21.3%, high maximum power output of 425W, and appealing visual aesthetics with invisible busbars [19]. As they are specially designed for residential rooftop, they have gained recognition in the UK and are available at a very competitive market price of around £142 before tax [20].

4.2.2. Roof Geometry

Based on the roof geometry, three roofs were proposed for initial solar panel fitting. Figure 7 displays the areas of interest on a 3D model of the house in PVsyst. The key measurements were acquired using Google Earth Pro. The roof height and possible tilt angle were estimated from Google Street view for the property. Due to the complicated geometry, multiple roof elements and nearby trees, the house presents several challenges when designing a PV array. Firstly, the roof located South is shaded by roof windows. Therefore, the panels can be placed over the garage instead, also facing South. The roof facing East is shaded from a similar roof window as well as the frontal part of the house. In addition, the spacing would allow a maximum of three panels there, and their different shading conditions due to orientation implies a challenge for fitting in the inverter.

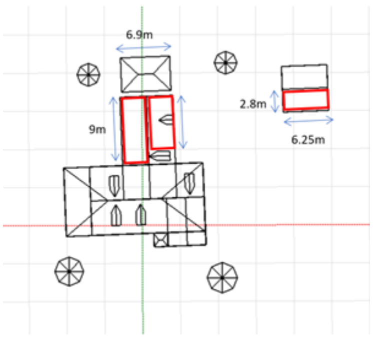


Figure 7. Roof Layout.

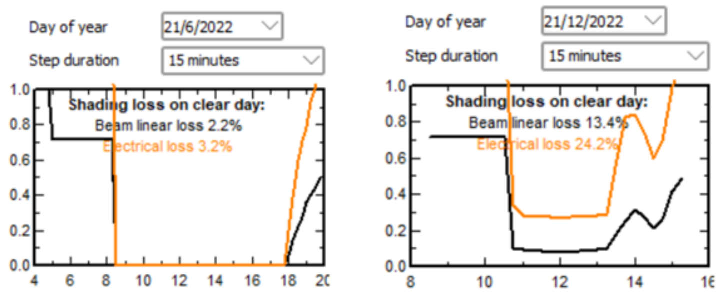


Figure 8. Roof Shading Analysis.

The design aims to maximise the energy yield while keeping the project inexpensive. Therefore, a shading analysis has been performed to distinguish the optimum location for solar PV.

Computed in the software, Figure 8 shows the results of the losses during two important annual cases. The shading loss recorded in the summer for the beam linear loss and electrical loss at 2.2% and 3.2% respectively is lesser than the shading loss recorded in the winter for the beam linear loss and electrical loss at 13.4% and 24.2% respectively. At the specified tilt angles, the panel locations proved they operate at the best in the summer the worst case being winter-time.

4.2.3. Array Layout

To maximise the limited roof space, the array layout has been proposed as shown on Figure 9. The modelling and analysis were performed using PVsyst. The design proposes a total of 15 modules on the main building's roof and 6 modules on the garage, as shown on Figure 9.

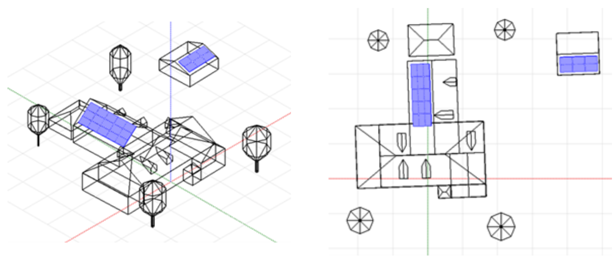


Figure 9. 3D Model of Array Layout Proposal in PVsyst: Perspective View(left) & Planar View(right).

The orientation and number of panels are summarised in Table 2.

Table 2. Solar Array Layout and Orientation.

	Tilt Angle (deg)	Orientation (deg, 0° – South)	Number of Panels	Array Rated Power (kW)
Set 1: West	40	88	15	6.375
Set 1: South	20	-2	6	2.550

The array layout for both sets are referred based on the area of the rooftops and the load demand profile of the household consumers. The panels facing west fitted on 30m² roof area and the panels facing south fitted on a 12m² roof. The total number of PV modules for the PV modules and total array rated power can be calculated from (1).

$$P_{array} = P_{panel.max} \times N_p = 425 \times (15 + 6) = 8.925kW \tag{1}$$

4.2.4. Inverters Selection

The UK market offers a wide range of solar inverters. The selection of the inverters must be according to the output rating of the solar panels hence with two sets of solar PV panels, two inverters have been selected: for array West: SMA Sunny Tripower 7000TL-20 with rated power 7kW [21], and for array South: SMA Sunny Boy 2500TLST-21 with rated power 2.5kW [22]. The power limits of each inverter were fitted so that the inverter/array power ratio is between 0.8 and 1. Exceeding this limit will unnecessarily increase the inital costs. The inverter ratios are 0.91 (West) and 0.98 (South). The inverter compatibility with the proposed arrays have been examined in terms of maximum voltage and current parameters for the extreme temperature conditions as shown in Table 3 and 4. Figure 10 presents the single line diagram.

Table 3. Calculation for Worst Scenarios.

Scenario	T_a **(°C)**	G_t **(m^2)**	η_e **(%)**	**V-T Coef. (% /°C)**	**I-T Coef. (% /°C)**	V_{oc}**(V)**	V_{mpp}**(V)**	I_{sc}**(A)**
Lowest Recorded temp.	-20.6[23]	1000	28.91	-0.25	-0.04	53.6	45.8	-
Highest Recorded temp.	36.4[24]	1000	25.71			-	-	10.66

The feasibility for the layouts are shown in Table 4.

Table 4. Calculation for Feasibility.

	V_{oc} **(°C)**	**Inverter Voltage Limit(V)**	V_{mpp}**(V)**	**MPPT Voltage Limit(V)**	I_{sc}**(A)**	**MPPT Current Limit(A)**	**Feasibility**
Array West	804	1000	687	800	10.66	15	Acceptable
Array South	321.6	750	274	500	10.66	15	Acceptable

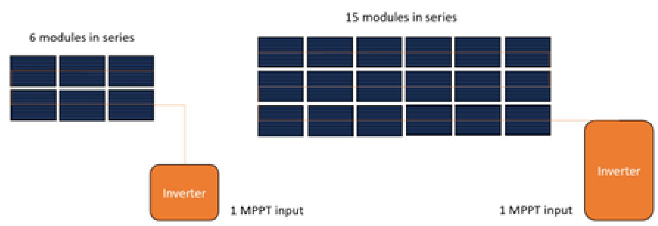


Figure 10. Single-line Diagram.

4.3. System Losses

4.3.1. Thermal Losses

The rooftop solar PV is using ‘Free’ mounting modules with air circulation giving the wind loss factor, U_v of 0 W/m²K m/s and constant loss factor, U_c of 29 W/m²K.

4.3.2. Soiling Losses

The accumulation of dirt, dust, pollen, and other debris on the surface of solar panels results in soiling losses, which can have significant effects on how effectively solar PV systems work. In general, soiling losses are lower in the winter when snow and rain can help to clear the panels and higher in the summer when there is more pollen and pollution in the air. In the UK is estimated to be between 3-5% [25]. Based on the location of this property farther than the city and not in a coastal region, the air pollution is expected to be low and thus may experience low levels of soiling loss, therefore, soiling losses are assumed to be 3% on an annual basis.

4.3.3. Other Losses

For other losses at small quantity, we give an average prediction on Table 5 with both sets of panels

Table 5. Other Losses.

Ohmic Losses	Module Quality Losses	Module Mismatch Losses	Aging Losses	Unavailability Time
1.5%	-0.4%	2%	0.55% [20]	0%

The detailed system losses are given in Appendix A1.

4.4. Simulation Results

The simulation carried in PVsyst are shown in Table 6.

