Feasibility and Economic study of Solar Photovoltaic System for Domestic Properties in Scotland

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***Abstract* - Solar Photovoltaic technology is continuously growing. It is providing benefits to, not only environment friendly people as a clean source of energy but it also became economically, a profitable source of energy. It is happening because of decreasing prices of Photovoltaic and mainly government's incentives. This feasibility study provides solar PV design related information, which could undertake by PV users to carry out the triple 'e' (energetic, economic, and environmental) analysis for building integrated systems. A number of examples have been introduced within this work as a means of facilitating the above-mentioned design and analysis process. This research work consist into two projects; one is feasibility study for Solas Scotland Group in which solar data for 13 sides gathered and processed to find out PV output on different aspect angles and slopes for those locations. Second is a feasibility study for FHC (Fairfield Housing Corporation), in which shading analysis assessment of three potential properties located in close proximity to FHC office has been done and a property has been selected for PV installation. This study also proposes a triple-string installation with 14 modules in each string. The total number of modules thus required would be 42. It is also recommended that three, 4kW inverters are used, one for each string.**

Keywords: Solar energy, PV implementation, renewable energy.

I. INTRODUCTION

A. Photo-Voltaic technology overview

There are two basic commercial PV module technologies available on the market today that are used by the Building Integrated Photo-voltaic (BIPV) sector:

• Thick crystal products include solar cells made from crystalline silicon either as single or poly-crystalline wafers.

• Thin-film products typically incorporate very thin layers of photovoltaic active material placed on glass or a metal substrate using vacuum-deposition manufacturing techniques similar to those employed in the coating of architectural glass. Like-with-like, commercial thin-film materials deliver roughly half the output of a thick crystal PV array.

a. Single crystal or mono-crystalline silicon cell

The work horse of PV industry has always been the crystalline silicon cell, fabricated from a single crystal or cast polycrystalline silicon that is sliced into wafer of about 10x10 cm in area and 350μm thickness. These cells show efficiencies between 13% and 15% depending on the material quality and the specific cell technology.

The single crystal of silicon is defined as having a grain size greater than 10cm. Modules made of this type of cell are the most mature on the market. Reliable manufacturers of this type of PV module offer guarantees of up to 20–25 years at 80% of nameplate rating.

b. Poly-crystalline or multi-crystalline silicon

These cells are made up of various silicon crystals formed from an ingot. They are also sliced and then doped and etched. They demonstrate conversion efficiencies slightly lower than those of mono-crystalline cells, generally from 13 to 15%. Reliable manufacturers typically guarantee polycrystalline PV modules for 20 years. Multi-crystalline and polycrystalline cells respectively have grain sizes which are 1μm to 1mm and 1mm to 10cm. Nano-crystalline cells grain size of less than 100nm [1&2].

B. Overview of PV module pricing, UK Feed-in Tariff and its future

Thanks to the use of Feed-in Tariff (FIT) program and led by Germany, the rest of the EU27 member states have very ambitiously exploited the use of BIPV. As a result of large-scale demand of PV modules the price has dropped quite sharply as indicated in Fig. 1. Professor Brian Norton writing in the Autumn 2011 issue of Energy and Environmental Management (page 33) has

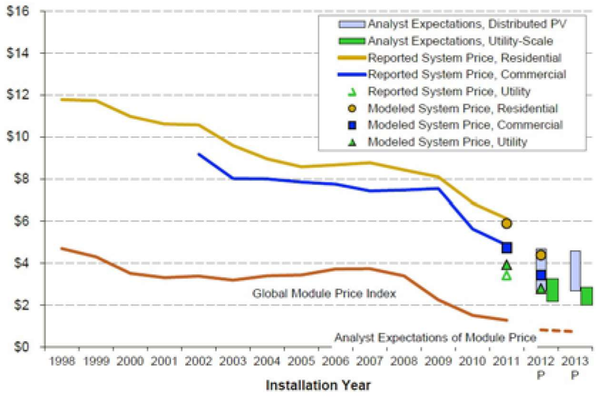


Figure 1. Historical drop in PV module price [Source: SunShot US department of Energy, November 2012].

observed that, 'the large total scale in this variety of applications has led to a very significant reductions in manufacturing costs, for example in 1992 it cost an average of about USD5.5/W_p to manufacture a PV module; today it costs less than USD0.5/W_p. This is because the manufacturing capacity has increased one hundred-fold, so today a fully installed PV system costs about USD4/W_p including inverters, controllers, framing and structural support. This compares with around USD12/W_p in UK in year 1990.

Feed-in Tariffs (FIT) were introduced by 15 of the EU27 countries much before the UK Government took any action. Belatedly introduced in April 2010 for the home owners and small-scale installations at a healthy rate of 43.3 pence/kWh the UK Government seems to be fast back-tracking. In the 29th October 2011 issue of The Independent newspaper, Scotland (page 19 of the 'News' section) a report claims that the above FIT rate will soon be dropped to 21 pence/kWh (implemented from 3rd March 2012). Needless to say that this policy will inevitably seriously hamper further PV installations as the pay-back period will double.

Note that with the previously available FIT rate of 43.3 pence/kWh a £10,000 investment on a PV installation in southern UK yields a healthy 7% per annum financial return. Before the advent of FIT in UK there were around 500 registered companies employing 3,000 people. Soon after the FIT was introduced the latter figures had jumped to 3,000 companies employing 25,000 people. The market forecasts were that by the year 2020 there would be 360,000 people employed in the PV procurement, design and installation sector. These forecasts are bound to change with the altered government policies.

