Department of Mechanical Engineering

Renewable Energy Strategy for Argyll & Bute Council

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Jean Luc Lefaucheur

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Abstract

The subject of the thesis is to look at a potential strategy for renewable energy generation in Argyll & Bute Council, Scotland. The main focus is to examine what can be done regarding the energy demand and reduction of carbon emissions relating more specifically to council buildings. The priorities are for the Council to obtain a reasonably short payment and reduce its carbon emissions as much as possible.

The objectives of the project are to:

- Identify the type of renewable energies that the Council should consider investing in
- Quantify the potential benefits of each technology or scheme
- Conduct financial analysis to establish what schemes are most attractive
- Analyze the key parameters which influence on the financial viability of each technology or scheme and provide recommendations accordingly

The investigation of the most promising resources available reveals that wind power, PV systems and biomass can provide the most appropriate and readily available solutions for the Council. Several tools for financial analysis of energy systems were created. We also have studied in details the financial viability of various scenarios for wind, solar PV and and biomass.

Wind generation has the largest potential but it would be necessarily to set up large scale wind operations, as small and medium wind can not contribute a large part. Operations between 500 kW and a few MW could be financially viable given the new Feed-in-Tariffs in place.

PV panels on Council buildings could contribute up to about a quarter of the Council's electricity demand. Financial viability for PV depends highly on the capital cost.

Biomass as a replacement of oil and/or gas could contribute a major part of buildings heating requirements with good payback period using local biomass fuel sources.

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"Earth provides enough to satisfy every man's needs, but not every man's greed."
Gandhi.

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Introduction

The EU energy strategy calls for a 20-30% target on greenhouse gas emissions (GHG) reduction, as well as reaching a 20% share in generation for renewable energies and 20% cut in energy consumption in 2020. The EU also has a target of 10% for renewable energies share in transports in 2020. For 2050 the objective is a 80- 95% reduction in GHG (compared to 1990 levels).

The UK Government has committed to reducing carbon emissions by 80% by 2050. It has identified the public sector as key to delivering carbon reduction across the UK inline with its Kyoto commitments and the Public Sector Carbon Management program is designed in response to this.
Fears regarding peak oil and concerns over climate change have driven the subject to the top of the political agenda worldwide but particularly in Europe and therefore in the UK.

Plans have been drafted UK-wide and in Scotland to:

- Increase large-scale renewable electricity generating capacity
- Increase micro-generation of renewable sources
- Greatly reduce energy consumption and carbon emissions

Argyll and Bute Council has set a target to reduce its carbon emissions by 20% by 2014. The Council aims in the first instance at reducing them by 10% by 2012.
The council wants to invest in and promote renewable energies.
The Council has identified that buildings represent the largest part in energy consumption, in particular space heating. The Carbon Reduction Commitment (CRC) does not currently apply to buildings within Argyll & Bute Council, however the Council is aware that the CRC could have a cost in the future.
The Council has already established a Carbon Management Plan and has initiated programs to review their buildings insulation and reduce employee mileage. A set of projects has been defined to achieve the 2012 target. These projects focus mostly on oil to gas conversion, reductions in energy use, car mileage and also a few proposals for biomass conversion or small wind turbines.
The Council wants also to consider a larger scale (short to medium term) strategy to address its own energy consumption via in particular the generation of renewable electricity and renewable heat for the buildings. We propose here a number of options and solutions for the Council to generate renewable electricity and heat in order to reduce their current carbon emissions and fossil fuel consumption, as well as making potential financial savings by investing in projects which provide a yearly profit.

Objectives

The main goal of this work is to develop a potential strategy for renewable energy generation in Argyll & Bute Council.

The Council has the following Vision (as stated in the CMP): "Reduce the Council‟s green house gas emissions by harnessing the imagination, commitment and innovation of our staff and the deployment of smart, well researched and reliable technologies which complement and maximize the fantastic opportunities afforded by our weather, landscape and seascape within Argyll & Bute"

We can translate this into well targeted objectives which would fit within the scope of this project.

- First we will look at what the opportunities are in Argyll & Bute relating to weather and landscape. Here we are basically talking about renewable resources that are abundant and 'easier' to harness and worthwhile for the Council considering investing into.
- Second we will evaluate the potential benefits of various technologies and the best way of implementing them..
- Third we will analyze the various scenarios from a financial standpoint and study the key parameters which influence on the financial viability of each technology or scheme

As defined by the Council, focus should be placed on resources which are local, available and abundant, provide a reasonable pay back period and offer the best carbon emissions reduction potential.

Scope and methodology

The subject of this work is to develop a strategy for future renewable energy generation for Argyll & Bute who wish to invest in green energy technologies. The Council have indicated that the focus should be put on generating renewable electricity and heat to cover the energy consumption relating to their buildings.
We will therefore consider different options and scenarios based upon the potential the various technologies offer. The financial and environmental benefits will be set as priorities.

For renewable electricity generation, the electricity may be produced either at buildings sites or separately and be consumed on site or exported to the grid. We are looking basically at offsetting the current grid electricity consumption by the Council.

The general methodology followed is as follows:

- Review the potential of renewable technologies in Argyll & Bute
- Assess data from the Council buildings
- Select the most appropriate options
- Review relevant background information
- Create a set of tools to evaluate renewables contribution and financial viability
- Conduct financial analysis for various scenarios
- Conclusion and recommendations

Renewable Energy Strategy for Argyll & Bute Council

1- Facts about Argyll and Bute

Argyll and Bute Council spreads over 6909 km2 on the west of Scotland. It extends from Campbeltown on the South to Oban on the North and is delimited on the east by Loch Lomond. It includes all the west coast islands within these latitudes, such as Islay, Bute, Cumbrae, etc.

Argyll and Bute is the second largest council in Scotland. Its population is only about 91,000 people, which is equivalent to a population density of 13 habitants per km2 [1,2]

Argyll and Bute has abundant renewable resources such as wind, hydro and wave energy. Its potential in biomass energy is still mostly untapped. The council has for instance 10% of the total UK coniferous resources [3]. The Council has set the following priorities in the past years with regards to renewable energies:

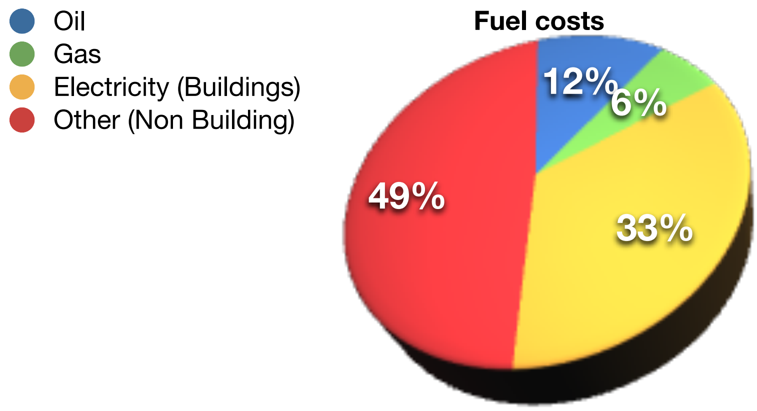
- Turn Islay into a green-powered island.
- Develop timber industry
- Assess and develop the large potential in tidal power
- Implement renewable heat into buildings, with focus on wood fuel

Argyll and Bute face nevertheless the following problems of geophysical or demographic origin:

- Geography is mostly composed of mountains, islands and peninsula, therefore the distances and travel time to central locations are significant.
- Overall climate is rough, mostly wet, cold and windy which requires a higher level of heating and energy consumption.
- Low income (70% of EU average) but high cost of living. Second worst economy in Scotland.
- Electricity grid network is restricted
- High transportation cost
- Low level of population. Imbalanced age structure
- Poor housing energy efficiency (below UK average) and fuel poverty
- Occasional poor air quality

2- Argyll & Bute Council energy demand and cost

Energy costs for Argyll & Bute Council are quite significant. Overall they amount to over £7,100,000 (2008 data). Schools, office buildings, nursery homes and recreational centers are among the largest consumers [4,5]. The Council spends over £1m on lighting alone annually. Fig.1 shows the distribution of the cost for energy.



Energy relating to Council buildings account for 51% of total energy cost incurred by the Council [5].
Within buildings about a quarter of the cost is from oil and over a third is for fossil fuels combined. Buildings energy demand amounts to about 36,000 MWh in heat yearly and the electricity annual demand is about 19,000 MWh [6]

Energy use for buildings accounts for approximately two thirds of the baseline CO2 emissions and within this building heating systems represent a large portion of buildings energy use. Heating oil represents 18% of the emissions baseline.
Electricity use in Buildings accounts for almost 40% of the emissions baseline and when added to electric use by street-lighting, this figure rises to approximately 50%.

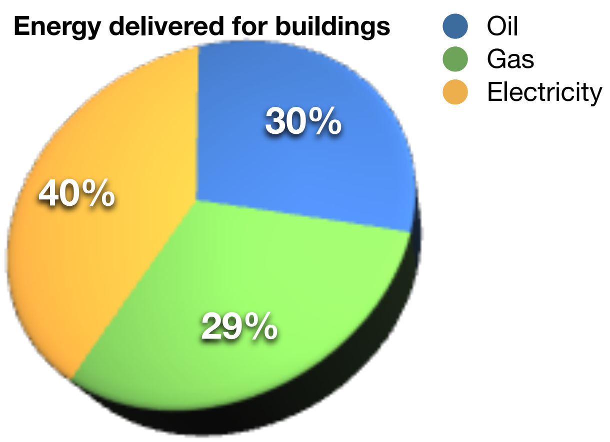


Fig.2

From the point of view of emissions, the Council's total amount at present is about 26,500 tons of CO_2 annually. Fig.3 shows the distribution of carbon emissions. Within the demand relating to buildings, electricity and oil are the largest single items.

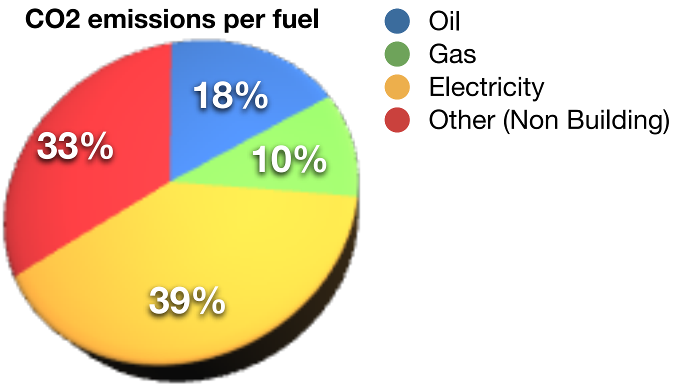


Fig.3

3- Objectives and targets for Argyll & Bute Council

The council aims at reducing costs and carbon emissions relating to its buildings and activities.
Argyll and Bute Council has identified the following areas as sources of emissions which will be covered within the initial scope of the Carbon Management Program [5]:

- Energy Consumption in Council buildings
- Energy Consumption by street-lighting.
- Fleet vehicle fuel consumption
- Employee Business Travel.
- Waste Management (arising from Council owned and tenanted premises)

The Carbon Management Plan (CMP) which Argyll and Bute Council have put together in 2009 sets a target to reduce carbon emissions by 20% by 2014. The corresponding CO_2 reduction is 5298 tons. To achieve a 10% reduction by 2012 means an absolute reduction in emissions of 2,500 tonnes of CO_2 [5]
The plan also calls for potential financial savings to the Council of about £800k per annum. The reduction of fossil fuel consumption should be 12% within the period of the plan [5]

The CMP targets the following areas:

- Organizational and behaviour
- Energy saving solutions

- Transport & travel
- Renewable energy technologies

In this work we shall only focus on the fourth point: renewable energy (heat and electricity) generation

4- Current plan of Argyll & Bute Council

The 2012 plan deals mostly with energy saving measures, fuel consumption reduction and replacement of oil heating systems by efficient gas boilers. There are also projects of oil replacement by biomass and a few small wind turbines are considered at some sites.
It is projected that achieving the 2012 target will require investment of approximately £2.5m in capital but could also also deliver £800k of revenue savings per annum [5]
The average payback period for projects is 4.7 years. The estimated average return over these projects (savings per annum divided by capital investment) was evaluated to be close to 30%
The average CO_2 saving normalized to the capital investment is 1 tCO_2 per k£ invested.
It is important to note that most of these projects do not involve renewable energy generation, many are oil to gas conversion, others are about insulation upgrade and other energy savings measures and several are actually direct costs or emission cutting measures such as mileage reduction for staff travel. These projects have a higher return and shorter payback period than project involving renewable energies.
A more detailed analysis shows the following:

Oil to gas conversion:

- The average return is 30%
- The average payback period is 3.5 years
- The CO_2 savings are 0.7 tCO_2 per k£

Oil to gas is therefore advantageous from the financial point of view (very short payback period) but below the average from a carbon saving standpoint. Note however that gas prices have been assumed constant and that in case of high gas price inflation the annual return would decrease!

Oil to biomass conversion:

- The average return is 11%
- The average payback period is 9.7 years
- The CO_2 savings are 1.05 tCO_2 per k£

The CO_2 savings are above the average despite a relatively high capital cost as compared most other projects

Biomass conversion provide an acceptable payback period and a good carbon reduction contribution

Wind turbine (small scale):

- The average return is 8%
- The average payback period is 13.7 years
- The CO2 savings are 0.4 tCO2 per k£

Small wind is not very attractive from a financial point of view and provide limited carbon savings in comparison with investment.

Overall we can see that payback period and CO2 savings per k£ invested depend strongly on the type of project!

5- Critical factors influencing renewable energy strategy

Oil and gas price volatility

Fig.4 shows the evolution of prices since 1950.

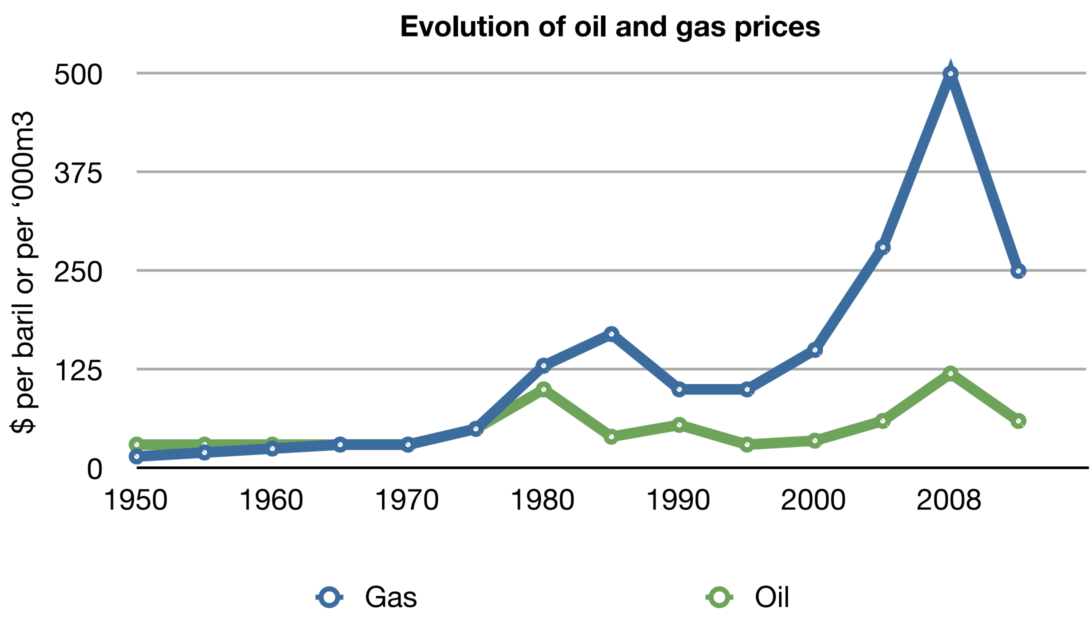


Fig.4

We note that the two curves show a similar trend. Prices were steady for about 20 years then went up during the two oil crisis in 1973 and 1979. Oil prices then dropped back from 1985 until 2000 when prices started to shoot up. 2008 saw oil prices reach almost $150 per barrel,

compared to barely $10 a decade before. Subsequently, oil prices collapsed back to $50-$60 per barrel due to the financial crisis [7,8].
Gas prices reached $500 per ‘000m3 in 2008 [9]

The main conclusion to draw here is that fossil fuel prices have showed very high volatility over the past 3 decades. Prices can triple over a few years simply due to what happens in the world economic environment. This does not take into account possible future large scale political conflicts involving countries having large reserves.
On the time scale of investments on typical energy systems and infrastructure (30 years minimum), the volatility of oil and gas prices poses therefore a major problem as if they were to change quickly (which would be most likely an increase!), they could impact heavily on the systems running cost.

It is also clear that fossil fuel depletion is coming closer and closer, with oil reserves due to run out in the next 50 years or so if world consumption continues to rise [10,11]. Natural gas reserves are evaluated to be about twice as much as oil.
It is therefore anticipated that fossil fuels prices will rise in the future, but no one knows by how much. We have taken this into account in our simulations by incorporating an average yearly inflation rate.
Another factor is the potential future adoption of a carbon tax, likely to be implemented in Europe first, which could impact further the price of energy generated from fossil fuels.

It is highly risky (in particular for Argyll & Bute Council) to depend on either oil or gas for their heating needs. Even local problems such as strikes in oil refining or distribution have in the past caused major concerns to the Council. The risk is therefore two-fold:

- Financially due to high volatility of prices and uncertainties regarding future market trends
- Security of supply due to possible disruption in local delivery network and the remote aspect of many of the Council’s facilities

Grid electricity price volatility

Rising fossil fuels prices will inevitably drive up (with a delay) the price of most other goods. Electricity prices in particular will be affected as most production is still from fossil fuels (including coal). Electricity prices may be stabilized early enough in the future if large scale implementation of renewable energies worldwide (and probably some additional nuclear capacity) is done early enough, but this is a challenge!

The good news 'in a way' is that higher electricity prices will make renewable energy generation more cost competitive as compared with fossil fuel based technologies and should therefore contribute to boost their development.

Fig.5 shows the price of electricity from now until 2040 according to various inflation rate scenarios.
Our average and standard scenario would be about 3% annual increase (slightly above the national RPI) leading to a cost of 28p/kWh in 2040. A rate of 1% would lead to only 16p per kWh in 2040 but is extremely unlikely in our view (for instance France recently announced that its electricity prices would increase by 10% over the next two quarters! [12])

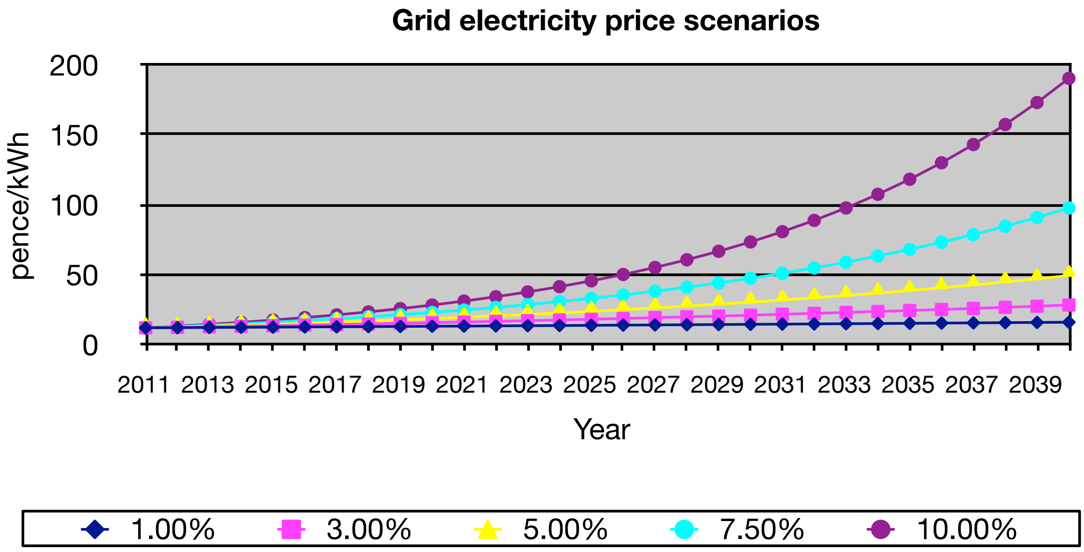


Fig.5

What may well happen however is that electricity prices increase faster, at rate of say 5% or higher. There are a number of reasons why this could happen, at least for a period:

- The decommissioning of nuclear plants in UK and other EU countries
- A larger demand in new EU members, and
- The fact that renewable energies new capacity is not growing as fast as needed.

Germany has announced in June 2010 it may delay the decommissioning of its remaining nuclear power plants by up to 20 years, despite strong public opinion opposition to this [13].

Financial incentives (FIT and RHI)

- FIT scheme:

Feed-In Tariffs (FIT) were introduced in April 2010 to help boost the renewable electricity market by shortening the payback period for installations.

The tariffs in place are summarized in table 1 below:

Technology	Range capacity	Pence/kWh	Years
Anaerobic digestion	≤500kW	11.5	20
Anaerobic digestion	>500kW	9.0	20
Hydro	≤15 kW	19.9	20
Hydro	>15 - 100kW	17.8	20
Hydro	>100kW - 2MW	11.0	20
Hydro	>2kW - 5MW	4.5	20
Micro-CHP	<2 kW	10.0	10
Solar PV	≤4 kW new	36.1	25
Solar PV	≤4 kW retrofit	41.3	25
Solar PV	>4-10kW	36.1	25
Solar PV	>10 - 100kW	31.4	25
Solar PV	>100kW - 5MW	29.3	25
Solar PV	Standalone[C]	29.3	25
Wind	≤1.5kW	34.5	20
Wind	>1.5 - 15kW	26.7	20
Wind	>15 - 100kW	24.1	20
Wind	>100 - 500kW	18.8	20
Wind	>500kW - 1.5MW	9.4	20
Wind	>1.5MW - 5MW	4.5	20

Table 1: FIT tariffs in UK starting April 2010

The FIT scheme applies to most renewable electricity sources and in particular to wind power and PV panels. FIT payments are for a period of 20 years for wind power and 25 years for PV. CHP systems are covered by FIT only at very small scale and within limits [14,15,16]
More information is provided within the financial analysis of wind power and PV.

- RHI scheme:

We have analyzed the information provided by the government [17,18] on the RHI scheme. One critical aspect of the scheme is that the RHI tariffs are set so that people don't generate more heat than they need. In fact it is pointless putting in a renewable heat system without ensuring first the building is energy efficient so RHI payments are based on the heat requirements of a properly insulated property.
Minimum energy efficiency criteria are used for the deeming approach to measure heat demand are based on a minimum energy efficiency. For domestic houses, this should include a loft insulation of at least 125mm and cavity wall filled where appropriate.

The RHI apply to most renewable heat systems apart from a few exceptions such as wood stoves for which the actual output and contribution is difficult to evaluate and measure. RHI also do not apply to CHP systems but apply to bio-diesel or biogas.

Table 2 summarizes the different RHI rates of interest:

Technology	Range capacity	pence/kWh	Years
Solid biomass	<45kW	9	15
	45kW-500kW	6.5	15
	>500kW	2.5	15
Solar thermal	<20kW	18	20
	20-100kW	17	20
GSHP	<45kW	7	23
	45kW-350kW	5.5	20
	>350kW	1.5	20
ASHP	<45kW	7.5	18
	45kW-350kW	2	20

Table 2: RHI rates

For small systems the payment will be based on a 'deemed' heat output calculated on what the installed system would be expected to deliver if the property were well insulated (see below). The building energy use will be assessed using Standard Assessment Procedure (SAP) or similar procedure, which identifies the appropriate heat demand of the building based on the minimum energy efficiency measures required.

For medium-scale solid biomass installations there will be the option of choosing the ‘deemed’ heat output approach described above or metering. If metering is chosen, the same tariff levels will apply however, if the metered amount of kWh used exceeds the deemed number, a lower tariff per kWh will be paid for the excess.

Part A - General Information

☐ WIND POWER

1- Background information

Basic theory

A wind turbine is designed to convert mechanical energy from wind into electrical energy. As air flows through the rotor it makes it turn to drive a generator and produce electricity.
The power output is proportional to the cube of the speed so there is a great benefit in operating where the wind speed is higher.
The maximum amount of energy that can be extracted from the wind kinetic energy is about 59% of the available energy, it is known as the Betz limit. The actual ratio between the energy extracted and the wind energy available is referred to as the power coefficient (Cp).
The power output can be calculated with the formula: $P = 0.5.\rho.A.Cp.V^3$ where ρ is the air density, A is the rotor area and V is the wind speed before going through the rotor.

Wind turbines are designed to rotate only when the wind has a minimum value (cut-in speed) and will stop if the wind speed is too high (cut-off speed), mostly to prevent equipment damage. Turbine are rated at a certain speed (and corresponding power), therefore when the wind speed is higher than the rated speed the power output remains constant.

Capacity factor

The maximum amount of energy that a turbine could produce in one year is equal to its rated power x 8760 hours, assuming the wind was blowing constantly at sufficient speed.
In practical situations the wind does not always blow at the rated speed so the energy produced is less. The capacity factor is the ratio of actual energy produced in a year to the maximum amount which could be generated at rated power. The capacity factor is a very important parameter to assess wind potential energy yield and financial viability.
The capacity factor is highly dependent upon the location where the turbine is installed and the environment of the turbine.
The capacity factor can be evaluated through simulation tools such as HOMER or MERIT using hourly climatic data taken at more specific locations. The capacity factor may vary from year to year due to different weather conditions.

Global status of wind power

The total potential (economically extractable) of wind power available worldwide is very important, even when we compare it to the current power demand. It is estimated at 72 TW, compared to about 15 TW worldwide demand (2005) [19,20,21]
The exploitation of this massive potential has been limited by high capital costs and competition from cheap fossil fuels, as well as lobbying from the existing energy industry, such as the nuclear sector. Recently wind power has started to grow at a fast pace, following rising concerns regarding global warming and fossil fuel depletion.

In 2009 the global market has grown by 41%, this demonstrates how attractive wind power is as compared to alternative (non renewable) technologies, leading all other forms of energy generation by a significant margin in US and Europe, and growing by more than 100% in China [46]

Global wind power capacity worldwide has increased by 32% to over 150 GW in 2009 [22]. It is anticipated that the world will have more than 200 GW of installed wind power capacity at the end of 2010, and this should double to 400 GW by 2014.

From a global finance standpoint wind power is one of the few technology fields that have managed well through the latest crisis. Offshore wind is creating some of the largest infrastructure projects in the world and the scale of investment is so massive that institutional investors like pension funds and other investor funds are now highly involved.

Renewable energy technologies are in general innovative and drive economic growth. Indications at present are that long-term prospects for renewable energies and specifically wind power are quite good, driven by climate change, future carbon tax exposure, rising fuel-price, energy security and fossil fuel depletion.
Short- term action is necessary to build the needed infrastructure which will ensure long term objectives, requiring massive amounts of investment to reach ambitious cleaner energy goals. According to the IEA's World Energy Outlook 2009 [23] the required amount of investment will reach US$500 billion per annum by 2020, and US$270 billion per year until 2030 for the renewable power sector (including large hydro). Public finance must play a more catalytic role by prompting a huge amount of private capital into renewable energy development, in particular wind power.

The US is the country which have the largest wind power capacity and it installed an additional capacity worth 10GW last year. China was however the world's largest market in 2009, more than doubling production capacity from 12.1 GW in 2008 to 25.8 GW and has passed Germany to become the world's second largest wind power market [22]

The top 10 countries for wind power account for 86% of global generation. The UK is currently ranked in 7th position in 2009 but will be installing the largest off-shore capacity in 2010 [22]

The EU remains the world's leader in installed wind energy capacity, and is among the strongest regions for new development, with 10 GW of new capacity in 2009 representing an increase of 15% to reach a level of 75GW.

In the EU, wind power is by far the most popular choice for new capacity among electricity generating technologies and has the largest market share. Wind power represented 39% of the overall 26 GW installed in the EU in 2009.
Germany has over 25GW installed capacity supplying 7% of its electricity demand and the wind power industry employs over 100,000 people there.

Offshore wind is becoming a major energy source as well. In 2009, the EU cumulative capacity increased to 2GW, mostly in the UK and Denmark.
For 2010, it is expected that another 1GW of offshore wind will be installed. In the long term offshore wind will surpass onshore wind as the potential is a lot larger, but offshore wind technology is not yet as mature as onshore.

The target for renewable electricity in EU is to provide over 30% of the EU's power by 2020 and wind power is set to contribute at least half of this. This brings total installed capacity of wind energy to 230 GW, producing 580 TWh of electricity.

The UK has among the best wind resource worldwide (highest in EU) but has taken a slow start. UK capacity however has grown by 1GW to reach 4GW in 2009, and another 10GW are in the pipeline to be on line by 2012 or so.
The UK has set the target to reach 14GW onshore in 2020 and has plans for setting up to 50GW off-shore.
Small and medium wind has also potential in UK. With the set up of new FIT in 2010 the UK government estimations are that 2% of the country's electricity demand could be met by small scale renewables (of which wind would be a significant part) in 2020.

Wind power penetration in national grids [21, 24]

Due to the unpredictability and intermittency aspects of wind, wind power penetration will necessarily have its own limits.
High penetration raises the cost of wind power due to added costs for regulation and demand management as well as grid inter-connection or storage.

It is important to note however that the larger the grid the higher wind penetration could be, hence the need to increase the grid infrastructure at European scale and also to potential remote on-shore and off-shore sites.
Wind penetration within national grids is still low overall however a few countries have relatively high penetration of wind energy: Denmark (19%), Spain (11%), Germany (6%). Denmark has a target to reach more than 30%.
These are average figures, if wind blows hard then wind power will provide a percentage of the power on the grid substantially higher than the penetration level for that grid. The record was achieved in 2009 in Spain when the wind energy produced during half a day covered more than 50% of the electricity demand [25].

Benefits of wind energy [1,2,3]

- Wind energy is among renewable energy sources with higher potential for Europe
    - Target 20% of electricity production in 2020
- Wind turbines produce
    - No pollution
    - No greenhouse gases
- Wind installations leave no damage to the environment after a site is dismantled
- Most activities such as agriculture can be maintained on a wind farm site
- Wind is competitive from a price point of view
- Wind capacity is fast to build
- Using wind power offsets pollution that would otherwise be generated by the utility company

Classification of wind power

- Small wind refers to turbines with typical power below 25kW. The swept area is generally smaller than 200 m2, corresponding roughly to rotor diameters smaller than 16m.
- Medium wind refers to turbines between 25kW and 100kW
- Large wind turbines range from above 100kW to 6MW for off-shore wind. Larger turbines of 10MW are under development.
- For on-shore wind turbines are smaller than for off-shore and usually below 3MW because there is a size limitation for road transport, according to information from GE [26] the blades length is limited to 60m
- Off-shore turbines need to be larger for cost reasons (installation and foundations are more expensive).

Standard costs for wind power

- Turbines cost from £1k to £5k per kW including installation [27]
- Larger turbines are cheaper on a kW basis and therefore more cost effective. For a turbine over 1MW installed onshore the cost may come close to £1k per kW, but it depends on the connections costs to the grid as well.
- Off-shore wind costs more due to installation and stands currently at £3k per kW but the capacity factors are usually higher. The short term target for off-shore wind cost is £2.5k installed [26]

Manufacturers

Modern wind industry started in 1979 in Denmark when several companies such as Kuriant, Vestas, Nordtank started making commercial turbines [21]. The first turbines were small averaging about 20 to 30 kW rated power. Many other countries have now developed a large scale wind turbine industry. In fact most of the major energy business companies have stepped into wind power through acquisitions (GE, Siemens, Areva,...) which shows that the industry is very promising.

The technology is well advanced and optimised. Turbines of various power ratings are available commercially from many companies. There are already a large number of manufacturers worldwide [28,29], who either make turbines or just specific parts, as well as related equipment (electrical, etc…)
For large size turbine (commercial use mostly) Vestas, GE and Siemens are among the largest suppliers. China wind industry has recently grown very fast, there are two chinese companies in the top five worldwide: Sinovel and Goldwind [22]
The main manufacturers for small wind include for instance Proven [30] or Ampair [31]. Proven has among the longest experience in the field and their turbines have been installed in various parts of the world.
While most large size equipment made by the big manufacturers will be of similar quality standard, this may not be the case for small and medium wind. The key differentiating parameters between these manufacturers include:

- Robustness, longevity
- Blade flexibility
- Material (composites) and design, which influence the maximum operating speed and turbine resistance to strong sustained winds
- Amount of maintenance needed

2- Information relevant to Argyll & Bute Council in relation with wind power

Importance of the site location

- The wind speed at the site must be properly assessed, usually by measuring the speed and direction for 1 year. Data available from maps with average yearly wind speed is not sufficient [32,33,34]
- The area must be clear of obstacles and well exposed. Obstacles will reduce the effective wind speed and/or cause turbulence. This will be a potential issue for Argyll & Bute Council to install small or medium wind on land adjacent to their buildings.
- The turbine must also be at a minimum distance from any building or even areas where people may often gather. This is driven by safety requirements and may make a number of sites with existing buildings run by Argyll & Bute Council not adequate for small wind.
- The turbine should be set at optimum height. If the hub is higher the wind speed will be also higher and more energy will be produced. The installation however will have more constraints, which may also be an issue from the point of view of acceptance procedures for small or medium wind next to Council buildings.
- The distance to the grid should be kept as small as possible to minimise the connection costs.

Capacity factor

Capacity factors in UK range from 25% up [35]. The best reported capacity factors can reach 40-50% in some areas of Scotland. The Whitelee wind farm, which is the largest in Europe, runs at about 30%.
There are numerous reports showing that micro and small wind turbines installed near dwellings will very often perform below what is expected based upon the wind resource available in the area. The issue has been covered in detail in other reports [36,37]
For Argyll & Bute, we could probably say that there should be a wide range of locations where capacity factors will be 25%-35% and that most locations will be above 20% unless turbines are located near buildings where capacity factor could drop below 15%.

Environmental issues

- Visual: there are restrictions on where turbines can be installed and most installations require a permit [38,39,40]

- Noise: a minimum distance should be kept from inhabited areas or buildings, typically a few hundred meters depending on size
- Birds death rate from wind turbines is reported to be small as compared to other human related causes. It is much less than house cats, electrical lines or even windows.
- The influence of wind turbines on bats is not fully understood

Safety issues

- There is an excellent track record so far, the probability of a wind turbine installation or a blade falling down is reportedly very small based upon current data so far.
- Wind turbine installations require electrical installations which therefore pose a potential risk like any other high power electrical equipment.
- Another risk relating to turbine is by far ice formation in winter, leading to potential ice throwing when it melts and blades are rotating. It is essential that turbines installed in the vicinity of inhabited areas or areas where there is a likely presence of people be appropriately monitored, protected or fenced to ensure safety.

Financial issues

- A key financial aspect for wind turbines is the capital cost on a 'per kW' basis.
- Maintenance cost must also be kept low, typically below 2% of capital cost. This may depend upon the manufacturers, in particular for small and medium wind!
- Feed-in tariffs (FIT) are now in place in UK and various countries in order to develop wind power. The FIT are set so that good installations installed in adequate areas can bring a reasonable return to the owners but poor installations (or poor locations) would not.
- The UK feed-in tariffs [15] are dependant upon the power of the turbine.

❑ SOLAR PV

1- Background information

Photovoltaics are semiconductor materials (mostly silicon) which absorb light from the sun and convert it into electricity.
PV systems have been used for decades. Initially they were developed for space applications. The Japanese company Sharp recently celebrated its 50th year in the business [41]

PV systems produce clean energy and nowadays have short carbon lifecycle period. They don't make noise and have little visual effect on most buildings They also require very little maintenance other than cleaning of the surface after they are installed.
PV panels can be recycled, giving the opportunity to reuse the raw materials that have been utilized during the initial production process and reduce the carbon footprint.

