A Product Design-Centred Approach to Micro-Wind

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Declaration of author's rights

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Abstract

More and more micro-wind turbine companies are emerging, claiming that their products will contribute up to one third of the average UK household's annual electricity requirements. Some are well established in their niche markets, some have only just brought products to market whilst others seek investment in their new technologies: generally in response to perceived market opportunities – opportunities that are unlikely to be sustainable in the long term. As an embryonic sector, with unproven technology in many cases, it stands to reason that there is something of a question mark hovering over the future of domestic wind power. Already, proprietors of domestic wind turbines are beginning to venture that perhaps their turbines are actually not useful, should not be put on houses; and that the manufacturers are misleading the public through fanciful energy yield claims.

Conversely, the cumulative benefits of micro-wind, as a contributory part of the bigger microgeneration movement, have been heralded as a multi-faceted solution to the inherent difficulties in tethering the public's collective conscience to the issues of energy use and profligacy – not to mention, of course, the all-important carbon savings; however, this is also true of alternative microgeneration technologies which are currently competitive.

The true picture is therefore quite ambiguous, due in no small part to complex relationships existing between technological, political and social drivers and inhibitors. Thus, by utilising traditional best practice Product Design principles, it was possible to better identify the opportunities and threats that exist for micro-wind; a more realistic assessment of the market scope; technological and process improvements that may need to be put in place; and also, public perceptions of wind energy and how the customer need can be better integrated into the design and manufacture process. In essence, therefore, this effort constitutes a balanced and comprehensive consideration of micro-wind with the express desire of unifying best practice process methodologies to aid proficiency and suitability for purpose of micro-turbine design[1].

Foreword

In terms of commercial viability, a few companies may well stand to profit in the domestic turbine market sector, but it is not as straight forward for domestic wind as it can be for many mass-market consumer products as a predominantly ‘technology-push’ (as opposed to ‘market-pull’, for example) inspired product. Significant efforts to decrease design and manufacture costs will be required to foster market penetration, as even with the availability of capital grants, badly administered technology will not be commercially viable and could damage the cause as a whole: a turbine costing £1000 pounds producing only 10kWh per annum, even with a 30% capital grant and low interest loans cannot, obviously, pay for itself in its rated life time. Surprisingly, this is based on information from an owner of a rooftop turbine which was rated at 250W, and achieved a (rare) maximum of only 70W in high winds[2]. Actual test data are also something of a rarity on many manufacturers’ websites, and if performance in key market areas is of such low calibre as has been suggested by some, it is not hard to see the merits of such ambiguous data. To redress this situation vast process and design improvements are necessary to reduce purchase price, as cost and Return On Investment are the number one influencing factors on potential consumers[3]. The industry cannot rely solely on economies of volume to reduce these costs, however, especially with the technology administered as it is at present, because consumer confidence will be undermined by negative publicity, in turn diluting the market. The industry must rely instead on utilising best practice design methods such as Design for Manufacture and Assembly (DFM&A), Design for X, concurrent engineering/manufacturing process improvements, for example, continual improvement, public relations and education measures, proactive advertising and adapting technology to suit the customer’s specific requirements, rather than foisting an idea of technological excellence on an, as yet, undiscerning demographic.

To illustrate this point, only one small turbine manufacturer of those investigated boasted of utilising DFM&A or best practice design methods in their product. This is in stark contrast to many others that rely on laborious manual assembly of difficult subsystems such as field coil windings; reducing profitability and passing extra costs onto a consumer that cannot support them on a wide scale.

In that regard, a further aspect of turbine technology that offers great potential for influencing value addition and hence, customer appeal, is turbine control. Coupled with specifically catered performance to deployment topography and a system for translating performance metrics into customer needs such as QFD (Quality Function Deployment) will have a huge bearing on product worth. For example, even though customers value product cost over safety[4], a system without fail-safe over-speed control could sink a company through overall life cycle costs, PR mitigation, indemnity and product liability, as defined in British law (The Consumer Protection Act 1987, The EEC Directive on Liability for Defective Products, The Royal Commission on Civil Liability and Compensation for Personal Injury or equivalent), and various BS/ISO standards.

By utilising a structured design process it should be possible for the agile company to offer a product that is desirable, viable and attractive, whilst aiding, rather than compromising, quality, based on an intrinsically heterogeneous engineering input. Such technology improvements still will not in many cases offer the kind of energy yield purported by several vendors, but careful scrutiny of methods will at least facilitate realistic market growth, and ROI, whilst balance and design trade-offs can be made expedient and better applied.

The future of micro-wind is not as bright as we may be led to believe, but a focussed evolution of the design process specifically catered to this type of product will help in many ways to offer the public what they want, as this, essentially, is what will ultimately ‘make or break’ a product.

Contents

1. Objectives

The key objective of this thesis is to assimilate a holistic appreciation of micro-wind in order to understand the likely market potential of the burgeoning domestic turbine, and in turn, its technologically-ideal topology. In attempting to achieve this, a structured, iterative approach was utilised based on traditional Product Design process methodologies, as it was identified in the early stages of research that perhaps micro-wind as a whole could benefit from a less sporadic application of tried and tested design philosophies. Similarly, by tailoring an existing design process to micro-wind, from research to manufacture, in the first instance, and following the process, the benefits would be fourfold:

1. Utilise traditional, structured design processes and tools to better understand the vital aspects of the market, consumer, environment and technology in focus;
2. Assess whether a unified prescriptive process could benefit the mass-market oriented turbine-design process and isolate current deficiencies;
3. Highlight physical and cultural processes and technology improvements that might increase the potential for micro-wind to penetrate identified markets;
4. Discern key drivers for micro-wind, opportunities and how to exploit them and if indeed, true opportunities exist.

The rationale behind the study was that in treating micro-wind as a product first and foremost, and through a successful investigation of the above factors, the following results would be arrived at:

1. possible Design Process improvements
2. possible Manufacturing Process improvements
3. possible technology and topology improvements
4. understand political and social drivers and barriers regarding micro-wind
5. understand the market, its scope buoyancy and receptiveness
6. understand how to tailor products to particular markets
7. understand market forces and how to operate within technology-push markets
8. better understand the customer, and their needs
9. better understanding of technology application

10. isolate the most significant factors of turbine performance and suggest how to better reconcile these with the customer need, i.e., isolate essential design trade-offs and balance them against customer needs:

    - performance vs. cost
    - redundancy and fail safe vs. perceived value addition and LCC (Life Cycle Costs)
    - aesthetics vs. yield
    - Return On Investment vs. consumer confidence
    - public perception of micro-wind vs. perception of large wind and renewables as a whole

Some of these objectives can be gleaned though a comprehensive literature review and are more of a collating task than anything; however, the assessment of customer needs, aspirations and perceptions, in line with prescribed Product Design market research methods, necessitate information extraction through focus groups, interviews and/or surveys. As shall be seen, often the output will have both a predictable element based on a population's reaction to media activity for instance, and also a very unpredictable element. For example, it is often stated that a VAWT (Vertical Axis Wind Turbine) will be more aesthetically appealing, but this is patently untrue in some cases.

Finally, with the process running according to plan, it will be possible as a secondary output to suggest a modification or amalgamation of process methodologies to help a turbine developer ensure that their product is as saleable as possible. As both a product and means of addressing ecological issues, success in a market context for micro-wind will be necessary to drive the secondary social benefits of the technology.

2. Introduction

There is a strange, almost intangible, air of gleeful anticipation surrounding microgeneration at present. The Labour Party, the Conservative Party and the Liberal Democrats have all voiced their support and enthusiasm for this new, wonderful idea; indeed some have gone a step further and are even installing their own micro-turbines. Various energy consultancies have similarly had their say, and judging by the overall positivity, the future is theoretically redoubtable for this particular brand of decentralised generation. But what of the individual mechanisms, and constituent micro-parts of the greater movement? Certainly, the DTi's figures of 40% energy generation by 2050 from microgeneration look appealing, but just what does this kind of mass-adoption necessitate in terms of technology, knowledge, opportunities and commercial viability?

This thesis sets out to answer these questions, among others, for micro or domestic wind energy generators, and ultimately, illuminate what might be realistically expected from the technology. In order to achieve these goals, an ambitious approach was embarked upon: to create and test a methodology at the same time – the purpose of which being to realistically assess the commercial prospects of micro-wind, and suggest how this might best be achieved. To facilitate this method, traditional Product Design Process methodologies are sufficiently insightful, and with a little tweaking, should allow for the addition into the balance of mechanical design issues unique to wind turbines. On the same note, this activity should also help the investigation into many important social issues, the result of which will be to put such a controversial technology in context.

Therefore, this thesis will work through a set of steps in an attempt to garner as much information as is possible (and useful to the commercial design process for micro-wind), and set it out in a practical way. Hence, the following information is intended to equate to more than a simple feasibility study – although this is at its heart – but, rather a feasibility study which by its means of its operation will highlight the most important areas of the Product Design process for small wind turbines, and structure the findings in a specifically tailored methodology for any who wish to use it.

3. Initial approach

It was hoped in the early stages that following a traditional design processes might help to generate alternative technologies to better suit an identified market need, but after completing a great deal of research it became apparent that the field was more complicated than initially thought, and also, something of a paradise for budding inventors. Thus, it was difficult to generate concepts that had not been conceived of previously in some capacity, so the approach necessarily had to shift its focus away from technology alone to the process as a whole. Therefore the following work is the result of a significant progression from the original brief.

The approach consists of the following basic steps:

1. Define the problem; that is, what exactly this thesis seeks to address.
2. Suggest and qualify a method of attacking and answering the problem; i.e., Design Process methodologies.
3. Follow the selected process and adapt as necessary.
4. Collate the information and insights that the process highlights.
5. Generate conclusions and suggestions.
6. Appraise approach taken and identify if targets have been met.

The following (figure 3.1) represents both the initial approach taken to tackle the identified problem, and also, an initial estimate of how best to integrate into the process factors highlighted previously. By visualising the investigative path in this way it was hoped that each part could be tackled in a timely, logical fashion, whilst the process path ensures important information is not left out.

In the way illustrated in figure 3.1, below, a basic process methodology has been created by utilising aspects of existing Product Design theory, and combining them. It is hoped that by operating in this way the methodology should facilitate the gathering of the required information, (since it is an established, tried-and-tested processes) whilst also allowing something akin to a self test, as the process will develop as is required in following it. At the end of the process an adapted, finalised approach shall be suggested based on development necessitated during the investigation.

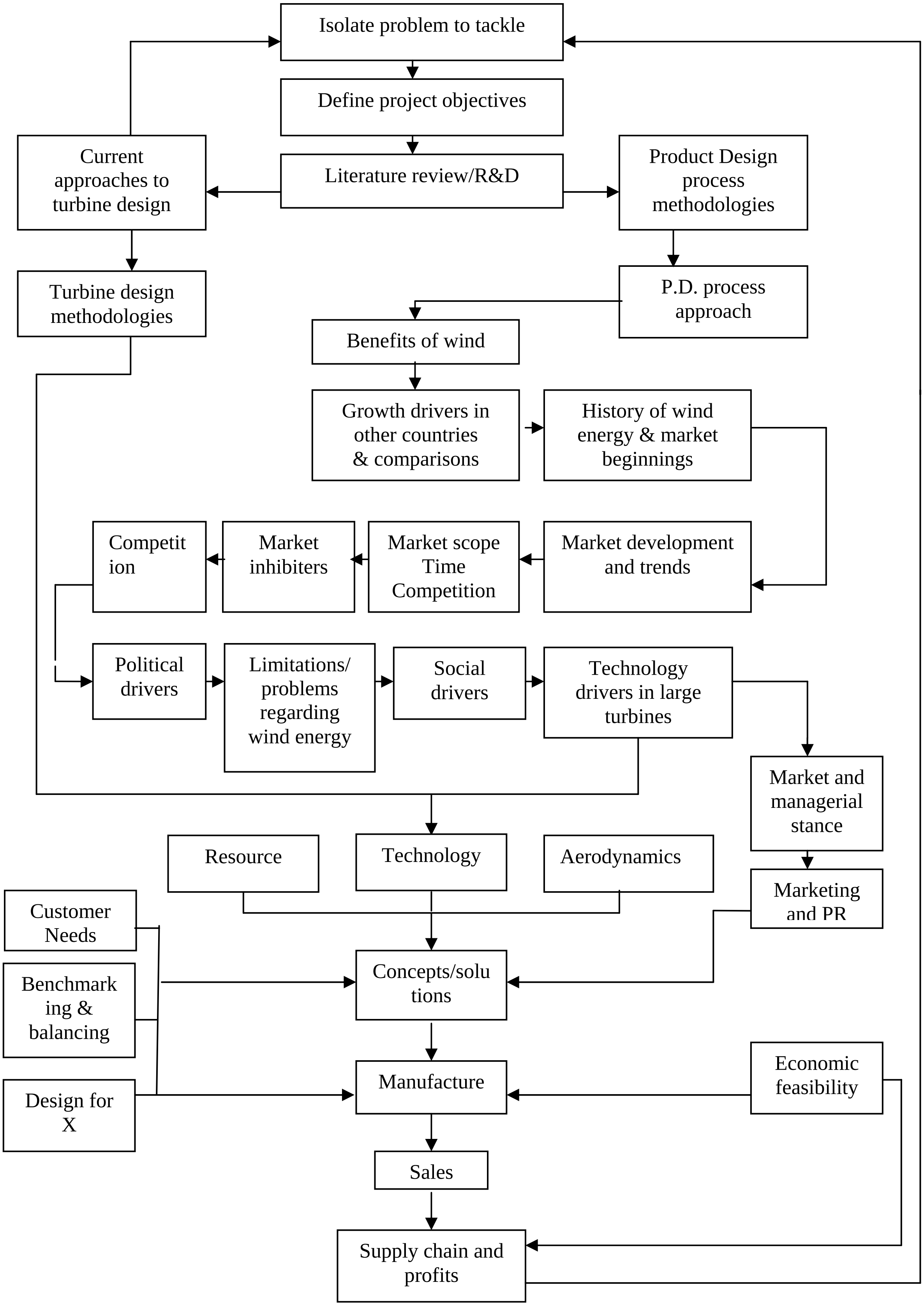

Fig. 3.1 Steps in the research process and initial estimate of distinct areas to combine

4. Product Design

4.1 Introduction

As a discipline, Product Design is well established and firmly routed in industry's history. It evolved into its current form by means of academic input, the experienced and experts in the field, and a great deal of practice. The capitalist vehicle supports and encourages excellence in this field, as those companies who are unable or unwilling to adapt, are continually swallowed up by the markets that once supported them, the result of which is that consumer choice is inversely proportional to the duration of an established market sector, as the successful firms take over or squeeze out others.

Successful Product Design is inherently ruthless as a necessary characteristic of its propagation: evolving because it is lured by profit. There are those who are unaware of its proficiency though, seeing methodologies and processes as 'just common sense'. This is not a view that should be taken with domestic wind, and companies will need to adopt the precepts it offers if they wish to exist beyond the next few years.

The competitive nature of vehicle and white goods manufacture particularly in countries such as Japan has lead to a plethora of prescriptive approaches to manufacturing, the design process, logistics and even overall business philosophies such as Kaizen (Continual Improvement), JIT (Just in Time), Collaborative Forecasting and Planning, Lean, and Agile, not to mention distinctive process improvement approaches such as MRP 1 and 2 (Materials Requirements Planning), and amalgamated logistics theory. On a similar note, design methods ranging from Life Cycle Costing, Failure Mode and Effect Analysis, Value Analysis, Design for Environment to Quality Function Deployment and the House of Quality and Concurrent Engineering (CA) all have a valuable input into the design process.

Such approaches exist because they have worked for organisations, but by the nature of the industry that uses them, the approaches and methods must be used correctly, moulded to the application, and evolved as necessary to gain a competitive advantage.

Companies such as Motorola and Toyota, in the 80's dramatically slashed time to market, lead times and manufacturing costs while increasing quality and customer satisfaction through implementing approaches such as Concurrent Engineering. In CE, distinct teams or cells operating on particular aspects of the Product Design process use interdisciplinary approaches and overlapping information and process transfers to markedly compress the time to market.

It is not only large companies and industries that can benefit from initiating these types of changes; small businesses can do very well by means of a successful process administration too. It is with this in mind that the small wind turbine manufacturers were investigated, in order to highlight opportunities for process improvement, in a number of areas.

There happens to be either a great deal of secrecy surrounding, or a complete lack of tried and tested design process-augmenting practices in the case of small wind turbine manufacture. Therefore, non-company specific design process improvements were sought, as a broad-brush approach to ensure the future potential of small wind turbine companies can be met.

