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Study of Renewable Energy Project Risk Factors Influencing the Insurance Industry

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Copyright Declaration

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Signed: Gary Bratt Date: 10/09/2010

Abstract

Until recently, the uptake of renewable energy technology for electricity generation has been slow, with most projects being larger scale developments. The introduction of new governmental policies over the past 20 years has helped encouraged development in this sector. However, only the recent introduction of Feed-in Tariffs has made the market truly accessible to large numbers of small-scale producers. Although small-scale, these new entrants require financial backing to realise their developments from both capital investment and insurance perspectives, just as the large-scale developments do. Unfortunately, the financial services industry has limited experience and understanding of renewable energy projects and their associated risk factors. This project summarises the technical risk factors pertaining to the renewable technologies of most interest to new sector entrants.

By considering the nature of the renewable resource being used by each technology and examining both the commercially available and prototype device technology, it is possible to realise the technology specific risk factors, as well as the more generic technical issues common across technologies during construction and operational phases of a development.

Once collated, the findings are arranged to form a conceptual model, summarising the relevant technological risk factors as a basis for insurance underwriting purposes, with the potential for further actuarial development leading to a full model and thus improved insurance products.

Acknowledgments

I would like to thank Dr. Andrew Grant, my academic supervisor for this project, for his regular supply of encouragement, guidance and humour which has been instrumental in the timely completion of this project.

My thanks also go to Derek Skinner for organising my placement with Bruce Stevenson Risk Management Ltd and all of the staff who made me feel welcome, and part of their team.

Finally, I will be forever indebted to Gill and the support she has provided, without which this course of study would not have been possible, and family and friends who have provided me with light relief when required.

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Chapter 1- Introduction

1.1 General

The renewable energy industry in the UK is entering a phase of rapid expansion over the next decade in order to reduce the volume of fossil fuels used for generating electricity, and their associated carbon dioxide gas emissions, to achieve pollution reduction targets defined by governmental policy. Although appreciable growth has taken place over the past twenty years, it pales into insignificance compared to the level of activity required over the next ten year period. Of course the financial motivation for industry to develop projects has often been inadequate in past years, and there has not been the necessary policy structure in place to encourage participation.

Since 1990, there has been a delivery program for electricity generation from renewable sources in the UK. This began with the renewable Non-Fossil Fuel Obligation (NFFO) which was followed by the Renewables Obligation (RO) in 2002, and more recently, in 2010, the Feed-in Tariff scheme.

The original intention of the NFFO, however, was not directly to support energy generation from renewable sources, but rather to provide a subsidy to the nuclear generation industry, after it became obvious that privatisation presented too many difficulties. Before providing support to nuclear power, the Government was required to seek permission from the European Commission where they formally requested 'non-fossil fuel' support. To pay for the NFFO, the Electricity Act of 1990 allowed a levy on fossil fuels to be raised and the definition of non-fossil fuels technologies included renewable energy technologies.

It is therefore apparent that the initial support mechanism for renewable energy in the UK was in effect a by-product of another policy demand; one that had deep-rooted implications which served to polarise opinion on whether a specific mechanism to support renewables is as effective as a general mechanism for achieving carbon reductions. It could also be argued that the inclusion of renewables into the NFFO actually prevented the implementation of a feed-in tariff mechanism, such as those becoming commonplace across continental Europe at that time and only now being introduced in the UK.

The European Commission sanctioned the adoption of the NFFO to support nuclear power for only an eight year period running between 1990 and 1998. No initial capacity target for generation from renewables was set, but at the announcement of the NFFO first round (NFFO-1) contracts, a target of 600 MW declared net capacity (DNC) was finally revealed. Of the NFFO-1 contracted capacity, around two-thirds was with existing renewable energy power plants, which were either already generating or had previously sought government support. This meant that payments per kWh for NFFO-1 contracts were arranged in advance of the generator's contract bid, so there was little in the way of competition. This was followed by NFFO round 2 (NFFO-2) which targeted 1000 MW DNC, and was different in that the contracts were now for 'new' capacity and therefore gave rise to a degree of competition.[1]

1.2 Implications of the NFFO

The opportunities presented by having renewables integrated into the NFFO have had quite serious and ongoing implications. As the revenue period for a project started with the point of plant commissioning and ran until the end of 1998, there was a huge incentive to maximise the use of the best sites and to do so as quickly as possible. As all contracts for a particular round were awarded on the same day, projects were therefore running in parallel to one another and to similar timescales. It became particularly evident with wind projects that planning permission was being applied for at approximately the same time by a number of developers, and the construction of wind farms was also taking place on similar sites simultaneously.

This apparent 'wind rush' generated much concern amongst the public and saw a number of campaigns against wind farms being organised during this period. There was little understanding in the public arena that imminently approaching funding deadlines were driving the pace of wind farm development at an accelerated rate, which would be unlikely to be sustained at the same pace. The development activity led to an enduring anti-wind feeling, which has served to delay the progress of further onshore wind developments. The creation of this anxiety can be directly attributed to the renewable NFFO contract end in 1998, which in turn is due to its close association with the nuclear NFFO, the original intention of which was to support the nuclear industry rather than the renewables industry. This opportunistic use of another policy unintended for renewables use has therefore compounded many of the issues experienced by the industry in its early development.

1.3 NFFO Development

Further to this, with some technologies it was just not economically viable to complete development and bring projects to fruition, given the time restriction imposed by NFFO-1 and -2. In considering waste-to-energy power plant contracts under NFFO-2, it was found that the time taken to be granted planning permission was so great, that there was too little time left to generate revenue and achieve an economic return before the contract would end. In effect the complexity and content of the planning permissions for a project was so time and labour intensive that it acted to prohibit entry at that time. As the situation was clearly becoming unworkable for future rounds, the Government requested the European Commission to extend the NFFO contracts for renewable energy only.

The rules pertaining to the subsequent rounds, NFFO-3 through NFFO-5, were also amended to include a five year grace period after a contract was awarded. This provided adequate time to obtain planning permission and enable a reasonable economic return via an index linked premium payment for the following 15 years. Other changes included introducing a band split for wind energy to distinguish between smaller and larger developments, with the aim of enabling community projects and having a new technology band dedicated to energy crops.

1.4 Contract Completion Rates

NFFO-3 contracts were awarded in 1994 and the capacity target was raised further to 1500 MW or 3% of the national electricity supply, but the optimism felt in the UK renewable energy industry was short-lived as the reality of delivery became apparent. Planning permission was difficult to obtain, in part due to the concerns that had been born out of NFFO-1 and -2. Following the Labour party assuming power in 1997, with their manifesto policy for 10% of UK electricity to come from renewable sources, NFFO-4 was announced with 1700 MW DNC and NFFO-5 (1177 MW DNC) was launched at the end of 1998.[1] Unfortunately, many of these contracts were never realised as low bids were winning the contracts even though they were uneconomical, a consequence of there being no penalty for failing to take up a contract. The aim of some was even to secure a contract while having no intention of fulfilling it, just to prevent a competitor from gaining a contract. Coupled with the continuing difficulties of obtaining planning permission, this meant that the rate of delivery was actually slowing instead of accelerating, as shown in Fig. 1.1.

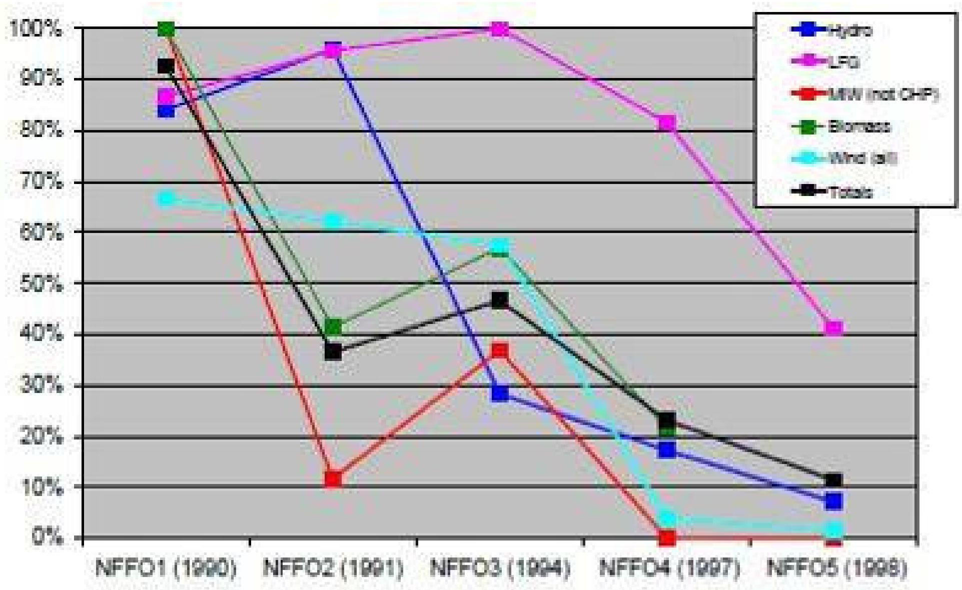


Fig. 1.1: Overall completion rates for NFFO contracts in 2003. (Source: [2])

The failure of the renewable NFFO to deliver acceptable completion rates highlighted that with the advent of a new, replacement mechanism for NFFO, a different approach to contract tender, bidding and fulfilment would need to be adopted.

Also contributing to the design of the new mechanism was the Kyoto Protocol, drawn up in December 1997 and scheduled to become active in 2005. This protocol was an output of the United Nations Framework Convention on Climate Change with the aim of tackling global warming through a reduction in green house gas emissions. Although eventually, 187 member states signed up to this agreement, the exact terms and conditions of many nations' participation varied considerably as did their self-imposed emission reduction targets. The UK was one of a group of 34 nations who agreed to target an average reduction of 5.2% on 1990 levels of green house gas emissions, more specifically carbon dioxide, methane, nitrous oxide, sulphur hexafluoride, hydrofluorocarbons, and perfluorocarbons, by 2012. This translated to a national commitment by the UK to reduce green house gas emissions by 8% from their 1990 levels by 2012.[3] The prime means of achieving this commitment was intended to come from increasing the proportion of electricity generation from renewables and therefore the Kyoto target had to be incorporated into the mechanism succeeding the renewable NFFO.

1.5 Renewables Obligation

The mechanism chosen to replace the renewable NFFO started in April 2002 and was called the Renewables Obligation (RO), which is still active today. It originally set out to achieve 10% of the UK electricity supply from renewable sources by 2010 but was updated in 2003 extending this to target 15% by the year 2015-2016.[1] Year on year targets are illustrated in Fig. 1.2. Originally scheduled to last until 2027, it was extended in 2010 until 2037. Additional policy introductions (e.g. Feed-in Tariffs) have seen further government targets set at 20% by 2020 and a longer term goal of between 30% and 40% by 2050 in order to achieve a targeted total carbon dioxide reduction of 60% in the same year.[4]

Fig. 1.2: Renewables Obligation Size (% of supplier volumes). (Source: [5])

The basis of support under the RO is achieved by requiring electricity suppliers to purchase a predefined and annually increasing proportion of their electricity from renewables. The suppliers must prove to the energy regulator Ofgem that they have delivered on their obligation by providing the required number of Renewable Obligation Certificates (ROCs) each year, where each ROC is equal to 1 MWh of electricity generated from renewable sources.

ROCs are issued to the generator by Ofgem and can be either purchased from the generator or bought in a trading market.

However, the supplier can also 'buy-out' of its obligation by paying a fixed rate per kWh of renewable electricity they should have delivered to meet their obligation. The buy-out price was originally set at £30/MWh and annually increases in line with inflation with the buy-out prices to date, shown in Table 1.1. [11]

Obligation Period	Buy-out Price (£/MWh)
1st April 2002 to 31st March 2003	30.00
1st April 2003 to 31st March 2004	30.51
1st April 2004 to 31st March 2005	31.39
1st April 2005 to 31st March 2006	32.33
1st April 2006 to 31st March 2007	33.24
1st April 2007 to 31st March 2008	34.30
1st April 2008 to 31st March 2009	35.76
1st April 2009 to 31st March 2010	37.19
1st April 2010 to 31st March 2011	36.99

Table 1.1: ROC Buyout Price by Year. (Source: [6], [7], [8], [9], [10])

This buy-out revenue is returned back to the participating suppliers when they submit their ROCs – if a supplier was to submit 10% of the total submitted ROCs, they would then receive 10% of the 'buy-out' fund. A summary of the RO mechanism is shown in Fig.1.3 below:

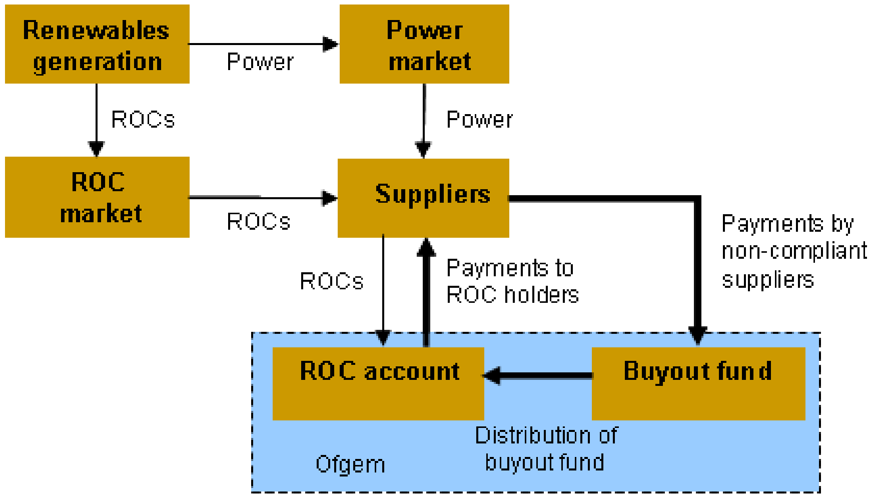


Fig. 1.3: Renewables Obligation System (Source: [4])

Under the RO system, developers are also required to negotiate all agreements with the suppliers, who offer differing lengths of contract depending on the price they pay per kWh. This has resulted in three main risks being assumed by the developer, rather than absorbed by government or intermediaries:

- Price risk - the price paid to the generator is only guaranteed for the contract duration, typically over a short-term
- Volume risk - the uncertainty over being able to sell future generation, especially once the targets are met or even exceeded
- Market risk - the value of generation if governed by the market rules

Although considered a positive step forward in comparison to the NFFO, the RO remains a complex and risky mechanism which has not delivered in a number of key areas. These include failing to encourage new entrants or smaller operations into the market and only catering for electricity based renewables while ignoring non-electricity generating technologies for applications such as heating and transport. It similarly fails to support emergent technologies, as only the cheaper, more established technologies are rendered profitable, given the rates paid.

1.6 Feed-In Tariff Scheme (FITs)

In an attempt to rectify these perceived failings, the Feed-in Tariff scheme (FITs) was introduced in April 2010, not as a full replacement for the RO but as a complementary mechanism specifically targeting the small scale market, defined as being less than 5 MW of installed capacity. Below 5 MW, a new development qualifies for FITs support instead of the RO, while at capacities greater than 5 MW the RO continues to operate as before. Two elements of payment are made to generators under FITs and these are paid for by licensed electricity suppliers. Only the largest suppliers (those which supply over 50,000 domestic customers) are obliged to offer FITs while smaller suppliers may opt to participate or not, as they deem appropriate.

The first element is paid per kWh of electricity generated, metered by the generator, and is known as the generation tariff. It is determined by technology type with each technology sub-divided into bands defined by the scale of installed capacity, with higher tariff rates for smaller capacities and reducing rates as capacity approaches 5 MW. This is an attempt to enable an almost seamless tariff transition when moving from the FITs to the RO regime, preventing instances of development downsizing to gain a preferential tariff rate. The generation tariff is paid regardless of whether the generated electricity is exported to the local electricity network or consumed on site. The duration of the payment is determined by the technology type although typically this is either 20 years or 25 years (a full table of generation tariffs planned up to 2020 can be found in appendix 1).

The export tariff is the second payment element, applicable only to the generated electricity that is exported onto the local electricity network. Again, the generator can meter this with a fixed amount paid per kWh exported, but in the case of very small-scale generation, a proportion of the total generation can be assumed to be exported in a given period without the need for additional metering.

This two-tariff approach rewards both on and off grid generation while allowing for a combination of the two. The export tariff rate at the introduction of the scheme was 3p per kWh with future values linked to inflation, although generators have the possibility to opt out of the export tariff altogether to sell their electricity on the open market.[11]

On the surface it appears that the inception of the complimentary FITs does address the main issues experienced with the RO system alone, for those who were most affected by them – the smaller generators. Much of the price risk associated with short-term contracts is eliminated, since tariffs are guaranteed for 20 or 25 years, depending on the technology used. Similarly, the volume risk is only evident at the end of the guaranteed tariff period as only then will a contract need to be re-negotiated with the supplier. Finally, since the tariff values are defined for the whole of the tariff duration, all uncertainties regarding market fluctuations in the value of generation are negated until the end of the guaranteed tariff period is reached. One criticism which can be raised is that because the generation tariff rates step between scale bandings, it could encourage developers to downsize generating capacity from the lower end of one band to the higher end of the band below in order to achieve a larger tariff rate. Summed over a number of projects, this lost capacity could prove to be significant and only makes achievement of the government set targets for energy proportion achieved by renewable means more difficult.

Although it remains to be seen whether FITs are ultimately successful at bringing in new entrants while also adding a valuable contribution to the overall renewable electricity generating capacity, it is apparent that it represents a significant simplification when compared to the RO alone. It provides greater financial support and income security, making small-scale renewable generation much more attractive to those who previously would not have considered it a worthwhile enterprise. There is also hope that by encouraging the smallest scales of generation at a domestic level, it will engender the societal behavioural changes necessary for tackling climate change, as awareness of the value of electricity is realised and it is used with more responsibility and efficiency.

1.7 Current Commitments

Under "The EU's Target for Renewable Energy: 20% by 2020", the UK agreed on having 15% of the total national energy consumption being sourced from renewables by 2020. To achieve this, 40% of all electricity generated was to come from non-fossil fuel sources with at least 30% from renewables and 10% from nuclear, both existing and new build. Green house gas emission targets, also for 2020, have been set at a 34% reduction on 1990 levels while a further commitment an 80% reduction also exists, to be achieved by 2050.[11]

Although contributing to the UK targets and sharing the same 2050 green house gas reduction, Scotland has set a more aggressive plan whereby a 42% reduction on 1990 levels is achieved by 2020. To do this, 20% of the total energy used and 50% of electricity generation is to come from renewables [13]. This is not just an indication of the renewable resources available in Scotland but also the result of the Scottish Government's refusal to allow any new nuclear power construction to take place.

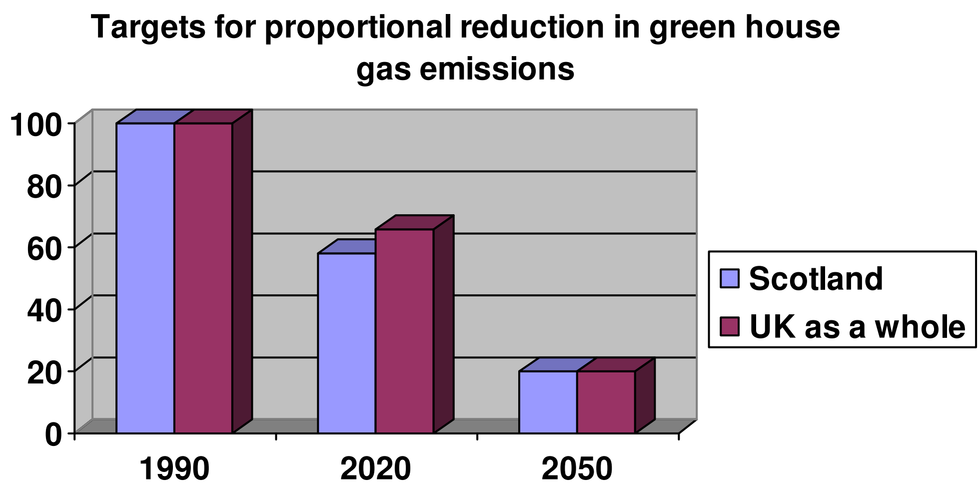


Fig. 1.4: Comparison of targeted rate of reductions (Source: [12], [13])

1.8 Structure of the Industry

The structure of the renewable energy industry in the UK has evolved as the industry has grown and will likely continue to do so as this period of anticipated accelerated growth continues. There are a vast number of businesses involved with all aspects and scales of renewable energy but it is the “key players” who determine the evolution of the industry within the constraints of governmental policy.