Table 6. Simulation Results.

Energy Production	Specific Energy (Energy Yield)
8099 kWh/Year	907 kWh/kWp

4.5. Financial Appraisal

The component values without VAT (government incentive) are presented in Table 7. In the absence of expertise-derived data, the other component pricing was estimated based on online commercial sources [26, 27]. The detailed system costs are given in Appendix A2.

Table 7. Components Pricing & Installation Costs.

Description	Price (£ per unit)	Quantity	Total Price (£)
PV Modules	142.00 [19]	21	2,982.00
Inverter (West)	1,536.33 [28]	1	1,536.33
Inverter (East)	397.74 [29]	1	397.74
Wiring & Cables	300.00	1	300.00
Combiner Box	200.00	1	200.00
Monitoring System	300.00	1	300.00
Measurement System	300.00	1	300.00
Surge Arrester	150.00	1	150.00
Installation Labour Cost	1,980.00	-	1,980.00
Grid Connection	300.00	-	300.00
Note: Prices without VAT (20%)			

The installation and maintenance prices for solar PV systems are expected to be high since solar is still considered as new to the industry. Without a quote from a potential installer, it is challenging to estimate the installation pricing. Therefore, it was assumed than each panel will cost roughly £80 to install, and an inverter £150, giving £1980 without VAT price. In addition, the grid connection might account to around £300, as the location is relatively remote. The final installation casts are shown in Table 7.

The feasibility of the project was assessed using built-in PVsyst feature. The OPEX price was estimated to be £100 per year, a price of a single consultation. In terms of electricity supplier, Scottish Power offers the highest tariff in Essex. The household eligibility was assumed (smart meter, connectivity, etc.) [30]. Table 8 presents the financial appraisal conducted using Power World.

Table 8. Financial Summary.

Total Installation Costs (CAPEX)	Total Yearly Cost (OPEX)	Fixed Feed-in Tariff	Levelized Costs of Energy (LCOE)	Payback Period	Net Present Value (NPV)	Internal rate of return (IRR)
8,356.54 £	100 £/year	0.15[30] £/kWh	0.0522 £/kWh	7.4 Years	21,157.80 £	12.49%

4.6. Project discussion

A battery energy storage was proposed to decrease the load on the grid or sell the energy when the highest tariff occurs. However, the capital costs of a battery brough the payback period to over 11 years, and IRR down to 6%. It also imposed a challenge of estimating the ratio between power supplied locally and sold to the grid. Secondly, a single inverter for both arrays has been considered. However, due to largely different orientations of the panels, the inverter input power would become imbalanced and heavy losses would occur.

The project could be improved in terms of efficiency if the local load demand was known, to match the PV layout and capacity. In terms of economic feasibility, the costs could be reduced by joining ECO4 scheme, if eligible, and negotiating solar panels bulk order pricing.

5. Comercial Solar Panels Design in Santa Barbara, USA

5.1. Location Analysis

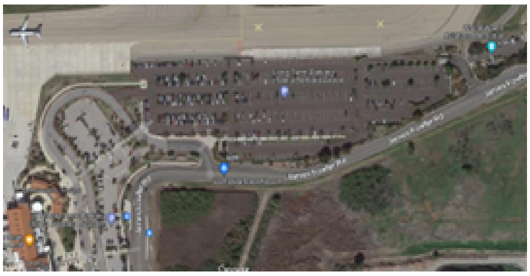


Figure 11. Car park at Santa Barbara Airport.

Located in Southern California, Santa Barbara has abundant solar resources and policies that promote photovoltaic (PV) energy use. The city is situated at 34.427 N, 119.84 W. Its sunny climate provides an average annual solar irradiation of about 5.3 kWh/m² per day, making it an great solar resource.

The growing popularity of electric vehicles has led to increased demand for EV charging. The Santa Barbara Airport car park, shown in Figure 11, is an optimal location for a PV charging station. With shuttle buses, car rentals, and passenger vehicles requiring numerous charging stations, the site meets significant demand. The Solar Microgrid program in the SBUSD area supports solar plant installation, while the airport's remote location prevents shading from tall buildings. These factors make the Santa Barbara airport car park a favorable location for solar EV charging.

5.2. Design Methodology

5.2.1. Solar PV Panels Selection

SunPower SPR-X20-445-COM is a utility-scale solar panel produced by SunPower, USA. As a part of SunPower's P-Series solar panels, it uses a special shingled-cell design to maximize the panel efficiency of up to 22.3% as well as the maximum power output of 445 watts, which are one of the highest in the industry. In addition, SunPower's manufacturing facilities are located in Oregon and California, therefore, the transportation costs are low.

The manufacturer guarantees long-lasting durability even in harsh conditions with wind and snow loading of up to 2400 Pa and 5400 Pa respectively. The panel can maintain high performance even in hot climate, which fits the subtropics weather conditions of California.

5.2.2. PV system layout

Car park Structure

Based on the length and width of the parking area, two types of fields are proposed to fit the ground. The size of the field and a carport sample are shown in Figure 12.

Figure 12. Car park at Santa Barbara Airport (Google Earth Pro).

The first type of parking area is 74 m long and 12 m wide. The second is of 115 m long and 12 m wide. The average car height in the US is lower than 1.8-2 meters. Thus, a minimum height of 3 m for the installation of solar panels should be set.

Surrounding Impact

The power station is located next to the landing strip, therefore, the impact of solar panels on aircraft landing and take-off has to be addressed. As shown on Figure 13, the main landing and take-off routes of planes at Santa Barbara Airport are in the east-west direction. Furthermore, the north-south runway is used only for south-facing take-offs (rear-side to the solar panels), making the reflection effects bearable. Considering the impact on the takeoff and landing of the aircraft, solar panels can only be built facing south direction.

Figure 13. Takeoff and Landing Routes of the Aircraft.

Array Layout

To match the area and load demand criteria, the array layout was proposed using PVsyst. To cover the whole planning area, 10 PV modules are connected in series with 346 strings in parallel. The total number of PV modules can be calculated:

$$N_p = N_r \times N_{p/r} = 346 \times 10 = 3460 \quad (2)$$

The system's rated power is therefore:

$$P_{array} = P_{panel.max} \times N_p = 445 \times 3460 = 1540kW \tag{3}$$

5.2.3. Inverters Selection

There are some alternatives for inverters available in the market that can be suitable for this project. However, when selecting an inverter, factors such as model, size, price, and availability must be taken into consideration. In this particular project, the Canadian Solar CSI-66KTL-GS 66kW grid tie inverter- 480V has been chosen due to its impressive performance, competitive pricing, and availability in California.

For the inverter, at least 21 inverters are needed. The total power of inverter is: 21×66=1386kW. The inverter/array ratio is 1386kW/1540kW=0.9.

The result is within the range of 0.8-1.0 , which is suitable to the whole PV system.

In order to optimize the system's area usage, the modules are distributed into several tables by PVsyst. Each table contains 5 modules in length and 12 in height, as shown in Figure 14 (left). The whole PV system is shown in Figure 14 (right).

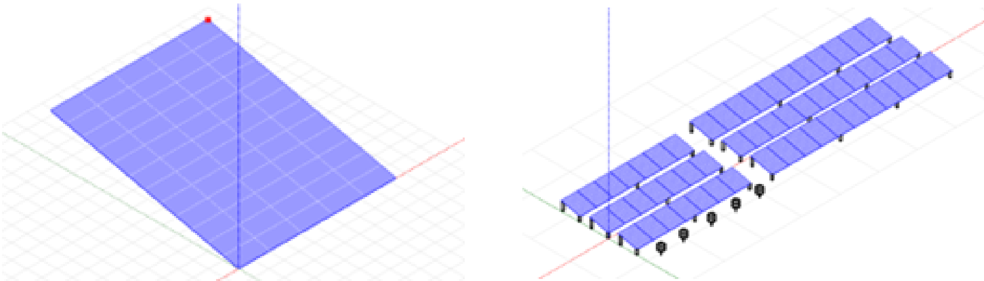


Figure 14. 3D Model in PVsyst: Single table (left) & Array Layout (right).

