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DOES THE STRUCTURE OF THE UK FEED-IN-TARIFF FOR RENEWABLE ELECTRICITY ENCOURAGE PERSONAL CARBON OFFSETTING SCHEMES?

John G. Rogers[1]

[1] *Department of Mechanical Engineering, University of Bath, Bath, UK*

Abstract: Carbon offsetting – the investment in carbon reduction activities to compensate for the carbon emitted by other activities – is a way for people to use carbon fuels without adding to global environmental damage. In 2010, the UK government introduced a feed-in-tariff scheme, which guaranteed small scale generators of electricity from renewable sources at a fixed price for the power they produced that is considerably above the wholesale market price. This was done specifically to encourage consumers to generate their own electricity. Under the scheme, it is unlikely that all the power will be generated by renewable means when it is needed, but it is possible to export surplus electricity to the grid, which can offset the exported electricity when the equipment is not generating. By exporting more electricity than is needed, it is possible to offset the carbon emissions from heating. This paper looks at the potential for using photovoltaic cells (PV) to provide a carbon offsetting scheme. It investigates the impact of the structure of the tariff to see if it encourages installations that are capable of offsetting the carbon used by a range of households.

Keywords: *PV, carbon offsetting, feed-in-tariff*

1 Introduction

This paper looks at the financial viability of domestic PV from the point of view of the owner and the possible net savings in CO_2 emissions that can be achieved. No account is taken of the emissions associated with the production of the equipment. There are economies of scale in PV installations and the feed-in-tariff (FIT) has reduced prices for larger installations so the economics will depend on the size of installation. The paper concentrates on PV as it can be fitted on a much wider range of buildings than other micro generation options. Only the carbon footprint caused by the electricity and heat consumption within the home has been considered. Although this is part of an individual’s carbon footprint, it is still a challenging target to achieve.

[1] Dr J.G. Rogers, J.G.Rogers@bath.ac.uk (corresponding author)

2 Potential CO_2 savings achievable with domestic PV

2.1 Potential PV generation from a domestic roof mounted installation

An estimate of the potential generation from PV installations has been made by Šúri et al. (2007). This estimates an annual generation from an optimally mounted standard PV module, which could achieve a performance ratio of 0.75 in the southern UK between 750 – 950 kWh/kW. The most popular PV module installed under the "Low Carbon Building Programme" was the Sanyo HIP 215 hK HE5 (Bergman & Jardine, 2009). This has an output power density of 168 kW/m^2. This would give an annual generation of 126 – 160 kWh/m^2 depending on location. If it is assumed that a small house has an available south facing roof area of 12 m^2 (4 m length of slope and 3 m building frontage) and a large house an area of 50 m^2 (5m length of slope and 10 m building frontage) then the annual generation achievable on domestic property will be in the range 1500 – 8000 kWh.

2.2 Marginal grid carbon intensity

The marginal grid carbon intensity is the carbon intensity associated with the generation technology that is displaced by the PV generation. The emission calculator published by The Carbon Trust (2010) quotes the CO_2 emissions from grid electricity as 0.544 kgCO_2/kWh. This reflects the mix of fuels for generation in 2009, which included nuclear, wind and other low carbon generation. The marginal plant is likely to be coal or gas fired combined cycle gas turbine (CCGT), which would produce 0.322 kgCO_2/kWh and 0.184 kgCO_2/kWh from coal fired and gas fired plants, respectively (Carbon Trust, 2010). Assuming average plant efficiencies from *The Digest of UK energy statistics* (DUKES) Table 5.10 (DECC, 2010) with an 8% allowance for transmission and distribution losses, the CCGT plants have a gross efficiency of 43%, which would give a carbon intensity of 0.428 kgCO_2/kWh, coal fired plants with a delivered gross efficiency of 33% would have a carbon intensity of 0.976 kgCO_2/kWh. The marginal grid carbon intensity will be between these two values. Table 1 shows the range of CO_2 savings that could be made by displacing grid based electricity with locally generated PV for different marginal grid carbon intensities.