Probably the most influential and diverse of these key players are the electricity suppliers, whose primary involvement is to provide connection for all scales of generator to the national grid. The reality of accomplishing this is complex as the aging distribution network in this country struggles to cope with accepting local generation, often of an intermittent nature, onto a system originally designed purely for supply purposes. With many renewable resources being extracted from areas remote to the population centres, there is also a requirement for extensive expansion to the national grid infrastructure to allow renewable energy developments to become viable. In addition to providing electricity connections, many suppliers also operate their own generation sites which to date have tended to be larger scale onshore wind farms.

Developers constitute the next important group in the industry, and range from large entities working on projects around the globe, to small, one-man enterprises, for example a landowner whose aim is to develop a site on their property before becoming the operator and generator. The developer will identify the site for a project, design and develop the project, take it through planning and financing, engineering and construction before finally into operation.

The most visible of the key players are the manufacturers whose products are designed, developed and manufactured for the purpose of operating efficiently and reliably at a given site thereby offering a good return on investment. Much emphasis is being placed on the development of manufacturing technologies and capability within the UK to supply "home-grown" solutions for renewable systems but this is proving challenging as there are much more established European manufacturers, with market leading technology, already competing for their share of the UK market. Economic development agencies are targeting every level of the supply chain in renewables for support in attempt both to boost the economy and ensure attainment of the targets from the Kyoto Protocol.

Banks are an essential element in the market, financing projects (at least large projects) when they consider the risk of their investment and rate of return to be acceptable. Smaller projects have found more difficulty in gaining finance from banks, mainly due to the insecurity of income streams in the past. Cooperative Bank have thus far been leaders in this market, but with the advent of FITs, more banks are beginning to take notice of the reduced risk to smaller projects, and an increase in financial offerings could ensue.

Gaining finance requires insurance to secure any investment a bank may make. Insurance providers, similar in nature to the banks, have been hesitant about becoming involved in this relatively new industry with unknown risks, again this trend being particularly noticeable with smaller projects. However, demand for insurance is increasing as the number of projects increases. Insurance can cover construction phases (construction, transportation, project interruption, public liability) as well as operation (liability, loss of earnings).

Of those insurance providers active in the market, most decline to advertise openly the types and levels of insurance available for renewable specific projects, requiring the increasing use of Insurance Brokers in this industry, to create the vital links between those requiring the insurance and those providing it.

1.9 Insuring Renewable Energy Developments

Due to the relatively young nature of renewable energy as a viable enterprise for electricity generation, sale and ultimately profit realisation, developers still face challenges in securing insurance and financial backing for projects. Financial markets continue to face difficulties in providing risk management instruments for new renewable technologies.[14] Little historical actuarial data on risk factors, and severity and frequency of occurrence of key risks is available to enable accurate assessment.

In their thematic background paper for the International Conference for Renewable Energies held in Bonn in 2004, Sonntag-O'Brien and Usher [15] consider the issues surrounding mobilising finance for renewable energy projects. Among their conclusions, they note that more should be done to "change underwriting risk perceptions to increase the availability of risk transfer products" and "develop appropriate new underwriting rating methodologies".

The paper also cites that "underwriters have limited understanding of RE projects and associated risks and have difficulty aligning strategies for dealing with them" as one of the key barriers to the development of risk management instruments.

The development of a conceptual model considering each of the relevant technological risk factors associated with the types of development would form a basis for actuarial extrapolation and data collection. Increasing the knowledge and understanding of those operating as insurance underwriters and in insurance brokering would begin to address the challenges faced by developers in securing insurance and thereby finance, enabling the industry to grow. This model can subsequently be developed by actuaries to include statistical likelihood and generate assessment of suitable premiums. As this is used more frequently and becomes a more robust model, the availability of insurance products and packages should increase. More information on the performance of new renewable energy technologies will also ultimately reduce the costs of insurance.

As part of the research undertaken for this thesis, I undertook a placement with Bruce Stevenson Risk Management Ltd, an insurance broker and risk management company, involved with the arrangement of insurance cover for small and medium scale projects (those covered by FITs and smaller scale RO).

Chapter 2 - Bruce Stevenson Risk Management Ltd.

Since the company was established in 1981, Bruce Stevenson has grown to become one of the leading insurance brokers within the UK insurance and financial services market, providing bespoke insurance solutions to private and business customers. Based in Scotland, with offices in both Edinburgh and Glasgow, Bruce Stevenson is an owner-managed entity and remains a wholly independent insurance broker in order to provide the best possible service to the client.

The services offered by Bruce Stevenson cover areas such as property, commercial & business, private client, financial services and recently a team dedicated to renewable energy. The creation of this team came from an early recognition of the levels of growth required in the renewable energy industry, to achieve governmental targets for electricity generation from renewables and green house gas emission reductions. To achieve this growth, new commercial developments of all scales are required. In fact, the introduction of Feed-in Tariffs in April 2010 is encouraging higher numbers of small-scale generators to enter the market, many of whom need customised insurance solutions.

The current business strategy targets small-to-medium scale commercial projects, which represent the majority of new entrants to the sector, but avoids large scale developments as they often involve lengthy and expensive tendering processes. As such, this influences some of the renewable technologies Bruce Stevenson finds itself involved with. For example, onshore wind is developed at all scales and accounts for a large proportion of Bruce Stevenson's client portfolio, but the development of offshore wind currently lies exclusively in the realms of large scale, both in terms of turbine and array size, in order to benefit from economies of scale, and so for now is out with the current strategic scope of Brice Stevenson.

Other established technologies which fit the strategic footprint of this small-to-medium scale model, are hydro and anaerobic digestion. As much of the UK's larger hydro resources have already been developed, most new proposals fall into the small scale, below 5MW, category. Likewise, a typical anaerobic digestion plant designed to fit into a farm location is liable to be classified as small scale.

It is also important to Bruce Stevenson to have an involvement with the "younger", less well developed technologies, so they have an understanding and experience of them when commercially viable products finally see deployment. Typical examples would include wave and tidal devices and solar photovoltaics (although already seen in continental Europe, there are currently no commercial solar PV installations in the UK).

The aim of my placement with Bruce Stevenson was to deliver a series of training sessions specifically for the members of their Renewable Energy team to expand their knowledge of the range of renewable devices available, their function/ failures/ limitations, the conditions necessary for them to work well and the likelihood of the performance expectations cited in project proposals being achieved. To facilitate this I investigated a number of different technologies currently available commercially together with prototype technologies undergoing development and was involved in client discussions for active projects.

Chapter 3 - Wind Power

3.1 Resource

Wind is the result of the heating and cooling of the Earth's surface and atmosphere, leading to convection currents in the air. These currents are present in the volume between the surface of the Earth and the stratosphere, but only a relatively small proportion of the total wind resource is accessible from just above the Earth's surface, due to both technical and economic reasons.

The UK possesses the largest wind energy resource in Europe with it estimated that more than 1000TWh of electrical energy could theoretically be extracted from the wind each year, equivalent to approximately 3 times the national annual consumption. In practical terms though, the real available resource from utilising only the more economic sites and observing protected areas is closer to 50TWh/year of electrical energy, or about one sixth of the national annual demand.[16]

The reason for the availability of this vast resource in the UK comes from its location on the edge of the North Atlantic Ocean and its proximity to the Gulf Stream. Combine that with the long, exposed coastal areas and low mountain ranges of the UK landmass and an ideal environment for extracting power from the wind is created. Generally speaking, wind speed increases with height above the ground and wind speeds at 50m above ground level are around 75% faster than those at average head height. Good commercial sites will have annual mean wind speeds of about 7m/s at 45m above the ground, therefore it is sites with this level of resource which developers are keen to exploit.[16] A wind map of the UK is shown below in fig. 3.1:

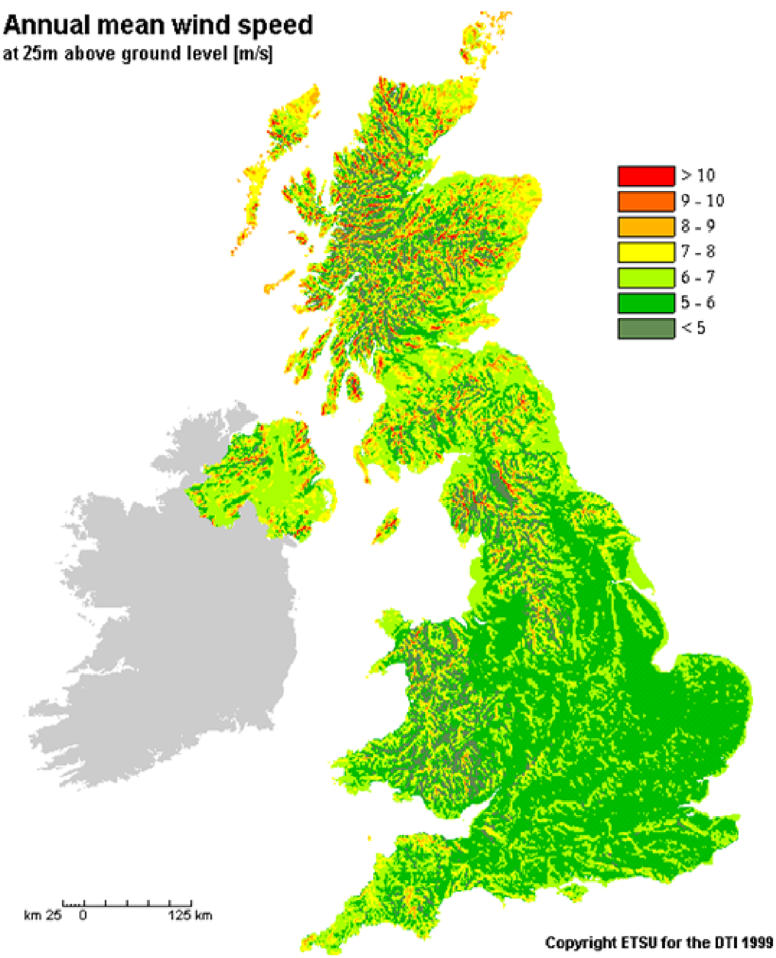


Fig. 3.1: Map of annual mean wind speeds in the UK (Source: [17])

When determining the suitability of a site for developing a wind installation, it is important that the wind speed is monitored over an appropriate duration, typically for a year, in order to allow a reasonable model of the wind's behaviour throughout the seasons to be created. To achieve this, an anemometer is mounted on top of a temporary tower at the chosen site together with data logging equipment. The height of the temporary tower should ideally match the eventual wind turbine hub height, as locating the equipment significantly lower or higher will yield different wind speed data from the intended development, skewing the analysis and potentially endangering the viability of the project.

The most commonly used anemometers are mechanical versions with a propeller or rotating cups and these offer acceptable levels of accuracy for an equally acceptable cost. Other, more high tech, anemometers include those employing ultrasonic, laser interferometry and Doppler laser techniques. Although these can deliver high levels of accuracy and precision, this significantly exceeds the genuine requirement needed for characterising a proposed wind development, so the complexity and cost render them an unlikely and in fact less suitable choice.

Once the wind-speed data-logging period has passed, the collected wind speed data can be organised in a statistical representation, which when plotted on a graph of the probability of occurrence versus wind speed, results in a Weibull distribution, Fig. 3.2.

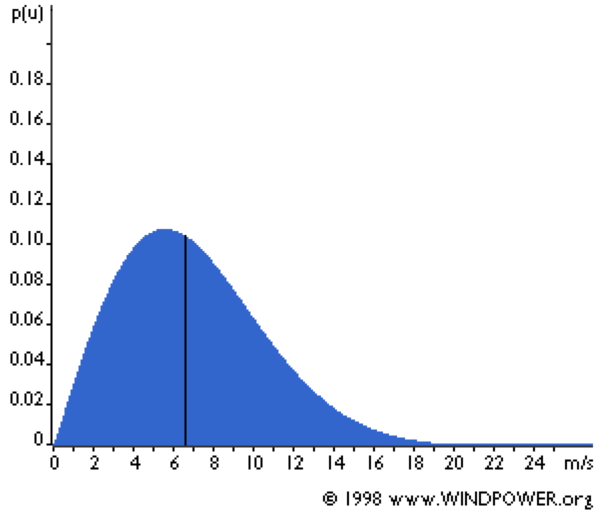


Fig. 3.2: Weibull Distribution (Source: [18])

Further rearrangement of this data can be used to graphically depict the wind speed in relation to the duration in which this wind speed was achieved. This is known as a velocity exceedence curve (Fig. 3.3) and the area under the curve divided by the data collection period is equal to the average wind speed, a key value in determining the viability of the proposed site for development.

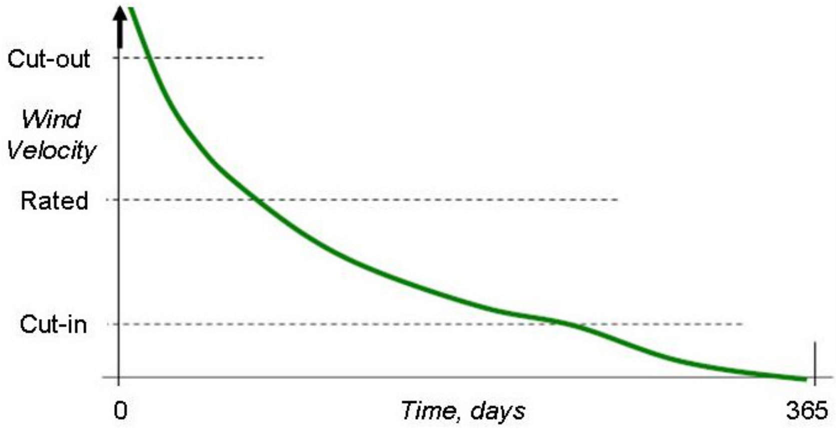


Fig. 3.3: Velocity Exceedence Curve

The amount of power carried by the wind is dependent on its speed, the density of the air, and the area it is passing through.

This can be shown by:

$$P = \frac{\rho A V^3}{2}$$

Where,

P = Power (W)

ρ = Density of air (kg/m^3)

A = Area (m^2)

V= Wind speed (m/s)

Of course, of the available power, only a portion can be extracted for use. It is not possible to capture all of the energy contained within the flow of wind past a given point as determined by Betz in describing his analysis of a one-dimensional flow through a wind turbine rotor.

3.1.1 Betz' Law

Betz' law assumes that the cross-sectional area of the fluid flowing upstream of a turbine, increases as it approaches the turbine and continues to do so after passing by, resulting in a drop in pressure across the turbine where the extraction of energy from the flow has taken place. Corresponding to this pressure change, both the flow speed and the linear momentum decrease as is dictated by the conservation of energy and momentum. Consequently, Betz' law states that a maximum of 59.3% of the total available energy in a fluid flow can be extracted.

The power coefficient (C_p), or efficiency, of a wind turbine is the ratio of the maximum power obtained from the wind, to the total power available in the wind. A C_p factor of 0.593 is therefore the maximum theoretical efficiency of a wind turbine and it is known as the Betz coefficient. As yet, no wind turbine has achieved this level of efficiency and is not likely to, due in part to the simplistic nature of the Betz analysis, which fails to account for all the rotor losses or drive train and generator inefficiencies.

The amount of power extracted from the wind by a given turbine can therefore be written as:

$$P = \frac{C_P \rho A V^3}{2}$$

As wind speed is variable over time, it follows that the power extracted from the wind is also variable. Add to this the fact that wind turbines only operate within a certain range of wind speeds as defined by the cut-in and cut-out wind speeds. Below the cut-in wind speed a wind turbine will not turn, as there is not enough power in the wind to create the driving torque required to turn the rotor. At the cut-out wind speed the turbine is deliberately stopped from turning as the high wind speeds greatly increase the stresses on structures and components, simultaneously increasing the risk of their failure.

A further key characteristic for a wind turbine generating electricity is the rated speed. This lies between the cut-in and cut-out wind speeds and identifies the wind speed at which the maximum electrical power is generated. Beyond the rated speed the electrical output will remain at the rated level until the cut-out is reached.

Taking the velocity exceedence curve and applying the power equation transforms it into an equivalent power curve. The area enclosed by this curve and the cut-in, cut-out, and rated wind speeds is equal to the total energy captured, as shown in fig. 3.4 below.

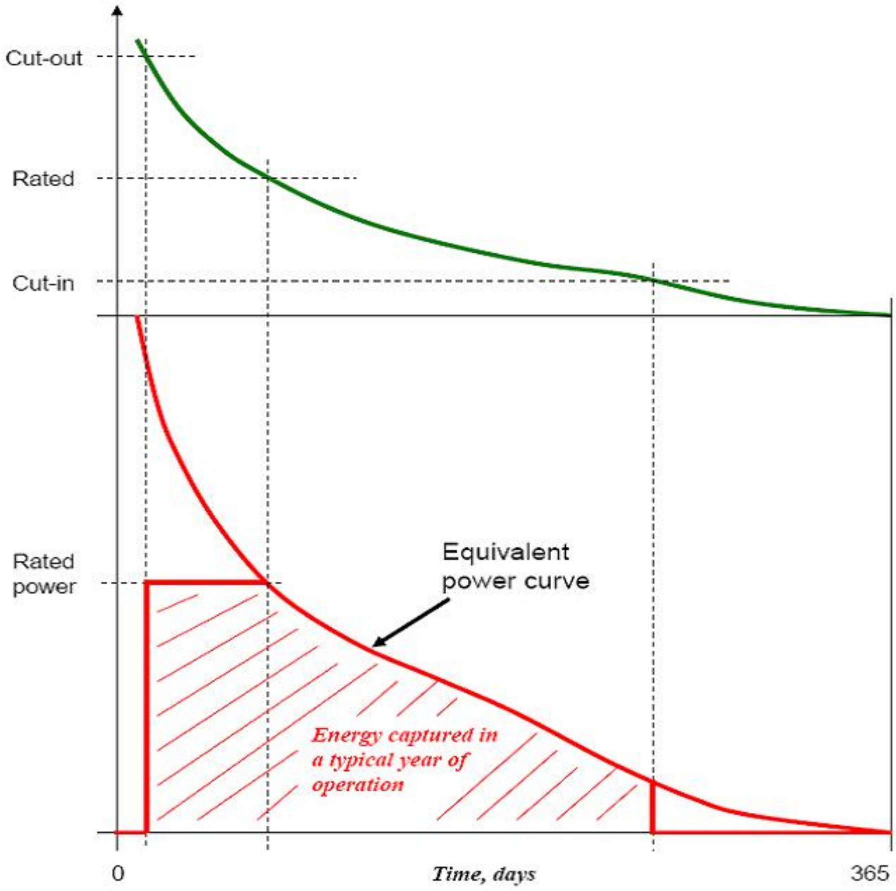


Fig. 3.4: Velocity Exceedence Curve to Equivalent Power Curve

Given the variability in wind turbine power output, average power can be calculated simply by taking the total energy captured over a period of time and dividing it by the period duration. The ratio of this average power to the rated power gives rise to the capacity coefficient, an indicator of the wind turbine's utilisation.

It is in the interest of developers to try to maximise the total energy captured in a typical year, within the budgetary constraints of a viable cost-benefit analysis. Additional investment may yield minimal additional results, so the balance between investment and performance is crucial.

3.2 Configurations

There are two categories of wind turbine configuration – horizontal and vertical axis. The horizontal axis wind turbine (HAWT) is the most commonly seen configuration where a vertical tower supports a two or three bladed rotor turning round a horizontal axis. These can be either upwind, with the rotor facing upstream into the wind, or downwind, with the rotor facing the same direction as the wind flow. Nearly all devices, with the exception of a few smaller ones, are upwind, since downwind variants tend to suffer from blade fatigue and structural failure due to the turbulence experienced as the blades pass through the tower's wind shadow.

The vertical axis wind turbine (VAWT), as the name suggests, rotates about a vertical axis by using either vertically mounted blades which generate lift, causing the turbine to rotate, or curved scoops which experience more drag as they move with the flow of wind, compared to when they are moving against the direction of wind flow. The vertical bladed system is known as a Darrieus turbine, although a variation on this idea using vertical blades which wrap round the vertical axis in a helical fashion is called a Gorlov turbine. The curved scoop system is referred to as a Savonius turbine.