The inverter compatibility has been examined in terms of maximum voltage and current parameters for the extreme temperature conditions (Table 9).

Table 9. Calculation for Worst Scenarios.

Scenario	T_a **(°C)**	G_t **(m^2)**	η_e **(%)**	**V-T Coef. (mV /°C)**	**I-T Coef. (% /°C)**	V_{oc}**(V)**	V_{mpp}**(V)**	I_{sc}**(A)**
Lowest Recorded temp.	-7[31]	1000	24.75	-215	-0.045	96.8	82.3	-
Highest Recorded temp.	42[31]	1000	21.58			-	-	6.29

There are two different types of layouts for this design, shown in Figure 15.

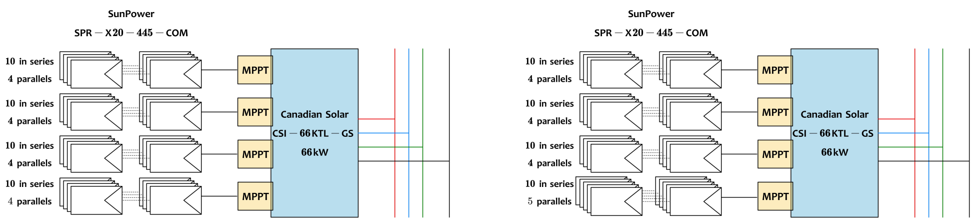


Figure 15. Layout A (left) & Layout B (right).

The feasibility for the layouts are shown in Table 10.

Table 10. Calculation for Feasibility.

	V_{oc} (°C)	Inverter Voltage Limit(V)	V_{mpp}(V)	MPPT Voltage Limit(V)	I_{sc}(A)	MPPT Current Limit(A)	Feasibility
Layout A	968	1000	823	850	25.16	55	Acceptable
Layout B	968		823		31.45		Acceptable

5.3. EV Load Estimation

As the primary airport in the city, Santa Barbara Airport car park experiences a significant amount of traffic. To help reach Net-Zero, the power generated from the solar panels should be used to charge the EVs as priority. The surplus electricity can be injected into the local solar power grid. To figure out the load consumption, an estimation of the daily energy demand for the EV is made.

In the EV charging station, the charging power required for a battery varies, ranging from 4kW to even 20 kW. Besides, the driving distance, charging mode, vacant battery capacity, and the energy demand for each vehicle also differs. Therefore, a Monte-Carlo-simulation based methodology modal proposed on this perspective is able to give a precise prediction to the EV demand [32]. The article constructs the EV charging power model by Bernoulli distribution. Then the initial battery state of charged can be calculated by fitting the probability dense function of daily EV travel distance with normal distribution. By obtaining the data of probabilistic character of the charging start time, the Monte-Carlo simulation methodology can be constructed to calculate the precise EV charging load demand during the day.

An average EV traffic flow during the day can be represented using the model constructed by [32], as shown in Table 11.

Table 11. Average EV Traffic Flow

Time Period	Number of parking EVs
7:00-10:00	50
10:00-16:00	70
16:00-19:00	60
19:00-7:00	40

Judging from the numbers of the EVs, the charging profile can be set to 50. So the total power demand for 50 charging profile can be imported in to the simulation software. According to the result of Monte-Carlo-simulation, the plot of charging power is shown in Figure 16 when the charging file is 50.

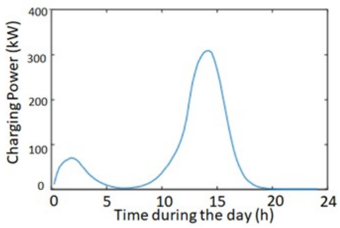


Figure 16. Load Profile, modified for project data based on [32].

5.4. Orientation and Shading

To build the solar panels based on the instruction, several characteristics should be considered. Firstly, the height of solar panels installation should be limited due to the car height and shade between parking areas. In order to receive more solar energy coming from the south side, the panel array need to be inclined to increase the power input. The tilt angle of the car park's roof should be limited to prevent losing its shading over the cars and exceeding the height limitation from architecture perspective.

Because car park PV ceilings are usually composed of multiple panels together as a whole directly, it's usually more convenient and economical to set a fixed tilt plane for the PV panels' orientation. Santa Barbara lies at 34°N, 120°W, so when the tilt angle for the PV panel array is 34°, the yearly average irradiation yield will be able to reach its maximum point, which is shown in Figure 17. At this angle, the transposition factor is up to 1.15 and the loss with respect to optimum is 0.

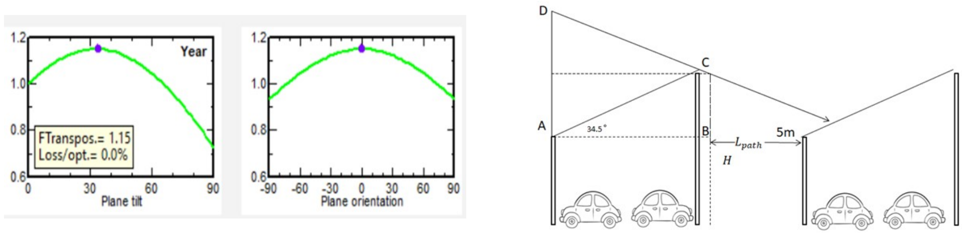


Figure 17. Plane Tile and Orientation (left) & Carport Row Distance (right).

However, this inclination causes an additional height beyond the ceiling of the PV plant, which will result in shading for other PV panels as Figure 17. Besides, the maximum height of the panels array can be calculated:

$$H_{max} = H_{min} + h_{array} \times sin34.5 = 10.2m \tag{4}$$

The height of the car park is too elevated, which can increase the construction cost and negatively impact the aesthetics. Additionally, the excessive height can cause shading to the adjacent panels. Large shading factor is leads to decrease in power generation.

According to the simulation in PVsyst (Figure 18), the beam linear loss on 22th Dec is 12.5%, which is larger than an acceptable level 5-10% for commercial solar station. Decreasing the tilt angle to 13°, causes the shading effect to decrease to 1.3%. To make a trade off among the maximum energy generation, shading effect and architecture feasibility, a table comparing different generation and efficiency at different angle are shown in Table 12.

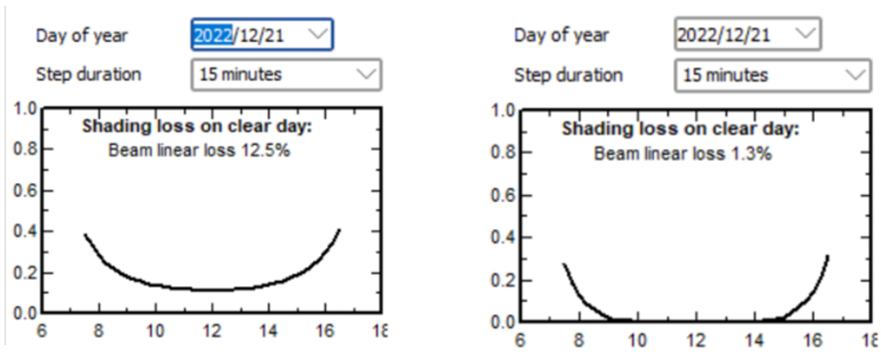


Figure 18. Beam Linear Loss at 34° (left) & 13° (right).

Table 12. Simulation for Different Tilt Angle.