On 31st October 2011 the above-mentioned FIT reduction policy consultative document was released at [3] and implemented from 3rd March 2012. Titled, 'Government has confirmed cuts to the feed in tariff scheme. Support for domestic solar photovoltaic has been cut by more than half; the document reveals a dramatic shift in government policy.

Under the new policy rates are roughly halved for all bands of solar installations up to 50kW (to 21p/kWh)with cuts of around a third to schemes from 50kW to 150kW (to 12.9p/kWh) and trimmed slightly for 150-250kW schemes (down 2.1p to 12.9p/kWh). The implemented new tariffs applied to all installations accredited on or after 12 December 2011. The consultation also proposes that properties also have to meet minimum standards of energy efficiency to qualify to receive the proposed feed in tariff rates. In this respect it is difficult to know where would the FHC property under discussion fit, i.e. since the property is of an older stock it might not meet the proposed new 'minimum standards of energy efficiency'. Only an application made to the FIT scheme can ascertain the final outcome.

Firms such as the major energy companies or other companies that operate rent a roof schemes in aggregate and claim the feed-in tariff revenue has got a reduced rate (80 per cent of individual installations) from 1 April 2012.

There is however one consolation. Even if the FIT effect was gradually diluted, the PV module price has shown a steady decline. The German PV industry and PV installation sector are all predicting a further price reduction and the forecasts are that by the year 2016 the module price would reach USD1/W_p. At that price solar electricity will compete with fossil fuel electricity. With the closure of Nuclear power plants in Germany this could be a real possibility.

II. SOLAS'S PROJECT

A. Project overview

The Solas Scotland Group was created 21 years ago in a community initiative set up in Dumbarton to provide insulation to vulnerable households. The group was amongst the first installers to be accredited under the Government's HEES (Home Energy Efficiency Scheme) insulation program which began in 1991 and has continued through all the changes in the scheme. During these early years the Group worked mainly with Local Authorities targeting the Government grants at the most vulnerable households and for owner occupiers who qualified for assistance. The Group has also successfully applied for funding from the National Lottery which allowed it to create a hardship fund for the needy families to receive the insulation.

The transfer of council tenants to housing associations also provided the opportunity to create new partnerships with many of the housing associations to continue to bring their tenants government grant funding - originally directly and latterly through Communities Scotland.

In 1998 the Group opened a satellite office in Greenock. Called INVEST (Inverclyde Energy Saving Team - later Inverclyde Energy and Safety Team) this was a partnership between Solas Insulation and Inverclyde Council aimed at improving the insulation in all council homes to the current best standard and providing jobs and training for Inverclyde residents.

As it became apparent that quality energy advice had an extremely significant part to play in reducing energy use, Solas developed an innovative energy advice, training and support service for delivery to households. Along with its clients Solas soon realised that that service could be expanded to include advice on home safety and security with an option of relevant upgrades for home security.

In future, the Group expects to play an important role in making renewable energy more readily available to households.

B. Selection of locations and climatic data

For the past 38 years the renewable energy team at Edinburgh Napier University (ENU) has been at the forefront of research activity. The team has been recognized for its high-quality research output via numerous awards and grants. It has maintained a healthy output of research publications, i.e. references [4-13].

As Principal Author for Solar Data section of the CIBSE Guides A and J [12], one of the authors of this paper (T Muneer) has gathered, quality controlled and processed large climatic data sets for solar radiation, temperature and other variables. However, acquisition of measured data from the UK Meteorological Office is an expensive affair. Even purchase of a few years data for a small number of locations costs thousands of pounds. As such for the present study long-term data was downloaded from NASA's satellite-based measurements, details of which are provided in [13].

C. Potential shading of PV modules

Note that shading of PV modules ought to be avoided as much as possible as even one shaded cell within a given module can potentially reduce the power output by up to 50%! Likewise, one shaded module within a string can also reduce the output of the entire string. In this respect Fig. 2 shows dramatic loss in PV efficiency due to a single cell under shade. Fig. 3 Dramatic loss of power output for a London based PV installation due to shading effects.

D. Modeling and findings of the present study

The solar PV power output and energy generation modeling procedure followed in the present study is shown schematically in Fig. 4. Basic solar radiation data for Annan (principal site), Scotland was obtained from NASA website. The latter data are for only total (global) horizontal radiation and mean-daily temperature. In the present study though, hourly outputs were required and as such Muneer's European reference model for slope radiation was used in conjunction with PV module

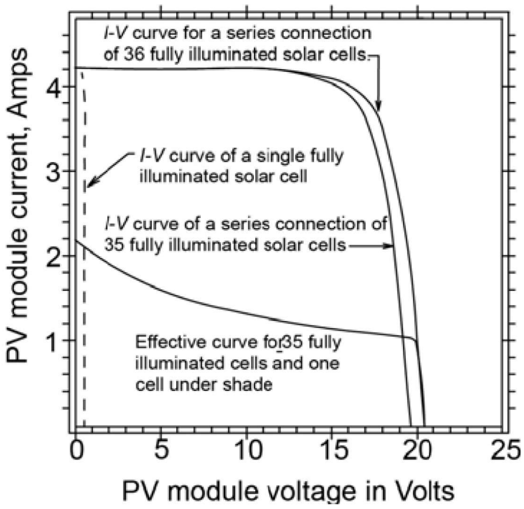


Figure 2. Dramatic loss of PV performance due to a single cell under shade

Figure 3. Dramatic loss of power output for a London-based PV installation due to shading effects.

characteristics for the Schott product that has been recommended by one of the local supplier, Sidey. [11] Provides details of the evaluation of the Muneer's slope radiation model that were carried out by the European Solar Radiation Atlas task group.