Table1: Possible CO_2 savings in tonne per year from PV installations

generation rate	750 kWh/kW		950 kWh/kW	
roof area m^2	12	50	12	50
generation kWh/y	1 512	6 300	1 915	7 980
CCGT base electricity	0.65	2.70	0.82	3.42
grid electricity	0.82	3.43	1.04	4.34
coal base electricity	1.48	6.15	1.87	7.79
50% coal 50% CCGT	1.06	4.41	1.34	5.59

From the National Grid Company's (NGC) seven-year statement (National Grid Company, 2010), it would appear that on a summer day (when most of the PV generation will occur), the ratio of coal generation to CCGT generation is 66%. However, it would appear that most of the peak load was generated by coal plant, but this reflects the relative cost in 2009. In the absence of any policies to manage the generation mix, it is assumed that the marginal plant mix is 50% coal and 50% gas fired CCGT.

3 Carbon burden of the energy consumed in a typical house

3.1 Electricity Consumption

The DUKES (DECC, 2010) defines three classes of electricity consumers: small 1000 – 2499 kWh a year, medium 2500 – 4999 kWh a year, and large 5000 – 15000 kWh a year. The "large" consumer group includes users of electric storage heaters. As heating will be considered separately when calculating the CO_2 burden this group will not be considered in this paper.

3.2 Heat consumption

In 2006, 91% of UK homes had central heating with 87% of them burning gas. The average boiler thermal efficiency was 74% (Utley and Shorrock, 2008). The amount of gas used varies with house size. Gare's (2011) website includes an estimation table, which was originally published by the Energy Watch organisation, based on the number of bedrooms. Using the gas consumption figures from the table and the reported average boiler efficiency, it is possible to calculate the heat supplied to the property (Table 2).

Table 2: Approximate heat loads for UK households

number of bedrooms	**gas consumption kWh/y**	**heat supplied kWh/y**
2	15 000	11 250
3	25 000	18 750
4	29 000	21 750

Possible ways of supplying this demand are shown in Table 3. The CO_2 emissions generated by each of these systems have been calculated using the Carbon Trust emission values of 0.544 for grid electricity, 0.184 kgCO_2/kWh for gas, and 0.247 kgCO_2/kWh for burning oil.

Table 3: CO_2 emissions from heating

heat supplied kWh	11 250	18 750	21 750
storage heaters	8.16	13.6	15.78
oil boiler average efficiency 74%	3.71	6.18	7.16
gas boiler average efficiency 74%	2.76	4.60	5.34
condensing gas efficiency 90%	2.30	3.83	4.45
heat pump COP 3.6	1.70	2.83	3.29

The electric heat pump considered has a coefficient of performance (COP, ratio of heat output to electricity input) of 3.6 which was the best achieved in a field trial carried out by The Energy Saving Trust (2010).

4 Potential for offsetting

The area of panel needed to offset a given carbon load has been calculated by assuming an average saving of 0.1 tCO_2/m^2 of PV panels installed (taken from the data in Table 1). In order to keep the proliferation of case down, electricity consumption and heating will continue to be treated separately.

Table 4: PV needed to offset electricity consumption

use kWh	1 000	2 000	3 000	4 000	5 000
CO_2 burden t/y	0.544	1.088	1.632	2.176	2.72
area PV m^2	5.4	10.9	16.3	21.8	27.2
rating of PV kW	0.9	1.8	2.7	3.7	4.6
generation kWh	777	1 554	2 330	3 107	3 884

Table 5: PV needed to offset heat supplied by gas condensing boilers

heat supplied kWh	11 250	18 750	21 750
CO_2 burden t/y	2.30	3.83	4.45
area PV m^2	23.0	38.3	44.5
rating of PV kW	3.9	6.4	7.5
generation kWh	3 284	5 474	6 350

Table 6: PV needed to offset heat supplied by heat pump with a COP of 3.6

heat supplied kWh	11 250	18 750	21 750
CO_2 burden t/y	1.70	2.83	3.29
area PV m^2	17.0	28.3	32.9
rating of PV kW	2.9	4.8	5.5
generation kWh	2 428	4 046	4 693

If it is assumed that a two-bedroom house has a usable roof area of 12 m^2, it is apparent from Table 4 that it will only be able to offset the emissions from a low electricity consumption. From Table 5, it would appear that for a four-bedroom house with a roof area of 50 m^2, it would be possible to offset the emissions of a condensing boiler, but not as well as the electricity consumption. If the same house is equipped with a high performance heat pump, it would be possible to offset a low to average electricity consumption as well as heating. It is clear from Table 3 that the CO_2 emissions associated with a house can only be offset by PV generation if a low carbon heating system is used.