Tilt Angle (°)	Power Generation (kW)	Efficiency	Total Price (Maximum Height (m))
34.5	2718	0.844	10.2
20.0	2761	0.869	7.4
15.0	2738	0.876	6.3
13.0	2722	0.878	5.9

It was found that as the tilt angle increases, the power generated remains relatively unchanged. That's because when the angle becomes smaller, the shading effect also decreases, which will raise the total efficiency. When the angle is 13°, the car park height is only 5.9 m and the power generation still exceeds 2700 kW. Therefore, 13° is chosen as the tilt angle.

5.5. System Losses

5.5.1. Field Thermal Losses

For the car park with "Free" mounted modules with air circulation, the Wind loss factor U_v can be set as 0. For the constant loss factor U_c, according to the data from the 7 grid-connected system on PVsyst, 29W/m² was chosen.

5.5.2. Soiling Losses

The soiling loss is a key factor that contributes to the energy losses in a PV system. During the dry season in California, vast dust and long-lasting drought can cause blockage of the panels. The soiling loss factor depends on the frequency of rainfall and manual panel cleaning. During the rainy months in Santa Barbara from November to April, due to the unpredictability of the rain; the average month soiling factor to 2% is set[33].

During the dry months from May to October, a linear regression fit to the entire 145 data points is applied to solve the data during the drought period. The result can be observed in Figure 19, where the soiling losses during that 149 drought days were found to be -0.0029/day. Setting the panel cleaning frequency as once per month, the monthly soiling factor can be calculated by f=(0.0029×30)/2=4.35%, shown in Figure 19.

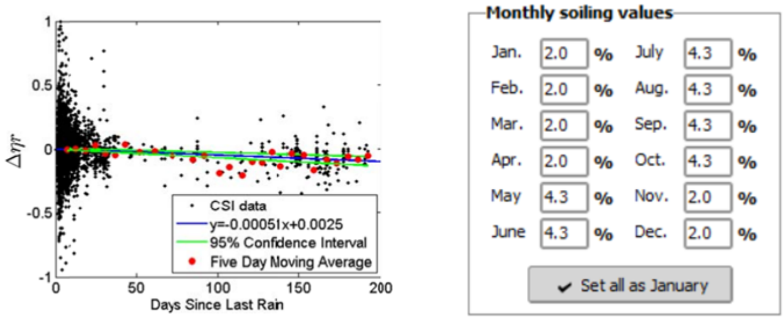


Figure 19. Linear Regression Fit for Soiling Losses (left) & Monthly Soiling Values (right).

5.5.3. Other Losses

For other losses at small quantity, an average prediction is given in Table 13.

Table 13. Other Losses.

Ohmic Losses	Module Quality Losses	Module Mismatch Losses	Aging Losses	Unavailability Time
1.5%	-0.8%	2%	0.4%	1%

The detailed system losses are given in Appendix B1.

5.6. Simulation results

The simulation results are given in Table 14.

Table 14. PVsyst simulation results.

Energy production	Specific energy (Energy yield)
2,528.9 MWh/year	1642 kWh/kWp

5.7. Economic Evaluation

After reviewing some large-sized PV panels system quotes, some cost assumptions are made based on the local conditions and regulations in Santa Barbara as shown in Table 15 and Table 16. Based on the made assumptions, it can be concluded from PVsyst calculations that the payback period is 7.5 years. The detailed system costs are given in Appendix B2.

Table 15. PVsyst simulation results.

Description	Price ($ per unit)	Quantity	Total Price ($)	Total Price (£)
PV Modules & Supports	570.00	3460	1,972,200.00	1,576,675.29
Inverters[34]	3870.00	21	81,270.00	64,971.30
Other Components	-	-	419,000.00	334,969.55
Studies and Analysis	15,000.00	5	75,000.00	59,958.75
Installation	-	-	442,700.00	353,916.52
Insurance	5,000.00	10	50,000.00	39,972.50
Land Costs	1,500,000.00	1	1,500,000.00	1,199,175.00
Total Taxes	-	-	153,066.82	122,369.27
Total Installation Cost			4,693,236.82	3,752,008.18
Note: USD/GBP=0.80 at UTC 10:26, 4/4/2023 (More details in Appendix B.2)				

Table 16. Financial Summary.

Total Installation Costs (CAPEX)	Total Yearly Cost (OPEX)	Levelized Costs of Energy (LCOE)	Fixed Feed-in Tariff	Fixed Consumption Tariff	Payback Period
3,752,008.18 £	43,221.07 £/year	0.0959 £/kWh	0.19 £/kWh	0.32 £/kWh	7.5 years

6. Environmental Analysis

Because the power generation from PV system is completely zero-emission, it can save the CO_2 emission during the project lifetime. The carbon balance of the two PV systems can be calculated as the equation below

$$Carbon\ Balance = E_{grid} \times h \times LCE_{grid} - LCE_{system} \tag{5}$$

The E_{grid} is the energy generated by the PV system. The h is the life period of the system. LCE_{grid} represents the average amount of CO2 emissions per Energy unit for the Electricity produced by the Grid in that country and LCE_{system} represents the total amount of CO_2 emissions caused by the construction and operation of the PV installation. Based on the data from the IEA report incorporated within PVsyst, the total carbon balance of the two systems and the graph of carbon balance accumulation can be calculated.

Table 17. Financial Summary.

Project	E_{grid}	h (years)	LCE_{grid} (gCO_2/kWh)	LCE_{system} (tCO_2)	Carbon balance (tCO_2)	Carbon balance (tCO_2/kWp/yr)
UK	8192.0kWh	20	470	0.9	69.252	0.388
USA	2527.7MWh	25	528	3404.9	26212.949	0.681

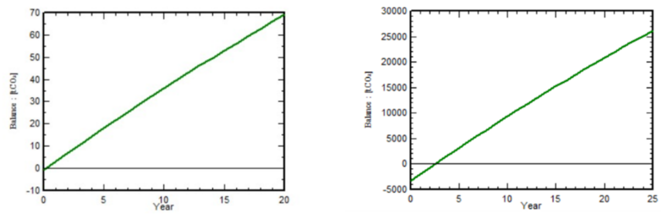


Figure 20. Carbon Balance during Project Lifetime in the UK (left) & the USA (right).

7. Thermal Application

7.1. Thermal Application in the UK

7.1.1. Current Solar Thermal in the UK

Solar thermal technology has gained wide attention in the UK as a space and water heating supply. Similar to the solar PV system, this fully zero-carbon technology utilises sun irradiation and helps reduce energy bill prices [35]. According to the Energy Saving Trust (EST), solar thermal panels can provide around 90% of hot water demand in summer, however, only 25% in winter due the limited sunlight source [36].

The government has provided plenty of incentive to encourage growth of solar thermal installations, as shown in Figure 21. Although the Renewable Heat Incentive (RHI) was discontinued in March 2022, as well as the Green Homes Grant in March of the following year, the technology is expected to have established a consistent growth due to its various benefits [36].

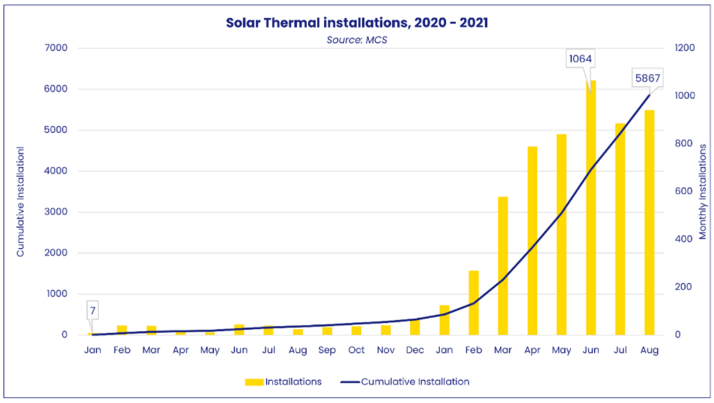


Figure 21. Solar Thermal Installations, 2020-2021.