4.2 The Product Design Process

The Product Design Process is the title given to a series of prescriptive steps that facilitate an expedient journey for an artefact, from inception to sales. By structuring and planning an approach to the design and manufacture effort, it is more likely that sufficient prioritisation can be directed at each sum part of the product's development, ensuring that profitability will be as high as possible, whilst allowing the minimisation of costs through good design – it is a discipline, and an art form for those who excel at it. Traditionally, many product designers felt that they could approach this task with a level of intuitiveness that would be sufficient to ensure product success. This is not the case latterly, as the bar has been raised a great deal in the last 50 years in terms of company operations and the design effort, meaning that with today's typically complex products and market competitiveness, the risk involved in a naïve approach to planning is unacceptably high for most businesses.

To this end therefore, several methodologies have been created with the intention of shaping the Product Design process to the aid of those using the approach; those approaches being in basic agreement with each other. It is not uncommon, however, that application-specific methodologies are created, as generic methodologies may not offer enough guidance or support to the design team. An early example of this might be Evans' ship-design 'spiral', which proposed a more focussed method of arriving at a desired result, whilst catering for heuristic or iterative design improvements as a matter of course, particularly for the novice designer. Thus, it is contended, in a similar regard, that the small wind industry could benefit strongly from a technology specific methodology also.

While it is possible to find prescribed steps or even manuals on turbine design, the focus is almost completely on technology and topology optimisation. These typical approaches should be supplemented with a more holistic, market-centred design process approach, to ensure that, vitally, there exists an accessible method for integrating into the process the Voice of the Customer – an ethos in itself in some of the most successful companies in the world.

Possibly the most popular, or at least widely-known, assessment of the Product Design Process (figure 4.21) is that of Stuart Pugh: ‘Total Design’, named as such in view of its ability to cover all required bases in the creation of a product[5].

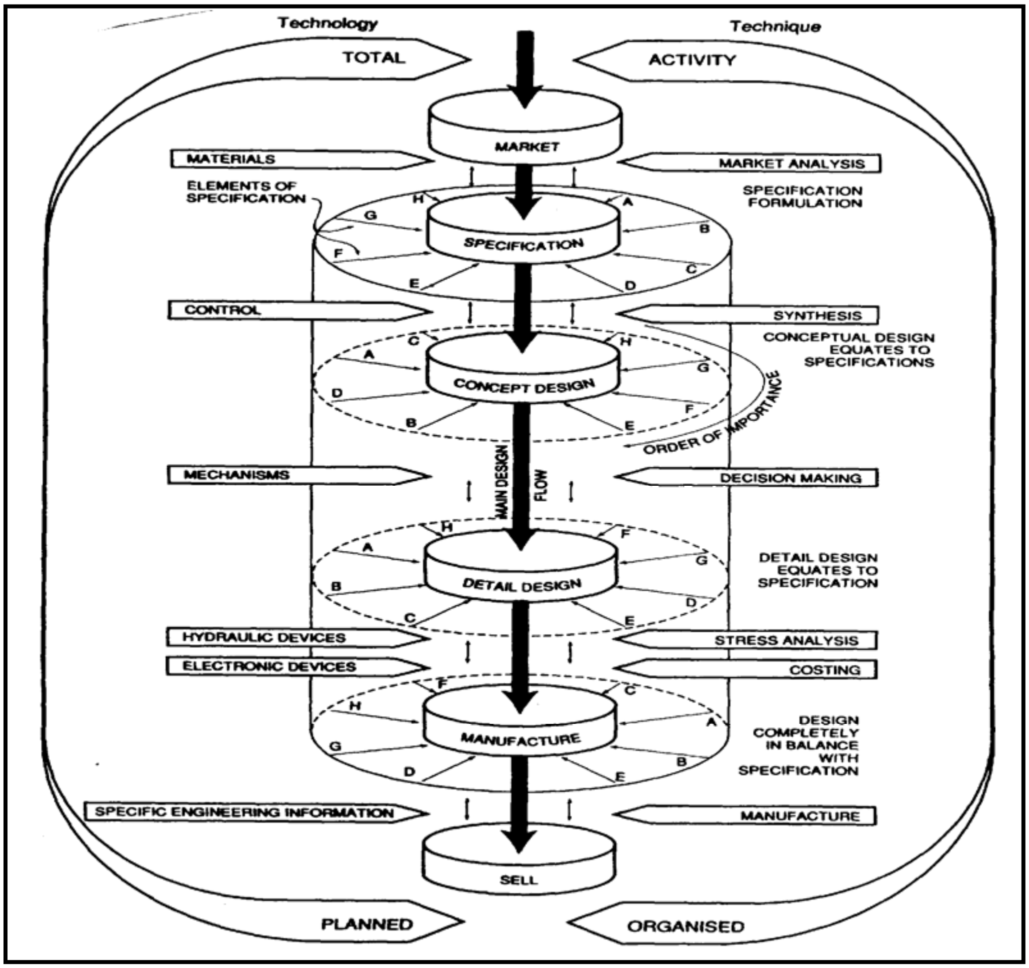

Fig. 4.21 The Product Design Process as found in *Total Design* Pugh (1991)

Pugh’s approach is comprised basically of the following steps:

- Market research
- Product Design Specification creation {Front end of the design process}
- Concept design
- Detail design
- Manufacture
- Sell

Out of context, the graphic is quite difficult to understand, but it operates as follows:

- An encompassing market research activity should be undertaken. It cannot be stressed enough how important this is. It should establish, importantly, likely market worth, penetration, competitors, patents, window of opportunity and give rise to the formation of market and even managerial strategies if undertaken successfully.
- A detailed Product Design process should enable the creation of a detailed document called the Product Design Specification, or PDS, which attempts to apply parameters and constraints on any potential design, such as conformance with applicable standards, politics, shipping, aesthetics, performance, environment, operating temperatures and robustness, etc. The more detail at this stage, the better, although it should be recognised that the PDS is a dynamic document which should be altered and supplemented as and when design and process evolution requires.
- Concept design deals with the creation of initial concepts through, for instance, thought exercises and individual and group activities. At this stage, no idea is discounted, as something that might appear unrealistic can spark an improvement by another member of the design team.
- Detail design comes about after a concept selection process, which is based on performance metrics garnered from the PDS.
- Manufacturing can be undertaken once proof of concept models have been created and tested and fitness for purpose has been established. It may be necessary to completely reconfigure aspects of a product based on economic models. Manufacturing processes themselves, such as tooling, changeovers, subcontracting, materials selection, modularisation of components, or shared product family platforms are some of the considerations that must go into this part of the process.

- If all the previous steps have been undertaken effectively, then it should be possible to sell the product. Necessary marketing strategies, stances, advertising and PR exercises may form part of the 'Sell' part of the process.

The letter sequencing under each stage represents an indication of the hierarchy or importance ascribed to particular aspects of the PDS and hence, design parameters; while the arrows indicate information exchanges, feedback loops and organisational and planning structure improvements and ordering.

Similarly, within each of these distinct parts of the process there also exists a plethora of design tools, Decision Support Tools (DST) and design methods that can further supplement the operation, some of which will be discussed in following sections.

Variations on the Pugh's theme exist, but are not generally as encompassing; for instance, figure 4.22[6]:

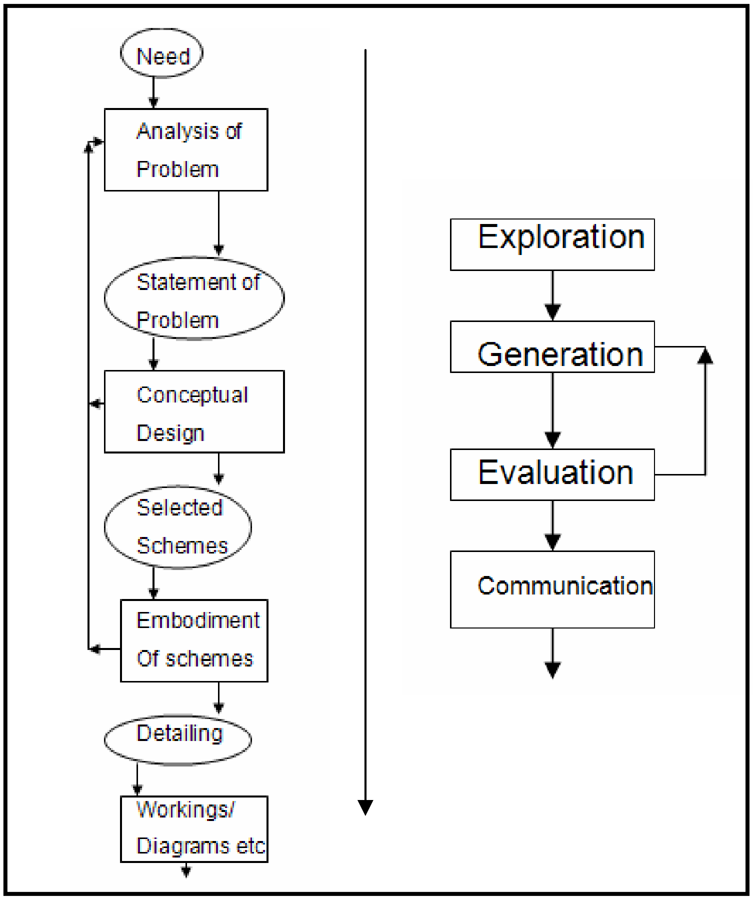

Fig 4.22 French's (left) and Cross' (right) process models

While all have their uses, it is suggested that Pugh's model is the most comprehensive and as such, may offer the most advantageous basis for a unified Turbine and Product Design process.

4.21 Turbine design process

As a product, a wind turbine is fairly complicated, not simply in terms of functionality, but also in terms of the dynamics of deployment, resistance to deployment, and opinions on the efficacy or appropriateness of the technology for certain applications. Designing a turbine is not simply a case of concentrating on best technical formats, but rather tailoring these to an indicated receptiveness of the market bases, in which ever form that may be. According to Manwell (2002), in order for a turbine to be competitive it must:

- produce energy
- survive
- be cost effective.

It can be said, however, that in order to accomplish these goals, a turbine must satisfy several other, initial conditions, rather than using the above as primary factors in deciding turbine operational parameters; for example, to be cost effective, a turbine might not necessarily encompass the very cutting edge of technology, but still be simple enough to be maintainable by a customer, although this will be approached in more detail in later sections.

There have been methodologies (of sorts), proposed to help the potential wind-turbine designer through the decision making process such as that of Manwell (2002), which is notable as it most concisely represents the thinking of many others in the industry. By following the model, it is likely that the most appropriate decisions can be made regarding technological issues, but perhaps not the best decision for the customer. Manwell (2002) also focuses mainly on larger turbines, though the process is generally suitable for small turbines as well. The steps are as follow:

1. determine application
2. review experience
3. select topology
4. preliminary loads estimate
5. develop tentative design

6. predict performance
7. evaluate design
8. estimate costs and cost of energy
9. refine design
10. build prototype
11. test prototype
12. design production machine

The logic of the process above seems solid, but it is implicit in the ‘determine application’ and the accompanying description in the text, that the application is simple, has been promoted and is distinct from any other steps due to it concerning primarily large farms; that is, the application is ‘a medium size farm’; or, the application is for ‘a remote rural community’. Thus, the inference is that an opportunity has been identified in some other distinct investigative work, or by an entrepreneur of some kind. Where small wind differs, is that there is *no* distinct opportunity, or at least it is not easily identified and satisfied due to the idiosyncratic nature of the individual consumer demographics that will eventually form the target market.

It is posited that a solution may be found with a combination of aspects of both Manwell’s and Pugh’s’ methodologies, in addition to the integration of pertinent design methods for the application, and a mechanism for translating the consumers voice into performance metrics via this unified approach.

4.22 Design methods and Design for X

Design Methods are first and foremost techniques or tools which may supplement the overall design effort and may take the form of guidelines, programmes, matrices or comparisons. Design for X is a term given to any generic product aspect. Of the many important Design methods, perhaps the most directly influential on production costs will be the implementation of Design for Manufacture and Assembly principles:

> *“Materials and processes to be used are dictated by the design. Therefore subsequent improvements in, for example, manufacturing efficiency, serve only to reduce the costs that have already been created by the original design”* Mair (n.d.)

A good design will also ensure that the manufacturing processes that are required, as well as the product itself can have a minimal impact on the environment. Such factors should be inextricable for the production for an intrinsically ‘green’ product such as a wind turbine.

The design and manufacturing stages of a product should be viewed as a concurrent activity as much as possible – the design considerations being tailored to manufacture using the following guidelines:

- Assess likely volume of product, and choose appropriate tooling. For instance, high volume products would benefit from casting rather than machining for internal components. Though the initial cost is higher, net savings can be passed onto the customer.
- Minimise the amount of individual parts. Some designs and topologies will naturally better comply with this condition, such as natural stall regulation rather than an active, mechatronic approach.
- Attempt to make components as similar as possible, in terms of shape, material or manufacturing processes.
- Utilise redundancy only when absolutely necessary.
- Designs should facilitate ease of assembly; i.e., clip-together parts, vertical stacking or conical recesses for screws to aid location.
- Determine permissible tolerances, and stipulate which components may have wide tolerances yet retain functionality.
- Standardisation and modularisation are extremely important in cost reduction, especially with long term business plans, as will be discussed.

Figure 4.31 below describes the typical life cycle of a product. Note that any particular product will eventually meet ‘decline’ as the market saturates or other products win over consumers. Thus for continual buoyancy, a company must strive to have products enter the market such that they will reach maturity as close as is possible to the point before the primary product begins to decline. These secondary products can be seen every day on television, and display a certain level of iterative-innovation; that is, a claimed product improvement, but one which is geared to entice and excite the consumer whilst allowing the luxury of further, easy product improvement.

An example might be nappies, which on consideration have been ‘dry’ for many years, yet get increasingly drier every few months.

To ensure that long-term product innovation can be assured, many companies offer a pseudo-bespoke range of products which usually take the form of a family of slightly different specification products based around a single platform. The benefits of this type of modularisation are threefold:

1. manufacturing processes can be used for different products which are already accessible
2. economy of volume is increased as shared parts are used across a whole range
3. the speed with which a company can seemingly adapt to the life cycle decline of existing products, or competitor action, is dramatically improved.

Similarly, standardisation and the ability to purchase many components ‘of the shelf’ can dramatically reduce costs and should be utilised as much as is possible.

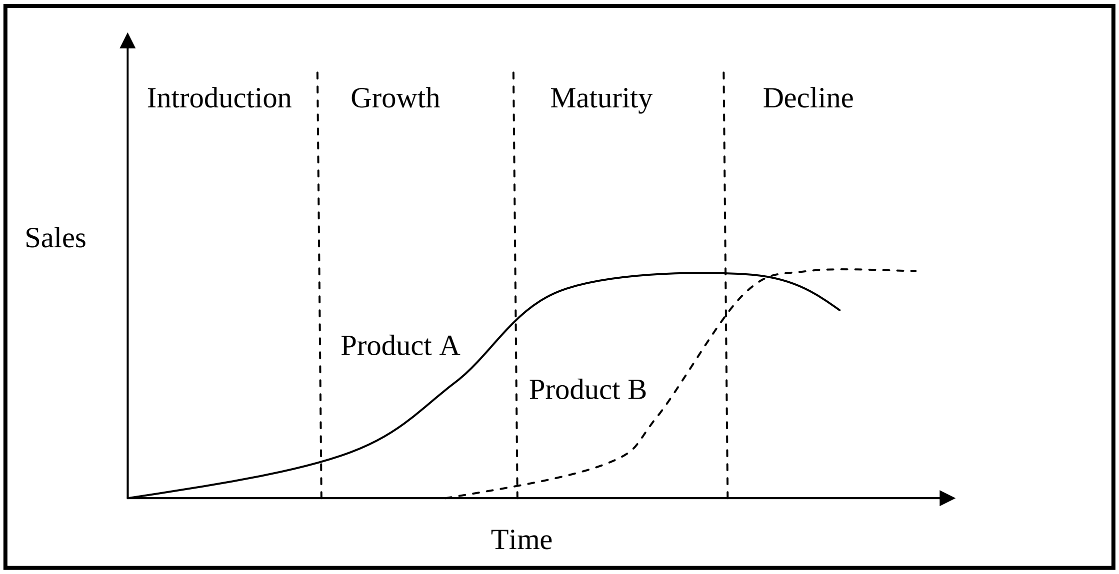

Figure 4.31 The Product Life Cycle

While the general principles are fairly intuitive, specialised knowledge in the form of best practice Design for X approaches will not necessarily be at the disposal of a small wind turbine company. Process selection and design for casting, part reduction, welding, machining, sheet metal, fastening, adhesives and moulding are several examples of recognised design for manufacture methods. Other processes which broadly fall under the same bracket are Value Analysis, Ergonomics, Human Factors and Failure Mode and Effect Analysis. All may positively contribute to the quality of a Product, and much scope exists for their integration into turbine design based on many of those presently available.

