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Energy and Stochastic Economic Assessments of Photovoltaic Systems in the East Midlands

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Abstract: This study implements techno-economic evaluations of different photovoltaic (PV) systems in the East Midlands of the UK. Three application case studies, including an office building, a domestic building, and a poultry shed, are achieved. The building electricity consumption is obtained according to hourly automatic meter readings, and the PV electricity production is predicted based on the Engineering Equation Solver 8.4 software. Meanwhile, the 25-years' complete economic profitability investigations of the three PV systems are conducted on the basis of the Monte Carlo method; the sensitivity analyses of payback period and net present value are also carried out by using the @RISK 8 software. Furthermore, the payback period and yearly savings are investigated and compared between the Smart Export Guarantee (SEG) and feed-in tariff (FiT) schemes. Technical investigation outcomes conclude that the three PV systems are able to satisfy electrical energy requirements in summer, and the additional electricity could be exported to the grid in this period. In winter, however, the systems have less electricity output resulting in power shortage and input from the grid. Economic study results exhibit that the net present values of the office building, domestic building, and poultry shed are £9108.4, £1717.91, and £7275.86, respectively, corresponding to the payback periods of 6.15 years, 9.12 years, and 9.41 years. This implies that there is an acceptable payback period (<10 years) for the PV system installation; meanwhile, the FiT scheme has the shorter payback period compared with the SGE scheme.

Keywords: photovoltaic system; hourly electrical output; net present value; payback period; Smart Export Guarantee

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1. Introduction

Electricity generated by fossil fuel-based resources such as oil, natural gas, and coal are widely employed in the world currently [1,2]. This results in ozone layer depletion, global warming, and environmental pollution [3–5]. It is reported that the share of renewable energy in electrical energy generation has risen from 34.7% in 2019 to 36.9% in 2021 [6]. In parallel, the World Green Building Council (WGBC) has issued a new sight to decrease 40% carbon dioxide emissions by 2030 for realizing 100% net zero emission buildings by 2050 [7,8]. Consequently, the search for affordable green energy for building applications becomes more urgently for these targets. Solar energy is one of the most favourable renewable energy sources, conducive to solving the challenges related to the greenhouse effect and environmental pollution.

In light of existing solar energy techniques, photovoltaic (PV) technology is the most broadly deployed to produce electricity for building applications [9–11]. In the UK, the PV system installations are facilitated by the government incentive measures involving the export tariff (ET) and feed-in tariff (FiT) [12,13]. Presently, numerous researches have been performed to optimize the PV systems for various building applications. For example, Simola et al. [14] assessed grid-connected PV systems for building applications in Finland and demonstrated that the optimized sizes are 89 kWp for grocery store, 28 kWp for dairy farm, and 5.2 kWp for domestic building, respectively. Mateus et al. [15] explored electrical energy output of a PV unit in a detached family house in Portugal and revealed that the PV array could meet over 60% of the house energy consumption. Nacer et al. [16] evaluated the feasibility of PV systems in Algerian dairy farms and found that 4.8 kWp PV array is suitable for coastal field farm, and 4.32 kWp system is proper for highland farm. Osma-Pinto and Ordóñez-Plata [17] analysed the effects of various parameters on the PV electrical energy output including roof category, height of installation, and ambient velocity. They discovered when the installation height of the PV module is in the range of 50 cm to 75 cm on a green-vegetated roof, the PV module could produce 1.3 $\pm$ 0.4% more electrical energy in comparison with one installed on a concrete roof. Saheli et al. [18] performed a feasibility assessment of PV coupled to an oscillating water column (OWC) system in Iran and found that approximately 95% of the energy is provided by the PV module in three ports, namely, 11,885.6 kWh/year for Noshahr, 11,607.4 kWh/year for Anzali, and 13,419.2 kWh for Torkaman, respectively.

Economic evaluations of the PV system have been explored broadly in the domains of buildings and industries. A number of researches have been implemented to forecast the system payback period (PBP) and net present value (NPV) based on the life-cycle cost (LCC) and levelized cost of electricity (LCOE) approaches in different countries. Saheli et al. [18] implemented a financial analysis of the OWC system with PV module in three different ports, Iran, and revealed that the LCOEs are 5.46 $/kWh in Noshahr, 5.59 $/kWh in Anzali, and 4.83 $/kWh in Torkaman, respectively, indicating that the Torkaman is the best place for the PV module installation. Zimmerman et al. [19] conducted an economic analysis of vertically mounted PV panels with the third-generation material in the USA, and demonstrated that the LCOE is within the range from 18.3 $/kWh to 23.1 $/kWh when the vertical PV panels are mounted facing towards south; by comparison, the LCOE falls in the range between 11.8 $/kWh and 14.2 $/kWh when the vertical PV panels are installed facing towards east or west. Ozcan et al. [20] completed a techno-economic investigation of a PV system with 30 years' life expectancy and found that the system could produce approximately 3913.84 kWh~4323.94 kWh of electrical energy and the PBP is less than 7 years. Ahmed et al. [21] discovered that the PV plant has the lowest cost of energy, 0.026 USD/kWh, resulting in the lowest PBP of 3.2 years in Pakistan. McKenna et al. [22] built a financial methodology to control the PV self-consumption for a domestic building in the UK and confirmed that approximately 45% of the power requirement could be covered by the mounted system, leading to a power cost saving of approximately £138 annually. Koppelaar [23] established numerical model of solar PV for investigating the net energy ratio (NER) and energy payback time (EPT) value, and found that an average of NER for mono- and polysilicon solar-PV could reach 8.6 and 9.2 times whereas the average EPT is 3.9 and 2.9 years, respectively. Mirzania et al. [24] investigated the income loss induced by the cancellation of the FiT scheme and indicated that the return on investment (ROI) and internal rate of return (IRR) are the vital factors of the profitability in the model; the project NPV is also improved when the ROI and IRR are enhanced, especially for larger solar PV arrays.

The main objective of this study is to assess energy and economic performance of the PV systems in three typical buildings in the East Midlands area of the UK, including an office building, a domestic building, and a poultry shed. At first, in the technology aspect, the PV systems are simulated to evaluate their monthly and hourly electrical energy production. The profiles of building electrical energy consumption are obtained by automatic meter reading (AMR). Then, an innovative economic model is developed according to the Monte Carlo method, and the 25 years' cumulative NPV and PBP are explored on the basis of the FiT scheme through the @Risk software. Afterwards, the economic sensitivity analyses including NPV and PBP distributions, NPV variation with the uncertain input parameters, and comparative distribution of probability between NPV and PBP are achieved as well. Finally, the influences of government subsidies involving the FiT and new Smart Export Guarantee (SEG) schemes are investigated for the annual savings and PBP variation. The output of this study contributes to promoting the PV application in various building categories.

2. PV System Designs

2.1. Building Description

The East Midlands is one of nine official regions in England, and includes Derbyshire, Nottinghamshire, Lincolnshire, Rutland, Northamptonshire, and Leicestershire, as presented in Figure 1a. The region has an area of 15,627 km^2 and a population of approximately 4.8 million. In this study, three typical buildings including an office building, a domestic building, and a poultry shed are utilized to explore the techno-economic performance of the PV system. As presented in Figure 1b, the office building, called the Markeaton lodge, is situated at the University of Derby in Derbyshire, and the southern orientation of the roof and entire floor regions are approximately 70.34 m^2 and 270 m^2, respectively.

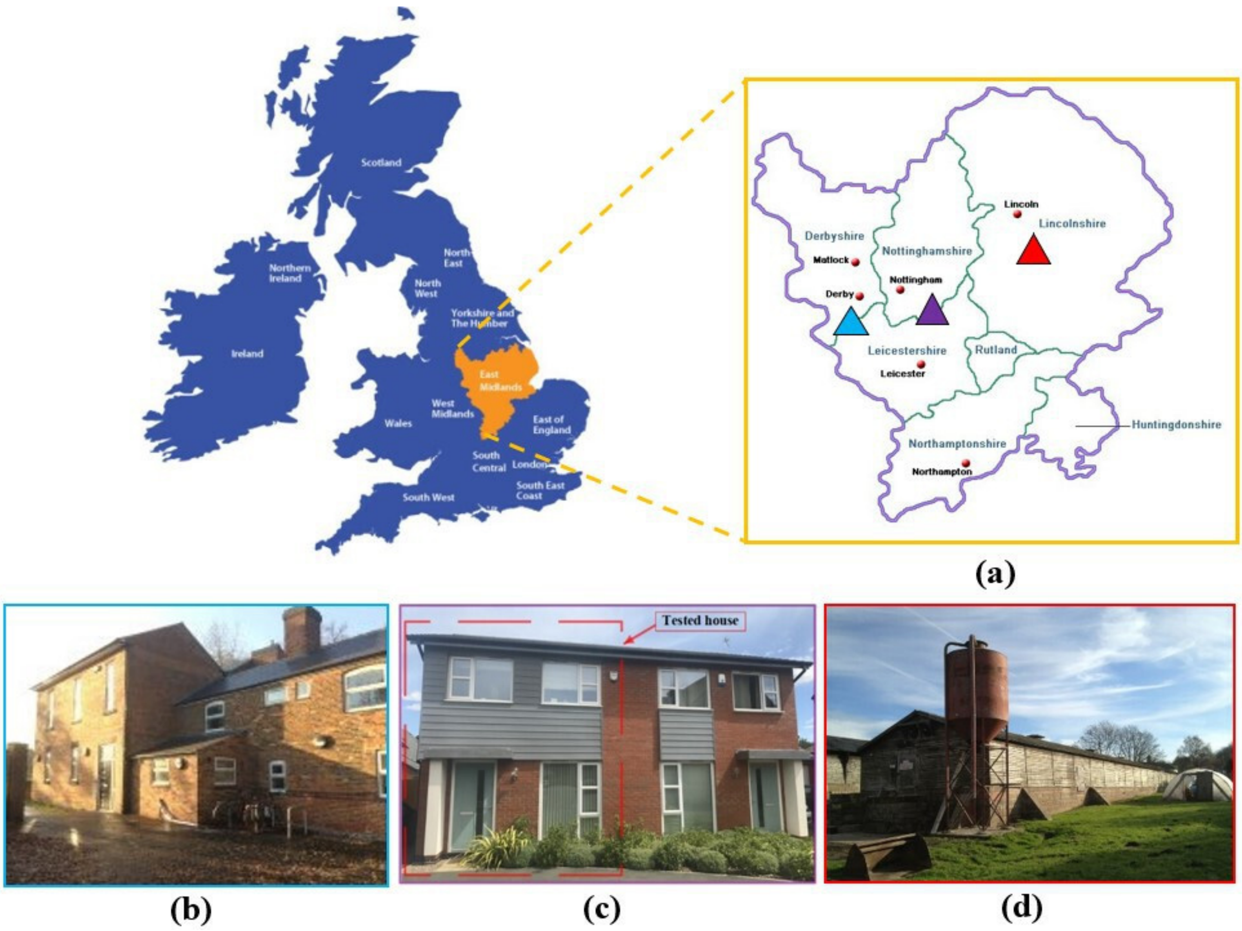


Figure 1. Views of different buildings in East Midlands, UK: (**a**) East Midlands location; (**b**) office building at the University of Derby (Derbyshire); (**c**) domestic building in Beeston (Nottinghamshire); (**d**) poultry shed in Newark (Lincolnshire).

As exhibited in Figure 1c, the domestic building is a semi-detached domestic building located in Beeston of Nottinghamshire; there are three bedrooms with an overall floor region of 117.18 m^2, and the southern orientation of roof region is approximately 32.3 m^2. As displayed in Figure 1d, the poultry shed is situated in Newark-on-Trent in Lincolnshire, and it has the dimensions of 63 m × 8 m × 2 m (L × W × H) for feeding 6700 chickens; the main energy consumption equipment is two 66 kW electric heaters.

2.2. Weather Conditions

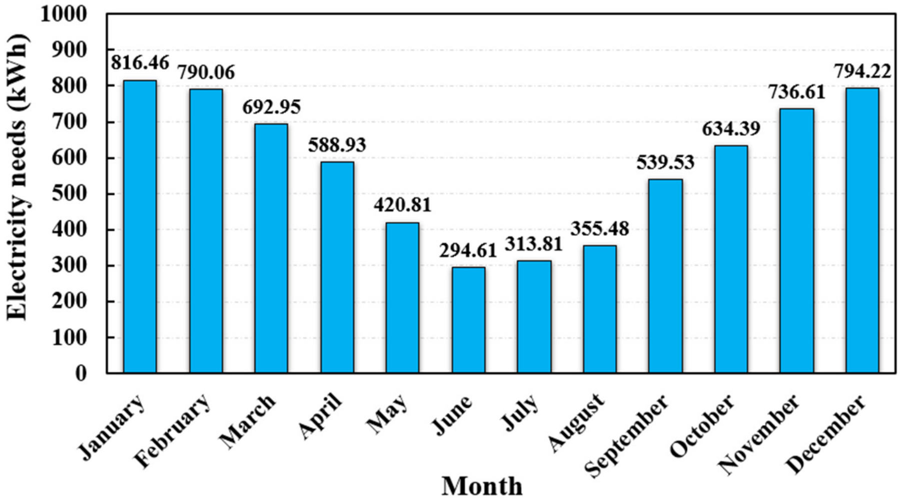
Air temperature and solar irradiation are the key factors to affect electrical energy production of the PV system (Table 1); the PVSYST 6.0.1 software is employed in the study to obtain the wind velocities, air temperature variation, and monthly average solar irradiations for Derby, Beeston, and Newark-on-Trent of East Midlands, UK [25,26].

Table 1. Meteorological data in Derby, Beeston, and Newark-on-Trent, UK [26].

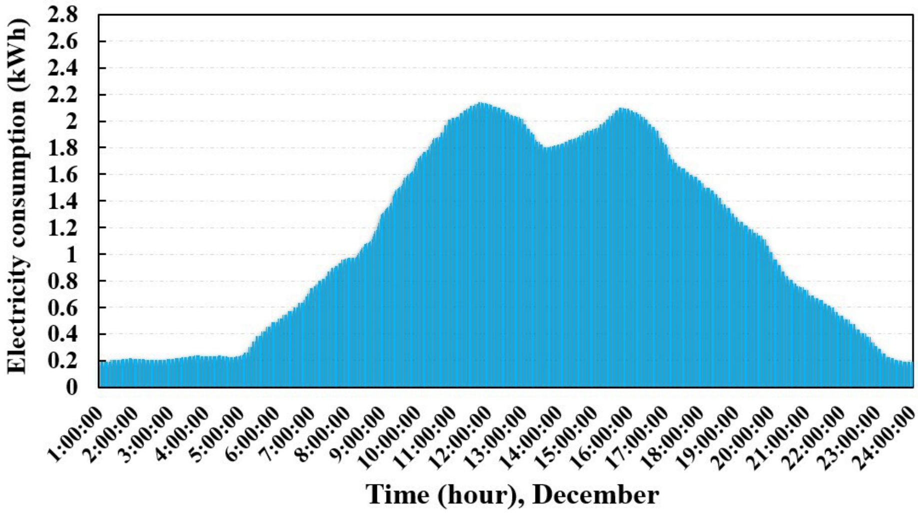
	Derby											
	January	February	March	April	May	June	July	August	September	October	November	December
Solar radiation (kWh/m^2/month)	20.80	34.10	74.40	114.60	143.10	148.60	144.40	118.5	89.01	49.34	27.05	17.93
Ambient air temperature (°C)	4.90	4.90	6.40	8.60	12.10	15.01	16.62	16.80	14.11	10.9	7.20	4.73
Wind speed (m/s)	5.20	4.80	4.79	4.20	4.19	3.80	3.79	3.59	3.80	4.29	4.69	4.49
	Beeston											
	January	February	March	April	May	June	July	August	September	October	November	December
Solar radiation (kWh/m^2/month)	18.96	33.03	69.19	100.06	133.69	144.57	139.78	120.42	85.63	51.29	25.22	14.82
Ambient air temperature (°C)	5.66	5.79	7.72	9.58	12.98	16.29	17.85	18.39	15.50	11.69	7.91	5.32
Wind speed (m/s)	4.27	4.51	3.89	3.81	3.92	3.68	3.51	3.11	3.41	3.91	3.49	3.92
	Newark-on-Trent											
	January	February	March	April	May	June	July	August	September	October	November	December
Solar radiation (kWh/m^2/month)	21.30	32.23	73.22	117.84	142.43	148.61	145.17	114.10	88.60	49.62	26.40	17.72
Ambient air temperature (°C)	4.50	4.60	6.30	8.70	12.20	15.01	16.70	16.81	14.10	11.02	7.01	4.52
Wind speed (m/s)	5.50	4.99	5.00	4.49	4.39	3.90	3.89	3.79	4.00	4.59	4.89	4.69

2.3. Electricity Consumption

Monthly electricity consumption of the three buildings is obtained from the UK electricity supplier (British gas). For the office building, the biggest electricity requirement is approximately 794.22 kWh in December, the lowest is approximately 294.61 kWh in June, as presented in Figure 2a, the annual power consumption is 6977.86 kWh, and it can be found from Figure 2b,c that in December and June, both of the months have two high hourly power consumption phases which are from 10:00 to 12:30 and from 15:00 to 16:30, respectively. In terms of the domestic building, the highest electricity demand is approximately 531.57 kWh in December, while the lowest is roughly 70.42 kWh in June, as defined in Figure 2d. The total electricity consumption is 3743.02 kWh per annum, and only one high hourly power requirement occurs in the period from 17:00 to 24:00 in December. By comparison, two high hourly power consumptions appear in the periods from 7:00 to 10:00 and 18:00 to 21:00 in June, as depicted in Figure 2e,f. As for the poultry shed, it can be seen from Figure 2g that the highest electricity requirement is approximately 1155.77 kWh in March, whereas the lowest is approximately 778.81 kWh in June, and the power consumption is 12,472.4 kWh per annum, the hourly electricity consumption has a flatten tendency, and the highest electrical energy consumption periods are in December and June occur from 21:00 to 24:00, as described in Figure 2h,i.