Fig. 3.5 VAWTs – (left to right) Darrieus, Gorlov, & Savonius
(Source: [19], [20])

To date, HAWTs have proved to be the default format for commercially available systems, while VAWTs, although capable at smaller scales, have not yet been shown to be durable enough when scaled up, in the case of the Darrieus systems (blade breakages), or efficient enough in the case of the Savonius device. On this basis, the next section of work will focus only on HAWTs and their design.

Although wind turbines can outwardly appear to be very similar, there are many variations across both manufacturers and turbine size scales. At the top of a wind turbine tower sits a nacelle which houses many of the sub-systems required to convert wind power into electricity. At the front of the nacelle is the rotor assembly, comprising a hub and usually three blades constructed from composite material. On larger machines, the blades are pitch adjustable to allow the amount of force transferred from the wind to be varied, in order to control the speed at which the rotor turns. Pitching the blades out of the wind completely will slow the rotor and it will eventually stop turning.

Although 3 blades are still common on smaller wind turbines, some manufacturers use only 2 blades. Full length pitch adjustability of the blades is also seen when down scaling, but there are systems where only the blade tips are pitch varied, while the rest of the blade remains fixed. Totally fixed blade systems are found on the smallest scales so they have no means of aerodynamically moderating the speed of the rotor and have to rely on other methods.

Controlling the direction the rotor faces on a large wind turbine is a wind vane, normally positioned on top of the nacelle. As it turns, the wind vanes movement is detected by a control system which activates a yaw mechanism rotating the entire nacelle around the vertical axis of the tower on a large main bearing, thus ensuring that the rotor is always facing into the wind. Also found on top of the nacelle is an anemometer linked to a second control system which adjusts the pitch of the rotor blades according to the wind speed measured by the anemometer.

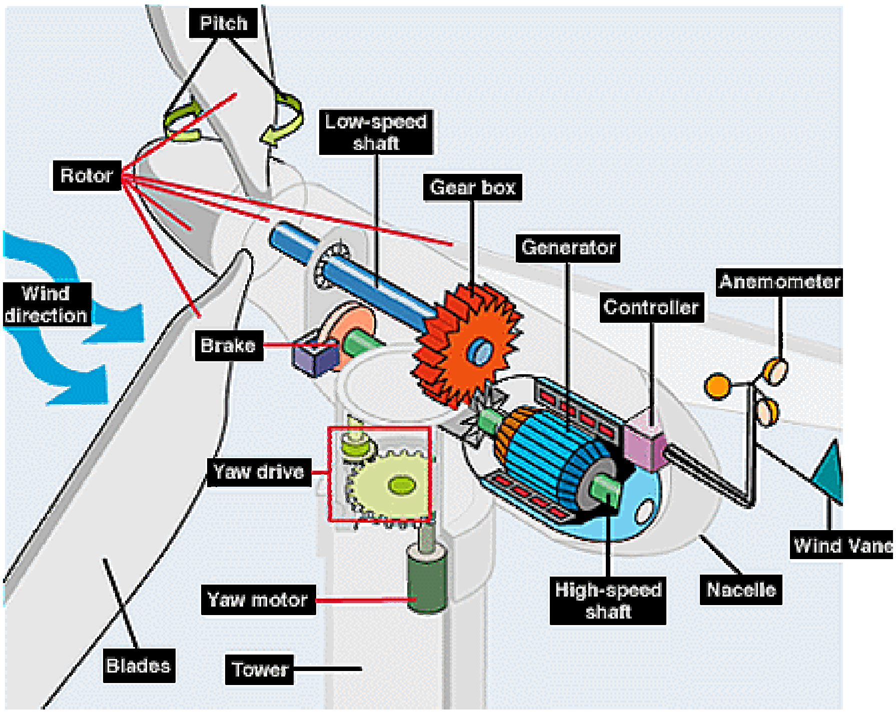


Fig. 3.6: Diagram of typical HAWT configuration (Source: [21])

While smaller wind turbines can also use such control systems, the complexity and expense involved often means simpler and cheaper alternatives are used. For controlling yaw, smaller upwind turbines can have a vertical fin positioned aft from the nacelle causing it to rotate with the wind. Downwind turbines will naturally position themselves into the correct orientation without the need of electro-mechanical systems or a turning fin although some have a fin attached below the downwind section of the nacelle to improve yaw stability. Likewise, mechanical means can be used for controlling the pitching of blades or blade tips on smaller wind turbines, such as weighted spring systems mounted inside the rotor hub. With this system, increasing rotor speeds lead to centrifugal forces causing a sprung weight to move and this movement, via mechanical linkages, adjusts the pitch of the blade.

Running back into the nacelle from the rotor hub is a low speed shaft, which either directly runs into a generator, or connects via a gearbox to a high speed shaft and then to the generator. The low speed shaft rotates, at the same speed as the rotor, but transfers a large torque, while the high speed shaft turns much faster but with lower torque. Both direct drive and geared systems have large bearings supporting the shafts and somewhere on both systems a disc braking system will be attached to a shaft to lock the system completely. This prevents any turning motion during stoppages or can be used to help slow the rotation of the rotor in an emergency.

The generator is commonly an asynchronous machine and is directly connected to the electricity grid. This is made possible because a gearbox increases the rotor speed of 5-20 rpm up to about 750-3600 rpm at the generator. Direct drive systems use gearless permanent magnet synchronous generators which operate at much lower rotational speeds. The main benefits in comparison to an asynchronous machine include lower levels of mechanical wear from the lower rotational speed, and less machine stress, as there is a higher degree of speed variability. This variability in speed also means that the electrical output must be converted to DC and then back to AC before reaching the electricity grid, as the voltage and frequency are a function of the speed of rotation of the generator.

During operation, generators produce high levels of heat and therefore require continuous cooling. This can be achieved by incorporating air ducts which channel air around the generator, or by using a water cooling system which requires a radiator to be placed outside of the nacelle for transferring the heat from the cooling water to the outside air.

3.3 Risks

The unavailability of a wind turbine when the wind is blowing translates to a financial loss, as electricity isn't being generated. It seems ironic then, that the very resource which allows a wind turbine to generate electricity (and thereby income) can also cause damage to it (requiring further expenditure to repair or replace). The vast power of the wind and the forces it imparts on a wind turbine can cause a multitude of failures which could result in a wind turbine being shut down for weeks, if not months, or even completely destroy it.

The most commonly documented failures are those related to the rotor blades. They experience large forces both from the wind, causing them to bend, and from their rotation about the hub axis. Blades have been known to break along their length or even separate from the hub while rotating simply because of the stresses and strains they are experiencing. Other outside influences can also come into effect causing similar results, such as lightning strikes, bird collisions, damage during transport and manufacturing defects where the blade structure is weakened and eventually fails when there is enough force on the blade.

Fig. 3.7: Wind Turbine with both a damaged blade and a missing blade (Source: [22])

However, blade failure can often be the final result of another system's failure, where control of the rotor speed is lost and it accelerates beyond normal operating speeds with an eventual blade failure caused by extreme loading beyond its designed value. The consequences of blade failure can be quite far reaching, literally. Particularly with large machines where blades can be over 50 meters long and rotating quite fast, a broken blade can be thrown hundreds of meters, potentially causing damage to anything in its way such as another wind turbine, a building or an unlucky observer.

Not only blades suffer from the force of the wind. All mechanical parts linked to the rotor are subject to huge forces, including the shafts, their bearings and the gearbox. Such are the demands placed on gearboxes and so common the resulting failures, that some manufacturers are removing them completely from their designs and resorting to direct drive transmissions. Replacing such large mechanical components can be very time consuming since their positioning at the top of a tower requires a large crane and favourable weather conditions.

Likewise, the main bearing at the top of the tower which supports the nacelle and allows it to rotate, experiences large loads and should it develop a problem necessitating its replacement, the entire nacelle would need to be removed before the main bearing could be reached.

Even the towers of wind turbines are not immune from risk. Should a tower be struck by a blade, broken or otherwise, it can impart enough force to cause it to collapse. There have even been reported cases of towers buckling in storms and folding over in half without the assistance of a blade strike.

Fig. 3.8: Collapsed wind turbine tower (left) and turbine fire (right)
(Source: [23], [24])

Generators tend to be more reliable than gearboxes as the mechanical stresses and wear experienced are significantly lower, but they are a potential fire hazard, particularly if they are not cooled correctly. Similarly the electrical systems can present risk, as they too have the potential to start a fire, and consist of a great many components which could fail.

Other risks associated with the realisation of wind turbine developments exist long before they become operational, during the transportation and construction phases. Particularly with large scale machines, the physical size and weight of individual transportable sections (rotor blades, tower sections, nacelle, etc) leads to greater risk of handling damage when transporting by road and when lifting with cranes either between transport and site or at final erection.

Chapter 4 - Hydro Power

4.1 Resource

The movement of water down rivers and from lakes gives rise to hydro power, or when electricity is produced, hydroelectric power, where the word "hydro" is derived from the Greek "hydra" meaning water. At a higher vertical position, water possesses stored potential energy but as it flows to a lower vertical position under the influence of gravity, the fluid gains kinetic energy. A turbine can be used to extract energy from this downwards flow, converting it to mechanical energy and if a generator is connected, into electrical energy.

Estimating the total potential hydro resource available in the UK is difficult due to the vast number of waterways covering the country and the variability in their seasonal flows. Development of the areas with the largest hydro resource was mostly undertaken in the 1950's and 1960's in Scotland and Wales so there is little scope remaining for further projects of the same scale today. However, there remain significant opportunities at smaller scales.

A flow of water down through a vertical distance, whether a stream down a hillside, a waterfall, or water flowing over the top of a weir, can be used to obtain hydraulic power. Characterising the amount of power obtained are the head and the flow rate. The head is the vertical height difference between the water inlet to the turbine and the turbine itself. This is often referred to as the gross head while the net head is the effective vertical height once the losses associated with transporting the water to the turbine are accounted for. The flow rate is the volume of water which passes a point each second.

A suitable site for a hydro project must have a supply of water with sufficient flow rate and head characteristics, with suitability improving as these characteristics become larger. It must also be taken into account that flow rates are likely to fluctuate significantly throughout the year in response to rainfall variations. Therefore, in determining the suitability of a proposed hydro installation, it is important that a thorough hydrological analysis is performed through either making river flow measurements over an extended period, or by using computer modelling software. Unfortunately both of these methods have serious shortcomings with measurements difficult to make reliably as each measurement only represents a snapshot in time of the overall situation, and computer models using historical weather data sets are not necessarily representative of the current or future situation.

Once data is collected, an analysis similar to that for wind turbines can be performed, with flow rate replacing wind speed to create a flow rate exceedence curve and an equivalent power curve. The power equation required for this is derived in the section below.

The energy released by a flow of water through a vertical height can be described as:

$$E = mgh$$

Where,

E = Energy released in J

m = mass of water in kg

g = acceleration due to gravity in m/s^2 (typically 9.81 m/s^2 on the Earth)

h = vertical distance or gross head in m

As mass is equal to the product of density and volume, the energy released now becomes:

$$E = \rho V g h$$

Where,

ρ = density in kg/m^3 (typically 1000kg/m^3 for water)

V = volume in m^3

If we consider substituting volume with volume per second, or flow rate, then the equation changes to energy released per second, or power, thereby giving:

$$P_g = \rho Q g h$$

Where,

P_g = gross power in W

Q = volumetric flow rate in m^3/s

Gross power, however, is an ideal situation that ignores various losses experienced in a working system such as pipe work friction and mechanical losses associated with turbines and generators. To take account of these losses, an efficiency factor can be included to give the net power.

$$P_n = \eta \rho Q g h$$

Where,

P_n = net power in W

η = hydraulic efficiency in %

Using this equation to convert a flow rate exceedence curve to an equivalent power curve then allows the total energy generated to be calculated in the same way as for a wind turbine.

4.2 Configurations

There exist three classifications of hydro scheme: storage, run-of-river, and diversion, sometimes known as canal. All of them share the main components of; an intake, penstock (pipe from the intake to the turbine), powerhouse containing a turbine, tailrace (the channel which returns water having passed through the turbine back to the river or lake) and an electrical substation for connecting the generated electricity to the local network.

In a storage configuration, water is amassed upstream of the power house using either an existing lake or loch, or by construction of a dam to create a reservoir. This enables the flow of water downstream to be controlled. Storage schemes will often have a sufficient volume of water to overcome seasonal fluctuations in water flow into the catchment area, thus providing a consistent supply of electricity throughout the year. A variation of this layout, where the water is also stored in another reservoir after passing through the turbine so it can be pumped back up to the top reservoir, is called pumped storage. Periods of low energy demand (off-peak hours), such as during the night, can be used to pump water to the upper reservoir so it can be re-used during periods of high energy demand (peak hours). Instead of generating electricity onto the grid, the generator can be run in reverse as a motor, consuming electricity from the grid to turn the turbine in reverse so it acts as a pump (Fig. 4.1). An alternative is to have two sets of plant dedicated to either generating or pumping. Although the total power generated increases, the extra delivered from pumping cannot entirely be considered renewable as the electricity used when running the generator as a motor was likely generated, at least in part, from fossil fuelled sources. Pumped storage is really just a method of storing excess electricity during off-peak periods and returning it again during peak periods.

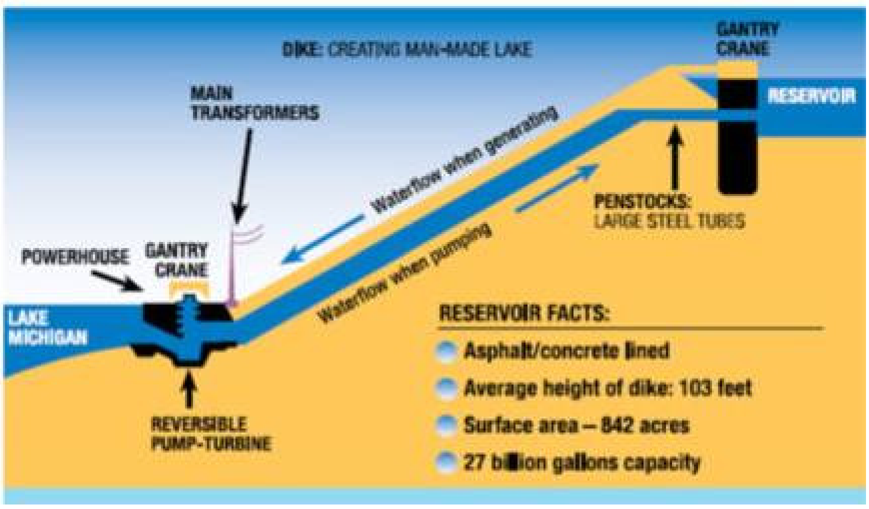


Fig. 4.1: Pumped Storage Scheme, Ludington, Michigan. (Source: [24])

With a run-of-the-river configuration (Fig 4.2), a dam or weir is constructed across a river, not to stop the flow of the river, but to divert some of the flow into an intake and to a turbine. As it is the flow of the river that is being used, there is little storage available, so power output can be greatly affected by seasonal fluctuations in weather.

Fig. 4.2: Run-of-the-river scheme: The Lower Granite Dam, Washington. (Source: [25])

When water is diverted away from its river or stream source and towards a turbine, it is known as a diversion or canal system (Fig. 4.3). A dam or weir is used to divert some of the flow either along an open channel or through a penstock towards the turbine location.

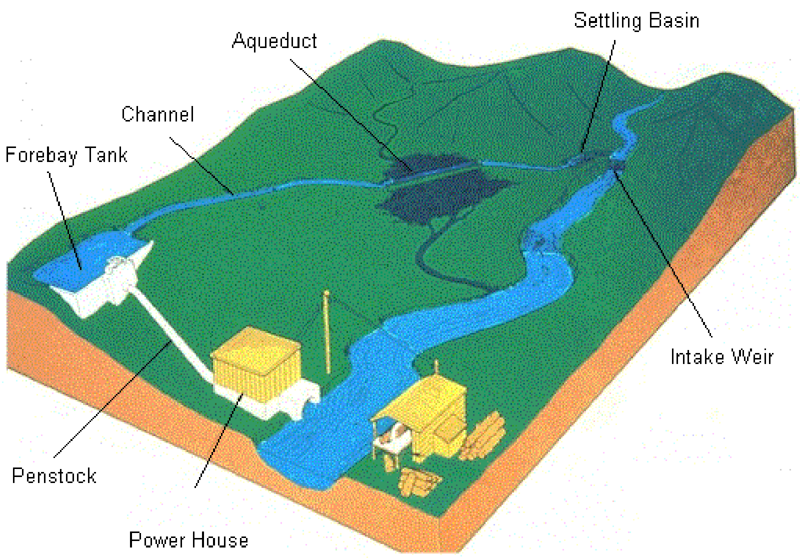


Fig. 4.3: Diversion Scheme (Source: [26])

Since different hydroelectric sites possess particular properties, a variety of hydro turbine technology has been developed to reflect this so that the converted energy can always be extracted in the most efficient manner. As water can be sourced from mountainous regions or low lying rivers, the amount of head can vary significantly, as can the flow rates experienced. There exist hydro turbines designed to suit all types of location and water sources.

A hydro turbine converts the movement of flowing water into the mechanical rotation of a shaft. Choosing the turbine best suited to a particular site will strongly depend upon the key characteristics of head and flow for the site. Other parameters that should be considered are the generator running speed and whether the turbine is required to be producing power when only part flow conditions are applicable. Different turbines possess particular design characteristics meaning they perform with optimum efficiency at particular speeds under certain flow and head conditions.

Turbines can be grouped as either reaction turbines or impulse turbines, with the former more suited to lower head applications and the latter to higher heads. The middle ground, medium heads, accommodates both classes of turbine with other factors, such as flow, required to determine which is best suited for a specific site.

In a reaction turbine, power is produced both from velocity and pressure forces so large surfaces are required for these forces to act on. Their defining characteristic relies on the casing containing the runner being completely filled with water in order for it to function. To achieve optimum performance, the direction of water flow on entering the turbine is important. Three types of reaction turbine exist: Francis, propeller, and Kaplan.

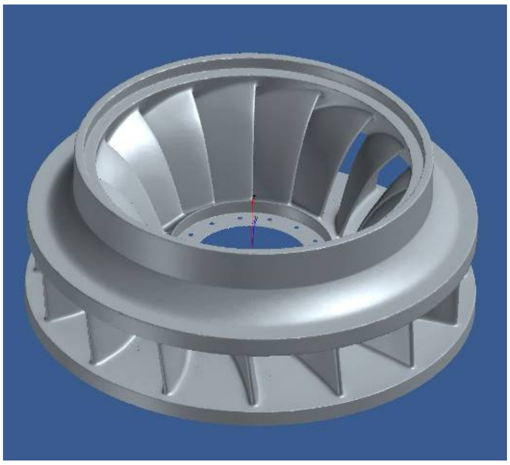


Fig. 4.4: 3-D render of Francis runner (Source: [27])

Fig. 4.5 (Source: [28])

A Francis turbine (Figs 4.4-4.6) is comprised of a wheel, or runner, constructed with fixed blades sandwiched between two rims, surrounded by a circle of adjustable guide vanes used to control the amount of water reaching the runner and causing it to spin.

The vanes are enclosed by a spiral casing, which carries the supply water to them. After passing through the runner from the side, the water exits the centre of the runner and down a draft tube to the tail-race. Also classed as radial flow reaction turbines, Francis turbines are generally designed specifically to meet the needs of the intended installation. The complexity of the vane system, together with the design specialisation, makes Francis turbines less suited to smaller scale hydro projects due to the design and development costs involved, despite the high efficiency of the end product.