Since books have been written on many of these subjects, further explanation is not viable given the main focus of the report; suffice to say however, understanding how each design method fits into the design process and the benefits they may have for turbine design will be of great value.

4.3 The problem

Type " 'wind turbine design' " into a well-known search engine and 532 results will be returned from the UK – indicative of the vast academic and industrial endeavour in the field. Due to the heterogeneous nature of mechanical-design input, there tends to be a focus on the (often arcane) technical issues associated with wind energy, which will become apparent after quickly exploring these results. There are books, pamphlets, courses and websites available, which can all represent invaluable input for a budding turbine designer, whilst the best of them will also delve into economics and disadvantages, and suggest standard methods of limiting impact and making profit. One can expect to find dedicated tools for blade design; models for resource estimation and power outputs; CFD for turbulence and flow visualisation; multiple streamtube models for new types of turbine; FEA for structural integrity; even terrain models and a myriad of mathematical equations. Look hard and one can even find projections for overall contributions from wind energy to the overall future mix, as well as planning advice and support.

Conspicuous by its absence, however, is a model for *listening to the customer*. It is the author's opinion that wind energy is widely regarded by industry to be a fix-all technology; ergo, an instant sales success owing to the nature of the perceived undertaking: 'saving the planet'. Wind turbines (including micro-wind turbines) are first and foremost products, and they must be treated as such to ensure that any positive social and environmental impact is assured. If manufacturers cannot make money from a venture, they must look else where for viable markets. This would be a great shame for micro-wind, as it constitutes an excellent opportunity to tailor itself to impending energy market opportunities, whilst sequentially, and by default, doing its bit for the environment.

There tends, perhaps, to be an over-emphasis on technology generation itself, or advances therein, but even the most amazing technology can falter if consumers are not prepared to buy it, such as the Sinclair C5 for example, justifying extra attention to market research.

4.4 Meeting the customer's needs

Whilst following a design process methodology will aid the design team, it is of the utmost importance that any designs embodied have the customer's needs in mind:

> *"If a manufacturing company is to survive, it is essential that it produces well designed products. Should a company's products not be designed to meet* ***the needs of the customer****, then competitor's products will be purchased and the company will fail"* Mair (n.d.)

> *"The economic success of manufacturing firms depends on their ability to identify* ***the needs of the customer*** *and to quickly create products that meet those needs and can be produced at low cost. Achieving these goals is not solely a marketing problem, nor is it solely a design problem; it is a product development problem involving all of these functions."*

And:

> *"..successful product development results in products that can be sold profitably".* Ulrich (2003)

What are the customer's needs though and how are they identified? There are a number of methods of gathering information from consumers, which are described by Ulrich (2001) as follows:

1. The first step is to attempt to gather raw data from the customers using various techniques such as feedback forms from existing products if they exist.
2. The data must then be interpreted and related to customer needs, possibly through the use of surveys, etc.
3. Any established needs should then be organised to form a hierarchy.
4. Establish the relative importance of these needs.
5. Reflect on the results and the process.

Additionally, interviews, polls, immersive research and focus groups can be used to great effect to identify both explicit and latent needs, the latter being those secondary needs that increase the perceived value of a product, but are not necessarily functions which are ostensibly desirable. The output of this research will likely be a large amount of data, which should in turn provide the justification for Product Design decisions, and it is often seen that latent needs can have a huge impact on the all-important customer satisfaction. It is desirable to attempt to translate customer needs into product performance metrics: for example, if customers define as a need, that a wind turbine should be quiet, then a performance metric that satisfies this desire might be: "operate at 35 dBA", although some needs will be much harder to translate into tangible parameters, especially if they are of little intrinsic technical value Ulrich (2001). The real difficulty, however, lies in trying to balance customer needs against initial design constraints, competitors products, economics and product performance itself, although techniques such as QFD can help organise the data, if used correctly (figure 4.41).

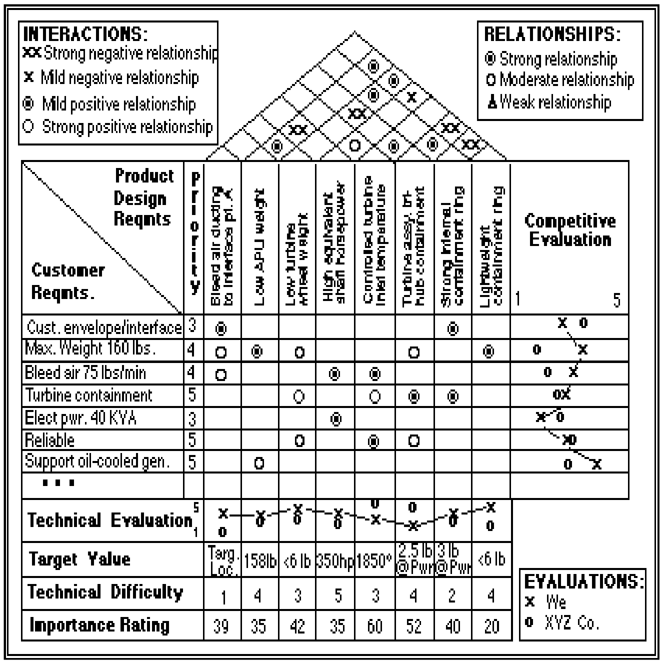

Fig 4.41 An example of a QFD matrix Crow (2002).

It is not enough, however, if the company wants to be as competitive as possible, to design a product based around the customer needs and pay no attention to corporate orientation and strategies.

4.41 Structuring the Design Process.

Steps in the Product Design process can be conceptual or organizational rather than physical. It is pertinent to ensure that even organizational structure is tailored to the design effort, as this in turn dictates the marketing and product orientation, for instance. Cultural change must often accompany design method/ethos implementation in an organisation. Further instances of possible design process option follow:

Product Orientation: Domestic wind turbines can be categorised more as a 'technology-push', rather than many familiar, high volume 'market-pull', consumer products, although they do exhibit qualities of both to an extent. They are therefore quite a high-risk proposition. As such, technology-push products rely on finding or carving out a particular market opportunity to be profitable, rather than responding to an obvious market need. Consumers do not necessarily 'need' to generate some of their own electricity, although some would like to. A particular risk in this case is the fact that there are a number of alternative, proven technologies available that can possibly fulfil any existing consumer desires to this end, such as Combined Heat and Power, micro-hydro, Solar Water Heating or Ground Source Heat Pumps, so if micro-wind does not offer clear advantages, it may not drive long-term uptake. Is there any evidence that it can? Or what must the technology offer to ensure that it can be construed as advantageous? These are very important questions, and fundamental to the decision to pursue such a product. Fortunately, a comprehensive market study based on the Product Design process previously mentioned should yield the answer.

Unifying the process: According to Ulrich (2001), the Product Design process may need "minor modifications" to best serve their unique needs; thus, customer needs must be integrated into the turbine design and manufacture process to successfully shape product topology.

Competitive strategy: Companies may subscribe to either of the following basic competitive strategies in order to gain a market advantage or differentiate themselves from competitors as the situation and timing dictates:

- Technology-Based drive – Market leading through the creation of superior technology to competitors
- Cost Advantage – Emphasis on competitiveness based on low price products, potentially as a result of excellent production efficiency, low lead times or similar.

- Customer Focussed – Perhaps not the cheapest products, but those which are superiorly placed to satisfy the customer; aided by company agility.
- Rival Mimicking – Risk is minimized through basically mimicking competitors until a lucrative opportunity arises, although returns may not be as high as with other strategic approaches.

After selection of a suitable strategy, a company may then decide on pricing strategies such as ‘skimming’ off the early adopters even at high prices, or rapid penetration, low-price, high-volume selling.

Constraints: Ulrich (2002) also advocates that any design constraints should be worked into the design process and decided upon at the earliest possible stage, perhaps even as part of the mission statement or brief; for example, Design for Environment and recyclability will constrain the concept generation process fairly widely, and may form a key part of the company ethos in itself.

4.5 Process Integration

It should be possible to discern simple, basic customer needs through market research, which can then be used to set out domestic turbine-specific design constraints and tools to reduce overall process ambiguity. A key part of such a unified approach will comprise integration of tailored benchmarking techniques for product function against competitors and overall market opportunities. A large part of this approach should be dedicated to the adaptation of existing methods to turbine-specific problems, such as Function-Means concept exploration and Control Convergence Matrices. This should be conducive to establishing over all viability, and essentially, the aspects of micro-turbines that must be improved to allow profitability.

4.6 Conclusion

From this perspective, the inherent complexity of the Product Design process demands a structured approach, this being especially true for technology-push type products. From this study, current approaches do not offer the level of support required to ensure excellent competitiveness is achieved in all cases.

At this stage it is clear how difficult and convoluted it can be to successfully sell a product, and there are a great many pitfalls that exist. The demands of the market on turbine manufacturers may present a significant hurdle for many of the less proficient operators.

5. Wind turbine and market overview

Based on currently available literature, interest in domestic renewable energy applications as a means of meeting a significant portion of the UK's energy requirements is steadily growing, in particular the potential for small-scale wind. Small-scale wind-energy conversion devices also afford an interesting opportunity to provide electricity for off-grid residences, as competition and expertise drives down costs and in turn, pushes turbine performance slowly upwards. An interesting difference between small (generally, sub-100kW) and large-scale wind turbines lies in the necessary design complexity each must exhibit to fulfil its function, dependant on environmental, physical and operational parameters. As generator efficiency increases in relation to up-sizing, notwithstanding economic advantages of scale, the design of large-scale wind turbines can accommodate, for example, active control systems; indeed, safety constraints often necessitate such a provision. This factor is less relevant in small-scale turbines, which can be less dangerous or expensive to fix, by virtue of their limited mass and the structural forces they must withstand. This, however, is by no means something that can be neglected due to the close proximity to people they will have.

As a product primarily designed to fulfil a need, wind turbines present a fascinating, and multi-faceted, area for investigation from a design point of view. For the sake of clarity, large-scale turbines are those of several hundred kW, commonly deployed in farm-type arrangements; small-scale turbines will refer to turbines that augment domestic or industrial energy requirements, and normally differ form their larger counterparts in terms of secondary functionality. Generally, the mode of operation is very similar between the two distinct groups, converting a portion of the kinetic energy bounded by their swept areas into electrical energy. The key differences lie in how each different technology group deals with the following:

- gearing and generator configuration
- positioning its rotational axis into the direction of the oncoming wind (if applicable)
- altering blade pitch to attain the optimum tip-speed ratio/starting torque etc
- shedding load to deal with gusts outwith the design capacity
- shutting down or stopping for maintenance

Much of this investigation is focussed on technology, and to be specific, the non-electrical engineering oriented points, as basic Product Design, and technology orientation constitute the most pressing factors in meeting customer needs.

A particular aspect of turbine operation that can have a huge bearing on product operation, and hence deign trade-offs, is that of control. There seems to be several different commercial methods of achieving over-speed and blade control that warrant distinct attention.

> *"Improved control strategies are responsible for an important part of the increase in wind turbine productivity in recent years"* Soren (2003)

Similarly, there exists scope for further inventive approaches in control systems as interest grows in different configurations of wind, and even marine current, turbines, further highlighting its importance. As intimated, a distinct part of this investigation is dedicated to turbine control, chiefly because if a turbine cannot be effectively controlled, it is in effect, useless[11]. On the same note, because of the effectiveness good control measures can have on the performance of turbines in both operation, and as a product, control system investigation should prove an interesting and valuable opportunity to increase and enhance knowledge and understanding.

Often it is seen that leaders, or favoured designs, emerge after market-driven technologies mature, restricting diversity once a certain technology reaches a profitable level of acceptance and proficiency. However, there still seems to be some kind of tacit mass-acceptance of vertical axis wind turbines (VAWTs) despite their previously publicised shortcomings, so perhaps, the merits of this technology for domestic applications, on examination might be worth while, alongside its fitness for niche applications, as nascent VAWTs come to the fore.

6. Why renewables?

This may seem like an easy question to answer – the media report on global warming frequently – but how singular is this message to sustaining growth in renewables? On reflection, from a Product Design and political vantage point, this simple question takes on much more depth. Renewable energy technologies are still products, and it is often seen how an artificial market need can be created by a company: no-one knew that they wanted an i-Pod^{tm} until it became available, desirable, even. Similarly, if car manufacturers wanted their vehicles to last the lifetime of the customer, it has been suggested that they could easily do it. Indeed, 'designed-in' obsolescence can open-up to vehicle manufacturers a secondary, created, spares and servicing sector; otherwise, they would find it difficult to sustain market penetration with new products since the market would tend towards saturation fairly quickly.

Marketing and advertising moguls sell their precept of glamour and exclusivity on a daily basis, justifying a premium for many consumable items, so could it be that renewable energy is contrived to appeal to a niche market demographic; one who believes it is 'trendy' to be socially aware and responsible?

These are some of the questions that will be explored in later sections of the literature review, specifically with a view to understanding the buoyancy of the renewable technology market, what we may expect of it in the coming years, and specifically, the place for small-scale wind in the mix.

6.1 Advocating renewables

Traditionally, many arguments for the purpose of advocating renewable energy tend to focus on a cause-and-effect-type logic:

- Fossil fuels cause x to occur.
- X is bad.
- Renewable energy alleviates x.
- Renewables are good because x is bad.

The key clauses in this argument can be tacit, moulded or formed through disinformation or misunderstanding proclaimed facts, but generally, the logic is sound and it is accessible. (Conversely, however, the argument can also generally be reversed in objection to renewable technology.) A problem in using this type of reasoning occurs when the subjectivity of certain factors in the argument come into question, (partly touched on earlier, in the discussion of artificial market needs), tending itself to cause uncertainty and disagreement, thus disrupting potential renewable technology deployment. At national, and particularly local, governmental level in Scotland, the 'x' in the argument is climate change, as it is a for a number of other European countries,[12] and the Scottish Executive justifies its energy policy by means of it:

> *"..climate change is the single most important long-term threat facing our planet and* [the Scottish Executive] *is committed to contributing to international efforts aimed at curbing harmful emissions of greenhouse gasses."* Scottish Executive (2005)

While there may be some academic disagreement regarding the validity of this premise, the disagreement becomes itself academic if the assertion eventually motivates policy change, as it has in Scotland. The constituents must then entertain the consequential outcome, even if they disagree in principle; for example, the Scottish Executive's legislation on ROCs (Renewable Obligation Certificates) is binding until 2027, with year-on-year increases of the mandatory renewable energy share of the market; e.g., 10% in 2010 and 15% per supplier by 2015. In this way the market for renewable energy, and therefore the market 'need', (while arguably artificially created), is driven by a binding energy policy, which due to its nature, is self-sustaining and incremental[14].

It should be noted that, to avoid market stagnation, some dedicated renewable energy generators will hold onto more than their obligatory minimum amount of ROCs, forcing in turn larger companies, dependant on traditional thermal generation, to deploy renewables, rather than simply buying certificates from others. Legislation that has similar effects is that of the Carbon Levy, which allows tax breaks in proportion to renewable energy generation. In some instances certificate trading is more lucrative than energy sales, fetching up to £47 per MW in ROCs. From a small-scale wind standpoint, this system can have benefits for any domestic consumers owning accredited generation devices (providing their homes first meet the standards of energy efficiency required) as they can sell surplus electricity back to the grid and in certain cases, become eligible for ROC and the Carbon Levy benefits[15].

By means of the political climate, therefore, the question "why renewables?" becomes partly redundant as the answer is: "because one must", or importantly, "because it is economically viable". With a political system in place that drives the market and creates a product need, further technological advancement will occur. Funding for experimental projects can then be made available, planning and application procedures are streamlined, incentives for generation are mandated, and critically, investor confidence in private sectors is increased. In turn, the most mature technology can then be used as a pull-through device for emerging technologies such as marine current and wave power, as necessary infrastructure improvements are made to facilitate the growth in decentralised generation[16]. Because of the tendency for the energy generating industry to favour the most competitive technologies, it has been seen that most investment is geared towards large-scale wind ventures, undermining the hope that wind will in fact constitute a pull-through technology. To alleviate this situation the government is now attaching clauses to ROCs that drive diversity in the market through 'banding' – by dividing the ROC into segments, and stipulating the economic advantage associated with each different technology band, proprietors of ROCs are required to diversify into other renewable areas to gain the greatest return on initial outlay.