(**a**)



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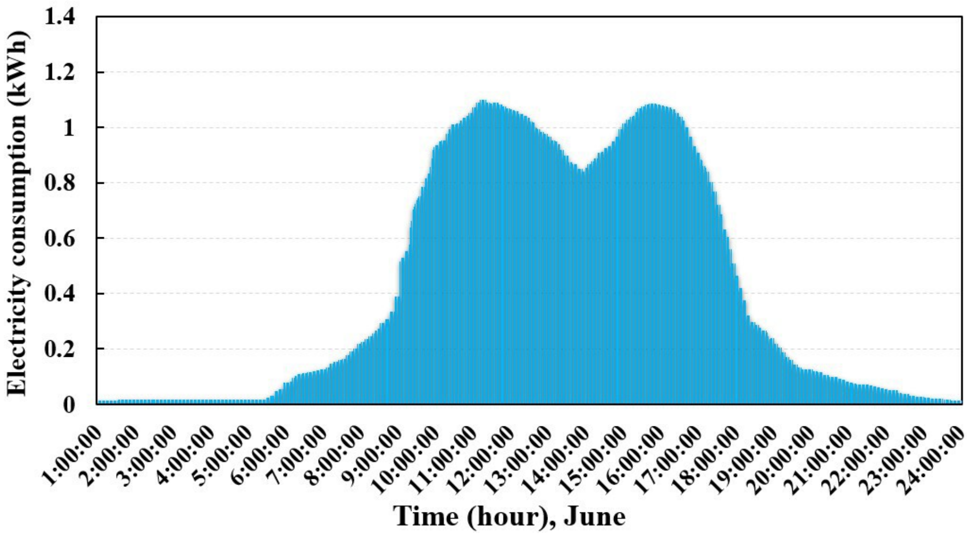
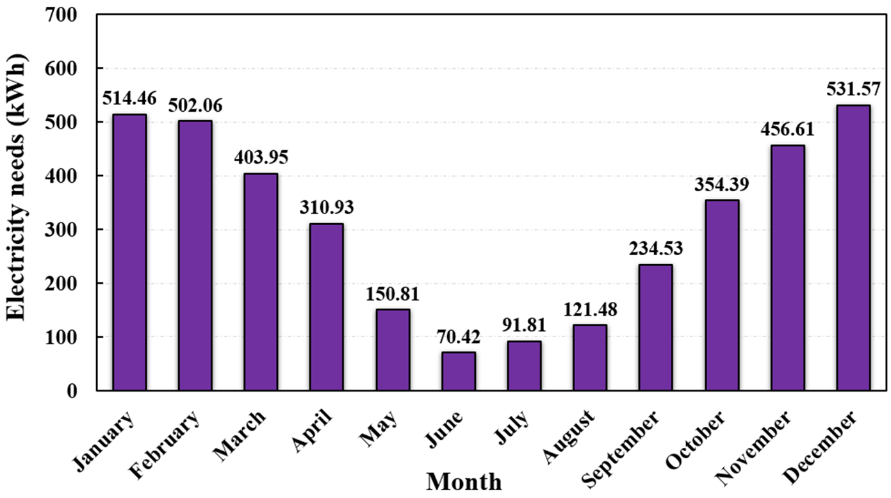


(**c**)

Figure 2. *Cont*.



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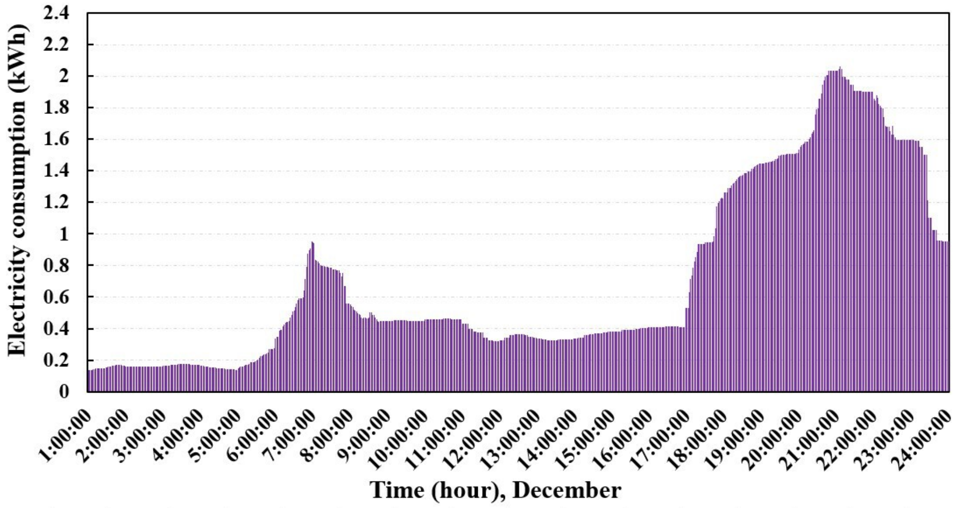
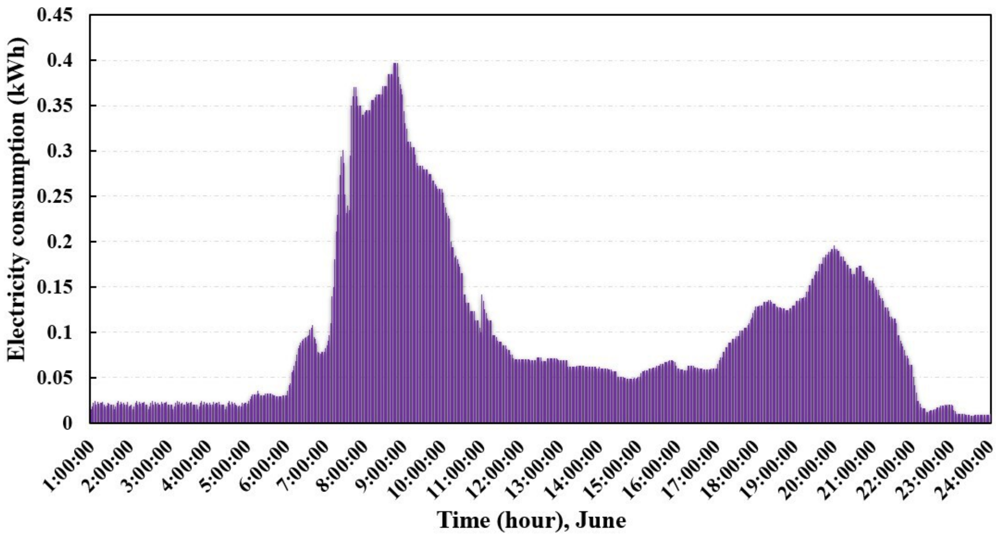
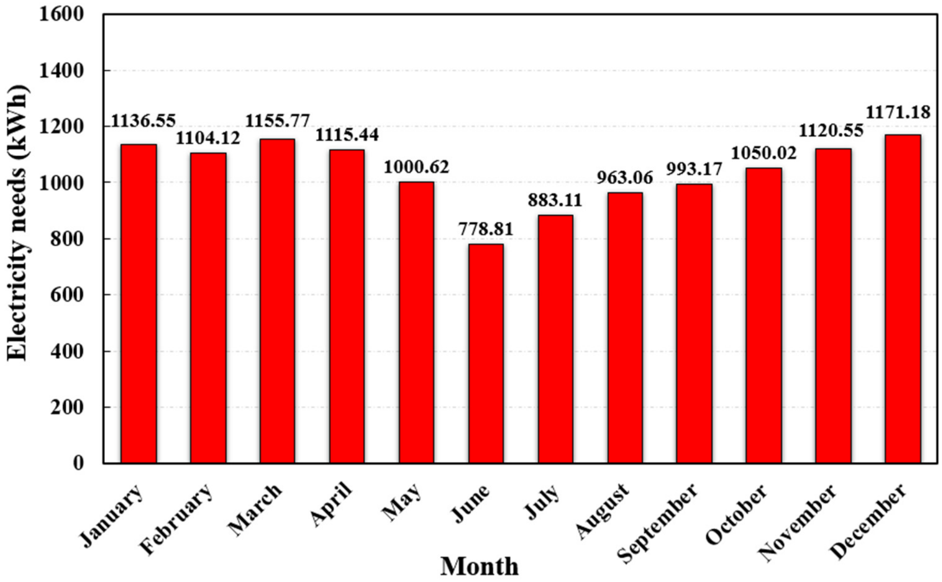


(**e**)

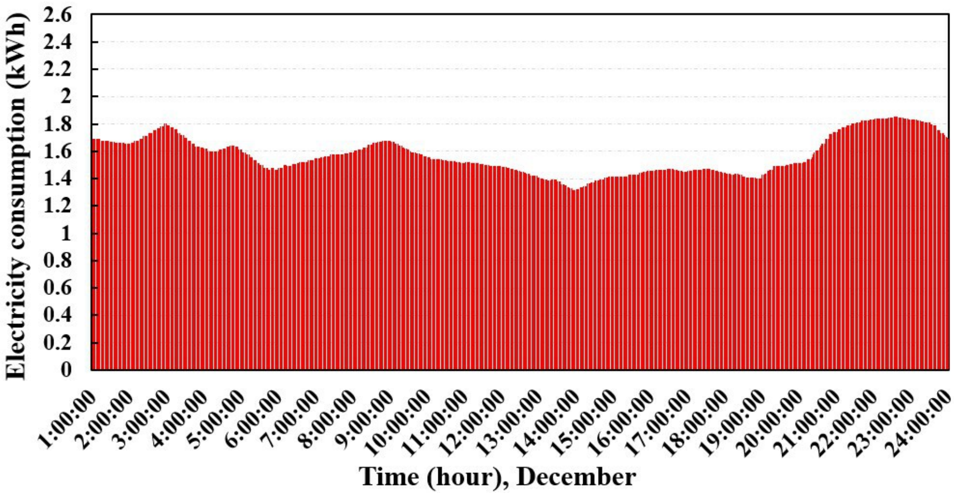


(**f**)

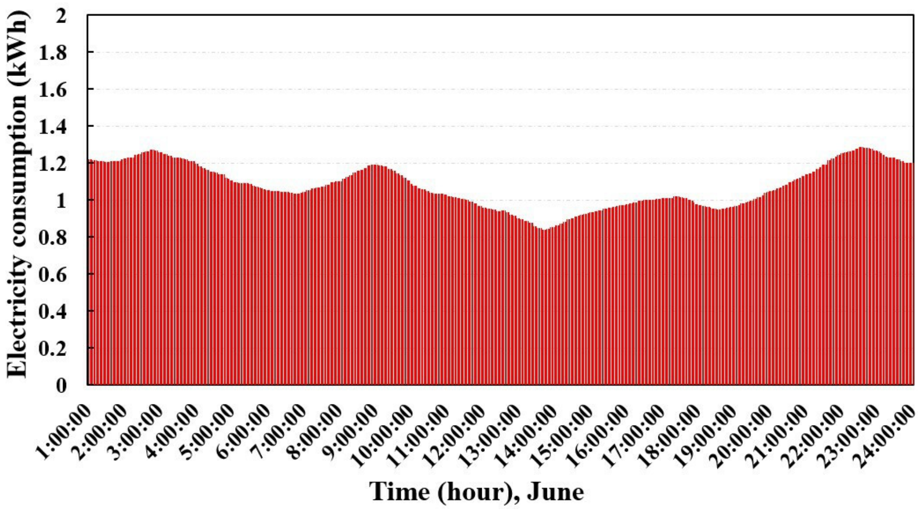
Figure 2. *Cont*.



(g)



(h)



(i)

Figure 2. Average monthly and hourly electricity energy consumption in: (**a**–**c**) office building (blue); (**d**–**f**) domestic building (purple); (**g**–**i**) poultry shed (red).

2.4. System Specifications

ND-R250A5 (250 Wp) solar PV module from Sharp Company [27] is selected in the study; its operating temperature is in the range from −40 °C to 85 °C. According to the three-building electricity consumption, 22 panels are used for the office building, 12 panels are adopted for the domestic building, and 52 panels are accepted for the poultry shed. These panels are installed at different tilt angles, 30° for the office building, 25° for the domestic building, and 20° for the poultry shed, all of them are oriented to the south. Three different types of inverters (Afore HNS4500TL for the office building, Afore HNS3000TL for the domestic building, and Afore HNS6000TL for the poultry shed) are chosen to match the system electrical energy output [28]. The PV system parameters are illustrated in Table 2.

Table 2. PV unit parameters for three buildings [27,28].

Item	
PV Module	
Module size (single)	1.652 m × 0.994 m × 0.046 m
No. of PV module	22/12/50
Cell type	Poly-crystalline
Efficiency	15.5%
Maximum voltage/current	30.90 V/8.10 A
Packing factor	0.94
Exposed roof area and title angle	
Active entire region	59 m^2/30 m^2/85 m^2
Title angle	30°/25°/20°
Inverter	Afore HNS4500TL/Afore HNS3000TL/Afore HNS6000TL

2.5. Initial Investment and UK Government Subsidies

The detailed costs of the PV systems are presented in Table 3. The main cost items are the PV panels, inverters, pipelines, labour, and power meters. The overall capital investments are approximately £4167.24 for the office building, £2273 for the domestic building, and £9949.84 for the poultry shed. The life expectancy of PV panels is typically assured for 20–25 years, whereas the lifetime of the inverter is regularly stipulated ranging from 7 to 12 years [29]. The financial parameters, component budgets, and program expenses are illustrated in Table 4. Specifically, 10% of the total capital investment is used as the initial deposit, and the remaining of the capital investments is tendered when the interest rate is defined as 8.2% over a period of 25 years. An inflation rate of 4.5% is utilized to determine the annual maintenance and insurance costs [30]. Because all three systems are operated in early 2019, the feed-in tariff for renewable power production is suitable for the financial evaluation [31]. The UK energy prices are regulated by Ofgem [32], the feed-in price and export price are defined as £0.1097/kWh and £0.052/kWh on average, respectively [32,33]. The annual maintenance and insurance costs for the three PV systems are anticipated to be £150, £80, and £240, respectively. The average effective income tax rate is 20% over the period of the life cycle.

Table 3. PV system cost breakdown for the three various buildings.

Item	Office Building	Domestic Building	Poultry Shed
PV array	£4167.24	£2273	£9949.84
Inverter	£370	£370	£740
Pipeline	£660	£300	£1360
Isolation switch and power meter	£200	£200	£200
Labour budget	£1200	£800	£2375
Total capital investment	£6597.24	£3943	£14,524.84
Estimated maintenance Budget	£150	£80	£240

Table 4. Economic factors utilization.