Typical PV products carry a 25-year performance guarantee that efficiency remain above 85% of initial value [42]. For instance BP3230T panels produced by BP solar [43]
In practice, high quality PV systems would under normal conditions be expected to last over 30 years and remain close to 90% efficient for most of their lifetime.

Technology

Most PV are based on crystalline solid-state silicon technology, which represents today over 90% of the photovoltaics market. They are the most efficient technology available in terms of energy generated as compared with the solar energy received [44,45,47]

- Mono-crystalline panels are the most efficient and therefore well suited to installations where space is limited. Mono-crystalline panels have an efficiency of 12% to 15% typically
- Polycrystalline PV are considerably cheaper than mono-crystalline but the cells are less efficient (a few percents) because of the imperfections in the crystal structure. As a result they have a slightly lower power output.

Crystalline (mono or poly) silicon-based PV arrays tend to lose more efficiency under high temperature or when shadows fall across the array, as compared to other technologies such as thin films.
Thin films PV based on cheaper technology (lower production costs due to simpler manufacturing process) look very promising for the future, as well as organic materials. The main problem is the lower efficiency (8% or less) but the research community is confident this will improve rapidly. There are novel technology for thin film based on materials with three different band-gaps.

Thin film PV include amorphous silicon, CIGS, CdTe [45,48]
Amorphous silicon is a thin film PV module made of a thin semiconductor film deposited on glass or some other medium.
This technology is still in development and the efficiency of is still much lower than for crystalline modules but the cost per kWp however is also much lower.
Thin film technology is preferably used in large scale projects where return on investment is critical and where there are no space constraints.

One very important fact is that they also perform better in high temperatures or in low/diffuse light than crystalline modules. This allows them to produce around 10% more energy per kWp within the same period.
It is also important to point out that raw material (purified raw silicon) has been a limitation in PV production. If silicon PV production is to keep expanding at high rate then technologies that require less raw material will be preferred.
Single junction amorphous silicon layers are > 500 thinner than those of crystalline silicon and therefore are less exposed to volatility in raw material prices and shortages
The production process is also more energy efficient and therefore has a shorter energy payback time (less than 2 years). As energy prices will increase this will make thin film amorphous silicon technology even more competitive overall compared to solid-state crystalline panels.

PV integrated to buildings (BIPV)

The integration of photovoltaic energy in buildings provides a good opportunity of development for the local construction sector. A number of PV applications can replace conventional building components and provide different functions such as weather protection or heat insulation, etc.

Note that in some European countries (but not in UK) BIPV receive a higher feed-in tariff per kWh generated than standard building adapted PV (BAPV).
This allows to compensate for the extra cost of integrating PV as part of the building envelope. For instance in France and Italy, BIPV already represent over one third of the annual market. In UK, Germany and Spain, where support is not differentiated between both types of systems, BIPV only represents a small share of the market [49,50,51]

Efficiency of PV

The efficiency of standard PV panels commercially available at present ranges from 6% or 7% for thin film materials to 14% or 16% for the best mono-crystalline solid-state materials.

The efficiency of solar cells can be improved by increasing the proportion of the solar spectrum energy converted into electricity within the device. At present the standard way to do this is by connecting several solar cells with different band gaps in series, which is an expensive technology.

It is important to note that efficiencies of 35% or more have been reached for advanced PV technologies involving multi-layer designs. Such high efficiency is higher than standard

thermal based electrical generation processes. However this is based on a costly technology which won't be available for a number of years.
Below are some of the latest developments with regards to efficiency:

SunPower Corporation (CA, USA) announced in June 2010 it has produced a full-scale solar cell with a conversion efficiency of 24.2%. This is a new world record confirmed by the U.S. Department of Energy [52]

A recent breakthroughs on thin film technologies was reported earlier in 2010 by RoseStreet Labs Energy, who have demonstrated the first known multi-band photovoltaic device which includes three distinct light absorption regions integrated into a single layer thin film device. Although we may be still some years away from commercial inexpensive devices, this technology illustrates great promise for high efficiency thin film solar efficiencies which may reach over 35% by potentially capturing most energy within the solar light spectrum [53]

In late 2009, Sharp Achieved 35.8% Efficiency with a triple-junction compound solar cell which utilizes photo-absorption layers made from compounds consisting of two or more elements such as indium and gallium. Due to their high conversion efficiency, compound solar cells are used mainly on space satellites [54]

Germany based Q-Cells announced in June 2010 it has set a record for thin film CIGS PV modules at 13.0% efficiency, confirmed by the Fraunhofer Institute [55]

In February 2010, Mitsubishi Electric achieved a photoelectric conversion efficiency of 14.8% in a 5mm x 5mm thin-film silicon PV cell, which has a triple junction structure that converts a larger part of the solar spectrum [56]

Matsushita and Nanosys are developing solar coatings that could be applied directly to roofs and external building walls. This technology will have lower efficiency but may long term reach very capital cost per kWp [57]

Organic solar coatings are also under development at GE and IBM. They are also the focus of the MolyCell project (€4.6m) in EU headed by France Atomic Energy Agency and involves Siemens, aimed at producing solar power systems at a capital cost of $1k per kWp [58]

Performance of PV systems

PV performance should be measured based upon the energy they produce per year per kWp installed when in operation.

The *capacity factor* is the key metric to consider, it is defined as the ratio of electricity actually produced in a year over the maximum amount which could be produced assuming optimum solar conditions would apply all the time.

The capacity factor would normally be about 8% in Argyll & Bute. It can also be evaluated through simulation tools such as HOMER or MERIT using hourly climatic data taken at more specific locations. The capacity factor may vary from year to year due to different weather conditions.

The performance of a PV installation depends upon the following specific parameters:

- Type of technology (the various types will be presented later)
- Operating temperature. Efficiency is rated at a temperature of 25°C. The power output drops at higher temperature. The life time may also decrease if operating at high temperatures.
- Orientation PVs must face south (northern hemisphere) to operate at optimum capacity factor.
- Tilt angle. The optimum tilt angle depends upon the latitude at the location. PV are more effective if they face the sun as much as possible since their electrical output is determined by the incidence of solar radiation to the surface. The average irradiance in kWh/m^2 per day is the critical parameter which should then be maximum.

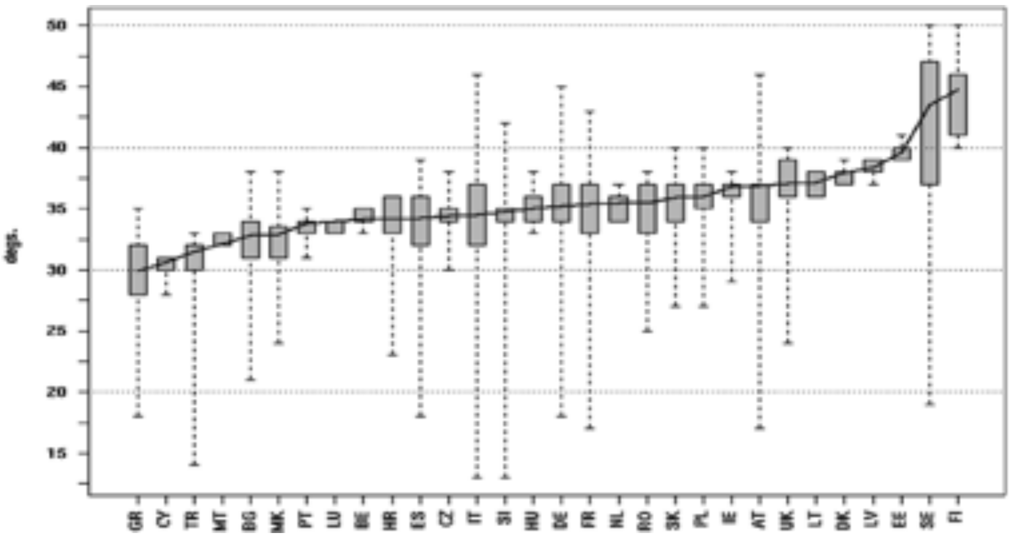


Fig.6: influence of tilt angle
Marcel & Huld - Potential of solar electricity generation in the European Union member states and candidate countries [59]

- Shading. PV systems are extremely sensitive to shading effects as irradiance levels will drop a lot. Thin film solar PV cells are less sensitive to shading effects .
- Irradiance potential at the geographic site:
  - It is the main parameter influencing on the capacity factor of the PV devices. The latitude of the location and the climate conditions are the key drivers. On the

map below, blue areas will have a capacity factor of 6% or less, green areas range from 7% to 9%, yellow and orange are 10% to 14% and dark red areas reach 15% or more.

- The energy produced yearly ranges from 700kWh/kWp (Scotland) to 1000kWh in Germany, up to 1510kWh/kWp in Portugal.

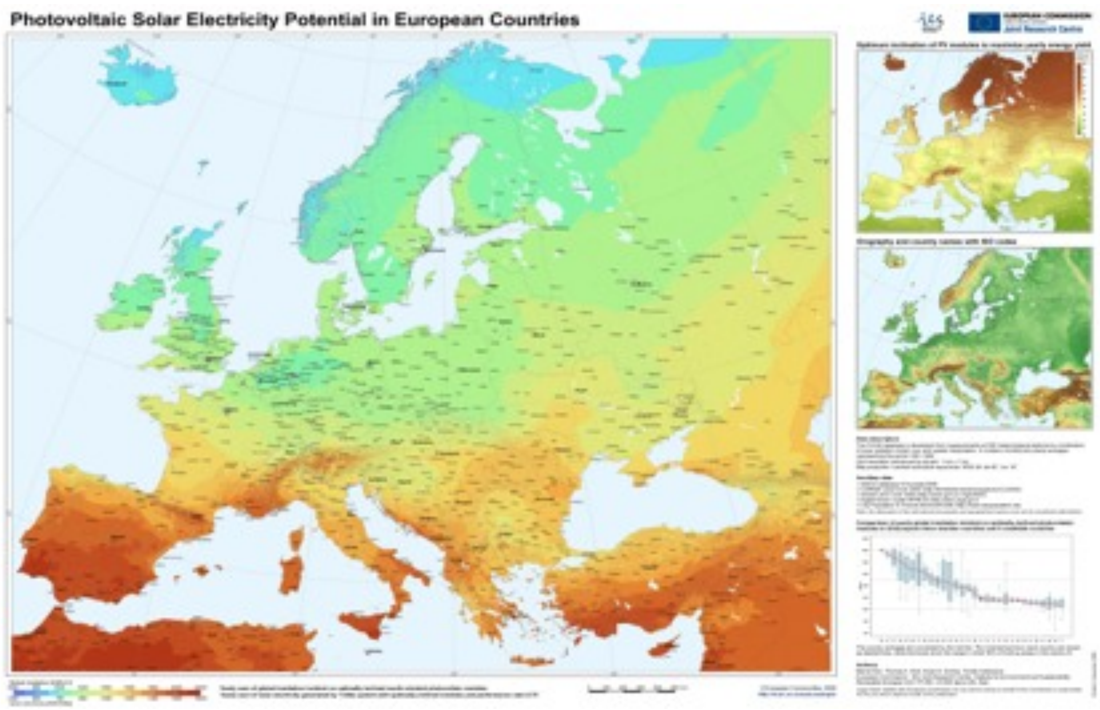


fig.7: Solar map EU [60]

We have taken an average of 8% as capacity factor for Argyll & Bute who benefit from a decent solar resource compared with UK average. Cornwall has the best solar resources in the UK where the capacity factor can reach close to 11% (see below for recent article)
It was announced (Aug. 17, 2010) that German manufacturer SOLON SE and British project developer 35 Degrees Ltd plan to build the first ground-mounted solar power plant in the UK, with capacity of 1.3 MWp solar power plant in Cornwall. 35 Degrees Ltd is planning to install 100 MWp of solar energy over the next five years with in the UK, concentrating in the South West of England.
SOLON's monocrystalline Black 280/11 modules will be used for the PV power plant, located over a 3-hectare ground. Once construction is complete, the solar power plant in Bissoe will generate about 1.25 million kWh of electricity annually (over a 25-year period warrantee).
This is equivalent to a capacity factor of more than 10% [61]

Another example in Germany is the installation of a 162kW solar PV farm in Ettlingen. Once in operation the system should produce 169,000 kWh yearly, which is slightly more than 1 MWh/year per kWp and is equivalent to a capacity factor of 11.9% [69]

World market for PV

Europe is the largest PV market, followed by Japan and the US. Germany is the leader with a cumulative PV power installed of 10 GW, and new capacity of 3.8 GW installed in 2009. Italy is a promising short term market with an additional 711 MW in 2009 [51]

From 2004 till now, the overall world PV capacity has been increasing by about 60% yearly to reach about 25 GW early 2010, but it still represents a small fraction of the 4800 GW of global generating capacity.
EPIA SET for 2020 study [63] states PV could provide up to 12% of the EU electricity demand by 2020 under adequate conditions assuming PV is competitive with other electricity sources in as much as 76% of the EU by 2020, without any subsidy. The future price erosion and competitiveness of PV is a critical point which in discussed in detail later.

In terms of yearly growth EPIA has forecast that the World PV Market for 2010 should reach between 10.1 GW and 15.5 GW of new installations for the year.
In their Policy-Driven scenario, the annual PV market could reach up to 30 GW in 2014.

NB: PV systems operate with capacity factors generally lower than 15% so 1 GW of PV capacity does not produce as much much electricity as 1 GW or nuclear or fossil fuel based capacity!

Manufacturing of PV

Global PV production in 2009 was 12.3 GW with the top ten manufacturers accounting for 45% of this capacity.
Germany, Japan, US and China are the leading manufacturing economies for solar PV.
The leading companies are First solar (1.1 GW), Suntech, Sharp, Q-Cells and the chinese manufacturer YingLi (500MW) [64,65]

Below are some recent developments in the field from the press:

China manufacturer LDK Solar Reached 2 GW Wafer Production Capacity in February 2010.
Flextronics announced in March 2010 the opening in Singapore of a new PV module manufacturing facility, to reach 1 GW Capacity in 2012.

Japanese PV manufacturer Kyocera is planning to reach 1 GW production capacity by 2013 Sharp recently announced it plans to increase its UK manufacturing capacity to 500MW [66,67]

2- Key facts relevant to Argyll & Bute Council relating to solar PV systems

PV systems in Scotland have been largely under-developed mostly due to the high capital price which has made them not competitive. Because of the low insolation levels the amount of electricity produced is small and the payback period is extremely long.
Typical capacity factors for PV systems in the UK would be from 6% to 10%. Previous simulation work conducted using climatic data from Glasgow (see group project 2010: Hybrid energy systems in low carbon buildings [37]) has shown that taking into account inverter losses the capacity factor was 6.9%.

For most parts of Argyll & Bute Council we have assumed a capacity factor of 8%.
Just for comparison, typical southern Europe capacity factors will reach over 15% while large scale PV farms in Arizona and southern California record capacity factors from 19% to 21%. Note however that even in these regions PV systems are not yet financially attractive without incentives due to the current low electricity price versus high capital cost.

The introduction of Feed-In Tariffs (FIT) in April 2010 should help to boost this market by allowing the user to shorten the payback period for PV installations. The FIT scheme will also apply to installations commissioned since July 2008 when the policy was announced. FIT payments are for a period of 25 years [68]

Despite its high capital cost today, PV is however regarded as a technology of choice for the future.
First, the price of PV panels is also expected to drop significantly in the medium and long term as industrial manufacturing yields improve with volume
Second, it is anticipated that the price of electricity will rise in general, making renewable energies more competitive with regards to fossil fuels based electricity.
There are hopes therefore that solar PV may become fairly quickly a competitive form of renewable electricity generation.

3- Future price erosion of PV systems

Today, the installed cost of high-efficiency silicon solar panels varies significantly depending on the location and the size and type of installation.

The US and Germany are two among the best established markets and can be used as benchmarks. The cost of PV installed is about $3k per kW in US at present.
A recent project was done in Ettlingen, Germany by Parity Solar [69] for installation of 162 kWp of PV panels manufactured in China. We contacted Parity Solar for further info. Although the project cost was confidential they stated that a standard cost for large systems in Germany would be €3k per kWp fully installed on roofs. This would be equal to about £2.5k per kWp.

In the UK where the market is still a lot smaller installed cost for domestic PV systems can reach £6k per kW.
In Sicily (Italy) the installed cost has dropped to €4k per kW for large projects.

A recent approved project (June 2010) in Australia features the installation by Trina Solar of PV modules to the University of Queensland in Brisbane, Australia. A total capacity of 1.2 MW solar PV which will be installed on the roofs of four buildings. The system should produce 1,750 MWh of electricity annually.
The total project cost is £4.41m (AUS $ 7.75m). The normalized cost is therefore £3600 k per kWp installed [70]
Higher costs in Australia are no surprise. They can be accounted mostly for the fact that it is a remote location where the market is much smaller than Germany or EU.

The costs we should anticipate for large projects in UK (and EU) should be converging towards the Germany costs as the market grows.

There are three main components in the future price drop for installed PV systems:

- A reduction of installation costs with larger volume and increased competitiveness.
- A reduction of manufacturing cost with larger overall manufacturing volumes (this has already started)
- Last but not least, innovation to develop new and more efficient technologies

The company Solaicx Inc based in California predicts that residential and commercial solar panels made with its silicon material will soon compete with conventional fossil-fuel electricity which costs about $0.1 per kWh.
Their prediction is based on a capital cost of solar cell systems to reach about $1000 per kWp of generating capacity. At this price it is expected that solar cells could generate electricity as low as $0.06 per kWh.
Solaicx has based its low price strategy on making the silicon wafers 40% thinner and increasing carrier lifetime to gain efficiency, allow to overall reduce the panel size per kW rated [71,72]

Today high quality cells are about 16% efficient. Increasing carrier lifetime has led to demonstrate prototype solar cells that are 21% efficient.

❑ BIOMASS

1- Background info

Types of biomass

Biomass fuels include:

- Wood (logs, chips and pellets)
- Agricultural by-products (straw)
- Forestry residues
- Waste from industry (wood, waste grains, etc) [75]
- Energy crops (willow, etc)

All types can in principle be used for producing heat.

Wood is by far the most common source of biomass fuel for heating buildings, and is primarily used in the form of logs, chips or pellets. Industrial large scale boilers use primarily chips and pellets for automated loading.

Whatever the form it is processed in, the quality of wood fuel depends primarily on its moisture content, which is directly related to the fuel calorific value.

Modern biomass boilers are low maintenance, equipped with self cleaning functions and with sensors that monitor various parameters of the combustion process to maximize efficiency.

In addition to pellets, chip and log burning boilers, other specifically designed boilers can also accommodate a variety of feed stocks such as other residues, etc...[73]

We will focus strictly the financial analysis work on wood biomass for heat production by direct combustion, as we are looking at resources to cover space heating and hot water for the Council's buildings.

We also mention here about the main alternative to direct combustion. This include bio-chemical process and processing of waste grains from distilleries or beer breweries.

Waste grains processing could potentially be applied in parts of Argyll & Bute Council such as Islay as it provides a readily available source of fuel. The most straightforward way to proceed would be to dry the waste grain biomass into a fuel with lower moisture content to be burnt in boilers. We will limit ourselves here to providing general info regarding the potential treatment of waste grains, we have not assessed the actual potential resource in Argyll & Bute Council which would need to be done as a separate project.

Biochemical processes for biomass

Anaerobic digestion (AD) of organic waste is the main biochemical process. AD is now at very advanced stage and used at large scale, it has several advantages over aerobic treatments (which are using oxygen) including the production of natural gas and a low energy consumption. Aerobic treatment does not produce gas and consumes a lot of energy for mixing [76,77]

The main problems with AD are the capital investment required. In addition, the fact that it is implemented on large scale only could be an issue in certain areas.

There is also ongoing research for alternative processes (or complementary) to AD such as microbial fuel cells. Israel is the most advanced country in this field. This technique produces no gas but requires no input energy and allows to produce electricity at the same time waste is processed. They can be adapted to processing waste grains as well.

Calorific Value – Moisture Content

The calorific value indicates the energy released as heat when the fuel undergoes complete combustion with oxygen, this is usually expressed in kWh per kg. Note that there is little intrinsic difference in calorific value between different types of trees, it is the moisture content that makes most of the difference.

The moisture content affects the calorific value of a given wood fuel for two different reasons:

- First, any amount of water present within the fuel means that the mass of actual wood matter is less, for instance 1 kg of wood chips with 30% moisture content contains only 0.7kg of 'actual wood'.
- Second, some of the energy produced by the combustion will actually be wasted on heating and evaporating the water present within the fuel. This amount is far from being negligible as both the heat capacity and the latent heat of water are high (respectively 4.18 kJ/kg.C and 2260 kJ/kg).

The calorific value and fuel density must be provided by the supplier.

The range of moisture content (MC) in the raw material can be wide.

- Green wood can reach up to 60% MC which requires drying before using as a fuel.
- Air dried wood is typically around 20% MC
- Oven dried biomass will have a moisture content usually at less than 5%.

It is standard to quantify biomass as a resource to use 'odt' units (oven dried ton) which provide an accurate measure of the biomass fuel value.

In general it is recommended to use fuel with a maximum value of MC=30% [78]

It is necessary to know the moisture content of wood in order to evaluate its energy content, it is common to refer therefore to dry weight calorific value (the energy content at 0% moisture) As an example, the broad chemical characteristics of SRC willow on a percentage basis are: Cellulose 40 %, Hemicellulose 30 % and lignin 30 %. SRC willow has a net calorific value of around 18.5 GJ/ton (5140 kWh) dry weight. This value is roughly equal for most wood [79]

Density of biomass fuel

Another important parameter of biomass fuel is the density (in kg/m3) as it affects the total volume requirement for a given amount of energy within the fuel. It is very relevant to the storage scheme as denser fuel requires less storage space for the same volume or the same total amount of energy available per kilogram of wood.
It is standard to use the dry bulk density as a measure of density, typically 190-195 kg/m3 for softwood and 250-260 kg/m3 for hardwood [80,81].
Logs have several advantages over chips including a lower cost and higher energy content (when air dried) but as a fuel logs are more labour intensive in terms of maintenance as boilers normally require manual loading of logs. Installations using logs as fuel also have lower cost.
In the case of large size boilers requiring automated loading the choice is therefore limited to chips or pellets. The main factors influencing whether to choose one option or the other are:

- The financial cost (installation and fuel)
- The storage space restrictions
- The availability of a fuel supplier locally

These are of course to be evaluated on a case by case basis

Waste grain processing into biomass fuel

The brewing sector is likely to see some changes in the near future due to changes in various waste disposal regulations coming into force in most EU countries, where dumping of organic waste with a total organic carbon content (TOC) exceeding 5% has or is about to become prohibited.
As a result, industry will now have to look for ways in which waste substances from breweries can be efficiently used. Note that the waste yield is quite high, approximately 200 kg are produced per 1 m3 of beer [75,82]

Spent grain are a by-product in the brewing process, usually it is discharged by mash filter and holds a moisture content of approximately 75–80%. At this level of moisture content the grain is not biologically stable and has to be further treated to prevent biological degradation.

At present spent grains are usually fed to cattle. In a wet state, they have to be used within 2–3 days so to make them suitable for longer storage it is necessary to dry them. This has been done mainly with so-called contact dryers, which is relatively cost-intensive and raises the sales price considerably. The cost of thermal drying is significantly higher for high moisture content, the mechanical drying route should be preferred until moisture content is low enough for the drying process to be viable.

Possible other use for spent grain are:

- Use as additive in lightweight brick manufacture.
- Production of pressboard for the construction industry.
- Additive in foodstuff or in animal feed.
- Use as biomass fuel for heat generation, however the very low calorific value is a problem
- Use in bio-chemical process

The brewery will have to pay for every disposed ton of spent grain not processed. Another possibility of using it is as a source for thermal energy on-site or locally.
Thermal energy is required for the brewing process. Energy prices have been rising in the past and will keep on rising in the future, making the energy supply of a brewery a growing cost factor.
The key is to find a process to make the energy accessible at a reasonable cost, therefore it must be focused on high energy efficiency.
Alternatively the fuel can be sold to a local facility equipped with an appropriate biomass boiler.

The basic problems are summarized below:

- High water content (about 80%) therefore a very low calorific value.
- Mechanical drying is necessary as thermal drying is too expensive.
- Water pressed out will have a very high organic compound content.
- Separate thermal drying should be avoided.
- Attention should be paid to NOx formed in the combustion as they differ for different types of biomass fuel.

The basic treatment of spent grain would include:

- De-watering process (mechanically)
- Combustion in a biomass boiler. The thermal energy from the combustion can be used to generate saturated steam or hot water to cover up to 80% of a brewery heat demand.
- By-products such as water (pressed) and ashes are also recycled. The water obtained can be processed through anaerobic treatment which will provide clean water and

biogas. The biogas can be used on site for secondary combustion process. The ash produced can be used for fertilizer manufacturing locally.

The key steps in the energy treatment of spent grain are the pressing and the combustion.

- For the mechanical dewatering stage pressing devices such as screw presses and belt presses can be considered, according to past experiments belt presses offer the best results. The water content is reduced from 80% to less than 60%. This allows the material to be stored between 2 and 3 days.
- For the combustion the biomass boiler should be adapted to the special burning characteristics of the spent grain.

Combustion in an air-cooled moving grate furnace could provide about 1 kWh of thermal energy by processing 1 kg of wet (<60%) spent grain.

The boilers can run at +/-25% of nominal rating, providing flexibility to respond to changes in the amount of energy required during the brew cycle. The refractory lining in the boiler is designed so that heat is available for preheating and drying of spent grain in addition to pressing process.

The calorific value of the spent grain is directly related to its moisture content. The dryer the grain, the higher the heat content.

For biomass in general, the calorific value of the dry substance is similar to lignite coal and is equal to approximately 21 MJ/kg (or 5.14 kWh/kg).

This calorific value varies linearly with the moisture content (assuming the biomass is preheated to a temperature above 100C and the sensible heat relating to the water can be neglected)

In order to be used as a fuel, the water content of spent grain has to be below 60%. Drier material will be more efficient, at MC=25%-30% the energy content becomes about 3.4 kWh/kg

At a water content of about 80%, wet spent grain has practically no calorific value because all the energy goes toward evaporating water. Pre-drying is therefore necessary.

Ash from spent grain is totally different from ash from wood. For 1 ton of wet spent grain approximately 9 kg ash are generated. This ash has a high P_2O_5 content above 60% which is a very important component in fertilizers.

20,000 tons of wet spent grain would generate 180 tons of ash per annum. This amount is sufficient to produce 920 tons of high grade fertilizer, this value of P_2O_5 makes a contribution toward operational expenses.

Two different methods to recycle pressed water are applicable: It can be either treated in an anaerobic wastewater plant or be directly sent back to the process by mixing it with brew water.
The mechanical dewatering from 20% to more than 40% dry matter results in 520 liters of water per ton of wet material.
By mixing it with brew water for mashing at a ratio of 10:90 the brewery gains additional extract. One percent more yield in the brew house is possible. The benefits are water savings, energy savings, and malt savings. An important issue is the effect on beer quality is not adversely effected. An increased content of amino acids and unsaturated higher fatty acid

To summarize therefore, financial benefits form processing wet spent grains into biomass fuel for heat generation can be obtained from:

- The reuse of pressed water
- Combustion of grains
- The sale of ash
- The biomass RHI payments

Production of biomass versus area of land

Biomass wood crops are usually willow, poplar, cottonwood or eucalyptus.
Tree planting densities range from 2,450 to over 6500 trees per ha. Higher yields are obtained using weed control (either mulching, composting, or a combination) [83]

The water content varies with the age of the trees, it is about 60% for trees less than 4 years old which which makes it the optimum time for harvesting wood biomass. The moisture content will only drop by a few percents within the next several years.

Yields for eucalyptus plantations (up to 6600 trees per ha) can reach around 60 tons of dry matter per hectare (25 ton per acre) per year.
The final wood chips dry weight is about 80% of raw harvested weight, so the maximum energy content of final wood chips (assuming 5140 kWh per ton dry matter) would be about 250MWh per hectare. This value is very high and can be achieved only when all conditions are optimum

Willow coppice yields are somewhat smaller. In UK they can reach 44 ton of dry matter per ha (18 ton per acre) per year [84]
These are maximum values obtained for the better species with high density of trees planted in the best areas. (DEFRA, 2002)

On average the UK commercial yields for willow are over 10 ton of dry matter per ha each year. The energy content is evaluated to be about 41 MWh per ha (assuming an 80% yield on wood chip processing and 5140 kWh per ton dry matter)[88]

For comparison, it is estimated that the energy yield obtained for bio-energy crops converted via silage to methane is about 20 MWh per ha (2 GWh/km^2), which is about half the value of direct combustion of biomass [85]

Returns in US farms for wood chips sold at $30/ton are about $240/acre/year including costs, which is equivalent to about £350/ha/year [86]

Manufacturing of biomass fuels

Processing of wood chips is done by mechanical shredding of trees, branches and smaller products into wood chips. The raw material comes from forest up-keeping, arboricultural, energy cropping or residues from commercial activities.
The size range is quite important as different types of boilers will have different specifications for this.
Wood is generally dried before processing into wood chips. Moisture content for wood chips can reach over 50% but above 30% MC there is limited storage possibility due to decomposition and mould formation. Storage conditions can be critical, especially long term and require adequate ventilation.
Example: Type M30 (Moisture ≤ 30%) is suitable for storage

Processing for wood pellets is mostly done by compressing saw dust or wood shavings. This process allows to obtain a higher density and a lower moisture content than wood chips, usually from Type M10 (Moisture ≤ 10%) or M20 (Moisture ≤ 20%) and produce less ash. This makes storage and maintenance of the system more efficient. Wood pellets are a very flexible fuel, which can be used both for small residential heating or large power generation plant.
Pellets have the highest calorific value, the highest density for storage and are easy to handle but they are more expensive.

Biomass boilers

Biomass boilers are now standard technology and fully optimized, with efficiency around 90%.
Ash content is generally limited to about 0.5% and can be used directly as fertilizer.

Boilers are designed to work at high power rather than low power. They should be used in continuous mode, avoiding cycling as much as possible.
They are therefore not suited to deal with peak demands. Sizing a boiler based on the peak demand would lead to issues relating to the boiler working most of the time at lower power and low efficiency [89]
The turn-down ratio is the minimum power output for which good efficiency can be obtained, typically this value is around 30%.
The fuel should be as dry as possible for the combustion to operate at high efficiency. The fuel goes through a drying process before entering the combustion chamber, which can be done by using the energy generated by the boiler itself (waste heat) or through a secondary source of heat. In either case, below a given power output, the boiler will lose efficiency and the emission levels will increase.
This requirement for boilers to be sized below peak demand will often require a backup system to be added to the installation (gas or electrical being the most common options).

Thermal storage buffer tank

The purpose of a buffer tank is to store water at high temperature is order to:
- Provide readily available hot water
- Prevent the boiler from switching on and off too often (cycling)
- Act as a central point for the generated heat to be delivered when using more than one source of heat.

There is a large variety of buffer tank configurations, designed to cope with hybrid heat systems comprising different components such as: biomass boiler, heat pump, solar collectors and a gas boiler or electrical heaters.

2- Alternative application of biomass: Carbon offset from trees

One option which has been considered in the past may be to plant trees and maintain forests on a permanent basis for instance as national parks (this would be separate from forest grown for producing biomass where trees are cut and burned then replanted).
Activities within the park could help finance the cost. Maintenance of the park should also include efficient recovery of waste wood biomass which would provide additional carbon savings.
In UK climatic conditions forests allow to compensate for carbon emissions at a rate of 10,000 tons of carbon dioxide per km2 over 100 years [90,91,92].
To offset 10,000 tons yearly would require therefore 100 km2 of forest.
Clearly this method does not provide an effective solution from a space and effort point of view, however it may contribute to reduce some small proportion of the emissions. Let's not

forget that the UK targets an 80% for 2050 therefore a scheme which would only offset 4% of today's emissions would offset 20% of emissions in 2050.

The current total yearly emissions of Argyll & Bute Council amount to 26,500 tons of CO_2
To offset this using permanent forests would require 265 km2 of forest, which is obviously a very large number!
Assuming emissions were reduced by 80% (UK 2050 target), the area required to offset the remaining 20% (5,300 t CO_2) would be 53 km2.
To offset 20% of emissions in 2050 could be done with an area of only 10.6 km2

Based upon the size of Argyll & Bute Council, it seems quite realistic that a significant part of the long term remaining emissions of CO_2 be offset through the maintenance of parks or other types of green grounds.
The use of wind farm land should also be considered for this application as the presence of turbines requires very little actual ground space occupation.
Such a scheme is to be considered also along with biomass (wood ships) production from the remnants coming from maintenance of the grounds.

Obviously the question of ownership and who should get credit for carbon offset from trees in a national park is outside the scope of this work. We have looked here purely at what can potentially be done technically in the short to long term.

3- Potential for biomass in Scotland

In Scotland 30% of primary energy consumption is for heat, but just a fraction of this comes from biomass. The limiting factors to expansion of the sector have been:

- Equipment capital costs
- Availability of trained professionals
- Lack of local production

Forestry is already an extremely important part of Scotland's economy – forests currently cover around 17% of the land area and produce around 7 million m3 of timber a year. It is anticipated that the production will increase over the coming decade [94]

In order for (woody) biomass to be considered a sustainable and renewable resource it is essential to re-plant as trees are consumed. Between 2001 and 2005 about 38,000 hectares of new planting has been achieved. Forestry Commission Scotland is currently looking at ways to boost these planting rates [94]

Current estimates in Scotland are that the total potentially available volume of virgin woody biomass is approximately 323,000 odt (which roughly represents 650,000 m3)
At 5140 kWh per odt the energy content is roughly equal to 1.6 TWh.

Estimates are that around 50,000 to 90,0000 ha of land would be suitable for SRC planting, but obviously the implementation will depend on incentives and relative values of crops.
At 20 MWh per ha, the potential energy production would be 1 TWh to 1.8 TWh per year.
In September 2005 the Scottish Executive's grant aid for farmers to establish SRC willow or poplar as an energy crop was brought into line with the equivalent grant in England. The new grant now pays an all-inclusive, flat rate of £1,000 per hectare. Payments will be made to farmers who have a supply contract with an end user [95,96]

Biodiesel crops will compete with biomass in terms of land utilization. The major biodiesel feedstock crop grown in Scotland is Oil Seed Rape (OSR). It is already widely grown and yields are high. A total area of c. 35,000 ha of OSR was planted in Scotland in 2005 producing 124,000 tonnes, of which 9,000 ha was planted as non-food set aside and energy crop.
However, it is a relatively expensive feedstock for biodiesel production. In addition the energy balance for biodiesel production is not good environmentally as compared with other biomass processes [97,98]

There are an estimated 4.3 to 5.2 million tonnes of waste biomass generated each year in Scotland.

- The domestic sector (subject to recycling and landfill diversion targets) accounts for about 0.8 to 1.6 million tons
- The commercial and industrial sectors for 3.6 to 4.4 million tons and is largely under-developed

By using residual waste from the waste management stream which would otherwise go to landfill, thermal treatment facilities have the potential to reduce risks of leachate and soil and water contamination. It also avoids the production in landfill sites of methane which is powerful climate change gas

All resources combined together, Scottish Renewables reported in June 2006 that Scotland's biomass resource could produce over 5 terawatt hours (TWh) of heat and electricity by 2020 [99]

4- Environmental impact

The impacts on the environment from the development of a biomass feedstock will depend on the land use the biomass crop is replacing, the choice of crop and the way it is managed.
For woody biomass, the UK Forestry Standard covers the sustainable basis of all forestry practice in the UK
Potential impacts on the soil quality from the growth and harvesting of wood biomass feedstocks are largely addressed through compliance with the UK Forestry Standard and associated guidance such as the Forestry Commission
It is also important to consider emissions from biomass combustion, although most of the air quality problems identified to date (local scale) have been in large urban areas and are caused by vehicle emissions rather than biomass processing plants.