Energy policy, as can be seen, is a crucial determining factor in sustaining the product need, and at the moment, wind power is in an excellent position to fill it. The question remains however, of how micro-generation will fare alongside large-scale ventures; a closer look at the receptiveness of social groups and the market should yield some useful insights.

6.2 Wider social impacts

On a less subjective scale, there are very plausible reasons for decreasing developed countries' dependence on fossil or non-renewable fuels. The climate change debate is on-going, despite the Government's position (pro its existence[17]), though it does seem as if the case for climate change is gaining weight. Anthropogenic activities account for 5% of the carbon cycle at present[18], and it can be said presently, with certainty, only that this *may* cause changes in the climate; or that it is likely to increase as developing nations ramp-up their energy use unless net carbon emissions are checked; or that it presents a significant-enough risk to call for immediate action. It is broadly recognised that concerning anthropogenic carbon cycle alterations, along with the issue of over-consumption of natural resources, there are consequently two possible courses of action for a society:

1. voluntarily redistribute resources and wealth, as a result, potentially reducing qualitative standards of social behaviour/existence in ‘wealthier’ regions;
2. push for growth until a natural tipping point is reached, forcing change and adaptation; or, expect further detrimental constraints on growth as are naturally applied.

In a climate focussing increasingly on social responsibility, fair trade and trade justice, the second of these options becomes quite difficult to justify, despite capitalist regimes:

> *“As a result of* [modern] *development the different status between the most developed and the least developed regions, with respect to energy use as well as general access to innovations, seems to have continued to widen, and particularly during the recent centuries of industrialisation.”* Sorensen (2000)

Based on the limits to growth theorem, it becomes quite difficult to reconcile profligacy of energy use in the pursuit of wealth, with social responsibility, and the call for equality; all of which have led to a significant paradigm-shift in consumer behaviour over recent years. Perhaps it is not always entered into for the ‘right’ reasons, but while this trend continues, the market for renewable and sustainable energy practices should be promulgated. The argument, therefore, for a drive towards renewable energy based on developed countries using more than their fair share of the natural resources, and the detrimental affect on living standards that impending shortages will have, is both pervasive and difficult to counter. This is due in part to ethical companies promoting their own markets; thus, generally increasing awareness of the cause, unless met with apathy. As an example, Christian Aid is focussing much of its campaigning (at the time of writing) on the inextricable relationship between climate change, or environmental irresponsibility and poverty, with other charities sure to follow suit. AEA Technology’s Future Energy Solutions (formally ETSU), a chief renewable energy consultation body, also recognises this link, as stated in their project literature.

Britain is currently consuming over 300% of its own fair share of the earth's natural resources[1]; clearly a practice that is unsustainable by nature, and which can only lead to a reduction in social advantages brought about by this level of consumption, or a radical change in the generation portfolio of the region. Indeed, Sorensen (2000) gives a very compelling argument for adopting renewable energy based on a longer-term view, which he in turn cites as being at odds with traditional "short-sighted" economic theory. (It has been suggested that economic stability is strongly linked with energy use, but a fuller discussion is outwith the bounds of this investigation.) He describes a graph of energy use against mankind's time on earth, the x-axis divided into increments of 10^6 years. At time zero (the present), there is a vertical line representing energy use in industrialisation, and how, including fissile material, our time-scale dependence on non-renewable energy forms could not extend beyond the width of the line:

> *"It is suggested that from a long-term point of view, man must base his energy use on either renewable energy sources or nuclear fusion or a combination of both of these, if mankind is not to suffer a dramatic reduction in population size"*
> Sorensen (2000)

Currently, there is (despite the recommendations in the 2005 energy white paper) a likelihood that the UK Government will expand its nuclear energy programme, according to the Prime Minister, and many people see it as a viable alternative to obtrusive renewable energy conversion devices. The fact is, however, from a long-term view point, the estimated potentially available energy yield from fissile material is approximately only equal to all the remaining fossil fuel's yield, at 10^22 J[18]. There is also a general reluctance in society to adopt the technology on a wide scale due to perceived risks, which may include, but are not limited to, contamination, waste storage difficulties and wide-spread problems from leaks (such as atmospheric disturbance / destruction of stratospheric ozone shield and water table contamination Sorensen (2000).

While nuclear energy may be feasible for contribution to the energy mix, it is hard to conceive of it negating or suppressing the renewables market to any significant degree; perhaps it is more likely to replace fossil-derived fuels than renewables, due to the other market forces previously discussed. It remains to be seen how nuclear energy will fare in the immediate future, but its threat to (large-scale) wind power one might venture, is minimal at present, whereas the political

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[1] BBC news website

and social climate is geared towards creating opportunities for renewables, and in particular at present, microgeneration.

7. The counter argument

Due to perceived subjectivity in the argument for renewable energy, there tends to be both credible and incredible grounds for objection to technology deployment in the minds of those averse to its potential impact. More specifically, this can be seen with wind farms, due in part to the scale and rate of growth of this market and the media coverage it warrants, and also its visibility. Consequently, the proliferation of renewable technology can be hampered, despite an advantageous political climate, by secondary factors in the market place, ranging from unsuitable infrastructure to negative public perception or unwillingness to allow wide-scale adoption.

Due to the ostensible nature of wind energy conversion, it can, in some instances, be quite an unpopular method of generating electricity. In the Western Isles, it is claimed that there have been 5,000 letters of complaint lodged to the Scottish Executive against Amec's application for a 700MW farm[20] (though the most vocal opposition do not always represent the majority they claim). There are several grounds on which wind turbines can be opposed, though as mentioned, perceived subjectivity plays a vital role in some of these areas. Interestingly, small-scale wind or micro-generation may present something of a solution to many of the commonly cited points of contention; however, thus far there has been some difficulty in gaining planning consent for micro-wind turbines from local authorities in typically conservative areas.

Aesthetics (or loss of 'visual amenity') is perhaps one of the most significant factors leading to wind-farm objections[21], and is one which is hard to mitigate in some circumstances. It is the author's opinion, based on the level of current public debate in Lewis, that this is actually the cornerstone for much of the opposition, though is often camouflaged by objection on grounds that, by nature, will seem less selfish; for example, there was a recent appeal for a hedgehog cull to protect bird eggs, to which there was strong opposition, yet avian mortality risks are often cited as a chief reason not to build the proposed wind farm. Such examples often undermine serious academic opposition in the minds of those in a position to hinder applications, due to ambiguity in the case against. The ruling authorities also believe, thanks to polling, that the level of concern falls away rapidly after a wind farm has been built, intimating unconfirmed trepidation in the minds of many people averse to the proposals[22]. In much the same way as it matters little whether or not climate change is actually occurring, due to a political position, a community opposing a change administered by a ruling body, even if the community is fundamentally wrong, will still feel that their elected governors are failing them, or are simply not listening – a feeling that can dramatically alter the composition of a council or party come election time. The onus, therefore, is very much on education and informed public debate, before contention causes a group at odds with a large scale change to dig their heels in and stop listening. It makes sense to do things in the right order, rather than hammering legislation through, consequently exacerbating the situation.

What are the main points of opposition particularly to wind generation technology, both large and small-scale, and are they really founded on solid empirical evidence? If it can be proved otherwise, then the potential for a key market to reject technology based on a spurious position will diminish as demographics evolve: successive generations will be immersed in (often) sensationalist media rhetoric geared towards extolling the virtues of the technology and responsibility we have for combating climate change.

Some chief environmental impacts include the following[23]:

- noise
- land use
- perceived negative impact on tourism
- avian impacts
- damage to ecosystems during construction
- electromagnetic interference
- flicker or frequent shadowing effects

Some of these points are negated in their entirety by micro-generation, or indeed by careful planning and application of the technology, but each warrants separate analysis, which will follow. By understanding the receptiveness of key markets, and the barriers to implementation (or sales, in this case), it should be possible to also gear a marketing and PR strategy accordingly, ensuring the best possible chance of market penetration. It should be remembered that as a product rather than just technology (that may or may not do any ‘good’), micro-wind turbines can be fashionable, desirable and ultimately saleable, if the market can be conditioned appropriately. One major barrier that cannot be allayed, however, is that of a culture of relative profligacy and decadence which often is seen to accompany high social standing. Perhaps this will be alleviated through disincentives (taxation of some kind) and social pressures; it is hard to say with certainty, but the burden of responsibility for responsible energy use may fall firmly with the consumers, based on inferences drawn from the energy white paper.

7.1 Commonly cited objections

As previously stated, a lack of clarity, understanding or ambiguity can lead to heated debate, where one person might, on a completely rational scale, be completely incorrect in their assertions, but steadfast nonetheless. By trying to understand where this subjectivity causes problems, a clearer and deeper understanding of potential market forces will be gleaned, and help essentially, in creating a relevant and encompassing PDS. Some of the most pertinent points are discussed in the following sections.

7.11 Money

Monetary factors have different implications depending on the scale of generation. In large-scale farm arrangements, people in the vicinity can often feel as if they are being exploited, or at least disregarded, by archetypical, faceless, ‘big businesses’ who reap the reward of inconveniencing the people who must live with the infrastructure. A recent opinion column in the Telegraph also related the reliance on wind to higher taxes, a decreased standard of living and alluded strongly towards economic collapse. Rightly or wrongly, again, this falls in line with traditional short term economic theory, indicating that people can have a predilection for suiting themselves. Logically, any such view should be undermined very easily by highlighting the likely future state of the energy supply network if it descends into lack of security and abundance, not to mention the potential effects of climate change, but this is not always the case[24].

> *“What is so absurd is that, no matter how many wind turbines we build, global dependence on fossil fuels will scarcely be diminished at all. Indeed, if we are not careful, we ourselves could end up relying even more on precisely the sources of power the Government claims it is against.”* Ferguson (2006)

This type of attitude is hard to fathom regarding concerns of diminishing fossil *and* radioactive fuels, and the general acceptance of the fact that limiting a service or commodity tends to inflate its price, in any case. Without an alternative means of generating electricity in place at that juncture, the economic burden for any constituents will surely be a good deal heavier.

Nonetheless, it is a justifiable concern in the eyes of some, and cannot be taken lightly, though perhaps this ideology presents an open door to micro-wind – if the price is right.

At present, domestic wind energy generators are widely regarded as being too prohibitively expensive to drive wide-scale adoption, bar certain exceptions such as remote powering of plant, powering off-grid residences, or for certain individuals who extol their benefits sufficiently. This presents something of a problem as many of the small scale wind turbine manufacturers are relying on economies of volume to drive down prices for the next generation of potential buyers. Conversely, many established electronics companies, for example, are exponents of quite transparent marketing strategies, whereby a product that they can produce at a certain price is marked-up (skimming) to generate maximum profit from early adopters who are keen to be the first to own something new. Due to the complicated social and political system that turbine manufacturers must operate in, a maximum penetration, low-price, high-volume approach would be a more suitable option. However, as they are constrained by manufacturing costs and other barriers to mass-adoption, they promote the appearance of the first approach whilst gaining little from the market-retarded transition to the second. This is the nature of attempting to sell a difficult, high-value product that people may not be entirely ready to purchase.

What value has this insight? As up to 80% of the total cost of producing a particular consumer artefact is committed in the design process (perhaps only 20% of the total time to market), if a company is to gain a significant market advantage they must be able to create the cheapest, functional and reliable turbine, and by a fair margin over their nearest rivals. This is a relatively simple case of utilising the design process efficiently and intelligently, including prescribed Design for Manufacture and Assembly, Reliability, Environment and Life Cycle Costing techniques; it seems, however, that this is not always the approach taken. One simple factor alone could be enough to give buoyancy to a particular product, and that is the potential Return On Investment.

By viewing renewable energy devices as a product rather than simply a panacea to impending energy problems, companies should succeed in their goals of making a profit and helping the environment. The two must go hand in hand, and can go a way to combating the resistance from the marketplace, whilst also decreasing our reliance on fossil fuels.

7.12 Intermittency

Intuitively, it is quite difficult to reconcile the chief operating characteristics of wind power to the requirements of demand matching in the UK's current energy generation strategy – one which is likely to ensure that at any given time, the probability of any customer receiving high quality electricity is 0.9999[26], facilitated greatly by our nuclear-powered base load. This is especially true when considering that the average capacity factor for a site with a good wind resource is in the order of 0.3; that is, one could expect a wind farm to generate at full capacity for almost a third of a year. A commonly stated objection is that, as a result, wind is wasteful and "so inefficient"[25], despite the fact that the efficiency of thermal electricity generation rarely exceeds 38%[27]. The diffuse and stochastic nature of the wind resource can, however, be something of a problem, as energy storage on such a large scale is prohibitively difficult, except perhaps in the case of pumped storage. Electricity derived from wind farms, therefore, cannot feasibly be expected to meet base-load requirements with a comparative reliability, but rather, they can be utilised more effectively for meeting fluctuating demands *above* the base-load. The UK generation strategy currently employs only a one hour "gate closure" system, at which time-scale the forecasting for individual windfarms is highly accurate; thus, bringing on-stream windfarm output is no more of a challenge than preparing conventional systems for operation – insofar as the wind resource is actually available[28].

A key point to consider, however, is that given the land mass required to generate a substantial portion of the UK's energy requirements from wind, redundancy dictates that there must be many more wind farms available to 'take up the slack', as it were; assuming again that the wind resource is available. It seems that it would be sensible to utilise large-scale wind as a constituent part of the energy mix in its current guise, rather than as a leading contributor.

Given, therefore, the concerns over stability and security of an electricity supply based predominantly on large-scale wind farms, there exists an excellent opportunity for small-scale wind generators to step into the fray, as many of the concerns are negated by small-turbines.

It has been suggested that by putting the responsibility of energy management back into the hands of the individual, significant steps can be taken towards redressing "the out of sight, out of mind" attitude many consumers have towards electricity use and wastage. A scenario often explored, resultant from a renewables-based energy strategy, is one where the consumer base must expect to lose service at the discretion of the power companies; i.e., by switching off the electricity supply at certain times during the day[15]. It is hard to conceive of this being an acceptable situation, and the metering and potential for selling energy back to the grid generated from micro-wind, for instance, offers a very appealing alternative if it can be implemented widely enough:

> *"The ideal approach is to tackle both of these at once – combining the urgent supply-side need for low and zero carbon solution with the demand side need to re-engage consumers with their daily use of energy.. …micropower technologies do precisely this."* Sowden (2006)

Inherently, energy storage is less of an issue for small scale turbines, as careful matching of supply and demand (turbine selection) coupled with battery banks for instance, and the potential for distributed generation, practically makes light of the issues facing full-scale implementation of 'big' wind. This situation presents a very compelling case, and hence, opportunity, for micro-generation as a whole, especially as the cumulative benefits could be significant[1].

7.13 Noise

To give an indication of relative variation in turbine-generated 'noise', consider the following:

- Noise is defined as: "*a sound, especially one that is loud, unpleasant and disturbing*"[30], inferring that it has components which are both qualitative and quantitative. The action of describing a turbine as something which creates noise, thus, immediately evokes mildly-negative connotations.
- The dBa scale is logarithmic, so tripling the energy of a sound will yield an increase of 5 dBa, and the threshold of hearing is at 0 dBa, whereas the threshold of pain is at 140 dBa.
- Multi MW turbine, for instance, have a sound pressure energy of approximately 49 dBa at 200 metres in a typical wind speed of 8m/s, which itself causes some ambient noise based on surface roughness and topography, etc[31].
- A car travelling at 40 mph at a distance of 20 metres is closer to 70 dBa[32].
- Renewable Devices' Swift 1.5kW turbine's acoustic emissions are given as <35 db(A) in their literature, which Manwell (2002) gives as analogous to living room or library sound levels.
- XCO2 state that their range of "quietrevolution" helical VAWTs are "almost silent", which is generally taken to be an advantage of vertical axis machines.

According to a report produced for the Scottish executive:

> *"New designs of micro-wind systems have greatly reduced noise levels due to improved blade design and reduced mechanical noise. Modern turbines are also easier to control and can be shut down at very high wind speeds.*
>
> *Noise stemming from micro-wind turbines will generally be of an acceptable level. However, to protect nearby residents from any potential noise, a condition can be attached to any consent controlling the level of noise. A detailed noise assessment should not be required. Where turbines are fixed to a building, there may be a risk of noise disturbance from vibration to the building itself or neighbouring buildings and a condition might be attached that appropriate measures should be taken to mitigate any such vibration."* Scottish Executive (2006[33])

Thus, noise should not technically present an obstruction to consumer adoption – if the consumers can be made to understand the true likely impacts.