Item	Value
Electrical price	Feed-in-tariff (building usage): £0.1097/kWh Export tariff (to the grid): £0.052/kWh
Deposit	10%
Interest rate of payment of principal	8.2%
Inflation rate of inverter price	3%
Inflation rate of M&I	4.5%
Council tax for property tax	2%
Inflation rate of electricity price	6%
UK discount rate	8.75%
Income tax rate	20%
Inflation rate of extra property tax	4%

3. Energy Models

A mathematical model is established to determine the PV electricity generation by considering important factors as a function of the meteorological variables including wind speed, air temperature, diffuse radiations, and horizontal beam based on the Engineering Equation Solver software. Consequently, the PV module electrical output, panel surface temperature, soiling loss factor and shading losses, solar inverter overload, and electrical losses are determined based on the energy model. Additionally, based on the recent literatures [34,35], it is demonstrated that the PV model degradation loss has a significant influence on the PV system performance and economic analysis, however the restrictive factor of the long-term PV degradation rate assessments is the lack of extensive validation because the real value of degradation is unidentified; therefore, the PV model degradation loss is ignored in this work.

3.1. Radiation on a Tilted Plane

The meteorological report includes the solar radiation record at the horizontal plane, which should be transferred in order to apply on the PV cell. Hence, the global irradiance on a tilted plane G_t is expressed as [36]:

$$G_t = B_t + D_t + R_t \tag{1}$$

where B_t is the beam direct irradiance on a tilted surface (W/m^2); D_t is the diffuse irradiance on a tilted surface (W/m^2); and R_t is the reflected on a tilted surface (W/m^2).

The beam direct irradiance on a tilted surface is defined as [36]:

$$B_t = B \cdot r_b = B \frac{\cos\Theta}{\cos\Theta_z} \tag{2}$$

where Θ_z is the solar zenith angle; and Θ is the incidence angle of the radiation.

The tilted diffuse irradiance is written as [36]:

$$D_t = D_h r_d \tag{3}$$

$$r_d = F_{Hay} r_b + (1 - F_{Hay}) r_{d,LJ} \tag{4}$$

$$F_{Hay} = \frac{B_h}{G_0 \cos\Theta_z} \tag{5}$$

$$r_{d,LJ} = \frac{1 + \cos\beta}{2} \tag{6}$$

The reflection of the radiation from the module surface is considered using a K_θ incidence angle modifier (IAM) calculated with the following equation [36]:

$$K_\theta = 1 - b_0\left(\frac{1}{\cos\Theta} - 1\right) \tag{7}$$

The b_0 is an incidence angle modifier coefficient which has a typical value of 0.05 for PV modules.

The solar radiance loss is ascribed to the dust accumulation, soil loss factor, and tilt angle, so it is deliberated in the model. The correlation equation is expressed as [36]:

$$l_{\text{soil loss factor}} = 0.01385 - 0.00015\beta \tag{8}$$

where β is the slope/tilt/inclination angle of the PV module.

3.2. Shading Losses

In terms of multiple rows, the shading is a crucial influence factor that needs to be considered.

Hence, the modified isotropic diffuse transposition factor is depicted as [36,37]:

$$r_{d,LJ,mod} = \frac{1 + \cos(\beta + \alpha)}{2} \tag{9}$$

In view of all the above mentioned factors, the solar radiation on the PV array surface is determined [36,37]:

$$G_{PV} = \left\{B_h r_b K_{\theta,b} + D_h[F_{Hay} r_b K_\theta + (1 - F_{Hay}) r_{d,LJ,mod} K_{\theta,diff}] + \rho_g G_h r_r K_{\theta,relf}\right\} \cdot (1 - l_{soil}) \tag{10}$$

$$G_{PV,sh} = [D_h(1 - F_{Hay}) r_{d,LJ,mod} K_{\theta,diff} + \rho_g G_h r_r K_{\theta,relf}] \cdot (1 - l_{soil}) \tag{11}$$

3.3. PV Module Model

The cell temperature T_c is calculated as follows [36,37]:

$$T_c = \frac{U_{PV}(\nu) T_a + G_{PV}[\tau\alpha_c - \eta_{STC}(1 - \mu_{P,mp} T_{STC})]}{U_{PV}(\nu) + G_{PV}\eta_{STC}\mu_{P,mp}} \tag{12}$$

where U_{PV} is the heat transfer coefficient; T_a is the air temperature (°C); α_c is the absorptance coefficient; η_{STC} is the efficiency (%); and $\mu_{P,mp}$ is the temperature coefficient of the module's maximum power under standard test conditions (STC): G_{STC} = 1000 W/m^2, T_{STC} = 25 °C. τ is the transmittance of the glass cover (%).

The UPV is a linear function of wind speed v as:

$$U_{PV}(\nu) = 26.6 + 2.3\nu \tag{13}$$

The current of PV (I) [38] is defined as:

$$I = I_p - I_D - I_{sh} = I_L - I_o\left[\exp\left(\frac{V + I \cdot R_s}{\Theta N V_{th}}\right) - 1\right] - \frac{V + I \cdot R_s}{R_{sh}} \tag{14}$$

where I_p is the photocurrent in the standard test condition (STC) (A); I_D is the diode reverse saturation current (A); Io is the diode reverse saturation current (A); R_{sh} is the shunt resistance (Ω); R_s is the series resistance (Ω); Θ is the diode ideality factor (equal to 1.5); N is the number of PV module; and V_{th} is the thermal equivalent voltage (V) and written as:

$$V_{th} = \frac{kT_{cell}}{q} \tag{15}$$

where k is the Boltzmann's constant (1.381×10^{-23} J/K); and q is the electron charge (1.602×10^{-19} coulomb).

3.4. Inverter, Cable, and Other Losses

Taking voltage reduction and electrical loss into account on the DC wires, the input current I_{DC}, voltage $V_{DC,}$ and power P_{DC} of the inverter are determined [36,39].

$$I_{DC} = N_P I_{mp} \tag{16}$$

$$V_{DC} = N_s V_{mp} - I_{mp} R_{c,DC} \tag{17}$$

$$P_{DC} = N_s N_p P_{mp} - I_{mp}^2 R_{c,DC} \tag{18}$$

$$R_{e,DC} = \Delta \nu_{DC} \frac{N_s V_{mp,STC}}{I_{mp,STC}} \tag{19}$$

$$\eta_{inverter}(V) = \frac{K_0(V)}{(P_{DC}/P_{inverter})} + K_1(V) + K_2(V)(P_{DC}/P_{inverter,max}) \tag{20}$$

The electrical energy output of the inverter P_{AC} is defined as:

$$P_{AC} = \min(\eta_{inverter}(P_{DC}, V_{DC})P_{DC}, P_{inverter,max}) \tag{21}$$

The losses of the AC components are taken into account via the transformer loss factor l_{tr} to obtain the electricity fed into the grid P_{grid}:

$$P_{grid} = P_{tr}(1 - l_{tr}) \tag{22}$$

4. Economic Models

One of the main contributions of this paper is employing a financial approach to assess the PV system economic characteristics by taking full account of volatile economic alteration, uncertain influence elements concerning interest and discount rates, life expectancy of assets, expected maintenance budget, and payback period based on the @RISK 8.0 software. Moreover, the yearly income and saving are required to make a composition between the SEG and FiT schemes [40,41]. Specifically, the expenses of the entire PV system consist of the panel, support assembly, solar inverter, electrical and mechanical fixing, as well as structure anchor and cables protections costs. As stated in the studies [21–23], all components of PV system would have 25 years of life expectancy excluding the inverter. In order to obtain an optimistic rate of return (ROR) from the PV system, the replacement period of the inverter is anticipated for 10 years on the basis of the product specification [28]. If the inverter has been employed beyond 10 years, some issues will occur such as ultrasonic vibrations, over-voltage, over-current, mechanical and electrical wear of capacitors, etc. These issues not only have a direct bearing on the efficiency of the PV system and thermal loading of the inverter, but also result in the extra expense in light of maintenance over the operating period.

4.1. Net Present Value and Payback Period

To achieve the optimality and efficiency design, it is necessary to assess life-cycle cost (LCC) for the feasibility of investment:

$$LCC = O_{IE} + O_{SEEE} + O_{MP} + O_{M\&I} + O_{ITS} + O_{PC} \tag{23}$$

where O_{IE} is the components of the PV unit outlay (£); O_{SEEE} is the electrical energy expense of the PV unit (£); O_{MP} is the mortgage outlay (£); $O_{M\&I}$ is the maintenance and insurance outlay (£); O_{ITS} is the savings and income outlay of the PV unit (£); and O_{PE} is the periodic outlay of PV unit (£).

The NPV represents the overall cash flow of a project, in which a positive value indicates that the project is going to be profitable while a negative value leads to a net loss. The NPV is expressed as:

$$NPV = -O_{IE} + \sum_{N=1}^{N'} \frac{O_N}{(1+\gamma)^N} \tag{24}$$

where O_N is the net cash inflow over the operating phase N (£); and γ is the discount rate (%).

The PBP is employed to determine the time required to recoup the fund expended within an investment:

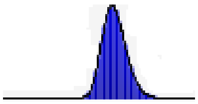
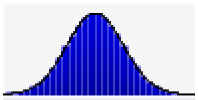
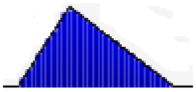
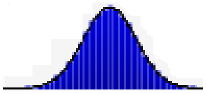
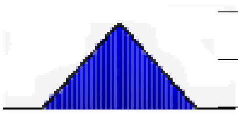
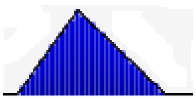
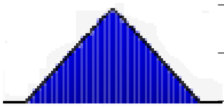
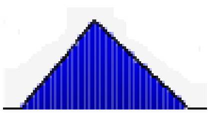
$$PBP = X + \frac{Y}{Z} \tag{25}$$

where X is the last period with a negative discounted cumulative cash flow (£); Y is the discounted cumulative cash flow (£); and Z is the discounted cash flow (£).

4.2. Monte Carlo Method

The Monte Carlo method has been employed within the context of the economic management of the renewable energy system because it takes into account the probability density functions and processes considerable data for random input variables. Traditional economic analysis approaches, such as the LCOE and LCC, usually use point values to estimate upper and lower boundaries. This means that they are restricted, owing to the lack of a sense of the likelihood of various results. In comparison, the Monte Carlo method is a comparatively straightforward and mature approach involving uncertainty or fuzzy design and forecast parameters in quantitative models. Furthermore, the calculation process of the Monte Carlo method needs to be carried out many times, and the outcomes are based on its own setting of input designated parameters randomly from pre-defined variable distributions. Accordingly, in order to analyse the economic sensitivity of the PV system with the Monte Carlo method, a proper scope and a distribution for each variable are required to be first defined, such as log normal, normal and triangular. To be more specific, very high capital investment is possible in terms of the PV module price, which would have a big range with a higher frequency in the lower value, hence a log-normal distribution is defined as the parameter input. Similarly, the electricity price is somewhere closer to the lower termination of the scope, so a triangular distribution is chosen for the calculation process. Table 5 illustrates the values of A, B, and C as the representation of different input parameters for the three categories of distributions. For a log-normal distribution category, A represents the mode, B represents the μ parameter, and C represents the σ parameter. For a normal distribution category, A is the average value, and B is the standard deviation. For the triangular distribution category, A is the low termination of the distribution boundary, B is the peak value, and C is the upper termination of the distribution boundary. For constant parameters, the scope denotes the value utilized. For the stochastic analysis of the economic sensitivity presented in this study, 10,000-iteration repetitions of the Monte Carlo simulation are completed by using the @RISK software. The viability of each scenario can be obtained when each input parameter is changed in the range of assumed future market condition. Figure 3 depicts the simulation program of the economic analyses for the three PV systems.

Table 5. Variable parameters.

Input Variable	Probability Distribution Type	Parameter	Office Building	Domestic Building	Poultry Shed
Capital investment		**Range**	5831–7200	3500–4300	13,500–18,000
		A	6597	3943	14525
		B	2.8	1.1	7.4
		C	1.9	0.18	4.3
PV electrical generation		**Range**	8500–11,000	3500–4500	12,000–16,000
		A	8500	3500	12,000
		B	9770	3938	14,060
		C	11,000	4500	16,000
Electrical price		**Range**	0.055–0.22	0.055–0.22	0.055–0.22
		A	0.055	0.055	0.055
		B	0.1097	0.1097	0.1097
		C	0.22	0.22	0.22
Maintenance cost		**Range**	120–185	72–88	210–280
		A	150	80	240
		B	0.070	0.31	0.61
		C	N/A	N/A	N/A
Deposit cost		**Range**	488–1466	200–588.6	730–2174
		A	488	200	730
		B	977	394.3	1452.5
		C	1466	588.6	2174
Discount rate		**Range**	0.065–0.11	0.065–0.11	0.065–0.11
		A	0.065	0.065	0.065
		B	0.875	0.875	0.875
		C	0.11	0.11	0.11
Inflation rate		**Range**	0.055–0.065	0.055–0.065	0.055–0.065
		A	0.055	0.055	0.055
		B	0.06	0.06	0.06
		C	0.065	0.065	0.065
Inverter replacement cost		**Range**	350–400	350–400	700–800
		A	370	370	740
		B	0.22	0.22	0.48
		C	N/A	N/A	N/A

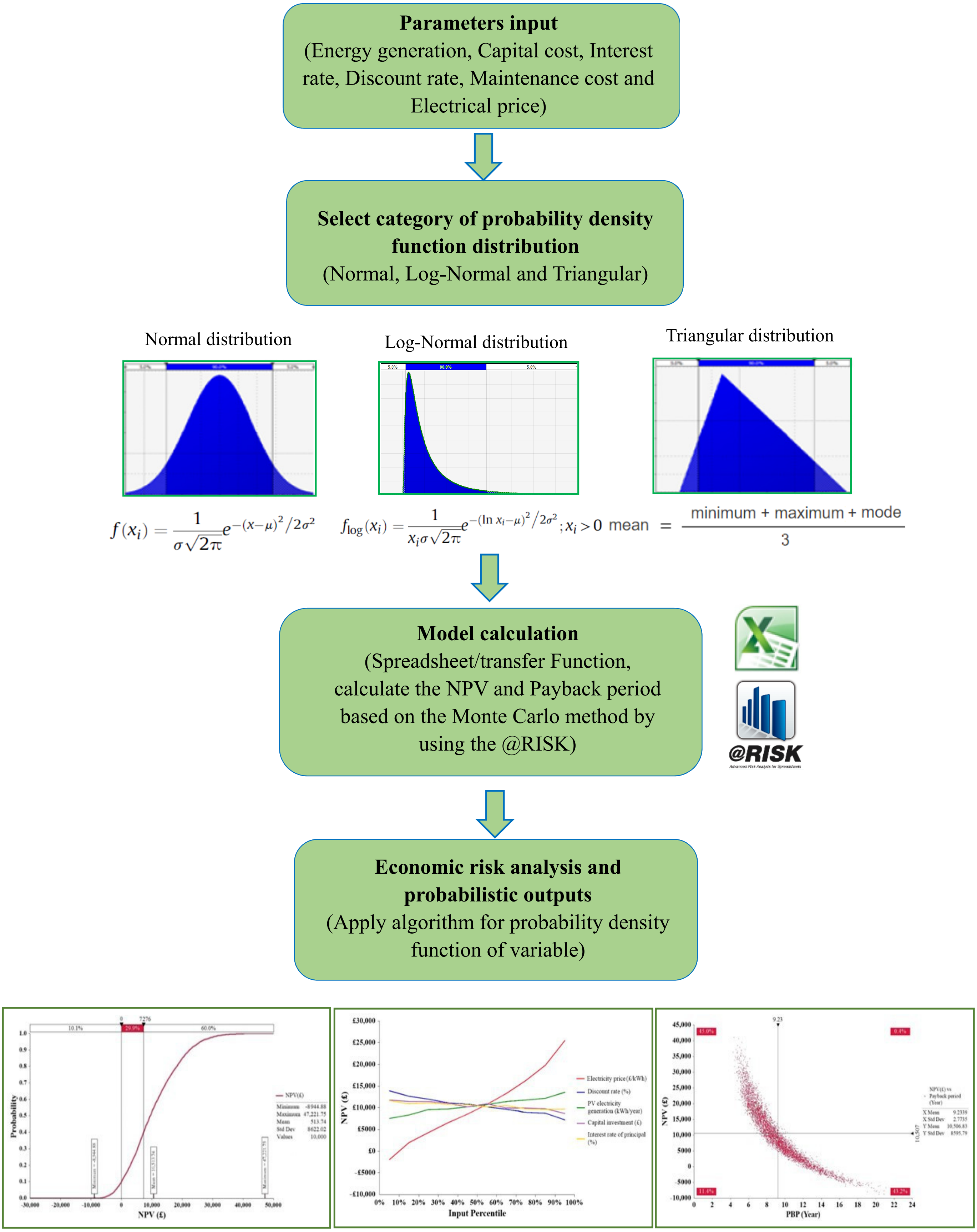


Figure 3. Monte Carlo decision tree modelling.

