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Determination of payback periods for photovoltaic systems in domestic properties

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Abstract:

The paper reports on the two year performance of photovoltaic (PV) systems which were installed on 23 new build properties in South Yorkshire, UK, and the impact of the feed-in-tariff on payback periods. The majority of the properties (17 No.) were fitted with a 3.02 kiloWatt peak (kWp) photovoltaic system, designed to supply, on average, up to 2400 kiloWatt hours (kWh) of solar energy per annum whereas the remaining six systems were 3.75 kWp systems providing, on average, up to 3000 kWh per annum. The photovoltaic panels were integrated into the roofs at the time of construction. Datum readings were taken during commissioning in Summer 2007 with subsequent readings taken as close as possible to the second anniversary in 2009.

A discounted cashflow model was developed which determined payback periods based on actual and assumed performance and different economic scenarios. A comparison is made between the Renewable Obligation Certificate (ROC) and the Feed-in-Tariff (FiT) schemes in determining payback periods. Huge variations in payback periods are shown, for example, a poorly performing 3.02 kWp photovoltaic system irrespective of quantity of electricity used in the home will take in excess of 100 years to payback under the ROC scheme. The same system under the FiT scheme with 25% electricity exported to the grid would have a payback period of 66 years. However, if the same system performed to its designed specification, the payback period would decrease to 16 years. This highlights the need of ensuring the photovoltaic systems are working to their full potential and that householders are fully aware of how to get the best from their systems.

Keywords:
energy generation, feed-in-tariff, payback period, photovoltaics, renewable obligation certificate

1 Introduction

Approximately 27 percent of energy used in the UK is due to the housing sector (Department of Trade and Industry, 2006). Renewable energy technologies, such as solar photovoltaics (PV), offer an opportunity to reduce carbon dioxide (CO_2) emissions from homes and contribute to the Government's target of generating 15 percent of the UK's energy supplies from renewable sources by 2020 (DECC, 2009).

However, an area of concern is the time taken for these technologies to pay for themselves. This paper investigates the payback period for PVs in domestic housing and focuses on an Eco-Homes development in South Yorkshire, UK. The development of 23 three-bedroom affordable homes with state of the art renewable energy technologies was completed in September 2007. All homes are fitted with solar PV and solar hot water systems. The performance of the PV systems will be presented in this paper only. Electricity generated from the PV systems is immediately used by the residents ahead of grid electricity. Surplus electricity is exported back to the grid. Residents have the opportunity of selling the surplus energy to their supplier in the form of Renewables Obligation Certificates (ROCs) as this was the scheme in place at the time of installation. This has since been replaced by the feed-in-tariff and the paper will compare the payback periods for both schemes.

2 Research Significance

The 2006 review into the sustainability of existing buildings (Department for Communities and Local Government, 2006) found that 152 million tonnes of carbon (MtC) were produced by the UK in 2004. In total, 27% of this figure was attributable to the domestic building stock, or 41.7 MtC. Domestic emissions will have to fall by 24.7 MtC to 17 MtC by 2050 if the domestic sector is to reduce in line with overall carbon emissions targets. In addition, The Stern Review (Stern, 2006) predicted that, due to climate change, there will be less cold related deaths in the winter but more heat related deaths in the summer. As a result, gas consumption will decrease in the winter but due to an increased use of air conditioning in the summer months for cooling, electricity consumption will increase (Department for Communities and Local Government, 2006). Regardless, the onus remains on the use of renewable energy technologies to reduce domestic building stock emissions and the results presented in this paper will help determine PV has the potential to generate renewable energy at an affordable price.

3 Research Methodology

Three different design of properties exist in the development. A total of 8 properties were fitted with a 3.02 kWp photovoltaic system (fifty eight PV tiles) on a roof pitch of 40°. Nine other properties had a similar photovoltaic design except the roof pitch was 27°. Finally, six properties were supplied with a 3.75 kWp photovoltaic system (seventy two photovoltaic tiles) on a 27° pitch.

The energy generated from the photovoltaic panels was manually monitored using the household kWh electricity meter. Electricity meter datum readings were taken upon commissioning the systems in August or September 2007. Final readings taken as close as possible to the second anniversary of the commissioning two years later.