Table I Delivered energy, kWh/240 W module per day for principle location and shows a comparison between the PV generated electricity calculations that were

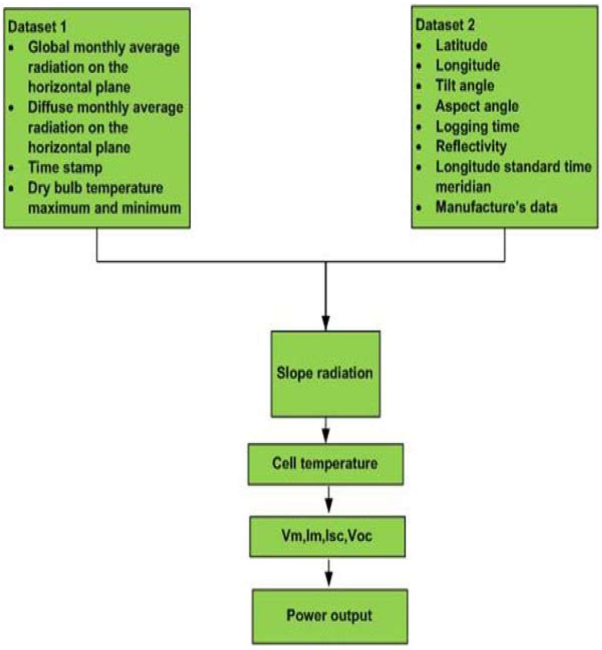


Figure 4. Steps to generate slope solar irradiation and PV power output.

presently undertaken and those provided by the Energy Saving Trust for Annan. The essence of this table is to provide a validation for the present set of work. Note that this table was produced for an aspect (Ψ) of 180 degree and slope (β, tilt from horizontal plane) of 40 degree for the PV modules.

Table II shows delivered energy, kWh/240 W module per day for all selected location with aspect (Ψ) of 180 degree and slope (β, tilt from horizontal plane) of 45 degree for the PV modules.

The difference between annual energy outputs between the two sources is less than 10%. The difference between the two sources may be due to a large number of factors such as:

Different climatic databases

- Different horizontal diffuse irradiance models
- Different slope radiation models
- Different detail with respect to modeling the behavior of PV modules with respect to energy generation.

Refer to Fig. 5 which provides the geographical details of the Scottish locations chosen for this study.

The coverage is from a latitude sweep of 55 through to 58 degree North and a longitude sweep of 2 through to 6 degree west. The principal location (Annan) is shown asred pin. For each of these locations the averaged-daily PV outputs were obtained using the same rigorous

TABLE I.
DELIVERED ENERGY, kWh/240 W MODULE PER DAY FOR PRINCIPLE LOCATION

Month	Principal Location $\beta=40^0$ $\Psi=180^0$	EST[1] quote for Principal Location $\beta=40^0$ $\Psi=180^0$
JAN	0.237	0.235
FEB	0.424	0.33
MAR	0.618	0.464
APR	0.788	0.722
MAY	0.951	0.841
JUN	0.879	0.801
JUL	0.887	0.831
AUG	0.823	0.788
SEP	0.674	0.609
OCT	0.424	0.444
NOV	0.294	0.27
DEC	0.216	0.162
Annual output	**219**	**198**

1: Energy Saving Trust quote for principal location
Principal location: Annan, Latitude = 54.988 deg N, Longitude = 3.257 deg W

TABLE II.
DELIVERED ENERGY, KwH/240 w MODULE PER DAY FOR DIFFERENT LOCATIONS

Month	Lat55°N Long3°W $\beta=45^0$ $\Psi=180^0$	Lat55°N Long4°W $\beta=45^0$ $\Psi=180^0$	Lat55.86°N Long4.43°W $\beta=45^0$ $\Psi=180^0$ (Glasgow)
JAN	0.264	0.264	0.293
FEB	0.498	0.498	0.525
MAR	0.68	0.68	0.746
APR	0.843	0.843	0.977
MAY	1.019	1.019	1.137
JUN	0.921	0.921	1.049
JUL	0.896	0.896	1.004
AUG	0.872	0.872	0.985
SEP	0.713	0.713	0.822
OCT	0.496	0.496	0.539
NOV	0.329	0.329	0.333
DEC	0.228	0.228	0.201
Annual output	236	236	262

Month	Lat55.93°N Long3.36°W $\beta=45^0$ $\Psi=180^0$ (Edinburgh)	Lat56°N Long4°W $\beta=45^0$ $\Psi=180^0$	Lat56°N Long5°W $\beta=45^0$ $\Psi=180^0$
JAN	0.296	0.246	0.213
FEB	0.528	0.457	0.414
MAR	0.699	0.635	0.594
APR	0.854	0.827	0.838
MAY	1.026	1.013	1.024
JUN	0.925	0.937	0.918
JUL	0.9	0.898	0.862
AUG	0.881	0.866	0.835
SEP	0.728	0.7	0.676
OCT	0.517	0.463	0.42
NOV	0.343	0.278	0.25
DEC	0.265	0.206	0.16
Annual output	242	229	219