5. Results and Discussion

The simulation results of monthly building electricity need and electricity generation of the PV system are illustrated in the following section; the hourly power consumption data of the three buildings are provided by UK British Gas.

5.1. Energy Performance

5.1.1. Office Building

As described in Figure 4a, the PV system electricity generation of 2141.21 kWh enables it to meet the office building electrical energy demand of 3771.74 kWh for the period from October to February. This indicates that approximately 1630.53 kWh of power is required to be bought from the grid in the heating season. However, it can be found from Figure 4b that the system power generation of 7629.59 kWh outdoes the building energy requirement of 3206.12 kWh from March to September, especially in the summer season such as June and July. The extra electricity of approximately 4423.47 kWh could be fed into the grid. The entire power generation from the PV system is approximately 9770.80 kWh annually. The monthly electrical energy obtained from the PV system could reach the maximum value of 1241.79 kWh in June and the minimum value of 332.12 kWh in December.

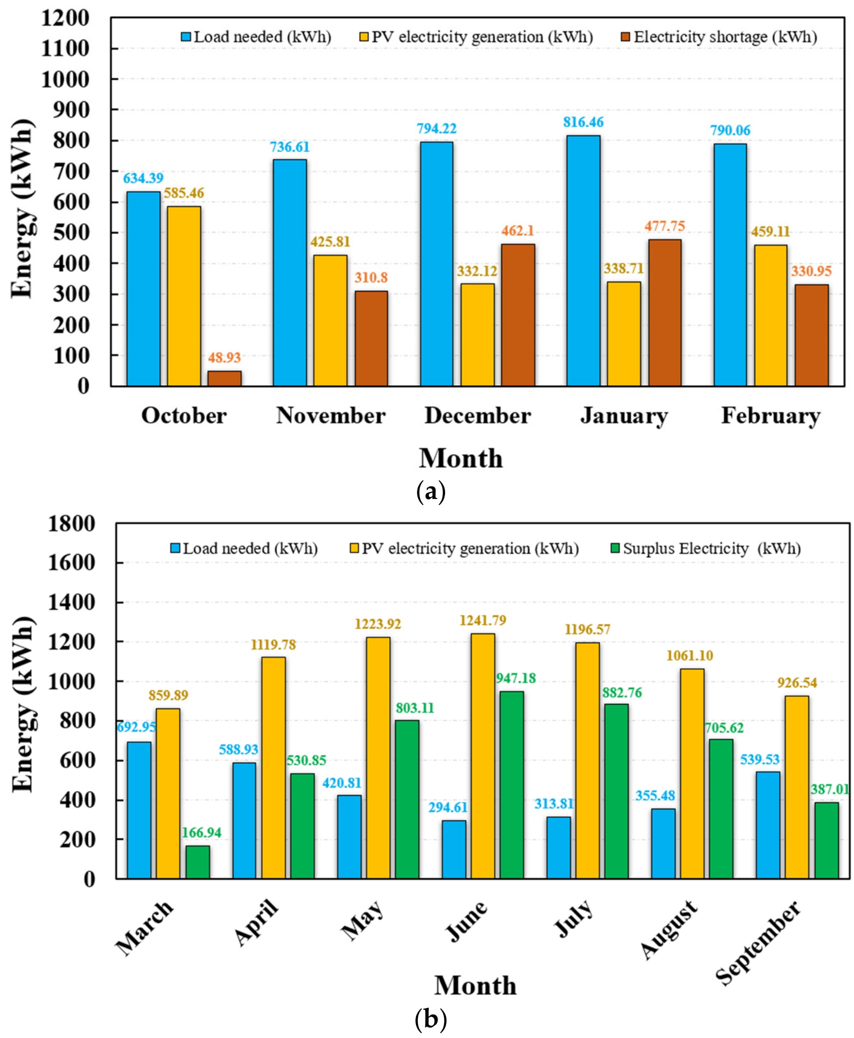


Figure 4. Monthly electricity loaded requirement, production, shortage, and surplus in the office building: (**a**) from October to February; (**b**) from March to September.

Figure 5 depicts the detailed office building power consumption and production in December and June; the primary power consumption and production periods are 9:00 to

17:00 and 9:00 to 15:00, respectively. This phenomenon causes an incongruity between the power production and consumption. In the meantime, the entire daily electricity generation of 16.26 kWh is less than the entire daily power consumption of 25.62 kWh, which means that the PV system cannot meet the office building power requirement in December. Nevertheless, in June, the main power consumption time is from 10:00 to 16:00, which could yield sufficient electricity of 41.35 kWh from 6:00 to 21:00. This implies that the building electricity need of 9.82 kWh could be achieved by the PV system, and the extra power of 31.57 kWh could be fed into the grid.

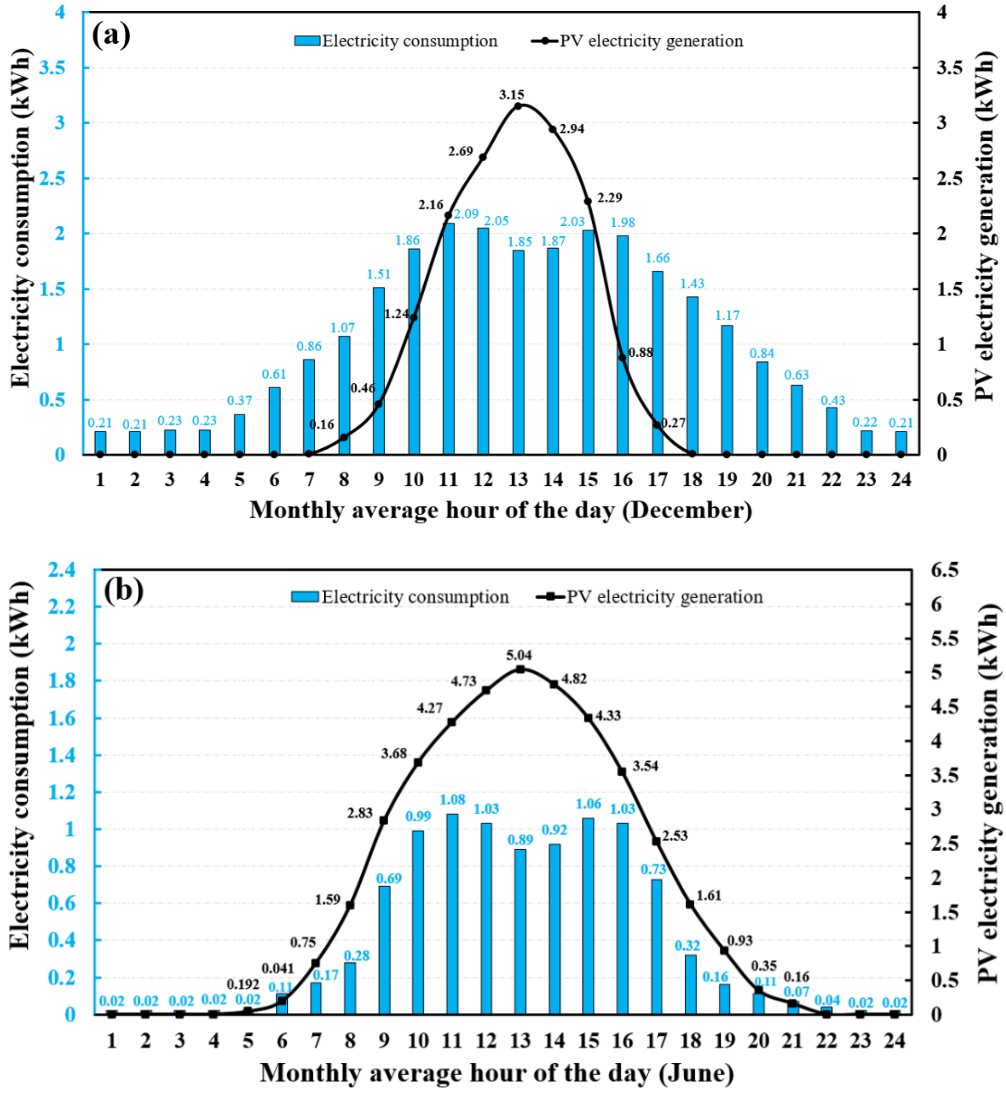


Figure 5. Office building power consumption and production: (**a**) December; (**b**) June.

5.1.2. Domestic Building

Figure 6 depicts the monthly domestic building power requirement and the PV system electrical energy production. It is demonstrated from Figure 6a that the system power generation of 1072.77 kWh is unable to cover the overall building power requirement of 2408.64 kWh; meanwhile, the power of 1335.87 kWh needs to be provided from the grid over the heating season. By comparison, from April to October, the system power production of 2864.60 kWh surpasses the domestic building energy requirement of 1334.36 kWh, which means that approximately 1530.23 kWh of surplus power could be fed into the grid. Additionally, the PV system produces approximately 3937.37 kWh of electricity annually, and the lowest and highest monthly electricity outputs are 151.33 kWh in December and 494.45 kWh in June, respectively.

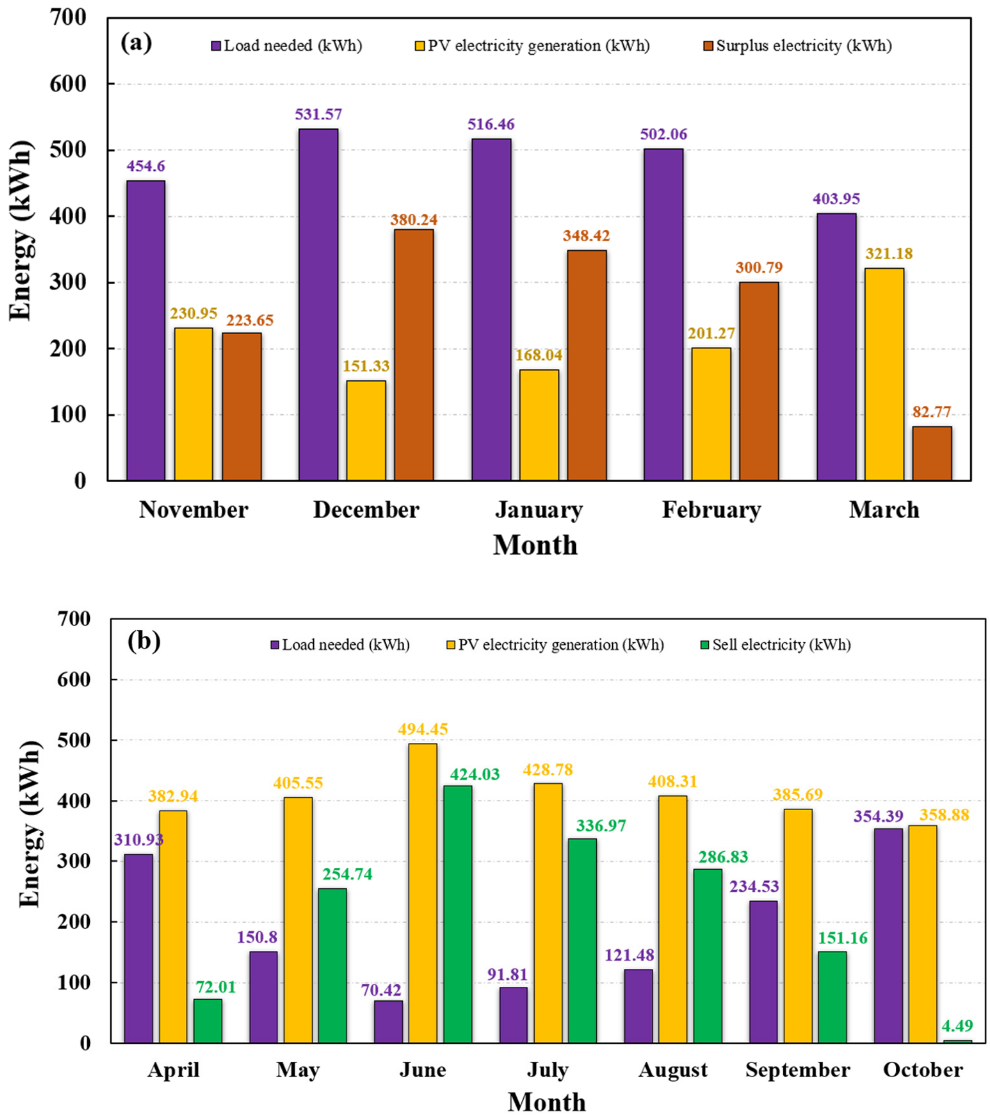


Figure 6. Monthly electricity loaded requirement, production, surplus, and sell in the domestic building: (**a**) from November to March; (**b**) from April to October.

The domestic building power consumption and PV system's electricity for the monthly average hours of the day are illustrated in Figure 7. In December, the period of the building power consumption is from 10:00 to 17:00, while the period of the power production is from 9:00 to 15:00. Furthermore, the total daily electricity generation of 16.26 kWh is less than the daily electricity consumption of 25.62 kWh. This means that the system does not cover the domestic building power demand in December. In contrast, in June, the period of the power consumption period ranges from 10:00 to 16:00, indicating that the PV system could cover the building daily electricity requirement from 6:00 to 21:00, and the extra power of 11.97 kWh can be exported to the grid.

5.1.3. Poultry Shed

As exhibited in Figure 8a, the PV electricity production is 4145.02 kWh from October to March, which is less than the poultry shed need of 6738.19 kWh in the period. This demonstrates that approximately 2593.17 kWh of electricity should be acquired from the grid. Nevertheless, from April to September, the PV system power production of 9915.60 kWh outstrips the building electricity need of 5734.21 kWh, as defined in Figure 8b, especially the period from May to August, indicating that approximately 4181.39 kWh of extra power could be sold to the grid. Moreover, annual 14,060.60 kWh of electricity could be produced by the PV system, and the lowest and highest monthly electricity output are 484.94 kWh in December and 1890.32 kWh in June, respectively.