4 Findings and Discussion

4.1 Solar PV performance

Table 1 gives details of the solar PV systems and energy generated over the two year monitoring period. The property identification is given in col. 1. The solar energy generated is given in col. 2, Table 1. Two roof pitches were used in the design of the properties (27° and 40°) and these are shown in col. 3. Col. 4 shows if the roofs were subjected to shading. The monitoring duration for each property is given in col. 5 and varies slightly due to the inability to gain access to some properties for the second anniversary readings. Comments on the performance of the systems are given in col.6.

Referring to Table 1, col. 2, the best performing PV system generated 5717 kWh during the monitoring period whereas the worst system generated only 1512 kWh. In addition, five of the 3.75 kWp systems (I, Q, K, R, L) performed reasonably well in relation to the other properties and occupy five of the top eight positions in Table 1. However, system U is also a 3.75 kWp array and performs less well, but others reasons are responsible for its

Table 1: PV monitoring data for case study 2

1	2	3	4	5	6
ID	Solar Energy (kWh)	Roof Pitch (°)	Shad-ing	Time (yrs)	Comments
I*	5717	27	no	2.04	
Q*	5367	27	no	2.03	
F	4927	40	no	2.08	
K*	4852	27	no	2.04	
A	4649	40	no	2.15	
R*	4318	27	no	2.03	
T	4275	27	some	2.03	
L*	3718	27	no	2.04	
O	3228	27	some	2.04	
H	3206	40	no	2.02	Vandalism to power supply, Mar-Jul 09
P	3191	27	some	2.04	
C	3177	40	no	2.03	Encountered grid supply turned off, 15/7/09
D	3163	40	no	2.04	
G	2541	40	no	2.03	
N	2535	27	some	2.04	
E	2436	40	no	2.03	
J	2427	27	some	2.04	
S	2244	27	some	2.03	
W	1827	27	some	2.03	
U*	1815	27	no	2.07	Encountered PV switched off, 15/7/09
V	1785	27	some	2.03	Encountered PV switched off, 8/4/09
B	1515	40	no	2.04	Not operational Jan-Aug 09, switched off
M	1512	27	some	2.04	Inverter not operational, Jul-Aug 09

* indicates 3.75 kWp, otherwise 3.02 kWp

poor performance as described below. The 3.75 kWp arrays were designed to provide, on average, 3000 kWh of energy per annum (6000 kWh over two years) but none of 3.75 kWp systems met this specification.

The 40° roof pitches are all fitted with 3.02 kWp systems and are shade free. However, their performance varies considerably, property F having the third best performing system and was the only array to exceed the design specification (4927 kWh over two years as opposed to the design specification of 4800 kWh). However, six of the nine properties which were categorized by the designer as being shade affected exhibited a performance at the lower end of the table, occupying six of the lowest nine positions in Table 1. These properties also exhibit a 27° roof pitch. Shade affected properties T, O and P performed better (also 27° roof pitch). Properties H, C, U, V and B all suffered operational problems within the final quarter of monitoring (Table 1, col.6) and unsurprisingly, occupy the last four positions in Table 1. For example, the PV arrays in properties U, V and B were inexplicably switched off for an unknown length of time within the final seven months of monitoring, with the residents not knowing why this had happened. This highlights the need for proper training or coaching for residents to help them gain maximum benefit from living in a home fitted with renewable energy technologies. The external power supply to unoccupied property C was switched off for a period of time. This was also the case for unoccupied property H, due to vandalism of the mains power supply. Property M did not exhibit an increase in meter readings in the final month of monitoring. These operational issues had a bearing on the output from the PV arrays and obviously influenced their performance.

Irrespective of the reasons for the varied performances, the focus of the paper will be on the payback period for two of the PV systems described here. It will enable private investors, scheme funders or housing associations to make more informed decisions on whether or not to install PV as part of their development strategy and takes into account a number of different performance scenarios as presented in the following section.

4.2 Solar PV payback analysis

Renewable Obligation Certificate

Solar PV performance data for two of the above properties (N and L) were used to undertake a payback analysis. These two properties were selected on the basis that they were neither the best or worst performing systems. The purpose of the payback analysis was to:

- determine how long it would take for the PV systems to pay for themselves under different economic conditions;

- compare the payback periods based on assumed and actual performance data, so as to determine the financial cost of system under-performance.