- Potential of renewable energies in Scotland

Renewable energies in Scotland have a massive potential by EU but also by global standards. The overall renewable electricity generating capacity is currently estimated over 60 GW, which in comparison is considerably greater than the existing fossil fuel based capacity at about 10 GW [101]
For instance most of the UK hydro is in Scotland with an existing installed capacity of 1.3 GW.
The estimated potential for wind is 36.5 GW
The potential capacity for tidal is 7.5 GW, representing 25% of the estimated total EU capacity
The estimated potential for wave power is up to 14 GW, or 10% of the EU capacity.
Solar energy potential in Scotland is low but can be estimated at about 500 MW [100]
The total biomass potential energy (heat and electricity) could reach 5 TWh annually

The four major resources combined represent 98% of the potential:
Wind represents 60% of total potential capacity, wave and tidal represent 35% combined, hydro is over 3% and geothermal heat for heat pumps represents about 2%
Solar and biomass (wood) are less than 1% of capacity.
We have plotted on fig.8 the distribution of the potential renewable capacity (100% = 62 GW)

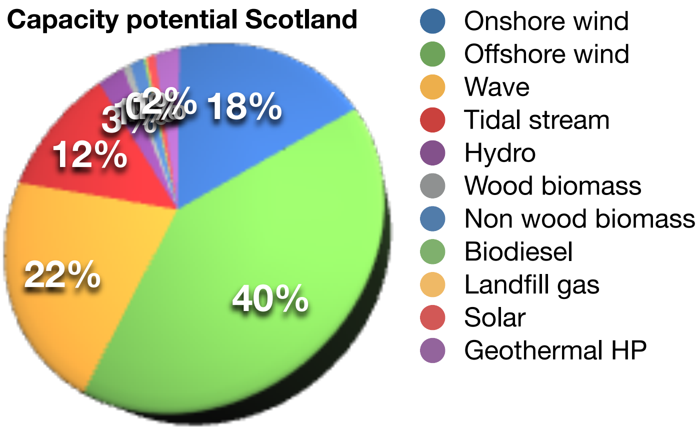


Fig. 8

The total estimated potential annual energy production from renewable resources is about 235 TWh.

In 2002, Scotland consumed a total of 175 TWh of energy in all forms. This number is roughly equal to the 1990 consumption. Only 20% was electricity, the majority of it being from the burning of oil (41%) and gas (36%) [102,103]

In 2006 the total installed electrical generating capacity from all renewable energies was less than 2 GW. Renewable energies are now contributing over 19% of total electrical production and represent 4% of all energy usage [104]

Scotland has ambitious targets for renewable energy production, despite the fact that it has significant quantities of fossil fuel reserves:

- Over 60% of the EU's proven reserves of oil
- Over 12% of the EU's proven reserves of gas
- 69% of UK coal reserves [105]

In 2005 the target was set for 2010 to reach 18% of Scotland's electricity production by renewable sources, increasing to 40% by 2020

In 2007 the target was increased to 50% of electricity from renewable energies by 2020

A new target to reduce overall greenhouse gas emissions by 80% by 2050 was announced in the 2009 Climate Change Delivery Plan [106]

The 2006 stern report proposes a 55% reduction by 2030 [107]

Part B: Analysis of renewable energy resources in Argyll & Bute Council

1- Overall analysis

We have compiled a summary table (see table 3 below) listing all potential renewable technologies and the key parameters for evaluation where we have scored the technologies on each parameter and compiled the totals. We are looking for the highest total score without any minimal score (min = 1).

	Availability of resource	Council's authority	Applicable to buildings demand	Maturity of technology	Financial risk	Acceptance procedures	Physical installation	Carbon benefits	Potential for local economy	Total
Wind Onshore	5	4	4	5	4	2	3	5	4	36
Wind Offshore	5	1	1	3	3	3	2	5	4	27
Tidal	4	1	1	3	5	3	1	5	4	27
Wave	4	1	1	1	1	4	1	5	3	21
Hydro	3	1	1	5	4	3	3	5	3	28
Biomass Wood	4	5	5	5	4	5	5	4	5	42
Biomass Non-wood	3	5	4	5	4	5	4	4	5	39
Bio-diesel	2	2	2	3	2	2	2	1	3	19
Solar	3	4	5	5	4	4	5	5	3	38
Landfill gas	2	3	3	5	4	4	3	5	3	32
GSHP	3	5	5	5	2	5	4	2	2	33

1 - not feasible or not worthwhile for the Council
2 - not advantageous or difficult
3 - acceptable
4 - advantageous or easy
5 - of high interest

Table 3

As we explained previously the Council wants to focus on generating renewable electricity within their own authority and make use of renewable heat for their buildings needs (schools, offices, recreational facilities, etc). Not all renewable resources will therefore be adequate or available options to the Council.
From a point of view of jurisdiction the Council has no authority over the sea, which is managed by the Crown Estate. This means that off-shore wind, tidal or wave energies are not to be considered.
Most hydro projects will be outside the authority of the Council and therefore hydro power will not be considered in this study.
The council is already looking at landfill gas or AD which are known technologies and are straightforward to install. We will limit ourselves to provide general information on AD in this report but will not conduct any financial analysis work.
CHP systems run mostly of fossil fuels and therefore will not be considered in this work.

In terms of electricity generation this leaves mostly onshore wind and solar PV.
Due to the intermittency and unpredictability of wind and solar, only part of the production will be used on site and the rest will have to be exported to the grid (more than 50% likely).
The Council is therefore looking at offsetting its own grid electricity consumption with renewable electricity production to reduce its CO_2 emissions.

From the point of view of heating buildings, the Council has set the priority to make use of local biomass resources as much as possible.
One important aspect to take into account is the fact that most of the council buildings are already equipped with wet distribution systems (fitted to oil or gas boilers), there is an obvious financial advantage in replacing oil (particularly) with biomass as this would allow to keep the internal central heating infrastructure.

One alternative option which could apply instead of biomass is heat pumps. Air source heat pumps would have limited benefits in rough climates in winter are most more adapted to mild winters. Both cases can be found in Argyll & Bute.

Ground source heat would provide better benefits from an environmental point of view but are more expensive. The potential energy which could be harvested using heat pumps is large but this is not specific to the location as geothermal heat for ground source heat pumps is available everywhere.
Heat pumps are a very well known and mature technology and their installation is straightforward, most of the time the decision on whether or not to install a heat pump will be down primarily to the cost.

The financial advantages and disadvantages of heat pumps versus biomass have to be evaluated on a case-by-case basis as many parameters are involved (demand profile, biomass fuel cost, emissions regulations, etc). Ground source heat pumps require also a significant amount of space outside the building to install heat collectors, so this may not be feasible in a number of cases for the Council's buildings.
In general, heat pumps are more expensive than biomass boiler installations however the maintenance is easier and there are no emissions associated with them, so they may be a good alternative to biomass for buildings sites where either maintenance or emissions could be an issues.
Heat pumps require electricity to work, so as long as the bulk of grid electricity will be either from fossil fuels or nuclear (or both) then their environmental benefits will remain limited. This is likely to remain the case for quite a while! This will be the case for air source heat pumps in particular as they would operate at a fairly low COP in Scotland (less than 3) [37,62]
Although we feel heat pumps can a good alternative to biomass for some specific cases, we will not cover this subject further within this work as they are less of interest to the Council as compared with biomass and their potential benefits must be evaluated for specific sites.

Another option would be solar thermal. The problem with solar thermal is that only 40% or so of the demand would be covered and therefore the back up system (most likely gas) would have to supply a large part of the demand, which would be only a limited benefit from the point of view of reducing emissions. We will therefore not cover thermal solar systems in the present work, however the combination of solar thermal and another form of renewable heat such as heat pump or biomass as a hybrid system could be considered in some specific building cases in future work. One main advantage would be that heat produced from solar thermal receives a higher RHI than that from biomass or heat pump.

As per the Council's priorities we will focus mainly on biomass for heating, in particular wood biomass. We also believe that waste grains biomass could be potentially of interest in the future for the Council. We will discuss this subject from a general point of view only but will not run any financial analysis.
Bio-diesel will not be considered as it is not advantageous from an energy balance point of view.

The potential capacity (over Scotland) for the resources most available to the Council are summarized below:

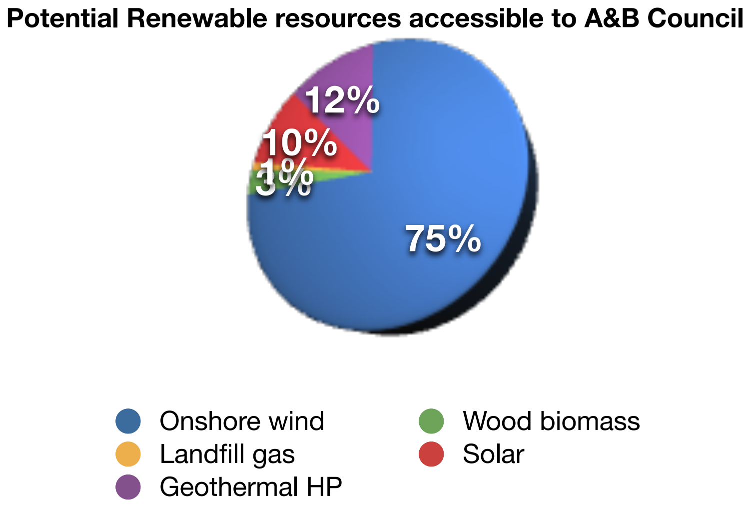


Fig. 9

Potential generation for Scotland:

- Onshore wind: 45 TWh per year
- Wood biomass: 1.6 TWh per year
- Landfill gas: 0.6 TWh per year
- Solar PV: 5.8 TWh per year
- Heat Pumps: 7.5 TWh per year

We could probably make the assumption that the distribution of resources within Argyll & Bute would follow roughly that for Scotland as a whole, except that biomass resources are quite large in the Council and Landfill gas may be lower due to the low level of population. On-shore wind represents in any case the main resource, followed by geothermal, solar and biomass.

We will next look at wind power, PV and biomass more in detail.

2- On-shore Wind in Argyll & Bute

Wind power is a renewable technology which produces no GHG during operation. Because the technology is now established and its potential is very large, wind is the fastest growing among all renewable energy technologies in most parts of the world and in Scotland.

While most turbines in the UK produce electricity at an average capacity factor of 25% [108,110], in Scotland capacity factors average 30% or better and they reach close to 40% on the west and northern coasts. The world record was established in Shetland on Vestas V47 660 kW turbines which recently achieved 58% over one year [109].

The potential for onshore wind in Scotland is estimated at 11.5 GW, which could produce up to 45 TWh of energy yearly

2.1 Contribution of onshore wind

On-shore wind however represents the renewable source of energy with largest potential for Argyll & Bute Council.

There has been no exact evaluation made on what the potential could be if a massive effort was made to build large on-shore farms across Argyll & Bute Council; however it is easy to conclude that with 11.5 GW available for Scotland and knowing that most of the high capacity factors are located on the west coast and in the north part of the country we can conclude the resource is large, probably over 1 GW might be achievable there (obviously we are talking about technical potential)

The fact is at the scale of what the Council is consuming in terms of electricity, even 1 GW or so would be about two orders of magnitude more than what we need to off-set the electricity demand of the Council.

On-shore wind could therefore on its own and using probably less than 1% of the overall potential in Argyll & Bute provide all the electricity needed by the Council.

The next question is really the type of scheme that should be considered, the options are as follows:

- Option 1: Small or medium wind turbine located on Council land adjacent to a building
- Option 2: Large size turbine located on limited size land owned by the Council, remotely from communities
- Option 3: Small size wind farm (4 large turbines or so) located on land

The Council own electricity demand for buildings amounts to 19,160,000 kWh. We have plotted on fig.10 the required capacity installed that would be needed to fulfill or offset that demand, depending on the average capacity factor which the turbines would operate at.

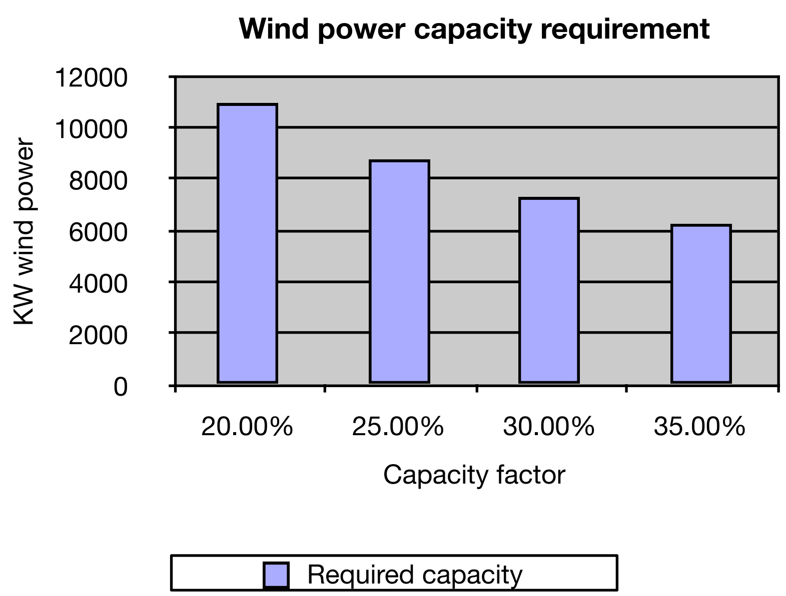


Fig.10

Assuming an average capacity factor of about 25% (which is roughly the UK average for existing wind farms) the required installed capacity would be about 8.6 GW. In the west of Scotland the wind resource available is better and assuming a capacity factor of 30% we would then require only about 7 GW of capacity.
Let us look at an example of a potential wind development plan over the Council comprising of different schemes, represented on fig.11 which shows the contribution of various options at capacity factors of 25% or 30%.

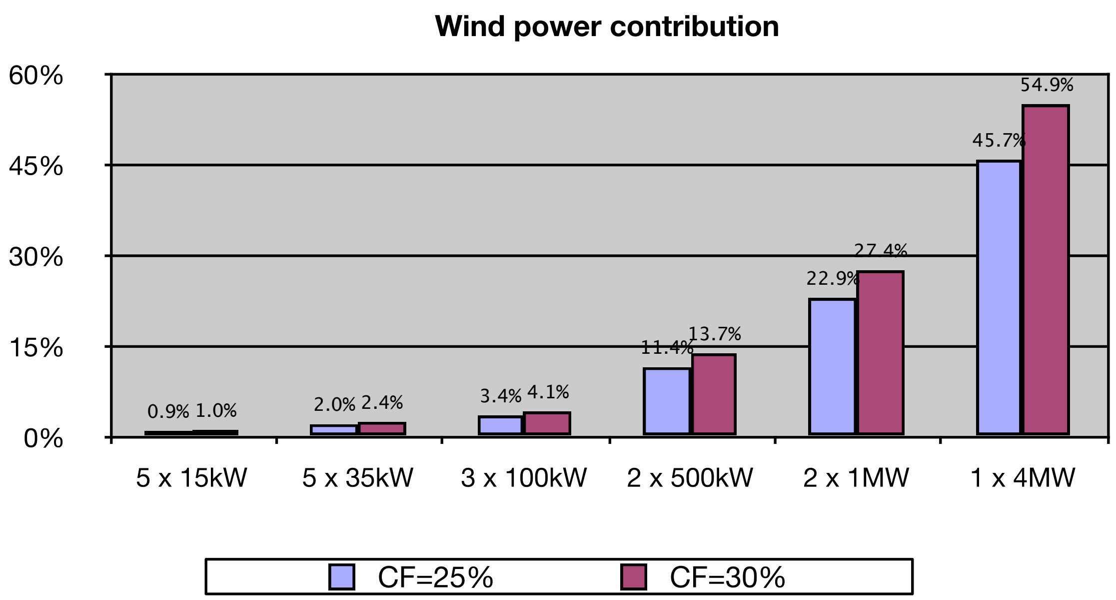


Fig.11

We see that all ten sites with small wind turbines installed near buildings (probably the maximum amount feasible according to information from the Council) would contribute only 2.9% or 3.4% of the demand depending on the capacity factor. The three medium size 100kW turbines would contribute only 4.1% of the demand at CF=30%
The large turbines together would supply 86% of the demand at CF=30%

It seems obvious therefore that small and medium wind turbines cannot contribute to fulfill or offset a major part of the Council's demand. To do this will require installing large scale wind power.
It is interesting to see however that only a few large turbines installed in a few well chosen sites could offset the major part or even all of the Council's electricity demand.

Option 1: Small or medium wind turbine located on Council land adjacent to a building

The rated capacity would probably be limited to about 100kW at most due to the proximity of the community. Based upon information obtained from the Council, most of the land attached to their buildings is actually quite small and in most cases projects involving wind turbines of any size will actually not be feasible.
For the few sites where it may be feasible, it is likely that turbine ratings will be limited to about 35kW or even less. We have used 35kW for the financial analysis of small wind.

The potential benefits of a small wind installation on land adjacent to council buildings are:

- Higher FIT tariff income per kWh
- Smaller overall project cost
- Easier and faster installation
- Lower connection cost to grid

The potential disadvantages of a small wind installation on land adjacent to council buildings are:

- Higher capital cost per kW installed
- Potentially significant losses in capacity factor due to buildings nearby
- Smaller revenue and carbon benefits
- Longer pay-back period
- Amount of effort will be higher to conclude projects in proportion to overall benefits
- Acceptance procedure is likely to take longer due to proximity of community

The next step is to evaluate the financial viability of small wind projects and to understand what critical parameters influence on the financial benefits.

The feed-in tariffs in place are:

- <1.5 kW: 34.5 p/kWh
- 1.5kW to 15kW: 26.7 p/kWh
- 15kW to 100kW: 24.1 p/kWh

Micro-wind - up to 1.5 kW:
The FIT of this category of turbine is 34.5 p/kWh
Micro-wind turbines below 1.5kW are usually roof mounted and due to obstruction by the building they do not work. We will not go into details on this issue as it has been largely addressed already in a number of reports [37].
Considering the large normalized investment cost (in £/kW) it is very likely also that such small installations will not pay back for themselves.

The other thing is the amount of electricity generated from such small equipment is really small compared to the scale of the Council demand and most likely not really worthwhile given the amount of work involved in acceptance procedures.
We therefore do not recommend the Council to consider wind power of such small scale.

Small and medium wind:

- The FIT is 26.7 p/kWh from 1.5kW to 15kW
- The FIT is 24.1 p/kWh from 15kW to 100kW

The difference in feed-in tariff is quite small between these two categories of small and medium scale wind power installations. We have therefore for simplicity reasons run financial simulations only for the 15kW to 100kW range (using a 35 kW turbine). The results would apply to smaller turbines as well (such as a Proven 6 kW for instance for which most parameters would not be not so different).

- Such type of small wind installation would be installed on land adjacent to a council building and would benefit from a relatively high FIT tariff income per kWh.
- The overall project cost would be relatively small but the normalized cost would be high.
- Grid connection should be relatively easy and inexpensive due to line proximity.
- Acceptance could be difficult to obtain but afterwards the installation would be fast. One problem with lengthy acceptance procedures and the potential issues relating to the site being near local communities is that the Council would incur costs before knowing whether project will be legally feasible.

Given that the Council would be looking simultaneously at a number of different sites the overall risk of spending time and money for projects that may not even be accepted could be high. This should therefore be considered with extreme caution.

To conclude, if we take into account the high normalized capital cost, the risk associated with acceptance procedures and the limited contribution small wind can have on the overall Council strategy on electricity generation and carbon reduction, we would not recommend small wind installations attached to buildings unless they benefited from an exceptionally good site, meaning:

- High capacity factor (taking into account the surroundings)
- High probability of acceptance
- Reasonable pay-back period

<u>Option 2:</u> Large scale wind power

The potential benefits of a large scale wind installation on separate and remote land are:

- Smaller normalized project cost (per kW installed)

- Higher capacity factor (exposed site with no buildings nearly)
- Higher revenue and carbon benefits
- Amount of effort to conclude projects is worthwhile given the overall benefits

The potential disadvantages of a large scale wind installation on land adjacent to council buildings are:

- Lower FIT tariff income per kWh
- Overall cost of project is large
- Higher connection cost to grid

The next steps are to evaluate the financial viability of large wind projects and to understand what critical parameters influence on the financial benefits.

The feed-in tariffs in place are:

- ◻ 100kW to 500kW: 18.8 p/kWh
- ◻ 500kW to 1.5MW: 9.4 p/kWh
- ◻ >1.5MW: 4.5 p/kWh

The FIT are quite different for each category, basically they are cut by half each time the rated power goes up a step.

There could be financial interest to limit power of a site to 500kW (one turbine) to take advantage of the higher 18.8p/kWh FIT. The critical point will be the overall capital investment (turbine and connection) which will be higher on per kW installed basis than for larger size turbines or larger installations.

The next category (500kW to 1.5MW) would correspond for instance to a single large turbine. The FIT income would be half of the 500kW but the capital cost would likely be smaller. We have modeled the financial return for a 1MW turbine

Next category (>1.5MW): FIT = 4.5 p/kWh
The lowest FIT rate applies to unlimited power beyond 1.5MW so would correspond to wind farms rather than single turbines.
While the tariff is low there will be obvious financial benefits to this scheme, the main ones will be likely the lower normalized costs for capital and connection to the grid, as compared with the other two options which receive higher FIT rates but are limited in rated power.
For this category we have modeled financially a 4MW operation.

2.2 Financial analysis for wind power

2.2.1 Small-medium wind

A turbine with power rating of 35kW is classified as small wind equipment but it stands at the higher end of this category.
We have run a number of financial scenario for a turbine with power of 35kW, such as the model supplied by Proven Engineering.

The key parameters are:

- The FIT applicable
- The rated power of the turbine
- CF = Capacity factor for the installation
- The percentage of electricity that is used onsite
- Capital investment cost, expressed in £ per kW of rated power
- Loan interest rate
- Loan duration in years
- O&M cost per year, expressed as a percentage of the turbine cost
- The cost of electricity purchased and exported to the grid

Capacity factor:

We run a series of simulations using capacity factors ranging from 15% to 35%.
A CF of 15% is quite poor in Scotland, most remote and relatively well exposed places should have a better wind resource, however for most place which are not well exposed or in the vicinity of buildings the capacity factor is quite likely to be below 15% even if the area is normally windy.
A capacity factor of 35% would be considered very good, although not uncommon in Scotland, however the site requires to be well exposed and the turbine installed at sufficient height and distance to buildings in order to achieve this.
Most sites will normally show capacity factors between 20% and 30%

The other parameters are set at:

- On-site usage is 50%
- Capital cost is taken as $5220 /kW (this price was provided by the Council, it was obtained from a quotation for a 35kW Proven turbine at £150k + connection costs)
- Interest rate is 5%
- Loan duration is 20 years
- O&M cost is £3500/year

- Grid rate is 10p
- Export price is 3p
- FIT applicable is 24p

The total value of energy consumed on site is therefore equal to 34p/kWh and the total value of exported electricity is equal to 27p/kWh.

Fig.12 shows the payback period of the installation depending on different capacity factors

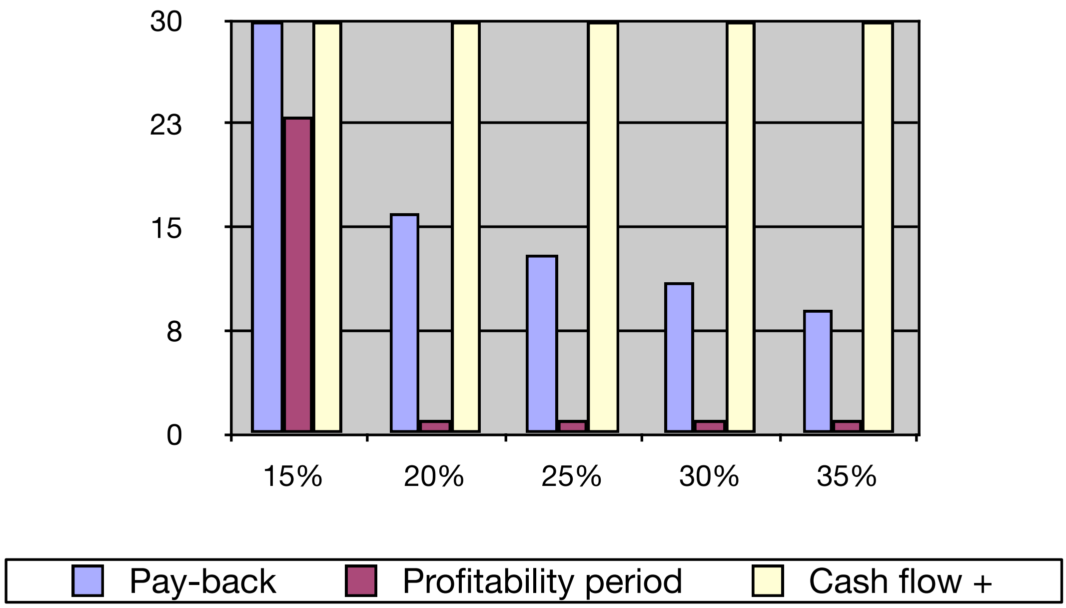


Fig.12

The payback period is over 30 years for a low capacity factor of 15% and drops to 16 years for a capacity factor of 20%. It then decreases slowly to 10 years for a capacity of 35%.
The graph shows therefore that it is critical to install the turbine in an adequate site with good wind resource.
The red line show the profitability period, meaning the number of years after which the revenue exceeds the costs.
It is 23 years for a capacity factor of 15% and drops to 1 year when the capacity factor is 20%. This is totally in line with the data obtained on the pay back period.

The reason why a capacity factor of 20% is so much better than 15% is because the additional energy generated (5%) become free additional income on top of what the installation produces under a capacity factor of 15%. The additional income from the turbine makes the installation generate a profit from the first year and then pays itself back much quicker.

The turbine does not achieve a positive cash flow after 30 years, this is mostly because we have assumed an onsite usage of 50%, the value of which is not counted in the cash flow.

In some way, reaching a capacity factor of 20% could be seen here as a minimum requirement to obtain a payback period of 16 years which in itself is still a lot but not totally unacceptable considering that the installation does make a profit from the first year. Obviously other parameters will influence as well the payback period but the capacity factor has a very large contribution.

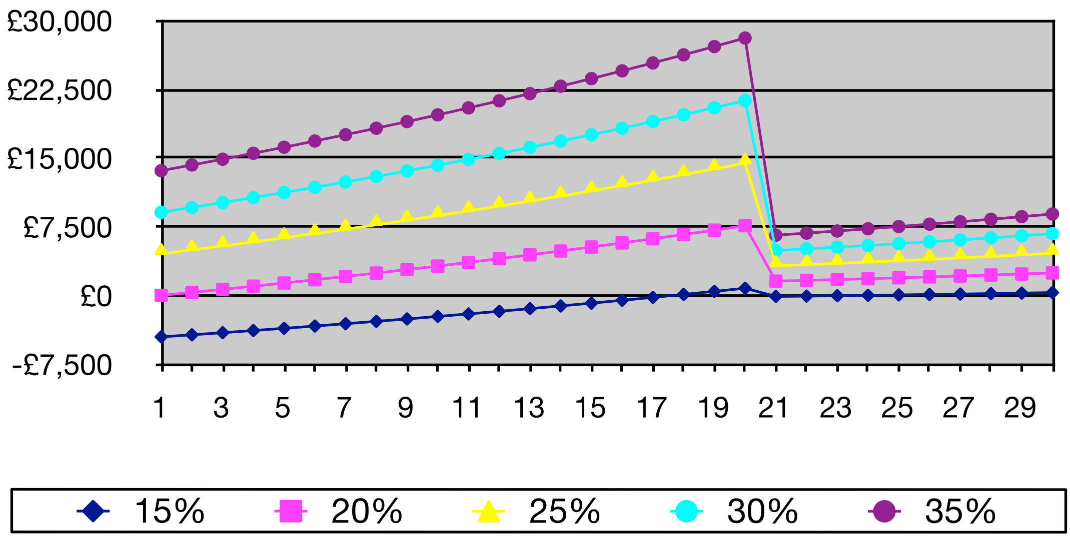


Fig.13

Fig 13 shows the profit realized each year from the turbine for different capacity factors.
We note that with a capacity factor of 15% the turbine starts making profit at year 18 until FIT ends then it operates at a small loss until year 23 when it becomes very slightly profitable again.
The curve shows clearly that under 15% CF the turbine rarely makes a profit and it is easy to see why it cannot pay for itself within the 30 year lifetime period considered.

With a capacity factor of 20% the turbine becomes profitable from the start, and the profit increases yearly as more revenue is generated based on inflation (RPI) rates for the electricity value and FIT, the O&M cost increases as well but has a lesser contribution. The profit reaches £7500 on year 20 before FIT ends then drops but remains positive without FIT. Basically with 20% capacity the turbine can sustain itself even without FIT, once the capital cost is fully paid for.

The other curves representing the profit obtained with higher capacity factors show the same trend. The profit increases to a maximum at year 20 then drops sharply when the FIT ends.

Let's remember however that after year 20 the loan payments stop as well so the yearly cost of the turbine drops but the curves show that the contribution of the FIT is significantly larger than the loan yearly payment therefore overall when both the loan and FIT end, the profits drop.

For a capacity factor of 30%, which is not uncommon in Scotland, the profit reaches over £28k on year 20 then drops to £6500 on year 21 to reach £8800 on year 30.
The accumulated profit of the turbine is:

- £ 350k over 30 years
- £ 321k over 25 years
- £ 295k over 20 years

The cash generated by the turbine is (the cash is equal to the profit minus the value of electricity used on site):

- £ 141k over 30 years
- £ 159k over 25 years
- £ 175k over 20 years

Note that the profit generated increases after year 20 while the cash generated decreases after year 20, this is due to the fact that once the FIT period is over the only cash income is from exported electricity which offers a low rate of 3p and cannot pay for the O&M cost of the turbine. The value of electricity used on site however is higher and allows to still make a profit.

Capital cost:

We then run financial simulations using different values for capital cost
A typical cost for a small wind turbine would range from £3k to £5k. Large size commercial turbine have a much lower cost which can reach £1000.
Installation costs vary depending on the location, in certain cases the installation may cost more than the turbine itself if for instance long cables are required for the connection to the grid.
Between turbine and installation cost we therefore assume a range between £3k and £7k total capital cost per kW.
Grants are unlikely to be available for wind turbine installation in addition to FIT, at least from the government. It is possible however that financial help be obtained elsewhere (charitable foundation, fund raising, etc...) towards the cost of a small wind turbine, for instance as part of an educational project. We will assume therefore a 'best case scenario' for capital cost to be £1500 per kW.

The other parameters are set at:

- Capacity factor is set at 15% (worst case) and 25% (normal case)
- On-site usage is 50%
- Interest rate is 5%
- Loan duration is 20 years
- O&M cost is £3500/year
- Grid rate is 10p
- Export price is 3p
- FIT applicable is 24p

The total value of energy consumed on site is therefore equal to 34p and the total value of exported electricity is equal to 27p.

The reason to run simulations for 2 different capacity factors is that with financial help towards installation there may be justification (financially!) for installing turbine is areas where the wind resource is at the lower limit (CF = 15%). This could be the case when turbine becomes part of an educational project for instance.
The capacity factor of 25% is what we would consider to be a typical value for most sites in Scotland where wind turbines would be installed.

- Capacity factor = 15%

The payback period is over 30 years when capital cost is £5k per kW, we knew this from the previous simulations using the capacity factor as a variable, the period to reach profitability was 16 years (it was 18 years in the other simulation but the capital cost was slightly higher).

With a reduced capital cost of £3k per kW the payback period drops significantly to 14 years and the turbine becomes profitable the first year.

With the best case scenario when the capital cost is down to £1500 per kW then the payback period is 7 years only, this is quite short with such a low capacity factor.

- Capacity factor = 25%

We have assumed in this case capital costs ranging from £3k to £7k per kW installed, providing a more realistic capital cost.

At a low capital cost of £3k per kW the payback period is 8 years.
At a capital cost of £5k per kW the pay back period becomes 12 years

Payback period reaches 17 years for a high capital cost of £7k per kW.

Regardless of capital cost the turbine is profitable within 1 or 2 years.

We have already mentioned before that the capacity factor was among the most critical parameters of an installation, we basically reach the same conclusion here. We show in fact that even at a high capital cost the payback period remains 'acceptable' when it operates in a good site. Note that a CF of 25% is by no means over-optimistic for Scotland.

The yearly profiles for the profit generated are shown on fig.14
The lifetime profit or loss is basically the area below the curve.

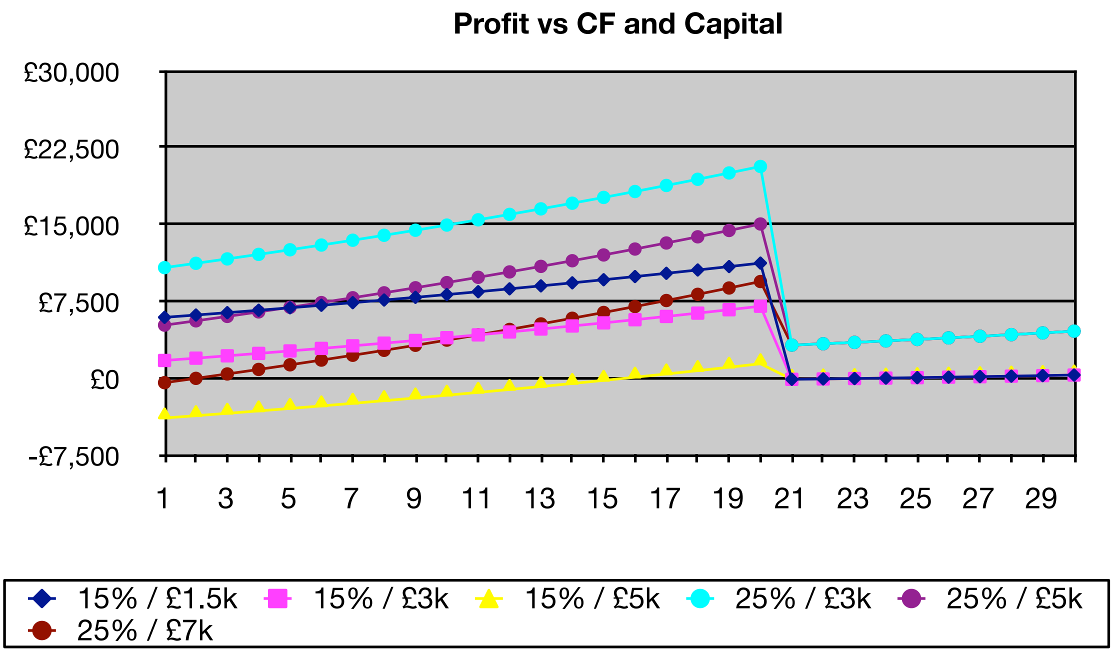


Fig.14

Only the worst case scenario with a higher capital cost of £5k operating at 15% CF does not pay for itself.
The accumulated profit/loss over 30 years is minus £133k, the bulk of the financial losses takes place in the first 12 years or so.

We see that all other schemes are profitable all the time (or nearly). This means that from a profitability point of view there is a significant difference between that specific scheme or one with either a better Capacity factor or a lower capital cost.
The worst case scenario option will result in an overall financial loss while the others will generate a decent profit, even if the pay-back period is relatively long.

It is therefore essential for the investor to consider carefully the business case before making decision, particularly when key parameters such as the capacity factor may be at the lower limit of the acceptable range.
It goes without saying that the longevity of the turbine and its reliability are critical here. We have a financial plan over 30 years, should the turbine fail at an early stage or require regular and extensive repairs, all profits would be lost rapidly. The selection of the turbine supplier should be taken with extreme care as we know that small wind turbines are made mostly by small companies with little history to show how reliable they are, apart from a few exceptions such as Proven.
(this is different for large size turbines as they are manufactured by big companies and are less likely to show major technical problems during their normal lifetime)

It is important to note also that all schemes relating to a low capacity factor of 15% yield little or no profit after 20 years (this is due to the end of FIT), this means that if other(s) parameter (s) were to be worse than we have assumed then these schemes could easily become money losers after 20 years and the 30 years accumulated profit could in some cases be driven towards negative values as well.
When the capacity factor reaches 25% the profit remains clearly positive after 20 years.