7.1.2. Potential Solar Thermal Market in the UK

A £450 million grand funding for the Boiler Upgrade Scheme (BUS) has been announced in April 2022 to support sustainable thermal solutions [37]. This scheme acts to reduce the initial investment in solar thermal and encourage alternatives to fossil fuels. Solar thermal panels absorb the sun's energy and transfer it in a form of heated water stored in the hot water cylinder [38]. In addition to hot water bills, solar thermal technology can also facilitate high space heating demand when connected to radiator water circuits.

7.1.3. Emerging Technology

As claimed by the Committee on Climate Change (CCC), the UK is expected to obtain a balanced net-zero pathway by heat pumps in 2050 supplied from electricity and/or hydrogen [39]. An incentive provided by the government aims to lead to over 150 GWth (megawatt thermal) solar thermal deployment by 2050 contributing to annual hydrogen savings of up to 240 TWh and 90 TWh electricity increment due to backup heating technologies. As energy sources for space heating and hot water, electricity and hydrogen will be the utmost sustainable and highly incorporated with advanced heating technologies.

Considering long-term expenditure, solar thermal systems will benefit from cost reductions from rates and scaling effects [39].

A newly introduced combined solar photovoltaic and thermal solar (solar PVT) generating both electricity and heat uses excessive energy for heating [40]. The heating system in most cases is expected to maximise 100% of water heating during the summer. Giving an extra boost to the heating system during the winter, the boiler and heat pumps are necessary, especially as the climate in the UK is the determining factor for the efficiency of the system. Overall, the right size of solar heating system is very likely to have a positive impact on cost benefits.

7.1.4. Notable Projects

Solar thermal requires high solar irradiation levels, which poses a limitation for this technology in the UK climate. The UK does not currently possess any solar thermal power plants, however, the technology is still vastly used both in residential and commercial sectors. With the non-domestic Renewable Heat Incentive (RHI), more businesses can afford the installation. Some of the examples involve solar thermal on a hospital in Birmingham [41], or Wilton Plaza in London [42]. Solar thermal in the UK is recommended for locations with high hot water demand as it significantly reduces the costs of water heating.

7.2. Thermal Application in California, USA

7.2.1. Current Solar Thermal Market in California

The solar thermal market in California is one of the most developed and mature markets in the US due to favorable climate and policies promoting renewable energy generation.

The California Energy Commission has implemented a number of incentives and rebates to encourage the adoption of solar thermal systems, including the California Solar Initiative Thermal Program and the Self-Generation Incentive Program. According to the Solar Energy Industries Association (SEIA), California had 1,066 MWth of installed solar thermal capacity in 2020, which represents 47% of the total installed capacity in the United States [43]. The California Solar Initiative Thermal Program and the Self-Generation Incentive Program also provide incentives for the installation of solar thermal systems, which supported installation of over 87,000 solar water heating systems.

However, the market also faces challenges such as competition from other renewable energy technologies like solar PV and wind power, as well as the high upfront costs of installing solar thermal systems.

7.2.2. Potential Solar Thermal Market in California

The state has set ambitious renewable energy targets, aiming to achieve 100% clean energy by 2045, and solar thermal technology can play a crucial role in meeting this goal.

For the public policy, the California Public Utilities Commission (CPUC) approved the Solar Water Heating Initiative which aims to install 200,000 solar water heating systems in California by 2030 [44]. It provides incentives for low-income households, multi-family dwellings, and non-residential buildings.

Apart from solar thermal heating, the state also promotes the development of novel solar thermal technology, for example, in industrial processes, such as food processing or textile manufacturing, to provide extra heat. The researchers in the US also work on developing new and more efficient solar thermal technologies to reduce the cost and increase the performance. The new solar thermal includes new types of collectors, thermal storage systems, and hybrid systems that combine solar thermal and PV technologies [45].

7.2.3. Emerging Technology

With the development of the solar thermal, more and more emerging technologies are applied. One direction for the future development of solar thermal is to combine the solar thermal system with other energy generation to maximize the efficiency and performance.

One is the Hybrid Solar Thermal-PV Systems. Hybrid systems combine solar thermal and photovoltaic (PV) technologies to generate both heat and electricity from the same system. They're able to convert solar energy into electricity and domestic hot water. These systems can increase the overall energy output of a solar installation and reduce the amount of land required for separate solar thermal and PV systems [46].

Another one is the Concentrated Solar Thermal (CST). It is a system using mirrors or lenses to concentrate sunlight onto a small area, which heats up a fluid that is then used to generate electricity or provide space heating. Electricity is generated when the concentrated light is converted to heat, which drives a heat engine connected to an electrical power generator or powers a thermochemical reaction [47].

Nanofluid-Based Solar Thermal Systems is a new thermal technology which replaces the water with Nanofluids. Nanofluids are fluids that contain small particles, usually on the nanometer scale, which can enhance the heat transfer properties of the fluid. In solar thermal systems, nanofluids can increase the efficiency of heat transfer from the collector to the working fluid, which can improve overall system efficiency. Nanofluid-based solar thermal systems are still in the experimental stage, but have shown promise in laboratory tests [48].

7.2.4. Notable Projects

The California Energy Commission is planning to construct a 570-megawatt Palmdale hybrid power plant, as shown in Figure 22, in Los Angeles County, which will integrate solar thermal technology in the project's natural gas-fired system. The facility uses parabolic troughs to concentrate sunlight onto a heat transfer fluid, which is used to generate steam and drive a turbine. The plant can also switch to natural gas as a backup fuel source when solar energy is not available.

Figure 22. Palmdale Hybrid Power Plant.

Two natural gas-fired combustion turbine generators, two heat recovery steam generators, and one steam turbine generator will be utilized by the combined-cycle equipment. Arrays of parabolic collectors will be employed by the solar thermal equipment to heat a high-temperature working fluid. The hot working fluid will be utilized to boil water to generate steam. The combined-cycle equipment and solar equipment are thermally integrated at the heat recovery steam generators and both will use the same steam turbine generator. The solar aspect of the project will contribute approximately 10% of the peak power generated during daylight hours when the parabolic solar thermal collectors are operational. It will also supply heat directly to the heat-recovery steam generators, reducing the natural gas consumption at the facility. [49]

8. Comparison and Discussion

The designs comparison differ significantly, with one serving a commercial purpose and the other serving a residential purpose. While the solar resource in these two locations is fundamentally different, the projects can still be compared in terms of energy yield and economic feasibility. The two projects have a very similar payback period of around 7.5 years. However, the Californian project promises a much higher return on investment

(ROI), as its installation lifespan is five years longer and its favorable climate leads to over 80% higher energy yield. As expected, the commercial installation in California has a 50% larger Levelized Cost of Energy (LCOE) value than the residential installation, due to its higher equipment and operating costs.

The results of this comparison confirm the reasoning behind the development of numerous large-scale commercial solar installations in California, while the UK leads in low-capacity rooftop PV installations. Residential solar panels in the UK are an attractive investment, thanks to the government incentives, including the 0% VAT scheme to reduce initial investment costs. Additionally, if households can benefit from the ECO4 and SEG schemes, savings can increase even further [50]. Conversely, government incentives in California focus more on large commercial PV installations. Besides, the lower population density in the US increases installation costs. As of March 2023, the average cost of residential solar system in the UK is £1-1.17 per watt, whereas in California, the cost is around $2.68 per watt, much higher than in the UK [51].

Despite less favorable conditions, solar technology can still offer satisfactory outputs in the UK. However, in California, the abundant natural resource makes most projects feasible, with higher irradiation resulting in much greater PV power generation. Higher market prices and feed-in tariffs also make it more profitable to cover the cost of large-scale solar installations. Therefore, constructing centralized commercial PV systems in California can maximize utilization of the solar resource. The UK does have multiple successful commercial PV installations. For example, an EV charging equivalent car park project, operational since 2020, is located in Essex as well [52]. However, in this PV system, solar energy generation is not the main source of electricity sold to consumers, unlike the proposed Californian project.