The first stage of the payback analysis involved constructing a discounted cashflow model using specified annual PV performance data, that is to say the electricity that would be generated by the solar PV systems if they were operating to their design specifications. For the 3.02kWp system (property N), the specified annual output was 2,416kWh and for the 3.75kWp system (property L) it was 3,000kWh. The main assumptions included in the model were as follows:

- avoided electricity cost: 14p/kWh
- export electricity tariff: 14p/kWh

- degradation rate of PV: 0.5%/yr
- interest/discount rate pa: 5%
- Increase in electricity prices pa: 5%
- export tariff income increase pa: 0%
- inverter replacement every 10 yrs: £450

An excerpt from the payback model using assumed data for Property L is shown in Table 2 (covering the first seven years only due to space restriction). The payback model comprises:

- the annual output of 3,000 kWh for PV system in Property L, which was estimated to degrade by 0.5% per year (Table 2, Row A)

- the avoided electricity costs to the residents, that is to say the cost of the electricity that the residents would have drawn from the grid if they were not using electricity from the solar PV system. Given that it is unlikely that residents would use all of the PV generated electricity, three different scenarios were devised in which residents used either 25, 50 or 75 percent of the electricity generated. The cost of electricity was estimated to be 14p/kWh and this was increased annually by an inflation factor of 5 percent. The example in Table 2 assumes 75% was used in the home (Table 2, Row B)

- the export income generated by the solar PV system, based on an assumed export tariff of 14p/kWh and modelled using the three different scenarios described above. The export income was not subject to an annual inflation factor, however, the impact of changes in the export tariff can have on the payback periods of the solar PV systems will be discussed below (Table 2, Row C)

- both the avoided electricity costs and export income were adjusted to account for degradation of the solar PV performance over time (Table 2, Rows D and E)

- maintenance costs are assumed to be 0 (except for replacing the inverter every 10 years, Table 2, Row F)

- the capital cost of buying and installing the solar PV systems (£18,010 for the 3.02kWp system, £21,582 for the 3.75kWp system). Since the PV systems were roof integrated, the avoided capital of a standard roof covering (estimated to be £3,500) was subtracted from the installation cost, to give a final installation cost of £14,510 and £18,082 respectively (Table 2, Rows G and H).

- annual net cashflows were calculated by subtracting the total annual expenditure from the total annual income (Table 2, Row I). The present value of each annual net cashflow was then calculated using Equation 1 (Table 2, Row J), in order to reflect the time value of money.

Equation 1 $PV = \frac{C}{(1+r)^t}$ where:

PV = net present value

r is the discount (or interest) rate

CF = is the net cash flow (annual income – expenditure) at time t

t is the time of the cash flow (i.e. year 1, year 2 etc…)

- the cumulative discounted cashflow (Table 2, Row K) was calculated by adding each successive discounted cashflow over the analysis period (100 years). The capital cost of the solar PV system was then subtracted from the cumulative discounted cashflow in each year of the analysis period, in order to determine the payback on the initial capital investment (Table 2, Row L).

Table 2: Excerpt from the solar PV payback analysis for property L based on specified performance data and 75% used on-site

Output pa		Yr 0	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7
A	PV output (adjusted for degradation at 0.5% pa)	0	3000	2985	2970	2955	2940	2926	2911
Income									
B	Avoided electricity costs (75% used, £)	0	315	331	347	365	383	402	422
C	Export income (at 14p/kWh, £)	0	105	105	105	105	105	105	105
D	Avoided costs (adjusted for degradation, £)	0	315	329	344	359	375	392	410
E	Export income (adjusted for degradation, £)	0	105	104	104	103	103	102	102
Expenditure									
F	Maintenance costs (£)	0	0	0	0	0	0	0	0
G	Installation cost (£)	-21,582	0	0	0	0	0	0	0
H	Installation cost minus avoided cost of standard roof (£)	-18,082	0	0	0	0	0	0	0
Calculations									
I	Net cashflow (£)	-18,082	420	434	448	463	478	494	512
J	Discounted cash flow (£)		400	393	387	381	375	369	364
K	Cumulative discounted cashflow (£)		400	793	1,180	1,561	1,936	2,305	2,669
L	Installation cost + cumulative discounted cashflow (£)	-18,082	-17,682	-17,289	-16,902	-16,521	-16,146	-15,777	-15,413

Net present value at 100 years: £6,762

- the net present value (i.e. the present worth of all the cashflows) at 100 years (Table 2, footnote) was calculated by taking the sum of all the annual discounted cashflows and subtracting the capital cost of the solar PV system.