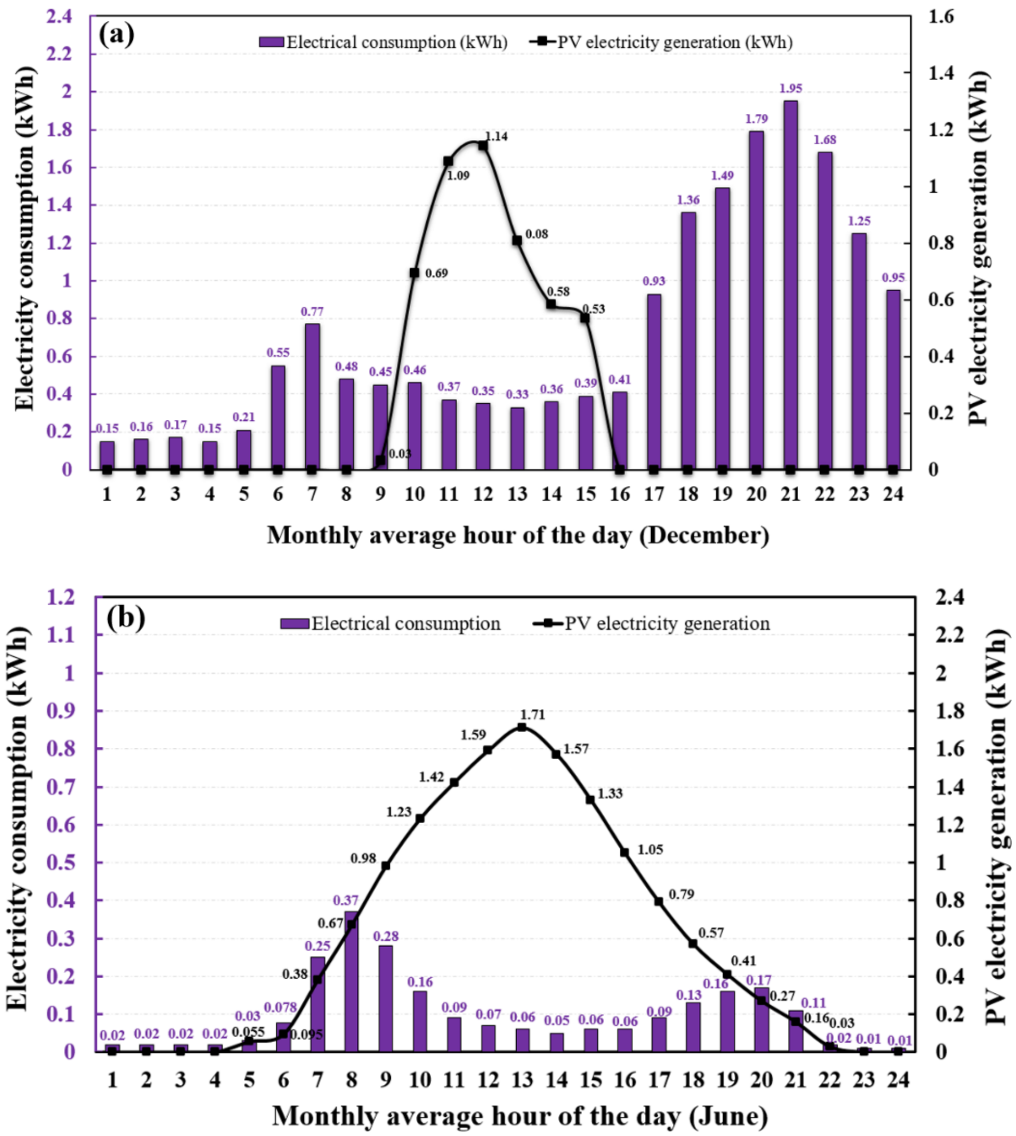
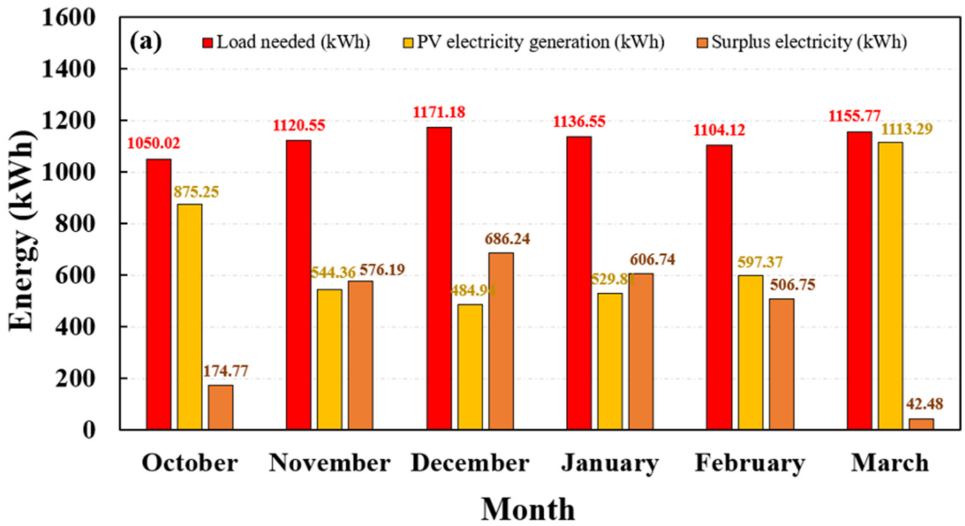


Figure 7. Domestic building power consumption and production: (**a**) December; (**b**) June.

It is found from Figure 9 that the average hourly PV electricity output could cover the shed energy demands from 11:00 to 15:00 in December, and the average hourly electrical energy need can be satisfied from 9:00 to 19:00 in June. This demonstrates that the mean daily electricity generation of 15.64 kWh is less the daily electricity consumption of 37.78 kWh in heating season, but, in summer, the average daily electricity generation of 60.34 kWh is able to cover the poultry shed electricity need of 25.96 kWh, resulting in surplus electricity of approximately 34.38 kWh that can be exported to the grid.

5.1.4. PV Temperature and Efficiency

The monthly average surface temperatures and efficiencies of three PV systems are presented in Figure 10. The PV maximum monthly surface temperatures for the office building, domestic building, and poultry shed could reach 32.01 °C, 31.58 °C, and 30.1 °C in June, associated with electric efficiencies of approximately 15.48%, 15.43%, and 15.17%, respectively. By comparison, the minimum monthly surface temperatures for them are 10.18 °C, 9.91 °C, and 8.87 °C in December, with corresponding electric efficiencies of approximately 10.89%, 10.65%, and 10.11%, respectively. In the meantime, the annual average efficiencies and surface temperatures of the three PV systems are 13.26% and 20.11 °C for the office building, 13.01% and 19.39 °C for the domestic building, and 12.71% and 18.28 °C for the poultry shed, respectively. Generally, the PV modules performance is affected by a high temperature of solar modules and external environmental conditions, such as the ambient temperature and dust deposition. When the PV cell temperature is raised, the efficiency is decreased owing to the enhancement in the inner carrier recombination rate. In this context, in the UK, there is not enough solar radiation to provide the PV cell panel in winter; even though the PV temperature is low, the PV efficiency cannot reach a high value. By comparison, in summer, the abundant solar radiation can assist to obtain the sufficient energy for the PV cell; even if there is a high PV surface temperature, the PV efficiency could keep a high level because of the stability in the carrier concentration and the internal carrier recombination rate.



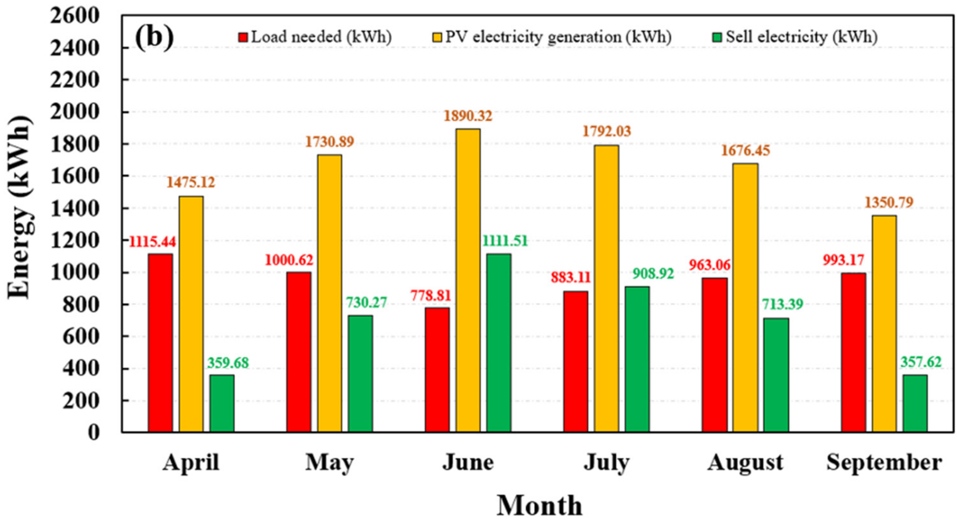


Figure 8. Monthly electricity loaded requirement, production, shortage, and sell in the poultry shed: (**a**) from October to March; (**b**) from April to September.

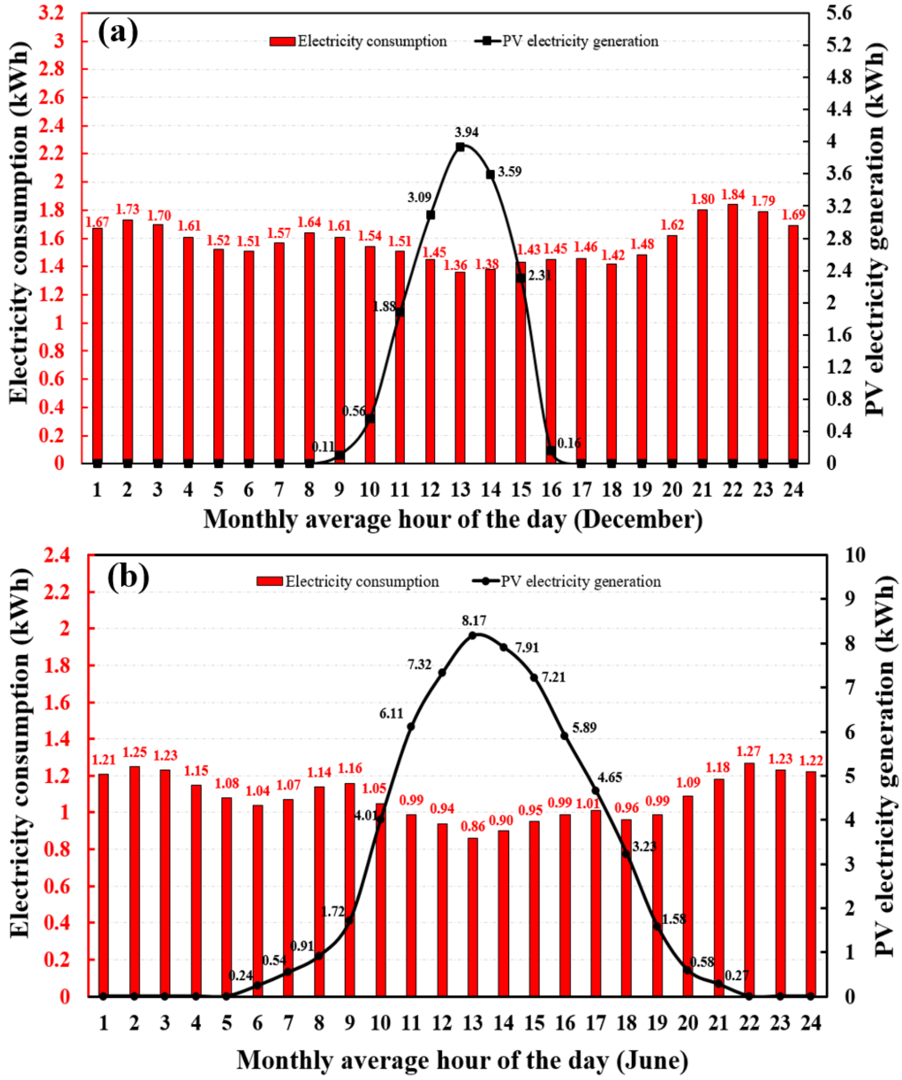


Figure 9. Poultry shed power consumption and production: (**a**) December; (**b**) June.

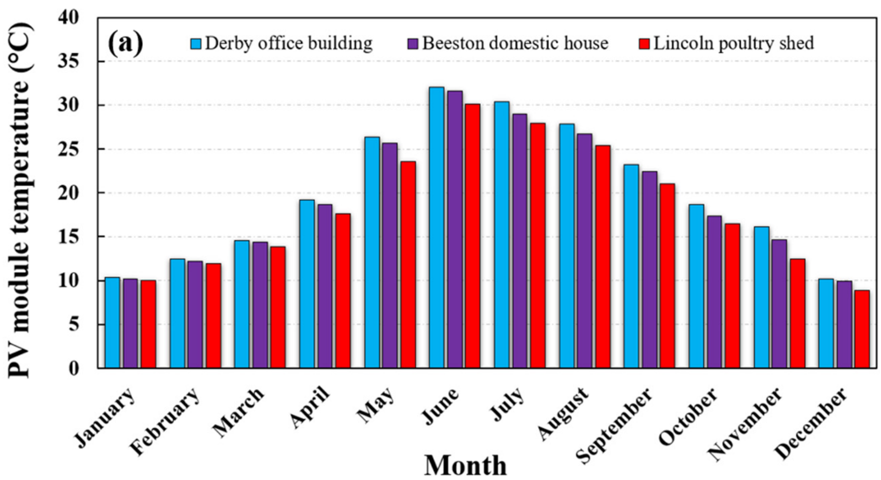


Figure 10. *Cont*.

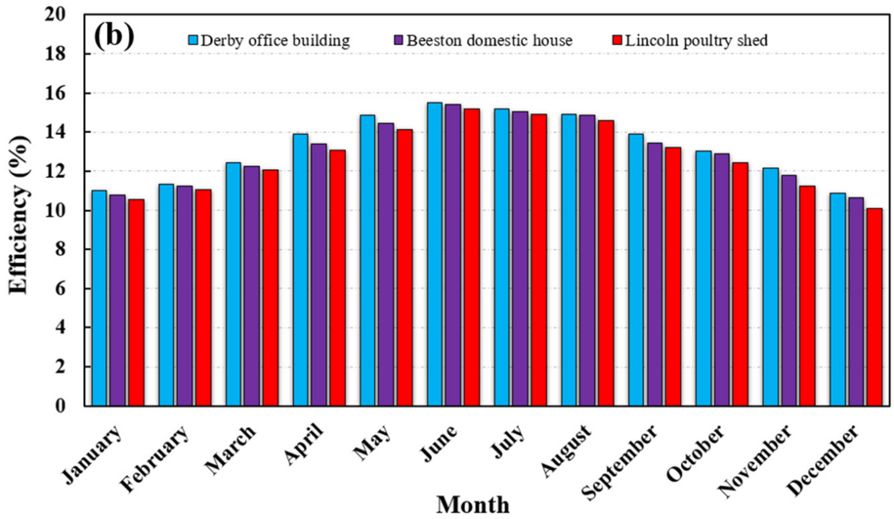


Figure 10. Results comparison among three buildings: (**a**) module temperature; (**b**) efficiency.

5.2. Economic Performance

5.2.1. Results for the 25-Year Operating Period

This subsection exhibits the predicted outcomes for the cost scenarios. It can be observed from Figure 11 that all three cash flows become positive from the first year. Nevertheless, they fluctuate and become even negative because of the costs produced via the replacements of the inverter in the tenth and twentieth years. For the office building and poultry shed, the cash flow values reach £349.51 and £37.59, respectively, during the overall course of LCC evaluation. This is because the electrical energy productions of the two systems are high, but their capital investments and maintenance costs are low. By comparison, the cash flow of the domestic building at the end of the tenth year reaches -£114, owing to the inverter replacement and high maintenance costs. The NPVs of the PV systems are £386.47 for the office building, £126.06 for the domestic building, and £458.69 for the poultry shed at the market discount rate of 8.75% during a 25-year operating phase, respectively. More detailed quantitative results for the three scenarios are provided in Figure 12.

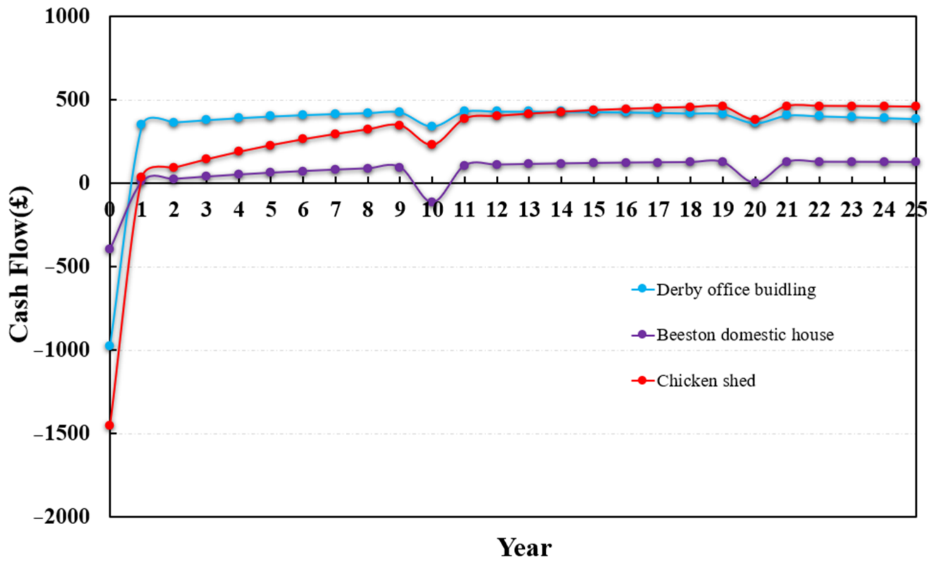


Figure 11. Results comparison of annual system cash flow variation for the three buildings during the 25-year period for the office building, domestic building, and poultry shed.