5 Economic analysis

5.1 Capital cost estimation

Capital cost estimations have been taken from the sources shown in Table 7.

Table 7: Capital cost of PV installations

source	cost equation	years	nature of source
Bergman and Jardine (2009)	C = 2101 + 4979 Q	2007/8	UK survey of actual cost
Barbose et al. (2010)	C =1875 + 4605 Q	2005/9	USA survey of actual cost
Centre for Alternative Energy (2011)	C = 2400 + 3500 Q	2011	estimate tool from web site
SEAGEN (2011)	C = 2810 + 3157 Q	2011	estimates for 11 systems sized from 1.4 to 3.9 kW

Bergman and Jardine (2009) investigated the cost of micro-generation installed under the Low Carbon Building Programme. The equation they derived gives an average specific costs of £6380/kW which is similar to that found by Cook (2009), who also looked at UK installations and had a specific cost of £6200/kW for 1-3 kW installations. The survey by Barbose et al. (2010) in the USA has been included to give a world market perspective. An exchange rate of $1.57/£ (bank of England average spot rate for 2009) has been used with this data. It should be noted that the exchange rate varied between $2/£ and $1.5/£ over the last five years, so the USA data need to be used with care. The estimate by Bergman and Jardine (2009) appears higher than the others. This may be that there has been a fall in equipment cost, (Philbert, 2011), or that the survey included extra site specific cost in the real installations that are not covered by the generic estimators. For the rest of this paper, either the Bergman and Jardine (B&J) or the Centre for Alternative Energy (CAT) estimation formulas will be used.

5.2 Payments for electricity generation

It is assumed that the owner will take advantage of payments under the FIT scheme for retrofitting PV systems on existing buildings which are given in Table 8.

Table 8 : Feed-in-tariffs for domestic PV systems from 1/4/11

plant size	payment p/kWh
under 4 kW	43.3
4-10 kW	37.8
10-100 kW	32.9
over 100 kW	30.7
export payment	3
free standing system	30.7

The export payment is an additional payment made if the electricity is not used on-site. If the owner uses the power on site, they would save the cost of the power they are not taking from the grid, which is typically 12.06 p/kWh (DUKES Table 5.6.2, June 2010 prices). This has been considered as an income in the simple payback period and annual rate of return calculations. If full export metering is not available, it is assumed that the owners use 50% of their generation on site. This may be reasonable for systems that are used to offset electricity production, but it is unlikely to be true if they are trying to offset the consumption of a heat pump, which is unlikely to be running when the PV is generating large amounts of power. In this paper, it is assumed that for systems up to 4 kW, 50% of the power will be used on site. For larger systems, it is assumed that 1700 kWh/y of production is used on site, and the rest exported to the grid.

5.3 Simple cost of generation

The simplest measure of economic performance is the simple cost of generation (SCG), i.e. the lifetime production cost of electricity divided by the lifetime electricity production. Given the lack of operation and maintenance cost for PV systems this is a simple calculation to do. PV modules do suffer some deterioration in output over time. Most manufactures will guarantee that this should be no more than 10% in the first ten years and a no more than 20% over 20 years. A report by Chainese et al. (2004) on the long term performance of a PV module indicates that real performance is likely to be better than this (they found a 3% deterioration over 20 years). However as this is a developing technology, it is worth taking a cautious view and assume a deterioration in output of 1% per year. The SCG has been calculated using the capital cost of PV systems, and the B&J and CAT estimates. An average production rate of 850 kWh/kW decreasing by 1% a year has been used. The results are shown in Figure 1 along with the FIT payment, including export payment for the full output.