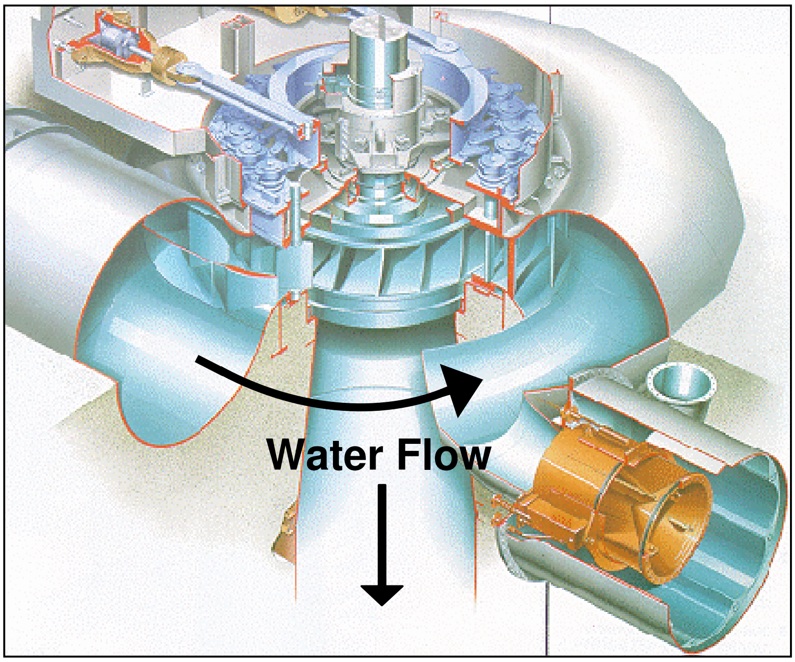


Fig. 4.6: Cutaway of Francis turbine (Source: [31])

When only a small head of water is available, a propeller turbine, which resembles a ship's propeller, is frequently suitable (Fig. 4.7). The propeller is located within the penstock with the turbine shaft exiting the pipe where a change in direction occurs. Upstream of the propeller is a set of fixed blades or swivel gates, also known as wicket gates, to control the flow of water. As the pitch angle of the blades is fixed, this device is also known as a fixed blade axial flow turbine. The efficiency of such a system is seriously compromised if the penstock is not full of water (part-flow) at the turbine due to the fixed pitch angle of the blades, but some allow blade pitch to be changed to match the flow of water.

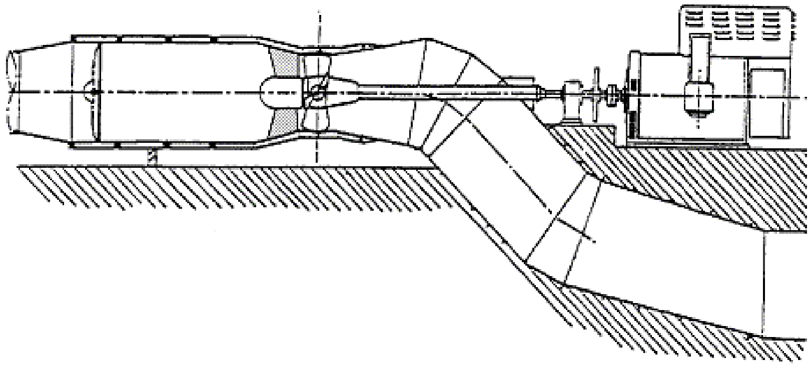


Fig. 4.7: Cross-sectional view of Propeller Turbine configuration. (Source: [30])

More sophisticated propeller turbine devices are used at large scale hydro installations where to achieve the best efficiency, not just blade pitch and wicket gate adjustments are possible, but the flow of water is conditioned with some swirl before reaching the turbine runner. Swirl, is absorbed by the runner, so that a straight flow is returned to the draft tube. Mounting a set of guide vanes upstream of the runner can induce the desired swirl or snail's shell housing, as in a Francis turbine, where water is forced to spiral as it exits the snail shell tangentially. This type of turbine is known as a Kaplan or variable pitch turbine. As with other propeller turbines, a Kaplan is quite versatile during installation as it can be positioned vertically, horizontally or at any angle.

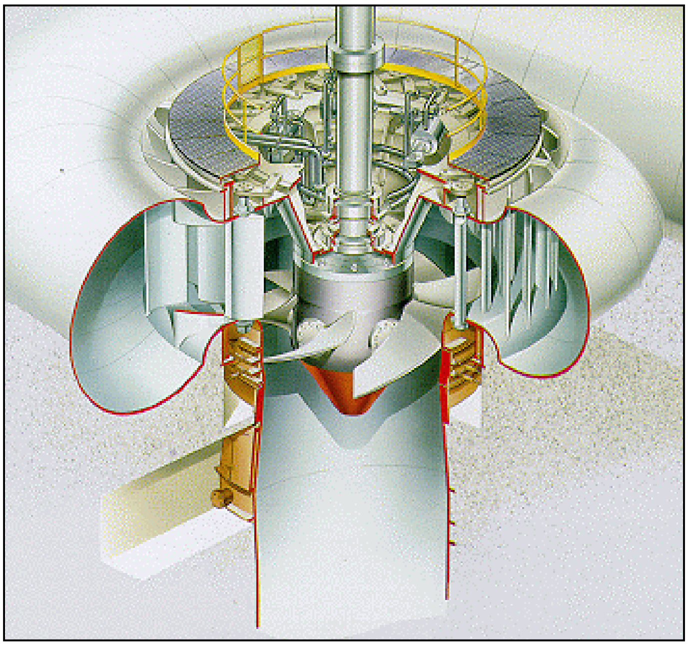


Fig. 4.8: Cutaway of Kaplan turbine (Source: [31])

Unlike a reaction turbine which operates best when fully immersed in water, an impulse turbine operates in air while extracting power from jets of water striking an arrangement of blades or cups around a wheel, causing the wheel to turn. The three common types of impulse turbine are the Pelton, Turgo, and Crossflow.

Being probably the best known tangential flow impulse turbine, the Pelton wheel (Fig. 4.9) operates efficiently over a wide range of flow rates but is particularly suited to low flow situations with larger heads. With cups or buckets placed round the outer edge of the rim, the Pelton wheel bears a striking resemblance to the wheels found at water mills of yesteryear. At the end of the penstock are one or more nozzles (fig.4.10), which direct a jet or jets of water at high speed into the buckets, causing the wheel to rotate. The buckets are profiled into left and right halves to smoothly deflect water away from the incoming jet, thus preventing their central area from being a dead spot. The notch at the outer edge of each bucket allows the water jet to propel a leading bucket for a longer period before the following bucket cuts off the jet. It also serves to provide a smoother entrance to the jet for the bucket.


Fig. 4.9: Pelton wheels (Source: [32], [33])

Having multiple jets allows a smaller wheel to be used and this increases the rotational speed for a given flow. If flow reduces, good part-flow efficiency can be achieved by reducing the number of jets being used with the remaining jets still receiving an optimum flow. It is also possible to have two Pelton wheels mounted on the same shaft, instead of a large single wheel, to achieve faster rotation or to accommodate a large number of water jet nozzles.

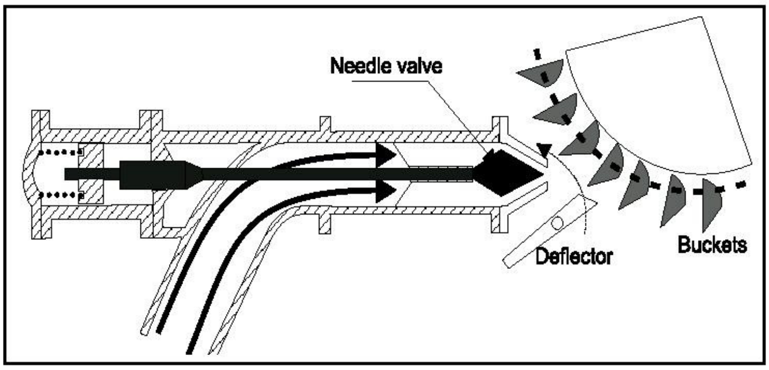


Fig. 4.10: Nozzle arrangement (Source: [34])

A Turgo turbine is like an asymmetrical Pelton wheel with the water jet nozzle being directed at a slight angle to the wheel (Fig. 4.11). The blades on the runner are asymmetrically designed to best extract energy from the angled water jet while maintaining a small physical size and high rotational speed. It is particularly suited to small-scale projects with its rugged design being quite tolerant of abrasive material suspended in the water supply. Although the complexity of the blades and their arrangement on the runner (Fig. 4.12) result in difficult fabrication and high cost, the main disadvantage of this system configuration comes from the axial loading experienced on the runner as a result of the angled water jet causing accelerated bearing wear.

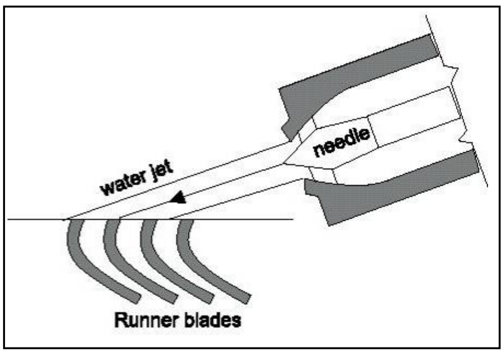


Fig. 4.11 (Source: [35])

Fig. 4.12 (Source: [36])

The Crossflow turbine is also known as either a Banki Crossflow turbine or a Mitchell Crossflow turbine after its inventors who developed the turbine independently in a similar time period. It is comprised of a cylindrical runner made up of blades, and rotates about a horizontal axis. The incoming flow of water is shaped into a sheet along the length of the runner and directed tangentially to the blades at the top of the runner about halfway across its diameter (Fig. 4.13).

The water exerts a force on the blades as it passes through them at the top before crossing the empty central part of the runner and re-entering the blades, now at the bottom of the runner, exerting a further force on the blades before finally exiting (Fig. 4.14). This double pass for the water through the blades in both directions makes the turbine self-cleaning, as particulates deposited on a blade surface during the first pass are cleaned away again during the second pass. The cylindrical nature of the runner allows the turbine to run as a multi-cell unit using only part of the runner with low flows, but expanding to use the full length of the runner for higher flows.

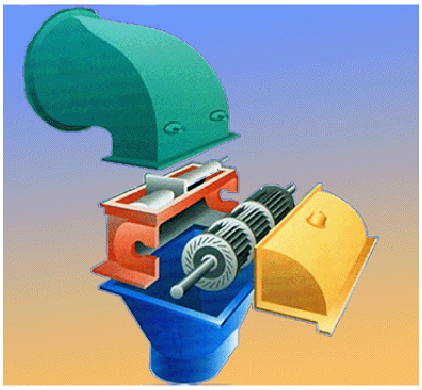


Fig. 4.13: Crossflow turbine (Source: [37])

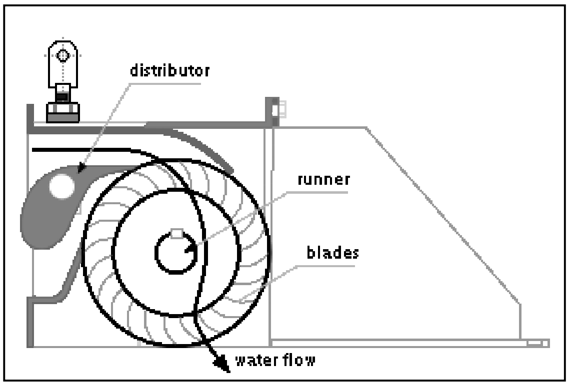


Fig. 4.14: Path of water flow in Crossflow turbine. (Source: [38])

A chart of how various combinations of head and flow are suited to different types of turbine is shown below in Fig. 4.15:

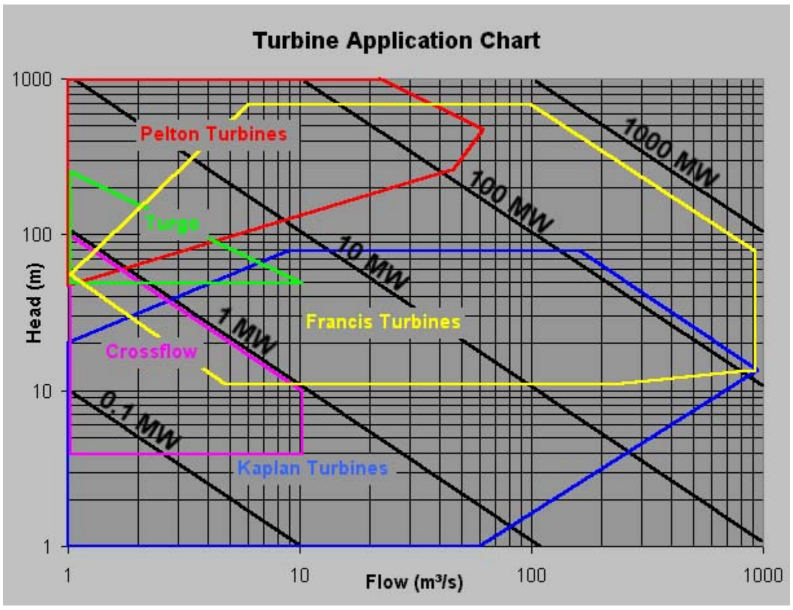


Fig. 4.15 Turbine Application Chart (Source: [39])

4.3 Risks

For all hydroelectric schemes, whether they are storage, run-of-river, large scale or small scale, the operator will always be concerned about having to shut down generation in order to carry out repairs on machinery, as this negatively impacts revenue. All turbine types will experience surface wear on their runners from of erosion and, in the case of reaction turbines only, cavitation (Fig. 4.16), but the severity of this wear can vary significantly between sites as the amounts and types of impurities in the water differ.

Intakes commonly feature some form of trash screen to prevent floating debris and other foreign bodies from entering the penstock but they can't stop much smaller material from passing through. Silt, for example, if present in the water, will pass through a trash screen and reach the turbine causing additional runner surface wear due to its abrasive nature.

If a runner was to be damaged from debris or just wear out from use, the performance of the system will decrease. The time required to replace it, scales with turbine size. A smaller scheme may be able to replace a runner in a matter of hours assuming parts are available, whereas a for a large scale plant it could take weeks or even months, particularly as very large hydro turbine runners are custom built to order. The other common wear issue concerns the bearings on which the runners turn, but if monitored and maintained correctly, terminal failure should not occur.

Fig. 4.16: Francis Turbine showing cavitation damage (Source: [40])

In terms of generation, the availability of water may present a risk, particularly in a scheme where there is little or no water storage. An extended dry spell will see river levels drop leading to either reduced output or a complete stoppage. This is less of a problem with a storage scheme but depending on its size and the severity of the drought, it can still impact upon the amount of electricity generated. This also holds true for periods of extreme cold where water is frozen and water flows are reduced.

Although hydroelectric power is considered a clean alternative to using fossil fuels, it can still have a large impact on the environment with the flooding of biologically rich and productive land to create reservoirs, causing population migration and habitat fragmentation.

Building dams and weirs can cause mud and silt to be released downstream and the changes to downstream river flows all play a part in effecting a change to the natural order. Even with the construction of fish ladders, to assist fish movements between both sides of a dam, there can still be a significant impact on fish populations as spawning areas upstream are affected.

The biggest risk associated with a dam holding back a reservoir, irrespective of the scale, is the potential for causing damage and loss of life if the dam fails. Good design and construction cannot guarantee survivability from seismic activity, sabotage or even terrorism.

Chapter 5 - Solar Power

5.1 Resource

Energy from the sun is responsible for many of the things we take for granted on a daily basis, be that daylight, heat, wind, or plant growth. Harnessing this energy for something other than heating is a relatively recent phenomenon as technological development has not only made electricity generation possible, but more affordable. However, as demonstrated by other European countries, the key to electricity generation from solar energy being more widely adopted, is clear policy implementation supported by generous feed-in tariff rates. The UK, having learned from this, is also now also taking this approach.

The amount of solar energy reaching the Earth's surface at any one time is about 89 petawatts (PW), or 89×10^{15}W, but this is not uniformly distributed or consistent over time at a given location on the surface.[41] This is primarily due to the Earth's rotation bringing day and night, as well as its tilted axis causing seasonal changes, and cloud cover. Unlike other renewable sources such as wind, the availability of solar energy is very predictable (sunrise through to sunset), although less predictable is its actual intensity at ground level because of changeable weather influences.

The UK is not renowned for its availability of sunlight when compared to other locations around the world, but it is still possible to generate electricity effectively and with the introduction of Feed-in Tariffs, also economically. A solar irradiance map of the UK and Ireland is shown in Figure 5.1 and it highlights the variation of global horizontal irradiance experienced between the north and south of the country.

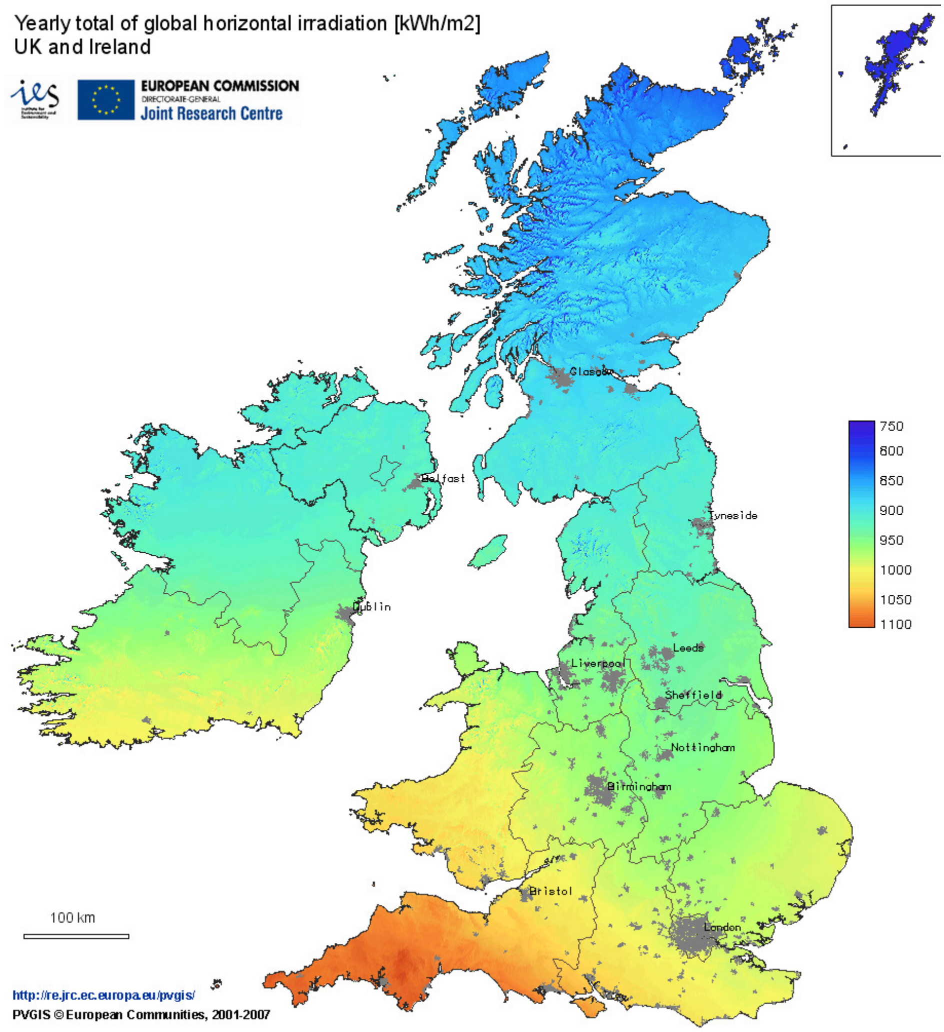


Fig. 5.1: Map of UK Solar Irradiance (Source: [42])

Solar radiation reaching a point on the Earth's surface directly from the sun is called direct, or beam radiation. Light scattered in the Earth's atmosphere before reaching the surface is known as diffuse radiation. The distinguishing feature of direct radiation is that it can be focussed, whereas diffuse cannot. Therefore, the total radiation reaching the surface of the Earth is combination of direct and diffuse radiation:

$$I_t = I_b + I_d$$

Where,

I_t = total radiation reaching the Earth's surface in W/m^2

I_b = beam radiation reaching the Earth's surface in W/m^2

I_d = diffuse radiation reaching the Earth's surface in W/m^2

There are a number of devices used to measure solar radiation over continuous periods, for the creation of models or performing analysis. A pyranometer is a device used for measuring the total broadband (~280 to 3000 nm) solar irradiance on a planar surface, or total global irradiance, by using a sensor designed to measure the solar radiation flux density (W/m^2) for a 180 degree field of view.[43] Although widely used for meteorology and climatology, pyranometers are also frequently found next to solar panels, mounted on the same plane as the panel (Fig.5.2).

Fig. 5.2 (Source: [44])

Fig. 5.3 (Source: [43])

For measuring direct beam solar radiation, a pyrheliometer can be used (Fig. 5.3). To do this it must track the path of the sun across the sky and so will often be integrated with a solar tracking system.

A device for measuring both the total global irradiance and the diffuse irradiance on a planar surface is called an integrated pyranometer. It is very similar to a normal pyranometer except it employs a series of internal shades to block the direct beam radiation from the sensor. Since both total global and diffuse irradiance are measured, the direct beam radiation can be easily calculated as the difference between the two.