Figure 1 shows the estimated payback period for the solar PV system in property N, based on the above assumptions and working at its design specification. The cumulative discounted cashflows for the three different scenarios suggest that the solar PV system has a very long payback period, although the time taken to break-even (when the cumulative cashflow becomes positive) on the initial investment varies depending on what proportion of PV generated electricity is used on-site or exported to the grid. For instance, the payback period is 67 years when 75 percent of the PV electricity is used on-site, but in excess of 100 years when only 25 percent of PV electricity is used on-site. However, even if a 5 percent inflation factor is applied to the export tariff, the payback period is still 54 years, which is clearly longer than the design-service life of the PV system. Figure 1 also shows the payback period of the solar PV system in property N based on its actual performance over the two year evaluation period. The annual output of the system (based on its average performance over two years) was 1268kWh, which means that the system was performing at 52 percent of its design performance. The cumulative cashflows for all three electricity consumption scenarios indicate payback periods in excess of 100 years. Even when the export tariff is inflated by 5 percent per year, the payback period under all three scenarios remains in excess of 90 years. This highlights that impact that under-performance can have on the cost-effectiveness of solar PV systems. Indeed, even when the export tariff is inflated by 5 percent per year, every 10 percent decrease in system performance results in a 7.5 year increase in the estimated payback period.

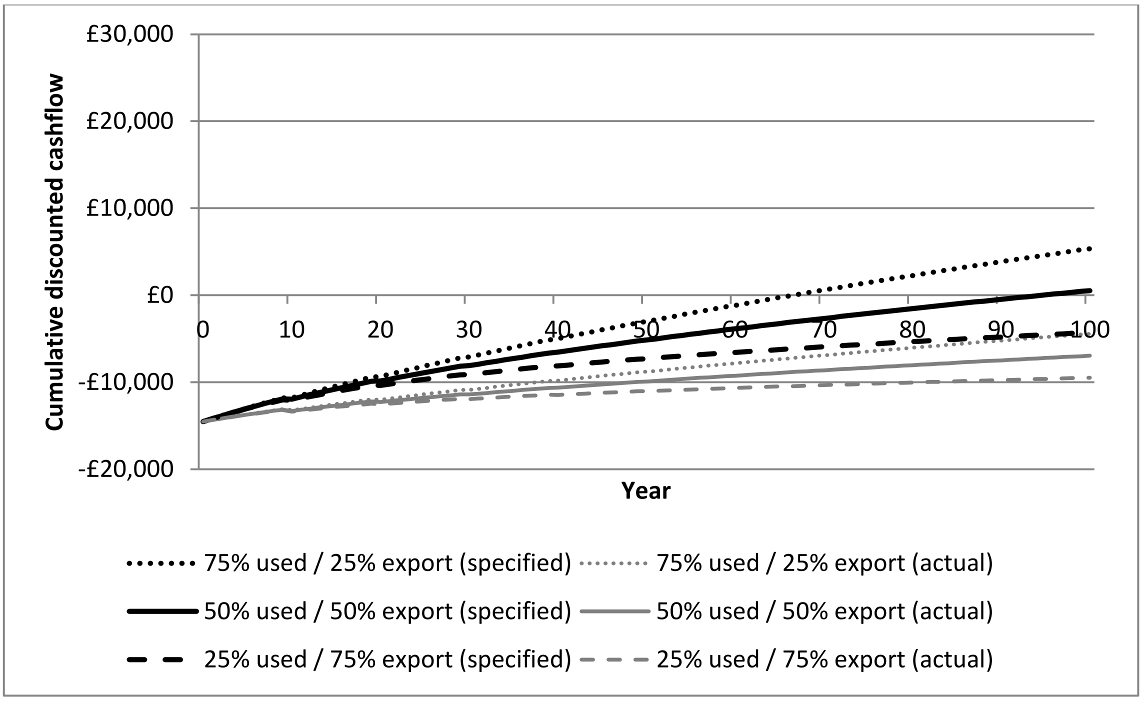

Figure 1: Solar PV payback periods for property N (3.02 kWp) based on specified and actual performance and different electricity consumption scenarios