Once again this leads us to the conclusion that the capacity factor is an essential parameter to consider carefully and preferably we want it to be above 20% , preferably closer to 25% for safety.

The higher capital cost schemes show a slower profit increase over the first 20 years, which is quite logical as the loan repayments are higher.

The installed turbine at £3k operating at 25% CF represents an average case which could be achievable for Argyll & Bute Council.
It provides excellent financial results, with yearly profits starting at more than £10k reaching up to about £20k on year 20 and dropping to about £3k after the FIT expire.
The accumulated profit after 20 years in operation is £307,919 and it is £346,672 after 30 years

Fig.15 shows the profit/loss and cash flow for various capital costs under a capacity factor of 25%:

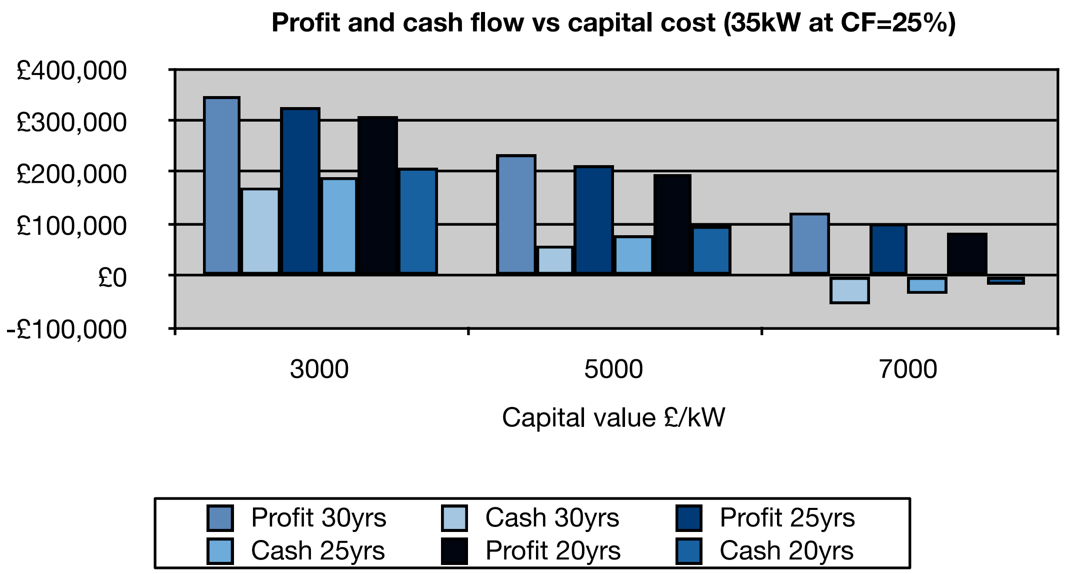


Fig.15

We note that the accumulated profit after 20 years and 25 years are lower than after 30 years because subsequent years after end of FIT are still profitable.

On the other hand the accumulated cash flow is higher after 20 years than longer periods, the reason being that after the FIT period is over the only cash income is exported electricity and does not compensate for the annual cost.

The trends are similar for all levels of capital cost. At very high capital cost of £7000/kW the accumulated cash flow is negative (despite a positive profit), meaning that even with FIT in place the cash income cannot compensate for the running cost (loan payment + O&M)

Loan interest rate

The next simulations investigate the influence of the interest rate.

The rate we model are 2%, 5%, 8% and 10%.

2% would be the best case scenario while 10% would represent a worst case scenario rate.

A typical and normal range would be 5% to 8%. The default rate used for most simulations has been set at 5% as the Council should be able to obtain a decent rate.

The other parameters are set at:

- Capacity factor is set at 20%
- Capital cost is £5222 per kW installed
- On-site usage is 50%
- Loan duration is 20 years
- O&M cost is £3500/year
- Grid rate is 10p

- Export price is 3p
- FIT applicable is 24p

The total value of energy consumed on site is therefore equal to 34p and the total value of exported electricity is equal to 27p.

The capacity factor was set at 20% because we have already seen from previous simulations that capacity factors under 20% may lead to a financial loss over the lifetime of the turbine. Having now set the capacity factor at what we would advise to be a minimum value required we will see whether the influence of high interest rate might influence the viability of the installation.

The payback periods we obtain for various loan interest are:

- At a very low rate of 2% the payback period is 13 years
- At 5% it becomes years 16 years
- It is then 24 years for a rate 8%
- For a rate of 10% the payback period would be over 30 years.

The interest rate therefore has a fairly significant impact on the payback period, particularly between 5% and 8% when the payback period increases by 8 years. The change from 2% to 5% is not as dramatic as the payback period only increases by 3 years only.
The reasons why this is the case is that higher interest rate is responsible for a higher yearly repayment and therefore a reduced profit each year. When the profit approaches zero then the time to pay back for the investment (plus the accumulated O&M cost so far) increases significantly. This is clearly visible on the yearly profit curves below.

The profitability period confirms this finding. It is 1 year for 2% and 5% rates and jumps to 11 years for a rate of 8%. It is 18 years for a rate of 10%.
When the rate is 8% or more the installation operates at a loss for the first (10) years before the increased FIT and electricity prices (according to inflation) allow a profit to be made. Cash flow remains negative for the lifetime period, due to the high proportion of electricity used on site and resulting value.

Fig.16 shows the yearly profit
The first thing we note here is the fact that the profitability depends a lot on the interest rate. We see clearly that for 8% and 11% the system operates at a loss for a good part of its lifetime while below 5% the operation is profitable from the start and reaches a very healthy profit at the end of the 20-year FIT period.

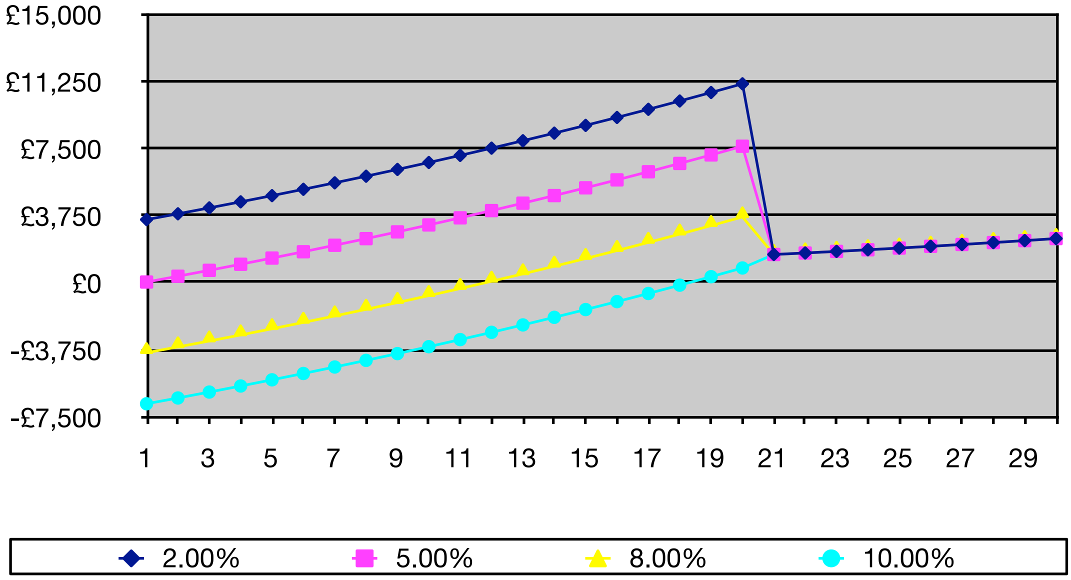


Fig.16

We also see that after the loan period is over (20 years) all schemes profits become the same as we would normally expect.
The sharp change in profit between years 20 and 21 is interesting as it is a combination of both the end of loan repayments (increasing profitability) and the end of FIT (decreasing profitability). Whether the step is negative or positive will depend upon which one is higher (at year 20) between the FIT income or the loan repayment.
At a low rate of 2% the profit goes down sharply because the loan repayments is smaller than the FIT income. At 10% however the profit increases slightly because the corresponding loan re-payment was very high.

Loan duration

The next simulations investigate the influence of the loan duration.
We compare the effect of loan periods of 10, 15, 20, 25 years

The other parameters are set at:

- Capacity factor is set at 20%
- Capital cost is £5222 per kW installed
- On-site usage is 50%
- Loan interest rate is 5%
- O&M cost is £3500/year
- Grid rate is 10p
- Export price is 3p
- FIT applicable is 24p

The total value of energy consumed on site is therefore equal to 34p and the total value of exported electricity is equal to 27p.

Fig.17 shows the payback periods obtained:

The payback period is shorter for a 10-year loan at 13 years, and increase gradually to reach 18 years for a 25-year loan. This is normal as longer loans cost more in terms of interest. The profitability period however is shorter for longer loan as yearly repayment is lower and reduces yearly cost versus income.

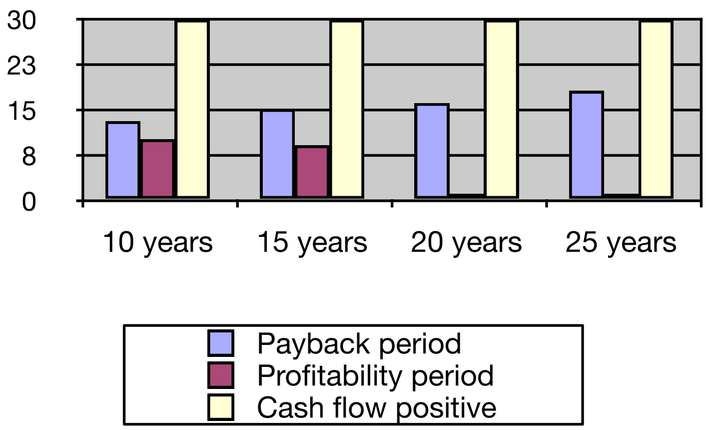


Fig.17

Fig.18 shows the profit realized over 25 years based on various loan durations.
The accumulated profit over a period of 25 years varies from £136k for a 10-year loan down to £48k for a 25-year loan. It is £90k for 20 years.

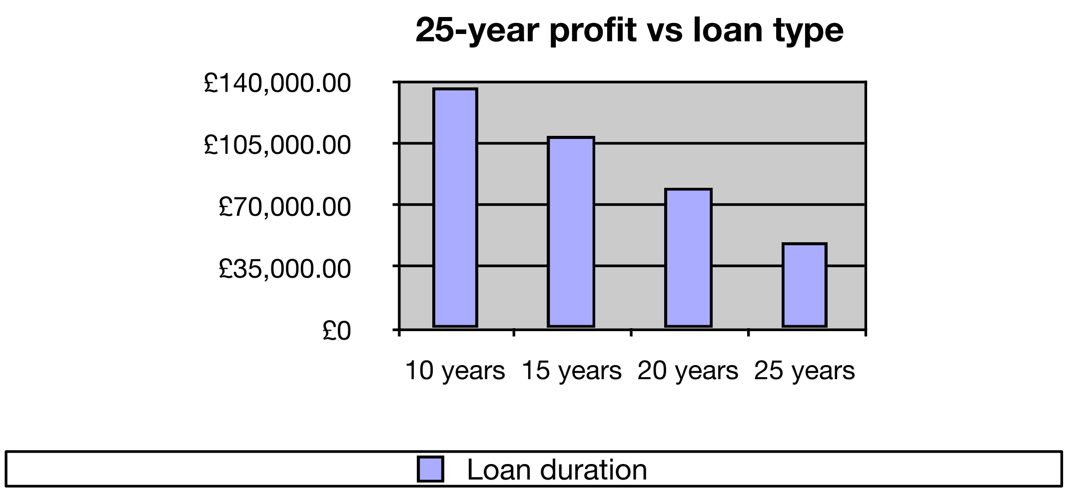


Fig.18

Fig.19 shows the yearly profitability of the operation:

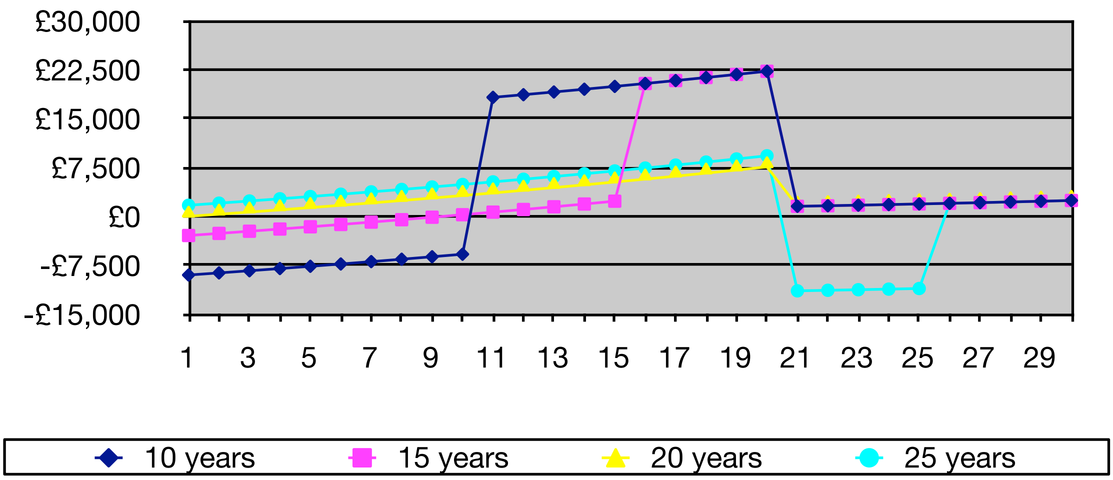


Fig.19

Yearly profits for short loans (10 and 15 years) show a financial loss for the first 10 years or so followed by high profitability periods after loan is paid-off, until the FIT stops and then profitability drops but remains positive.
The 25-year loan show a small profit till year 20 (end of FIT) then a period of high loss from 20 years to 25 years until loan is paid off. After that we show small positive profitability again.

The choice concerning loan duration could be down to 2 main questions:

- How much is the overall profit over the lifetime?
- Will we profitable every year? Or do have to incur losses?

Taking both into account, a loan duration of 20 years (same length as FIT contact) may be preferred as it provides a steady yearly profitability and a decent overall profit in the end.

Cost of grid electricity

At present grid electricity is assumed to cost near 10p per kWh.
Global demand versus generation may influence greatly this price in the future. It is generally accepted that energy prices will rise but at the same time there is political motivation to keep energy price inflation in general within control to avoid a slow down of the global economy. We have therefore assumed a default value of 3% for most simulations.
Given that we are looking at lifetime of equipment of 30 years, there is however reasonable chances that grid electricity price may increase at an average rate significantly higher than 3% during the lifetime of the installation. It makes sense therefore to look at the impact of

different grid price inflation rate on the financial of the system. We have therefore simulated inflation rate of 3%, 5%, 8% for electricity price.

The FIT and export prices will be kept at the 2% inflation rate as they are supposed to follow the UK RPI.

The grid price will influence mostly the value of the electricity consumed on site (proportion at 50%)

The other parameters are set at:

- Capacity factor is set at 20%
- Capital cost is £5222 per kW installed
- On-site usage is 50%
- Loan interest rate is 5%
- Loan duration is 20 years
- O&M cost is £3500/year
- Export price is 3p
- FIT applicable is 24p

The total value of exported electricity is equal to 27p. The total value of energy consumed on site will therefore now vary.

Fig.20 shows the payback period obtained for several scenarios

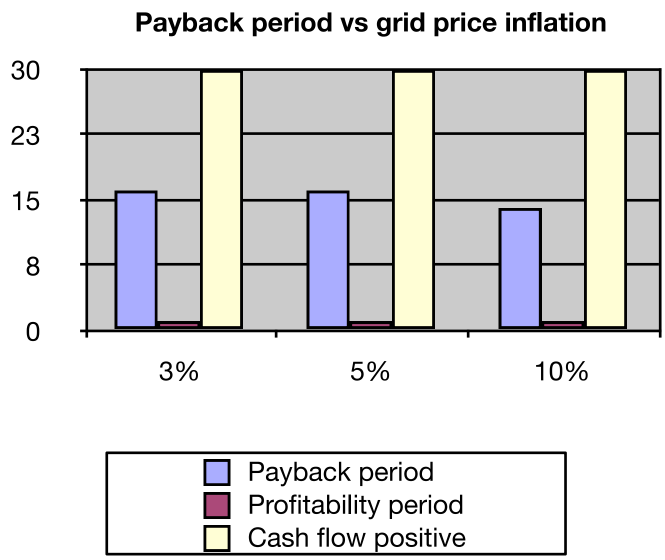


Fig.20

- For the normal inflation rate of 3% or the slightly higher rate of 5% we have a payback period of 16 years.
- If the inflation rate increases to 10% the payback period drops to 14 years

- The profitability period is 1 year in all cases.

It is logical that with higher grid electricity price the payback period should be shorter because the value of the electricity produced and used on site is higher.

The payback period however does not change much despite large changes in inflation rates resulting in significant variations in grid prices. The reason for that is that the biggest changes take place within the latter part of the period simulation, the effect of a higher inflation rate is rather low within the first years.
In other words in the years following year 14 the incremental yearly profit become quite large so that within just a few years it is sufficient to pay back the investment.

This is quite noticeable looking at the aggregate profit over the period. For instance going from 5% to 10% inflation rate, the aggregate profit more than doubles from £113k to £263k. Most of this difference actually takes place in the last years where grid prices have most increased under higher rate of inflation.
Over 30 years the aggregate profit is multiplied by a factor of three.

Fig.21 shows the accumulated profit for the different scenarios

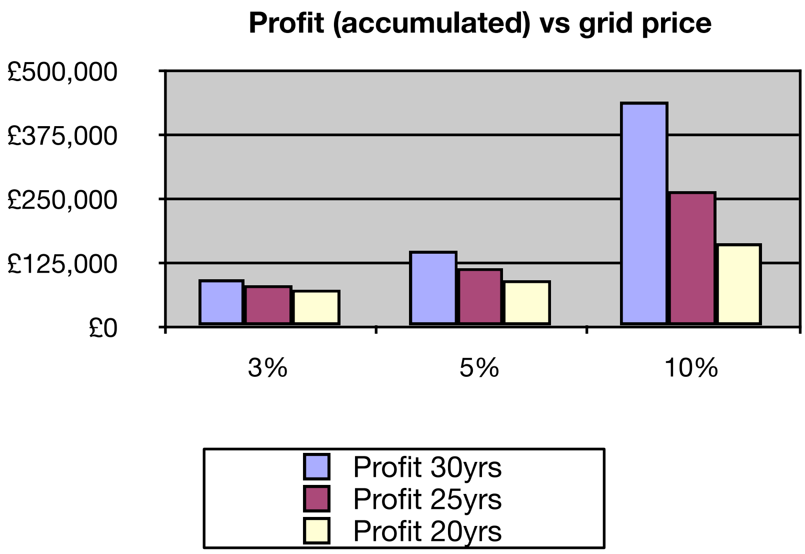


Fig.21

Fig.22 shows the yearly profit for each scenario.
For rates of 3% to 5% we see a similar profile as discussed in previous simulations, where profit increases until year 20 and then drops to a lower value.

We see that at 10% inflation the profitability makes a significant jump as the additional income from the high electricity price is all profit! In fact the profit become quite high even after the end of FIT.
Note that at a rate of 10% the profitability at year 21 (without FIT) is higher than the profit made at the rate of 5% on year 20 (with FIT)!

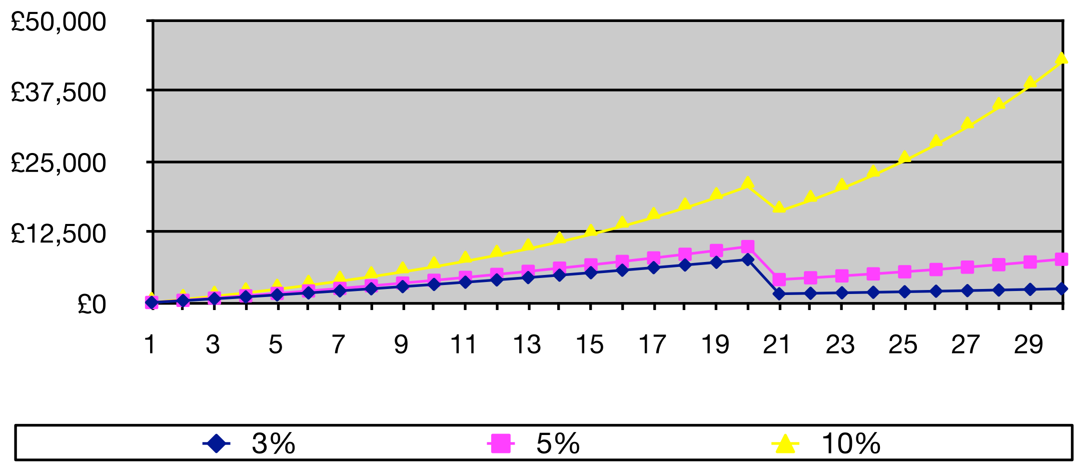


Fig.22

Obviously inflation rates of a level of 10% average are quite unlikely over a period of 30 years, but it is also unlikely that grid electricity will increase by a standard modest inflation rate of only 3% based upon most predictions on future electricity demand and supply.
It is not unreasonable to look at an inflation rate of 5% or more and in this case we conclude that wind power become significantly more profitable over the lifetime of the turbine even though the payback period does not change much, as he bulk of the extra profit is realized during the latter part of the period.
This is assuming of course that a decent amount of the electricity produced is consumed on site (50% in the simulation).

Remark: For the simulations we have kept the RPI at 2% as the inflation for export price and O&M cost but at high utility price we would expect these to be higher as well, which would increase the installation profitability even more.

Conclusions - Small/medium wind

- The location and wind resource is critical. The capacity factor resulting should be higher than 20%, and preferably 25% or better
- Capital cost should be below £5000/kW (of rated installed power), preferably closer to £3000/kW

- With good capacity factor, small wind remains profitable even if capital cost is high, but the payback period is longer
- Payback period can be as low as 8 years if the capital cost and wind resource at the site are appropriate
- For the loan, effort should be made to obtain an interest rate no higher than about 5% as profitability of installation decreases significantly when rate gets to about 8%
- The future cost of electricity could influence a lot the profitability of small wind installations beyond the FIT period of 20 years, however the payback period does not change dramatically.

2.2.2 Large scale wind power financial analysis

Case 1: Capacity < 500W

The purpose of the installation would be primarily to produce electricity to be exported to the grid rather than use on-site as it is unlikely that the turbine would be on a building site. In this analysis we will consider a very small on-site usage (2%).
The FIT would be 18.8p/kWh
For Argyll & Bute Council a turbine of this size would require to be installed on a dedicated land plot, rather than in the vicinity of council buildings. The land would have to be either purchased or lease, this cost is included within the capital cost in the following simulations, as capital cost ranges between £1M and £2M for the complete installation, the cost of a small plot in a rural location would represent a relatively small share of this.

The main differences from a financial point of view between large scale commercial turbine operations and small or medium wind turbines will be:

- The capital cost will be lower on a kW basis
- The FIT will be less than for small turbines
- There is less electricity used on site

The main parameters influencing on the financials are:

- The capacity factor
- The capital cost per kW installed
- The future price of electricity
- The loan interest rate

Capacity factor

We run a series of simulations using capacity factors ranging from 25% to 35%

A capacity factor of 25% should be relatively easy to achieve in Scotland, based on the fact that most UK wind average about this value. This is taken as the normal case scenario.
A capacity factor of 35% would be considered very good, although not uncommon in Scotland, however the site requires to be well exposed and the turbine installed at sufficient height in order to achieve this.

The other parameters are set at:

- On-site usage is 2%
- Capital cost is taken as £2k per kW for best case scenario to £4k for the worst case scenario (including connection costs)
- Loan interest rate is 5%
- Loan duration is 20 years
- O&M cost is 2% of capital cost
- Grid rate is 10p per kWh
- Export price is 3p
- FIT applicable is 18.8p

The total value of energy consumed on site is therefore equal to 28.8p and the total value of exported electricity is equal to 21.8p.

Low capital cost of £2k/kW
The payback period is 6 years for a normal capacity factor of 25%. It then decreases to 4 years for a capacity of 35%. Both options provide a very good fast payback period.

The profitability period and positive cash flow period are basically the same because on-site usage is only 2% so the contribution of that is small compared with the total income.
In both cases, the operation is cash flow positive from the first year onwards.

In the case of large installations with the main objective to export electricity it is more interesting to look at the annual return rather than the profit as the what may look like a large profit (in the absolute term) may not be that attractive once you compared it with the initial investment.
Fig.23 shows the yearly return obtained for various capacity factors

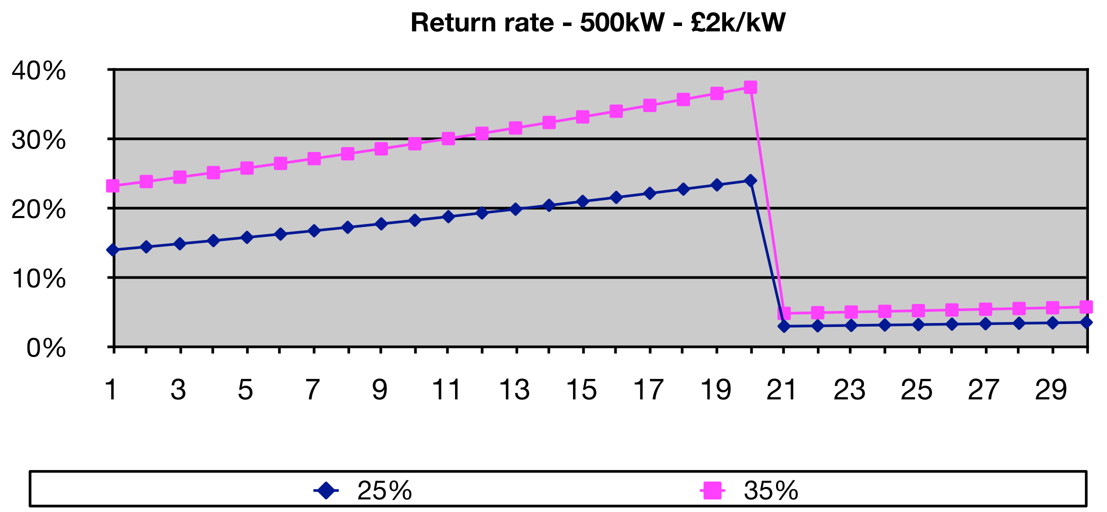


Fig.23

We see that returns are quite high for both capacity factors of 25% and 35%.
At 25%, it remains between 13% and 23% the first 20 years then drops to about 3%. This shows the importance of the FIT contribution. After the FIT period though the loan is paid for so a lower return is not a major problem.

High capital cost of £4k/kW
The payback period is 12 years for a normal capacity factor of 25%. It then decreases to 9 years for a capacity factor of 35%. Both options provide an average payback period.
In both cases, the operation is cash flow positive from the first year onwards.

Fig.24 shows the yearly return obtained

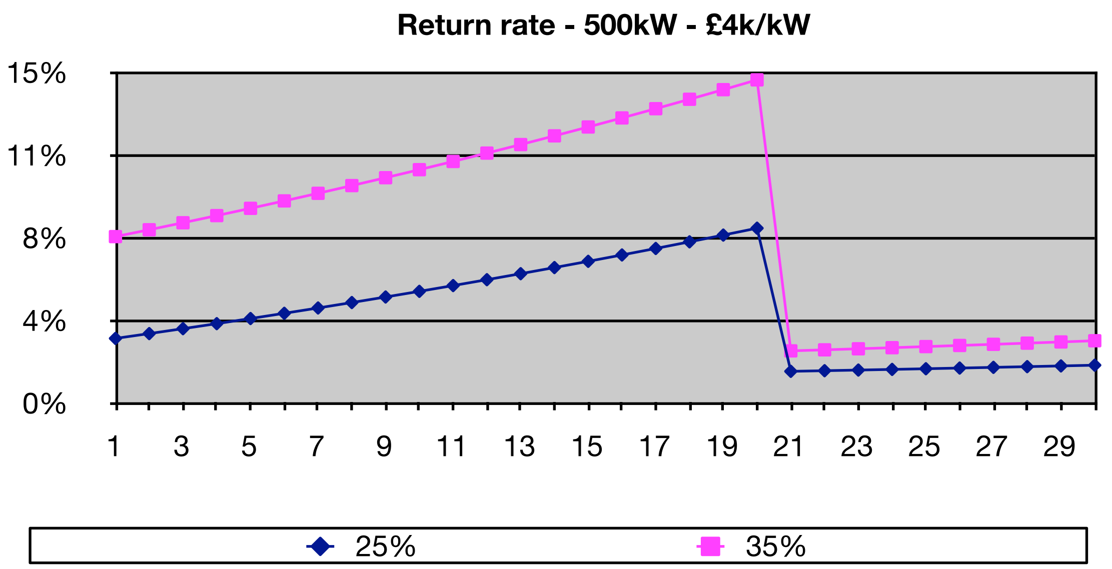


Fig.24

At 25% capacity factor the return rate is not so attractive, starting at 3% up to 8%, then it drops to below 2%. Given the other parameters uncertainties which could affect the financials, such as O&M cost, etc, it is preferable to plan on a better return.
At 35% capacity factor the return rate is quite attractive. It starts at 8% up to 15% on the 20th year then it drops to about 2.5%.
We should point out that £4k per kW for a 500kW turbine would be considered quite a high cost, but having said that £2k per kW would seem quite inexpensive.

Fig.25 summarizes the return rates on year 1, year 20 and year 30 obtained for different schemes. The objective should be to obtain an average return near 10% or better for the first 20 years followed by a return higher than 5% afterwards once loan is paid off.

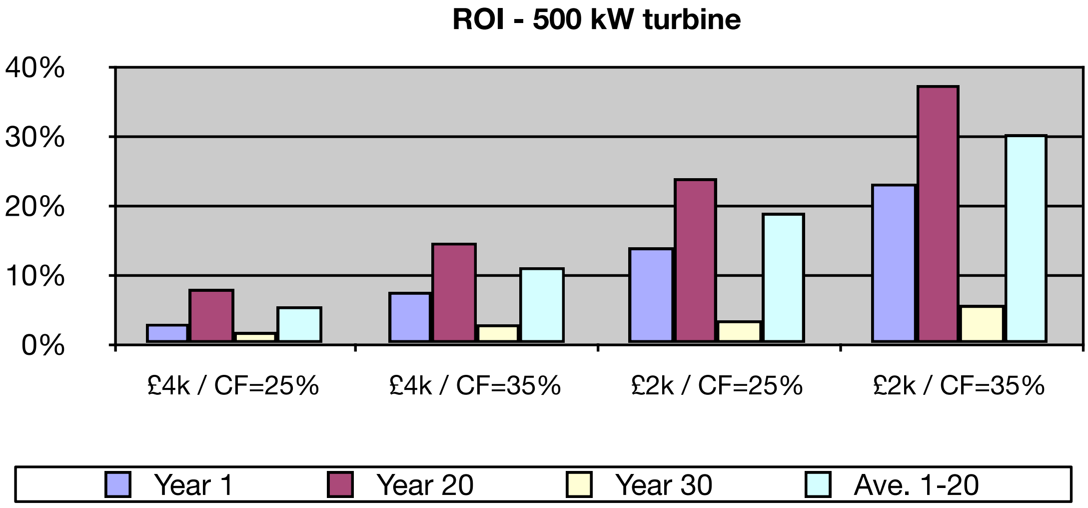


Fig.25

We could therefore conclude that:

- The capacity factor should be 25% at least and the capital cost should be well below £4k/kW
- At CF = 25% and about £2k/kW capital cost the return is high for years 1-20 but low afterwards
- For a capital cost near £4k/kW, even a high capacity factor of 35% provides only an average return

<u>Case 2:</u> Capacity from 500 kW to 1.5 MW

The FIT applicable is 9.4p per kWh

We have modeled a single turbine with power rating of 1 MW. The purpose of the installation would be primarily to produce electricity to be exported to the grid, so in this analysis we will consider a very small on-site usage (2%).
For Argyll& Bute Council a turbine of this size would require to be installed on a dedicated land plot, rather than in the vicinity of council buildings. The land would have to be either purchased or lease, this cost is included within the capital cost in the following simulations, as capital cost ranges between £1.5M and £3M for the complete installation, the price of a small plot in a rural location would represent a relatively small share of this.

The main differences from a financial point of view between large scale commercial turbine operations and small or medium wind turbines will be:

- The capital cost will be lower on a kW basis
- The FIT will be less than for small turbines
- There is less electricity used on site

The main parameters influencing on the financials are:

- The capacity factor
- The capital cost per kW installed
- The future price of electricity
- The loan interest rate

Capacity factor

We run a series of simulations using capacity factors ranging from 15% to 35%. As capital cost can be lower than for previous schemes we have conducted also a simulation for a capacity factor of 15%. A capacity factor of 15% is quite poor in Scotland, most remote and relatively well exposed places will have a better wind resource, this is taken therefore as a worst case scenario location
A capacity factor of 35% would be considered very good, although not uncommon in Scotland, however the site requires to be well exposed and the turbine installed at sufficient height in order to achieve this.
Most sites will normally show capacity factors of 20%-30%

The other parameters are set at:

- On-site usage is 2%
- Capital cost is taken as £1500 per kW, including connection costs
- Interest rate is 5%
- Loan duration is 20 years
- O&M cost is £18k yearly increasing by 2% (RPI) each year

- Grid rate is 10p per kWh
- Export price is 3p
- FIT applicable is 9.4p

The total value of energy consumed on site is therefore equal to 19.4p and the total value of exported electricity is equal to 12.4p.

Fig.26 shows the payback period of the installation depending on different capacity factors

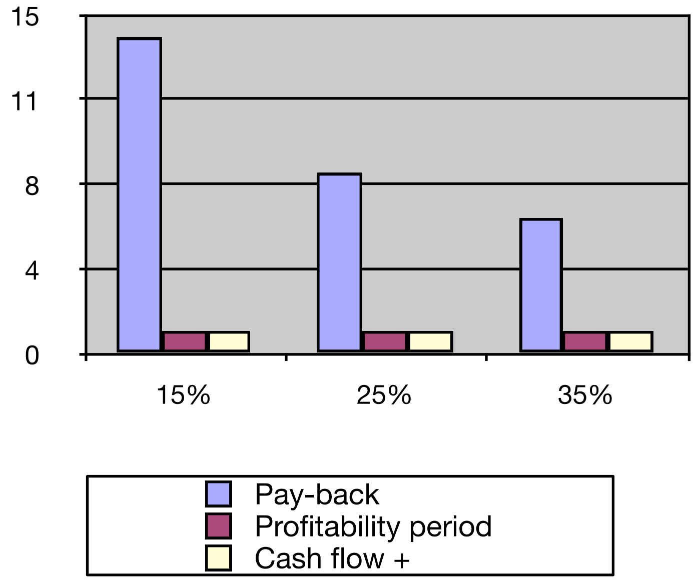


Fig.26

The payback period is 14 years for a low capacity factor of 15% and drops to 8 years for an average capacity factor of 25%.
It then decreases to 6 years for a capacity of 35%.
It is therefore essential to operate within a sufficient capacity factor (preferably higher than 25%) to obtain a reasonably fast payback period.

The profitability period and positive cash flow period are the same because on-site usage is only 2%.
The operation is cash flow positive from the first year onwards.