For the environmental impact, both PV systems can make carbon balance to reduce the emission. Because the system in US has higher efficiency and the LCE of the grid in US is higher, the system in California can save more CO_2 in total.

9. Conclusions

The report provides an overview of the solar energy situation in the UK and the US. The UK has a lower average solar energy availability, however satisfactory in the southeastern part of the country. In contrast, the US has a concentrated solar energy supply, especially in the southwestern region, particularly in California. Both countries have supportive policies and a positive environment for PV system development.

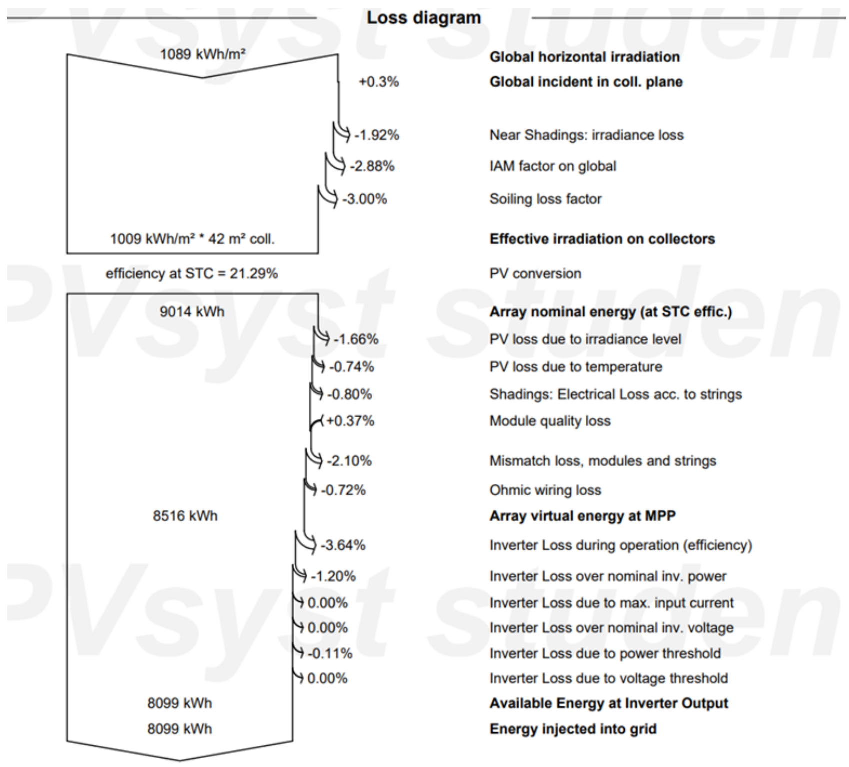
The report proposes two PV systems: a residential rooftop system in Essex, UK, and a car park system at Santa Barbara Airport in California, US. The Essex system generates power for the residence and the grid, while the California system supports EV charging and injects extra power into the grid for a tariff. Both systems have similar payback periods and satisfactory economic outputs, with a detailed analysis of their system components, demand estimation, and financial evaluation. The report suggests that the UK is more suitable for residential PV systems due to incentives and a higher population density, while the US is better suited for large-scale PV systems due to abundant solar resources.

For the solar thermal aspect in both countries, the conclusion is similar. California applies more large-scale centralized thermal projects while the UK concentrates more on small-scale application with the same reason behind.

Author Contributions: Abstract, Nurhanani Zulkeffeli,; Introduction, Ziming Zhang.; Solar Resouces, Polices and Market in the UK, Daniela Szumilas and Nurhanani Zulkeffeli.; Solar Resouces, Polices and Market in the US, Ziming Zhang and Yifan Chen.; System Design in the UK, Daniela Szumilas and Nurhanani Zulkeffeli.; System Design in the US, Ziming Zhang and Yifan Chen.; Economic Analysis, Yifan Chen and Daniela Szumilas.; Environmental Impact, Ziming Zhang.; Thermal Systems, Ziming Zhang and Nurhanani Zulkeffeli.; Discussion, Daniela Szumilas and Ziming Zhang.; Formatting and coding, Yifan Chen.; Editing, Daniela Szumilas. All authors have read and agreed to the submitted version of the manuscript.

1. Appendix A

1.1. Appendix A.1 UK Loss diagram



1.2. Appendix A.2 UK System Costs

Cost of the system

Installation costs

Item	Quantity units	Cost GBP	Total GBP
PV modules			
TSM-DE09R-08W-425wp	21	142.00	2,982.00
Supports for modules	21	25.00	525.00
Inverters			
Sunny Tripower 7000TL-20	1	1,536.33	921.80
Sunny Boy 2500TLST-21	1	397.74	397.74
Other components			
Wiring	300	1.00	300.00
Combiner box	200	1.00	200.00
Monitoring system, display screen	300	1.00	300.00
Measurement system, pyranometer	300	1.00	300.00
Surge arrester	150	1.00	150.00
Installation			
Global installation cost per module	21	95.24	2,000.00
Grid connection	300	1.00	300.00
		Total	8,376.54
		Depreciable asset	4,826.54

Operating costs

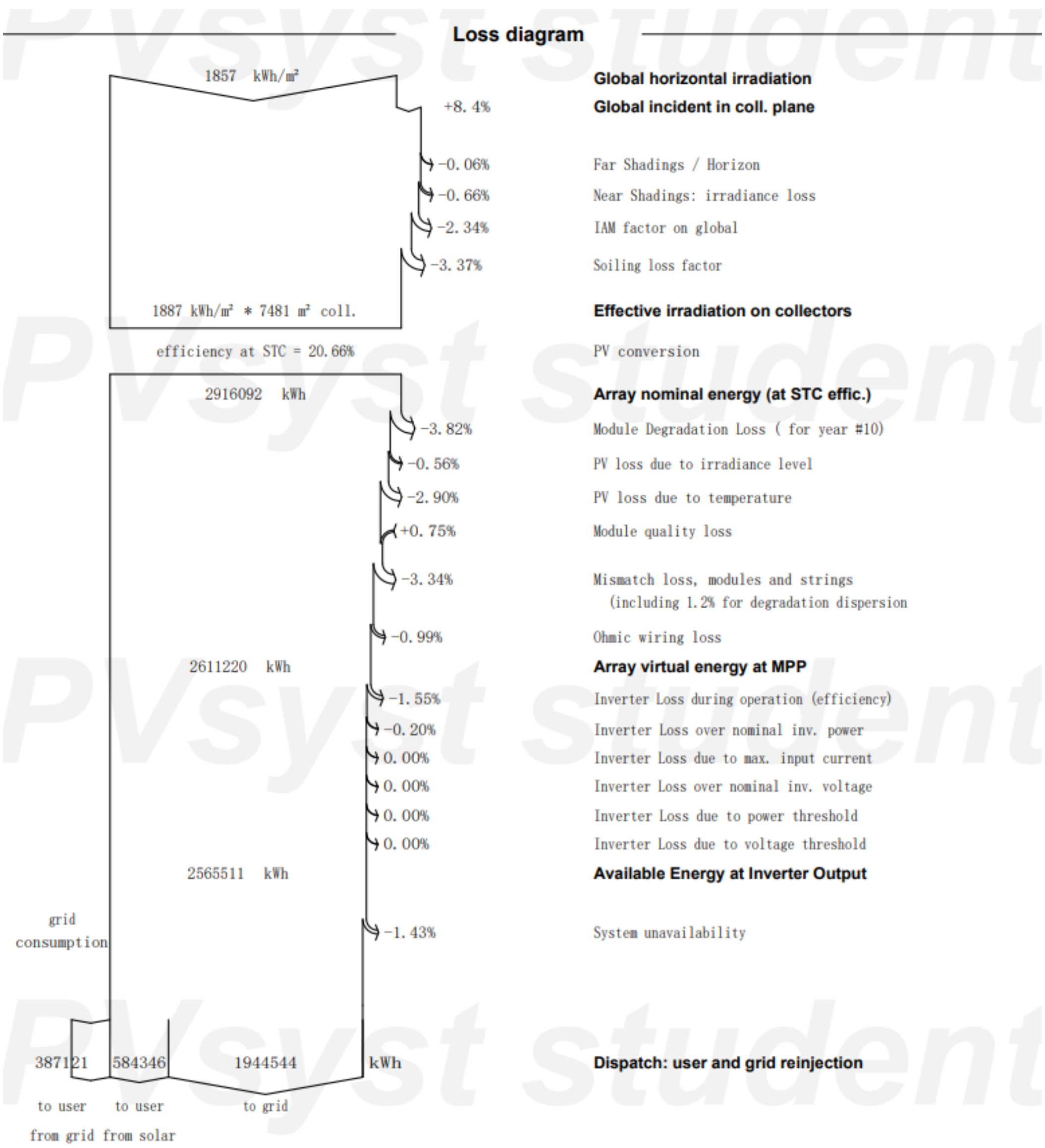
Item	Total GBP/year
Maintenance	
Provision for inverter replacement	109.96
Total (OPEX)	109.96