TABLE III
DELIVERED ENERGY kWh/240W MODULE PER DAY FOR SOUTHERN ASPECT FOR DIFFERENT SLOPES

Principal Location: Annan, Latitude = 54.988 deg N, Longitude = 3.257 deg W					Factor*		
Month	$\beta=30^0$ $\Psi=180^0$	$\beta=45^0$ $\Psi=180^0$	$\beta=60^0$ $\Psi=180^0$	$\beta=90^0$ $\Psi=180^0$	$\beta=30^0$ $\Psi=180^0$	$\beta=60^0$ $\Psi=180^0$	$\beta=90^0$ $\Psi=180^0$
JAN	0.212	0.247	0.269	0.262	0.856	1.085	1.058
FEB	0.392	0.436	0.456	0.416	0.899	1.045	0.954
MAR	0.593	0.625	0.625	0.524	0.948	0.999	0.838
APR	0.779	0.785	0.752	0.575	0.992	0.957	0.732
MAY	0.960	0.939	0.871	0.615	1.022	0.928	0.654
JUN	0.897	0.863	0.788	0.538	1.039	0.913	0.623
JUL	0.901	0.873	0.803	0.557	1.032	0.919	0.638
AUG	0.822	0.817	0.771	0.571	1.006	0.944	0.699
SEP	0.655	0.677	0.664	0.537	0.967	0.981	0.793
OCT	0.400	0.432	0.440	0.387	0.927	1.020	0.896
NOV	0.265	0.306	0.329	0.315	0.867	1.075	1.030
DEC	0.190	0.227	0.251	0.252	0.834	1.106	1.107
Total annual output	**215**	**220**	**213**	**169**	**0.977**	**0.971**	**0.767**

* factor to convert energy output from southern aspect with slope of 45 degrees to any required aspect/slope

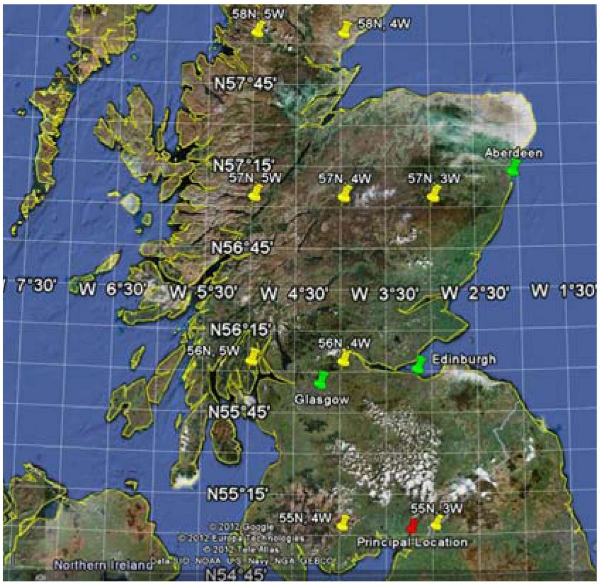


Figure 5. Scottish locations chosen for this study.

procedure that was outlined in Fig. 4. However, for retrofit applications it may not always be possible to site the panels for the latter aspect or slope. For any given location and any given month the factors shown in Tables III-V may be used to determine the PV output for any given aspect/slope combination. The following example demonstrates such assessment.

Example 1

A detached house in Aberdeen is to be retrofitted with the view to have a 4kWpeak PV array. The slope of the PV modules shall be 30 degrees and the roof has an eastern aspect. Calculate the monthly-averaged daily PV electricity generation profile for January for the latter location.

Solution

Refer to Table IV-V and note the 12 monthly values of 'factors' from the β=30- and Ψ=90 degree column, e.g. for January we note the factor = 0.496. Thus the output for January for Aberdeen (Table IV refers) will thus be = 0.242*0.496 = 0.125kWh from a 240W_p PV module. Thus the output from a 4kWpeak PV array will be = 0.125*4/0.240 = 2.08kWh/day in January.

Example 2

It is now customary for engineering reports to provide answers to the queries regarding the three 'es', i.e. economic, energy and environmental impact performance. In Example 1 demonstration was provided for the energy analysis regarding the PV generated electricity for one location in Scotland. In the present example we shall explore assessment with respect to the other 2 'es', i.e. economic and environmental impact. The following price quote has been provided for a 10.08kWpeak roof-mounted PV facility. Provide an assessment of the economic and environmental payback.

TABLE IV
DELIVERED ENERGY kWh/240W MODULE PER DAY FOR EASTERN ASPECT FOR DIFFERENT SLOPES

Principal Location: Annan, Latitude = 54.988 deg N, Longitude = 3.257 deg W					Factor*			
Month	$\beta=30^0$ $\Psi=90^0$	$\beta=45^0$ $\Psi=90^0$	$\beta=60^0$ $\Psi=90^0$	$\beta=90^0$ $\Psi=90^0$	$\beta=30^0$ $\Psi=90^0$	$\beta=45^0$ $\Psi=90^0$	$\beta=60^0$ $\Psi=90^0$	$\beta=90^0$ $\Psi=90^0$
JAN	0.123	0.121	0.113	0.084	0.496	0.489	0.458	0.341
FEB	0.278	0.274	0.258	0.191	0.637	0.629	0.591	0.437
MAR	0.494	0.487	0.455	0.332	0.791	0.778	0.728	0.531
APR	0.716	0.697	0.644	0.454	0.912	0.887	0.820	0.577
MAY	0.932	0.901	0.825	0.563	0.993	0.959	0.879	0.600
JUN	0.891	0.855	0.778	0.527	1.032	0.990	0.901	0.611
JUL	0.886	0.853	0.778	0.530	1.016	0.977	0.891	0.607
AUG	0.775	0.751	0.691	0.482	0.949	0.920	0.846	0.590
SEP	0.572	0.560	0.522	0.376	0.845	0.827	0.770	0.555
OCT	0.310	0.304	0.284	0.210	0.718	0.704	0.659	0.486
NOV	0.167	0.166	0.158	0.120	0.546	0.544	0.516	0.392
DEC	0.100	0.099	0.094	0.072	0.439	0.437	0.415	0.316
Total annual output	**190**	**185**	**170**	**120**	**0.864**	**0.840**	**0.775**	**0.545**