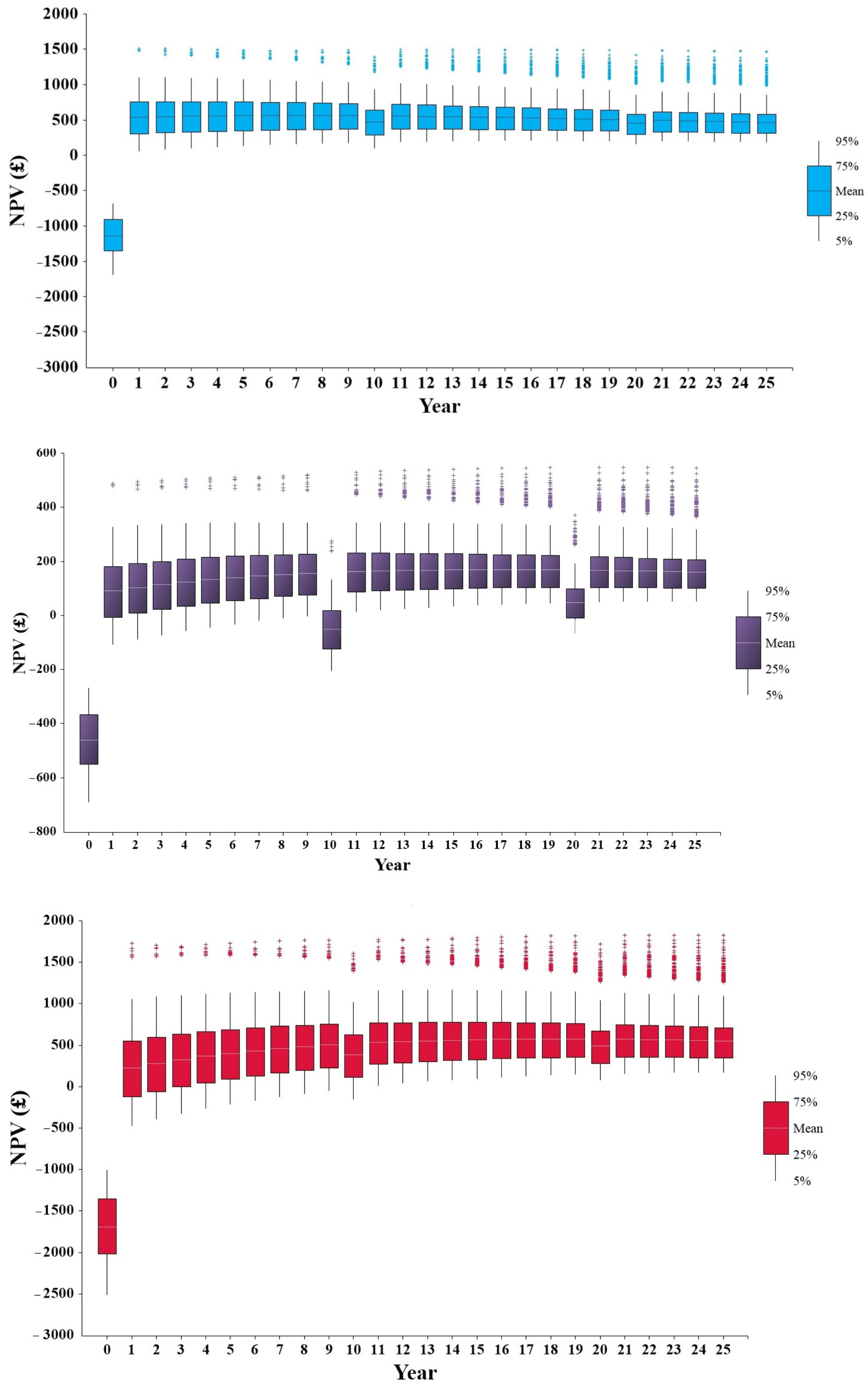


Figure 12. Detailed quantitative results comparison: Derby office building (Blue); Beeston domestic building (Purple); Lincoln poultry shed (Red).

The annual NPV values are grouped into equidistant bins of similar yearly requirements. The box, from bottom to top, indicates 25% (Q1), average, and 75% (Q3) percentile values. The white lines in the boxplots denote the median NPV for each bin, which is obtained by Q3 − Q1. The lower and upper whisker risks are defined as the minimum and maximum values. The NPV spreads between the upper and lower quartiles, which is approximately ±25% of the NPV around the median ranges between £500 and £750 for the office building, between £100 and £200 for the domestic building, and between £250 and £550 for the poultry shed inside each bin. Accordingly, the spread of the NPV between the lower and upper quartiles within each bin is bigger in comparison with the NPV variation between two neighbouring bins. In other words, the load shape of the building energy demand should be considered in light of the investment decision.

Additionally, the 25-year predictions of the system cumulative NPV and PBP are illustrated in Figure 13. The NPV and PBP values are £9108.4 and 6.15 years for the office building, £1717.91 and 9.12 years for the domestic building, as well as £7275.86 and 9.41 years for the poultry shed, respectively. This is perceived as a receivable PBP (<10 years) for an engineering project of this nature and demonstrates the clear profit of implementing such a system in the UK context. In this paper, the profitability of grid-connected PV installation is investigated by three different cases located in the East Midlands. The PV electrical energy generation is studied based on the cases of a Beeston domestic house, Derby office building and Lincoln poultry shed with direct electric space heating and power. It is also found that with the Derby office building or Lincoln chicken farm increasing the PV electrical production, the size of the PV system does not significantly decrease the internal rate of the return of the investment, indicating that a bigger unit could be selected without significantly reducing the profitability of the investment, compared with the proposed optimal PV unit. A larger PV system size can also be utilized to cover a possible rising in the power consumption in the future. Additionally, this is also explained by the fact that agricultural buildings and office building are supplied with higher government subsidies for PV fittings. Hence, increasing the tax credit for PV fittings contributes to integrating the system in the UK.

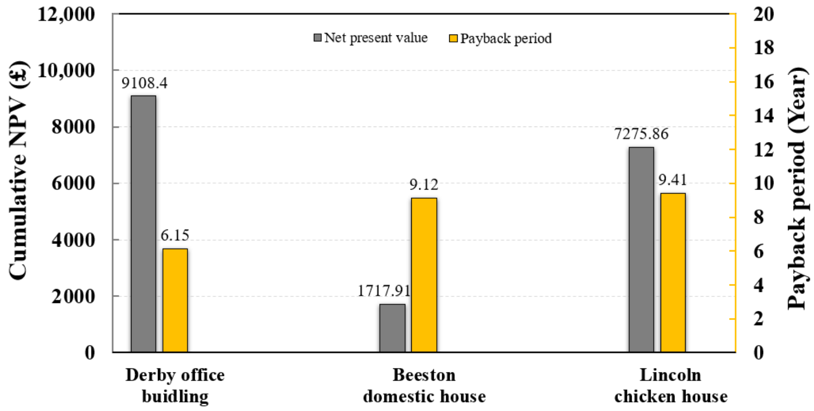
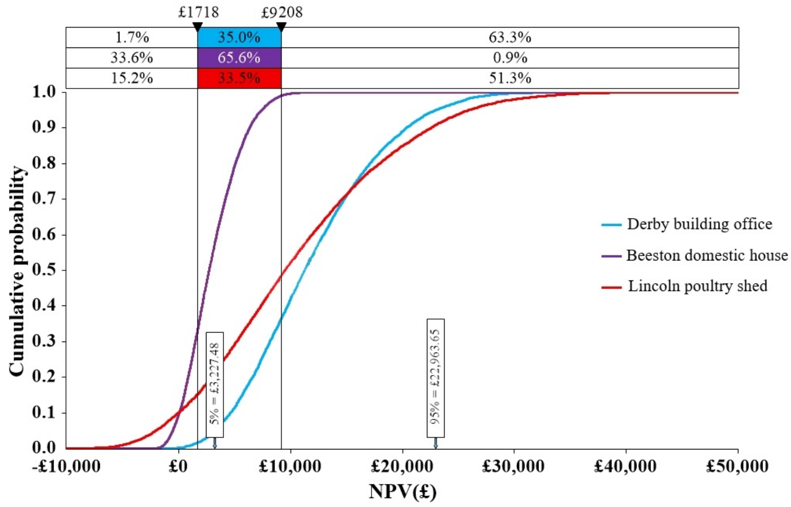
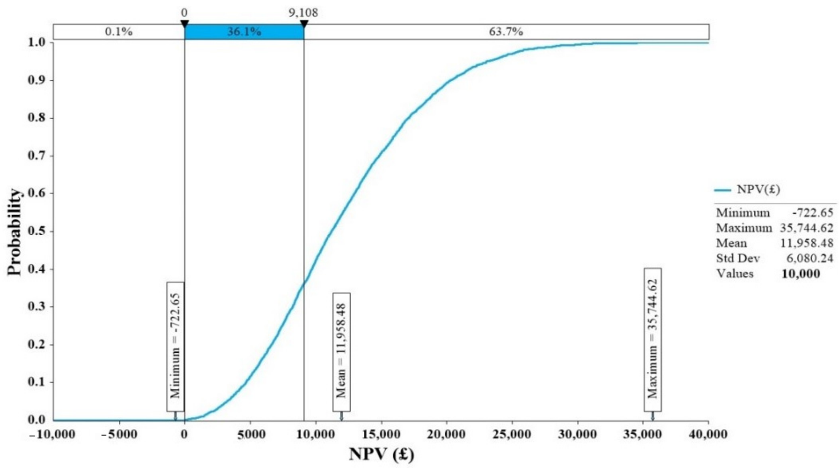


Figure 13. Cumulative NPV and PBP of the three buildings.

5.2.2. Sensitivity Analyses of NPV and PBP

The distribution diagrams of cumulative probability versus NPV and PBP for the three PV systems are exhibited in Figure 14; the incentives (FiT) are taken into account. The standard, maximum, average, and minimum deviations and numbers of iterations concerning the PBP and NPV are provided in the legend. The vertical lines denote the positive NPV and current case value ranging from £0 to £9108 for the office building (blue line), ranging from 0 to £1718 for the domestic building (purple line), and ranging from 0 to £7276 for the poultry shed (red line), respectively. Meanwhile, one row of percentages on the top of the diagram presents the probabilities associated with the NPV. To be more specific, the top row describes the probability concerning the NPV of PV system which is categorized into three regions. In terms of the office building, when the NPV is negative, it only makes up 0.1%; when the NPV is positioned between 0 and the current case value, it accounts for 36.1%; and when the NPV is greater than £9108, it accounts for a proportion of 63.7%. Similarly, in light of the domestic building and poultry shed, when the NPVs are less than 0, these make up 9.8% and 10.1%; when the NPVs are situated between 0 and current case value, these make up 24.0% and 29.9%; and when the NPVs are higher than the present case values, these occupy the proportions of 66.2% and 60.0%, respectively.





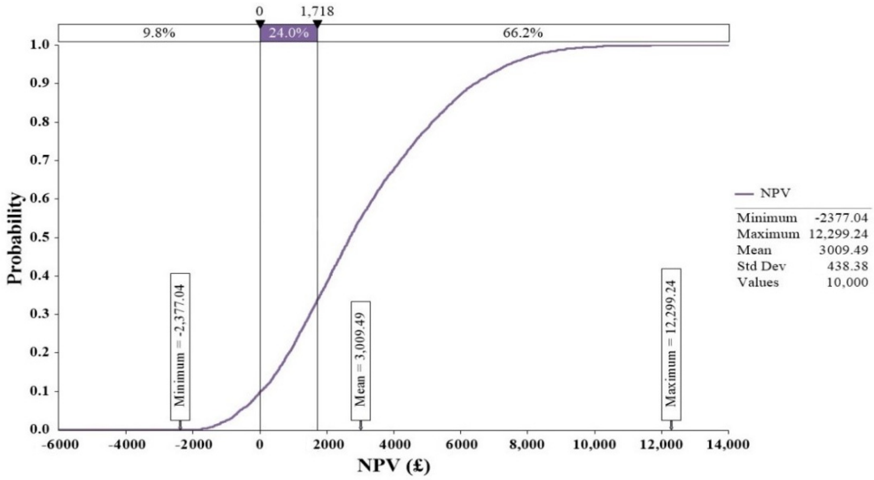


Figure 14. *Cont*.

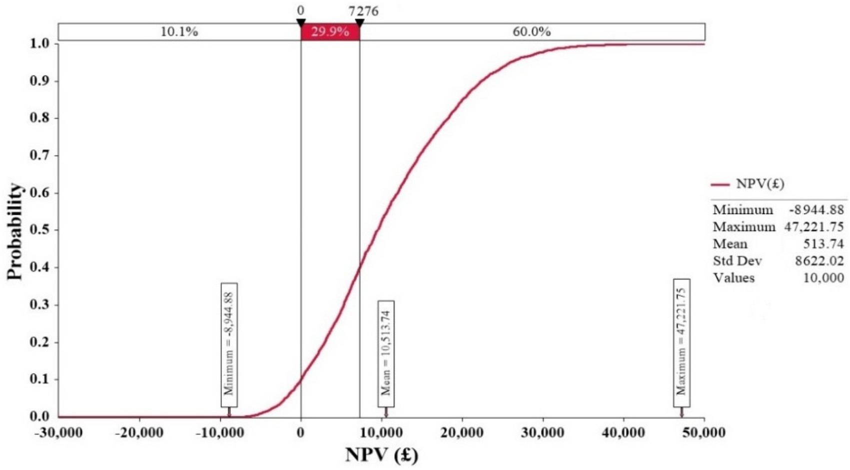


Figure 14. NPV distribution of three PV systems.

By comparison, the vertical lines indicate the minimum and present case values in the PBP for the three PV systems, as illustrated in Figure 15. Based on one row of percentages on the top of the graph, there are probabilities of 67.6%, 68.0%, and 59.3% that the system PBPs are between 2.70 and 6.16 years, between 4.10 and 9.13 years, as well as between 4.25 and 9.42 years; 32.4%, 31.9% and 4.7% of the PBPs are more than present case values (6.16, 9.13 and 9.42 years), while 0% of the PBP is less than 2.70, 4.10, and 4.25 years, respectively.

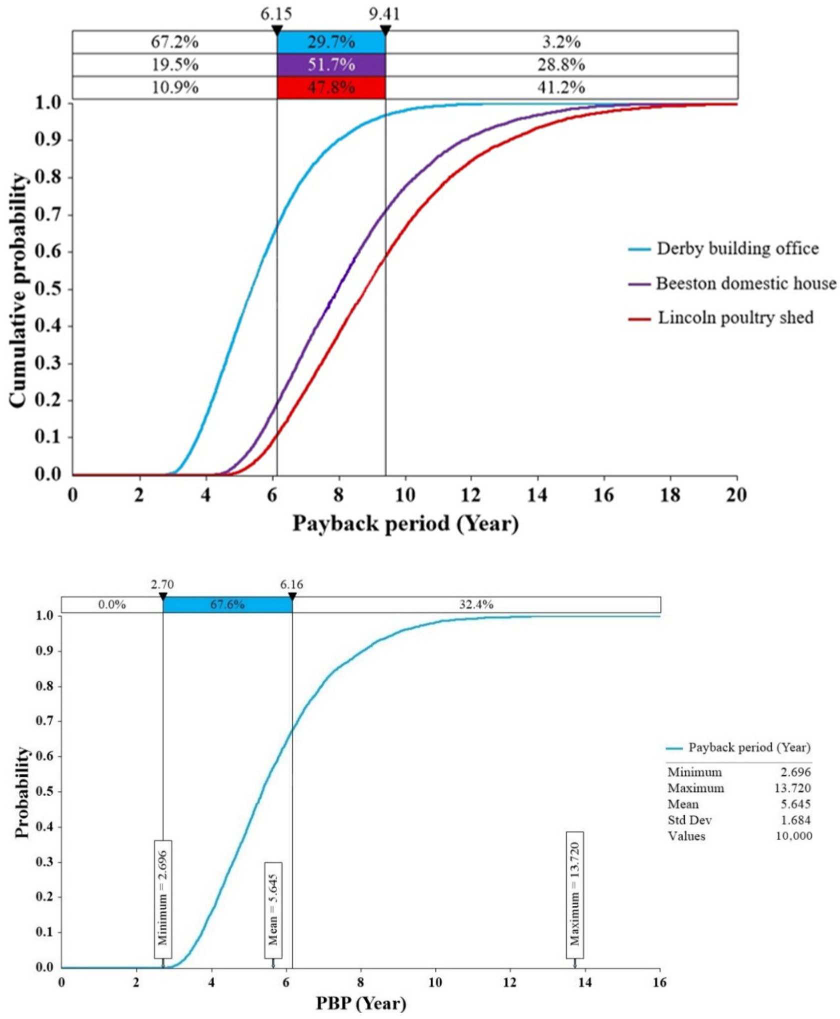


Figure 15. *Cont*.