Existing historical averaged data (such as Fig. 5.1) clearly shows where the locations of best solar resource are situated and taken in conjunction with a particular conversion device provides a reasonable prediction of electricity generating potential. However, localised weather adds an amount of variability, which is difficult to account for.

5.2 Configurations

Two methods currently exist for generating electricity from sunlight – a direct conversion process using photovoltaic (PV) technology and an indirect conversion process called concentrating solar power (CSP), where focussed sunlight heats a fluid for use in a heat engine connected to a generator. While PV devices can be employed at all scales of power generation almost anywhere in the world, CSP is particularly suited to larger scale projects in regions with the greatest natural sun resource. The following sections will expand upon the use of PV technology, which is better suited to the project scales and solar resource found in the UK.

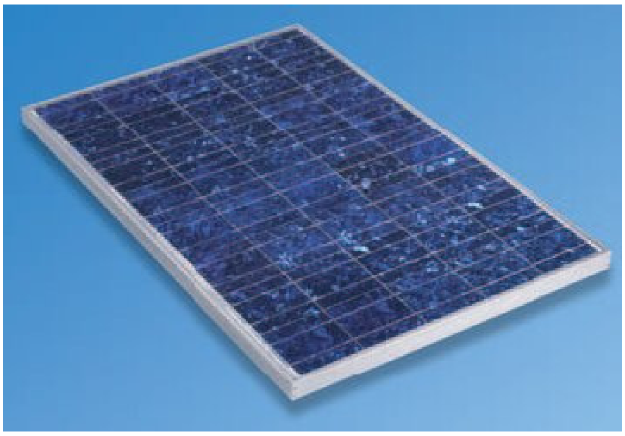


Fig. 5.4 (Source: [45])

The two most prevalent systems employed in PV devices are flat plate systems (Fig. 5.4) and concentrator systems (Fig. 5.5). With flat plate systems, the PV cells are constructed on a flat, rigid surface whereas concentrator systems use lenses to focus sunlight on to PV cells to increase the power output (Fig 5.6). Both systems are packaged into panels with multiple panels being connected in series or parallel to form arrays.

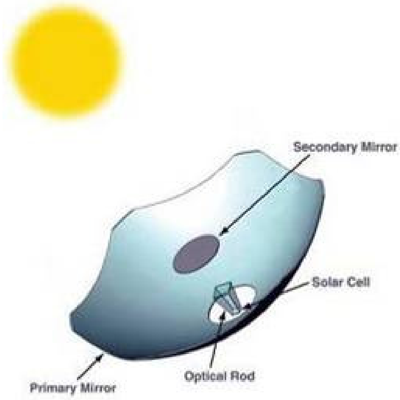


Fig. 5.5 (Source: [46]) **Fig. 5.6** (Source: [47])

The less complicated of the two systems is the flat plate arrangement, although it requires a larger number of PV cells compared to a concentrator to gain the equivalent output. Flat plate systems offer a large degree of flexibility, as they can be freestanding or integrated into the roofs and walls of buildings. Unusually for renewables, this makes these systems just as suitable for use in rural settings as for urban environments.

The more complex concentrator configuration requires a sun tracking system to optimally orient the device in relation to the position of the sun, so that the maximum direct beam radiation is captured. As diffuse light cannot be focussed by a concentrator system, these do not function well in cloudy conditions.

PV technology enables the direct conversion of sunlight into electricity through the photoelectric effect, where a photon of light striking an electron in a PV device becomes liberated and can flow into an external circuit, giving rise to an electric current. The efficiency of this process is dependent on a variety of factors but the materials used and construction methods are of primary importance.

Inside an atom, electrons form valance bonds with neighbouring atoms and are not free to move about. This is known as the stable state or valence band. If a photon of sufficient energy is incident upon one of these stable state electrons it absorbs the energy and leaves the valence band for a higher energy level in the conduction band, where the electron is now mobile and capable of conduction. The space left by the electron in the stable band is now occupied by a "hole", effectively a charge equal in size but opposite in polarity to that of an electron. If large numbers of electrons move to the conduction band, a current flow will result (a flow of electrons and holes).

The amount of energy required to raise an electron from the stable state to the conduction band is called the bandgap energy and is specific to different materials. If the incident photon possesses less than the bandgap energy it will not be absorbed and the electron will remain in the valence band. This means that light above a certain wavelength is not useful, possessing insufficient energy to effect this transition, according to the Planck-Einstein equation:

$$\mathbf{E = h\ c/\lambda}$$

Where,

E = energy in J

h = Planck's constant: 6.626×10^{34} Js

c = speed of light: 3×10^{8} in m/s

λ = wavelength in m

However, if an incident photon has more energy than the bandgap the electron will still only move with the bandgap energy to the conduction band while the excess is released as heat, effectively wasted energy. So the efficiency of energy conversion from a photon to an electron decreases as the photon energy increases beyond the bandgap energy. These criteria of wavelength usefulness and conversion efficiency place a fundamental limitation on the overall efficiency a PV device can deliver.

Realising this conversion of sunlight into electricity requires a p-n junction to be formed using a semiconductor material which is doped both as n-type, meaning an excess of electrons, and p-type, a deficiency of electrons. Having regions of p and n-type material neighbouring each other creates a p-n junction where a reverse electric field exists, promoting electron flow across the junction from p-type to n-type when an external load is attached to both p and n-type sides.

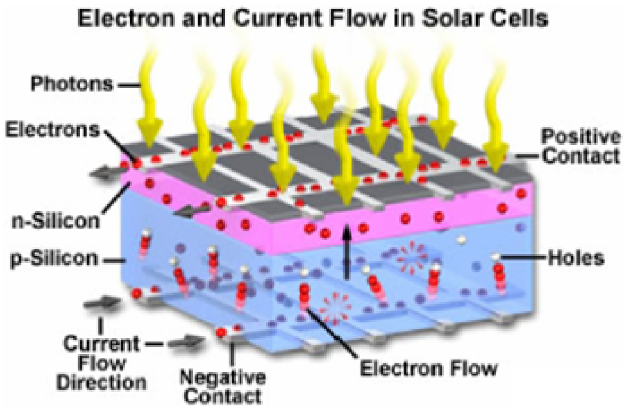


Fig. 5.7 (Source: [48])

The semiconductor materials required for making PV cells come in either crystalline or thin film forms, each offering varying levels of light absorption, energy conversion efficiency, manufacturing complexity and cost. The majority of crystalline materials used are single crystal silicon, polycrystalline silicon, and the compound semiconductor gallium arsenide.

Single crystal silicon is produced through the Czochralski method to form a single crystal ingot, which is then sawn to produce circular wafers between 200–400µm thick. The wafers undergo further processing to create individual PV cells before being interconnected and arranged into modules and arrays. Although single crystal silicon yields high energy conversion efficiency (~15-20%) and makes for a robust device, it is expensive due to the high manufacturing costs.[49]

Polycrystalline silicon consists of small grains of single crystal silicon and can be produced by either casting blocks of polycrystalline silicon and slicing it into wafers or through a ribbon growth method, such as edge-defined film-fed growth (EDF), where sheets of silicon are grown directly, thus simplifying manufacture by removing the need to saw blocks of material to form wafers and reducing cost. The electron flow however, is hindered by the grain boundaries, reducing the power output and decreasing the energy conversion efficiency by between 10-14% compared to single crystal silicon.

With a crystal structure similar to silicon, gallium arsenide (GaAs) is a compound composed of gallium (Ga) and arsenic (As). It has a high light absorptance so requires much less material thickness to absorb the same amount of sunlight as crystalline silicon, while also having a higher energy conversion efficiency of about 25-30%. This efficiency, together with its resistance to heat and high manufacturing costs makes GaAs ideally suited to concentrator systems, where high temperatures are realised but only a small area of PV material is required.

Thin film PV technology comprises a low cost supporting layer, such as glass, metal, or plastic foil, over which thin layers, often <5µm, are deposited to form the p-n junction and contacts (Fig. 5.8). The finished device can be assembled with a frame and glass cover to make a panel, as with other flat plate systems, or used as a surface covering when manufactured as a flexible film (Fig. 5.9).

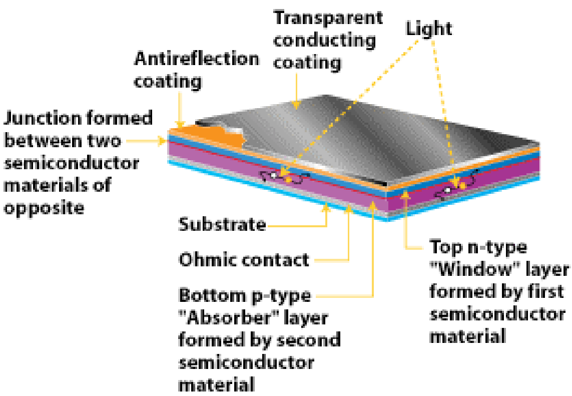


Fig. 5.8 (Source: [50])

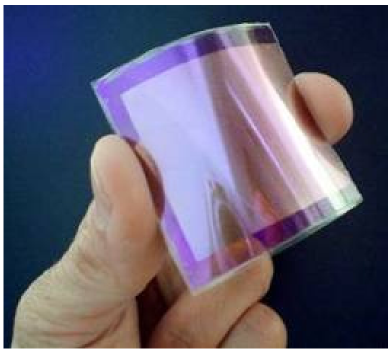


Fig. 5.9(Source: [51])

The light absorptance of a thin film is higher than crystalline material, while the relative thinness of the deposited layer offers significant cost savings, not simply due to the minimal quantities of deposited material being used, but also through the deposition techniques employed. The energy conversion efficiency however, is relatively low because of the non-single crystal structure. Three materials typically deposited to form thin film cells are amorphous silicon, cadmium telluride, and copper indium diselenide.

Amorphous silicon (a-Si) is a form of silicon which is non-crystalline in structure as its atoms are disordered. It has very good light absorptance and low manufacturing costs but only offers an energy conversion efficiency of 5-10%, which has been observed to degrade over time.

Similar efficiency can be gained with cadmium telluride (CdTe), a polycrystalline semiconductor compound comprising of the elements cadmium and tellurium. While it also has very good absorptance of sunlight and is cheap to manufacture, its device performance is less stable while greater care must be taken during manufacture as cadmium is toxic.

Another polycrystalline semiconductor compound is copper indium diselenide ($CuInSe_2$ or CIS), which has demonstrated efficiencies approaching 20% without experiencing degradation. Unfortunately, it is a complex material that is difficult and expensive to manufacture as the process involves using the extremely toxic gas hydrogen selenide.

Material	Structure	Manufacturing Cost	Efficiency	Typical Application
Si	Single crystal	High	15-20%	Flat plate
Si	Polycrstalline	Medium	10-14%	Flat plate
Si	Compound crystalline	High	25-30%	Concentrating
a-Si	Thin film	Low	5-10%	Flat plate/surface covering
CdTe	Thin film	Low	5-10%	Flat plate/surface covering
CuInSe2	Thin film	High	15-20%	Flat plate/surface covering

Table 5.1: Summary of PV materials (Source: [49])

5.3 Risks

For any prospective developer of a commercial solar PV project, the risks associated with the PV devices themselves are relatively low, as there are no moving parts to wear out or fail. This means there is unlikely to be any maintenance required over the device's lifetime, often quoted by manufacturers to be in excess of 25 years, with warranties spanning 20 years and greater. Common failure mechanisms in PV systems are frequently the result of water ingress or thermal stress.

The ease with which repairs to, or replacement of, individual modules are performed can vary greatly depending on their location (fixed frame mounted on the ground or on a difficult to reach roof top) and how they are connected to the rest of the array. If a large part of or even the whole array is required to be inoperative for work to take place, there may be a benefit in scheduling this work to be performed in the hours of darkness, in order to minimise the lost generating opportunity. However, this should be balanced against the potential need for additional health and safety considerations as well as potentially attracting premium labour rates.

As already mentioned, there can be some degradation in device performance over time, so there is a risk regarding the amount of time before degradation begins, the rate at which it proceeds and the level of performance which is eventually lost. Although manufacturers typically include a performance drop-off specification as part of their warranty cover, this still leaves a degree of uncertainty regarding the amount of electricity generated and the resulting revenue, even before the drop off meets, and finally exceeds this specification.

With concentrator systems, the added complexity of a sun tracking system with its mechanical and electronic systems introduces additional failure modes and so increases the chance of the system being unavailable either through planned maintenance or component failure.

Also important for achieving potential PV performance is the need to keep the front surfaces clean and shadow free to maximise the light incident on the PV cells. Wind and rain tend to leave surfaces coated with grime, and close proximity to busy roads or airports increases the chance of oily thin films forming as a result of exhaust pollution. Even bird fouling could play a negative role in reducing the amount of light reaching the PV cells so it is important to employ a rigorous cleaning regime to ensure performance is maximised. Shadowing can also result from sub-optimal positioning of the device and even overhanging obstacles such as tree growth over time can lead to partial shadowing during daylight hours.

Chapter 6 - Biomass Power

6.1 Resource

Biomass is a general term for living, or recently living, biological matter in most forms whether solid, like wood; liquid, like bio-ethanol; or gas, like methane. Not included are fossil fuels, as these organic materials have been absent from the carbon cycle for thousands of years, while geological processes have been forming them. Most commonly used as a fuel for heating or generating electricity, biomass, whether in its raw or processed state, ultimately undergoes combustion to release its embedded energy.

Unlike other renewable sources which are free to be harvested e.g. wind, solar, etc. biomass is a fuel and more often than not it will have to be purchased. The amount of biomass material available around the world is extensive, although much of this can be counted as food or required for other uses such as building materials. (This raises an interesting dilemma: as populations increase and there is increased demand for biomass, eventually compromises will have to be made as the total resource available will be insufficient to completely fulfil each of the types of demand on it.) For biomass to be viable over the longer term, it also has to be controlled sustainably with continued replanting otherwise fuel shortages can occur – not a desirable situation, especially for an operator whose revenue stream relies on the sale of a continuous flow of electricity generated from biomass.

6.2 Configurations

Composed of a mixture of organic molecules, primarily made up from carbon and hydrogen atoms, the structure of biomass often includes oxygen, nitrogen and sometimes alkali, alkaline earth, and heavy metals. The main sources of biomass are wood, crops, and waste. Although not currently a main source of biomass, algae is attracting much research interest as its composition seems suited to the production of liquid fuels. Transforming biomass to more useful fuels is achieved either through thermal or biochemical conversion.

Wood can be incinerated directly in large pieces or chipped (Fig. 6.1) to make smaller ones. Sawdust and waste wood can be reformed into pellets (Fig. 6.2), pucks (Fig. 6.3), and logs to form a material of greater density more suitable for transportation and feeding thermal generation systems. Although primarily used for space and water heating on both residential and commercial scales or for co-firing fossil fuelled systems, it is also possible to raise steam for powering an engine, which when linked to a generator, produces electricity. This can be the basis for a combined heat and power (CHP) scheme serving communities and businesses.

Fig. 6.1: **Wood Chips** (Source: [52])

Fig. 6.2: **Pellets** (Source: [53])

Fig. 6.3: **Pucks** (Source: [54])

Pulping liquor, sometimes called black liquor, is a by-product of the chemical breakdown of wood in the pulping and paper industries and is a major source of energy from wood. In fact many pulp mills have recovery boilers where the black liquor is burned, generating steam and recovering chemicals, both of which are re-used in the process. This greatly reduces reliance on other energy sources while also reducing waste products.

Crops, whether originally grown for food, or energy crops specifically grown for their energy content, can be incinerated but are usually more suited to the production of a variety of liquid fuels. Although particularly appropriate in the transportation sector, liquid bio-fuels also have a role to play in remote locations off grid, where engines are used to generate electricity or function as back-up systems.

Biologically produced alcohols, such as bio-ethanol, can be made from the fermentation of plant materials containing sugar, typically from sugar or starch crops such as wheat, sugar beet, sugar cane, and corn. Although it can be used as a fuel source for internal combustion engines in its own right, bio-ethanol is widely used as a petrol additive in some countries to increase octane level and reduce emissions.

Two forms of diesel can be extracted from crops possessing high oil content such as rape seed, jatropha, soy, and sunflower. Green diesel is produced when the extracted plant oils undergo the same fractional distillation process used for fossil fuel oil separation. This results in green diesel being a very similar product to fossil fuel sourced, or mineral, diesel and it can be combusted in a standard diesel engine without modification.

Biodiesel, however, comes from plant oils or animal fats which experience transesterification, resulting in a product similar in composition to petroleum diesel but with some stark differences. It is readily biodegradable, has low toxicity, and a much higher flashpoint. 100% pure biodiesel (B100) can be used in conventional diesel engines, however more modern common rail systems can only operate correctly with biodiesel if it is blended first with mineral diesel.

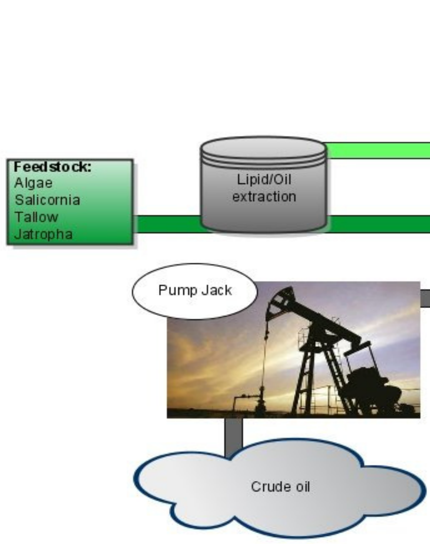


Fig. 6.4 Diesel Sources (Source: [55])

Although edible vegetable oil is not utilised as a fuel initially, once it has been used and becomes a waste product, it can be added to the transesterification process to produce biodiesel, or cleaned of particulates and water, and used directly as a fuel. Lower quality vegetable oils not considered edible can be used directly as a fuel without further processing. As with biodiesel, vegetable oil is suitable for combustion in conventional diesel engines, although it must first be pre-heated by electric coils or via a heat exchanger to reduce its viscosity to that of petroleum diesel to ensure correct combustion. Many diesel engine manufacturers also offer engines compatible with vegetable oil without modifications being required.

Biomass from waste is drawn from many different sources including forestry waste (wood), garden waste (grass and plants), unsold or non-conforming food crops, domestic refuse, and animal waste. Much of this would traditionally have either been buried in landfill or composted leaving the material to be broken down by naturally occurring bacteria in a process called anaerobic digestion. This process produces landfill gas, a 'dirty' version of biogas also known as methane. Having methane from landfill gas released to the atmosphere is not only harmful to the environment as a potent green house gas (GHG) but also wasteful, as it makes an excellent fuel when collected and combusted, where the resultant carbon dioxide and water are also less harmful forms of GHG.

A controlled version of anaerobic digestion can also take place in a closed tank, or anaerobic digester (Fig. 6.5), where the biomass feedstock is broken down as described previously, but the resultant biogas is collected and used to feed a gas engine, usually part of a CHP system, where it is combusted. At smaller scales, the heat captured in the CHP system can be re-used to help sustain the digestion process while the electricity generated is exported and sold to the grid. With larger systems, the amount of heat captured may also be sufficient for a district heating scheme to be implemented.

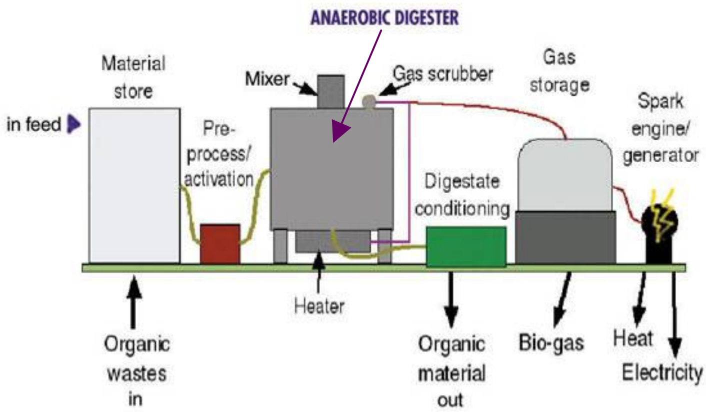


Fig. 6.5 Anaerobic digestion system for electricity generation (Source: [56])

If the digester is exclusively fed energy crop material such as silage it will result in the dedicated production of biogas. In Europe, these are known as biogas plants, while an agricultural anaerobic digester that accepts two or more feedstock types for simultaneous digestion are called co-digestion or co-fermentation plants. The leftover solid organic material from the anaerobic digestion process is rich in nutrients and it can be distributed back on to the land as an effective fertiliser.