* factor to convert energy output from southern aspect with slope of 45 degrees to any required aspect/slope

TABLE V
DELIVERED ENERGY kWh/240W MODULE PER DAY FOR SOUTH-EASTERN ASPECT FOR DIFFERENT SLOPES

Principal Location: Annan, Latitude = 54.988 deg N, Longitude = 3.257 deg W					Factor*			
Month	$\beta=30^0$ $\Psi=135^0$	$\beta=45^0$ $\Psi=135^0$	$\beta=60^0$ $\Psi=135^0$	$\beta=90^0$ $\Psi=135^0$	$\beta=30^0$ $\Psi=135^0$	$\beta=45^0$ $\Psi=90^0$	$\beta=60^0$ $\Psi=135^0$	$\beta=90^0$ $\Psi=135^0$
JAN	0.195	0.223	0.238	0.227	0.787	0.901	0.963	0.917
FEB	0.381	0.420	0.436	0.393	0.872	0.962	0.999	0.901
MAR	0.602	0.639	0.641	0.543	0.963	1.021	1.025	0.868
APR	0.810	0.830	0.806	0.636	1.032	1.056	1.026	0.810
MAY	1.013	1.015	0.964	0.720	1.079	1.081	1.027	0.767
JUN	0.947	0.934	0.874	0.635	1.097	1.082	1.013	0.736
JUL	0.950	0.943	0.888	0.653	1.089	1.080	1.017	0.749
AUG	0.859	0.870	0.836	0.646	1.052	1.065	1.024	0.790
SEP	0.673	0.702	0.695	0.572	0.993	1.037	1.026	0.844
OCT	0.396	0.426	0.433	0.379	0.917	0.987	1.004	0.877
NOV	0.250	0.285	0.303	0.285	0.819	0.931	0.990	0.933
DEC	0.171	0.201	0.219	0.215	0.754	0.886	0.965	0.945
Total annual output	**220**	**228**	**223**	**180**	**1.003**	**1.036**	**1.014**	**0.817**

* factor to convert energy output from southern aspect with slope of 45 degrees to any required aspect/slope

Data provided

Peak power generation: 10.08kW at a solar irradiance of 1000W/m^2 and cell temperature of 25^{o}C. Price quote: £26,316 (including 5% VAT).

Location: Annan, Scotland.

PV module aspect/slope: Due south at a tilt angle of 45 degrees (Ψ = 180 degree, β = 45 degree).

Bank interest rate: 4%, compounded monthly

Government supported feed-in-tariff: 21p/kWh for energy exported to the grid.

Solution

Note from Table III-V that the annual PV electricity generation per 240kW module for Annan would be 220kWh. In order to obtain 10.08kW peak output we would need 42 PV modules. This means that the annual generation would thus be 220 x 42 = 9,240kWh and that would bring an income of £1,940.40/annum, or £161.70/month.

The payback period would thus be 235 months (19.6 years).

Hint: The payback is obtained from the following compound interest payment formula:

Capital invested = Monthly payment [p/a, monthly interest rate, number of months of payback (n)]

For the present set of calculations:

£26,316 = £161.70 [(1.00333) n – 1] / [0.0033 (1.00333) n]

Thus, n = 235

The Carbon dioxide footprint associated with the proposed facility is estimated as 50 grams of CO_2/kWh of delivered electricity. This compares much more favorably than the present UK grid with a quoted figure of 516 grams of CO_2.

Example 3

This example deals with the issue of ageing of PV modules and the corresponding drop in their electrical energy output with time.

Refer to Example 2 wherein the annual electrical energy output for newly installed PV modules was presented. Calculate the above output for the first 10 years of service of the modules.

The manufacturer only guarantees a 97% value of the quoted PV output during the first year. Thereafter the drop in efficiency is probably 0.7% per annum. With the latter information Table VI has been prepared. The total monthly generation is shown in kWh for the first 10 years of module life. The total annual output is given as MWh.

TABLE VI
TOTAL MONTHLY GENERATION FROM 42 SCHOTT PV MODULES. THE EFFECT OF MODULE AGEING IS EXPLORED IN THIS TABLE

Month\Year	1	2	3	4	5	6	7	8	9	10
1	313	310	308	306	304	302	300	298	295	293
2	498	494	491	487	484	480	477	474	470	467
3	790	784	779	773	768	763	757	752	747	742
4	960	953	947	940	933	927	920	914	908	901
5	1186	1178	1169	1161	1153	1145	1137	1129	1121	1113
6	1055	1048	1040	1033	1026	1018	1011	1004	997	990
7	1102	1095	1087	1079	1072	1064	1057	1049	1042	1035
8	1032	1024	1017	1010	1003	996	989	982	975	968
9	828	822	816	811	805	799	794	788	783	777
10	545	541	538	534	530	526	523	519	516	512
11	374	371	369	366	363	361	358	356	353	351
12	287	285	283	281	279	277	275	273	271	269
Annual, MWh	8.97	8.91	8.84	8.78	8.72	8.66	8.6	8.54	8.48	8.42

III. FAIRFIELD PROJECT

A. *Project overview*

Fairfield Housing Co-operative (FHC) is a Registered Social Landlord based in the city of Perth, providing affordable homes to population of Perth city.