Fig.27 shows the yearly return obtained for various capacity factors

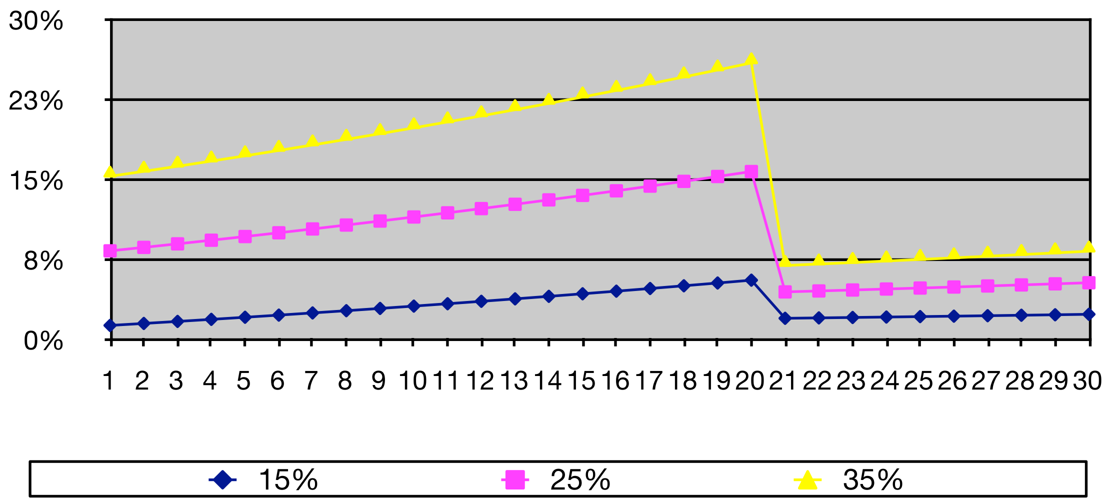


Fig.27

At 15% capacity factor the rate of return remains quite low at values below 7% all the time. It is even less than 5% during most years apart from the last 5 years of the FIT period. From an investor point of view the return is barely acceptable, taking into all the other parameters who could vary and lower the profitability. This confirms previous results showing capacity factors should be above 20%.

At 25% capacity factor the rate starts at 8% and goes up to over 15% on year 20 (end of FIT) then drops to about 6%.

This would be regarded as a decent return profile.

At 35% capacity factor the operation is very profitable throughout the 30-year period.

During the first 20 years (FIT) in particular the rate of return starts at 15% and reaches values over 25%.

Obviously it is important to stress that the capital cost value assumed is the low end and the capacity factor value is the best case scenario!

Capital cost

We have run financial simulations for different levels of capital cost

The capital cost we consider for large scale wind turbines varies from £1500 to £3000 per kW installed power. We have already provided results for capital costs of £1.5k per kW (see above at CF=25%) which is assumed to be a best case scenario

We look below at what happens if the capital cost rises to £3k per kW, which we consider to be a worst case scenario corresponding for instance to an installation requiring expensive installation and connection works.

The other parameters are set at:

- On-site usage is 2%
- Capacity factor is 25% and 35% (2 cases)
- Interest rate is 5%
- Loan duration is 20 years
- O&M cost is £18k yearly increasing by 2% (RPI) each year
- Grid rate is 10p
- Export price is 3p
- FIT applicable is 9.4p

The total value of energy consumed on site is therefore equal to 19.4p and the total value of exported electricity is equal to 12.4p.

The payback periods are 16 years for a capacity factor of 25% and 12 years for a capacity factor of 35%.
The payback period is therefore quite long at CF=25% showing that the capital cost is a critical factor when it comes to financials. This would indicate that for average values of capacity factors which should be characteristic of most sites in Argyll & Bute the capital cost must remain below £3k/kW and preferably closer to the £1.5k-£2k range.

Fig.28 represents the yearly cash flow obtained with a capital cost of £3k/kW for 2 different values of CF. The lifetime profit or loss is basically the area below the curve.

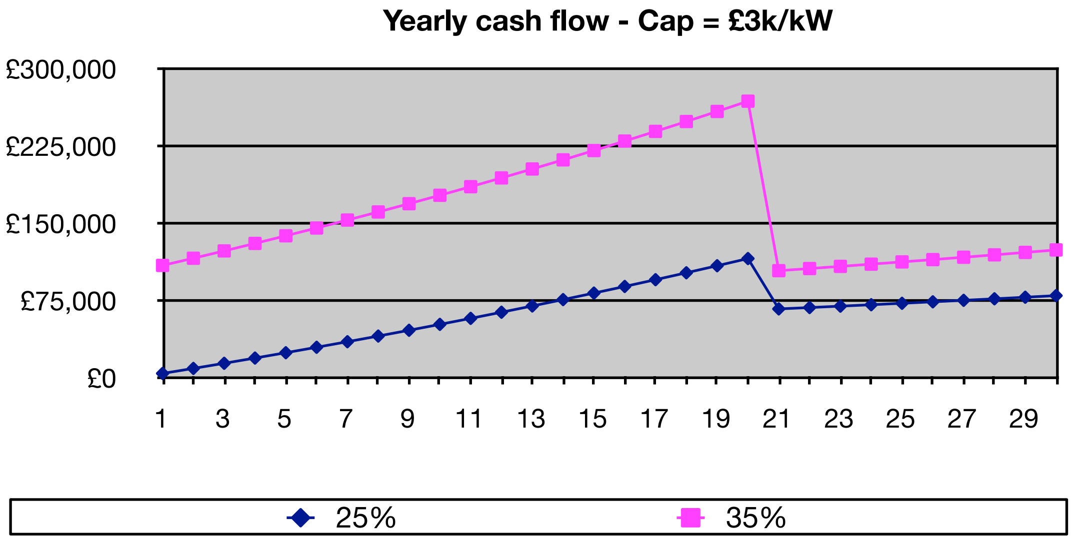


Fig.28

We note that we never hit a negative figure over the period however at CF=25% profits are small during the first 10 years of the operation, this accounts for the long payback period.

Note that after the end of FIT the profits fall but not as low as early years, this is because the loans payments have a big impact on profitability during the first 20 years.
At CF=35% the profits are obviously much higher, note that the FIT contribution being also significantly higher the profitability falls by a large margin at year 21 as compared to the situation when the capacity factor is 25%

Fig.29 shows the yearly return obtained for various capacity factors

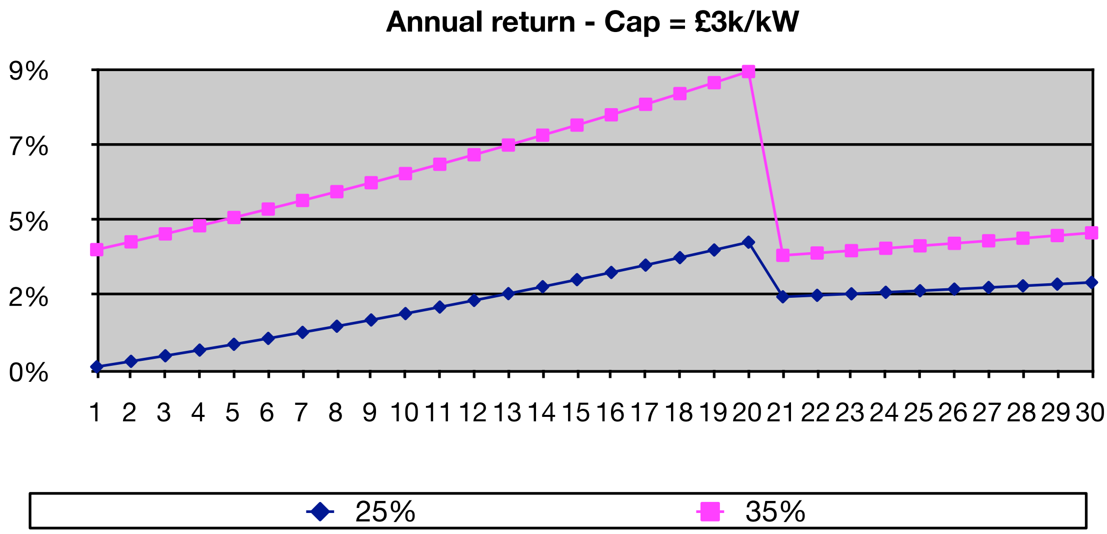


Fig.29

Overall the yearly return curves confirm what we have commented previously, the high capital cost has a major impact on the business overall.
At 25% capacity factor the rate starts near 0% and remains below 5% throughout the period. For an operation designed primarily to export electricity and make a profit (or at least without losing money) this is insufficient.
At 35% capacity factor the operation is reasonably profitable throughout the 30-year period however return are still below 5% for about 15 out of 30 years. Even at a CF=35% which is the best case scenario the returns would be regarded as minimal for investors however for a council whose primary objective is not to generate a profit they would be acceptable.

Loan interest rate

The following simulations investigate the influence of the interest rate.
The rate we model are 5%, 8% and 10%.
It is unlikely for a large scale installation that a very advantageous loan (for instance 2% rate) could be obtained.

A typical and normal range would be 5% to 8%. The default rate used for most simulations is 5%. A worst case scenario is assumed at 10%.

The other parameters are set at:

- On-site usage is 2%
- Capacity factor is 25%
- Capital cost is £1500/kW
- Loan duration is 20 years
- O&M cost is £18k yearly increasing by 2% (RPI) each year
- Grid rate is 10p
- Export price is 3p
- FIT applicable is 9.4p

The total value of energy consumed on site is therefore equal to 19.4p and the total value of exported electricity is equal to 12.4p.

The payback period was obtained for various loan interest:
At 5% it is 8 years
At 8% it becomes 11 years
At 10% the payback period would be 12 years.
Within the range considered the loan interest rate has a moderate effect on the payback period.
The operation is profitable within the first year regardless of the interest rate.

Fig.30 shows the annual return

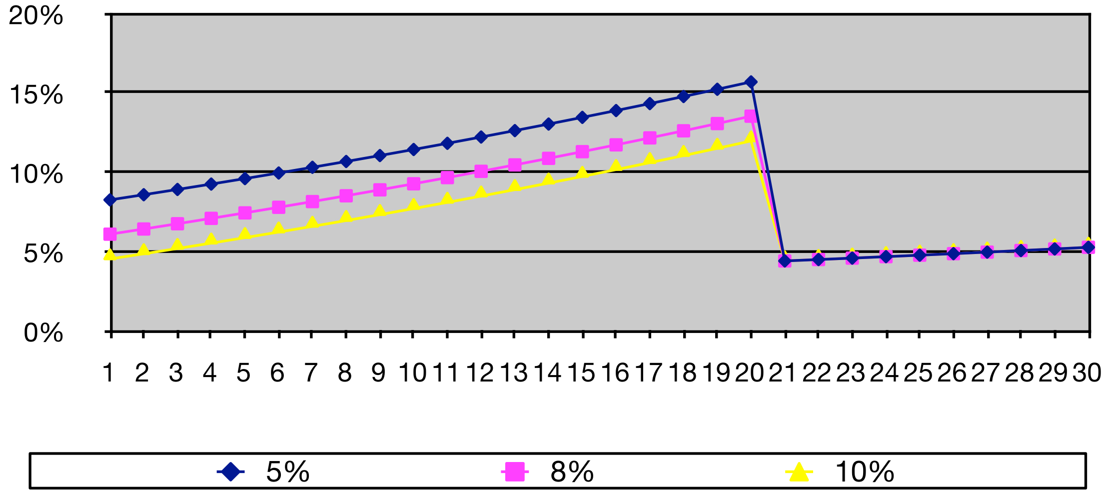


Fig.30

We note here that the rate of return depends only marginally on the interest rate.
We are profitable in all cases during loan period and after 20 years the interest rate has of course no effect. The return at 10% interest rate remains acceptable however the assumption for the capital cost was the lower end of the range, at a higher cost of capital and high interest rate it is possible that return on investment may be quite low.
A loan interest rate between 5% and 8% should nevertheless be considered largely preferred assuming all other parameters are taken as standard.

Cost of grid electricity

The present cost of electricity from utility companies is about 10p per kWh.
The current buying price (or export price) of renewable electricity for wind power (and other renewable generation) is set at 3p, which corresponds to 25-30% of the grid selling price.
The export price will increase yearly according to the UK RPI.
It is generally accepted however that energy prices will rise in the future and most likely they will rise faster than overall inflation (linked to the RPI). We should anticipate the possibility that export prices would follow the selling price trend and increase accordingly. It makes sense to run some financial simulations for scenarios where the export price increases faster than the RPI due to overall energy price increase.
We have assumed a default value of 2% for the exported electricity price inflation rate. We will now run a simulation for a 5% inflation rate.

The other parameters are set at:

- On-site usage is 2%
- Capacity factor is 25%
- Capital cost is £1500/kW
- Loan interest rate is 5%
- Loan duration is 20 years
- O&M cost is £18k yearly increasing by 2% (RPI) each year
- Grid rate is 10p
- Export price is 3p on year 1
- FIT applicable is 9.4p

The payback period obtained is 8 years and the profitability period is 1 year, which is unchanged as compared with the normal value of 2%.

We would normally expect that with higher grid electricity price the payback period should be shorter, but what happens here is that the biggest changes take place within the latter part of the period considered, rather than within the first years.

Fig.31 shows the return rate yearly for 2% or 5% inflation on export electricity price

As we would expect from the comments above rates are rather similar for the first 10 years, however there is significant difference afterwards.
At 2% inflation, rates remain within 12%-15% during the latter part of FIT period while they reach 20% and above at 5% inflation. After FIT the rate is 5% (rather low) versus 10-15% (quite good).

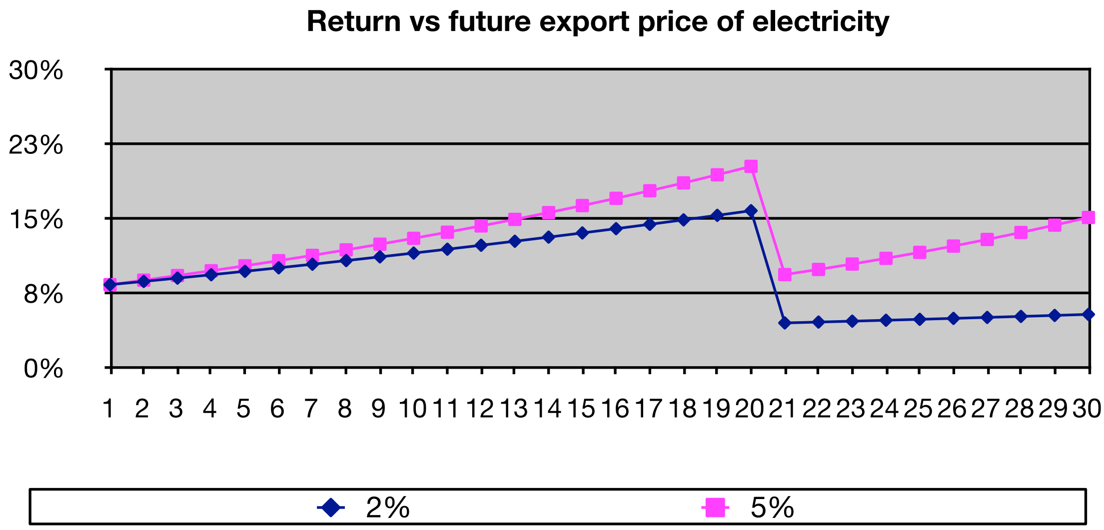


Fig.31

To conclude here we could say that a normal inflation of 2% would provide satisfactory return for most of the period while higher export electricity prices would make the investment significantly more attractive.

Fig.32 below shows the summary of return on investment rates for 1MW turbine. Ideally we are looking for a return near 10% over the first 20 years followed by a rate better than 5% afterwards when the loan is paid off.

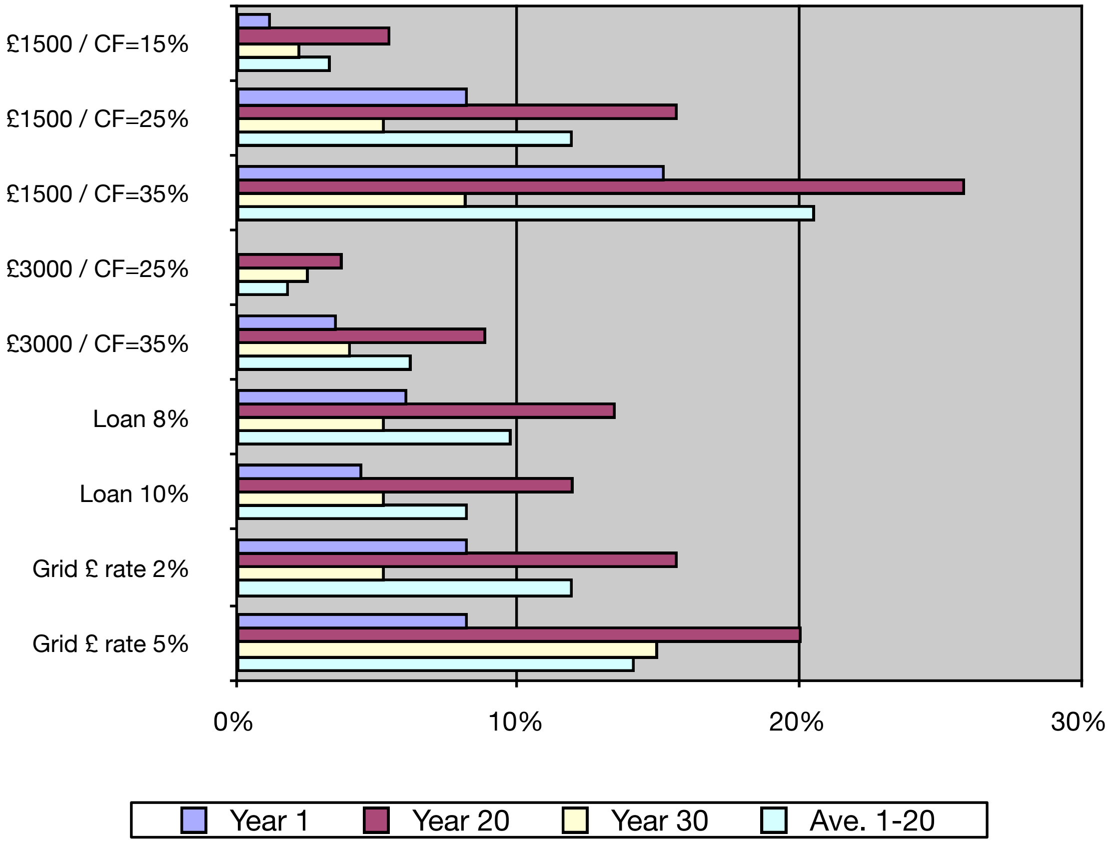


Fig.32

Conclusions

- A capacity factor of 15% is largely insufficient even at low capital cost. It should be 20% to 25% minimum.
- The capital cost must remain below £3000/kW and preferably in the range of £1500 to £2000 for the turbine to provide a good return
- At higher capital cost the turbine does not generate a decent return even at CF=35%
- The loan rate should remain within the normal range of 5%-8%
- The future price of electricity: A normal inflation rate of 2% for export electricity prices will provide satisfactory return
- A higher future electricity price provides a return above 10 % over the last 10 years and makes the investment significantly more attractive overall

<u>Case 3:</u> Capacity >1.5 MW

We now consider a larger installation of 4MW, using several large turbines (power rating of about 1 MW) to reduce capital and installation costs.

The purpose of the installation would be primarily to produce electricity to be exported to the grid, so in this analysis we will consider a very small on-site usage (2%).
For Argyll & Bute council an installation of this size would require to be installed on a dedicated land plot, rather than on land attached to council buildings. The land would have to be either purchased or lease, this cost is included within the capital cost in the following simulation, as total capital cost here will be approximately £6M, the price of a small plot in a rural location would represent a relatively small share of this.

The main differences between a 4MW and a 1MW installations from a financial point of view are:

- The FIT is lower for 4MW
- The normalized capital cost is lower for 4MW

The key parameters are:

- The rated power P of the installation is 4MW.
- The capacity factor for the installation will vary between 25% and 35%
- The capital investment cost is assumed to be £1500 per kW installed
- The FIT applicable is 4.5p per kWh
- Other parameters are unchanged

The total value of energy consumed on site is therefore equal to 14.5p and the total value of exported electricity is equal to 7.5p.

Capacity factor

We know from previous simulations that the capacity factor should preferably be 25% or more as it has a strong influence on the financial return of the facility.
For a large farm the decision making and preparation process regarding the choice for the site should be more thorough. We will therefore run simulations using capacity factors 25%, 30% and 35%.

- The payback period for CF=25% is 14 years
- The payback period for CF=30% is 11 years
- The payback period for CF=35% is 10 years

The longer payback period as compared with the 1 MW comes obviously from the lower FIT and related income.
As 14 years could be regarded as a long payback period for the owner / investors, it would therefore be preferable to ensure for such installation that it will operate at a capacity factor higher than 30% to reduce the payback period to 11 years or less.

These results are relatively consistent with numbers obtained from the Whitelee wind farm. The farm is operating at about 30% capacity factor, the investment cost was slightly lower than £1500 per kW and payback period is anticipated to be about 12 years.

The profitability and positive cash flow periods are 1 year in all 3 cases nevertheless.

Fig.33 shows the return each year for all three scenarios

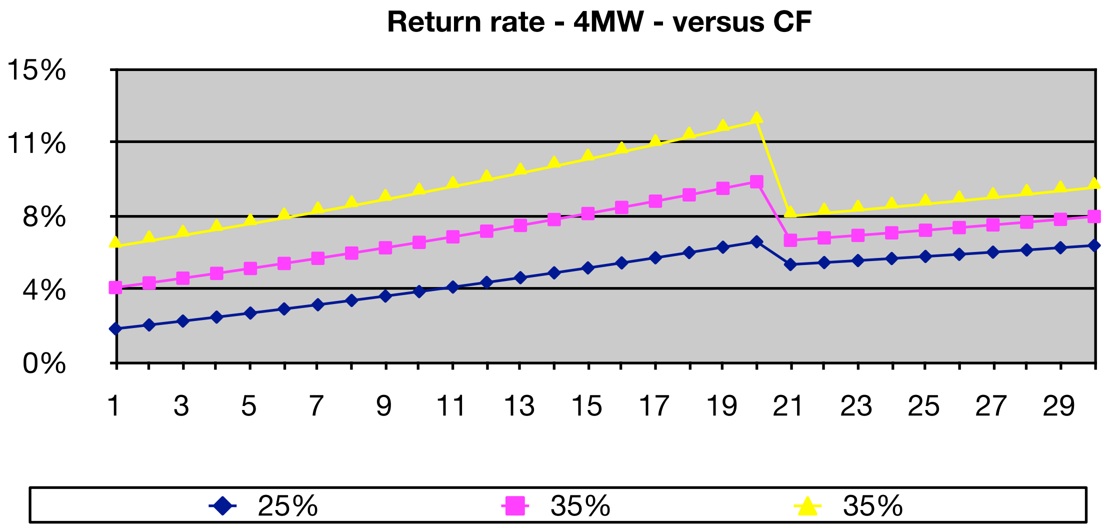


Fig.33

We note here that the drop occurring at year 21 is not as important as in the previous simulation (1 MW), the reason being that the FIT is lower so the related income is also smaller in proportion.
At a CF=25% the return rate remains below 7% and below 5% for the first 10 years. The operation is therefore profitable but with a slightly low return rate to be attractive to investors.
At CF=30% the return rate is almost always higher than 5% and exceeds 7% for about half the overall period. It reaches 9%. The operation becomes reasonably attractive.
At CF=35% the return rate is in excess of 8% most of the time and reaches 12%. The operation would be attractive.

The investment could be acceptable financially even at a capacity factor of 25% despite the longer payback period. However, due to the unknown parameters involved (capacity factor may occasionally vary, export price of electricity is based upon the RPI which may be lower than 2% on average), a capacity factor of 30% should be recommended.

Fig.34 shows the return on investment summary

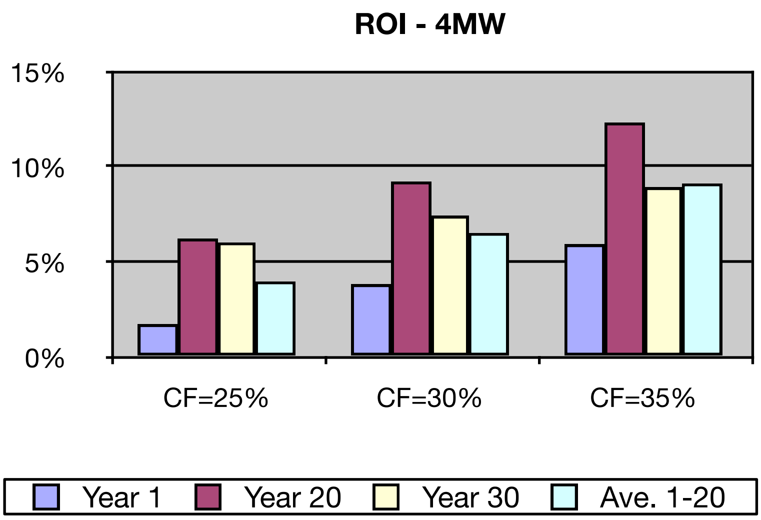


Fig.34

This can be compared with the actual case of Harlock Hill Wind farm in England run by BayWind Ltd. This a cooperative with a small amount of share holders.
We have contacted them for information regarding the farm operation and have also analyzed their published data [111] as well as AGM reports.
The farm has a capacity of 2.5MW and has been in operation since 1997.

The production of electricity over the last 12 years is shown on fig.35

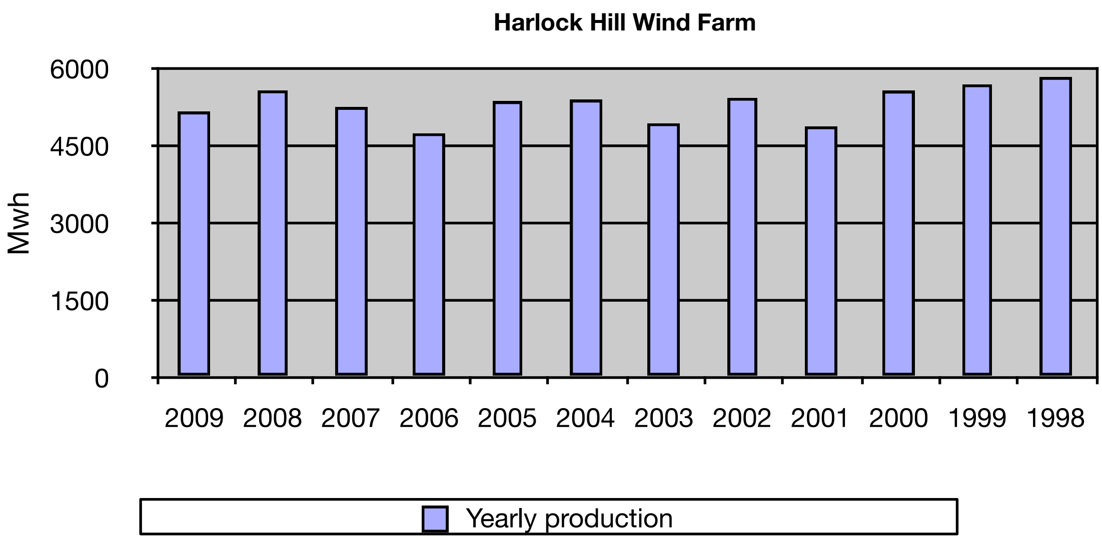


Fig.35

We note that there is some level of variability in production depending on the year, mostly due to capacity factor variation or (less likely) to downtime of turbines.
The capacity factor has been on average 24.2% over the period, the variations are shown on fig.36 below

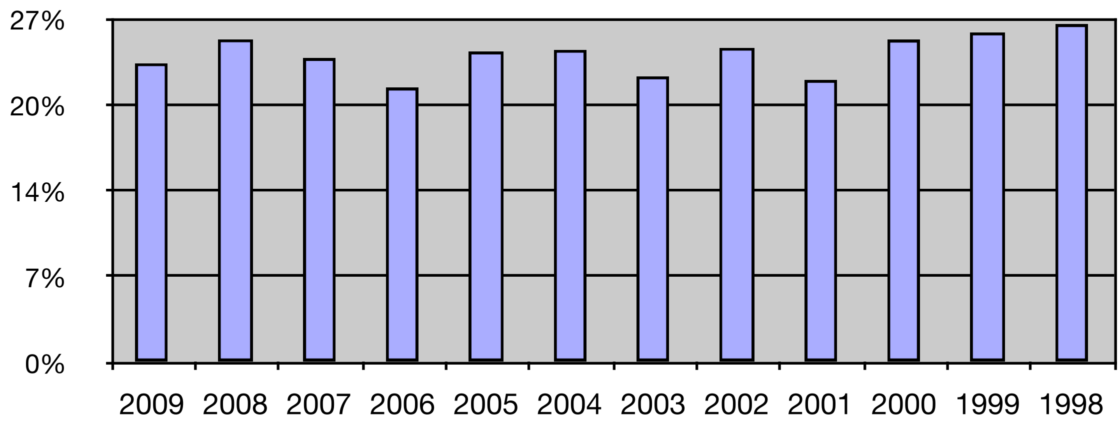


Fig.36: capacity factor over last 12 years at Harlock Hill wind farm

As we can see the variations in capacity factor follow exactly those in electricity production. We would expect a capacity factor at least as high as this in most parts of the west coast of Scotland unless the area is not exposed for a reason or another. Our assumptions of 25% or more should be therefore easy to meet in Argyll & Bute.
Note that between the worst and best years the variation of the capacity factor can reach about 1/5 of its value, which means we could expect the capacity factor to vary say between 25% and 30% between years but not much worse than that.

The farm sells electricity to the national grid through a NFFO (non fossil fuel obligation) contract. The price is about 10p per kWh based on the income and production reported.
The total investment cost was communicated to us to be £2.4m (a small grant for setting up the cooperative was obtained). This corresponds to a lower capital cost as compared to our conservative assumption of £1500/kW.
The O&M cost in 2009 was just over 3%, slightly higher than our assumption. We believe however that 1.5% to 2% is more likely to reflect the average based on up-to-date newer technology.
The return on investment in 2009 was 10.1% and it was 8.3% in 2008. These values are acceptable returns and are in line with our results overall:

- The 1 MW simulation assumes a higher capital cost but also a higher income per kWh (12.4p), as a result the return rate for a CF=25% is slightly higher on average over the first 20 years.
- The 4 MW scheme assumes a higher capital cost and lower revenue per kWh, at CF=25% the return is about half as high

Conclusions:

- Capacity factor should be 30% or more to provide reasonable return and pay back period below 11 years
- Operation is still profitable at CF=25% but payback period is long
- A capital cost significantly below £1500/kW (say near £1000/kW) would increase the return rate but we still recommend to operate at CF=30% to keep the return above 5% beyond year 20.

2.3 Conclusions for wind power

- Wind power has the largest potential for generating renewable electricity in Argyll & Bute.
- Given the size of the Council annual demand it would not be feasible to offset a significant part of the demand using small/medium wind. A few small turbines in well selected sites could nevertheless represent a good option
- A few large turbines would be sufficient however to offset the entire Council demand
- It is possible to obtain annual returns on investment above 8% from large wind installation. The FIT are essential to keep the operation profitable however after FIT ends (20 years) the operation remains profitable
- The capacity factor at which turbines operate is one of the most important parameters influencing on the profitability, it should be above 25% and preferably reach 30%
- Above 500 kW the capital cost should be kept near £1500/kW to provide a good return. At 500 kW the capital cost should be kept near £2000
- For small wind the higher FIT allows the capital cost to increase to £3000/kW
- The most profitable installation would be a single turbine just below 500kW operating at high capacity factor due to the higher FIT value of 18.8p and a moderate capital investment cost
- Large installations could be developed as cooperatives to reduce the investment needed from the Council
- Large scale wind farm land can also be used simultaneously for biomass growth or educational purposes

3- PV systems for Argyll & Bute Council

Methodology:

- Evaluate the available area (on Council buildings)
- Evaluate PV capacity which could be technically installed

- Calculate electricity generated yearly and resulting carbon reductions
- Run financial simulations on PV systems
- Conduct key parameter study

3.1 Evaluation of available area

Studies have been conducted in EU to look at large scale building integration of PV panels. It is estimated (European Photovoltaic Industry Association) that up to 40% of all building roofs and 15% of all facades in EU could be suited for PV applications [112,113]
The estimation has assumed a total ground floor area over 22,000 km2, this means that up to 1500 GWp of PV could technically be installed onto buildings in Europe which would generate annually about 1400TWh of electricity, representing 40% of the total electricity demand in 2020.

To evaluate Argyll & Bute Council roof and facade space, we will use the more conservative numbers of 10% of total facade area and 30% of total roof area as suitable for PV.
Precise data on roof space, facade space or even floor space could not be readily obtained from Argyll & Bute Council for their building portfolio. However floor space data was provided for a few of their buildings as well as space heating data for all their buildings [114]

Firstly we evaluated the heating consumption on a m2 basis for the few buildings (schools) for which floor space was known. We then calculated an average value and obtained 126 kWh/m2. It is difficult to comment on whether this value is high or low as Argyll & Bute Council Buildings range from old (and inefficient) to newer more efficient buildings, also other types of buildings may have a different heat demand profile than school.
Argyll & Bute Council have indicated that the major part of their buildings (and the largest ones) are either schools or offices, meaning they are not occupied at night, we can therefore consider this value as a reasonably close estimate.
Secondly we evaluated based upon the global heating consumption of Argyll & Bute Council buildings what the total building floor area would be.
We obtained approximately 200,000 m2.

3.2 Evaluation of potential capacity and generation

We have created a PV production evaluation tool that allowed us to work out the technical potential in Argyll & Bute Council.
A quick verification of the EU data above using our tool provided results within 5% using an average EU capacity factor of 11% (which is the average in France and the average between

the lowest Northern EU values of about 6% and the high values of about 16% in Southern parts of Spain, Italy and Greece)

For Argyll & Bute Council we must also make assumptions on the number of floors in buildings, which will influence the proportion of roof area. As most buildings (schools, offices) are either one floor only or two floors, we decided to use 50% for each.
The capacity factor in Argyll & Bute Council has been assumed to be 8%.
The PV efficiency was assumed to be 15% for roof and 8% for facade.
We obtained the following results below (table 4). The contribution is based upon the Council total electricity contribution for buildings only which is equal to 19,163,100 kWh yearly.

	Usable area m2	**PV capacity kWp**	**KWh produced**	**Contribution %**
Roof	45,000	6750	4,730,400	24.7%
Facade	16,000	1280	897,000	4.7%
Total		8030	5,627,400	29.4%

Table 4

The maximum PV capacity overall which can be installed is approximately 8 MWp
The contribution of facade installations is a lot smaller than that from roofs. Based upon current technologies and structure of incentives today, it makes sense to focus first on roof installations for PV.
An overall scheme of 2MWp would allow to produce 1,402,000 kWh of electricity or 7.3% of Argyll & Bute Council current consumption. It would allow annual savings of tons of 733 CO_2.
A larger scheme of 5MWp would allow to produce 3,504,000 kWh of electricity or 18.3% of the Council current consumption. It would allow annual savings of 1833 tons of CO_2.

The adoption of a large scheme of PV installations for Argyll & Bute Council could play a significant role towards production of renewable electricity and reduction of CO_2 emissions, in particular for the 2012 and 2014 targets set by the council.
While the potential for PV in Argyll & Bute Council is not as large as for instance wind technology, it is however significantly easier to implement. Acceptance procedures are simpler and physical implementation is straightforward, although as we speak there are few qualified professionals in Scotland to install PV panels, in particular for large scale projects.

NB: Argyll & Bute Council are well aware of the acceptance procedures and legal requirements for implementing PV systems and such requirements will not be covered in detail in this work.

The scale of such plan is quite high, as 1 MW of PV will cost a few million pounds to install, and this level of funding may not be easy to find.
Let us look at what contribution small PV systems could have to the overall Council electricity consumption and CO2 emissions:

- A 4kWp system would produce 2800 kWh of electricity or 0.015% of Argyll & Bute Council current consumption. It would allow savings of 1.5 ton of CO2 yearly.
- A 10kWp system would produce 7000 kWh of electricity or 0.04% of the Council current consumption. It would allow savings of 3.7 tons of CO2 yearly.
- A scheme comprising 20 systems of 4kWp and 20 systems of 10kWp installed on various buildings through the council would allow to generate 196,000 kWh of electricity or 1.02% of Argyll & Bute Council's current consumption. It would allow savings of 103 tons of CO2 yearly.