6.3 Risks

As with fossil fuels, the supply of biomass for a project has to be secured, leading to a biomass market being created. All scales and types of biomass technology rely on a steady flow of biomass throughout the year which can prove difficult to achieve as the amounts of grown biomass materials and waste change throughout the year. Crop volumes need to be properly planned to minimise the chance of shortages while other elements such as food crop waste are highly variable from year to year. With this area of renewables yet to become widespread, there doesn't appear to be a problem securing feedstock, but as the sector expands there will be much higher levels of demand, driving prices up. The importance of sustainable management becomes crucial to prevent shortages and interruption to the production of fuels, heat and electricity.

The quality of raw biomass feedstock is also variable in a number of different ways such as energy content, material composition, moisture content, and the presence of foreign matter. Where biomass is directly incinerated, the amount of energy released per tonne will change with material type and moisture content, leading to varying rates of consumption, temperature of incineration, and efficiency. All of these create uncertainty about the purchase and delivery of the feedstock and the amounts of heat and electricity produced.

For liquid bio-fuels the composition of the crop is important as this determines how much oil can be extracted per tonne and even for a particular plant species the oil content will vary depending on the type of soil and the weather experienced while growing.

With anaerobic digestion, material composition varies the digestion rate achieved and the amount of foreign matter present can, depending on type, work to suppress the digestion process, slowing the rate of biogas production.

Equipment concerns centre on the mechanical systems in use for chopping biomass into smaller pieces, feeding the incinerator, press, or digester, mixing digestate, pumping fluids and gases, and the different engines which can be used for combustion of the biofuels. These are naturally subject to a range of typical wear and failure modes and are therefore open to resultant safety risks, and down time (income) losses associated with maintenance, repair and replacement of parts.

Incineration of solid biomass carries a fire risk where incidents of fire spreading from the furnace back up the feeding mechanism are not unknown. When liquid and gas bio-fuels are being produced there exists an inherent fire and explosion risk due to their volatility, therefore high safety standards must be met and maintained in order to prevent accidents from occurring. Measures such as having a flare stack for burning off biogas in the event of an emergency to prevent an explosion are required to make the operation of these facilities safe.

Chapter 7 - Wave Power

7.1 Resource

The impact of wind (itself a result of solar energy heating areas of the Earth and causing convection currents) moving across open water, gives rise to the formation of waves. The extraction of the energy possessed by waves and its conversion to electricity can be achieved in a number of different ways. Although work in this area has been ongoing for some time with many prototype devices being demonstrated, there has yet to be a larger scale deployment of a particular technology.

Worldwide, the amount of power, or wave energy flux, carried by waves is immense, with many locations yielding averages in excess of 60 kW/m of wave front (Fig.7.1) with some locations approaching 100 kW/m also observed.[57] Being located on the edge of the North Atlantic Ocean, the UK not only lies in an area with a wealth of available wave resource, but also in being an island, has a long coastline providing good access to the sea, unlike other countries which are part of a larger landmass and have limited coastal area access. For these reasons, Scotland in particular offers developers a sufficient amount of resource to make future commercial electricity generation from wave power possible, although currently it is not cost competitive with other renewable technologies.

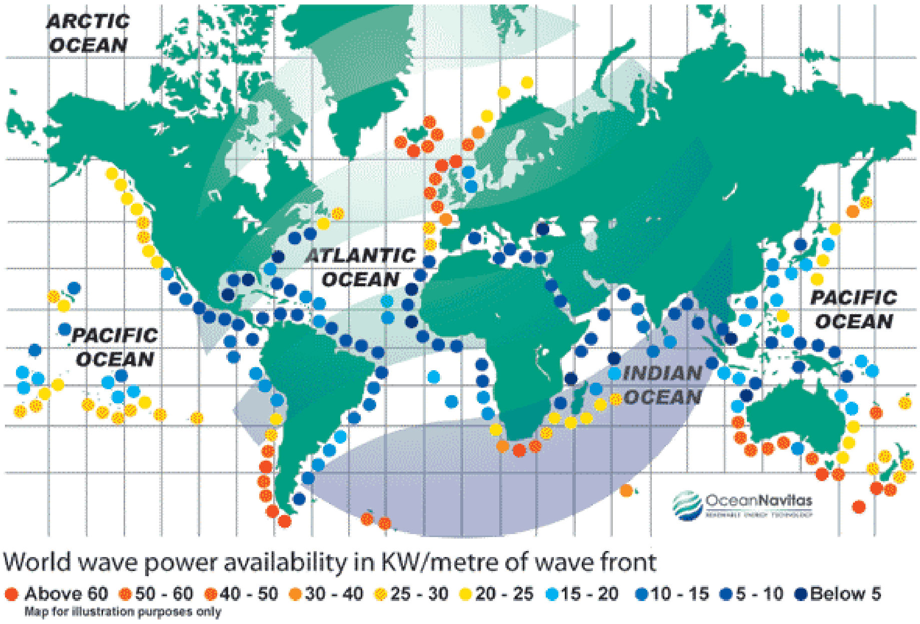


Fig. 7.1 (Source: [57])

The regions of the world possessing the largest wave resources are also the windiest, typically found between 40 and 60 degrees from the equator, in both the northern and southern hemispheres. As waves are driven by the presence of wind, they experience the same kind of variability and unpredictability in the amount of energy available at a given time.

A combination of friction between the water surface and the passing air, and the pressure differences that exist between the upwind and downwind sides of a wave crest cause a shear stress, leading to wave growth. The height of a wave is determined by a combination of; wind speed, the amount of time the wind has been blowing, the distance over which the wave is excited by the wind, and the depth and profile of the seabed, which can concentrate or disperse the wave energy. Larger waves are generally more powerful, but wave speed, wavelength, and water density are all factors that need to be considered.

The water particle motion within a wave is demonstrated in Fig. 7.2. Labels 1, 2, and 3 correspond to the direction of wave propagation, wave crest, and wave trough respectively; while ‘A’ shows the circular orbital motion in deeper water and ‘B’ the more elliptical orbital motion, present in shallower seafloor depths. In both cases, the radius of the orbit decays exponentially with depth.

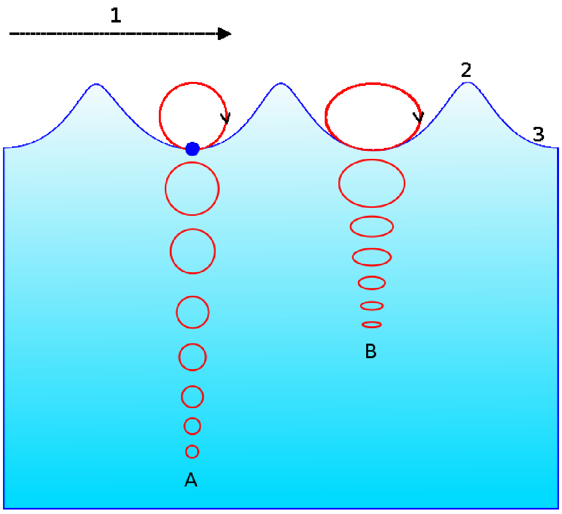


Fig. 7.2 Water particle motion in waves (Source: [58])

As water particle velocities are generally low (<1 m/s) and only moderate relative motion between particles exists, frictional effects are very small, hence the amount of energy dissipated as the wave propagates is also small. This makes surface waves a very efficient carrier, capable of transporting energy hundreds of kilometers across oceans.

If the profile of the water surface is assumed to be sinusoidal, linear wave theory can be applied for the purpose of analyzing the wave energy present. For waves propagating past a fixed point of reference, their period is related to their wavelength by the following equation:

$$T = \sqrt{\frac{2\pi\lambda}{g}}$$

Where,

T = period of the wave in s

λ = wavelength in m

g = acceleration due to gravity in m/s^2 (typically 9.81 m/s^2 on the Earth)

The power contained within a wave per unit width of wavefront can therefore be expressed as:

$$P = \frac{\rho g^2 a^2 T}{8\pi}$$

Where,

P = power contained in the wave in W

ρ = density in kg/m^3 (typically $1000kg/m^3$ for water)

a = amplitude of the wave in m

If the conditions are such that the waves break, in stormy weather, or as they approach the shore entering shallow water, linear wave theory is no longer applicable, as energy is being dissipated. The process of a wave breaking will occur when the wave reaches a maximum steepness of ~0.03, as defined by a/λ.

7.2 Configurations

Wave energy conversion devices can be categorised according to their environment as offshore, near shore and onshore. That which constitutes an offshore device, is one that operates in an open body of water, with a depth in excess of 50m. Near shore has been suggested as the area of sea within a distance of 12 miles from the shoreline, while onshore is considered to be at the shoreline or nearby.

No matter where a wave energy conversion device is placed, some desirable criteria must be met before a device can be considered successful:

- Given the hostile and corrosive nature of the environment, a device must function reliably, as access for maintenance can be difficult;
- An efficient conversion of low frequency cyclic wave motion into another form, most commonly electricity, must be achievable;

- For its particular location, a device must be able to survive the "50 year storm".

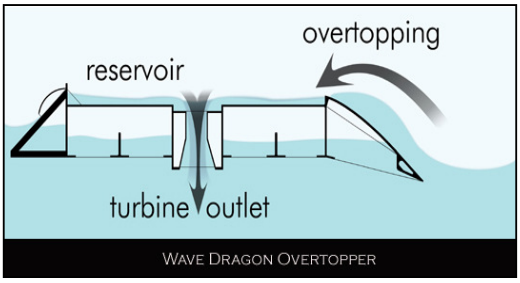
During storms, wave amplitude is greatly increased, with extreme offshore storms known to produce up to 30m high waves in deep water resulting in the power contained in them reaching MW/m of wave front. Existing constructions, such as oil platforms, are designed to survive such conditions but they are fixed, static structures, whereas wave energy converters, although fixed to the seabed by moorings, are exposed to massive structural loads as they are designed to be react dynamically with the movement of the waves.

Moving closer to shore into shallow water helps to mitigate these extreme conditions, but as smaller waves will be experienced at all other times, the loss of energy captured is significant, as the available mean power is reduced.

Onshore installations are not immune from the power of sea in storm conditions, with waves crashing on to the shore capable of causing damage to buildings and equipment fixed in position.

Instead of categorising wave energy conversion devices in terms of their relative positioning, they can also be classified by their method of operation. From this perspective, conversion devices can be classed as being either passive, relative motion, or oscillating water column systems.

Passive devices can be constructed on land at the shoreline or as floating structures moored to the seabed. By using collector arms to concentrate the wave energy, waves are able to run up a ramp above the surface of the sea before spilling over, in a process known as overtopping, into an elevated reservoir. The water then drains back to the sea through a conventional low-head hydraulic turbine, which turns a generator to produce electricity (Fig. 7.3). Prototypes of both shoreline and floating devices, such as Wave Dragon (Fig. 7.4), have been successfully demonstrated, with larger designs planned for the future.



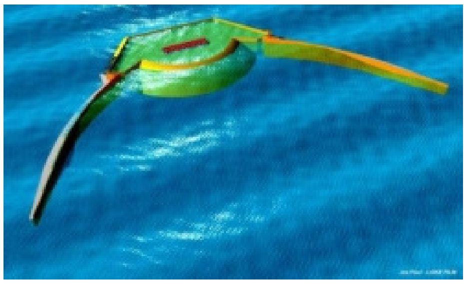


Fig. 7.3 (Source: [59]) **Fig. 7.4** (Source: [60])

Waves are used to cause parts of a device to move relative to one another, using the basis of relative motion technology. Articulation between sections of the device can be harnessed to drive a hydraulic system, where oil or water is used as the working fluid. Two such devices are the 750 kW Pelamis, developed by Pelamis Wave Power, and the 800 kW Oyster from Aquamarine power.

Pelamis (Fig. 7.5) is intended to operate at depths >50 m and is made up of a series of floating cylindrical sections joined together at their ends by hydraulic rams, to create a long snaking structure secured by mooring lines to the seabed. The passing of waves along its length induces movement in the sections, causing the rams to drive high-pressure oil around a circuit and through hydraulic motors. These, in turn, rotate an onboard generator and produce electricity, which is exported back to shore via an electrical cable connected using the mooring line (Fig.7.6).

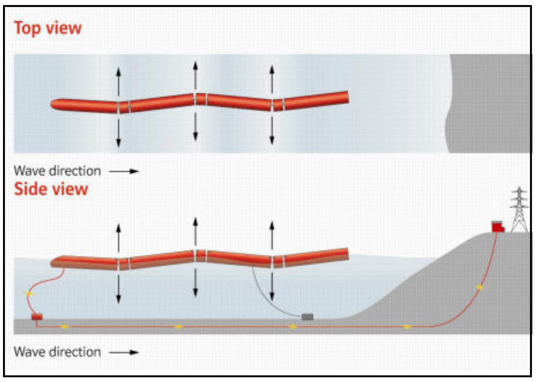


Fig. 7.5 **Pelamis P1 (Source: [61])** Fig. 7.6 **(Source: [62])**

Oyster (Fig. 7.7) is designed to operate closer to shore in depths of about 10m, where the water particle motion more is more elliptical, with the horizontal component being larger than the vertical. The device is essentially a large two section hinged flap, with one section flat on the seafloor while the other sticks up towards the water's surface. Waves cause the upwards reaching flap section to pivot to and fro with respect to the fixed base, causing the hydraulic rams connected between the two sections to pump high pressure sea water onshore, where a conventional hydro turbine and generator are located (Fig. 7.8).

Fig. 7.7 Oyster 1 (Source: [63])

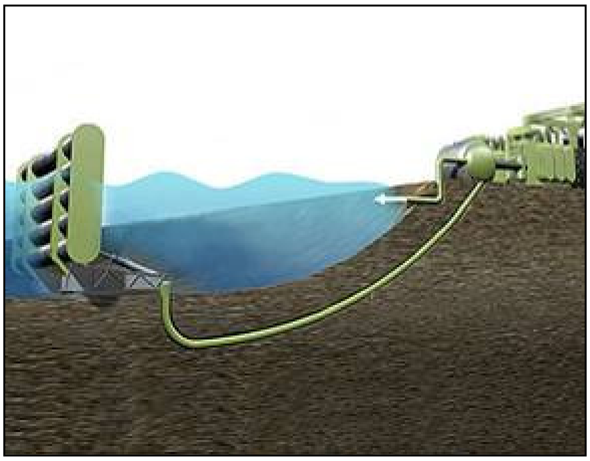


Fig. 7.8 (Source: [64])

Oscillating water columns can be located on the shoreline or deployed in the sea as a floating device tethered to the sea floor. The principle of operation uses a chamber open to water at the bottom and air at the top. Waves entering the chamber at the bottom cause the water level inside to rise and fall, pushing and pulling air out of and in through the top opening. When the chamber is correctly shaped, the oscillation of the water-free surface inside the chamber, induces an oscillating air flow with high velocity, which can be used to drive a turbine, connected to a generator (Fig. 7.9).

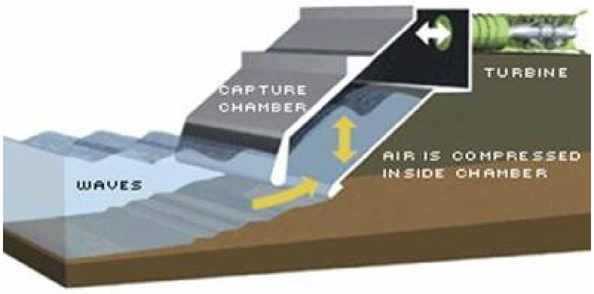


Fig. 7.9 (Source: [65])

Fig. 7.10 Limpet, Islay (Source: [66])

Some systems sought to rectify the oscillating air flow in an oscillating water column through the use of ducting and non-return valves, but a simple axial flow device called a Wells turbine can be used instead, as it will continue to rotate in the same direction irrespective of the direction of airflow. To achieve this, it employs symmetrical aerofoils with a high thickness-to-chord ratio to assist in the provision of an adequate starting torque. In the field, oscillating water columns with Wells turbines have proved to be up to 60% efficient, but introducing greater complexity to the design, such as guide vanes or variable pitch blades, could improve this further. A 500 kW oscillating water column device called Limpet (Fig. 7.10), made by Voith Hydro Wavegen Limited, is currently operational on the island of Islay, off the coast of Scotland.

7.4 Risks

Unlike land based renewable technologies, situating equipment in or even close to salt-water presents the developer with a unique set of challenges, which must be overcome to enable a profitable wave power project. Any wave energy conversion device must be able to endure the corrosive nature of the sea and wear from erosion, particularly moving parts; otherwise it ceases to be a viable enterprise. Bio-fouling and marine growth may also present a challenge by impeding the optimum operation of a device if allowed to develop. Finally, accessing deployed units for maintenance or cleaning purposes is far from straightforward.

The ability to access wave energy converter sites for either offshore or near shore device deployment, maintenance, or retrieval, requires favourable weather with relatively calm conditions. However, these devices are deliberately placed in areas that experience rougher seas and inclement weather for the purpose of tapping into a greater resource, so more energy can be extracted. Therefore a large element of uncertainty exists when planning activities, as the actual execution times could be shifted by weeks or even months depending on conditions.

Although normal everyday operation places a high demand on wave energy converters, in storms these can become extreme, with additional stresses and strains on devices and their moorings. A single device in a wave farm breaking free of its mooring also can cause serious damage to the other surrounding devices, potentially leading to large amounts of generating capacity being lost and revenues being negatively impacted. Even shoreline-based installations are not immune from storm damage, as they too have to survive the waves as they hit land. Survivability in extreme conditions is essential to minimise damage, maximise availability, and reduce the need to visit an installation, with its associated uncertainty of access.

The wave (and tidal) power industry (not to mention offshore wind) face a growing problem over the availability of vessels, more specifically vessels featuring dynamic positioning systems and appropriate lifting capabilities that can also operate in shallow waters. This shortage has serious potential consequences as the leasing cost of such vessels and the time it might take to construct additional ones may compromise planning, cause delays, and even determine the rate at which the industry can expand. This could, in turn, encourage potential developers to invest in alternative (onshore) renewable technologies rather than wave energy.

The effects of large-scale device deployment on marine ecosystems are not well understood and although it is acknowledged that initial installation does disturb the seabed benthos, it appears to recover and even thrives on man-made constructions. Other disturbances that might be caused by installed devices, such as sub-sea noise, are also poorly understood at this time. Should future research uncover undeniable evidence of permanent damage to marine ecosystems, future implementation of projects could be compromised. Positioning wave energy converters in the sea has consequences for shipping, fishing and even recreation, as a navigational hazard. These areas will often no longer be accessible, potentially leading to shipping channels being re-routed, fishing grounds being closed, and recreational activities disrupted, with a possible impact on tourism. All of these could prove costly to local economies, despite the fact that marine life may actually flourish in the excluded areas.

Near shore and onshore projects are more likely to see public opposition, as they are more visible than offshore projects and alter the look of the environment as seen from dry land. This, together with the construction of additional grid infrastructure to reach coastlines could complicate planning applications and delay the start-up of wave power projects, in a manner similar to that seen already with wind power.

Chapter 8 - Tidal Power

8.1 Resource

The gravitational interactions between the Earth and the Moon, and to a lesser extent the Earth and the Sun, create tidal forces, which are directly responsible for tidal motion when combined with the rotation of the Earth on its own axis. The rise and fall of sea levels associated with tidal behaviour requires vast quantities of water to be constantly moving around the Earth. These cyclic flows of water are better known as tidal currents and the kinetic energy they possess can be extracted and used for other purposes such as generating electricity.