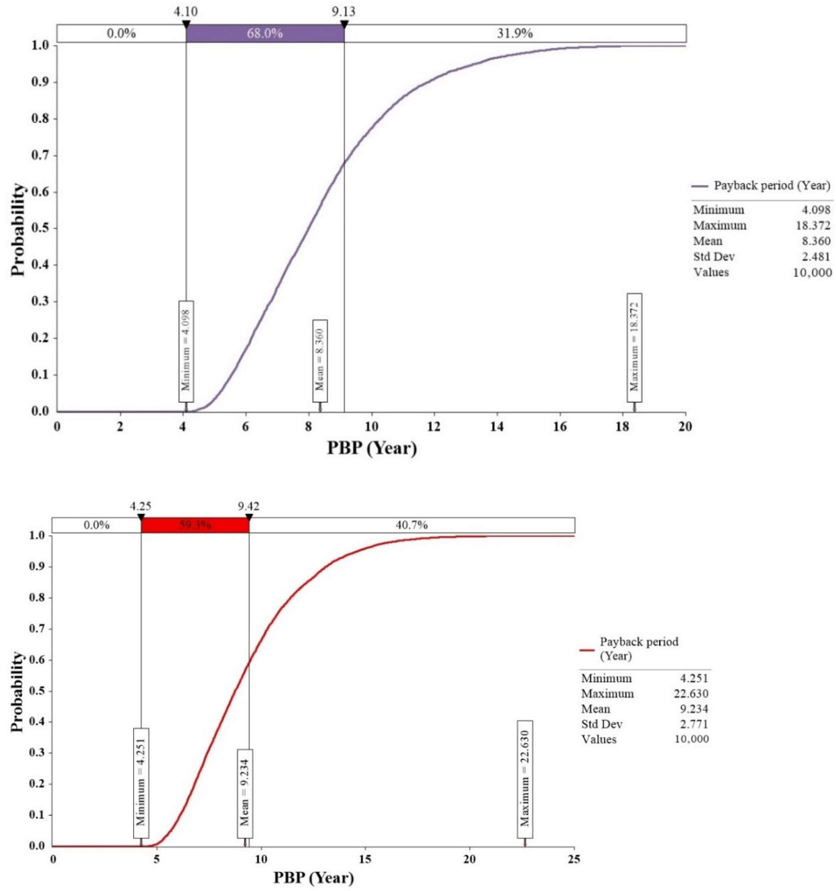


Figure 15. PBP distribution of three PV systems.

Figure 16a provides a scope of the NPV value and exhibits the uncertainty distributions for PV technology applied in the three buildings. A lower peak and wider curve mean a broader scope of possible outcomes and a greater uncertainty related to initial capital investment in the PV technology. Specifically, the domestic building has a comparatively narrow distribution; this indicates that the PV system in the domestic building is extremely less expensive than other two systems, with less variability in the NPV. By contrast, the NPVs of the office building and poultry shed are considerably higher on average and more uncertain, but they have long "tails" on the right side, primarily because of a higher uncertainty of possible initial investments. Additionally, it can be observed that the system in the poultry shed has the widest distribution, indicating it has the highest uncertainty in comparison with the other two scenarios. In light of the PBP, the systems in the domestic building and poultry shed have comparatively wide distributions, implying that they have longer PBP, more variability and uncertainty compared with those in the office building, as shown in Figure 16b.

In terms of the office building, approximately 42.4% of the probability of the NPV value is lower than the mean value of £11,958 when the PBP is over the average value 5.64 years, as explained in Figure 17a. Meanwhile, it can be seen that only 0.8% of the likelihood of the NPV is higher than the mean value, implying that the long PBP exhibits an adverse effect on the entire NPV. If the PBP can be realized before 5.64 years, there is a chance of 44.6% that the NPV value is higher, while there is a chance of 12.3% for a lower value in comparison with the average value (£11,958). Similarly, as for the domestic building and poultry shed, it is demonstrated from Figure 17b,c that the NPVs have the same probability of 43.2% when the PBPs are in excess of 8.36 and 9.23 years, respectively. When the NPV is lower than the mean value, there are merely 11.1% and 11.4% likelihoods that the PBPs can be below 8.36 and 9.23 years. In the case that the PBPs are more than 8.36 and 9.23 years, there are only 0.3% and 0.4% possibilities of the NPV compared with the mean values, respectively. This means that the high NPV value (the lower right side of the figure) could be accomplished when the PBP is shortened. This demonstrates that a short PBP and a high NPV (the upper left side of the figure) are favoured, despite the fact that more efforts are needed to be carried out for increasing the probability in this quadrant.

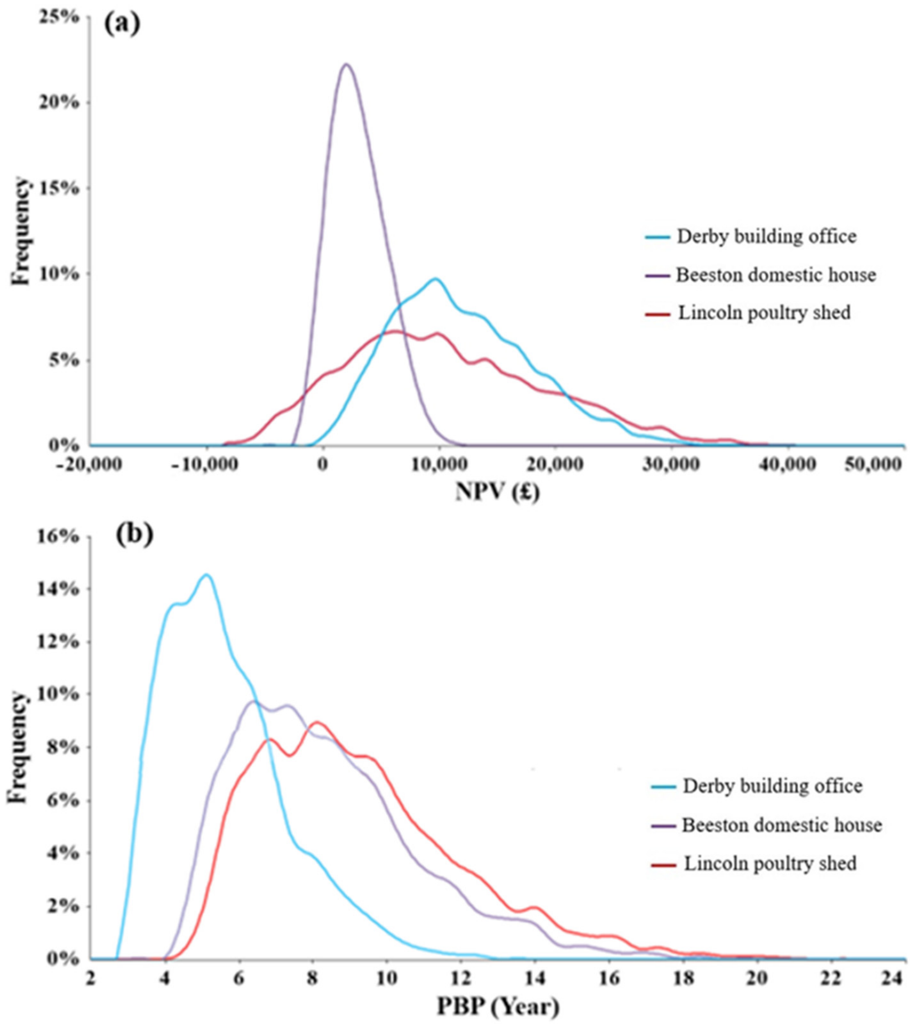


Figure 16. Results comparison of NPV and PBP distributions for three buildings: (**a**) NPV; (**b**) PBP.

Figure 18 illustrates the spider graphs of the NPV against input variables. The income from the electricity price is the most influencing factor on the NPV output because it overlays the largest vertical range, while the PV energy production is the second influencing factor on the NPV output; the NPV increases with both of them. By comparison, the discount rate and capital investment are of vital importance because the higher they become, the lower the NPV becomes. High discount rate and capital investment are warranted because of the prevailing fragile macroeconomic environment and business condition, which would undoubtedly engender an unprofitable platform for the PV technology. Therefore, the discount rate and capital investment are the main factors for the perception of risk. Nevertheless, the income tax rate has slightly less influence on the NPV output, which sustains a stability trend in all cases. Similarly, Figure 19 descripts the spider graphs of the PBP with input variables, which are interpreted by the slope of the lines. The steeper the slope, the more influence an input variable on the output. Thus, the most influential variables are initial investment, electricity price, and electrical energy production.

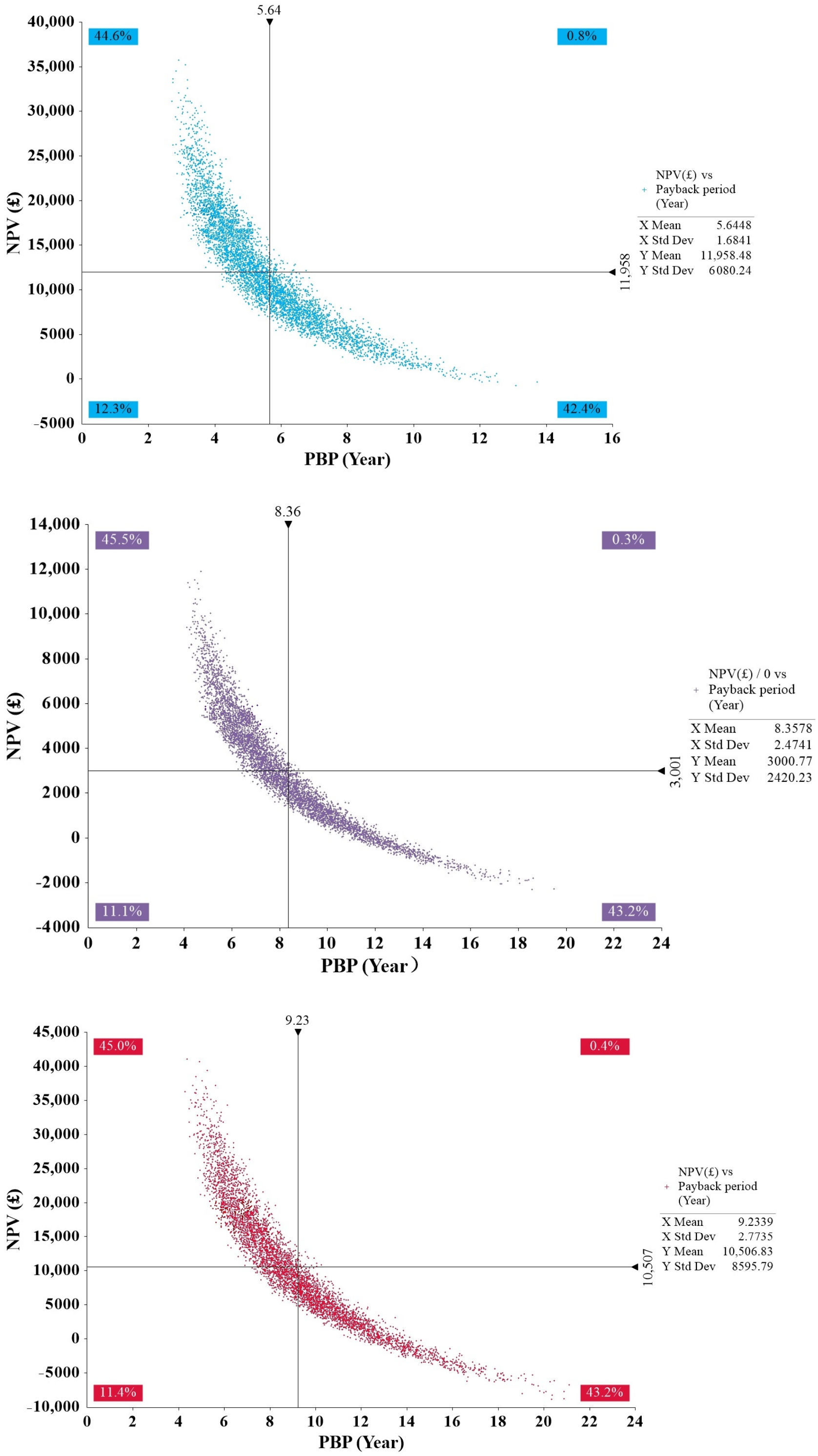


Figure 17. The comparative distribution of probability between NPV and PBP for three PV systems: Derby office building (Blue); Beeston domestic building (Purple); Lincoln poultry shed (Red).

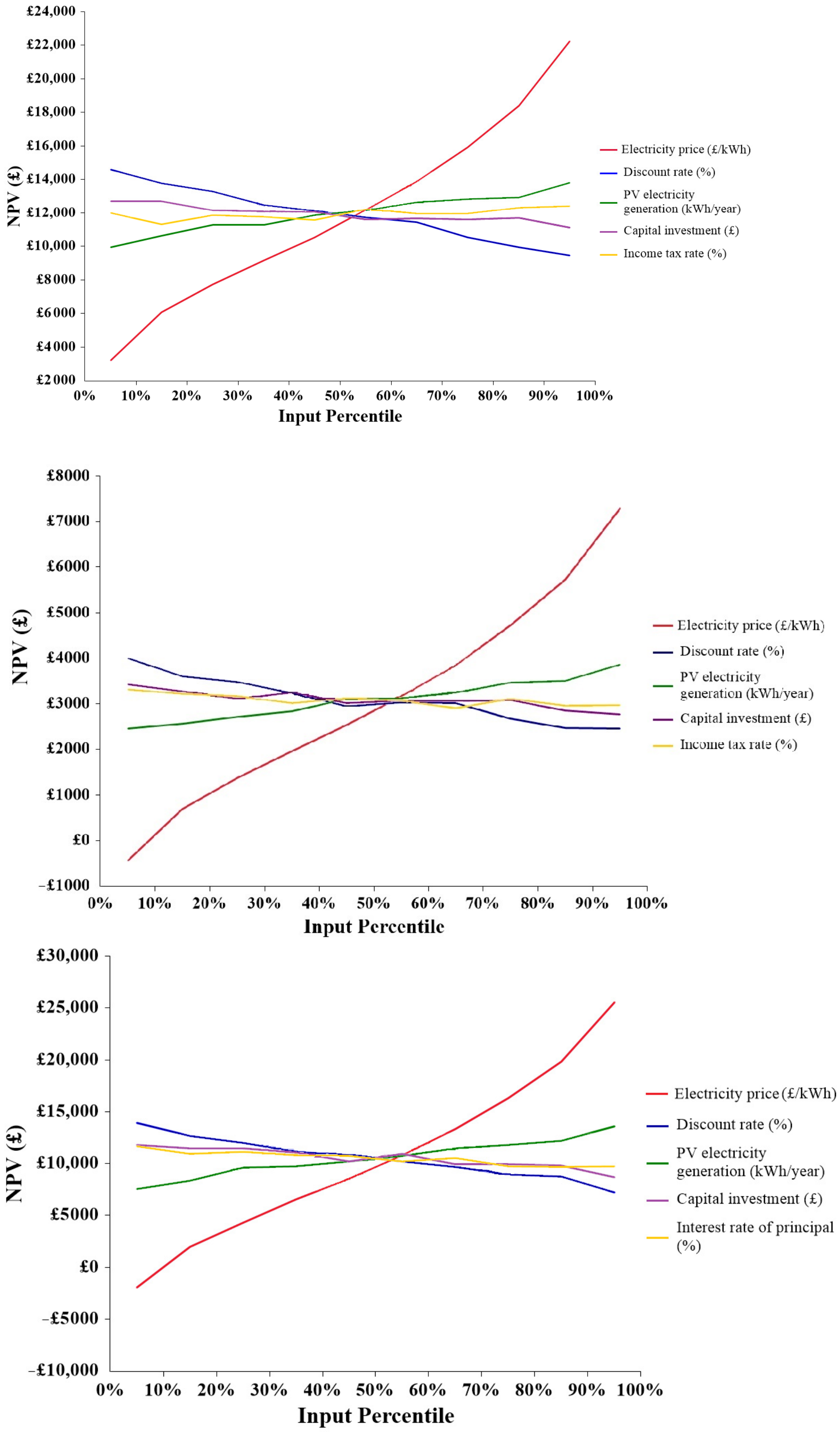


Figure 18. Spider graphs of NPV discrepancy with the uncertain input variables.