Figure 2 shows the payback periods based on the specified and actual performance of the solar PV system in property L (a higher output and better performing solar PV system). When the PV system is assumed to be operating at its design specification and 75 percent of PV electricity is consumed on-site, the payback period is 66 years, although this falls to 53 years when the export tariff is inflated by 5 percent per year. However, when the PV systems actual annual output (1859kWh or 62 percent of its design specification) is input into the model and even with a 5 percent inflation factor on the export tariff, the payback period increases to 96 years. Under these conditions, the PV system would generate a net financial saving of £260 in the first year of operation and cumulative net savings of £5,393 (net present value) in the first 25 years of operation ('savings' refer to the net discounted cashflow comprising of income and avoided costs). By contrast, the smaller capacity and poorer performing PV system in property N would generate a net financial saving of £177 in the first year of operation and cumulative savings of £3,535 (net present value) in the first 25 years of operation. However, if the PV system in property N had been operating to its design specification, the financial savings in year one would have been £338 and cumulative savings over 25 years would have amounted to £7,142 (net present value).

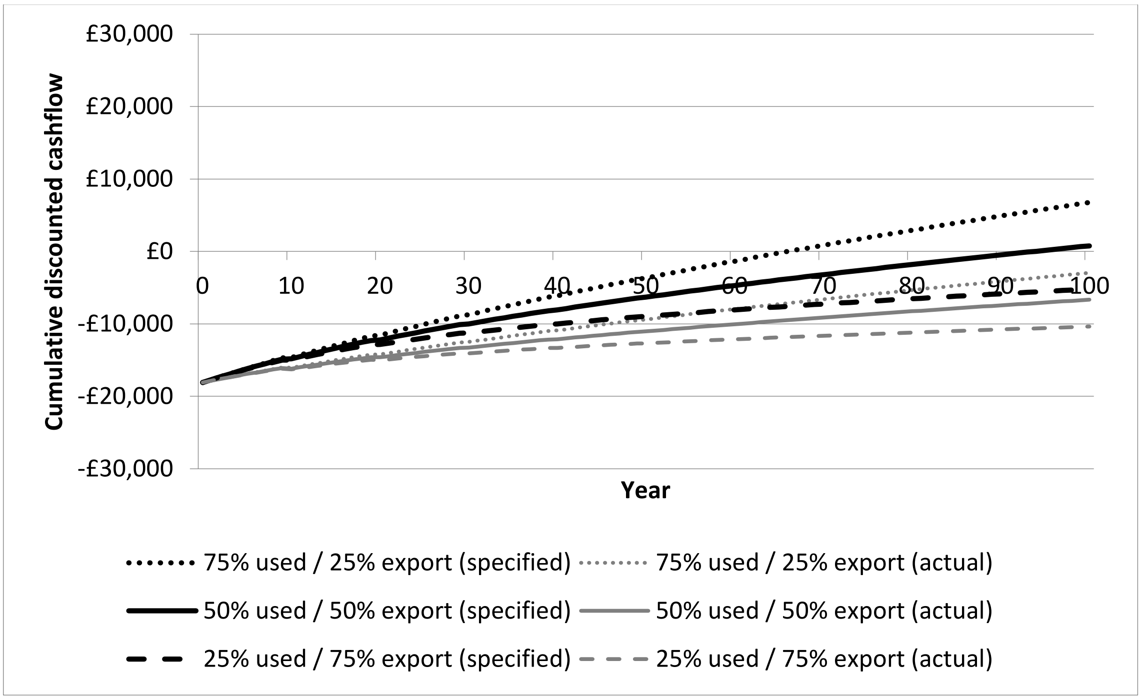

Figure 2: Solar PV payback periods for property L (3.75kWp) based on specified and actual performance and different electricity consumption scenarios

Feed-in-Tariff

The scheme was conceived before the introduction of feed-in-tariffs, hence the payback analysis described above reflects the economic conditions that were present at the time it was designed and constructed. However, a variant of the payback model was developed to investigate the impact feed-in-tariffs would have on the economics of the scheme. The feed-in-tariff, which is based on the electricity generated by the solar PV system (regardless of whether it is used or exported), was set at 37.8p/kWh (Ofgem, 2011) and was subject to a 2 percent annual inflation factor over the 25 year period that the tariff is receivable. The export tariff was set at 3.1p/kWh and was also subject to a 2 percent annual inflation factor. The results of the payback analysis for properties N and L are shown in Figure 3 and Figure 4, respectively. A summary of the different analysis scenarios is provided in Table 3. When using the specified output data, the shortest payback period for properties N and L is 16 years and 14 years, respectively, under a