A regeneration exemplar, FHC provides 450 homes at present with plans to build another 50 homes over the next few years. For twenty years FHC has been a momentous actor in the provision of sustainable housing design in the context of new build and refurbished homes, incorporating innovative features in relation to energy and air quality. Three FHC developments are featured in the national Sustainable Housing Design Guide, and their achievements have also been acknowledged by a host of national and local awards.

Regeneration is at the heart of FHC's work. Following the successful transformation of Fairfield itself, they have been working in partnership on the multi million pound Muirton Park project in Perth, turning around the fortunes of another very deprived area which is already showing a reverse in decline.

FHC is governed by a tenant board, which ensures a focus on high quality service delivery with consistent customer satisfaction and excellent performance indicators.

In these austere times, FHC have expressed interest in the potential value of PV installation on a retrofit basis. They are keen to examine the worth of this to individual tenants, or as an income generating vehicle with any potential profits being reinvested in its properties to tackle fuel poverty.

It is important to mention that FHC have obtained a quote from a local PV installer, Sidey who have offered a 41-module installed facility for a total price of £26,316, including 5% VAT. The present study proposes a triple-string installation with 14 modules in each string.

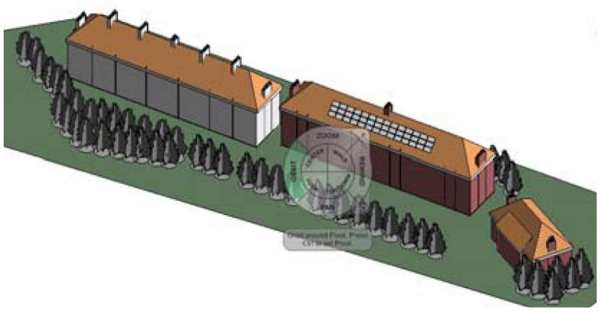


Figure 6. Isometric view of 'Fairfield' properties that have been identified for the first phase of installation.

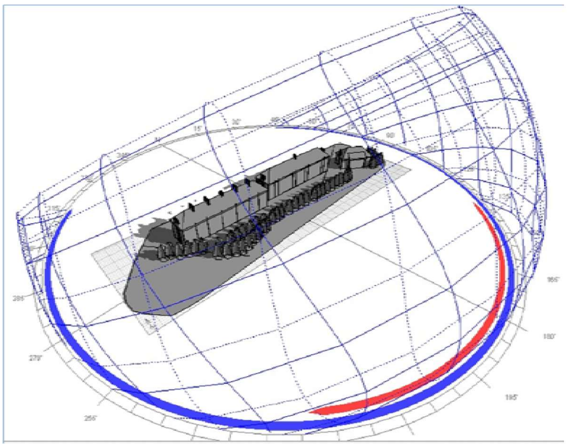
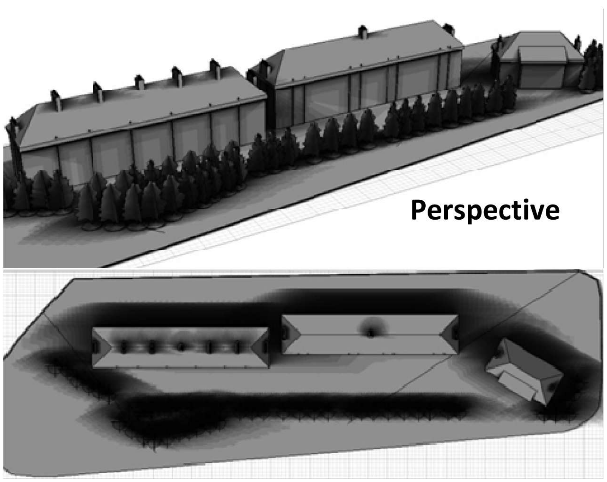


Figure 7. Annual Sun Path of Fairfield Avenue at Perth (Dundee weather file).

<u>Shading on 21st June</u>



Plan

<u>Shading on 21st September</u>

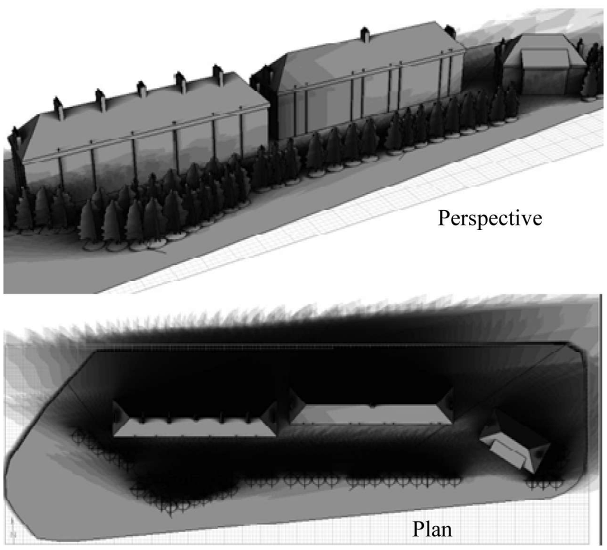


Figure 8. Shading analysis for the 'Fairfield' estate.