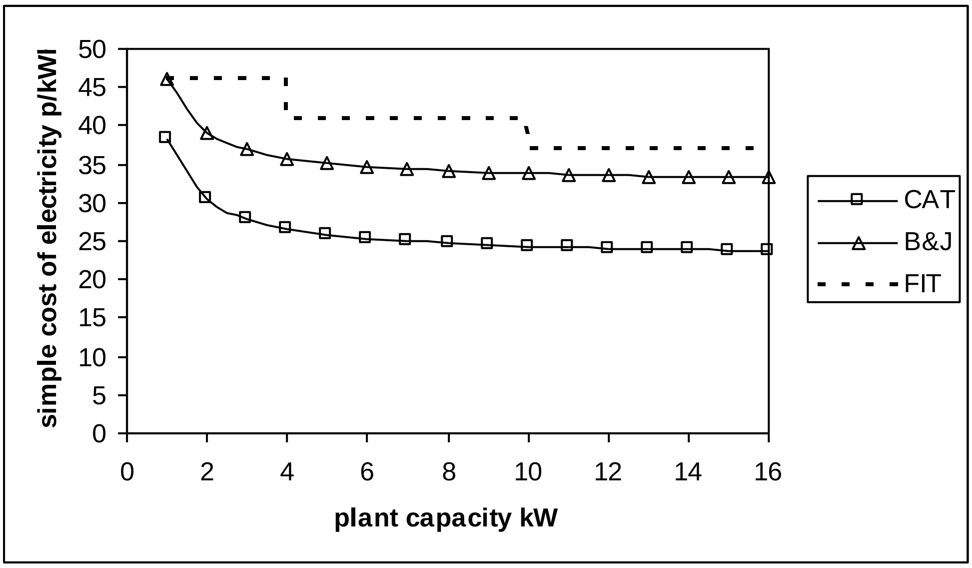

Figure 1: Simple cost of generation

The SCG takes no account of the time value of money, but it does give an indication of the minimum payment that must be received to make a system worth considering. From Figure 1, it would appear that PV systems receiving FIT payments could be profitable. The stepped nature of the FIT will result in jumps in profit with increasing installation size (Figure 2), which considers the lifetime profit that can be made from systems, assuming the low cost CAT system operating at 950 kWh/kW and the high cost B&J system generating at a rate of 750 kWh/kW.