The tidal forces experienced at the Earth's surface change according to the relative positions of both the Moon and the Sun, whose movements are independent of one another. When the Earth, Moon, and Sun are positioned in a straight line, corresponding to a new moon or a full moon, the alignment of gravitational forces acts to generate the maximum possible tidal range, known as a spring tide, and gives rise to the strongest tidal currents. When the Moon enters its first and third quarter positions, it is at 90 degrees to the Sun as viewed from the Earth, and this alignment produces a minimum tidal range and tidal current strength, called a neap tide. These scenarios are depicted in Fig. 8.1:

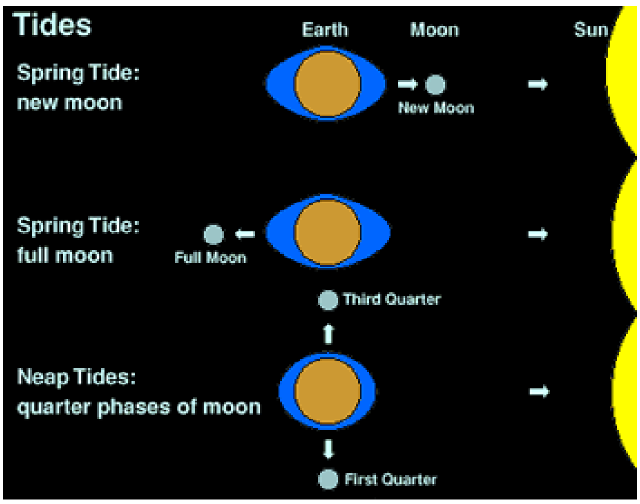


Fig. 8.1: Gravitational influence on tides (Source: [67])

As the movements and relative positions of the Moon and the Sun are well understood, so is the behaviour and predictability of the tides, with most locations experiencing semidiurnal tidal behaviour, meaning two high tides and two low tides every twenty-four hours.

There are two methods of harnessing tidal behaviour; with the first making use of the velocity of a tidal flow of water to cause the mechanical movement of a machine, usually then converted to electricity. The second makes use of large tidal ranges in geographically suitable areas, where a barrage can be inserted between the open sea and a closed basin, for the purpose of extracting energy as water enters or leaves the basin. The main difference with the barrage scheme is that it allows the flows of water to be controlled and enables a head of water to be built up on one side of the barrage compared to the other, thus making use of gained potential energy in a manner similar to a hydro scheme.

Although there are relatively few viable sites worldwide, extremely high civil engineering costs, and environmental issues, mean tidal barrage schemes are typically only undertaken when there is a high degree of government backing due to the scale of such endeavours. Without governmental investment and support, tidal barrage systems become less appealing to developers as the construction period is lengthy and expensive with far reaching environmental impacts. This lack of developer interest at present means tidal barrage will not be considered further in this section.

The velocity of a tidal current is determined by the positioning of landmasses and the channel created with the seabed. The highest velocities are localised and produced when tidal effects force water through a channel. A map of the UK showing spring tide peak flow speeds can be seen in Fig. 8.2 below:

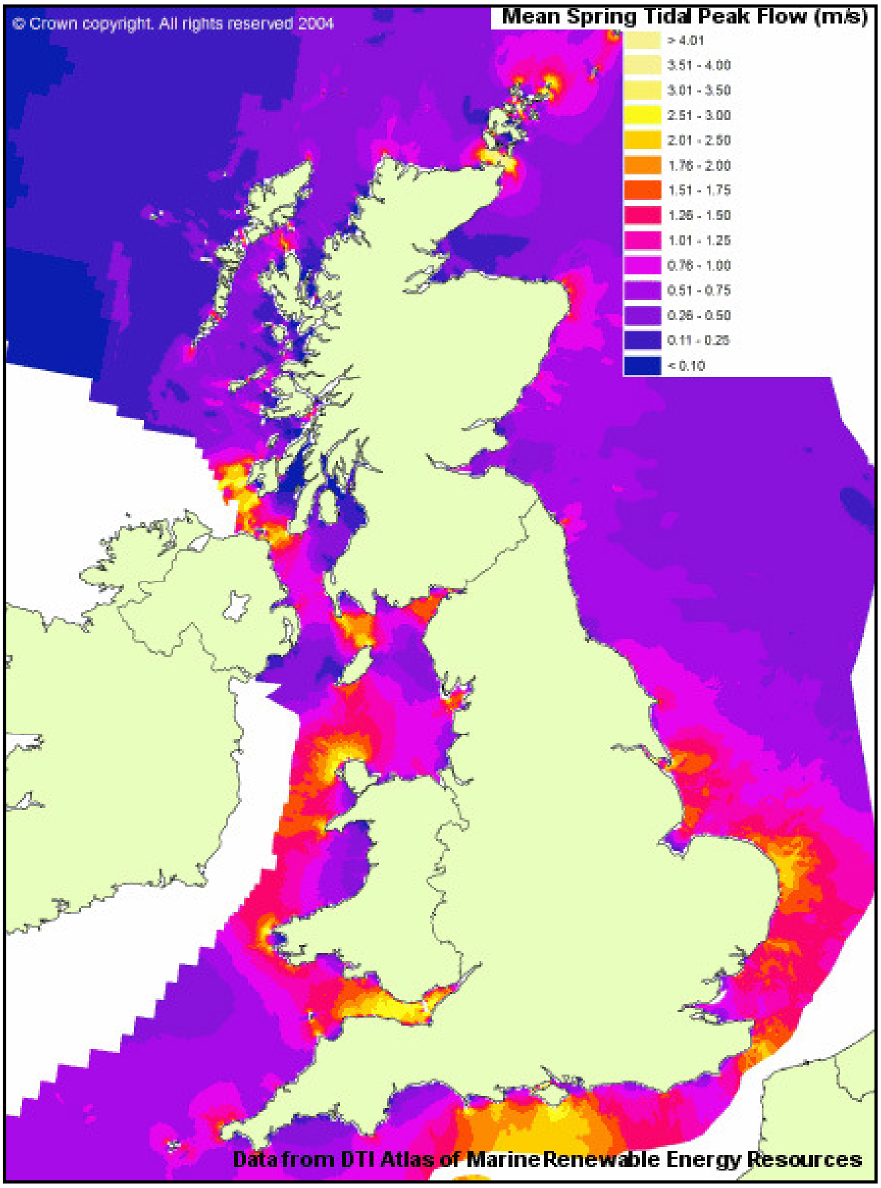


Fig. 8.2 UK map of mean spring tidal peak flow. (Source: [68])

The total UK tidal current resource has been estimated at ~110 TWh/year, which represents a technically extractible resource of 18 TWh/year, or ~5% of the annual UK electricity demand.[69]

Although tidal current technology is in its infancy, many design cues have been taken from wind turbines, as the fluid dynamic behaviour is similar with the possible complicating factor that the flow is confined by landmasses and a free surface. Therefore, as with wind turbine theory, the power contained within a flow of water can be considered as:

$$P = \frac{\rho A V^3}{2}$$

Where,

P = Power (W)

ρ = Density of water (kg/m^3)

A = Area (m^2)

V= Flow speed (m/s)

The extraction of the kinetic energy contained by the fluid flow and its conversion to another useful energy form is subject to the application of Betz' Law as previously discussed in Chapter 3. The actual power extracted from a moving fluid can therefore be shown as:

$$P = \frac{C_P \rho A_{Rotor} V^3}{2}$$

Where,

C_p = Efficiency, or power coefficient, or energy conversion

A_{Rotor} = Swept area of device rotor in m^2

The maximum theoretical efficiency is equal to the Betz coefficient (C_p = 0.593), as determined by Betz' analysis, which in practical terms is unachievable due to the operational losses (rotor and mechanical) experienced by devices.

With tidal flows however, the current velocity has a cyclic pattern, which is roughly sinusoidal in behaviour:

$$V = V_{\max} \sin \omega t$$

Where,

V_{max} = Peak velocity of the current in m/s

ω = 2π/T, where T is the period of the cycle (typically 745 minutes)

t = time into the cycle in minutes

The power extracted from the tidal flow can now be written as:

$$P = \frac{C_P \rho A_{Rotor} V_{\max}{}^3 \sin^3 \omega t}{2}$$

As tidal currents flow in both directions, marine current turbines are designed to generate power for either direction of flow, with the first half of a cycle in one direction and the second half in the other. It should be noted, that although the power characteristic of each half cycle with respect to time will be similar, they are not necessarily the same, since the value of V_{max} for each direction is often different due to a site's geographical asymmetry.

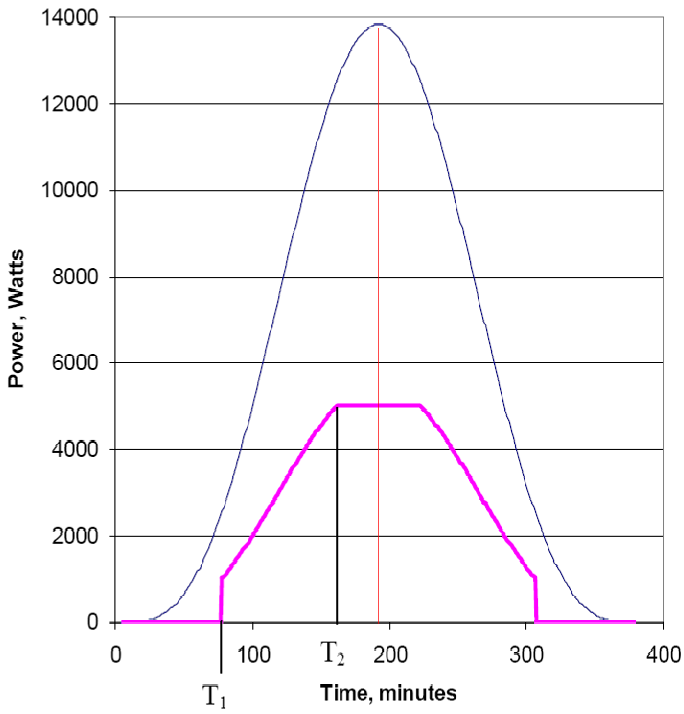


Fig. 8.3 Ideal tidal half-cycle

Fig. 8.3 shows a graph of an ideal tidal half-cycle where the faint blue line shows the total available power, with the predicted output power represented by the pink line. T1 and T2 correspond to the times at which the turbine achieves cut-in and rated powers respectively. A cut-out condition is not normally considered necessary due to the predictable nature of tidal forces.

The red line indicates the quarter-cycle time (the midway point of the half-cycle) of 186.25 minutes, where peak flow is achieved.

The total energy captured during one quarter of a full tidal cycle is given by:

$$\int Pdt = \int_{T_1}^{T_2} \left(\frac{C_p \rho A_{Rotor} V_{\max}{}^3 \sin^3 \omega t}{2} \right) + P_{Rated} \left[186.25 - T_2 \right]$$

Where,

P_{Rated} = Rated power in Watts

8.2 Configurations

In terms of device configuration, rotating tidal current turbines can be classified in a similar manner to wind turbines, with devices described as being either horizontal axis or vertical axis. Use of the term ‘vertical axis’ is perhaps misleading in this case, as it is generally accepted that these devices can also function with their axis positioned horizontally, unlike horizontal axis machines, which will not function if their axis is changed. A category of non-rotating tidal current device exists in the form of oscillating hydrofoils, where the direction of oscillation is used to categorise devices as either horizontal axis or vertical axis systems. Unlike the wind turbine market however, no single tidal stream technology has yet proved superior, with a variety of designs undergoing development and testing.

A number of design proposals exist for horizontal axis rotating tidal current devices, each seemingly offering benefits over the others, but few can back these claims with results from in-situ testing. One design concept, which has seen extensive testing, uses a single rotor attached to a tubular steel pile, mounted in the seabed. This bears a resemblance to a conventional wind turbine, with pitch adjustable blades for operating in bi-directional flow and the blade shape optimised for use in water.

Fig. 8.4
(Source: [70])

Fig. 8.5
(Source: [71])

Fig. 8.6
(Source: [72])

Marine Current Turbines Ltd has successfully deployed and operated two devices of this type – SeaFlow (Fig. 8.4), a 300 kW single rotor system installed in 2003 off the North coast of Devon, England; and SeaGen (Fig. 8.5 and Fig. 8.6) a 1.2 MW twin rotor arrangement, installed during 2008 in Strangford Lough, Northern Ireland. The towers for both devices extend above the water line, allowing the entire turbine and rotors to be raised out of the water for maintenance purposes.

An alternative approach to horizontal axis rotating tidal current design, is to employ ducting around the rotor to channel more water through the turbine, enabling the use of a smaller diameter turbine, thereby resulting in higher flow velocities. Ducted turbines have been shown experimentally to demonstrate a distinct advantage over non-ducted turbines. When the approach angle of the water flow is not perfectly in line with the turbine axis, they experience a lesser drop in power characteristics. Such a device currently being developed by Lunar Energy is the Rotech Tidal Turbine (RTT) as shown below in Fig. 8.7:

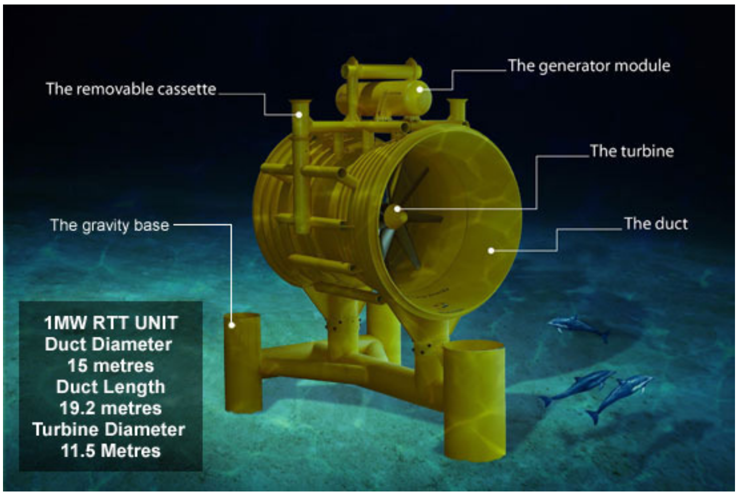


Fig. 8.7 (Source: [73])

It consists of bi-directional ducting and a turbine mounted on to a gravity base, a stable structure, which stands on the surface of the seabed by virtue of its own mass and without the requirement for piles to hold it fixed in place. Another feature with this particular design is that its modular construction allows the module containing the generator and turbine to be removed and raised to the surface for maintenance, leaving the ducting fixed to the gravity base in place.

Open Hydro makes another device that employs a duct, their Open Centre Turbine (Fig. 8.8). Instead of the rotor blades joining at a centrally positioned shaft, used to turn a generator or hydraulic pump, it has an open centre with the blades fixed to an outer ring inside the ducting structure, along with the generator. This configuration allegedly minimises the impact on marine life, which can pass through the centre without harm, and there are no exposed blade tips with which they could come into contact.

Fig. 8.8 (Source: [74])

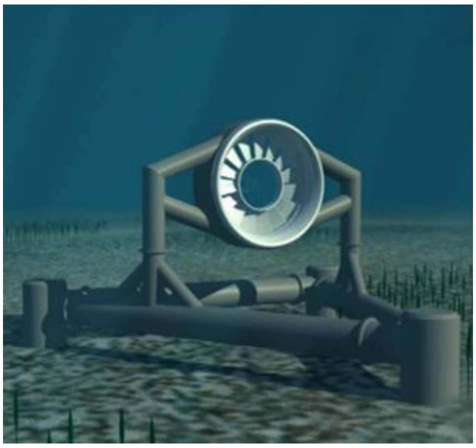


Fig. 8.9 (Source: [74])

A 250 kW prototype Open Centre Turbine has already been deployed and tested using both pile mounting (Fig. 8.8) and gravity base (Fig. 8.9) at the European Marine Energy Centre (EMEC) in Orkney, off the North coast of Scotland. A further deployment with a commercial scale 1 MW device in the Bay of Fundy, Canada is also underway.

Other proposed horizontal axis turbine ideas dispense with fixed mountings from piled towers or gravity bases, and instead use flexible tensioned moorings tethered to the seabed. The marine current turbines that employ this style of fixing, are typically buoyant structures featuring 2 contra-rotating rotors to prevent a reactive torque causing the entire device to rotate. SMD Hydrovision developed a tidal turbine called TidEL (Fig. 8.10) where a pair of contra-rotating 500kW turbines linked by a crossbeam lie side-by-side. The University of Strathclyde Energy Systems Research Unit (ESRU) has demonstrated a further device with the contra-rotating blades rotating around the same axis, (Fig. 8.11).

Fig. 8.10 (Source: [75])

Fig. 8.11 (Source: [76])

The mooring concept allows both of these devices to self-align downstream in the prevailing flow, without the need for additional external systems input. This makes for an economical and reliable means of tracking the tidal flow cycle, while the lack of structural support renders these devices suitable for operation in coastal waters and deeper offshore environments.

Vertical axis rotating tidal current turbines are remarkably similar to their vertical axis wind turbine cousins (see chapter 3) with Darrieus, Gorlov and Savonius devices proposed. The rotational motion produced can be converted in the same way as horizontal axis machines, to generate electrical power. These have the flexibility to be mounted in a vertical or horizontal orientation, using rigid piles or gravity bases on the seabed, or floating platforms, which enable the generator and other electrical systems to be kept above the surface.

The final category of tidal current device is the oscillating hydrofoil, where the flow of water over a hydrofoil is used to create an oscillating motion, which can operate hydraulic cylinders, drive a motor and when connected to a generator, produce electricity. Stingray (Fig.8.12) is an oscillating hydrofoil device developed by The Engineering Business as a seabed-standing device mounted on a gravity base.

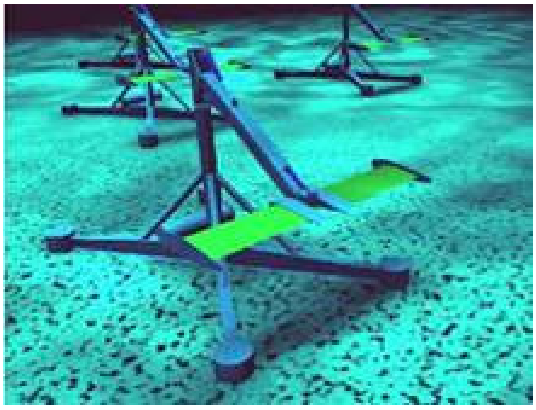


Fig. 8.12 (Source: [77])

In 2002, a 180 tonne, 150 kW prototype version of the Stingray was deployed for testing in the Yell Sound, located off the coast of the Shetland Islands, Scotland, and successfully recovered afterwards. The following year, Stingray was re-deployed with minor control systems updates and tested over a longer period.

8.3 Risks

Many of the elements of risk concerned with tidal current converters are exactly the same as those for wave energy conversion technologies as already discussed in chapter 7. The accelerated corrosion experienced in salt water plays a major role in the durability of a device, while erosion is possibly more influential on tidal current converters, as carefully profiled rotor blades and hydrofoils will operate less efficiently once their surfaces become scratched, pitted and generally tarnished. Cavitation however, is unlikely to be an issue with rotating tidal turbines, as rotor speeds are not expected to be high enough to induce the problem.

Similarly, bio-fouling and marine growth on rotor blade surfaces, hydrofoils or even ducting will also cause disruption to the flow of water around these surfaces and reduce the operating efficiency of the device. Extreme cases could even see the complete stoppage of devices through the build up of foreign matter. Seabed mounted systems may also be vulnerable to tidal flows re-shaping the profile of the sea floor, through the deposition of silt or by erosion, leading to partial burial or unstable seabed support for a gravity base.

For a developer, all of these issues and their potential severity need to be understood and accounted for. Despite the regular and predictable nature of tidal currents, a small drop in efficiency will accumulate over time, resulting in a significant drop in the accumulated electrical energy produced. A device stoppage will have the same, and possibly further reaching, effect.

The issue of vessel availability to deploy and retrieve tidal current devices experienced with wave energy convertors is just as relevant for tidal installations. Similarly, the utilisation of available vessels, as determined by weather conditions, and particularly when operating in locations of high current flow, with potentially much deeper seabed installations, increases the complexity of deployment, retrieval and maintenance tasks.

The same uncertainties of the longer-term effects of installed devices on the marine ecosystem are present for tidal installations, as for wave energy convertors. They are also equally susceptible to the risks associated with their positioning, potentially affecting shipping routes, fishing and tourism. In addition, the challenges of creating suitable grid infrastructure and negotiating planning applications could as easily delay these projects as the other technologies, incurring associated costs for developers.

Chapter 9 - Generic Issues

Thus far we have considered individual renewable technologies and the technical issues and risks associated with each of them. There are however, more general topics applicable to most renewable energy projects which introduce additional complexity, risk, and uncertainty, not just for the developers or project investors, but sometimes also to the development of the industry itself.

All renewables projects require a degree of civil works to be carried out, whether at a large scale like building a dam or tidal barrage, or something less obvious such as a concrete base for a small wind turbine. In between there are always requirements for foundations on which to place equipment, buildings to house it, and access roads to sites chosen for development as they are often remote from the existing road network infrastructure. To achieve any of these constructions requires land surveys to establish the ground composition and the extent of ground works required. Also necessary is design input for buildings as well as roads that comply with regulations, local authority permission to proceed with construction and final approval to gain completion certification. The length of time it takes to complete these tasks can be highly variable, so planning for them is difficult.