It is rather obvious therefore that in order for the Council to obtain noticeable benefits on their global carbon reduction targets from PV, they will have to go for large scale installations rather than the more common small scale (less than 10kWp) systems.
Another advantage of going large scale will probably be from the point of view of the capital cost of PV systems. Above a few hundreds of kWp it is quite likely that the price of PV panel on a per kWp basis could be discounted by negotiating with the manufacturers directly. The same idea may apply to the installation costs, although the council land is relatively spread, we would still be looking at a large capacity installed within a relatively well delimitated area.

3.3 Financial analysis for PV

As we mentioned above large scale implementation of PV systems on Argyll & Bute Council buildings could have a significant contribution toward reaching their targets and could be relatively easy and fast to implement, assuming the investment required was available.
The next step is therefore to look at the financial aspect of this.
First let's note that since the implementation of FIT there are no central government grants available to cover capital costs. Local Scottish grants (CARES,...) are also very unlikely to be obtained. We will therefore not include any funding in the financial simulations.
The next critical point is the value of FIT, which represents the main income and varies with the size of the systems.
The FIT in place for PV are:

- <4kW retrofit: 41.3p/kWh
- <4kW new build: 36.1p/kWh

- 4kW to 10kW: 36.1p/kWh
- 10kW to 100kW: 31.4p/kWh
- > 100kW: 29.9p/kWh

We have conducted analysis for small systems (up to 4kWp), medium systems (up to 10kWp) and larger systems (up to 100kWp). We have not modeled systems above 100kWp as this capacity already requires a total panel size over 700m2 and in addition, the FIT for larger system is quite close to the tariff for systems ranging from 10-100kW (29.9p versus 31.4p). We have however considered financial cases with different capital cost to reflect the effect of cost reductions from larger systems.

Small PV systems (capacity up to 4kWp)

The critical parameters used are:

- Capacity factor = 8%
- Usage factor = 100%
- On-site electricity usage = 50%
- O&M cost = 0.5% of initial investment (2% inflation)
- Grid price start at £0.1 (3% inflation)
- Export price is 3p/kWh indexed on RPI (2% inflation)
- Loan interest rate is 5%. Duration 25 years

Case 1: PV are retrofitted (FIT = 41.3p/kWh)

The value of electricity consumed on site is therefore 41.4p/kWh and the value of exported electricity is 34.4p/kWh.

The normalized capital investment cost varies from £3k to £6k per kWp.

The high cost of £6k/kWp is normal at present for most 1-off small systems, as the Council would likely invest in several systems it would be regarded as a worst case scenario.
The £3k/kWp could be used as a best case scenario, even in case the Council purchased a large number of PV panels to be installed in various sites at a discounted price from one manufacturer, it is unlikely a cheaper overall cost (installed) could be obtained given the high proportion of the installation cost associated.

Fig.37 shows the payback period and the profitability period.

We note at the cost of £6k per kWp installed the payback period is > 30 years. Such long ROI period is unlikely to be acceptable for the Council. It also takes 15 years for the system to become profitable, based upon assumptions we have made.

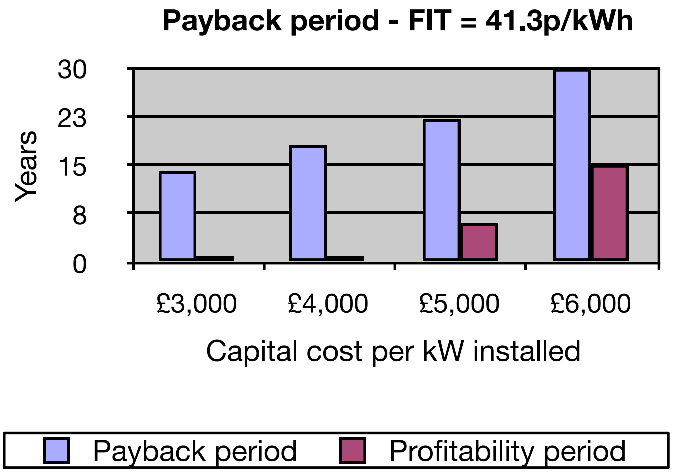


Fig.37

If capital cost drops to £5k per kWp then the payback period drops to 23 years, still quite high but system becomes profitable after 6 years.

At a lower capital cost of £3k and £4k per kWp respectively the payback period becomes 14 and 18 years, system is profitable from the first year.

It is interesting to note that the payback period is always relatively long (as compared for instance with wind or biomass systems), even when the system is profitable from year 1

This is due to the fact that yearly profit, despite being positive, is small as compared with initial investment. It also demonstrates that the payback period is not necessarily a good indicator of what is a good investment as it does not provide any information on how profitable is a system nor how long it will last beyond the payback period.

Fig.38 show the yearly profit generated over a 30-year period

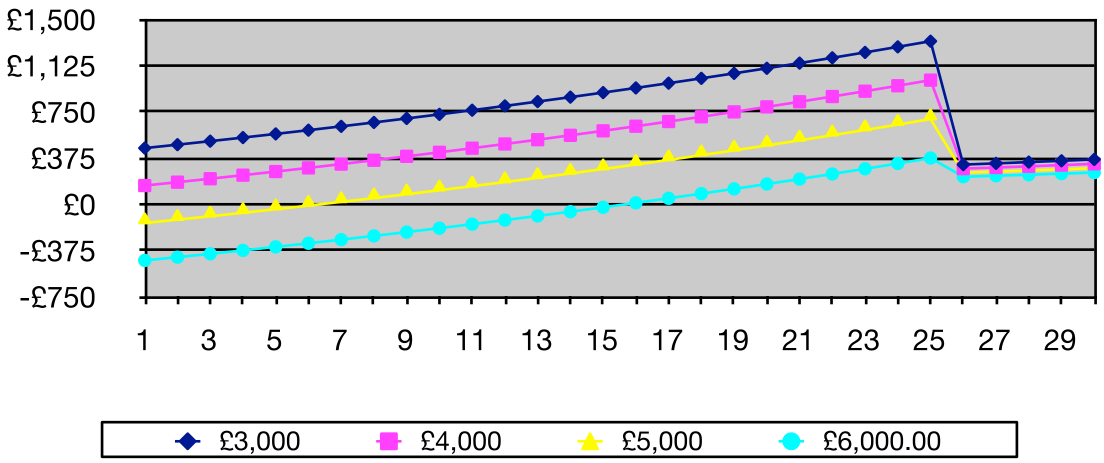


Fig.38

The area below each curve represents the aggregate profit/loss for the system over any period. We see that at £6k per kWp the system loses money (the exact amount is -£650 over 30 years and -£3300 over the first 20 years).
At £5k per kWp the system earns a small income of £7256 over 30 years. The fact is several assumptions have to be made with a given margin of uncertainty, in particular assumptions made regarding future prices of electricity and RPI inflation (on which the FIT is indexed), without which this scheme would be making a loss every year, therefore we do not recommend the Council to invest under such conditions.
It is far safer to invest in systems which are profitable from year 1, even when the payback period seems longer.
This will be the case if the capital cost falls below £4k per kWp. After the 25-year FIT period (and loan) the system provides a yearly profit of just over £300 (regardless of its initial cost)
At £4k per kWp the 30-year aggregate profit is just over £15,100 or £500 per year on average, with a maximum of £1007 during year 25.
At £3k per kWp the 30-year aggregate profit is just over £23,000 which is > £750 per year on average, with a maximum of £1323 during year 25.

We can conclude therefore that:

- Small PV systems retrofitted onto existing buildings would therefore be a good investment if capital cost installed remains below £4k per kWp.
- We would recommend to apply extreme caution when the installed overall cost is higher than that. If the cost is higher than £5k per kWp installed, the investment will likely not be of interest.

<u>Case 2:</u> PV systems for new buildings (FIT = 36.1p/kWh)

The value of electricity consumed on site is 46.1p/kWh and the value of exported electricity is 39.1p/kWh.

There is no current significant plan for Argyll & Bute Council regarding new buildings however the FIT is significantly lower (more than 10%) than for retrofit therefore we have run two simulations at £3k and £4k per kWp installed in order to see what influence the lower FIT may have on the system profitability.

The payback period is now 15 years (as compared with 14 years before) at £3k/kWp and remains at 18 years for £4k/kWp
Profitability period remains 1 year.
At £4k per kWp the 30-year aggregate profit drops to £9160, or £300 per year on average, with a maximum of £716 during year 25.

The conclusions we draw are that:

- Small PV systems onto new buildings would be a good investment if capital cost installed is below £4k per kWp but preferably closer to £3k/kWh
- The average profit obtained for a system which costs as much as £4k per kWp is low and therefore could potentially leads to financial losses should other parameters vary significantly from the normal values we have assumed.

Future price of electricity

It is generally accepted that electricity prices are set to rise in the future, but there is no certainty on how much and when it may happen.
Higher electricity prices will make renewable energy generation more cost competitive as compared with fossil fuel based technologies.
In the specific case of PV panels, once the initial investment has been made there is no fuel cost and the maintenance is very low cost therefore any rise in the value of the electricity generated will improve the profitability of the installation.
The rate of 3% inflation has been used for most simulations. We have modeled as well rates of 5% and 8% inflation (average yearly over the lifetime period) using a capital cost of £5k per kWp.
The choice of £5k is based on the fact that this number was found to be too high to provide good financial return under 'normal' conditions. The idea here is to see whether higher electricity prices would compensate for the disadvantages of high capital cost.

Fig.39 shows the payback period obtained for rates of 5% and 8%, as well as profitability period.
At 5% the payback period remains 22 years and at 8% it is 21 years, so there is only little benefit from that standpoint.
The profitability period however improves to 6 years and 5 years respectively, as compared with the 23 years at 3% grid price inflation.
The reason for these two results is that the benefits of a higher inflation rate are smaller during the first years so although the system become slightly profitable earlier it still takes a long time to pay for the large investment.

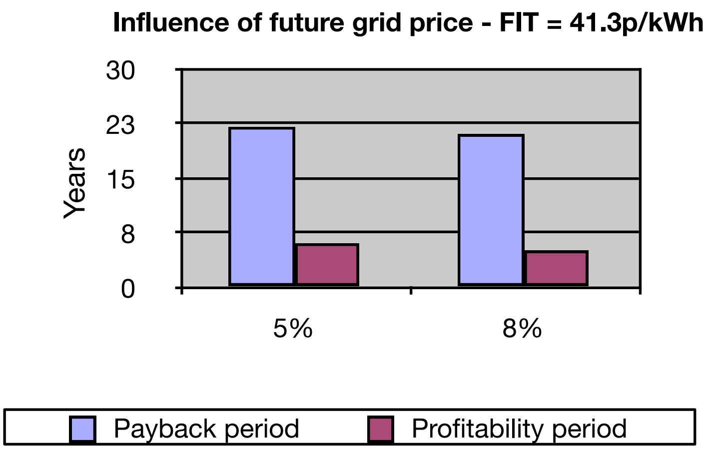


Fig. 39

The 30-year aggregate profit at 5% is now £8567 (rather than a loss earlier on!) or almost £300 per year, which makes the system now relatively attractive. At 8% the aggregate profit jumps to over £15k, we appreciate however that an inflation rate of 8% over the whole period is highly unlikely.
Given that there is no certainty electricity price will rise by more than 3% per year we would not recommend to make an investment based upon these results, however these results show that what may look today as an unattractive investment due to a prohibitive capital cost may end up being profitable, should certain assumptions prove exact.
Note also that this parameter is only relevant if a significant proportion of electricity produced is used on-site, as exported electricity value is normally indexed on RPI and may not follow the more volatile grid price!
In the next simulations for larger systems the on-site percentage of electricity will be decreased.

<u>Medium size PV system</u> (capacity up to 10kWp)
The critical parameters used are:

- Capacity factor = 8%
- Usage factor = 100%
- On-site electricity usage = 40%
- O&M cost = 0.5% of initial investment (2% inflation)
- Grid price start at £0.1 (3% inflation)
- Export price is 3p/kWh indexed on RPI (2% inflation)
- Loan interest rate is 5%. Duration 25 years
- FIT = 36.1p/kWh

The value of electricity consumed on site is 46.1p/kWh and the value of exported electricity is 39.1p/kWh.

The main difference with the smaller system of 4kWp or less (retrofit case) is the lower FIT it receives.
The FIT is actually the same value (36.1p per kWh) as for the smaller system installed on new buildings which have been studied previously so we know already that £4k per kWp will be close to the maximum acceptable capital cost to make the investment worthwhile.

There are however 2 other differences:

- First we have assumed a smaller on-site percentage use of electricity, this will decrease the profitability of the system as on-site electricity has higher value than exported electricity.
- Second we should hope that the installation cost (normalized) would be lower for a larger system which we know is critical to its financial viability.

We have run simulations for investment capital costs of £3k and £4k per kWp (installed)

Fig.40 shows the payback and profitability periods
Payback period is respectively equal to 16 years and 20 years at £3k and £4k capital cost per kWp
Profitability periods are respectively 1 year and 2 years
The little difference in profitability period with the previous simulation is due to the change in the proportion of electricity used on-site.

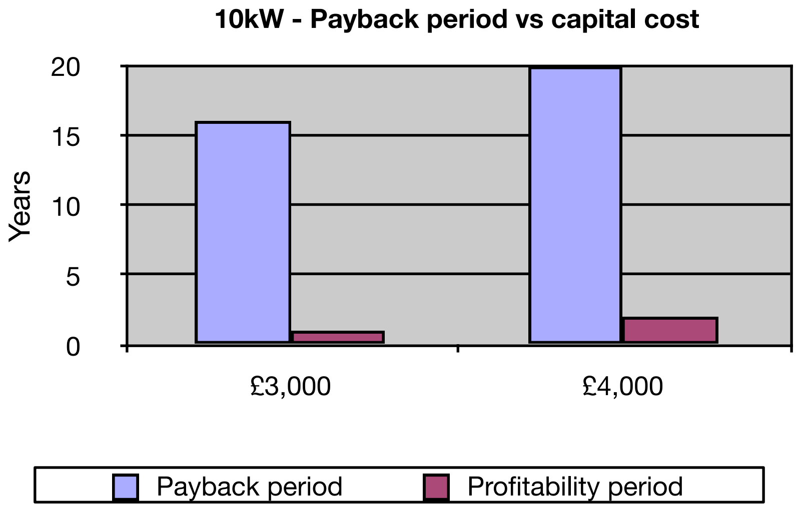


Fig.40

Fig.41 shows the yearly profit for the 10kWp system
At £4k per kWp the 30-year aggregate profit is just over £24,200, or £807 per year on average, with a maximum of £1682 during 25th year.

At £3k per kWp the 30-year aggregate profit is just over £40,200, which is > £1340 per year on average, with a maximum of £2472 during the 25th year.

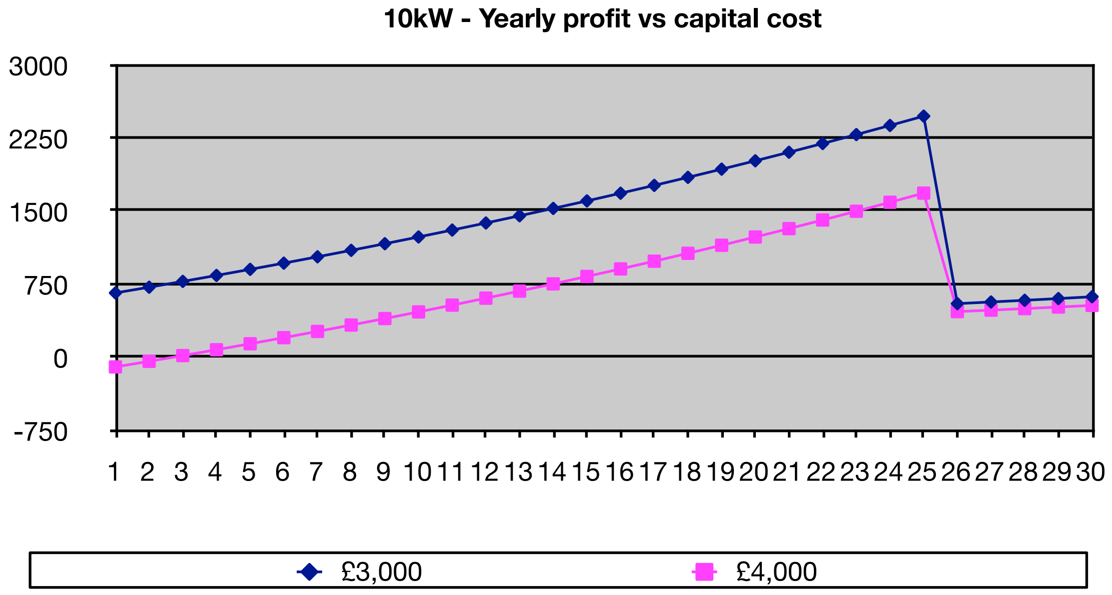


Fig.41

n both cases the investment looks acceptable, the lower on-site consumption does not affect highly the systems key indicators even if the return is lower on a per kW basis. In fact for such size system the priority is really to draw a safe profit and not incur a loss rather than realize a specific return rate.

We would conclude here therefore that for medium size systems (10kWp):

- A capital cost below £4k/kWp should still provide a decent investment, assuming the site where it is installed is such that the on-site consumption of electricity produced does not differ too much from 40%, which should be the case for schools and office buildings which have most of electrical consumption during daylight hours.

<u>Large size PV system</u> (capacity from 10kWp to 100kWp)

The present FIT for such systems drops to 31.4p which will constitute the main disadvantage as compared with smaller systems.
In addition, the on-site usage electricity which could be now significantly lower.
However the overall normalized capital cost should be reduced (installation playing a significant part).
We have run simulations for:

- Capital costs of £2.5k, £3k and £3.5k

- On-site usage ranging from 10% to 30%
- FIT = 31.4p/kWh

The other parameters are unchanged from the values used for the medium size system.

The value of electricity consumed on site is 41.4p/kWh and the value of exported electricity is 34.4p/kWh.

On-site usage of 30%

Fig.42 shows the payback period versus capital cost for an on-site usage of 30% (best case scenario)

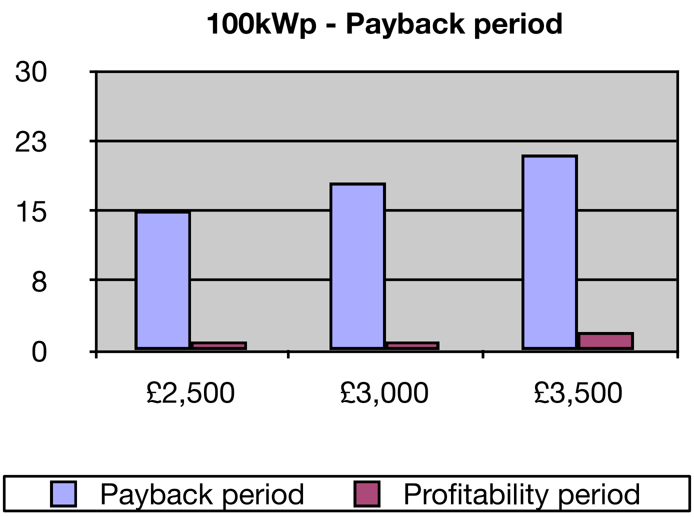


Fig.42

Payback periods are respectively 15, 18 and 21 years. Profitability period is 1 year for £2.5k and £3k and it is 2 years for £3.5k capital cost per kWp.

Fig.43 shows the yearly profit versus capital cost based upon 30% on-site usage.

All schemes are profitable from the start or nearly. The worst case scenario (higher capital cost) provides a 30-year aggregate profit of £172,730, or £5746 per year on average, with a maximum of £14,387 during 25th year.

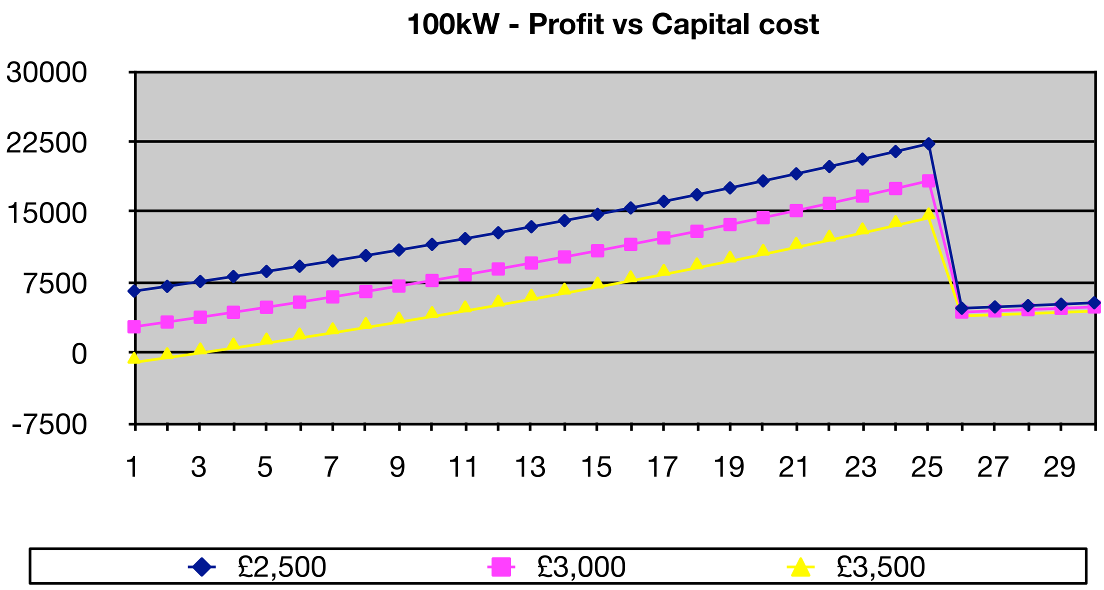


Fig.43

On-site usage of 10%

We have run simulations for £3k and £3.5k capital costs.

The payback periods obtained are respectively 19 and 21 years. The profitability periods are 1 year and 5 years.

Fig.44 shows the yearly profit for both capital costs

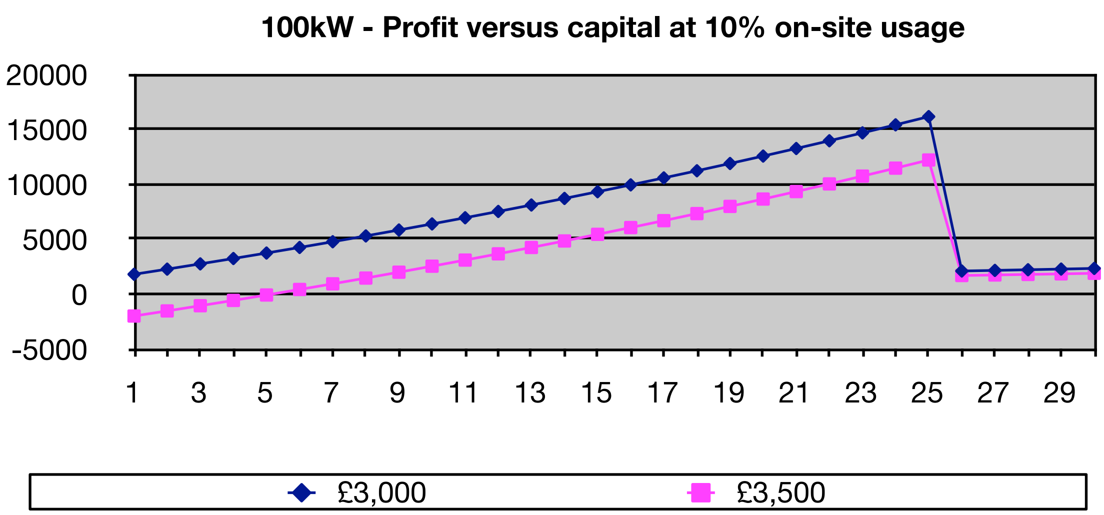


Fig.44

At £3.5k per kWp the 30-year aggregate profit is just over £123,100, or £4,103 per year on average, with a maximum of £12,213 during 25th year.

Although it is overall profitable this scheme is not attractive, it loses money for the first year then provides a small profit compared with capital cost.
At £3k per kWp the 30-year aggregate profit is just over £221,940, which is £7,398 per year on average, with a maximum of £16,163 during the 25th year.
In this case the project is only attractive from the point that it generates a profit every year however the return it offers is rather and the payback period is long!

We conclude here that:

- The proportion of electricity used on-site has a fairly important effect on the financials of the PV system. When it drops to 10% the project profitability decreases as expected and as a consequence it is preferred for the capital cost to be below £3k.
- At £3k/kW capital cost the scheme is not particularly attractive but still provide a profit each year

Loan interest rate

We now run a simulation using a worst case scenario for the loan rate, taken at 8%.
The on-site usage is 10% and capital cost varies from £2.5k to £3k per kWp
The payback periods we obtain are 20 years and 23 years respectively. The profitability periods are 1 year and 10 years.
The increase of the loan rate has therefore a very negative impact on the profitability when capital cost is £3k, because the overall loan value and yearly payments increases significantly.

Fig.45 shows the yearly profit obtained:

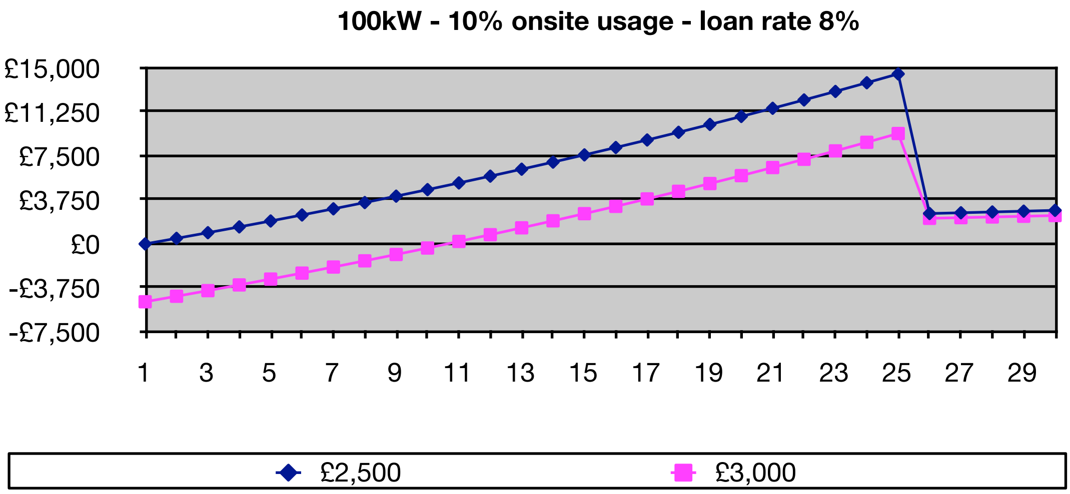


Fig.45

If capital cost is £3k then the aggregate profit over 30 years is very small at about £51k only, with the first 10 years making a loss. This scheme is not attractive!
At a lower capital cost of £2.5k the aggregate profit over 30 year is about £178,300, which becomes acceptable but barely.
We conclude therefore than when loan rate increases from 5% to 8%, a further reduction of about £500 per kWp is required to maintain the same scheme financially attractive and safe.

Conclusions

Capital cost for large PV operations operating with a 10% onsite usage should be limited to £2500/kWp
The loan rate should be kept near 5%.
An on-site usage of 30% allows to remain profitable with a capital cost of £3000kWp

3.4 Conclusions for PV systems

- PV could potentially contribute supplying or offsetting at least a quarter of the Council’s electricity demand. This would require however to install panels on the majority of south oriented roofs.
- Payback periods are usually about 15 years or slightly below, which is higher than most other renewable electricity generation such as wind for instance. It is possible however to invest in schemes that will be profitable from the first year.
- On the other hand PV systems are straightforward to install and lower risk than many other renewables.
- For small systems 4kWp and 10kWp the normalized capital cost must be below £4k/kWp and preferably near £3k/kWp. The on-site consumption should be about 40%.
- Larger systems (up to 100kW) require a lower capital cost to be attractive, preferably below £2500/kWp
- The loan interest should be kept near 5%, a rate of 8% has a similar effect on the profitability as a £500/kWp increase in capital investment.

4- Biomass in Argyll & Bute

Argyll & Bute is the second largest council in Scotland with a low density of population, it is mostly rural landscape and has a very large potential for wood biomass or SRC (short rotation crops).

The council could consider switching most of their buildings current heating schemes from fossil fuels (oil and gas) to solid biomass.

The main barriers to (large scale) implementation would be:

- Boiler capital cost at least twice that of fossil fuel
- Require more manual handling than fossil fuels
- Need local and inexpensive fuel suppliers
- Potential environmental issues (smoke, emissions)

Boiler and installation capital costs are discussed in the biomass financial analysis section. Although the boiler cost more there would be savings on the cost of fuel as well as income from renewable heat incentives.

Maintenance of the biomass facility is likely to be more important than for oil or gas. It should be considered on a case by case. Most likely staff in charge of other parts of building maintenance would have to handle the heating system.

The cost of fuel will depend on the distance to delivery. The council has a large resource of wooden areas and land (private) which could be developed into small scale biomass industry once there is a decent size market. The overall fuel demand from the Council itself would be sufficient for this. The specific aspects of establishing local suppliers within the council area will not be covered in this work.

4.1 Council buildings fuel demand for heating

Table 5 below summarizes the current annual demand in oil and gas for covering most of the buildings heating demand (Note that there are a few buildings heated with storage heaters) [6]
The council has for first priority to replace oil heating by biomass or gas. A number of projects are already in process or completed.
The focus of this work is to consider the benefits and costs associated with replacing fossil fuel heating by biomass. A first step could be to convert oil system and then install biomass boilers to supply heat instead of using gas.
It is important to remember that biomass boilers should not be sized for peak load and therefore require a back-up system. The preferred option is therefore to keep the gas boilers as back-up where possible.

	Oil	Gas	Total
MWh consumed	20,649	15,550	36,199
MWh delivered	14,450	13,995	28,450
Biomass MWh	16,060	15,550	31,610
Required ha	402	389	790
Tons chip 30% MC	4724	4574	9297

Table 5

We have first of all used our biomass simulation tools to evaluate the equivalent amount of biomass needed to replace oil and gas fuels, as well as the actual amount of land required to supply the fuel.

The assumptions are:

- Oil boiler efficiency = 70%
- Gas boiler efficiency = 90%
- Biomass boiler efficiency = 90%
- Energy content of wood chips (MC=30%) = 3.4 kWh/kg
- Yield for wood biomass = 40 MWh per ha (based on crops for UK average)

❑ To replace all oil installations with biomass would require just over 4700 tons of wood chips annually, which can be produced from approximately 400 ha of crops (or equivalent supply from other sources). The annual heat requirement is 16 GWh

❑ To replace both oil and gas would require about 9300 tons of wood chips annually, corresponding to a surface of 790 ha. The annual heat requirement is 31.6 GWh

This quantity is significant but nevertheless remains within the normal range for large operations. Below are examples which provide some actual comparisons:

- Biomass power plants typically consume 5000 tons or more of solid biomass fuel per MW installed.
- For comparison also we contacted the company Pentland Plants near Edinburgh. They use a 1.5MW wood chip boiler to heat their greenhouses.They consume about 3000 tons of chips per year.

- The Council's demand correspond also to the annual output production of Forest Fuels Ltd (One of the leading wood fuel supplier in South West & Western England) established in 2006 [116]

4.2 Cost of biomass fuel (wood chips)

The price of wood chips will depend on a number of parameters [114]

- First the moisture content: this is the most important parameters which the energy content depends highly upon
- Second the distance to delivery: for this reason the presence of a number of local suppliers will be important in order for the Council to be able to source inexpensive fuel
- Third the quantity: the demand from the Council could be quite high (several tons) and therefore it will worthwhile negotiating larger supply contracts if possible.

We have surveyed a number of suppliers in the west of Scotland for wood fuel prices and have obtained a wide range of prices [115]
There is a wide range of prices and moisture content ranging for instance from £65 to £150 per ton for a MC=30%. Using our biomass tool we have converted this back to an actual fuel energy cost in pence per kWh and obtain the following ranges:

- MC=25% 2.2p to 3p per kWh
- MC=30% 2p to 4.3p per kWh
- MC=35% 3.2p per kWh
- MC=40% 5.5p per kWh

Most wood chips suppliers provide chips with a MC=25% to 30% and a cost of 2p/kWh or more. Costs with any given supplier will vary also depending upon the delivery size, the global annual quantity purchased and the distance to delivery.
In the case of Argyll & Bute, the delivery size should be maximum (typically about 20 tons) as their demand on each site is quite large and storage facilities should be able to cope with this size of delivery.
The global annual quantity purchased should also be large (schools require several hundred tons of chips each per year), this should allow the price to be lower.

The main issue is the distance to delivery, the buildings within the Council are quite spread out, including on islands. The price of fuel could rise due to distances, it is therefore important that local suppliers be present near most towns at least where the bulk of demand will be. The Council has indicated that they are already working on this issue.

The manufacturing of wood chips from logs does not require a massive investment, unlike wood pellets, so it should be feasible within the Council strategy to develop the local biomass industry and establish local chips suppliers.
Assuming local sources are available then we should expect the Council to be able to obtain relatively cheap fuel (except maybe in the short term - next few years).
We will use for the simulation a range of 2p/kWh to 3p/kWh

We have also used our simulation tool to evaluate the relationship between price per ton, moisture content and price per kWh.
The results are summarized on fig.46 . The curves are quite informative as they allow to make direct comparison between fuels with different MC% and prices.

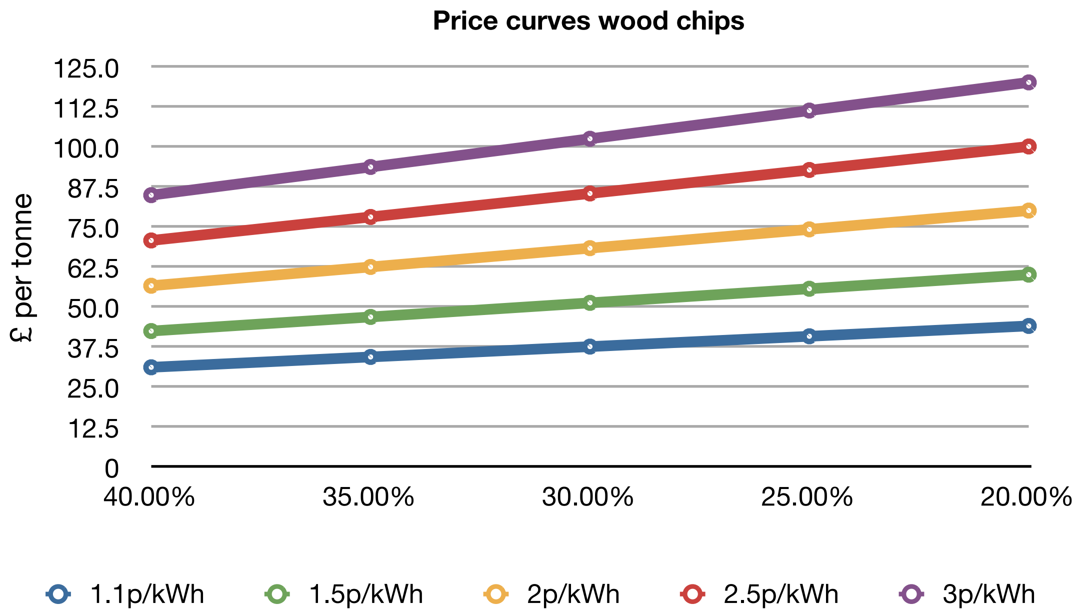


Fig.46

First we note that wood chips with MC=20% should be 50% more expensive than MC=40% based on their respective energy content.
Basically every time the moisture content increases by 5% the price of the fuel should drop by 10% to provide the same kWh value.