The subjectivity in this area results from the assessment of the qualitative qualities of the sound produced by turbines, which are:

- Tonal. Arises from the interactions in gearing mechanism, vortex shedding, or the effect of boundary layer instabilities, etc.
- Broadband. This is the term given to the characteristic turbine sound, of 'whooshing', and is the result of continuous sound generation of a frequency greater than 100 Hz.
- Low-frequency. This type of sound is more commonly associated with shadow effects on a down-wind turbine's blades from the tower, or particular types of wakes; the frequencies ranging from 20 – 100 Hz.
- Impulsive. Impulsive sounds are a type of short, acoustic emission which can be attributed to the deployment of aerodynamic brakes or disturbed airflow on the turbine blades Manwell (2002).
- Noise is therefore a function of rotational velocity, fundamental frequencies, number of blades and specific blade interactions[34]. It is often stated in manufacturer's literature that reducing blade velocity makes a particular turbine 'very quite', but it is not as simple as that. Resonance effects and harmonics between turbines have also been known to

effectively cause a compound increase in sound pressure, to the displeasure of those affected, in the vicinity.

While individuals may display different reactions to each type of sound, be that in terms of sensitivity or preference, it is often the thought that a turbine will simply be 'noisy' that manifests itself as a reason to oppose deployment, without real experience in many cases. By exposing a demographic to the likely sound a turbine will make, perhaps through a marketing initiative or for user centred research or focus groups, a design can be altered to suit the maximum percentage of a consumer base, whilst alleviating commonly held misconceptions in a wider audience.

It may be of use to also make a consumer base aware of the fact that their concerns may be initially unfounded, or overstated, by directing those affected to studies in the field. For example, the Scottish Executive carried out a survey of people living in the area of a wind farm development to ascertain the level of acceptance, before it was built, and afterwards; the results of which indicate that initial fears and concerns were overestimated, including concerns about noise, and that in the sample poled, support for the wind farm was wide-spread after deployment; that is, the majority responded positively towards the installation[35].

In conclusion, it should be possible to counter commonly held misconceptions on turbine sound levels, and cater for the qualitative preferences through anthropomorphic studies and design; i.e., intrinsically, essential design processes encapsulated in best-practice methodologies. It can also be concluded that micro-turbines are significantly quieter even at close range than MW turbines at a considerable distance, which could be a major selling point in a marketing strategy.

7.14 Political persuasions

A conceivable threat to the future commercial viability of micro-wind might manifest itself in the guise of a radical change of local or national government, and hence, renewable energy policy. Perhaps, in this scenario, local government officials would be voted into power based on a stance against wind farms, if the strength of feeling is sufficient, as has been threatened particularly on Lewis. This would create quite a complicated dynamic between the electorship and the hierarchy of the party in power, but it is still hard to imagine how this might alter the status quo. For example, it has been strongly suggested that the Scottish Executive might relax planning laws for domestic micro-generation[23], which must surely tread on the toes of local authorities loath to grant consent. If this is the case, then it seems as if the future of renewables might be quite bright, based on the Labour Party's current stance, the Liberal Democrats who's manifesto solely opposed a new round of nuclear plants, and the Conservative Party (who recently stated: "Micro renewable energy [is a] great opportunity for the UK economy"[36]), and who's leader is trying in earnest to appear green-minded – all of which are the most credible parties at the present time.

Even if there were to be a radical shift on the political front, it could not be said with certainty that the renewable market would stagnate as a result, meaning the realistic threat to commercial viability from this occurrence remains negligible at present. It also stands to reason that the advisory committees who are presently consulting with the government on energy strategies would come up with similar conclusions, even for a different party.

Since it has been found in some circumstances that the support for wind energy grows markedly after suitable exposure to a farm (sweetened on occasion by community ownership and hence, profit), the likelihood of a (dissenter-instigated) change of ruling party actually affecting the market for micro-wind generators, is in the author's opinion, insignificant. This is mostly due to similarities in the stated policy of the three most credible British parties; with the concession, though, that manifestos often elaborate on actual, likely occurrences; and finally, the compulsion to toe the party line for subordinate branches of government.

7.15 Avian mortality

Avian mortality is a contentious area, each opposing side having a great deal at stake, if the consent process can be influenced by their evidence. Due to this fact, the reliability of studies undertaken is often called into question. This area of concern is also relevant for all scales of wind generation.

Wind turbines are supposed, and correctly so, to kill birds. In the past, wind farms have been placed in migratory paths, which has led to the deaths of a disproportionate number of birds. To date, there have been several independent surveys on avian mortality, with the conclusion that turbines do kill birds, but with nothing remotely like the proficiency of other anthropogenic means, such as travelling/commuting, erecting large buildings, shooting and leaving fishing weights in the open, which birds often attempt to eat. In Spain, with a significant installed capacity of wind turbines, it will take seven years for one turbine to kill a single bird, based on the observable pattern so far[37]. Wind farm planners argue that the effect on avian mortality rates of wind generation can be minimised through careful attention to the risks of a given proposed farm, and to a level which should be acceptable given the useful nature of the end product. Quiet Revolutions also opine that the faster rotational velocities of their vertical axis small-scale turbines should create a blurring effect that will help birds identify that they are on a collision course with an object. However, in some studies this "motion smear" is cited as a contributory factor in some recorded bird collisions, as are aircraft warning lights, which often cause mass bird collisions with towers, buildings or guy wires[38]. A possible further cause of avian mortality may be attributed to the turbulence behind turbines which can force birds downwards (HAWTs) and onto a structure, wire or the ground. It is unclear if this effect can be expected from micro-wind turbines.

Any activity that has a potentially detrimental effect on wildlife populations is undesirable, but in the context of general industrial activities, so far, wind energy generation has a small proportional effect. It seems as if society has resolved itself to its environmental effects attributable to the current status quo in industrial activity, and anything that ostensibly increases these effects is to be avoided. If wind-derived energy can have a positive impact on society in most ways then perhaps it would be pertinent to offset ecological effects by limiting other industrial activities that cause harm, rather than renewable energy generation itself.

Conclusion: The argument that turbines kill fewer birds than some other activity, does not seem to sit well in many people's reckoning; potentially, therefore, the wisest course of action might be to find out why turbines do kill birds (circa 20% of deaths are often of unknown cause), and how best to stop them doing so: importantly, to been seen doing this should inspire confidence in the motives of the proprietary companies.

7.16 Climate change

It has been stated by some organisations, such as Views of Scotland, that despite the roll-out of renewables, we cannot stop climate change from occurring because the effort is inadequate, and therefore those who oppose wind farms for instance, have good grounds to justify their position on the subject. This type of argument presents a threat to the proliferation of micro-renewables as it is accessible and intuitive; however, there may be grounds to refute this perspective by drawing comparisons to the efficacy of voting. The cumulative action of voting is very powerful, despite the feeling that an individual vote is not terribly valuable. Given that Britain has binding obligations to tackle climate change through European directives and the Kyoto agreement, for example, it must do all that it can to redress the environmental impact of industry and energy production to act as a responsible nation should. In doing so, the UK can be seen to be leading by example, whilst playing its own small part in what must be a cumulative effort to address global warming. Giving up because the challenge is difficult, or there are too few other countries on board, is not a serious option, and to convey this type of public sector responsibility might alter negative stances on the subject.

Similarly, it is the risk that climate change poses to successive generations that makes it significant enough a cause to warrant immediate action, even if it turns out to be unlikely as more evidence comes to light. Consequently, the interests of the majority come first by default, sometimes even if this is a successive majority.

7.17 Tourism

Figures from BWEA suggest that tourism will not be adversely affected by wind energy generation, based on data gathered at Britain's first commercial wind-farm. A poll by Views of Scotland in conjunction with the Scottish Tourist Board, however, found that wind farms may well discourage a significant percentage of visitors from returning to Scotland. The rural, unspoilt landscapes around Scotland may actively encourage many of the annual tourists to visit, and windfarms could conceivably spoil some areas to the economic detriment of the region. Rather than sounding a death knell for all wind power, this situation, with all its inherent uncertainties, could play to the strengths of micro-wind, as additional infrastructure as required will generally constitute a peripheral element of existing man-made structures, detracting little from visual amenity compared to large windfarms in typically scenic areas.

7.18 Visual amenity

> *"And if the people of Britain do not act soon to halt this alien invasion, hundreds of miles of our ancient countryside and shoreline will be disfigured for a generation."* Ferguson (2006)

This ardent call to arms in a broadsheet's opinion column reflects the thinking of many vocal anti-wind activists, particularly those voicing opposition to Amec's plans in Lewis, where wind turbines have been compared to "dying stick insects", for example. Clearly the issue of aesthetics is important, and leaves scope for designers to influence public perception in terms of tacit design principles: colour, lighting, clarity, focus, hierarchy, harmony, order and balance[39]. While such attention to composition may lessen visual impact in certain areas, it has been suggested that micro-wind, and in particular vertical axis machines, have the advantage of being less objectionable, visually[40].

> *"Wind turbines can be designed as a piece of art helping to increase awareness and knowledge of renewable energy technology."* Quiet Revolutions (2006)

Quiet Revolutions state this in reference to their range of turbines, and a particular, a show-case VAWT, which has integrated LEDs, enabling them to create floating, video images. Innovations of this type may help the cause of micro-wind turbines, as should such an artistic, form/function design-based ethos – an approach that should be emulated with respect to visual amenity and counteracting preconceived distaste towards the traditional forms of wind-energy generators.

The aesthetic qualities of wind farms are subjective in most cases, but there are also other, more readily quantifiable effects to consider, such as flicker, which can be very irritating for those affected by it. In terms of micro-wind:

> *"The small diameter and likely location of micro-wind turbines greatly reduces the probability of shadow flicker occurring. Therefore in the majority of cases shadow flicker will not be an issue".* Scottish Executive (2006)

Turbines may very well 'spoil' the landscape, but when balanced against likely future difficulties they can address, a negative attitude could be touted as quite a frivolous concern, though it must not be expressed in such a way so that the proponent seems pious or condescending. The receptiveness to this type of message of the target group will depend on their knowledge, orientation and empathy concerning visual amenity against wider benefits; but it is not beyond the realms of possibility that the significantly smaller visual impact of micro-wind turbines, in contrast to their deployment environment, can constitute powerful leverage against resolutely unconstructive sensibilities.

7.2 Strengths, Weaknesses, Opportunities and Threats

Often, a type of specific analytical approach called a SWOT analysis (Strengths, Weakness, Opportunities and Threats) is employed by commercial research organisations to better organise any findings. In light of the investigation into wind energy so far, it will be advantageous to order any inferences that can be drawn in this manner, as follows:

7.21 Strengths:

- Energy policy favourable and drives and shapes market
- Increasing concerns over climate change, social responsibility and green ‘living’.
- Links between energy profligacy/environment damage with poverty
- Energy policy changing to ease the implementation of micro renewables
- Media interest
- Mass market products, rather than industrial, large-scale implementation
- Nascent, intriguing technology
- Scope for innovation/invention
- Energy storage, point of use demand/load matching
- Land mass required already occupied by a facilitating area or structures
- Will not affect visual amenity in the same way as larger counterparts
- Unlikely to dissuade tourists from visiting
- Virtually no potential damage to fragile eco systems
- Quieter

7.22 Weaknesses:

- Micro-wind tarred with similar brush as larger counterparts
- Prohibitively expensive to date
- Unproven technology
- Unproven energy yield claims
- Expense of grid connection, or lack of available grid connection depending on distribution network loads and capacity
- Distributed generation on the large scale may necessitate grid reinforcements
- Existing technology may cope poorly with urban turbulence and siting
- Potential risks to birds and bats, though small compared to large-scale wind

7.23 Opportunities:

- Combat misconceptions through PR exercises
- To empower end users in terms of their energy use and monitoring
- Combat climate change and collective footprint
- Offset rising energy prices from conventional generation
- Possibility of revenue generation for proprietors
- Grants and public funding available subject to efficiency requirements
- Possibility of encouraging responsible energy use
- Create sense of harmony for the self-sufficient, or carbon neutral residences and owners
- Instigate paradigm shift in energy portfolio
- Negates detrimental impacts of larger counterparts
- Potential to utilise product-centred marketing strategies and Product Design methodologies
- Vast opportunity for process and design improvements
- Economies of volume and hence price reductions
- Favourable opportunity for diversification of technology, or symbiotic/balanced technology relationships between different types of domestic renewables
- Level playing field for new companies/ initially receptive market place
- Lack of competition thus far, though not for long
- Lucrative market sector
- Redress supply security issues and diminishing fossil fuel reserves
- Tangible alternative to widespread proliferation of nuclear power in combination with other microgeneration technologies
- Planning relaxed for micro renewables
- Levy exemptions for businesses with increasing political burden for intensive energy consumers

7.24 Threats:

- Consumer apathy
- Efficacy questioned in media
- Reputation damage from bad publicity
- Function over form approach off-putting
- Grid instability

- Inability to reduce design and manufacturing costs
- Cheap imported gas offsetting market need
- Fusion technology potential a long term threat to all conventional generation
- Inexperience in installation, potentially leading to structural integrity issues and media response to failures
- Resistance from lobbying groups, conservative areas
- The most economic forms of renewable energy generation will saturate in the market, forcing companies to diversify, potentially cluttering the micro-renewable market

7.25 Summary

Based on the information found, the author expounds this type of research approach, as it encapsulates many of the areas that will be required during investigation by micro-renewables manufacturers, in terms of impact assessments, for instance. By consolidating a broad range of topics into a simple analysis, formulation of a Product Design specification should be made easier, and hence, a good picture can be built up at an early stage of how best, technologically, to meet a market need; in turn meaning marketing and business strategies can be influenced positively. In terms of market receptiveness, it would appear that micro-wind constitutes a lucrative opportunity for an organisation entering the sector at this time, providing the approach is inline with the stated opportunities. The window for such an undertaking will close slowly over the next few years as more and more companies see the potential for profit, and other renewable markets saturate. The consumer base may need to be the subject of considerable effort first though, in educating and stimulating public debate through public relations exercises. The potential benefits of micro-wind compared to large scale wind should also represent a good opportunity to drive the market need, if the virtues and advantages are sufficiently commended.

Micro-wind has great potential, though excellent Product Design and manufacturing will be required to keep costs down and facilitate wide-scale adoption. In terms of technological opportunities, which address the most significant barriers to promulgation at present, simplistic design encompassing passive control, strong reliability, aesthetics and performance seem to be the most prominent areas to address. These topic areas will be drive the main technical constraints in the concept generation and evaluation as documented in later chapters of the investigation.

8. The wind energy market

By understanding the relationship between investment, for instance, and the installed capacity of wind power in certain leading countries, it is possible to draw some conclusions that may be applicable to the small-scale wind market, whilst a more encompassing picture can be built up of political influence and opportunities.

8.1 A brief history of European wind energy

> *"I doubt the future of wind power in Germany. They are reaching for the Stars without first taking stock of the rooftop view".* – S Hugasson, (1981)

The long-term outcome of current energy policy is a 40% share in Scotland's energy mix from renewable energy sources by 2020[1], the seeds of which were, in effect, sown as early as 1976. Around this time the Department of Energy embarked on a wind energy programme in order to: "..develop the technology in order to define its economic potential and benefits in large-scale electricity generation[42]", though they deemed their efforts modest in comparison to those of the US under the Carter administration. One reason for this was that industry felt that the lack of Governmental support hindered their efforts, something that seems to reverberate around the marine renewables field today, perhaps intimating a comparison of the state of maturity of the market, and its likely end result. This apparent slowness to in the early stages was a result of the 'CONUC' energy policy at the time – strongly favouring proven 'technologies' of coal, nuclear and conservation. (It has been stated in economic literature that the NFFO which came along in 1989, (the energy industry being privatised at this time), was something of an unlikely precursor to renewable energy incentives of today, though the conservative government did not quite intend it to be, as it was more specifically aimed at subsidising the still-public nuclear energy industry[43].) Another factor that limited the research efforts into wind power was a perceived abundance of the UK's oil, natural gas and coal resources, giving credence to the assertion that economic theory can be short-sighted.