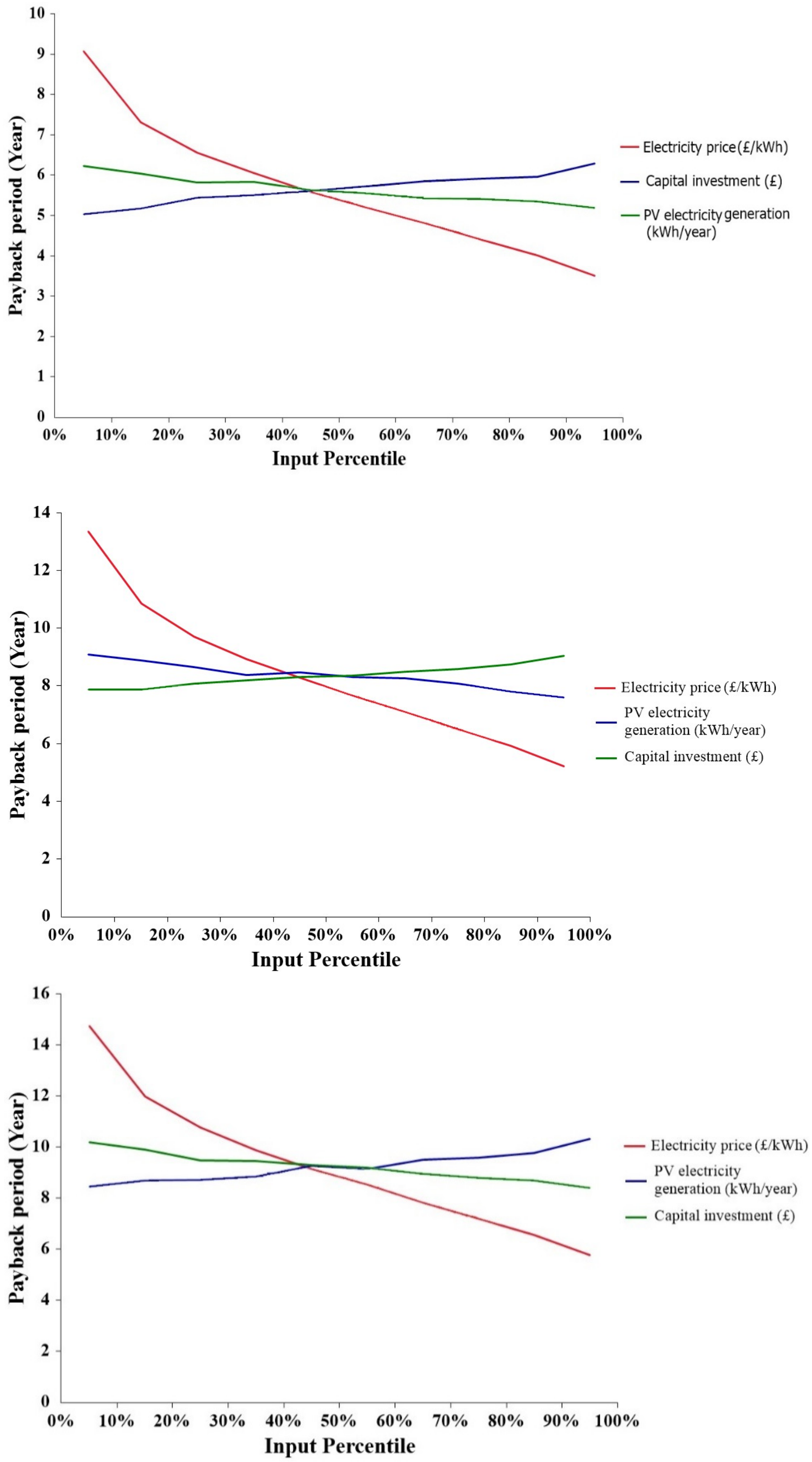


Figure 19. Spider graphs of PBP discrepancy with the uncertain input variables.

5.3. Profitable Analyses of FiT and SEG Schemes

The FiT scheme in the UK for small-scale renewables was officially closed on 31 March 2019. In order to achieve net-zero carbon emissions by 2050 in the UK, numerous energy suppliers have been enforced to disburse domestic, industrial, and commercial buildings for renewable electrical production since 1 January 2020. This is underneath the SEG scheme, which is set up to substitute the FiT scheme. The FiT scheme is defrayed by the UK government, which has a generation tariff (for the entire amount of renewable power as produced) as well as a further export tariff (for the renewable power as fed to the grid). In contrast, the SEG scheme is paid out by suppliers and has just one payment, substituting dated export tariff as well as rewarding consumers for the renewable power they send back to the grid [42]. Meanwhile, the energy suppliers could pay for electricity exported to the grid via a smart meter. As shown in Figure 20, the best SEG rate of 5.57 p/kWh is offered by the Bulb company, while the E. On Energy and Octopus Energy companies provide an extremely reasonable rate of 5.5 p/kWh. However, the British gas and EDF Energy can only pay 3 p/kWh and 1.5 p/kWh, respectively [43]. A price somewhere between 5 p and 6 p per kWh is recommended by the Solar Trade Association, which would be reasonable and fair. Therefore, in this study, two tariffs are considered: one is the fixed tariff for a reasonable market price of 5.5 p/kWh, and another one is the flexible price ranging from 10 to 15 p/kWh at peak phase and 4 to 9 p/kWh at off-peak phase [43,44]. This denotes that the varying price permits consumers to take into account the highly variable cosmically cost of electrical energy as well as export at the most precious time.

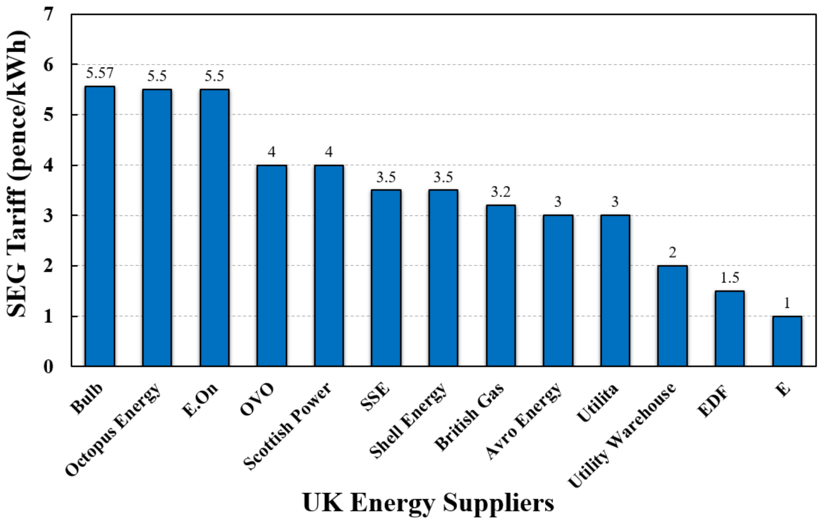


Figure 20. SEG tariffs from UK energy suppliers in 2021 [42].

Figure 21a exhibits that the yearly savings on the basis of the FiT and SEG schemes with flexible and fixed export tariffs, are £513.69, £346.37, and £215.66 for the poultry shed, £300.88, £146.43, and £84.16 for the domestic building as well as £389.15, £177.21, and £100.33 for the office building, respectively. The saving of the FiT scheme is almost four and two times more than those of the SEG with flexible and fixed export tariffs. Similarly, it can be found from Figure 21b that the PBPs depended on the FiT scheme are 9.41 years for the poultry shed, 9.34 years for the domestic building, and 6.15 years for the office building, which are individually far less compared with the SEG scheme with the fixed export tariff of 27.16 years, 26.93 years, and 22.13 years as well as the SEG with the flexible export tariff of 47.18 years, 46.85 years, and 41.92 years, respectively. Although the SEG scheme does not completely offset the loss from the FiT scheme, it makes great progress in the correct direction. Consumers with PV array will no longer feel like their idle power is being "wasted"; in the meantime, the SEG rates should be progressively boosted when the energy companies compete with each other.

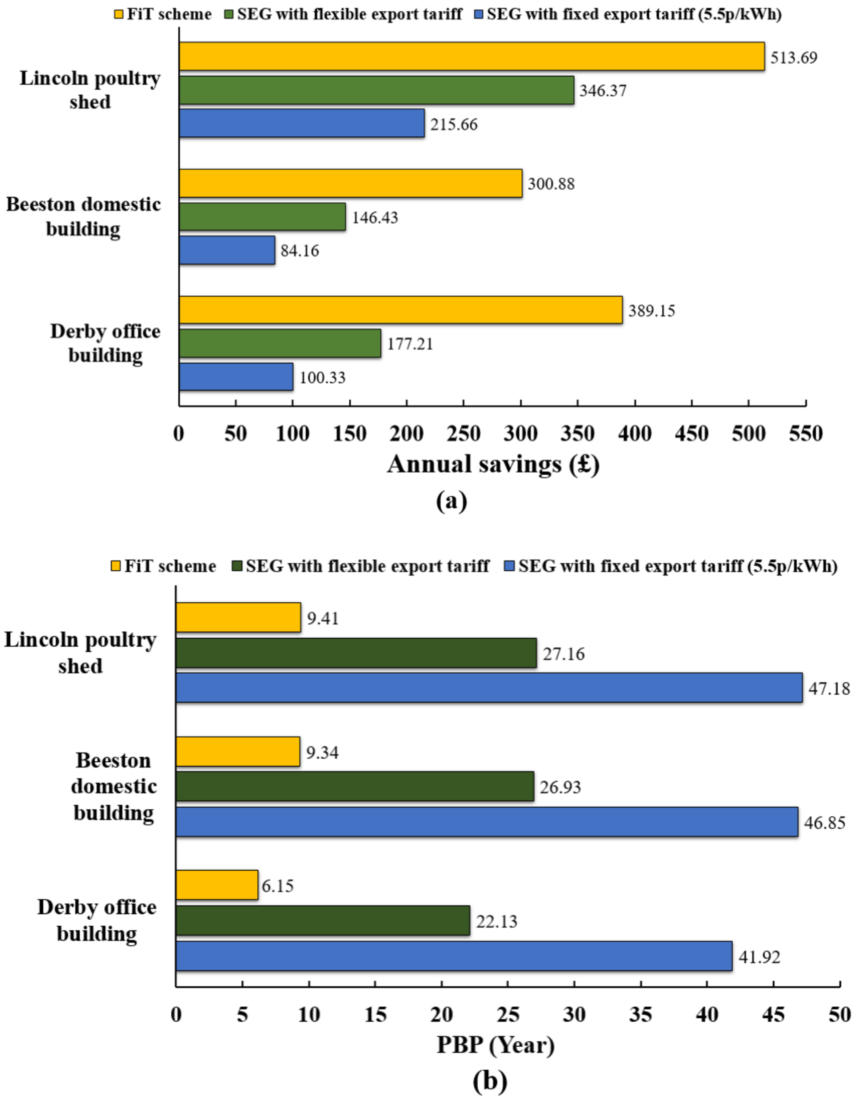


Figure 21. Comparison between SEG and FiT schemes: (**a**) annual savings; (**b**) PBP.

6. Conclusions

In this study, energy and stochastic economic rentability of the PV unit application are investigated through three example cases (including an office building, a domestic building, and a poultry shed) located in the East Midlands, UK. The energy model of the PV unit is developed to assess its monthly electricity generation, module efficiency, and surface temperature variation by the EES 8.4 software; meanwhile, the economic model is established to explore the NPV and PBP for three different systems based on the Monte Carlo method and resolved by @RISK software. A 25-year economic analysis is conducted in view of the UK discount rate, inverter replacement cost, maintenance cost, cumulative savings, and NPV. Meanwhile, as the sensitivity evaluations of the PBP and NPV are executed, the comparisons of annual savings and PBP with the FiT and SEG schemes are performed as well. Therefore, some vital outcomes can be summarized as follows:

- The highest and lowest electricity production periods of PV systems occur in June and December, reaching 1241.79 kWh and 332.12 kWh for the office building, 494.45 kWh and 151.33 kWh for the domestic building, as well as 1890.32 kWh and 484.94 kWh for the poultry shed, respectively.
- The annual electricity generation is less than the annual electricity consumption for the three cases. However, in summer, the PV systems could produce sufficient electricity from 10:00 to 16:00 to meet the building demands.

- The maximum average surface temperatures of the PV systems are in the range of 30.1 °C to 32.01 °C in June, and the corresponding electric efficiencies are in the range of 15.17% to 15.48%. By comparison, the minimum average surface temperatures are in the range of 8.87 °C to 10.18 °C in December, associated with electric efficiencies varying from 10.11% to 10.89%.
- Based on the 25-year lifetime, the NPVs of the office building, domestic building, and poultry shed are £9108.4, £1717.91, and £7275.86, with the corresponding PBPs of 6.15 years, 9.12 years, and 9.41 years, respectively.
- The economic sensitive evaluation indicates that the capital investment and discount rate have significant effects on the NPV and PBP; however, the income tax rate has less influence on the NPV and PBP.
- Yearly savings on the basis of the FiT and SEG schemes with flexible and fixed export tariffs are £513.69, £346.37, and £215.66 for the poultry shed, £300.88, £146.43, and £84.16 for the domestic building, as well as £389.15, £177.21, and £100.33 for the office building, respectively.
- The PBPs on the basis of the FiT scheme are 9.41 years for the poultry shed, 9.34 years for the domestic building, and 6.15 years for the office building, which are far less than those under the SEG scheme with a fixed export tariff for 27.16 years, 26.93 years, and 22.13 years as well as the SEG scheme with flexible export tariff for 47.18 years, 46.85 years, and 41.92 years, respectively. The FiT scheme has the shortest payback period compared with the SEG scheme.

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Abbreviations

Nomenclature

B_t	Beam direct irradiance on a tilted surface (W/m^2)
b_0	Incidence angle modifier coefficient
D_t	Diffuse irradiance on a tilted surface diffuse horizontal irradiance (W/m^2)
I_D	Diode reverse saturation current
I_p	Photocurrent
N	Number of PV module
P_{AC}	Electrical energy output of the inverter
V_{th}	Thermal equivalent voltage (V)
R_t	Reflected on a tilted surface (W/m^2)
R_{sh}	Shunt resistance (Ω)
R_s	Series resistance (Ω)
U_{PV}	Heat transfer coefficient
Ta	Air temperature (°C)
c	Thermal capacity (J/kg·K)
k	Boltzmann's constant (1.381 × 10^{-23} J/K)
q	Electron charge (1.602 × 10^{-19} coulomb)
T	Temperature (°C)

Greek Letters

β	Slope/tilt/inclination angle of the PV module
Θ_z	Solar zenith angle
Θ	Incidence angle of the radiation
α_c	Absorptance coefficient
η_{STC}	Efficiency (%)
$\mu_{P,mp}$	Temperature coefficient of the module's maximum power
τ	Transmittance of the glass cover (%).
Abbreviations	
AMR	Automatic meter reading
ET	Export tariff
FiT	Feed-in tariff
IAM	Incidence angle modifier
LCC	Life-cycle cost
LCOE	Levelized cost of electricity
NPV	Net present value
OWC	Oscillating water column
PBP	Payback period
PV	Photovoltaic
ROR	Rate of return
SEG	Smart Export Guarantee
STC	Standard test condition
WGBC	World Green Building Council

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