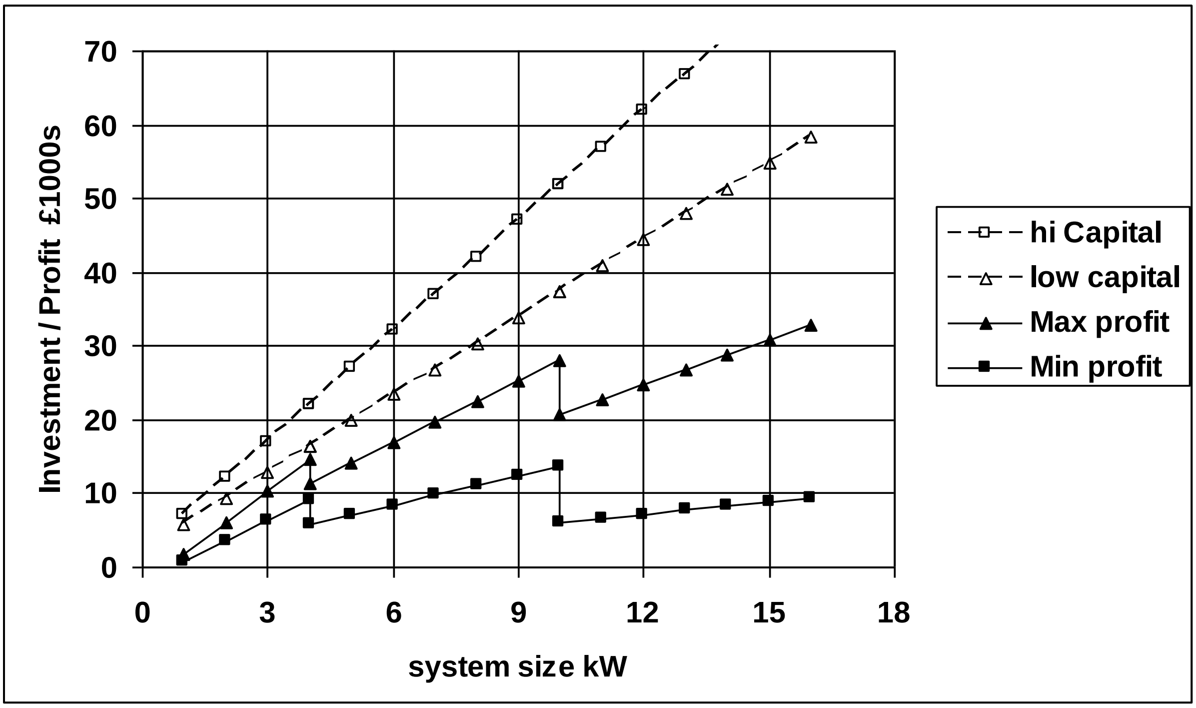

Figure 2: simple lifetime profit for different sized systems

Figure 2 shows that there is a disincentive to invest in systems with capacities in the ranges of 4 to 6 kW and between 10 and 18 kW. It also shows that for the high cost system, there is little incentive to install systems above 4 kW capacity.

5.4 Annualised rate of return

The FIT payments are guaranteed by the government and are increased each year by the retail price index. Income under the scheme is also free of UK income tax. National Savings are government backed and offer tax free incomes on some products, they may be considered as comparative investment vehicles. They are offered the following rates in May 2011 (from nsandi.com):

- Indexed linked certificate RPI + 0.5%
- Fixed rate savings certificate 2.25%
- Cash ISA 2.5%

In order to compare the return from a PV scheme with these investments, an equivalent interest rate is needed. This rate should be set such that the value of the investment on deposit and the interest that is earned are equal to the lifetime earnings of the PV installation. If it is assumed that the interest is withdrawn annually, then:

$$value = capital(1 + rate.life) = \sum_{0}^{life} Earning_{year}$$

$$rate = \frac{\sum_{0}^{life} Earning_{year}}{capital.life} - \frac{1}{life} \quad (1)$$

Where *earning* is the annual earnings, *life* is the operational life of the system and c*apital* the installed cost of the system including any fees. The interest rate calculated in this way is the Annualised Rate of Return (ARR).

The lifetime earnings have been calculated using an allowance for cell degradation at 1% a year, this leads to an equivalent operation lifetime of 18.1 years at rated output.

Table 9: ARR for PV installation

	750 kWh/kW		**950 kWh/kW**	
size	**B&J**	**CAT**	**B&J**	**CAT**
kW	**ARR %**	**ARR %**	**ARR %**	**ARR %**
1	-0.1%	0.8%	1.1%	2.4%
2	0.7%	2.3%	2.2%	4.3%
3	1.0%	3.0%	2.7%	5.1%
3.9	1.2%	3.4%	2.9%	5.6%
4	0.7%	2.6%	2.0%	4.4%
9.9	0.6%	2.8%	2.0%	4.7%
10	0.%	1.9%	1.22%	3.6%
16	-0.1%	1.9%	1.22%	3.6%

Systems with negative ARR are ones with simple payback periods longer than equivalent operational lifetime.

It appears that a PV system will give higher returns than National Savings, although there is no option to withdraw the capital. Not everyone has the capital to pay for a scheme, so if the ARR is above the repayment rate on a loan, it becomes economic to borrow money to install a system. Given that a PV system will probably add to the value of a house and is likely to keep working for at least 20 years it is likely that a house mortgage would be a suitable way to finance an installation. It is currently possible to get bank rate tracker mortgages with interest rates in the range of 3.4 – 5.5%. From Table 9 it would appear that in favourable situations it is possible for a PV installation to be self financing (i.e. not need any investment by the owner).

5.5 Simple payback period

A common project evaluation tool is to calculate the simple payback period i.e. how long it will take for the income from the installation to recover the lifetime costs associated with the installation. This is a useful comparison tool in cases where investors are more prepared to risk future profits than risk loosing capital. The payback period has been calculated using the B&J and CAT estimates of capital cost and production rates of 750 and 850 kWh/kW. No account has been taken of performance degradation with time. The results are shown in Table 10.