At this time, however, the research and development effort culminated in well publicised wind power projects on Orkney, with the installation of a 250kW and 3MW HAWTs – the latter appreciably scaled even by today's standards, representing the upper end of modern turbine capacity. Even at this early stage, there was talk of the potential for off-shore wind farms (which

Britain claimed to be taking the lead on), the first of which having only recently come on-stream, as opposed to European efforts which seem to have overtaken the UK.

In other European countries, test turbines were similarly ambitious in size, with many designs competing for prominence. Early British designs, such as the 3MW turbine in Orkney, generally favoured a two-bladed, fixed-pitch design. The blades on this particular design included a small (20%) length of variable pitch aerofoil towards the tip to smooth out fluctuations and aid braking. At this time there were also prototype Musgrove (variable geometry) and Darrieus style Vertical Axis Turbines on test, though it was found that cyclic blade stresses and bending moments on cross-arms were problematic.

Concurrently, the Danish and German efforts were concerned with full-blade pitch control using computer processing and hydraulics. This full, active control demanded very fast processing at the time, yet the single-blade Growian II turbine was rated at 5MW and operated with a power coefficient of 0.37 in 1981. During the 80s, the Danish 3 bladed, stall regulated turbine emerged, though somewhat perturbing aerodynamicists in the process[44]. Denmark's economy is now supported to the tune of approximately £3 billion per annum, aided in turn by a successful turbine export sector[46]. Similarly, in 2002, Germany employed approximately 45,000 people directly in the wind industry, which equates to 3.7 jobs per MW of installed capacity.

It is interesting that such good efficiencies were achieved with designs that would be considered less favourable by today's standards, where the favoured three-blade HAWT, at the cutting edge of aerodynamic proficiency may achieve a power coefficient of closer to 0.46 EWEA (2003). Despite the well publicised difficulties concerning, Vertical Axis Turbines particularly, these concepts have not really been laid to rest. Manufacturers in North America are also advocating a new range of 2 bladed turbines at this time, possibly indicative of something of a resurgence. It was similarly suggested in the early 80's that multi MW turbines would probably be the most viable and economical arrangement, which certainly seems to be the case in the present. It is telling, however, that it has taken 25 years for multi MW turbines to advance to the state where they are the preferred option, indicating the level of technological maturity that had to evolve before wind energy could seriously contend with traditional generation sources. It is also conceivable that the investment in research and development in the larger turbines will have trickle-down benefits for small and micro-turbines, whilst also highlighting the required social and political climates crucial to the success of this type of technology.

In summary, although the traditional three blade turbine is heralded by many as the clear favourite, there is still a wealth of interest in other technological concepts, with continued research and development. It is thought that blade aerodynamics are approaching the upper limits of performance, thus efforts will be focussed on improving other aspects of turbine performance, with likely benefits for the small turbine manufacturer, and for a significant period ahead. On the same note, as performance improvements can cost more as they are forced towards their theoretical limits, the scope for design improvements in other areas, to mitigate potential social impacts for instance, should also be fairly lucrative.

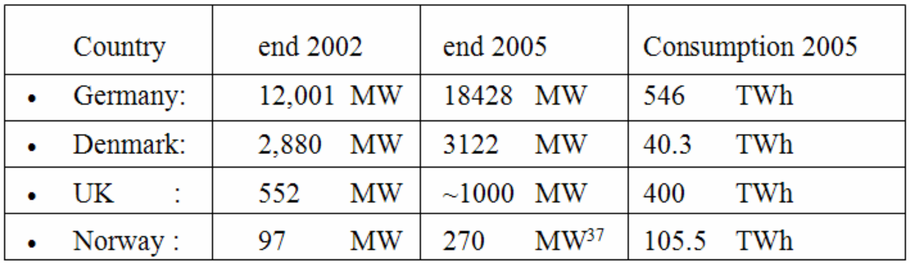
8.2 The impact of investment on future growth

At this juncture, it might be appropriate to compare Britain's energy investment with that of other European countries in order to highlight how political drivers effect market growth and technological maturity. When Europe began to collectively explore the merits of large-scale wind power, Government investment was made available at approximately the same time: around the late 70s, to differing degrees, though available funding in Britain was described as "modest". As an example of the rages of investment, consider the following[45]:

Country	Investment	Equivalent
• Germany:	118 million German deutsche marks	£41.5m
• Denmark:	15 million Danish kroner	£1.4m
• UK :	"Modest"	n/a in literature.
• Norway :	Norwegian kroner	£0.2m

Fig 8.21 Investment in first wind programmes in the late 70s

Installed capacity and total electricity consumption in the same countries is shown in figure 8.22[46]:



Country	end 2002	end 2005	Consumption 2005
• Germany:	12,001 MW	18428 MW	546 TWh
• Denmark:	2,880 MW	3122 MW	40.3 TWh
• UK :	552 MW	~1000 MW	400 TWh
• Norway :	97 MW	270 MW[37]	105.5 TWh

Fig 8.22 Energy use and installed capacity of wind energy in 4 European countries

Based on these figures, it may be postulated that investment is directly proportional to long-term growth in such a market, though as a percentage of overall consumption, Denmark is clearly the leader of all the early adopters, with an approximate generation share from wind energy of 20%, compared to approximately 6.5% in Germany – the country with the largest installed capacity in the world. Spain and the USA are currently in second and third place respectively, whilst India has overtaken Denmark to claim fourth place, in terms of installed capacity. Strong growth is also being exhibited in countries such as Portugal and China. There were an additional 11,531 MW of installed capacity, world-wide, by the end of 2005, up 40% on 2004[35] – bringing the cumulative installed capacity to 59,084 MW, up from 31,128 MW in 2002. In the UK, the increase in installed capacity was 11.1% in 2005, with the likelihood of continually increasing growth for several years[47]. Government support is clearly a major factor in the growth of wind energy, and in the UK, leaders of the three main parties are all proponents of micro renewables to some extent[48]. The UK Government has also recently pledged £50 million to support its micro-generation strategy, which bodes well if large scale wind investment can be applied as a model for likely growth to this area[49].

It is unclear when the wind market will begin to slow in the UK, but the addition of banded ROCs coupled with the fact that the UK has no clear targets for increasing wind capacity, means that they appear to be keeping their options open, in contrast to many other European countries with ambitious wind targets for 2030. There has, however, been speculation on offshore wind capacity increases, as the Crown Estate has identified 13 possible locations for this type of expansion around the UK's coast; similarly, outlining capital grants for the first generators to apply.

The 2001 European Directive promotes renewable energy sources, and mandates a target of 22% of electricity generated from renewable sources from each member state by 2010[50]. The Kyoto Protocol of 1997 also constitutes a binding international agreement for all signatories, and presents targets for the reduction of greenhouse gasses, also driving renewable energy policy.

Country specific targets for wind energy include:

- Denmark : 5500MW by 2030
- Italy : 2500MW by 2008-2012
- Spain : 1000MW by 2010
- Germany : 25GW offshore capacity by 2030

- UK : Arbitrary Share from wind by 2010

On the public side of the matter, it seems that the interest and awareness raised in renewable energy is having an impact on collective opinion:

> *"In 2005, Scottish Renewables surveyed Scottish attitudes towards wind farms. It found in March4, that 73% of Scots agreed that wind farms were necessary to meet current and future energy needs. In November, a follow-up poll found that the 73% result had not shifted (see Figure Two), in addition, as part of its coverage of the General Election, the BBC asked in an ICM poll a similar question and arrived at the same result. And then, towards the end of the year a study by St Andrews University confirmed that people living close to wind farms were most supportive of them and that their fears about the wind farm before construction were unfounded."* Scottish Renewables (2006)

Conclusion: It appears that dedication to certain renewable energy technologies can be gauged in terms of Government investment, and this almost proportionally relates to the most likely future scope of a given market. Investment parallels policy initiatives, which in turn, drive the market and alter public perception – to a notable extent. Successive UK governments have all had a role in promulgating large-scale wind energy, but there must be a natural point where balance will be achieved; that is, it is thought that the national grid could support up to 20% of total generation from large-scale wind energy or similar[52], before capacity and infrastructure dictates reinforcements in some suitable guise. With year-on-year growth of only 11%, we may expect that the market for large-scale wind would expand for several years to come, if other large scale forms of distributed generation are somehow completely inhibited. Thus, it theorized that to meet 2030 (and beyond) renewable energy and carbon reduction targets in the most economical manner, and taking into consideration opposition to wide spread grid reinforcements, that the deficit will be taken up by micro-renewables of various forms, and more likely still, further nuclear generation. In assessing large-scale wind it has been found that there is a significant opportunity for micro-wind to fill the void left behind by market stagnation which will eventually come about.

On the same note, technology improvements in small wind as a direct result of large-scale wind advancements may result, as a knock-on effect – further enhancing the scope of the sector, though market forces and competitiveness will likely constitute the greatest drivers for innovation and product differentiation.

Public interest coupled with the highest oil prices ever[53] will also surely fuel the age of microgeneration.

9. The market scope of small-scale wind

The potential size of the small-scale wind market is difficult to estimate without first establishing what factors will support or stifle it – these in turn being a function of several independent variables. One such variable is the, often-fickle, mass market consumer, being influenced by trends, advertising and public relation exercises, company strategy, image, fashions, disposable income, needs, mood, society and security. The consequential significance of many of these traits can only be accurately established through customer surveys and responses, while others can be postulated by examining apparently contributory factors. This section documents an attempt to this end, while consumer perceptions have been gauged and documented in later chapters.

9.1 Growth drivers

Capital funding/grants: Although there has been criticism levelled at capital funding to promote technology uptake based on the historical performance of such schemes, the DTi has recommended a strategy based around this premise in the Microgeneration Strategy (2005) – one which builds heavily on existing funding opportunities for those wishing to install domestic renewables. This has secondary, positive implications due to the tacit perception of high-level technology endorsement, which is obviously effective due it being the crux of many an advertising campaign. However, the public purse cannot feasibly support this in the long-term, and with technology available at economically-disadvantageous prices, the net burden on the tax payer in attempting to drive down costs and increase uptake, through volume, may be better spent elsewhere; unless design improvements can bring down costs in the first instance. Further to grant funding, the scenario modelled in the Microgeneration Strategy included the provision of low interest loans, specifically tailored to microgeneration technologies, which may be an attractive proposition for many interested parties if it comes to fruition.

It is not disputed that capital funding will benefit many of the early adopters, and aid proliferation through secondary promotion, but the sustainability and merit of such an approach in the medium to long term is highly questionable. Schemes that attempt to promote a market-pull condition include the following.

The Energy Saving Trust can facilitate the remittance of the “Clear Skies” grants, pending accreditation, and on the proviso that any recipient’s accommodation meets standards for energy efficiency and insulation. They also recommend assessing the wind regime with the NOABL database first, to ensure that those wishing to install a turbine at/on their residence have sufficient resource availability to justify the action. NOABL, however, operates with a limited resolution and further analytical factoring should be strongly advocated, lest failings be publicised because of low energy yields – potentially, a very damaging scenario.

Similarly, a partnership between the Scottish Executive and EST in Scotland has led to the creation of the Scottish Community Householder Renewables Initiative, which provides 30% of installed cost up to a maximum of four thousand pounds. Their ‘stream 2’ scheme is available for larger systems such as community owned farms, but again, only subject to energy efficiency measurements. It is also notable that the Scottish Executive includes microgeneration in their target of 40% renewable energy capacity by 2020, which in itself is ambitious, and higher than the UK’s net goals[54]. It is unclear what distribution microgeneration may have in this mix however, and more specifically, micro-wind’s place in the mix.

Another body which expounds and offers support for wind power is Argyll and the Islands Enterprise, who have set up a scheme to help communities who want to harvest wind energy.

Public and private sector support: Receiving the backing of any high visibility company, that has itself a positive public image, will have an effect on the collective consumer-psyche. By this type of association, a subliminal tie between the ‘authoritative’ opinions of a body seemingly operating successfully in some capacity as a ‘green’ business, similarly elevates the status of the item extolled. This can be thought of in terms of an opportunity worth seeking, or an existing PR bonus for any companies mentioned. As it stands, examples of this can be seen quite readily for micro-wind; for example Green-Alliance state how they look favourably on microgeneration, particularly so, as opposed to a new round of nuclear if it is a viable alternative. Opinion columns, newsletters and energy commentators can have a similar bearing on attitudes, and it seems that to date, supporters are more common than detractors, though the latter need not be voluminous to have a big effect.

Others that have voiced high visibility support include members of parliament, local authorities and large organisations, believing that an almost intangible benefit, in terms of image generated from the visibility of a turbine installation itself, is worth more perhaps than any energy savings it may generate.

As long as this type of support is credible and is not construed by the potential consumer base as cynical or contrived, then there could be very large benefits for the manufacturer in terms of free advertising, default support and championing of their product. Unfortunately for the sector, the dangers of the inverse of this situation are very real. As revealed by a market survey undertaken (the results of which are documented in section 14), appearing ‘green’ is viewed by the overwhelming majority as a fashionable pursuit; ergo, the mechanisms of achieving this in many instances can go out of fashion as easily as they come in – depending of course on public perceptions regarding the status of such product champions.

Potential difficulties aside, real instances of product championing can be seen by BP in particular, some of their forecourts sporting Swift Rooftop Turbines from Renewable Devices, a company in whom BP have thus been seen to put their faith in, and a turbine which the mid-Wales energy authority believe represents the current state of the art.

Another mechanism for furthering the cause of micro-wind are the design and innovation awards that seem to crop up very often, perhaps, although admittedly with a degree of cynicism, as a construct purely to bolster consumer confidence in the absence of concrete performance figures, in many cases.

Escalating Fuel Costs: The following figure may help the reader to understand in context the influence of the fuels market on the domestic consumer, and how it may cause them to embrace or shun microgeneration.

A DTi study states: Average UK households use 20,111kWh (2003) of gas and 4600kWh of electricity per annum, although some houses do not have access to gas. British Gas’ ‘typical’ tariff prices dictate that the first 4572kWh cost 2.17p and any units thereafter, 1.513p; equating to around £480 per year. Similarly, for electricity, prices are 4.89p to 6.33p to 9p/kWh depending on demand or time of day, for example. Oil prices are also predicted to rise year-on-year without deviation due, in no small part, to the increasing costs of locating and extracting oil as known supplies are used up, and the simple fact that it is a seller’s market.

Whilst large-scale wind-generated electricity falls in price, in stark contrast to that of fossil fuels, micro-wind is nowhere near competitive at the moment, in all but the very best locations, or where other means of generation are unfeasible.

In simple everyday situations, it can be seen that the scarcity of any commodity that is already popular, tends to inflate its price. This is due to the fact that demand in many instances rises while stocks diminish, (based on figures of energy consumption from the DTi for years 1990-2003, the average yearly increase of electricity consumption was 152,000 tons of oil or equivalent) meaning that companies involved in production can charge a premium, or are forced to do so, as extraction costs increase. Consumers will generally attempt to pay extra for a service or products they view as a necessity, or a luxury, insofar as they have sufficient income to allow this. This pattern can already be seen in the case of petrol and diesel costs, as global oil production is inhibited by politics, local unrest, and dwindling supplies. Many UK residents, according to the Government, are also said, currently, to be living in fuel poverty, while others are forced to spend more and more to heat their homes and maintain their quality of life, which itself, is very much facilitated by the security and availability of energy supplies in the UK. This has been a significant driver in shaping energy policy, particularly regarding energy wastage and building insulation, also advocated strongly by energy agencies and consultancies. It must be remembered, therefore, that while a consumer may regard a Return On Investment of 10 years as being unattractively high, the datum for relative measurement is, at present, the affordability of heating and powering one's home.

The nature of energy use in Scotland particularly, is set to change markedly without counter measures:

> *"Experts say Scotland produces more electricity than it needs but economic growth and a house building boom over the next nine years is likely to see demand rise by 10%. {The Royal Society of Edinburgh} predict that surplus capacity produced by the National Grid will have been used up and "there will be electricity rationing by 2015 unless significant new generating capacity is installed".*
>
> *Scots are not only being hit with higher fuel prices but they also face the threat of major blackouts."* RSE (2006)

While the problems facing Scotland may be unique to the area, rising fuel costs will generate a consumer need to reduce their heat and power consumption and hence, capital outlay. The options are:

1. Consumers will attempt to generate a portion of their own electricity, driving the market for viable microgeneration technologies. It is postulated that in these circumstances, consumers will seek the maximum benefit given their particular location and financial means.
2. National, Government-driven, initiatives will negate a latent desire in consumers to embrace domestic generation, through mandatory insulation standards, large-scale renewable efforts, or a role out of, for instance, a new round of nuclear power. The drawbacks of which might quickly become hazy in the face of adverse living conditions brought about by energy shortages.