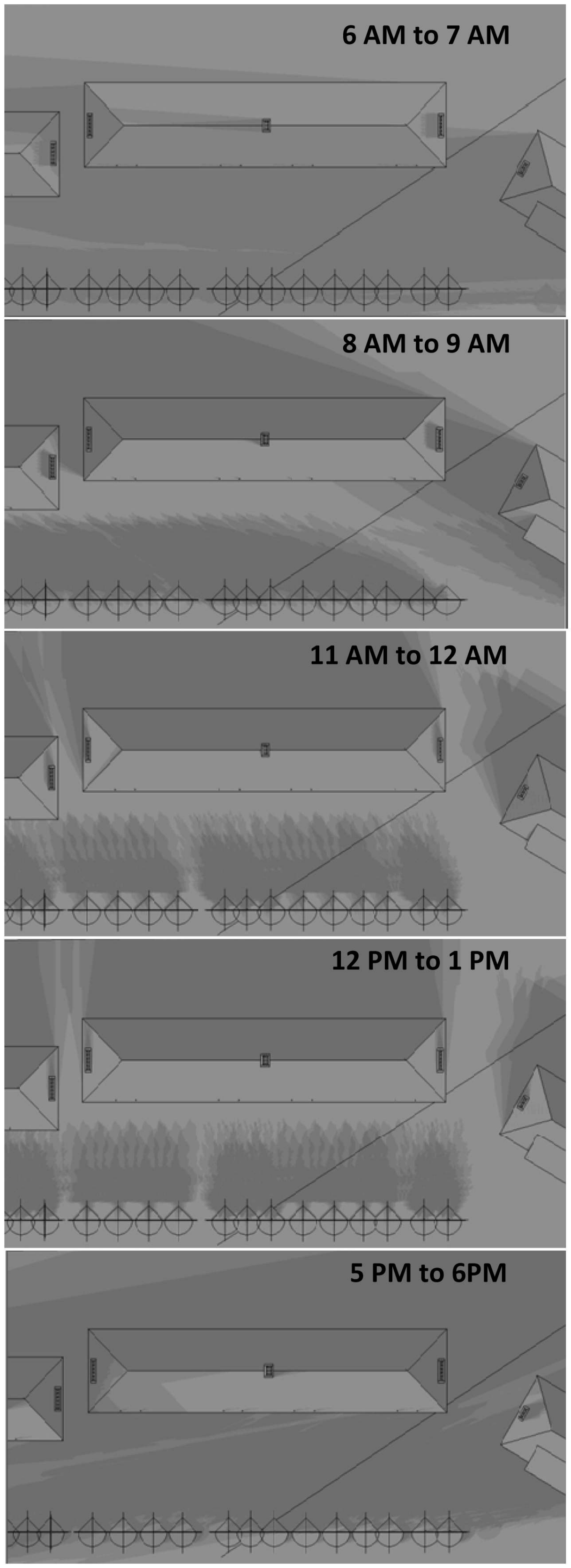


Figure 9. Hourly shading analysis for 'green' building-plan view on March 21st for selected hours.

The total number of modules thus required would be 42. It has been assumed that the Sidey price quote would remain unchanged.

B. Site description, survey and assessment

In October 2011 the Glasgow School of Art (GSA) and Edinburgh Napier University (ENU) teams visited the FHC office. A walk-about around the Fairfield estate was conducted which revealed the scope for a number of properties that had good potential for solar photovoltaic (PV) installations. Following discussions between FHC management and the present feasibility study team it was agreed that a second more in-depth survey of three properties would be undertaken and that in the first phase of development exploration of a 10kWpeak carried out for the most ideal of the three properties. An isometric view of the above-mentioned 'Fairfield' estate properties is shown in Fig. 6. Fig. 7 shows the sun-path diagram for the estate under discussion. Note that in the subsequent discussion the 'yellow', 'green' and 'red' buildings refer to the buildings that are respectively shown on the left, middle and right hand side of Fig. 6.

Figure 8. shows an abbreviated shading assessment for the estate. Furthermore, much more in-depth shading assessment was then carried out for the above-mentioned 'yellow', 'red' and 'green' buildings but those results has not been shown in this paper to avoid conjunction of figures.

Following the initial shading analysis assessment indicated above it was found that the most ideal building was the middle, 'green' building as it:

- faced 10-degree west of south
- had a roof slope with the optimally desired value of 45-degree
- Had only one central chimney of a short height

On the contrary the 'yellow' building, though having the same aspect and slope as the 'green' building, had multiple chimneys with the potential of shading of PV modules. Likewise, the 'red' building is also far from being an ideal host for the PV modules as its aspect is south-west and its roof is also at a reduced height.

Following the identification of the 'green' building being the ideal one to host PV strings, a more in-depth hourly shading assessment was carried out for the three key dates: the 21st of March (equinox), June (mid-summer) and September (equinox). Only results of 21st of March (equinox) selected hours has been shown in Fig. 9 to avoid lengthiness. All results indicate that the roof under discussion offers ideal, shade-free location for installation of PV strings.

Note that the above hourly shading analysis was not undertaken for December 21st (mid-winter) as the highest value of solar altitude (at solar noon) on that date is only 10 degrees for Perth. Even low lying buildings and trees in the neighbourhood would cast long shadows and the PV plant would be not very productive in mid-winter. Fig. 10 shows the isometric views of the 'green' building with proposed PV installation.

Figure 10. Isometric view of 'green' building with 42 Schott (240W$_p$) PV modules.

Note that shading of PV modules ought to be avoided as much as possible as even one shaded cell within a given module can potentially reduce the power output by up to 50%! Likewise, one shaded module within a string can also reduce the output of the entire string.