For wood chips at MC=30% (most common):
A price of £35/ton would provide energy at 1.1p per kWh (basic fuel cost only). If the price rose to about £62/ton then the energy cost is 2p/kWh. At £79/ton the chips provide energy at 2.5p/kWh.

4.3 Data on large biomass installations in schools

We have obtained [4] the following data relative to previous biomass (wood chips mostly) projects for schools in Argyll. We will use this data for the biomass systems financial simulations.

- Capacity of the installations range: 300kW to 500kW
- Normalized capital cost: £580/kW to £1200/kW
- Capacity factor range: 17% to 42%
- % of demand covered by biomass: 82% to 97%
- Ratio of capacity / peak demand: 0.39 to 0.8
- Ratio of yearly energy / capacity: 1500 kWh/kW to 3700 kWh/kW
- O&M cost: 1.1% to 1.7% (of initial capital cost)
- Cost of oil heat supplied: 5.7p to 7p per kWh
- Biomass required per year: 211 to 569 tons

Most installations required for Council buildings are likely to require installations of several 100kW capacity, as shown on the data above for schools in Argyll.
There would be an obvious advantage to limit capacity to 45 kW to obtain a more attractive RHI of 9p/kWh instead of 6.5p/kWh however the capital cost would be higher and most likely would offset this benefit.
There is an obvious disadvantage to size boilers above 500 kW as the RHI would then be reduced nearly by a factor of three.
A survey of the list of Argyll & Bute Council buildings shows that the large majority of buildings do not require a boiler capacity above 500 kW considering that all installations should have a back-up system (most likely gas) [3]

4.4 Renewable Heat Incentives

RHI	Starts April 2011		
		p/kWh (max)	Years
Solid biomass	<45kW	9	15
	45kW-500kW	6.5	15
	>500kW	2.5	15

Table 6: RHI for biomass

It makes sense therefore to focus on the RHI bracket of 45-500kW receiving an RHI of 6.5p/kWh.
Note that this RHI value is not guaranteed, it is a maximum that will be obtained only if the buildings meet minimum standards regarding energy efficiency, based on the ‘deemed’ heat

demand evaluated by the government. The RHI payments will therefore not necessarily cover the whole actual demand. See RHI section for further info.

4.5 Critical parameters

The normalized capital cost above reflects various systems sizes and different installation and accessories costs (such as thermal buffer tanks). The internal infrastructure and heat distribution costs are not to be included as it is assumed the existing wet heating system in most Council buildings can be used as is.
We will use a range of £500 to £1200 in the simulations.

The capacity factor depends upon the boiler size versus the demand as well as storage buffer tank size.
It is typical to use about 50l of water storage per kW of capacity. In addition the daily demand on a normal winter day should be taken into consideration and preferably water storage should be able to cover at least one day of heat demand.
The higher the capacity factor the better the financial return should be for the total amount of capital spent. In addition a higher capacity factor will often result in a higher proportion of the total demand being supplied from biomass, which will limit the fossil fuel cost and carbon emissions from the back up system.
For the capacity factor we will assume a worst case scenario of 15% and a best case scenario of 40%.
We have plotted on fig.47 the equivalence between hours in operation annually and resulting capacity factor.
It is typical for schools, office building or recreational facility (as well as other types of commercial operations) to require close to 4000 hours of operation annually to provide both space heating and hot water demand (1 year = 8760 hours)
For biomass boilers the average load should be 80% to 90% to obtain maximum efficiency.
A capacity factor is reached when the boiler runs between these 2 values for 4000 hours. The worst case scenario CF=15% would correspond to running at 80% load for about 1700 hours annually.

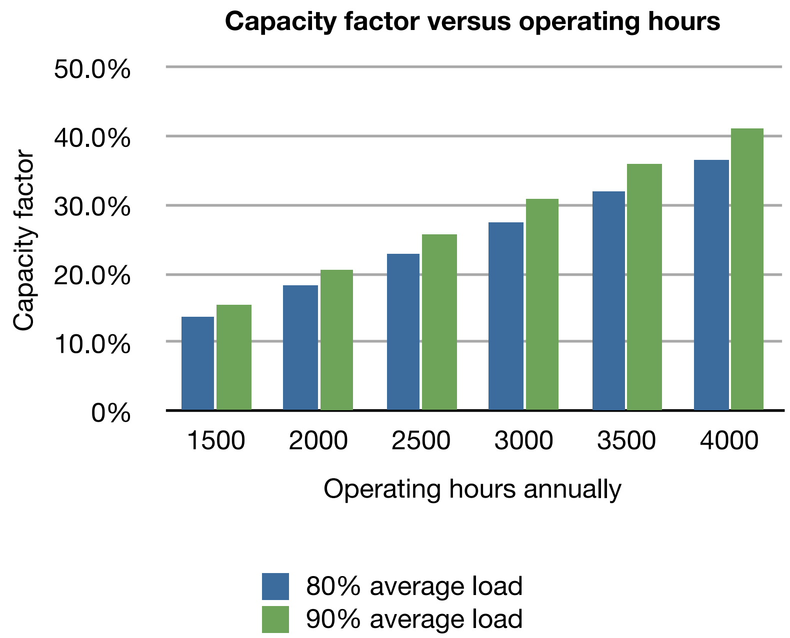


Fig.47

The ratio of installed capacity (kW) versus peak demand (kW) varies from about 0.4 to 0.8. It is normal when sizing the boiler not to size it to cover peak demand as preferably the boiler should work at high capacity for better efficiency.
The buffer tank allows to store energy before peak demand is required. In case this were insufficient the back up system would provide the additional energy required.

The ratio of yearly energy demand to installed capacity is directly related to the capacity factor. Preferably this ratio should be kept high to optimize the boiler average load utilization.

The maintenance costs are more or less 1.5% of capital investment.

The cost of heat by oil varies between 5.7p and 7p per kWh. The main reason for the variations is the boiler efficiency. We will use an average value of 6.4p per kWh corresponding to about 70% efficiency.

4.6 Financial analysis for biomass

We have made financial analysis for biomass boilers of medium size, ranging from 45kW to 500kW, which will be representative to most boilers required for building facilities (schools, offices, recreational facilities) within Argyll and Bute Council. For the simulations we use a rated power of 450kW.

The key parameters are:

- The rated power of the boiler is 450kW
- Capital investment cost, expressed in £ per kW of rated power
- The average load for the boiler over 1 year
- The number of hours boiler is in operation
- CF = Capacity factor for the boiler
- O&M cost per year, expressed as a percentage of the capital cost, is 1.5% per year
- The biomass fuel cost is 3p/kWh
- Loan interest rate
- Loan duration in years
- The cost of heat generated
- The RHI applicable is 6.5p per kWh (maximum)

Rated power and normalized capital cost of installation:
The type of boiler we are considering is medium size, within the range 45kW - 500kW. The RHI is constant within this range.
The main difference from a financial point of view between a 50kW and a 450kW boilers will be the normalized capital cost. The capital cost varies from £750/kW and £1200/kW, with an average standard value of £1000/kW. This range is based upon prices obtained from existing installation projects within the Council as well as standard suppliers information (see background section)

Boiler average load and operating hours
The average load (in kW) over the annual operation and the annual number of hours of operation for the boiler can be combined into the FLHE (Full Load Hours Equivalent):
FLHE = Average Load x Number of hours in operation

Capacity factor
The capacity factor depends directly upon the FLHE and represents the percentage of usage of the boiler compared full load continuous operation. As there are 8760 hours in a year, the capacity factor can be obtained by:
CF(%) = FLHE / 8760

The annual operations and maintenance cost is assumed to be 1.5% of capital cost. This is based upon information from the Council on existing installations.

The biomass fuel cost is assumed to be 3p/kWh, it corresponds to wood chips with moisture content of 25-30%. It is an average price based upon information provided by the Council as well as quotes from local suppliers. It is anticipated that the Council could negotiate lower prices (down to 2p or less) assuming the quantity was large enough. In the short term however 3p/kWh is a reasonable value. The cost is corrected yearly as per an inflation rate of 2% (RPI average)

Loan rate and duration are assumed to be respectively 5% and 15 years. Normal loan rates would range normally from 5%-8%, the Council has indicated it would normally be able to negotiate loans at the lower end of the bracket. The duration of 15 years was chosen to match the RHI period for simplicity purposes.

The cost of heat generated from biomass is equal to the cost of the fossil fuel heat that would otherwise be incurred. It depends upon the type of fuel which is currently used. For existing oil systems the data provided shows an average of 70% oil boiler efficiency and a resulting cost of oil in the range of 5.7p/kWh to 7p/kWh, we have assumed an average value of 6.4p/kWh.
For gas heating the fuel cost would typically about 3p per kWh. For fossil fuel costs we have assumed an inflation rate of 3%.

RHI applicable is 6.5p per kWh of heat generated based on a 'deemed' consumption assuming that the building meets minimum requirements in insulation (see RHI section). As some of the Council buildings may not fully meet these requirements we have assumed a 'corrected' RHI of 3.5p per kWh.
We did not find in the official government sites whether the RHI values are fixed in time or whether they will be adjusted yearly according to RPI, as is the case for the FIT.
We will therefore run a first simulation comparing financial returns between inflation rates of 0% (fixed rate) and 2% (RPI) applied to RHI.

We provide results on financial simulations done with various parameters. Key parameter studies have been performed.
The data we use to evaluate financial viability are mostly the payback period, the profitability period (this is the number of years it takes to earn money from the investment) and the yearly profit.
The profit is obtained from deducting costs from the income each year. Costs include the loan repayment, O&M cost and biomass fuel cost. The income is made of the RHI and value of the heat generated as defined above.

<u>Biomass as a replacement of oil</u>

RPI inflation rate
Simulations were made for fixed RHI vs 2% inflation rate

The other parameters are set at:

- Capital investment is £1000 per kW of rated power
- Capacity factor is 25%
- O&M cost per year, expressed as a percentage of the capital cost, is 1.5% per year
- The biomass fuel cost is 3p/kWh
- Loan interest rate is 5%
- Loan duration is 15 years
- The cost of heat generated is 6.4p/kWh (replacement for oil)
- The average RHI assumed to apply is 3.5p per kWh
- The total value of heat produced is therefore 9.9p/kWh

Payback period is 6 years in both cases.

Fig.48 below shows annual profit for either case. There is little difference between the two curves, the aggregate profit after 20 years using a corrected RHI (2% inflation rate) is about 5% higher than with fixed amount.

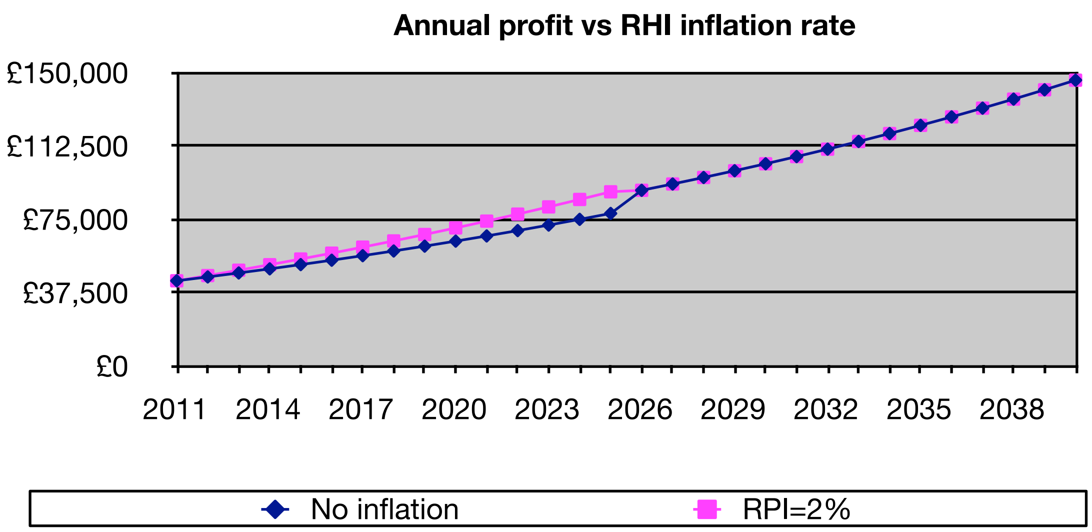


Fig.48

We conclude therefore that application of inflation rate on RHI is not very relevant and for the rest of the simulations we will assume that inflation does apply as for FIT (indexed to RPI).

Capacity factor

We run a series of simulations using capacity factors of 15%, 25% and 40%.

This range is typical for biomass boilers. Biomass boilers should not be sized based on peak load as they are made to work at high efficiency. In addition the fact that they are equipped with a water storage buffer tank allows to cover most of the demand (over 90% typically) with a boiler rated below the maximum peak demand. Lower capacity factors are obtained when boiler size is too high and/or the tank size is too small. Operating with a high capacity factor will be more financially attractive. An average value for the capacity factor should be about 25%. We will take 15% as a worst case scenario and 40% as a best case scenario.

The other parameters are set at:

- Capital investment is £1000 per kW of rated power
- O&M cost per year, expressed as a percentage of the capital cost, is 1.5% per year
- The biomass fuel cost is 3p/kWh
- Loan interest rate is 5%
- Loan duration is 15 years
- The cost of heat generated is 6.4p/kWh (replacement for oil)
- The average RHI assumed to apply is 3.5p per kWh
- The total value of heat produced is therefore 9.9p/kWh

The payback period we obtain is:
- 11 years at a capacity factor of 15%
- 6 years at 25%
- 4 years at 40%.

The profitability period is 1 year for all three cases.
Based on payback period it is therefore preferable to operate within a capacity factor of about 25% or better. This means the boiler must be sized accordingly based upon yearly demand rather than peak load and be equipped with sufficient hot water storage capacity.

Fig.49 shows the annual profit realized over a 30-year period.

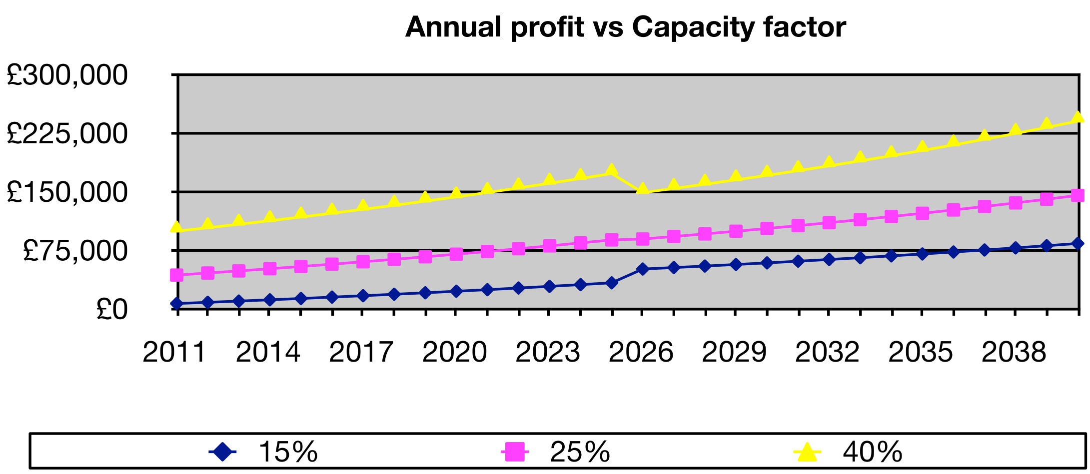


Fig.49

We can see that all curves are above the zero-mark, which reflects the fact that profitability period is 1 year.
It is important to only to be profitable soon enough but also to operate with a reasonable safety margin to account for potential variations of other parameters, for instance a fuel increase or an occasional higher maintenance cost, etc...
We see that the capacity factor has a lot of influence over the scheme profitability, for a 450kW system the difference between operating at 15% or 40% is of the order of £100k per year!
At a CF=15% the profit remains below £30k for the first 15 years then jumps to about £50k. The low profit accounts for the longer payback period. The investment is not so attractive and could incur losses if other parameters were to vary a lot.
Note the shape of the curve at year 21, the profit goes up showing that the loan repayment was more important than the income from the RHI.

At a capacity factor of 25% the scheme is quite profitable. The aggregate profit after 20 years is about £1.4m.
For a 450 kW boiler this would correspond to a demand of 990,000 kWh (a decent size size school or office building) covered by biomass. The back up system would have to supply probably between 5% and 10% of the total demand. The annual biomass fuel requirement would be about 325 tons (wood chips at MC = 5-30%)

When capacity factor reaches 40% the scheme becomes very profitable. Obviously the design of the system to be able to run at such high capacity factor over the year would require optimum sizing of both boiler and buffer tank.

Capital cost

We have studied the effect of financials of capital cost variations from the standard value of £1000/kW. The best case scenario is £750/kW and worst case scenario is £1200/kW.

The other parameters are set at:

- Capacity factor is 25%
- O&M cost per year, expressed as a percentage of the capital cost, is 1.5% per year
- The biomass fuel cost is 3p/kWh
- Loan interest rate is 5%
- Loan duration is 15 years
- The cost of heat generated is 6.4p/kWh (replacement for oil)
- The average RHI assumed to apply is 3.5p per kWh
- The total value of heat produced is therefore 9.9p/kWh

The pay back period is 5 years at £750/kW, 6 years at £1000/kW and 8 years at £1200/kW
The profitability period is 1 year in all cases.
All schemes are therefore quite attractive even at the higher cost of capital (which would apply to smaller systems within the medium range). This confirms our previous finding that the capacity factor (here set at the average value of 25%) is a critical parameter influencing on the financials of the system.

Fig.50 shows the annual profit for the system.
We can see that the capital cost within the range considered has a lesser effect than the capacity factor. Between the two extreme values considered the difference in profit is about £25k per year for the first 15 years. Obviously after the loan has been paid the initial capital cost has no longer an effect of profitability.

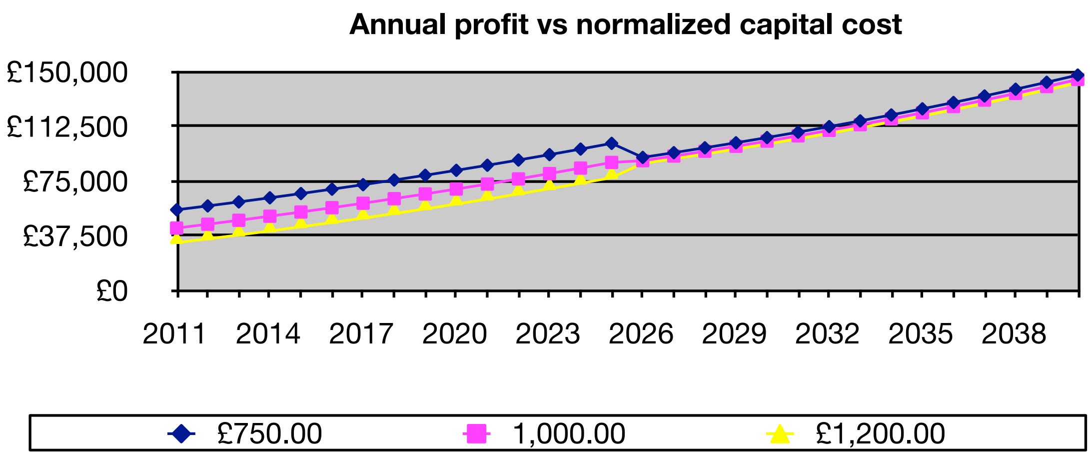


Fig.50

All schemes are quite profitable from year 1 (mostly due to the capacity factor value).
Note that for the higher capital cost the profit increase after year 15, showing that loan repayments is more important than FIT income in the first 15 years. For the lower capital costs it is the other way around.
The difference in aggregate income after 30 years between both extreme cases differs by about £420k, which represents less than a 20% variation.

RHI income

The RHI should be 6.5p per kWh assuming that the building makes the minimum requirement on insulation. Otherwise calculations will be made on the heat demand which the building would have assuming it were properly insulated, and payments will be made based upon a lower demand, which is effectively equivalent to reducing the RHI over the actual demand.

We have assumed in all simulation a corrected RHI value of 3.5p based on the fact that most buildings are old and unlikely to get the full RHI payment.
It is however true that some of the Council building are new and others have benefitted from an upgrade in insulation which will make them eligible for the full payment (actual demand kWh x 6.5p).

We have compared financial returns for both RHI rates, assuming all other parameters at their average values.
The payback period is reduced from 6 years to 5 years when RHI goes from 3.5p to 6.5p.

Fig.51 shows the annual profit obtained for both cases.
We note a significant difference in the profit during the first 15 years, despite the fact that payback period differs only by 1 year.

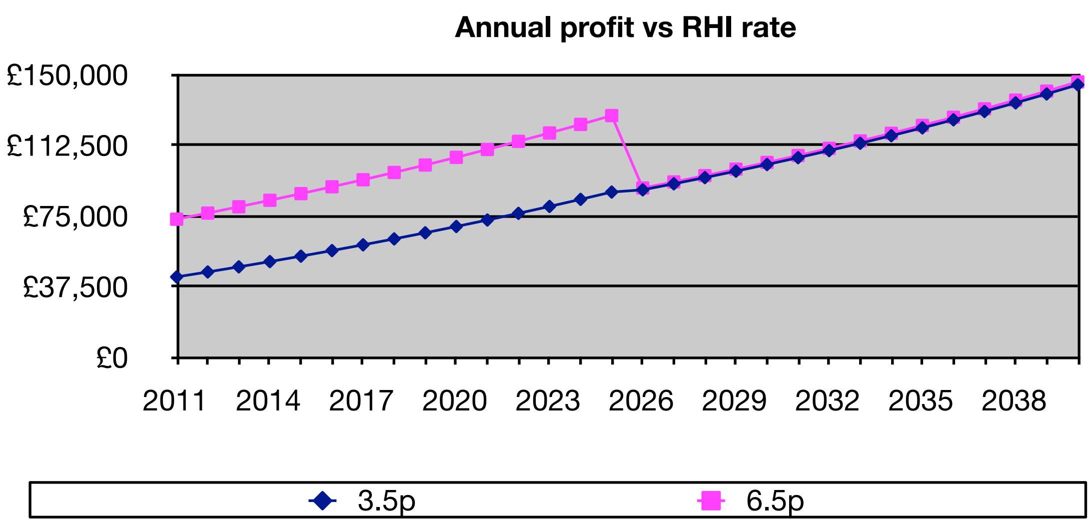


Fig.51

The aggregate profit after 20 years is higher by about £530k when RHI is 6.5p, representing an increase by about a third.
The conclusions would be that even with a corrected RHI of 3.5p per kWh most biomass systems will provide decent return (payback period and profit) however there is a clear potential benefit in conducting the required insulation upgrade which would allow to obtain higher income from a full RHI value.

<u>Biomass as a replacement of gas</u>

For the same biomass boiler installation, the main difference between replacing an existing oil or gas installation (keeping it however as a back-up to biomass) is the cost of the heat

generated. Heat from oil has an average cost of 6.4p/kWh while heat from gas (mains) has an average cost of 3.2p/kWh [source: A&B Council].
Replacement of a gas installation rather than oil will translate into the financial model in a lower value of heat generated from biomass and therefore a lower profitability.

The simulations we have conducted for gas replacement are the following:

- Variation of capital cost within range considered for medium size biomass installation
- Higher capacity factor at 40%
- Higher RHI at maximum value of 6.5p

Capital cost

The other parameters are set at:

- Boiler size is 450kW
- Capacity factor is 25%
- O&M cost per year, expressed as a percentage of the capital cost, is 1.5% per year
- The biomass fuel cost is 3p/kWh
- Loan interest rate is 5%
- Loan duration is 15 years
- The cost of heat generated is 3.2p/kWh (replacement for gas)
- The average RHI assumed to apply is 3.5p per kWh
- The total value of heat produced is therefore 9.9p/kWh

The payback periods we obtain are:

- 10 years at a capital cost of £750/kW with a profitability period of 1 year.
- 13 years at a capital cost of £1000/kW. Profitability period becomes 3 years.
- 18 years at a capital cost of £1200/kW and the profitability period is 10 years.

The same biomass installation replacing gas heating now becomes significantly less profitable as compared with oil replacement. At low capital cost £750/kW the installation is profitable from year 1 but still takes 10 years to pay for itself.
At the average normal capital cost of £1000/kW the first two years show a loss and payback period is quite long, making the investment not so attractive.
At higher capital cost the scheme is definitely not attractive as profitability period is too long.

Fig.52 shows the annual profit obtained for different values of capital cost in £/kW

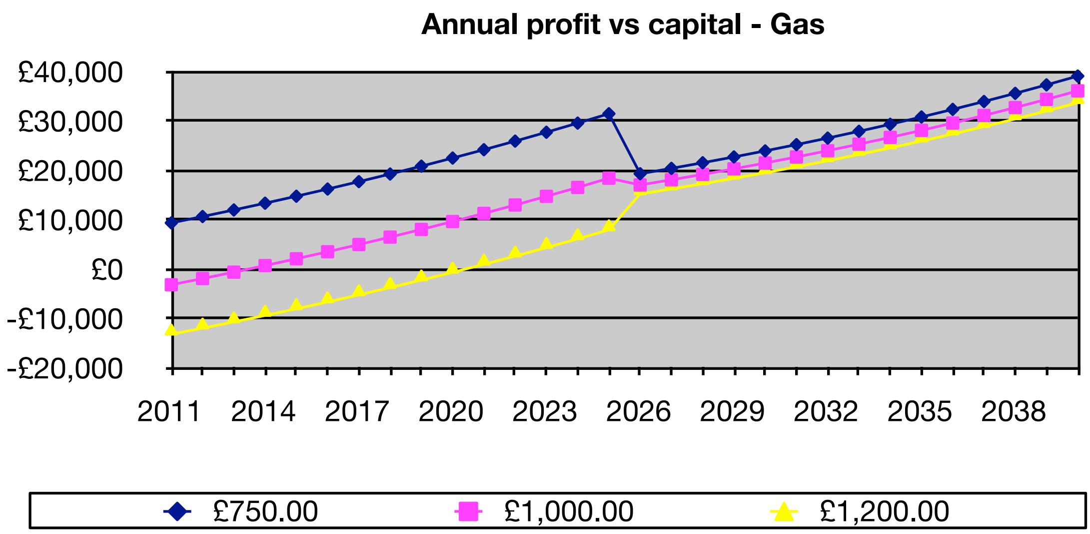


Fig.52

All schemes show nevertheless an aggregate profit after 20 years, but it is highly dependant on capital cost. At £750 it is £400k, dropping to £200k for £1000/kW and to just £36k for £1200/kW.

We conclude that:

- At a low capital cost replacement of gas by biomass should provide an acceptable return, but payback period still equals 10 years
- If capital cost gets close to average value of £1000, then we should look for other optimized parameters such as a higher capacity factor, better RHI (see below) or lower biomass fuel cost. In any case a careful financial evaluation of the site and installation should be done.
- The high capital cost scheme is too risky and could incur higher losses due to variations of other parameters.

Optimization of capacity factor and full RHI payment

We have seen that under average conditions the replacement of gas by biomass is not necessarily attractive financially depending upon capital cost.

There are two other parameters that will also influence profitability: the capacity factor and the RHI.

It is quite possible that for a number of thermal demand profiles a higher capacity factor than 25% be obtained through optimum sizing of boiler and storage buffer tank, we will model a CF=40%

The RHI has been assumed before to 3.5p/kWh, but it should be 6.5p/kWh for buildings which are properly insulated. Some of the Council’s buildings will meet this requirement and benefit from full RHI payments.

We have conducted simulation for either a capacity factor of 40% <u>or</u> RHI of 6.5p/kWh (not both!)
For these simulations the capital is taken to be £1000/kW and all other parameters are unchanged.

CF=40 % (RHI = 3.5p/kWh)

- The payback period is 8 years
- The profitability period is 1 year

RHI = 6.5p/kWh (CF=25 %)

- The payback period is also 8 years
- The profitability period is 1 year

Either scheme looks like an acceptable investment. Fig.53 shows the annual profit obtained for both cases

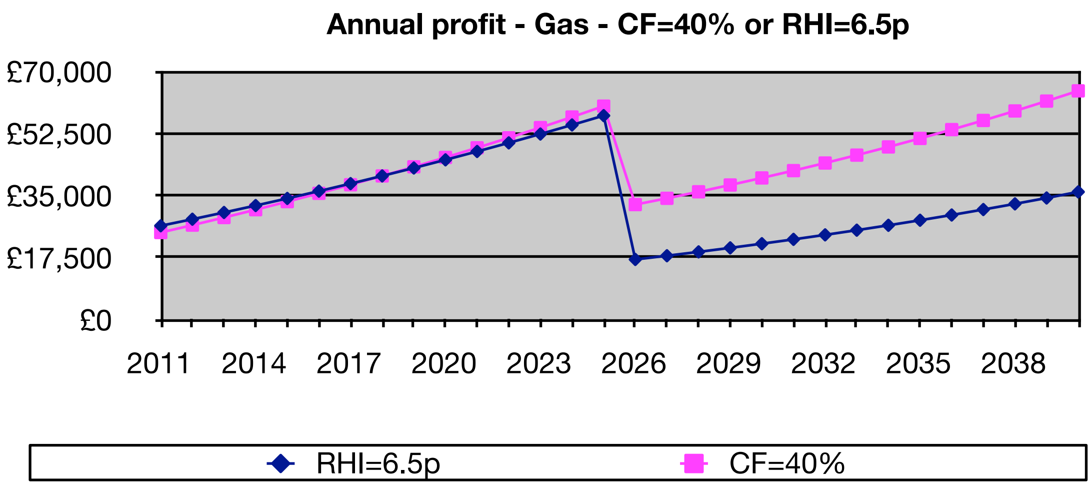


Fig.53

The profit looks very similar for the first 15 years, meaning the higher capacity and RHI bring a similar contribution financially.
After 15 years obviously the scheme with higher CF become more profitable simply because RHI payments are finished!
For gas replacement by biomass we therefore conclude that in order to obtain a reasonable return yearly and payback period no higher than 10 years we either need (taking all other parameters as average):

- The normalized capital cost to come down to about £750, or

- The capacity factor to operate near 40%, or
- The RHI to be at maximum rate of 6.5p/kWh (building insulation needs to meet requirements)

4.7 Conclusions for biomass

- Biomass boiler installations can provide excellent return and short payback period of 6-8 years when replacing oil systems
- The capital cost should be about £1000/kW or less and the installation should designed and sized to operate at a capacity factor of 25% or better
- Renewable heat incentives provide a good income but depend upon the buildings standards (energy efficiency). It is worthwhile ensuring the buildings does meet the standards in order to receive full RHI payment.
- The capital cost does not have a major impact on payback period (within limits!)
- Biomass installations to replace gas have a lower return and longer payback periods (10 to 13 years) due to the lower cost of energy from gas
- Such installation operating at a high capacity factor near 40% would nevertheless have a payback period of 8 years.
- Such installation benefitting for the full RHI payment of 6.5p would also have a payback period of 8 years.
- A 450kW installation could supply heat for a large school and provide an annual profit (or saving) of £70k on average over the first 20 years
- The annual wood chip requirements to replace all oil heating would be about 4700 tons. The corresponding required area for SRC to supply this quantity should be about 400 ha.
- The annual biomass fuel needed to replace both oil and gas would be about double this amount.
- The biomass fuel price is important and effort should be made to develop a local industry to supply the (potentially large) Council demand

Part C: General Conclusions

The key question we have basically tried to address is: “Should Argyll & Bute Council invest in renewable energies, what strategy could they follow?”
The answer is not simple but one key conclusion we can probably draw is that technically it is largely feasible to fulfill a large proportion of the energy demand using renewable energy resources available locally. It is also possible to do so with investments which will provide an annual profit from the start.

From the point of view of electricity generation we have found that wind power and PV panels provide the most readily available and best suited solution. Part of the electricity generated would be consumed directly at buildings sites and part of it would be exported to the grid, allowing the Council to offset corresponding carbon emissions from its own demand.

Wind power is the most abundant resource in Argyll & Bute Council and could easily offset all of the Council’s demand, however we have concluded that only large scale installations could make a significant impact.
Wind power is however difficult to evaluate and more complicated from the point of view of acceptance.
As Argyll & Bute Council have indicated that the land adjacent to their buildings is usually small, it is therefore anticipated that most wind turbines (especially large) would have to be located remotely. The Council may however consider a few selected sites where the conditions will make a small or medium wind installations worthwhile.
The payback period for most wind projects should range between 10-12 years.

PV installations could contribute a quarter of the Council’s demand based upon a large scale plan.
The payback periods are longer than for wind, near 15 years but the acceptance process and installation are far more straightforward. The critical parameter is the capital cost.

Regarding the buildings heat demand the most promising option is biomass from wood. It would make sense to develop a local industry and suppliers to fulfil the Council’s large demand. Oil replacement is more profitable than gas replacements, payback periods should be about 6-8 years versus a few years more for gas.
The capacity factor which the boiler operates under and the price of fuel are both critical parameters.
The buildings should also be upgraded to the minimum energy efficiency requirements in order to obtain full RHI payment, and allowing to reduce the payback period.

Suggestions for further work:

- Detailed case studies on large scale implementation of PV onto buildings
- Assessment of financials of a small wind farm and biomass crops on the same land
- Evaluation of Argyll & Bute potential for wood biomass and waste grain biomass

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Appendix 1: Wind power simulation tool for financial analysis

User information sheet

Entries are in black. Results are in red.
Do not make any entry in red color fields.

Section 1: Turbine

Power rating of the installation in kW

Capacity factor which the installation will operate at. This is defined as the ratio of actual energy produced in a year over the maximum amount that would be produced if turbine was constantly running at rated power.
The capacity factor can be evaluated through simulation tools such as HOMER or MERIT using hourly climatic data taken at more specific locations. The capacity factor may vary from year to year due to different weather conditions.

The usage factor represents the percentage of time when the installation is available to produce, meaning not being repaired or maintained. A value of 97% for wind is normally assumed.

Yearly energy: energy produced in a year in kWh

The on-site usage is the amount (percentage) of electricity produced which is used on site. This number can be obtained by measurement or by conducting numerical modeling on the matching of the site demand versus production using softwares such as HOMER or MERIT. It is assumed when using this tool that the on-site usage is known.

Exports: represents the part of the electricity that is not used on site. It is automatically calculated.

Section 2: O&M

Yearly inflation rate for O&M
O&M cost as a percentage of the capital cost. It is typically 1% to 2%
The actual cost in £ for year 1 is automatically calculated

Section 3: FIT incentives / Grid price

FIT applicable in £/kWh

Number of years it will be applied for

RPI (retail price index) inflation average rate

Export price in £/kWh of electricity sold back to the grid

Average yearly inflation rate

Current grid electricity price in £/kWh

Average yearly inflation rate

Section 4: Loan

Loan interest rate (r)

Number of years for the loan

The annual repayment and total loan amount are automatically calculated

The formula used is $C.r.(1+r)^n / [(1+r)^n - 1]$ where C is the capital cost

Section 5: Capital

Normalized capital cost per kW

The total capital cost is automatically calculated.

Summary results:

The payback period is the time taken for the aggregate income to reach the total capital loan cost + O&M costs

The profitability period is the number of years it takes for a positive profit to be generated

The cash flow positive period is the number of years it takes to generate positive cash input.

The cash input is the income minus the value of energy consumed on-site.