Thus, scenario two is conducive to a realistic situation where the merits of nuclear power are exhorted perhaps beyond the true balance of risk and reward, driven by economic development – in turn, strongly linked to energy generation in a particular region – and the plight of the poorer homeowner becoming foremost in the energy policy making process. Such a drive towards nuclear is already likely, though the scope is, as yet, unknown. While it was mentioned in chapter 6, that nuclear may not pose a huge threat to micro-wind, it should be made clear that this will be true for the chief exponents and supporters of the technology (‘early-adopters’ in design nomenclature), though this group will not constitute the cornerstone of the market, if levels of penetration of up to 10% are strived for. In this case, nuclear or alternative means of energy generation, pose a very real and credible threat to the proliferation of micro-wind, and as such, make the market a very risky proposition for anything but those quickest to market with their product.

It is hard to see how micro-wind can be a truly sustainable, medium to long term proposition, unless it can become competitive in a period closer to five years, than fifty. There are a great many potential consumers who will not opt for a technology at anything less than a lucrative index of ROI[56].

Security of supply: Approximately 35% of potential consumers polled believed that “wind energy is unreliable”. It stands to reason that if so many people believe this to be true, small wind may not be at the top of their shopping list any time in the immediate future, unless steps are taken to combat this. The costs versus return of a counter PR exercise could be outwith the scope of individual companies, meaning an uphill struggle could ensue – unless the Government steps into the fray as chief educationalist, bearing in mind the receptivity to this message indicated in the same poll (see section 14).

Even if small scale wind is widely regarded as being unreliable, it is surely done so relative to the excellent security of supply the UK enjoys courtesy of conventional generation. If it was shown how that situation may change due to dwindling energy supplies, unreliable imports of natural gas and increasing costs, versus the opportunity for the home owner to mitigate these situations, perhaps many consumers could be won over to the benefits of small-wind, assuming of course, that it is suitable for the individual's wind resource.

Even technical barriers such as grid integration can now be relatively easily approached through improvements and breakthroughs in power electronics – in many cases solving all distributed generation associated problems.

A further unique selling point is that microgeneration can offset transmission losses, hence increasing its net reliability, in all its guises.

Energy Policy: There is now strong scientific evidence that climate change is happening and it is being accelerated by human activity, with rises of 1.4° to 5.8° predicted for this century[57]. This situation has brought about many new types of legislation specifically geared towards the micro-renewables field, some of which include:

- Climate Change and Sustainable Energy bill. The bill passed its final parliamentary hearing only recently, and also gained royal assent, to become law. The bill will allow the Government to accept accountability for meeting microgeneration targets, whilst other measures in the Act will aid the financial mechanisms of ROCs. Emphasis is also placed in the bill on heat-generating microgeneration technology, and its promotion, particularly by local authorities. A further interesting provision in the bill is that of a cap on transmission charger on Scottish inlands until 2024, which is sure to enable large-scale generation in these areas, also[58].

- Various schemes. Schemes will also be introduced to reward customers for exported electricity. Microgeneration will may become semi-mandatory in new homes that are publicly funded, and primary legislation changes have been proposed by the Government which pave the way for microgeneration to eventually become a requirement of the building regulations.
- Some £80 million of funding has also been allocated in the next three years to the grants scheme supporting microgeneration.
- Code for Sustainable Buildings. Probable mandate that a certain portion of a new building's energy requirements are generated on site.
- Low carbon buildings programme – makes available grants for all types of microgeneration[59].

Further to these measures, the Government hopes that micro generation can help combat pollution, in accord with more general target legislation, whilst empowering an mobilising the individual in doing 'their bit':

> *The UK also has binding international commitments to meet targets for emissions of air pollutants, and for local and regional air quality, including acts of 50%* [reductions] *in SOx and 20% NOx from current levels from 2010".* DTi (2006)

Similarly, according to Energy Minister Malcolm Wicks:

> *We, as individuals, must make a contribution to the fight against climate change, as we can't just expect big institutions or governments to solve the problem for us, we all have to make a difference. A micro wind turbine will be installed on my own home shortly and I would like to see local level and community energy production like this becoming more commonplace. This will allow us get back in touch with where our power comes from and understand more about how much we are using or abusing."* GNN (2006)

As a means therefore to supplement industrial energy use, and driven by encompassing energy policy, the onus may fall firmly on the proprietors of such facilities to ensure a substantial percentage of their energy comes from 'green' sources. Coupled with the Code for Sustainable Buildings, the small to medium industrial market sector seems to be one of the most stable and lucrative. It may be necessary in such circumstances, depending on exact requirements, that a business utilise an economically favourable mix of technologies, of which wind may play a greater part – particularly since many such industries operate in brown-field or exurban locations, where the wind resource is likely to be significantly better.

9.2 Size

At present, information on the likely market size for micro-wind over the next few years is very limited. Even highly regarded market assessment organisations such as Keynote have no information yet on the subject, meaning initial estimates are available from very limited sources; consequently cross-checking revels little about the accuracy of the estimates. To date, the most in-depth assessment comes courtesy of the DTi, which speculates on a number of scenarios based around Governmental legislation, technology improvements and consumer attitudes, as the key parameters of market receptivity. Based on the author's research, the best-case scenarios presented are optimistic in the extreme, for a number of reasons, and differ by many orders of magnitude, as discussed in section 14 from those likely. The DTi speculate maximum growth rates of 70%, though agree that more research is needed to tailor estimates to different technology types. An important factor in their estimations, however, is based around a key rise in home-generation electricity prices:

> *"In order to stimulate uptake of microgeneration with high electrical export (wind, photovoltaics and oversized fuel cell CHP), it is essential that the current price distortion leading to low valuation of exported electricity, is corrected. Without valuing exported electricity at a higher rate it is likely all three technologies will fall well short of their potential deployment by 2050."* DTi (2006)

They also regard the potential for micro-wind as "significant", potentially giving a 4% contribution to UK energy requirements, culminating in a 6% reduction in C02 emissions, and cite this as of suitable worth to drive down costs – this point, taken at face value, is a little simplistic and misleading. Cost reduction will be a function of a great many variables, and not simply of the inferred economies of volume, although, given time they could have a beneficial impact:

> "…[a means of generating] *permanent reductions in the price of the goods and* [reducing] *the need for long-term subsidy is through economies of scale from volume production. This could bring down manufactured costs by up to 50% and reduce payback periods from 5–10 years to 3–5 years.* Micropower (2005)

To intimate, however, that such scale-dependent cost reductions are the crux of product opportunity could stunt the true potential for individual companies to instigate process improvement, design improvement and specific market-sector targeting.

The DTi also state that attaining an equitable price for exported electricity is the "single most important market change for small wind". While this statement may have merit, it can only be deemed true in the longer term, and also if the technology can generate a net surplus of electricity against instantaneous consumption, which, according to turbine owners questioned, is a long way away. It similarly dictates that the blanket assumption is made that small wind will pay for itself not solely in its operational lifetime, but in a time scale that the consumers deem as of suitable duration to warrant initial outlay; that is, for many consumers, although the price for exported electricity may rise, ROI cannot be reduced as effectively by export price as it could through initial turbine cost reduction, increase in yield and a great many other factors which will immediately influence uptake levels.

In terms of market support, in the long-term, obsolescence in turbine technology should similarly help sustain any existing market, as would other technologies. With expected lifetimes of fifteen or so years, replacement turbines, of a greater quality and technological efficacy, should help the long-term buoyancy of the market.

9.3 Scope

Microgeneration does not simply hold the keys to lower fuel bills, but also to reunite energy users with their consumption. In response to the fact that people often waste energy, and take little heed of advice on improving insulation and efficiency:

> *"…moreover, a recent study by the Sustainable Consumption Roundtable gives tangible evidence that micropower acts as a catalyst for cultural changes in consumer attitude, and provides evidence of the important impact it has on*

> *attitudinal and behavioural shifts towards energy use, re-engaging consumers with their use of energy.*
>
> *The ideal approach is to tackle both of these at once – combining the urgent supply-side need for low and zero carbon solution with the demand side need to re-engage consumers with their daily use of energy.. …micropower technologies do precisely this."* Sowden (2006)

Hence, justifying the thought that the cumulative benefits of microgeneration, coupled with better insulation and decreased energy waste, could be of greater worth than the sum of the individual actions. Putting this in economic terms is difficult, however, but further strengthens the case for small-scale renewables.

9.4 Receptiveness

Other mechanisms at work in the renewables market have been introduced in anticipation of a growing domestic electricity-export sector, such as that of Good Energy and their home generation scheme, which offers competitive tariffs and support. Good Energy, as a reputable energy generator, has been something of a trend setter in large-scale wind energy, and may cause others to follow suit.

A portion of the total available market will be receptive to micro-wind from the outset, yet the remainder may need to be cultivated through a programme of education, public relations and advertising to increase knowledge and raise burgeoning consumer awareness – an aspect of the market dynamic singled out as being of great importance by various bodies.

Translating this cultivational effort and propagating interest in the area into Product Design targets, goals, and essentially, performance metrics, will be difficult, but there are techniques in existence that can aid the process with a little adaptation. Techniques, such as Life Cycle Costing, have been used to good effect by many industries in an attempt to estimate the true costs of a product; thus, by modifying the technique to yield likely costs of the consumer awareness effort, a suitable estimate of expenditure versus growth, in this regard, may be generated. A further discussion of this principle can be found in later chapters.

9.5 Barriers

There are a number of potential barriers to the widespread adoption of micro-wind turbines, some of which may require considerable resources to address:

Price:

> *"There is no guarantee that putting a turbine on your roof will produce enough electricity to make worth while savings.*" Slavin (2006)

Price takes into account various aspects of the amount of money that installing a turbine will require, and the likely payback period. Cost to the consumer will entail the purchase of the turbine, brackets and fixings, masts in some cases, or bespoke fixing frames, depending on application, accreditation (extra insulation and energy saving measures necessary) or surveys, cabling, inverters or connection to immersion heaters, etc, battery banks, maintenance and installation. Cumulatively, these costs can be considerable, but will, by most consumers, be balanced against energy savings, carbon offset and returns, and also available grants. Further, if money is borrowed to pay for a turbine, compound interest on loans can accumulate quickly and heavily. It may be the case that some turbines will be purchased on the strength of their green credentials, but this would be most likely only for the most financially comfortable, or businesses to which perceived value will be added beyond the physical price of a turbine through installation, and probably a very small proportion over all. To offset costs, most customers based on investigation so far, will look for a ROI of less than ten years, and state that £2,000 is too much to pay for a turbine, though the right combination of loans and grants may raise these limits somewhat. In this regard, certain realistic targets can be set in terms of consumer cost.

In terms of meeting customer expectations so far, most commercially available turbines fall very short of the mark. Installed on a reasonably tall block of flats, even leading turbines fail to achieve a payback of under ten years, with a more realistic time-scale being in the region of 20 - 30+ years, using an average wind speed of 6m/s[65]. A home owner in an urban area is not likely to gain a ROI even close to these figures due to lower wind speeds and turbulence.

Price also encapsulates true life cycle costs, which may be huge, for example, if structural damage is caused by inappropriate installation. There is also a cost associated with detrimental impacts on the proprietor if they should occur, and the associated bad press, which conversely, the manufacturer must bear.

Legislation:

> *"Poorly informed planning decisions could increase costs and reduce the market quite significantly. An objective assessment of the environmental impact of domestic small wind systems is required to provide clarity on this issue, followed by guidance to planners on the key issues including permitted development statu*s." DTi (2006)

A significant percentage of those questioned thought that planning permission may be difficult to acquire, which should not be the case based on new regulations, though this may vary depending on devolved powers. There may be instances in such situations where Natural heritage issues restrict deployment, but it is thought that these occurrences will not be insurmountable.[67]

Low price for exported electricity: This factor is thought to hinder uptake considerably.

Bad press, poor performance and concerns over safety: Domestic wind turbine detractors such as Hugh Piggott and Paul Gipe, are beginning to spring up on the internet and in the press, most of whom are credible and respected in their fields, and will therefore wield influence over the undecided on, and even many supporters of, small wind. More worrying still is some of the data from actual tests that have been carried out of certain small wind turbines, many of which generated in a range very far from their stated power curves[68], and also from first hand accounts of severe problems. A well known turbine dramatically disintegrated causing a great deal of damage when on test on a house, while others were found to be unacceptably noisy.[69]

With this in mind, the already rocky relationship between consumer and wind energy could be brought into further disrepute if the perceived risk of installing a domestic turbine increases. In this regard it will be of paramount importance that companies can demonstrate due diligence and adherence to standards such as BS EN 61400-2 1996. There are several other standards applicable concerning structural integrity and noise, for instance, though there have been calls for greater regulation in the field for safety assurance reasons.

The damage that well documented turbine failures could have for the small-turbine market could also be severe.

Consumer awareness levels low and misgivings about the technology: If companies are proactive and strategic in approach, in accord with other efforts in the area by dedicated wind energy bodies and policy, this factor should be lessened considerably, though at present it may present a significant barrier to rapid market penetration.

Perceived negative impacts: Concerns over the effects of small wind are shared in part with those of their larger cousins; though, in many instances small turbines can be promoted on the way they negate many of the more important issue. A further bonus is that small turbines are unlikely to interfere with communications which cannot always be said of wind farms.[70]

Lack of available grid connection: Local electricity companies may limit the size of any turbines, and grid connection can be very costly.[71]

Network issues: According to the DTi, it is thought that network power quality and safety problems could be solved relatively easily through investment. Relative to the cumulative benefits, however, these cost estimates are worthwhile. It is likely that network reinforcement will be necessary in some instances, but also mandated to the benefit of all micro-renewables.

Physical: Many places of residence may not exhibit suitable structural strength to facilitate direct mounting, and in the case of blocks of properties, mast mounting of turbines may be unfeasible. Excessive turbulence, which is most likely to be found in urban settings, or exurban dwellings with particular topographic features, contributes to fatigue damage and reduces output power in most turbines. Vibration may also be an issue for direct mounting, exacerbated by turbulence, whilst the design-life could shorten, increasing net costs.

Other technologies: One of the biggest threats that micro-wind faces, is the possibility that the same effects (in the consumer's eyes) can be achieved in a more cost effective way, with a different microgeneration technology. Micro-wind should always have a place, but its scope will depend not only on progress in the field, but also on the progress made in other technological applications, such as photovoltaics. A brief synopsis of other viable technologies follows:

- PV. Technological development in photovoltaics is proportional to its popularity and wide-scale deployment. Luxemburg, for instance, boasts 58W per capita – the highest of any country, though Germany has a greater installed capacity and Spain also upped their capacity dramatically in the last year. Economies of volume, however, are counterbalanced to an extent through shortages in silicon at present, but breakthroughs offer to double efficiency of the technology, equating to slashed ROI times overall.[72] Photovoltaics are eligible for capital grants, have a very long operational life span, can negate tile replacement/roof repairs, and are known for reliability.
- Ground Source Heat Pumps and Reverse Cycle Heat Pumps are a viable technological alternative even for retrofit applications, and should yield 3kW of heat energy for every 1kW of electricity consumed in a well insulated house. It is a proven technology with 50 years of development and offers ROI times of 3-5 years.
- Solar Water Heaters have proven to be popular, are also eligible for full grants and offer ROI times in the region for 3-7 years. Their efficacy is also noteworthy.
- Hybrid PV for lighting, electricity and heating. Hybrid electricity generation and water heating through PV and heat exchangers, passive heating and cooling and natural lighting using fibre optics, are some of the newest applications to harness solar radiation.

In the same way as for micro-wind, the level of grant funding is tied to the annual increase in technology uptake for GSHPs under the Clear Skies initiative. Combined Heat and Power is increasingly being utilised by housing associations, and in some cases is operated with biomass fuels. Some of these options are themselves prohibitively expensive for many consumers, but continual improvement in such proven technologies will make them a very lucrative home-generation technology for those interested.

Thus, it is hard to imagine small-scale wind ever dominating a finite market that encapsulates so many diverse competitors, based on the evidence so far.

9.6 Summary and actions

While many of the points raised are true for micro-wind, and therefore represent opportunities for action, education and sustained growth, they equally apply to other microgeneration technologies. As such, since the most mature technologies are the focus of a greater research and development effort, and already enjoy economies of volume in excess of those which micro-wind can feasibly enjoy, micro-wind must undergo a serious transformation – and very quickly – to realise the potential so many believe it has.