C. Modelling and findings of the present study

In the present study though, hourly outputs were required and as such Muneer's European reference model for slope radiation was used in conjunction with PV module characteristics for the Schott product that has been recommended by the local supplier, Sidey. Note that [4] provides details of the evaluation of theMuneer's slope radiation model that were carried out by the European Solar Radiation Atlas task group [5]. Fig. 11 presents the daily-averaged output for each of the 12 months.

The present study proposes a triple-string installation with 14 modules in each string. The total number of modules thus required would be 42. It is also recommended that three, 4kW inverters are used, one for each string. This will ensure a better handling of the resource and also any shading issues if they arise.

Note that the annual energy generation in the first year of installation is expected to be 9,950kWh from the totalmodule area of 70.27m^2. It was shown therein that the total investment of £26,316 would be returned at the end of 7 years. However, bearing in mind the build-up of dust cover on the modules and any likely bird dropping and grime build-up, it is likely that around 10 yearswould be needed to effectively payback the cash investment (*Economic payback*).

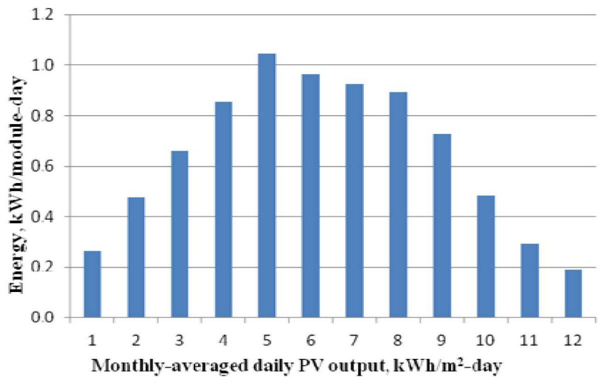


Figure 11. Daily energy output from 42 Schott, $240W_p$ PV modules.

Comparing the present results with those obtained from a six-year operating experience of a larger ($15kW_p$)

PV power-plant at Edinburgh Napier University; it was found that the embodied energy of the proposed facility will be paid back within 7 years.

The Carbon (or rather the carbon dioxide) footprint associated with the proposed facility is estimated as 50 grams of CO_2/kWh of delivered electricity. This compares much more favourably than the present UK grid with a quoted figure of 516 grams of CO_2.

Note that in all of the above assessments a linear, time-dependent drop in module efficiency was used, as quoted by the manufacturer.

IV. CONCLUSIONS

Although the FIT rates in future may not be that generous, in all likelihood the panel price will continue its downward trend and would therefore offer hope for the future.

Even though the previous generous FIT rates within the UK has been replaced with new low rates as well as tight rules (the new consultative policy document released on 31st October 2011 and implemented from 3rd March 2012), it would be wise to move from a smaller to a larger scheme of PV electricity generation.

A feasibility study was undertaken to investigate the performance of a 10 kW_p PV facility at Fairfield Housing Estate. The site offers exceptionally good aspect/slope combination. The price quoted by a local installer seems to be reasonable with a payback period of 10 years. The Carbon footprint associated with the proposed facility is estimated much more favourable than the present UK grid figure.

Comparing the present results with those obtained from a six-year operating experience of a larger ($15kW_p$) PV power-plant at Edinburgh Napier University; it was found that the embodied energy of the proposed facility will be paid back within 7 years.

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REFERENCES

[1] A Luque, S, Hegedus, Handbook of Photovoltaic Science and Enginering, Wiley, 2011.

[2] G. N. Tiwari, S. Dubey, Fundamrntals of Photovoltaic Modules and their Applications, RSC Publishing, 2010.

[3] Available at: http://www.utilityweek.co.uk/news/news_story.asp?id=196077&title=Feed+in+tariff+cuts+confirmed] Access on Dec 20011.

[4] T. Muneer, Solar radiation and daylight models, Elsevier, Oxford, 2004

[5]. T. Muneer, N Abodahab, G Weir and J Kubie, Windows in Buildings, Butterworth-Heinemann, Oxford, 2000

[6] T. Muneer, J Kubie and T Grassie, Heat Transfer – A problem solving approach, Taylor and Francis, London, 2003

[7] T. Muneer, Solar Energy (in Kempe's Engineers Yearbook), Miller Freeman, London, 2007

[8]. T Muneer, Sustainable energy options for the EU. Proc. of the NATO conf. on 'Energy security', Split, June 2009 [Ed:Frano Barbir Elsevier, 2010]

[9] T Muneer, M Asif & J Kubie, "Generation and transmission prospects for solar electricity: UK and global markets". Energy Conv. & Mgmt 44, 1, 35 –52, 2002

[10]. T Muneer, S Younes, N Lambert, and J Kubie, Life cycle assessment of a medium-sized photovoltaic facility at a high latitude location. Proc. IMechE Vol. 220 Part A: J. Power and Energy, London. DOI: 10.1243/09576509JPE253

[11]. CIBSE Guides A and J, The Chartered Institution of Building Services Engineers, London, 2006 (T Muneer, Principal Author for Solar Data section).

[12]. E. J. Gago, S. Etxebarria, Y. Tham, Y. Aldali and T. Muneer, Inter-relationship between mean-daily irradiation and temperature, and decomposition models for hourly irradiation and temperature. Int. J. of Low-Carbon Technologies, 6(1): p. 22-37.

[13]. European Solar Radiation Atlas, Ecole de Mines, Paris, 2000.