Example:

Parameters:

WIND TOOL		
Section 1: Turbine		
Power	35	kW
Cap factor	25.00%	
Usage factor	97.00%	
Yearly energy	74,351	kWh
On site usage	50.00%	
Exports	50.00%	
Section 2: O&M		
Inflation		2.00%
Cost %		1.50%
Cost year1		£2,625
Section 3: FIT and grid price		
2011	FIT	£0.241
	FIT years	20
	RPI	2.00%
2011	Sell price	£0.10
	Inflation (RPI)	2.00%
2011	Grid price	£0.12
	Inflation	3.00%
Section 4: Loan		
Rate	5.00%	
Years	20	
(1+r)^n	2.65	
Annual repay	£14,042.45	
Total loan	£280849.06	
Section 5: Capital		
Capital/kW	£5,000	
Capital cost	£175,000	
SUMMARY		
Payback period	10	year
Profitability period	1	year
Cash flow positive	1	year
Profit/loss 30yrs	£411,080	
Cash 30yrs	£198,844.29	
Profit/loss 25yrs	£352,162.42	
Cash 25yrs	£189,516.55	
Profit/loss 20yrs	£300,937.68	
Cash 20yrs	£181,068.13	
Rate of return (20yr)	5.17%	
Rate of return (25yr)	4.33%	
Rate of return (30yr)	3.79%	

Financial result over 30 year period:

Year index	Year	Export pri	Grid price	FIT	Loan re–pa	Loan re–pa Aggregate	O&M	O&M Aggregate	Year cost	Aggregate Cost	Productior KWh/year	FIT value
1	2011	£0.10	£0.12	£0.24	£14,042	£14,042	£2,625	£2,625	£16,667	£16,667	74,351	£17,918
2	2012	£0.10	£0.12	£0.25	£14,042	£28,085	£2,678	£5,303	£16,720	£33,387	74,351	£18,277
3	2013	£0.10	£0.13	£0.25	£14,042	£42,127	£2,731	£8,034	£16,774	£50,161	74,351	£18,642
4	2014	£0.11	£0.13	£0.26	£14,042	£56,170	£2,786	£10,819	£16,828	£66,989	74,351	£19,015
5	2015	£0.11	£0.14	£0.26	£14,042	£70,212	£2,841	£13,661	£16,884	£83,873	74,351	£19,396
6	2016	£0.11	£0.14	£0.27	£14,042	£84,255	£2,898	£16,559	£16,941	£100,814	74,351	£19,783
7	2017	£0.11	£0.14	£0.27	£14,042	£98,297	£2,956	£19,515	£16,999	£117,812	74,351	£20,179
8	2018	£0.11	£0.15	£0.28	£14,042	£112,340	£3,015	£22,530	£17,058	£134,870	74,351	£20,583
9	2019	£0.12	£0.15	£0.28	£14,042	£126,382	£3,076	£25,606	£17,118	£151,988	74,351	£20,994
10	2020	£0.12	£0.16	£0.29	£14,042	£140,425	£3,137	£28,743	£17,180	£169,168	74,351	£21,414
11	2021	£0.12	£0.16	£0.29	£14,042	£154,467	£3,200	£31,943	£17,242	£186,410	74,351	£21,843
12	2022	£0.12	£0.17	£0.30	£14,042	£168,509	£3,264	£35,207	£17,306	£203,716	74,351	£22,279
13	2023	£0.13	£0.17	£0.31	£14,042	£182,552	£3,329	£38,536	£17,372	£221,088	74,351	£22,725
14	2024	£0.13	£0.18	£0.31	£14,042	£196,594	£3,396	£41,932	£17,438	£238,526	74,351	£23,179
15	2025	£0.13	£0.18	£0.32	£14,042	£210,637	£3,464	£45,395	£17,506	£256,032	74,351	£23,643
16	2026	£0.13	£0.19	£0.32	£14,042	£224,679	£3,533	£48,928	£17,575	£273,607	74,351	£24,116
17	2027	£0.14	£0.19	£0.33	£14,042	£238,722	£3,604	£52,532	£17,646	£291,253	74,351	£24,598
18	2028	£0.14	£0.20	£0.34	£14,042	£252,764	£3,676	£56,207	£17,718	£308,971	74,351	£25,090
19	2029	£0.14	£0.20	£0.34	£14,042	£266,807	£3,749	£59,956	£17,792	£326,763	74,351	£25,592
20	2030	£0.15	£0.21	£0.35	£14,042	£280,849	£3,824	£63,781	£17,867	£344,630	74,351	£26,104
21	2031	£0.15	£0.22	0	£0	£280,849	£3,901	£67,681	£3,901	£348,530	74,351	£0
22	2032	£0.15	£0.22	0	£0	£280,849	£3,979	£71,660	£3,979	£352,509	74,351	£0
23	2033	£0.15	£0.23	0	£0	£280,849	£4,058	£75,718	£4,058	£356,567	74,351	£0
24	2034	£0.16	£0.24	0	£0	£280,849	£4,139	£79,857	£4,139	£360,706	74,351	£0
25	2035	£0.16	£0.24	0	£0	£280,849	£4,222	£84,080	£4,222	£364,929	74,351	£0
26	2036	£0.16	£0.25	0	£0	£280,849	£4,307	£88,386	£4,307	£369,235	74,351	£0
27	2037	£0.17	£0.26	0	£0	£280,849	£4,393	£92,779	£4,393	£373,628	74,351	£0
28	2038	£0.17	£0.27	0	£0	£280,849	£4,481	£97,259	£4,481	£378,108	74,351	£0
29	2039	£0.17	£0.27	0	£0	£280,849	£4,570	£101,830	£4,570	£382,679	74,351	£0
30	2040	£0.18	£0.28	0	£0	£280,849	£4,662	£106,491	£4,662	£387,340	74,351	£0

On site KWh/yea	On site Value	Export KWh/yea	Export value	Yearly Income	Aggregat Income	Net year Profit/los	Aggregat Profit/los	Cash Income	Yearly Cash flov	Aggregat Cash flov	Rate of return	Pay–back Period	profitabil Period	Cash flov positive
37,175	£4,461	37,175	£3,718	£26,097	£26,097	£9,430	£9,430	£21,636	£4,969	£4,969	2.84%	1	1	1
37,175	£4,595	37,175	£3,792	£26,664	£52,761	£9,944	£19,373	£22,069	£5,349	£10,317	3.06%	2	1	1
37,175	£4,733	37,175	£3,868	£27,243	£80,003	£10,469	£29,842	£22,510	£5,737	£16,054	3.28%	3	1	1
37,175	£4,875	37,175	£3,945	£27,835	£107,83	£11,007	£40,849	£22,960	£6,132	£22,186	3.50%	4	1	1
37,175	£5,021	37,175	£4,024	£28,440	£136,27	£11,557	£52,406	£23,419	£6,536	£28,722	3.73%	5	1	1
37,175	£5,172	37,175	£4,104	£29,059	£165,33	£12,119	£64,525	£23,888	£6,947	£35,669	3.97%	6	1	1
37,175	£5,327	37,175	£4,187	£29,692	£195,03	£12,694	£77,218	£24,366	£7,367	£43,036	4.21%	7	1	1
37,175	£5,487	37,175	£4,270	£30,339	£225,37	£13,282	£90,500	£24,853	£7,795	£50,831	4.45%	8	1	1
37,175	£5,651	37,175	£4,356	£31,001	£256,37	£13,883	£104,38	£25,350	£8,232	£59,063	4.70%	9	1	1
37,175	£5,821	37,175	£4,443	£31,678	£288,04	£14,498	£118,88	£25,857	£8,677	£67,741	4.96%	10	1	1
37,175	£5,995	37,175	£4,532	£32,369	£320,41	£15,127	£134,00	£26,374	£9,132	£76,872	5.22%	10	1	1
37,175	£6,175	37,175	£4,622	£33,077	£353,49	£15,770	£149,77	£26,902	£9,595	£86,468	5.48%	10	1	1
37,175	£6,360	37,175	£4,715	£33,800	£387,29	£16,428	£166,20	£27,440	£10,068	£96,536	5.75%	10	1	1
37,175	£6,551	37,175	£4,809	£34,540	£421,83	£17,101	£183,30	£27,988	£10,550	£107,08	6.03%	10	1	1
37,175	£6,748	37,175	£4,905	£35,296	£457,13	£17,790	£201,09	£28,548	£11,042	£118,12	6.31%	10	1	1
37,175	£6,950	37,175	£5,003	£36,069	£493,20	£18,494	£219,59	£29,119	£11,544	£129,67	6.60%	10	1	1
37,175	£7,159	37,175	£5,103	£36,860	£530,06	£19,214	£238,80	£29,702	£12,056	£141,72	6.89%	10	1	1
37,175	£7,373	37,175	£5,205	£37,669	£567,72	£19,951	£258,75	£30,296	£12,578	£154,30	7.19%	10	1	1
37,175	£7,595	37,175	£5,310	£38,496	£606,22	£20,705	£279,46	£30,902	£13,110	£167,41	7.49%	10	1	1
37,175	£7,822	37,175	£5,416	£39,342	£645,56	£21,475	£300,93	£31,520	£13,653	£181,06	7.80%	10	1	1
37,175	£8,057	37,175	£5,524	£13,581	£659,14	£9,681	£310,61	£5,524	£1,623	£182,69	0.93%	10	1	1
37,175	£8,299	37,175	£5,635	£13,933	£673,08	£9,955	£320,57	£5,635	£1,656	£184,34	0.95%	10	1	1
37,175	£8,548	37,175	£5,747	£14,295	£687,37	£10,237	£330,81	£5,747	£1,689	£186,03	0.97%	10	1	1
37,175	£8,804	37,175	£5,862	£14,666	£702,04	£10,527	£341,33	£5,862	£1,723	£187,75	0.98%	10	1	1
37,175	£9,068	37,175	£5,979	£15,048	£717,09	£10,826	£352,16	£5,979	£1,757	£189,51	1.00%	10	1	1
37,175	£9,340	37,175	£6,099	£15,439	£732,53	£11,133	£363,29	£6,099	£1,792	£191,30	1.02%	10	1	1
37,175	£9,621	37,175	£6,221	£15,842	£748,37	£11,449	£374,74	£6,221	£1,828	£193,13	1.04%	10	1	1
37,175	£9,909	37,175	£6,345	£16,255	£764,62	£11,774	£386,51	£6,345	£1,865	£195,00	1.07%	10	1	1
37,175	£10,207	37,175	£6,472	£16,679	£781,30	£12,109	£398,62	£6,472	£1,902	£196,90	1.09%	10	1	1
37,175	£10,513	37,175	£6,602	£17,114	£798,42	£12,453	£411,08	£6,602	£1,940	£198,84	1.11%	10	1	1

Appendix 2: PV simulation tool for financial analysis

User information sheet

Entries are in black. Results are in red.
Do not make any entry in red color fields.

Section 1: PV panels

Power rating of the installation in kW

Capacity factor which the installation will operate at. This is defined as the ratio of actual energy produced in a year over the maximum amount that would be produced if panels were constantly operating at rated power.
The capacity factor would normally be about 8% in Argyll & Bute. It can also be evaluated through simulation tools such as HOMER or MERIT using hourly climatic data taken at more specific locations. The capacity factor may vary from year to year due to different weather conditions.

Yearly energy: energy produced in a year in kWh

The on-site usage is the amount (percentage) of electricity produced which is used on site. This number can be obtained by measurement or by conducting numerical modeling on the matching of the site demand versus production using softwares such as HOMER or MERIT. It is assumed when using this tool that the on-site usage is known.

Exports: represents the part of the electricity that is not used on site. It is automatically calculated.

Section 2: O&M

Yearly inflation rate for O&M
O&M cost as a percentage of the capital cost. It is typically below 1% for PV
The actual cost in £ for year 1 is automatically calculated

Section 3: FIT incentives / Grid price

FIT applicable in £/kWh
Number of years it will be applied for

RPI (retail price index) inflation average rate

Export price in £/kWh of electricity sold back to the grid

Average yearly inflation rate

Current grid electricity price in £/kWh

Average yearly inflation rate

Section 4: Loan

Loan interest rate (r)

Number of years for the loan

The annual repayment and total loan amount are automatically calculated

The formula used is C.r.(1+r)^n / [(1+r)^n - 1] where C is the capital cost

Section 5: Capital

Normalized capital cost per kW

The total capital cost is automatically calculated.

Summary results:

The payback period is the time taken for the aggregate income to reach the total capital loan cost + O&M costs

The profitability period is the number of years it takes for a positive profit to be generated

Example:

Parameters:

SOLAR PV		
Section 1: PV panels		
Power	6750	kW
Cap factor	8.0%	
Usage factor	100.0%	
On site usage	50.0%	
Exports	50.0%	
Yearly kWh	4730400	
Section 2: O&M		
Inflation		2.00%
Cost %		0.50%
Cost year1		£168,750
Section 3: FIT and grid price		
2011	FIT	£0.41
	FIT years	25
	RPI	2.00%
2011	Sell price	£0.03
	Inflation (RPI)	2.00%
2011	Grid price	£0.12
	Inflation	3.00%
Section 4: Loan		
Rate	5.00%	
Years	25	
(1+r)^n	3.39	
Annual repay	£2,394,645	
Total loan	£59,866,136	
Section 5: Capital		
Capital/kW	£5,000	
Capital cost	£33,750,000	
SUMMARY		
Payback period	22	year
Profitability period	6	year
Profit/loss 30yrs	£12,245,756	
Profit/loss 25yrs	£9,925,669	
Profit/loss 20yrs	£4,826,094	
Rate of return (20yr)	-0.41%	
Rate of return (25yr)	-0.05%	
Rate of return (30yr)	-0.12%	

Financial result over 30 year period:

Year index	Year	Export price	Grid price	FIT	Loan re-pay	Loan re-pay Aggregate	O&M	O&M Aggregate	Year cost	Aggregate Cost	Production KWh/year	FIT value
1	2011	£0.03	£0.12	£0.41	£2,394,645	£2,394,645	£168,750	£168,750	£2,563,395	£2,563,395	4,730,400	£1,953,655
2	2012	£0.03	£0.12	£0.42	£2,394,645	£4,789,291	£172,125	£340,875	£2,566,770	£5,130,166	4,730,400	£1,992,728
3	2013	£0.03	£0.13	£0.43	£2,394,645	£7,183,936	£175,568	£516,443	£2,570,213	£7,700,379	4,730,400	£2,032,583
4	2014	£0.03	£0.13	£0.44	£2,394,645	£9,578,582	£179,079	£695,521	£2,573,724	£10,274,103	4,730,400	£2,073,235
5	2015	£0.03	£0.14	£0.45	£2,394,645	£11,973,227	£182,660	£878,182	£2,577,306	£12,851,409	4,730,400	£2,114,699
6	2016	£0.03	£0.14	£0.46	£2,394,645	£14,367,873	£186,314	£1,064,495	£2,580,959	£15,432,368	4,730,400	£2,156,993
7	2017	£0.03	£0.14	£0.47	£2,394,645	£16,762,518	£190,040	£1,254,535	£2,584,685	£18,017,053	4,730,400	£2,200,133
8	2018	£0.03	£0.15	£0.47	£2,394,645	£19,157,163	£193,841	£1,448,376	£2,588,486	£20,605,539	4,730,400	£2,244,136
9	2019	£0.04	£0.15	£0.48	£2,394,645	£21,551,809	£197,718	£1,646,094	£2,592,363	£23,197,902	4,730,400	£2,289,018
10	2020	£0.04	£0.16	£0.49	£2,394,645	£23,946,454	£201,672	£1,847,765	£2,596,317	£25,794,220	4,730,400	£2,334,799
11	2021	£0.04	£0.16	£0.50	£2,394,645	£26,341,100	£205,705	£2,053,471	£2,600,351	£28,394,570	4,730,400	£2,381,495
12	2022	£0.04	£0.17	£0.51	£2,394,645	£28,735,745	£209,819	£2,263,290	£2,604,465	£30,999,035	4,730,400	£2,429,125
13	2023	£0.04	£0.17	£0.52	£2,394,645	£31,130,391	£214,016	£2,477,306	£2,608,661	£33,607,697	4,730,400	£2,477,707
14	2024	£0.04	£0.18	£0.53	£2,394,645	£33,525,036	£218,296	£2,695,602	£2,612,942	£36,220,638	4,730,400	£2,527,261
15	2025	£0.04	£0.18	£0.54	£2,394,645	£35,919,682	£222,662	£2,918,264	£2,617,307	£38,837,946	4,730,400	£2,577,807
16	2026	£0.04	£0.19	£0.56	£2,394,645	£38,314,327	£227,115	£3,145,379	£2,621,761	£41,459,706	4,730,400	£2,629,363
17	2027	£0.04	£0.19	£0.57	£2,394,645	£40,708,972	£231,658	£3,377,037	£2,626,303	£44,086,009	4,730,400	£2,681,950
18	2028	£0.04	£0.20	£0.58	£2,394,645	£43,103,618	£236,291	£3,613,328	£2,630,936	£46,716,946	4,730,400	£2,735,589
19	2029	£0.04	£0.20	£0.59	£2,394,645	£45,498,263	£241,017	£3,854,344	£2,635,662	£49,352,608	4,730,400	£2,790,301
20	2030	£0.04	£0.21	£0.60	£2,394,645	£47,892,909	£245,837	£4,100,181	£2,640,482	£51,993,090	4,730,400	£2,846,107
21	2031	£0.04	£0.22	£0.61	£2,394,645	£50,287,554	£250,754	£4,350,935	£2,645,399	£54,638,489	4,730,400	£2,903,029
22	2032	£0.05	£0.22	£0.63	£2,394,645	£52,682,200	£255,769	£4,606,703	£2,650,414	£57,288,903	4,730,400	£2,961,089
23	2033	£0.05	£0.23	£0.64	£2,394,645	£55,076,845	£260,884	£4,867,588	£2,655,530	£59,944,433	4,730,400	£3,020,311
24	2034	£0.05	£0.24	£0.65	£2,394,645	£57,471,490	£266,102	£5,133,689	£2,660,747	£62,605,180	4,730,400	£3,080,717
25	2035	£0.05	£0.24	£0.66	£2,394,645	£59,866,136	£271,424	£5,405,113	£2,666,069	£65,271,249	4,730,400	£3,142,332
26	2036	£0.05	£0.25	0	£0	£59,866,136	£276,852	£5,681,965	£276,852	£65,548,101	4,730,400	£0
27	2037	£0.05	£0.26	0	£0	£59,866,136	£282,389	£5,964,355	£282,389	£65,830,490	4,730,400	£0
28	2038	£0.05	£0.27	0	£0	£59,866,136	£288,037	£6,252,392	£288,037	£66,118,528	4,730,400	£0
29	2039	£0.05	£0.27	0	£0	£59,866,136	£293,798	£6,546,190	£293,798	£66,412,325	4,730,400	£0
30	2040	£0.05	£0.28	0	£0	£59,866,136	£299,674	£6,845,863	£299,674	£66,711,999	4,730,400	£0

On site KWh/year	On site Value	Export KWh/year	Export value	Yearly Income	Aggregate Income	Net year Profit/loss	Aggregate Profit/loss	Cash Income	Yearly Cash flow	Aggregate Cash flow	Rate of return	Pay-back Period	profitability Period
2,365,200	£283,824	2,365,200	£70,956	£2,308,435	£2,308,435	-£254,960	-£254,960	£2,024,611	-£538,784	-£538,784	-1.60%	1	1
2,365,200	£292,339	2,365,200	£72,375	£2,357,442	£4,665,877	-£209,328	-£464,289	£2,065,103	-£501,667	-£1,040,451	-1.49%	2	2
2,365,200	£301,109	2,365,200	£73,823	£2,407,514	£7,073,392	-£162,699	-£626,987	£2,106,405	-£463,807	-£1,504,259	-1.37%	3	3
2,365,200	£310,142	2,365,200	£75,299	£2,458,676	£9,532,067	-£115,049	-£742,036	£2,148,534	-£425,191	-£1,929,449	-1.26%	4	4
2,365,200	£319,446	2,365,200	£76,805	£2,510,951	£12,043,018	-£66,355	-£808,391	£2,191,504	-£385,802	-£2,315,251	-1.14%	5	5
2,365,200	£329,030	2,365,200	£78,341	£2,564,364	£14,607,382	-£16,595	-£824,986	£2,235,334	-£345,625	-£2,660,876	-1.02%	6	6
2,365,200	£338,901	2,365,200	£79,908	£2,618,942	£17,226,324	£34,256	-£790,729	£2,280,041	-£304,644	-£2,965,520	-0.90%	7	6
2,365,200	£349,068	2,365,200	£81,506	£2,674,710	£19,901,034	£86,223	-£704,506	£2,325,642	-£262,844	-£3,228,364	-0.78%	8	6
2,365,200	£359,540	2,365,200	£83,136	£2,731,694	£22,632,728	£139,332	-£565,174	£2,372,155	-£220,208	-£3,448,572	-0.65%	9	6
2,365,200	£370,326	2,365,200	£84,799	£2,789,924	£25,422,652	£193,606	-£371,568	£2,419,598	-£176,720	-£3,625,292	-0.52%	10	6
2,365,200	£381,436	2,365,200	£86,495	£2,849,425	£28,272,077	£249,075	-£122,493	£2,467,990	-£132,361	-£3,757,653	-0.39%	11	6
2,365,200	£392,879	2,365,200	£88,225	£2,910,228	£31,182,306	£305,763	£183,270	£2,517,350	-£87,115	-£3,844,768	-0.26%	12	6
2,365,200	£404,665	2,365,200	£89,989	£2,972,362	£34,154,667	£363,700	£546,971	£2,567,697	-£40,965	-£3,885,733	-0.12%	13	6
2,365,200	£416,805	2,365,200	£91,789	£3,035,856	£37,190,523	£422,914	£969,885	£2,619,050	£6,109	-£3,879,624	0.02%	14	6
2,365,200	£429,309	2,365,200	£93,625	£3,100,741	£40,291,264	£483,433	£1,453,318	£2,671,431	£54,124	-£3,825,500	0.16%	15	6
2,365,200	£442,189	2,365,200	£95,497	£3,167,049	£43,458,312	£545,288	£1,998,606	£2,724,860	£103,099	-£3,722,401	0.31%	16	6
2,365,200	£455,454	2,365,200	£97,407	£3,234,812	£46,693,124	£608,508	£2,607,115	£2,779,357	£153,054	-£3,569,346	0.45%	17	6
2,365,200	£469,118	2,365,200	£99,356	£3,304,062	£49,997,186	£673,126	£3,280,241	£2,834,944	£204,008	-£3,365,338	0.60%	18	6
2,365,200	£483,191	2,365,200	£101,343	£3,374,835	£53,372,021	£739,173	£4,019,413	£2,891,643	£255,981	-£3,109,357	0.76%	19	6
2,365,200	£497,687	2,365,200	£103,369	£3,447,163	£56,819,184	£806,681	£4,826,094	£2,949,476	£308,994	-£2,800,363	0.92%	20	6
2,365,200	£512,618	2,365,200	£105,437	£3,521,083	£60,340,268	£875,684	£5,701,779	£3,008,466	£363,067	-£2,437,296	1.08%	21	6
2,365,200	£527,996	2,365,200	£107,546	£3,596,631	£63,936,899	£946,217	£6,647,996	£3,068,635	£418,221	-£2,019,075	1.24%	22	6
2,365,200	£543,836	2,365,200	£109,697	£3,673,844	£67,610,743	£1,018,314	£7,666,310	£3,130,008	£474,478	-£1,544,597	1.41%	22	6
2,365,200	£560,151	2,365,200	£111,890	£3,752,759	£71,363,502	£1,092,012	£8,758,322	£3,192,608	£531,861	-£1,012,736	1.58%	22	6
2,365,200	£576,956	2,365,200	£114,128	£3,833,416	£75,196,918	£1,167,347	£9,925,669	£3,256,460	£590,391	-£422,345	1.75%	22	6
2,365,200	£594,264	2,365,200	£116,411	£710,675	£75,907,593	£433,823	£10,359,492	£116,411	-£160,441	-£582,787	-0.48%	22	6
2,365,200	£612,092	2,365,200	£118,739	£730,831	£76,638,424	£448,442	£10,807,934	£118,739	-£163,650	-£746,437	-0.48%	22	6
2,365,200	£630,455	2,365,200	£121,114	£751,569	£77,389,993	£463,532	£11,271,466	£121,114	-£166,923	-£913,360	-0.49%	22	6
2,365,200	£649,369	2,365,200	£123,536	£772,905	£78,162,898	£479,107	£11,750,573	£123,536	-£170,262	-£1,083,622	-0.50%	22	6
2,365,200	£668,850	2,365,200	£126,007	£794,857	£78,957,755	£495,183	£12,245,756	£126,007	-£173,667	-£1,257,289	-0.51%	22	6

Appendix 3: **Biomass simulation tool for financial analysis**

User information sheet

Entries are in black. Results are in red.
Do not make any entry in red color fields.

Section 1: Boiler

Power rating of the installation in kW
Average load of installation over the year

The FLHE and the capacity factor which the installation will operate at are calculated automatically. The capacity factor is defined as the ratio of actual energy produced in a year over the maximum amount that would be produced if boiler was constantly running at rated power.

The yearly demand is calculated automatically

Boiler efficiency (%)
Fuel energy content in kWh per ton
The total fuel energy required is calculated automatically

Section 2a: O&M

Yearly inflation rate for O&M
O&M cost as a percentage of the capital cost. It is typically 1% to 2%
The actual cost in £ for year 1 is automatically calculated

Section 2b: Fuel costs

Inflation rate for biomass fuel
Fuel cost in £ per kWh (this can be evaluated using the curves provided in the biomass section from the price in £ per ton and moisture content)
The yearly fuel cost is calculated automatically
The yearly fuel quantity is calculated automatically

Fossil fuel cost in £ per kWh (oil or gas)
Inflation rate for fossil fuel

Boiler efficiency (fossil fuel)

The yearly fossil fuel cost is calculated automatically

Section 3: RHI + savings

RHI applicable in £/kWh

Number of years it will be applied for

RPI inflation average rate (when applicable)

The saving in fuel (fossil fuel cost - biomass fuel cost) is calculated automatically

Section 4: Loan

Loan interest rate (r)

Number of years for the loan

The annual repayment and total loan amount are automatically calculated

The formula used is $C.r.(1+r)^n / [(1+r)^n - 1]$ where C is the capital cost

Section 5: Capital

Normalized capital cost per kW

The total capital cost is automatically calculated.

Summary results:

The payback period is the time taken for the aggregate income to reach the total capital loan cost + O&M costs

The profitability period is the number of years it takes for a positive profit to be generated

Example:

Parameters:

BIOMASS TOOL					
Section 1: Boiler					
Power	450	kW	Load ave.	80.00%	
			Oper. hrs	4380	
Yearly demand	1,576,800	kWh	FLHE	3504	
Efficiency	90%		Cap factor	40.0%	
Fuel energy	1,752,000	kWh			
			Fuel energy	3400	kWh/ton
Section 2a: costs O&M			Section 2b: costs biomass fuel		
Inflation	2.00%		Inflation fuel	2.00%	
Cost O&M %	1.50%		Fuel cost	£0.030	Per kwh
Cost O&M year1	£8,100		Fuel cost	£52,560	Year 1
			Fuel qty	515	tons
			Oil/gas fuel cost		
			Cost kWh	£0.065	
Section 3: RHI + saving			Inflation	3.00%	
As of April 2011			boiler eff	70%	
RHI	£0.035		Oil cost	£146,417	Year 1
RHI years	15				
RPI	2.00%				
Saving fuel year 1	£93,857.14				
Section 4: Loan					
Rate	5.00%				
Years	15				
(1+r)^n	2.08				
Annual repay	£52,024.84				
Total loan	£780372.53				
Section 5: Capital					
Capital/kW	£1,200				
Capital cost	£540,000				
SUMMARY					
Payback period yrs	5				
Profitability period yrs	1				
Profit/loss 30yrs	£4,679,013				
Profit/loss 25yrs	£3,569,320				
Profit/loss 20yrs	£2,634,422				
Rate of return (30yr)	28.88%				
Rate of return (25yr)	26.44%				
Rate of return (20yr)	24.39%				

<u>Financial result over 30 year period:</u>

Year index	Year	Oil kWh price	RHI	Loan re-pa	Loan re-pa Aggregate	O&M	O&M Aggregate	Fuel cost	Fuel cost Aggregate	Expenses	Expenses Aggregate
1	**2011**	£0.065	£0.035	£52,025	£52,025	£8,100	£8,100	£52,560	£52,560	£60,660	£60,660
2	**2012**	£0.07	£0.036	£52,025	£104,050	£8,262	£16,362	£53,611	£106,171	£61,873	£122,533
3	**2013**	£0.07	£0.036	£52,025	£156,075	£8,427	£24,789	£54,683	£160,855	£63,111	£185,644
4	**2014**	£0.07	£0.037	£52,025	£208,099	£8,596	£33,385	£55,777	£216,632	£64,373	£250,017
5	**2015**	£0.07	£0.038	£52,025	£260,124	£8,768	£42,153	£56,893	£273,524	£65,660	£315,677
6	**2016**	£0.08	£0.039	£52,025	£312,149	£8,943	£51,096	£58,030	£331,555	£66,974	£382,651
7	**2017**	£0.08	£0.039	£52,025	£364,174	£9,122	£60,218	£59,191	£390,746	£68,313	£450,964
8	**2018**	£0.08	£0.040	£52,025	£416,199	£9,304	£69,522	£60,375	£451,121	£69,679	£520,643
9	**2019**	£0.08	£0.041	£52,025	£468,224	£9,490	£79,012	£61,582	£512,703	£71,073	£591,716
10	**2020**	£0.08	£0.042	£52,025	£520,248	£9,680	£88,693	£62,814	£575,517	£72,494	£664,210
11	**2021**	£0.09	£0.043	£52,025	£572,273	£9,874	£98,567	£64,070	£639,588	£73,944	£738,154
12	**2022**	£0.09	£0.044	£52,025	£624,298	£10,071	£108,638	£65,352	£704,939	£75,423	£813,577
13	**2023**	£0.09	£0.044	£52,025	£676,323	£10,273	£118,911	£66,659	£771,598	£76,932	£890,509
14	**2024**	£0.10	£0.045	£52,025	£728,348	£10,478	£129,389	£67,992	£839,590	£78,470	£968,979
15	**2025**	£0.10	£0.046	£52,025	£780,373	£10,688	£140,077	£69,352	£908,942	£80,040	£1,049,01
16	**2026**	£0.10	£0.000	£0	£780,373	£10,902	£150,978	£70,739	£979,681	£81,640	£1,130,65
17	**2027**	£0.10	£0.000	£0	£780,373	£11,120	£162,098	£72,154	£1,051,83	£83,273	£1,213,93
18	**2028**	£0.11	£0.000	£0	£780,373	£11,342	£173,440	£73,597	£1,125,43	£84,939	£1,298,87
19	**2029**	£0.11	£0.000	£0	£780,373	£11,569	£185,009	£75,069	£1,200,50	£86,637	£1,385,50
20	**2030**	£0.11	£0.000	£0	£780,373	£11,800	£196,809	£76,570	£1,277,07	£88,370	£1,473,87
21	**2031**	£0.12	£0.000	£0	£780,373	£12,036	£208,845	£78,101	£1,355,17	£90,138	£1,564,01
22	**2032**	£0.12	£0.000	£0	£780,373	£12,277	£221,122	£79,663	£1,434,83	£91,940	£1,655,95
23	**2033**	£0.12	£0.000	£0	£780,373	£12,522	£233,644	£81,257	£1,516,09	£93,779	£1,749,73
24	**2034**	£0.13	£0.000	£0	£780,373	£12,773	£246,417	£82,882	£1,598,97	£95,655	£1,845,39
25	**2035**	£0.13	£0.000	£0	£780,373	£13,028	£259,445	£84,539	£1,683,51	£97,568	£1,942,95
26	**2036**	£0.14	£0.000	£0	£780,373	£13,289	£272,734	£86,230	£1,769,74	£99,519	£2,042,47
27	**2037**	£0.14	£0.000	£0	£780,373	£13,555	£286,289	£87,955	£1,857,69	£101,510	£2,143,98
28	**2038**	£0.14	£0.000	£0	£780,373	£13,826	£300,115	£89,714	£1,947,41	£103,540	£2,247,52
29	**2039**	£0.15	£0.000	£0	£780,373	£14,102	£314,217	£91,508	£2,038,92	£105,611	£2,353,13
30	**2040**	£0.15	£0.000	£0	£780,373	£14,384	£328,601	£93,338	£2,132,25	£107,723	£2,460,86

Year cost	Aggregate Cost	Demand KWh/year	RHI value	Value KWh/year	Yearly Income	Aggregate Income	Net year Profit/loss	Aggregate Profit/loss	Rate of return	Pay-back Period	profitability Period
£112,685	£112,685	1,576,800	£55,188	146,417	£201,605	£201,605	£88,920	£88,920	16%	1	1
£113,898	£226,583	1,576,800	£56,292	150,810	£207,101	£408,707	£93,203	£182,124	17%	2	1
£115,135	£341,718	1,576,800	£57,418	155,334	£212,752	£621,458	£97,616	£279,740	18%	3	1
£116,398	£458,116	1,576,800	£58,566	159,994	£218,560	£840,018	£102,162	£381,902	19%	4	1
£117,685	£575,801	1,576,800	£59,737	164,794	£224,531	£1,064,549	£106,846	£488,748	20%	5	1
£118,998	£694,800	1,576,800	£60,932	169,738	£230,670	£1,295,219	£111,671	£600,419	21%	5	1
£120,338	£815,137	1,576,800	£62,151	174,830	£236,980	£1,532,199	£116,643	£717,062	22%	5	1
£121,704	£936,842	1,576,800	£63,394	180,075	£243,468	£1,775,667	£121,764	£838,826	23%	5	1
£123,098	£1,059,939	1,576,800	£64,662	185,477	£250,138	£2,025,806	£127,041	£965,866	24%	5	1
£124,519	£1,184,458	1,576,800	£65,955	191,041	£256,996	£2,282,802	£132,477	£1,098,343	25%	5	1
£125,969	£1,310,427	1,576,800	£67,274	196,772	£264,046	£2,546,848	£138,077	£1,236,420	26%	5	1
£127,448	£1,437,875	1,576,800	£68,619	202,676	£271,295	£2,818,143	£143,847	£1,380,267	27%	5	1
£128,956	£1,566,832	1,576,800	£69,992	208,756	£278,748	£3,096,890	£149,791	£1,530,059	28%	5	1
£130,495	£1,697,327	1,576,800	£71,392	215,019	£286,410	£3,383,300	£155,915	£1,685,974	29%	5	1
£132,064	£1,829,391	1,576,800	£72,819	221,469	£294,288	£3,677,589	£162,224	£1,848,198	30%	5	1
£81,640	£1,911,032	1,576,800	£0	228,113	£228,113	£3,905,702	£146,473	£1,994,670	27%	5	1
£83,273	£1,994,305	1,576,800	£0	234,957	£234,957	£4,140,659	£151,683	£2,146,354	28%	5	1
£84,939	£2,079,243	1,576,800	£0	242,005	£242,005	£4,382,664	£157,067	£2,303,420	29%	5	1
£86,637	£2,165,881	1,576,800	£0	249,265	£249,265	£4,631,929	£162,628	£2,466,048	30%	5	1
£88,370	£2,254,251	1,576,800	£0	256,743	£256,743	£4,888,673	£168,373	£2,634,422	31%	5	1
£90,138	£2,344,389	1,576,800	£0	264,446	£264,446	£5,153,118	£174,308	£2,808,730	32%	5	1
£91,940	£2,436,329	1,576,800	£0	272,379	£272,379	£5,425,497	£180,439	£2,989,168	33%	5	1
£93,779	£2,530,108	1,576,800	£0	280,550	£280,550	£5,706,048	£186,771	£3,175,940	35%	5	1
£95,655	£2,625,763	1,576,800	£0	288,967	£288,967	£5,995,015	£193,312	£3,369,252	36%	5	1
£97,568	£2,723,331	1,576,800	£0	297,636	£297,636	£6,292,650	£200,068	£3,569,320	37%	5	1
£99,519	£2,822,850	1,576,800	£0	306,565	£306,565	£6,599,215	£207,046	£3,776,366	38%	5	1
£101,510	£2,924,359	1,576,800	£0	315,762	£315,762	£6,914,977	£214,252	£3,990,618	40%	5	1
£103,540	£3,027,899	1,576,800	£0	325,235	£325,235	£7,240,212	£221,695	£4,212,313	41%	5	1
£105,611	£3,133,509	1,576,800	£0	334,992	£334,992	£7,575,204	£229,381	£4,441,694	42%	5	1
£107,723	£3,241,232	1,576,800	£0	345,042	£345,042	£7,920,246	£237,319	£4,679,013	44%	5	1