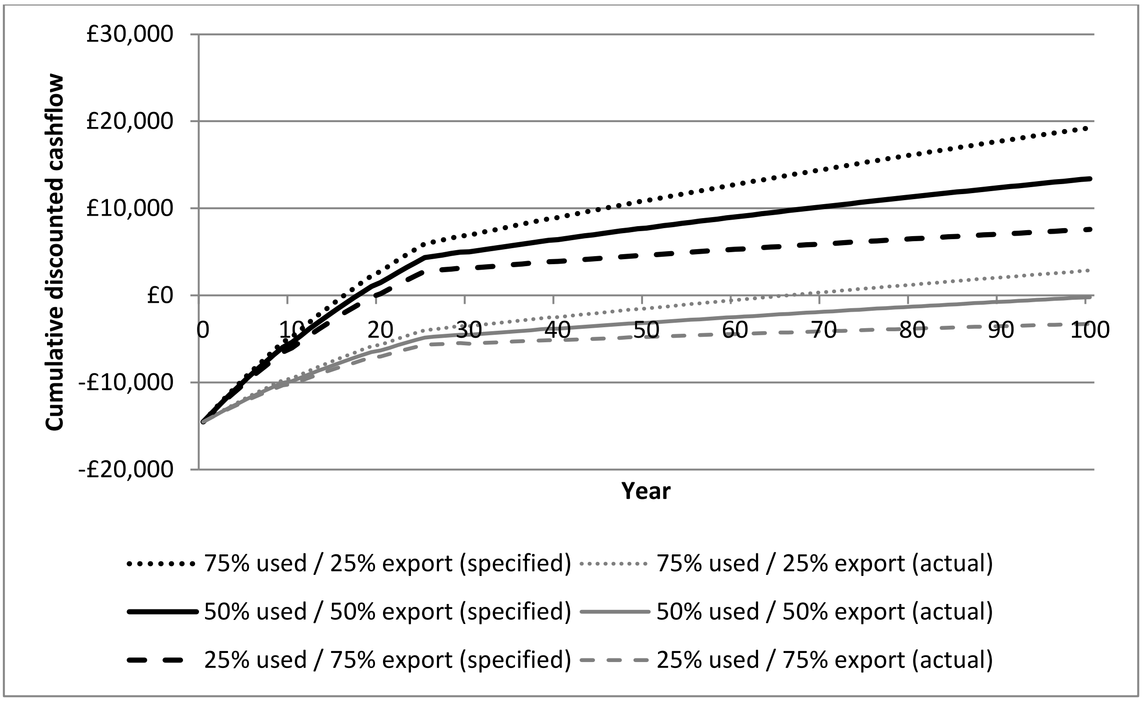

Figure 3: Solar PV payback periods for property N (3.02 kWp) based on specified and actual performance, different electricity consumption scenarios and feed-in-tariffs