System summary

Total installation cost	8,376.54 GBP
Operating costs	109.96 GBP/year
Produced Energy	8099 kWh/year
Cost of produced energy (LCOE)	0.051 GBP/kWh

2. Appendix B

2.1. Appendix B.1 US Loss Diagram



2.2. Appendix B.2 US System Costs

Cost of the system

Installation costs

Item	Quantity units	Cost USD	Total USD
PV modules			
SPR-X20-445-COM	3460	500.00	1,730,000.00
Supports for modules	3460	70.00	242,200.00
Inverters			
CSI-66KTL-GS	21	3,870.00	81,270.00
Other components			
Accessories, fasteners	6	50,000.00	300,000.00
Wiring	1	80,000.00	80,000.00
Combiner box	2	3,500.00	7,000.00
Monitoring system, display screen	1	10,000.00	10,000.00
Measurement system, pyranometer	1	10,000.00	10,000.00
Surge arrester	6	2,000.00	12,000.00
Studies and analysis			
Engineering	1	30,000.00	30,000.00
Permitting and other admin. Fees	1	15,000.00	15,000.00
Environmental studies	1	15,000.00	15,000.00
Economic analysis	1	15,000.00	15,000.00
Installation			
Global installation cost per module	3460	70.00	242,200.00
Global installation cost per inverter	21	500.00	10,500.00
Transport	1	20,000.00	20,000.00
Settings	1	20,000.00	20,000.00
Grid connection	1	150,000.00	150,000.00
Insurance			
Building insurance	1	25,000.00	25,000.00
Transport insurance	1	10,000.00	10,000.00
Liability insurance	1	15,000.00	15,000.00
Land costs			
Land purchase	1	1,500,000.00	1,500,000.00
Taxes			
VAT	1	0.00	93,857.93
Federal taxes	1	0.00	43,870.89
State taxes	1	0.00	12,690.00
Local taxes	1	0.00	2,119.00
Other taxes	1	0.00	529.00
		Total	4,693,236.82
		Depreciable asset	2,353,470.00

Operating costs

Item	Total USD/year
Maintenance	
Provision for inverter replacement	4,063.50
Cleaning	50,000.00
Total (OPEX)	54,063.50

References

1. IEA, Renewables. 2021. Available online: https://www.iea.org/reports/renewables-2021 (accessed on 4/3/2023).
2. Fig. Source: Energy Guide Available online: https://energyguide.org.uk/sunshine-hours-map-uk/ (accessed on 4/3/2023).
3. T. Huld, M. Suri, E. Dunlop, M. Albuisson, and L. Wald, “JRC Photovoltaic Geographical Information System (PVGIS) - European Commission,” re.jrc.ec.europa.eu, 2016. https://re.jrc.ec.europa.eu/pvg_tools/en/
4. Met Office, “Shoeburyness (Essex) UK climate averages,” Met Office Gov.UK, 2020. https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-climate-averages/u10t6ch7u
7. Global Horizontal Irradiance (GHI), Solar Resource, California | Data Basin Available online: https://databasin.org/datasets/ed9632cf804c4d34bcaed301ed212e7b/ (accessed on 4/3/2023).
6. Solar Resource Maps and Data | Geospatial Data Science | NREL. Available online: https://www.nrel.gov/gis/solar-resource-maps.html (accessed on 4/3/2023).
7. United States - U.S. Energy Information Administration (EIA) Available online: https://www.eia.gov/beta/states/states/ca/analysis (accessed on 4/3/2023).
8. V. Martin, “Chapter 5: Electricity,” 2022. Accessed: Mar. 03, 2023. [Online]. Available online: https://assets.publishing.service.gov.