Delays in construction times can have a serious impact on completion time for a project, especially when the task must be completed before further work can begin e.g. an access road must be completed, before the main site construction can begin. To actually carry out the required civil works will usually mean relying on contractors; a scenario that is often fraught with danger when trying to adhere to a strict project timeline. In general, the greater the scale of the civil works required, the greater the chance of encountering difficulties leading to a delay.

One of the biggest challenges facing developers of electricity-generating renewable energy projects is successfully exporting the power produced to the national grid. Often the first issues encountered are in identifying the most viable connection point, how far away this is from the key generation equipment, and how it is to be reached. The local electricity supplier will be able to provide advice on the best point of connection, but how this point will eventually be reached depends on a number of factors. The distance to be covered by a power cable is important in determining cost but the cable installation method also has to be considered:

- Overhead – mounting cable across pylons is the easiest and cheapest method
- Underground – burying the cable in a trench and backfilling it is expensive
- Underwater – necessary for some water sourced technologies, but expensive

As overhead cable routing is the cheapest method, it is also the developers' preferred choice; however local opposition is common, as pylons are commonly regarded as an unseemly blot on the landscape. Placing the cable underground has less visual impact, although the process is considerably more expensive than the overhead solution. It also requires an excavation phase, digging up stretches of land to enable the burial of cable, potentially creating an eyesore and scar on the landscape in this interim period, although with a less unsightly end result. The point of connection will also help determine which switch gear and safety systems are required and the voltage at which transmission will take place.

Perhaps more significant though, is that many renewable energy projects suffer from a lack of grid connection points close to the generation site. As sites are generally in remote locations with only small communities nearby being served by the existing distribution network, there is little capacity available on the network without significant investment and upgrading.

Chapter 10 - Risk factors and conceptual modelling

10.1 The need for a model

The analysis has shown that there are a series of risk factors associated with each type of renewable energy technology and the associated infrastructure development. It is the premise of this dissertation that these factors can be clustered together and rationalised leading to a summary of the pertinent factors depicting the level of risk associated with each endeavour under construction, thus informing the process of insuring such developments.

One of the more complicated aspects of the insurance business is the underwriting of policies. Insurers predict the likelihood that a claim will be made against their policies using a wide variety of data, and price their products accordingly. To inform this decision making, insurers use actuarial science to quantify the risks they are willing to assume and therefore derive the premium they will charge to take responsibility for them. Based on risk, the rate of future claims is projected through data analysis. Actuarial science uses statistics and probability to analyse the risks associated with the range of technological and economic factors appropriate for a development, with these scientific principles being used to determine an insurer's overall exposure.

Without the benefit of actuarial detail, the technological factors can be used to create a conceptual model for use in the insurance industry. It could form the basis of further actuarial study and development of a complete model for use in the insurance industry, addressing some of the concerns raised by Sonntag-O'Brien et al. in 2004:

"A number of insurers had bad experiences with wind power in the 1980s and early 90s, and although the industry has undergone enormous growth since then and the technology has matured considerably, many insurers are still reluctant to insure wind projects. There are some, however, who will do so, and a fully-financed wind project will usually find cover today. Cover for biomass is available for larger projects, however, what is still needed is a product to cover the security of fuel supply. Financiers want fuel supply insured, but as yet there is no product to do it. Large-scale hydro is well understood and can be insured. Run of the river hydro facilities are also catered to, however, small-scale and micro-hydro developers sometimes have difficulty finding sufficient cover".

10.2 Profiling

Profiling insurance risk factors is very important. The Pareto principle suggests that 80%~90% of the insurance claims may come from 10%~20% of the insurance group segments. Profiling these segments can reveal invaluable information for insurance risk management and is the process of identifying factors and variables that best summarize the segments. In the field of renewable energy developments, the segments can be classed as each of the key technology types, such as wind, hydro, wave etc. These can be represented pictorially in a decision tree, leading to an overall summary of relevant factors for a given technology.

Classification methods for profiling in insurance alone are often criticised as imperfect, due to the fact that insurance claims are in general very low ratio events, often less than 10%, which can skew the baseline data for decision-making. Insurers have to predict likelihoods based on a very limited data set, an effect that in the renewable sector is further exaggerated due to the limited number of developments, and the relative "youth" of the industry. Classification modelling is, however, a valid first step in the process, and will form the output of this study. The model can only be used effectively when expanded upon with statistical probabilities based on actuarial data.

10.3 Proposed conceptual model

There is a commonality of risk factors among the technologies, or segments, which lends itself to generalising at least half of the conceptual model, making it equally applicable for assessment of all forms of renewable generation. Once these generic risks have been accounted for, the second stage of the model allows the root causes of failures and delays to be specifically categorised by technology type.

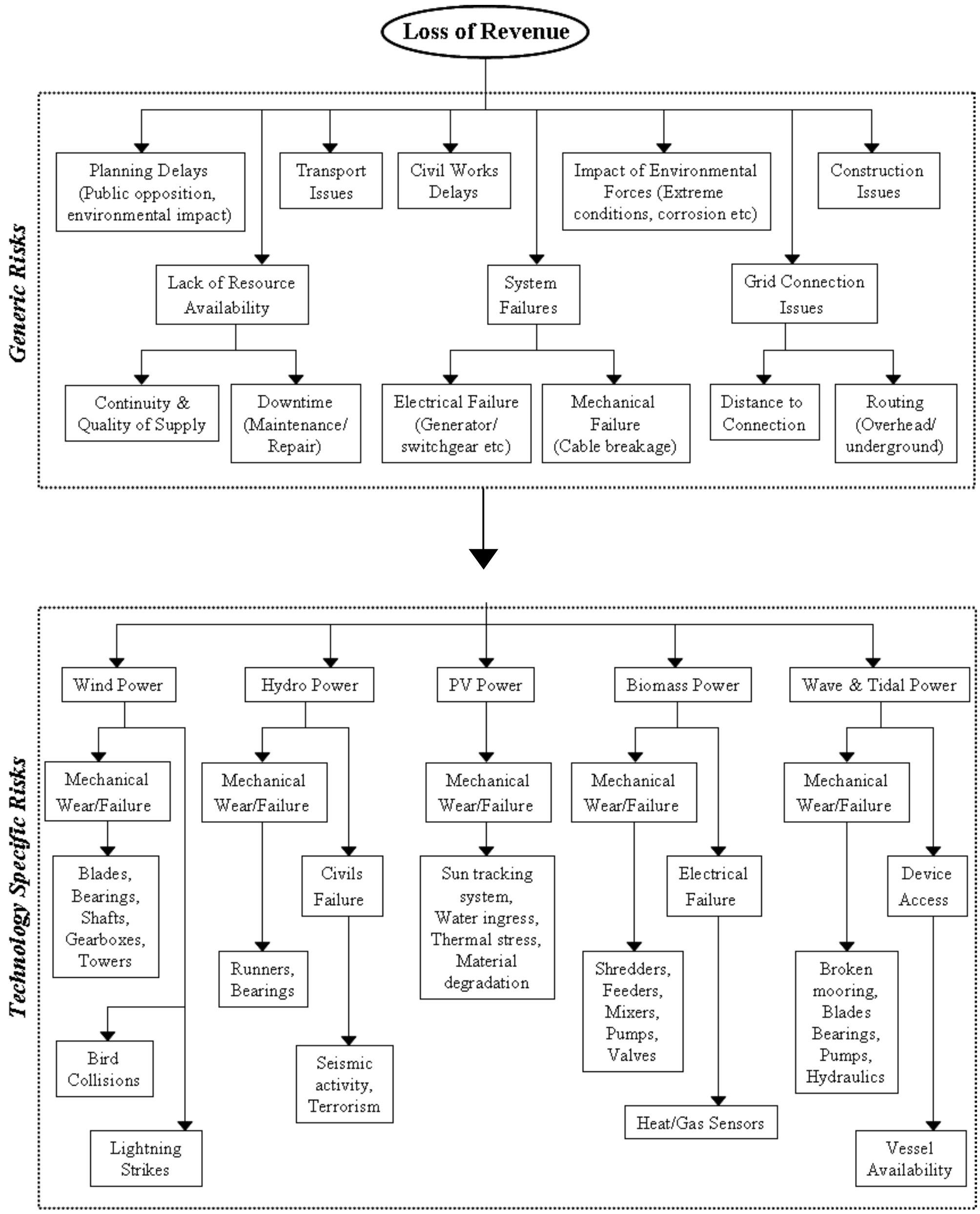


Fig. 10.1 **Proposed Conceptual Model**

(See Appendix 2 & 3 for zoomed-in representations of Fig. 10.1)

In the same way that actuaries frequently reassess databases of information for e.g. car insurance, to determine patterns of frequency and severity related to risk factors such as gender, age, car model etc. so must this work be undertaken with the factors represented above. It will then become apparent to both the insurance industry and to developers, the types of project risks to look for, and where possible avoid, minimising premiums and investing in sound development projects. This conceptual model provides a good basis on which to begin actuarial data collection and analysis.

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Appendix 1 (Source: [10])

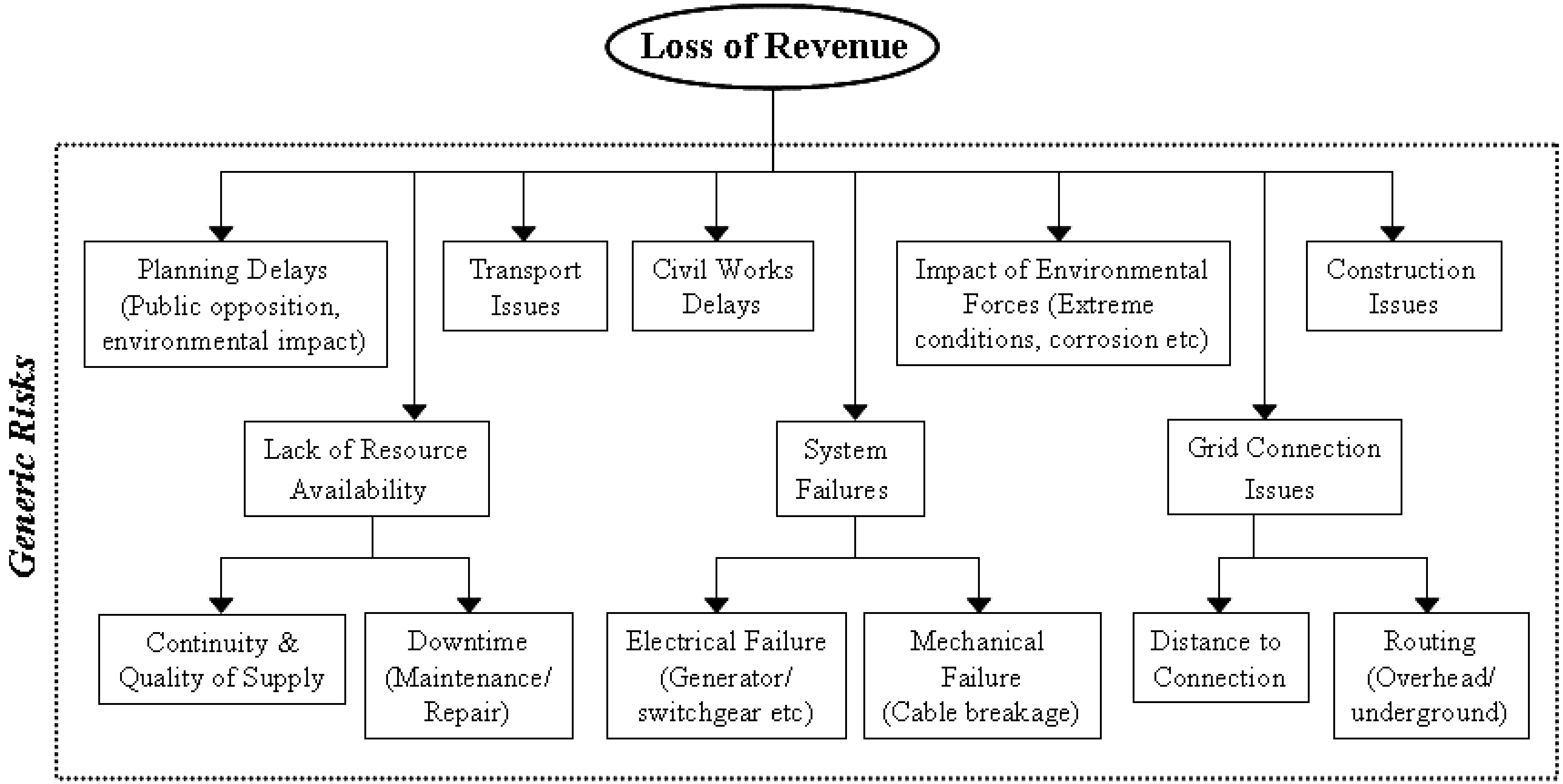
Table of generation tariffs to 2020

Technology	Scale	Tariff level for new installations in period (p/kWh) [NB tariffs will be inflated annually]											Tariff lifetime (years)
	Scheme Year	1 1/4/10 – 31/3/11	2 to 31/3/12	3 to 31/3/13	4 to 31/3/14	5 to 31/3/15	6 to 31/3/16	7 to 31/3/17	8 to 31/3/18	9 to 31/3/19	10 to 31/3/20	11 to 31/3/21	
Anaerobic digestion	≤500kW	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	20
Anaerobic digestion	>500kW	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	20
Hydro	≤15 kW	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.9	19.9	20
Hydro	>15-100 kW	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	17.8	20
Hydro	>100 kW-2 MW	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	20
Hydro	>2 MW – 5 MW	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	20
MicroCHP pilot*	≤2 kW*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10*	10
PV	≤4 kW (new build**)	36.1	36.1	33.0	30.2	27.6	25.1	22.9	20.8	19.0	17.2	15.7	25
PV	≤4 kW (retrofit**)	41.3	41.3	37.8	34.6	31.6	28.8	26.2	23.8	21.7	19.7	18.0	25
PV	>4-10 kW	36.1	36.1	33.0	30.2	27.6	25.1	22.9	20.8	19.0	17.2	15.7	25
PV	>10-100 kW	31.4	31.4	28.7	26.3	24.0	21.9	19.9	18.1	16.5	15.0	13.6	25
PV	>100kW-5MW	29.3	29.3	26.8	24.5	22.4	20.4	18.6	16.9	15.4	14.0	12.7	25
PV	Stand alone system**	29.3	29.3	26.8	24.5	22.4	20.4	18.6	16.9	15.4	14.0	12.7	25
Wind	≤1.5kW	34.5	34.5	32.6	30.8	29.1	27.5	26.0	24.6	23.2	21.9	20.7	20
Wind	>1.5-15kW	26.7	26.7	25.5	24.3	23.2	22.2	21.2	20.2	19.3	18.4	17.6	20
Wind	>15-100kW	24.1	24.1	23.0	21.9	20.9	20.0	19.1	18.2	17.4	16.6	15.9	20
Wind	>100-500kW	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	18.8	20
Wind	>500kW-1.5MW	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4	20
Wind	>1.5MW-5MW	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	20
Existing microgenerators transferred from the RO		9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	to 2027

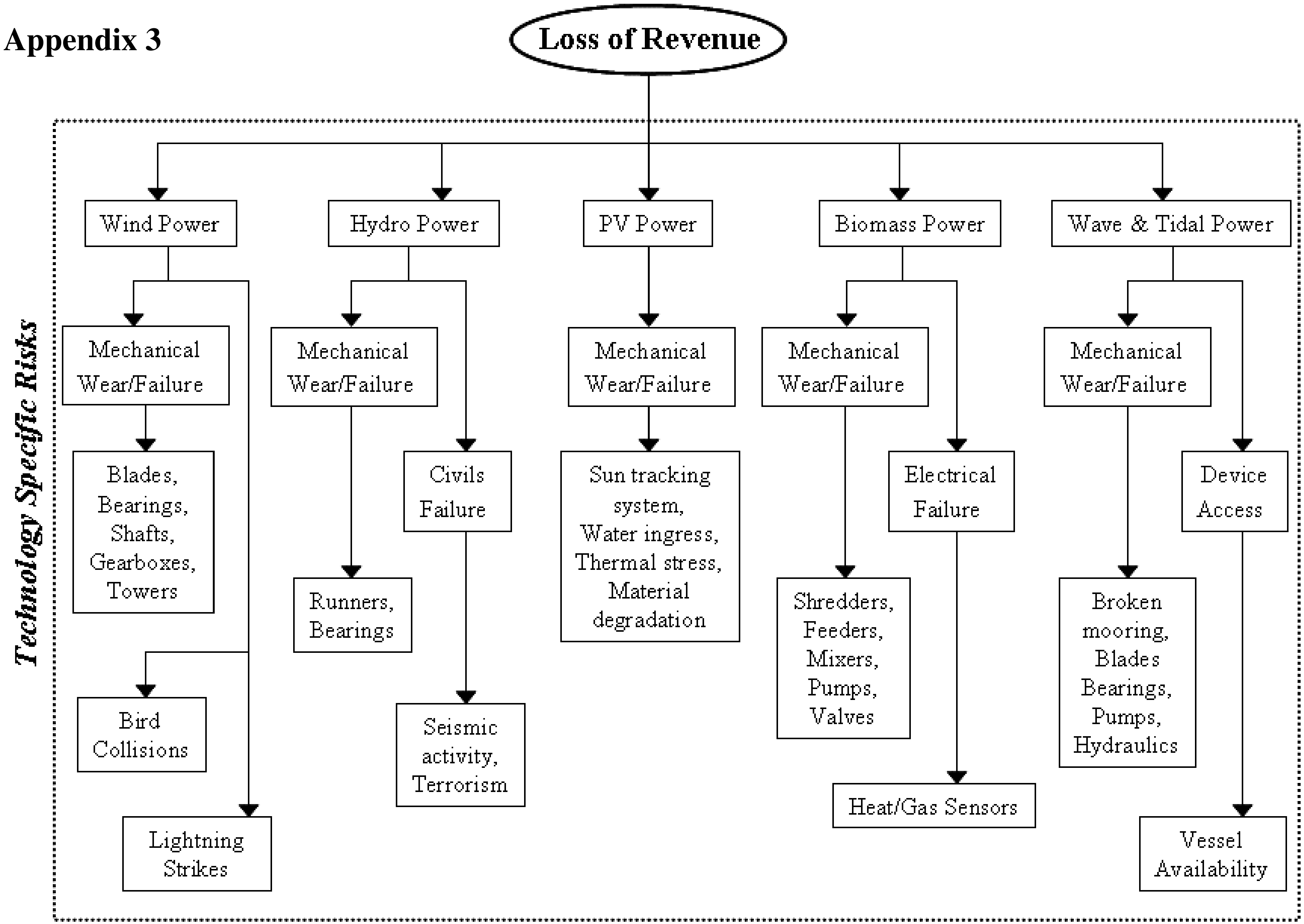
* Note the microCHP pilot will support up to 30,000 installations with a review to start when the 12,000th installation has occurred

** "Retrofit" means installed on a building which is already occupied ;"New Build" means where installed on a new building before first occupation ; "Stand-alone" means not attached to a building and not wired to provide electricity to an occupied building

Appendix 2


Loss of Revenue
Generic Risks
Planning Delays (Public opposition, environmental impact)
Transport Issues
Civil Works Delays
Impact of Environmental Forces (Extreme conditions, corrosion etc)
Construction Issues
Lack of Resource Availability
System Failures
Grid Connection Issues
Continuity & Quality of Supply
Downtime (Maintenance/ Repair)
Electrical Failure (Generator/ switchgear etc)
Mechanical Failure (Cable breakage)
Distance to Connection
Routing (Overhead/ underground)

Appendix 3


Loss of Revenue
Technology Specific Risks
Wind Power
Hydro Power
PV Power
Biomass Power
Wave & Tidal Power
Mechanical Wear/Failure
Blades, Bearings, Shafts, Gearboxes, Towers
Bird Collisions
Lightning Strikes
Mechanical Wear/Failure
Civils Failure
Runners, Bearings
Seismic activity, Terrorism
Mechanical Wear/Failure
Sun tracking system, Water ingress, Thermal stress, Material degradation
Mechanical Wear/Failure
Electrical Failure
Shredders, Feeders, Mixers, Pumps, Valves
Heat/Gas Sensors
Mechanical Wear/Failure
Device Access
Broken mooring, Blades Bearings, Pumps, Hydraulics
Vessel Availability