Table 10: Simple payback period for PV installations

	750 kWh/kW		**950 kWh/kW**	
size	**B&J**	**CAT**	**B&J**	**CAT**
kW	**years**	**years**	**years**	**years**
1	18.7	15.5	14.7	12.3
2	15.9	12.4	12.5	9.8
3	15.0	11.3	11.8	8.9
3.9	14.5	10.8	11.4	8.5
4	16.0	11.9	12.9	9.6
9.9	16.2	11.6	12.9	9.3
10	18.2	13.1	14.6	10.5
16	18.2	13.1	14.6	10.4

6 Discussion

The amount of carbon emissions saved by a PV installation depends on the marginal carbon intensity of the grid. It is expected that the carbon intensity of the grid will fall with time, but at least for the lifetime of an installation PV generation will be displacing fossil fired generation. This means that the marginal carbon intensity of the electricity will always be higher than the average grid carbon intensity. As the average grid carbon intensity falls, the amount of carbon emission from grid electricity consumption that can be offset by a PV installation will rise.

The situation with gas is different. If the only fossil fuel used for generation was gas, 1 kWh of PV electricity would save the same amount of carbon as released by supplying 2 kWh of heat from a gas condensing boiler.

The disincentive to invest in systems of 4 to 6 kW revealed in Figure 2 would appear to be a barrier to people investing in PV to offset the emissions as they are likely to need systems in or just above this size range. Few domestic installations are likely to be above 10 kW, but the drop in tariff at this scale would effect any business wishing to invest in PV. Given the nature of the cost curve for PV, it would be better to replace the stepped tariff with a single tariff and an annual fixed rate payment.

There is another problem with the existing tariff, which is that it provides little incentive to export electricity as it values at 3 p/kWh. This may reflect the minimum wholesale electricity price, but it is cheaper than some gas tariffs. It could lead to people using their PV electricity for low grade heating duties rather than exporting it. This situation could be avoided by reducing the FIT by 6 p/kWh and increase the export payment to 9 p/kWh.

It would appear from Table 10 that the FIT payments are designed to give a simple payback period of 12 years in sunny locations. Using the B&J estimate, the tariff structure should look like:

- Annual payment = 2100/12 = £175/y/installation,
- Export payment = 9p/kWh
- FIT = (5000/950*12) - 9 = 35p/kWh

These are high electricity prices and it may be worth establishing a minimum capacity of installation that will receive FIT payments.

As the owner receives more money in FIT payments than the installation cost, they have effectively free carbon offsetting. However, these payments ultimately come from the electricity consumer. The marginal grid intensity calculated in section 0 is 0.7 $kgCO_2$/kWh. Given that the value of the electricity is covered by the export price, the FIT payment could be considered to be the carbon price. At £620/tCO_2, this is around £600/t more than the prices quoted on some of the UK government approved carbon offsetting web sites (e.g. www.clear-offset.com and www.carbonfootprint.com). Plants operating under the renewable obligation certificate scheme receive a subsidy of around £52/MWh (OFGEM, 2011), which would correspond to a carbon price of £74/t, this would appear to be a better investment to reduce carbon emissions.

7 Conclusions

- Domestic PV systems should be able to offset the carbon emissions of a building’s electricity and heating loads, provided that energy efficiency measures have been implemented to reduce them to average or below average levels.
- It is unlikely that sufficient PV modules could be mounted on a house to offset the emissions from electric storage heaters, oil boiler or average efficiency conventional gas boiler.
- The level of the FIT is competitive with National Savings products however it may be unnecessarily generous if installation cost has fallen. The cost of all installation registered each year should be monitored and the FIT adjusted, so that it is just competitive with comparable income sources.
- The stepped nature of the FIT means that there is a disincentive to install systems in the 4 – 6 kW range. The structure should be reworked to match the cost profile and remove this anomaly.
- Although financed by the FIT scheme, it would appear that this is a very costly way of dealing with CO_2 emissions. Although this is a benefit of installing PV systems, it should not be given as the prime reason to do so.

8 Acknowledgments

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