uk/government/uploads/system/uploads/attachment_data/file/1094628/DUKES_2022 _Chapter_5.pdf (accessed on 4/3/2023).
9. Uk, "Statistical Release Energy Trends About this release Information on energy production, trade, and consumption in the UK for total energy and by specific fuels," 2022. Available online: https://assets.publishing.service.gov.uk/government/uploads/system /uploads/attachment_data/file/1126177/Energy_Trends_December_2022.pdf (accessed on 3/3/2023).
10. Mordor Intelligence, "United Kingdom Solar Power Market | Growth, Trends, and Forecast (2020-2025)," Available online: www.mordorintelligence.com. https://www.mordorintelligence.com/industry-reports/united-kingdom-solar-power-market-industry (accessed on 3/3/2023).
11. Mordor Intelligence, "UK Distributed Solar Power Generation Market | 2022 - 27 | Industry Share, Size, Growth - Mordor Intelligence," Available online: www.mordorintelligence.com. https://www.mordorintelligence.com/industry-reports/united-kingdom-distributed-solar-power-generation-market-industry (accessed on 3/3/2023).
12. Green Match, "Solar Panels Grants and Funding in 2023 in the UK | GreenMatch," GreenMatch.co.uk. Available online: https://www.greenmatch.co.uk/solar-energy/solar-panels/solar-panel-grants#reduced_VAT (accessed on 4/3/2023).
13. HM Revenue & Customs, "Changes to the VAT treatment of the installation of Energy Saving Materials in in Great Britain," GOV.UK, 2022. Available online: https://www.gov.uk/government/publications/changes-to-the-vat-treatment-of-the-installation-of-energy-saving-materials-in-in-great-britain (accessed on 3/3/2023).
14. Department for Business, Energy, and Industrial Strategy, "Energy Company Obligation Government Response," 2022. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1065823/eco4-government-response.pdf (accessed on 4/3/2023).
15. U.S. Solar Market Insight | SEIA Available online: https://www.seia.org/us-solar-market-insight (accessed on 4/3/2023).
16. California Solar | SEIA Available online: https://www.seia.org/state-solar-policy/california-solar (accessed on 4/3/2023).
17. Renewables Portfolio Standard - RPS | California Energy Commission. Available online: https://www.energy.ca.gov/programs-and-topics/programs/renewables-portfolio-standard (accessed on 4/3/2023).
18. Home - Santa Barbara Home Power (sbhomepower.com) Available online: https://sbhomepower.com/ (accessed on 4/3/2023).
19. Trina Solar, "BACKSHEET MONOCRYSTALLINE MODULE 425 W+," 2023. Available online: https://static.trinasolar.com/sites /default/files/Datasheet_VertexS_DE09R.05_EU_EN_2023_A.pdf (accessed on 25/3/2023).
20. 425W Trina Vetex S Mono Black Frame Solar Panel trade prices buy online – ITS Technologies Available online: https://www.itstechnologies.shop/products/425w-trina-vertex-s-mono-black-frame-solar-panel? (accessed on 25/3/2023).
21. SUNNY TRIPOWER 5000TL - 12000TL - The Three-Phase Inverter – Not Only for Your Home... (sma.de) Available online: https://files.sma.de/downloads/STP12000TL-DEN1723-V10web.pdf (accessed on 25/3/2023).
22. SMA, "SUNNY BOY 2500TL / 3000TL SINGLE TRACKER," 2012. Available online: http://www.geosolar.org.uk/Images /SB3000TLST-21-DEN122913W.pdf (accessed on 25/3/2023).
23. The Tornado and Storm Research Organisation, "TORRO | Extremes ∼ Minimum temperature date records,"www.torro.org.uk, 2022. Available online: https://www.torro.org.uk/extremes/date-records/min-temp (accessed on 25/3/2023).
24. The Tornado and Storm Research Organisation, "TORRO | Extremes ∼ Maximum temperature date records,"www.torro.org.uk, 2022. Available online: https://www.torro.org.uk/extremes/date-records/max-temp (accessed on 25/3/2023).
25. K. Ilseet al. "Techno-Economic Assessment of Soiling Losses and Mitigation Strategies for Solar Power Generation," *Joule* **Oct.2019**, *vol.3,no.10*, pp.2303–2321.
26. J. Jackman, "Solar Panel Costs 2019 | The Eco Experts,"Theecoexperts.co. uk, 2019. Available online: https://www.theecoexperts.co.uk/solar-panels/cost (accessed on 25/3/2023).
27. Cymru Sol, "Commercial Solar System Cost,"Cymru Solar. Available online: https://southwalessolarpanels.co.uk/commercial-solar-system-cost/: :text=A%2010kw%20solar%20photovoltaic%20system (accessed on 25/3/2023).
28. My Solar Shop, "Grid Inverter SMA Sunny Tripower 7000-TL-20 | Caravan Solar Panel Kits Chargers,"Grid Inverter SMA Sunny Tripower 7000-TL-20. Available online: https://www.mysolarshop.co.uk/product/grid-inverter-sma-sunny-tripower-7000-tl-20/ (accessed on 25/3/2023).
29. RenuGen, "Sunny Boy SB 2500TLST-21,"Renugen. Available online: https://www.renugen.co.uk/sunny-boy-sb-2500tlst-21/ (accessed on 25/3/2023).
30. Scottish Power, "Gas and Electricity Company | ScottishPower,"www.scottishpower.co.uk. Available online: https://www. scottishpower.co.uk/smart-export-guarantee: :text=To%20be%20eligible%20for%20SEG (accessed on 25/3/2023).
31. Santa Barbara Weather Records. Available online: https://www.extremeweatherwatch.com/cities/santa-barbara (accessed on 27/3/2023).
32. Ni, X., Lo, K. L. (2020, October). A methodology to model daily charging load in the EV charging stations based on Monte Carlo simulation. In 2020 International Conference on Smart Grid and Clean Energy Technologies (ICSGCE) (pp. 125-130). IEEE.
33. Mejia, F. A., Kleissl, J. (2013). Soiling losses for solar photovoltaic systems in California. Solar Energy, 95, 357-363.
34. Canadian Solar CSI-66KTL-GS 66kw grid tie inverter- 480v - Kinect Solar. Available online: https://kinectsolar.com/product/ canadian-solar-csi-66ktl-gs-66kw-grid-tie-inverter-480v/ (accessed on 3/4/2023).
35. B. Milne. "Solar Thermal Progress." solarenergyuk.org. Available online: https://solarenergyuk.org/the-solar-thermal-progress/ (accessed on 25/3/2023).
36. Energy Saving Trusts, "Solar Water Heating," Available online: https://energysavingtrust.org.uk/ (accessed on 20/3/2023).

37. Office of Gas and Electricity Markets, "Boiler Upgrade Scheme," ofgem.gov.uk. Available online: https://www.ofgem.gov.uk /environmental-and-social-schemes/boiler-upgrade-scheme-bus (accessed on 25/3/2023).
38. "Solar thermal panels," nidirect.gov.uk. Available online: https://www.overleaf.com/project/64026f3a7fdadde288f64aaehttps://www.nidi thermal-panels (accessed on 24/3/2023).
39. M. Mersch, A. V. Olympios, P. Sapin, N. M. Dowell and C. N. Markides, "Solar-thermal heating potential in the UK: A techno-economic whole-energy system analysis," in Proc. of Ecos 2021-The 34th Int. Conf. on ECOS., 2021, pp. 1-12, doi: 10.52202/062738-0173
40. "Solar PVT-Hybrid Solar Thermal/PV panels," thegreenage.co.uk. Available online: https://www.thegreenage.co.uk/solar-pvt-hybrid-panels/ (accessed on 24/3/2023).
41. Solar UK, “Industrial scale commercial solar thermal system,” Available online: http://www.solaruk.net/solarimages/solar-heating-images.asp?imageid=2504imagename=Industrial%20scale%20commercial%20solar%20thermal%20system (accessed on 26/3/2023).
42. Solar UK, “Large scale commercial solar thermal system in the south east,” Available online: http://www.solaruk.com/solarimages /solar-heating-images.asp?imageid=2291imagename=Large%20scale%20commercial%20solar%20thermal%20system%20in %20the%20south%20east (accessed on 26/3/2023).
43. Solar Energy Industries Association’s (SEIA), 2021, “Solar Industry Year in Review”. Available at: https://www.seia.org/research-resources/solar-market-insight-report-2021-year-review
44. California Solar, 2014, “Initiative Annual Program Assessment”, CPUC.ca.gov. Available at: https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/office-of-governmental-affairs-division/reports/2014/ca-solar-initiative-annual-assessment-2014.pdf
45. Global Data, 2022, “United States of America (USA) Solar Thermal Power Market Size and Trends by Installed Capacity, Generation and Technology, Regulations, Power Plants, Key Players and Forecast, 2022-2035”. Available at: https://www.globaldata.com/store/report/usa-solar-thermal-power-market-analysis/
46. S. Khajepour, and M. Ameri, 2020, Techno-economic analysis of a hybrid solar Thermal-PV power plant, Sustainable Energy Technologies and Assessments, Sustainable Energy Technologies and Assessments, Volume 42, doi:2020,100857.
47. K. M. Powell, K. Rashid, K. Ellingwood, J. Tuttle, B. D. Iverson, Hybrid concentrated solar thermal power systems: A review, Renewable and Sustainable Energy Reviews, Volume 80, 2017, Pages 215-237, ISSN 1364-0321,https://doi.org/10.1016/j.rser.2017.05.067.
48. Z. Said, S. Arora, E. Bellos, A review on performance and environmental effects of conventional and nanofluid-based thermal photovoltaics, Renewable and Sustainable Energy Reviews, Volume 94,2018,Pages 302-316,ISSN 1364-0321,
49. California green lights 570-MW Palmdale CSP hybrid plant: https://helioscsp.com/california-green-lights-570-mw-palmdale-csp-hybrid-plant/
50. Ofgem, “Energy Company Obligation (ECO4) Eligibility Requirements Form,”Ofgem.gov.uk, 2022. Available online: https://www.ofgem.gov.uk/sites/default/files/2022-10/ECO4%20Eligibility%20Requirements%20Form%20v1.0.pdf (accessed on 29/3/2023).
51. Solar panels: are they worth it? - MoneySavingExpert Available online: https://www.moneysavingexpert.com/utilities/free-solar-panels/ (accessed on 31/3/2023).
52. British Broadcasting Corporation BBC, “UK’s first electric car forecourt opens,”BBC News, 2020. Available online: https://www.bbc.co.uk/news/av/uk-england-essex-55223193 (accessed on 29/3/2023).