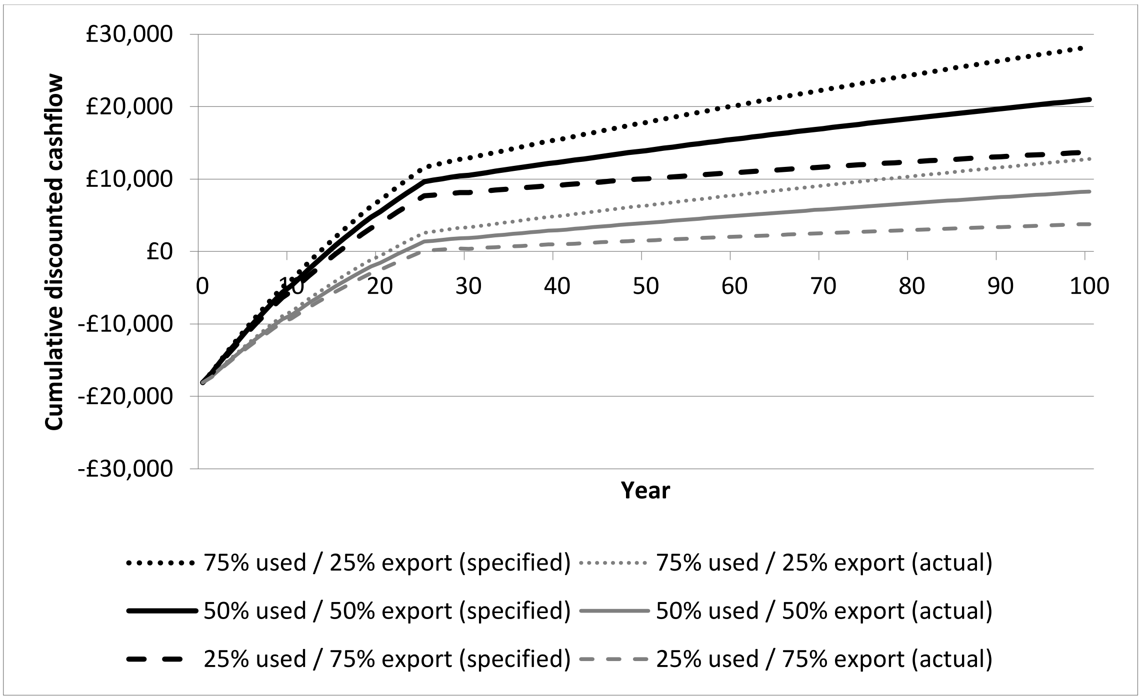

Figure 4: Solar PV payback periods for property L (3.75kWp) based on specified and actual performance, different electricity consumption scenarios and feed-in-tariffs

Table 3: Summary of the Solar PV payback analysis for properties N and L

Assumptions	**Property N (3.02 kWp)**		**Property L (3.75 kWp)**	
	Specified	**Actual**	**Specified**	**Actual**
Renewable Obligation Certificate				
Capital cost of system (£)*	14,510		18,082	
Annual solar PV output (kWh)	2,416	1,268	3,000	1,859
Electricity tariff (5% inflation)	14p/kWh			
Export tariff (0% inflation)	14p/kWh			
PV output degradation	0.5% pa			
Net present value at 25 years:				
25% used/75% exported (£)	-9,648	-12,171	-11,937	-14,444
50% used/50% exported (£)	-8,888	-11,772	-10,993	-13,859
75% used/25% exported (£)	-8,128	-11,374	-10,050	-13,274
Payback period:				
25% used/75% exported (yrs)	>100	>100	>100	>100
50% used/50% exported (yrs)	95	>100	94	>100
75% used/25% exported (yrs)	67	>100	66	>100
Feed-in-tariff:				
Electricity tariff (5% inflation)	14p/kWh			
Export tariff (2% inflation)	3.1p/kWh			
Feed-in tariff (2% inflation)	37.8p/kWh			
Net present value at 25 years:				
25% used/75% exported (£)	2,755	-5,664	7,675	137
50% used/50% exported (£)	4,347	-4,829	9,651	1,361
75% used/25% exported (£)	5,939	-3,994	11,627	2,586
Payback period:				
25% used/75% exported (yrs)	20	>100	16	25
50% used/50% exported (yrs)	18	>100	15	23
75% used/25% exported (yrs)	16	66	14	21

*minus cost of standard roof

scenario where 75 percent of the energy generated by the PV system is used on- site by the residents. The lower the percentage of PV electricity consumed on-site, the longer the payback period. For property N, the net financial savings in the first year of operation (with 75 percent of PV electricity used on-site) amounted to £1,186 and cumulative financial savings over the first 25 years of operation amounted to £20,449 (net present value). For property L, these savings amounted to £1,472 and £29,710, respectively. However, when the actual output data are used in the analysis (under the same consumption scenario), the payback periods for properties N and L increase to 66 and 21 years, respectively. For property N, the financial savings in the first year of operation amount to £622 and over the first 25 years of operation amount to £10,516 (net present value). These figures again underline the impact that under-performing PV systems can have on payback periods.

5 Conclusion and Further Research

The introduction of feed-in tariffs in the UK has clearly transformed the economics of solar PV systems and, in doing so, made them a much more cost-effective measure for generating renewable energy. Based on the evidence presented here, a 3.02kWp solar PV system performing to its design specification would have a payback period of just 16 years, under a scenario where the household is using 75% of the electricity generated on-site. However, without the feed-in tariff, the same system would have an estimated payback period of 67 years. This analysis underlines the importance of ensuring that solar PV systems are functioning properly; even with feed-in tariff income, the payback period for under-performing solar PV systems increases significantly. Further research is required to pinpoint reasons for poor performance, whether they are technical or user issues to ensure payback periods are minimised.

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