It is estimated that there are 650-700 micro-wind installations in the UK at present, so only time will tell if some of the concerns and barriers highlighted pose the kind of threats to the future market value that are outlined. What is clear, however, is that based on the uncertainties, complexity and competitiveness of any Product Design undertaking, any means of simplifying the summation process, and translating the results into meaningful product constraints and specifications should go a long way to ensuring a product will best fit its target market.

Based on this need to allay some of the ambiguity in the research stage of turbine development, a Life Cycle Costing design method will be proposed for integration into the process in later sections, with the intention of facilitating a summing of the positive and negative effects of market dynamics on a potential product; hence, yielding an index of viability and driving decisions on design trade-offs. LCC is fast becoming something of a discipline, exhibiting bespoke application in many different industries, and may have a very useful influence on the design process for micro-renewables, with a little adaption.

10 Wind turbines

10.1 A very brief history of wind power

There are a number of excellent books detailing the history of wind energy, so this chapter will focus mainly on the aspects of wind turbine design and technology that will have the biggest influence on performance. This must include some shared aspects between large and small turbines, as often, technological advances will trickle down. As part of the summation and assessment of market forces, a technological review is important to see where lessons can be learned, and for prioritising design decisions.

The earliest recorded instances of harnessing the power of the wind were by the Egyptians and Cretans who had sailing ships. It is also believed that Indians had primitive wind mills up to 2400 years ago. In Europe, as early as the in the 13th century, the Venetian's had corn grinding and land draining windmills that could be orientated into the wind, which seems quite sophisticated given the level of technology they would have had. By 1608, large scale water pumping was in use. Panemones and other drag-based devices have been utilised through the ages, also.

Early, lift-driven turbines used a multiple blade set up – the higher solidity meaning that they could have a larger starting torque, which was desirable for effective water pumping. Lower tip-speed ratios aided low speed cut-in, and even at these times, wind turbines were predominantly of the horizontal axial kind.

For thousands of years, therefore, the energy in the wind has been converted to produce useful work; and latterly for irrigation and wheat grinding purposes. Progress in the field has been accelerating recently, due mainly to the increase in knowledge of fluid mechanics brought about from technological efforts during the early par of the 20th century, and most specifically in development of powered flight for fighter planes during the 1st World War[73]. It has been in the last thirty years that certain designs have risen to prominence and favour, although there is still a good deal of research and development directed at the exploration of variations on a theme; i.e., orientation, blade number, control and blade technology being among the most significant.

A recent consequence of this effort has been the development of small turbines specifically designed for domestic, and small-scale, industrial applications. Small-scale turbines have been in use for many years for desalination and water pumping, though they were conventionally designed for high starting torque, and low tip speed ratios. It was found that for power generation, lift-driven devices were most efficient, and have, as a result, become the most common example of the technology, and have been in use as trickle chargers in marine environments for many years now. Lift devices also generally take the form of vertical or horizontal axis turbines, though there are a number of very diverse alternatives ranging from vortex machines to pitot-static, pressure-driven, type turbines. Although HAWTs are favoured, both they and VAWTs, have specific advantages and disadvantages that may make them more suited to different applications, for example, certain types of vertical axis turbine may yield more energy in turbulent areas.

10.2 Turbine topology: the basics

Modern domestic wind turbines generally supply from 200W to 15kW. Favoured designs seem to be three or five blade configurations, and are most commonly up-wind HAWTs with a tail vane to yaw with the wind direction, although VAWTs and helical type VAWTs are also available – some of which are very innovative and claim to generate similar amounts of electricity. Turbine blades appear to be configured with a very obtuse pitch, but it is the relative velocity that determines the angle of attack at all wind velocities. Larger turbines tend to use blades with a higher degree of twist than their smaller counterparts, though manufacturers do not tend to state why this is, beyond reasons relating to costs. Blade twist is desirable due to the different relative angle of attack that each blade segment (from the root outwards) will experience, due to their radius and increasing rotational velocity. It is rare, on the other hand, to find variable pitch blades, especially of the active type, on small turbines, due to design complexity. Small wind turbines are configured for relatively high tip-speed ratios and can rotate at anything up to 1200rpm for typical turbines.

10.21 Safety and reliability

Reliability is important in any product, not least to protect the reputation and image of a company (one which often takes a very long time to build up), which itself can be worth a great deal of money. This is particularly so for company branding associated with ‘viral’ products, or those which can lay claim to a following, or fashionable, status. Furthermore, a designer has a certain amount of responsibility to ensure a product is fit for purpose, and should withstand even a degree of *misuse*, lest they be liable to recompense any parties that suffer loss due to the unexpected failure of a product.

Since turbine have the capacity to cause a great deal of damage in the event of blade shedding, for instance, and as such a great deal of attention has been rightly placed on reducing the likelihood of failure through improved materials selection, modeling, good manufacturing, fail safe and redundancy measures – the latter being a key deign principle referred to as function distribution[74]. Large scale turbines, in order to achieve this, commonly rely on duplication of sensors and processing devices to run self-tests, and monitor a huge number of parameters, which helps, in turn, to redress the failure of a sensitive system component.[75]

Some other aspects subject to scrutiny include yawing mechanism which will generate gyroscopic forces on the bearings. Fatigue, shock loading and bending stresses must also be accounted for, whilst micro-turbines, in close proximity to people must surely have secondary overspeed protection systems – an important aspect of turbine performance which has been overlooked in the past.

Safety and control are also inextricably linked in the case of wind turbines. By way of illustration, consider the following: an absence of suitable control measures and a loss of load in even a 2m diameter turbine with a 4kg blade, if enabled to increase its rotational velocity to 1200rpm, would generate centrifugal forces in the region of 32*10^2N[76]; unquestionably sufficient to cause severe damage in the case of blade loss. Considering this fact, it can also be understood that the consequences of ice shedding at high speeds are also undesirable. Though there are fairly successful methods of combating this occurrence[77], it is extremely rare to hear mention of them in micro-turbine circles.

Other issues that must be considered in the design of building mounted turbines include vibration, which, if severe, may compromise structural integrity, and has the propensity to loosen fastenings in many instances. A further example of the possible dangers of vibration were demonstrated when the combined effects of three, building-mounted, turbines on a property in Ireland, caused damage due to resonance. Attention must therefore be paid to installing multiple turbines with inherently dissimilar natural excitation frequencies.

On the same note, the risk associated with blade shedding has caused some turbine manufacturers to run tension wires inside blade-support arms (on VAWTs, particularly) to ensure they cannot travel far should the worst happen.

10.22 Blade design

Materials: Turbine blades have evolved considerably, even over the last twenty years or so, both in terms of efficiency, and rotor materials. Steel and aluminium blades were initially discounted due to weight and fatigue problems, but wood-epoxy systems found favour before fibre-glass polyester began to dominate the field[78]. While the DIY turbine builder still uses wood for cost reasons, most small turbine manufacturers are turning to modern polymers such as polypropylene and carbon or glass reinforced composites. Carbon fibre blades can now be found on some small turbines such as the Quiet Revolution range. Though carbon fibre is still relatively expensive, it displays excellent resistance to fatigue, and is very light weight and rigid, increasing response to quickly changing wind speeds common to the urban environment.

Aerodynamics: Longer blades, or those with an increased aspect ratio to be more precise, help to minimise the effects of tip loses which can be significant, and occur due to radial flow of air along the span of the aerofoil and then over the tip[79]. This is just one example of many measures found to increase the efficiency of wind turbines. Other research and development drivers for blade efficiency and performance include the move towards stall regulation in large turbine control, and the demands that it places on rotor performance.

It has similarly been found that blade soiling can have a surprisingly detrimental effect on blade efficiency, and this in turn has spurred on the creation of blades with leading edges that are much less sensitive to this occurrence. Such dedicated turbine blade families cater to the particular nuances and requirements of certain turbine topologies much better than traditional NACA type foils can. The result of the combination of these measures means that blade efficiencies are approaching their upper limits.

Blade colour is also an area that should not be underestimated by the design team, as black blades have been shown to combat blade-icing more effectively due to the heat transfer processes, while design trade-offs against composition and balance make the choice a difficult one. A black blade amongst others of an alternative colour, also aids the perception of rotor rotation for some birds, lessening the risk of impacts.

One further design driver, principally apparent in small turbine design is the need to reduce noise levels, and this has led to many interesting approaches, rather than simply trying to keep tip velocities as low as possible.

Blade number: An ostensible diversification from the favoured large scale generator configuration is that of blade number. Two, three, five and six bladed turbines are currently available, though the merits of this decision are not immediately apparent as all can demonstrate comparable levels of efficiency. Judging by industry figures, there is no advantage to be gained from increasing the number of blades on cut-in speed, though a higher solidity may improve starting torque. A negative impact of increased blade numbers may come at higher operational velocities, as blade interactions reduce efficiency, as each blade enters a region of turbulent air caused by the preceding blade. Experiments in this area indeed indicate that at a fixed solidity, three blades are the most efficient, while for instance, 15% solidity is a good deal better than 10%.[80]

10.23 Generators:

Almost all small turbines investigated rely on efficient permanent magnet, direct-dive generators, which has the effect of decreasing complexity, reducing weight and expense, and also increasing reliability (yet there are one or two which utilize induction generators which is most common in large grid-connected turbines[81]). Another benefit comes from the greater freedom the designer may have over form, since the nacelle need not be so large. Within this range of wind energy converters, it is possible to find both synchronous and asynchronous generators, 3 phase, star connected, integral inverters and a range of bespoke DC Voltage outputs. The precise generator configuration is a function of turbine operation in most cases, and is directly related, in turn, to the control mechanism. As such, control is a very important aspect of product functionality and merits its own section, which shall follow. Generator and control integration encompass the decision to operate a turbine at variable or fixed speed, with provision for blade pitch in some circumstances.

Two main types of generator in wide spread use – diversity exhibited particularly in larger turbines – are synchronous, and asynchronous/induction generators. The former incorporates a stationary armature and rotating field, which driven up to operating speed by the prime mover before grid connection, while the latter type, being most common due to robustness and ease of connection/disconnection, are self-excited using reactive power drawn from the grid to generate the required electromagnetic fields for power generation.

10.24 Applications:

Small turbines are actually the most common type in use, due to their popularity for desalination and irrigation. Modern micro-turbines signify a tangible need to moderate our reliance on fossil fuels to generate heat and power. In this capacity, they can often be found augmenting domestic energy supplies in both on, and off-grid locations, heating water to maximize useful output and in battery charging – the latter being a mainstay of the smallest turbines conventionally found on yachts and caravans. Perhaps one of the most significant technological improvements that facilitate domestic augmentation, and particularly micro, distributed, generation is the decrease in price of the inverter, though metering itself represents further cost at around £75-£200.[82]

10.25 Pitch and stall

Aside from electro-dynamic (load-dumping into capacitor banks or torque control), passive mechanical, and active mechanical braking, the two foremost means of controlling a turbine, are pitch and stall regulation. In a stall regulated turbine, assuming a load or other mechanism can hold the rotor speed constant, as the wind speed increases, the relative velocity of the wind at the turbine blades tends increase their relative perpendicularity to the flow direction, inducing separation and turbulence; hence, shedding load. Blade twist and the differences in relative velocity at different radii mean that stall is progressive. The grid normally provides the inhibiting torque requirement which holds the blade speed constant. If this load is lost, the blades may still produce enough lift to overspeed, so a secondary brake is universally mandated. A stall regulated turbine will run at approximately constant speed – a speed which is conducive to AC generation at the region’s standard frequency.

Alternatively, it is possible to vary the rotor geometry, actively or passively, such that the blades either steepen relative to the wind direction, or feather to maximize the instantaneously available power in the wind, or shed it. This method allows blade speed to be held constant rather than relying on the grid, if so desired, and permits moderate variations in rotor speed depending on generator type. Overspeed control, by feathering the blades, is also possible and gives a smoother result, but the blades must rotate through a greater angle, making this approach more draining on resources, and slower. Due to this fact, pitch control in high wind speeds may be insufficiently fast-acting, subjecting the system to high loads and stresses; as a result, high-slip generators and variable speed drives are the subject of much exploration, as power quality in pitch controlled turbines is of suitable worth to necessitate this.[83,84]

10.3 Design considerations

Turbine control is one of the single most important factors of turbine design, as it encompasses and dictates many other aspects of performance. It is therefore hospitable to a wide degree of diversity, and is one of the major design drivers.

Other design drivers include:

Building integration: There are a number of very interesting concepts in existence that serve to fuel invention in the field of renewable energy integration with building fabrics. An example might be utilising building form to augment or channel flow that a turbine will receive. Changes to building regulations may aid in the development of such solutions.

The EWEA also list the following:

- low wind and high wind sites
- grid compatibility
- acoustic performance
- aerodynamic performance (load and performance rather than simply ‘efficiency’)
- visual impact
- offshore expansion

One key area conspicuous by its absence, in relation particularly to small wind, however, is that of listening to the customer, or market needs. Successful product development would insist that this factor be regarded with the utmost of attention, perhaps more than that of any other area.

As can be seen, the design considerations for wind energy generators are convoluted, with not much to choose between options. Such dilemmas, it is suggested, can be greatly eased through a mechanism for analysing the problem in an holistic fashion: a unified approach. Though the nuances of the technological configuration may be decided traditionally on physical requirements, there is a lot more to ‘making the right choices’ than it first appears. In this way, a comprehensive methodology is justifiable.

11 Resource

11.1 Introduction

> “*Thus, manufacturers who say you will get an average of 6 m/s on the roof at your site and this will generate 1,000 kWh/year from a 2-meter diameter wind turbine will overestimate production by 10 (ten) times! Those that say you can get 2,000 to 3,000 kWh on your roof top will overestimate your production by 20-30 times!”* Gipe (2006)

It is commonly stated that the UK has the best wind resource in Europe at up to 40% of the total available to Europe as a whole, but how does this translate into potential for micro-wind when the densest population centres are our cities, which happen to consume the most energy, and are likely to have the least favourable wind regimes[86]? By understanding the characteristics of the wind resource it is hoped that the scale of possible market penetration can be identified, whilst also aiding the inception of performance metrics for technological benchmarking and comparisons; ultimately driving concept selection, performance evaluation and siting considerations. It may be valuable for a manufacturer to use a set platform to create derivative products individually tailored to specific wind regimes, increasing the possible market penetration from one family of devices.

11.2 The global resource

According to Sorensen (2001), the energy cycle in the Earth’s atmosphere comprises approximately $2.8*10^{21}$J of potential energy and $7.5*10^{20}$J of kinetic energy (in circulation), with respective turnover times of 27.5 and 7.4 days. This energy ‘reservoir’ is the result of solar radiation flux, which causes atmospheric winds (such as the jet stream, trade winds, polar easterlies, etc) to occur, due to the resulting temperature and pressure differentials through uneven solar radiation absorption by the Earth. Upper-atmosphere, geostrophic winds, however, are mainly driven by the Earth’s rotation, as opposed to the lower-atmosphere’s, tropospheric winds, which arise due to a combination of both solar radiation flux and rotation. Other forces at play include the effect of gravity on vertical pressure gradients, in effect cancelling it out and causing horizontal, pressure-driven winds to be many orders of magnitude larger. There are also inertial and frictional effects of varying magnitudes depending on the scale of interest. Friction for instance, manifests itself as turbulence in the atmospheric boundary layer, which is something altogether undesirable for wind energy extraction and is the property this chapter will focus most upon.

11.21 The local resource

The variation in wind speed over a year will have a huge bearing on the average energy yield of a turbine. It must be remembered, however, that large annual variations in mean wind velocities are likely, to the extent that meteorologists advocate considering wind speeds for five years before arriving at what they would call a “reliable average”. If such data are not available, then the accuracy of likely average wind speeds from one year’s worth of information, is in the region of 10%, with 90% confidence Manwell (2002). Similarly, variations in average wind speed can be seasonal, monthly and vary between night and day depending on location. In the UK, the prevailing weather system brings wind in off the Atlantic from the south west, so coastal and rural regions will have the highest average wind speeds, at approximately 5.5m/s + ~ 1 m/s, whereas in urban areas one would expect to have to subtract from the average UK wind speed of 5.5 m/s, dependant on various topographical factors.

11.22 Turbulence

On a short-term scale, stochastic variations in wind speed over an interval of 10 minutes or less are generally characterised as turbulence induced variations. Using a sample rate of 1 Hz in an anemometer, it is possible to graph these variations and, ultimately, to decide on turbine design considerations for anything from power quality to structural excitation and fatigue. Turbulence can be categorised as a fluctuation in wind velocity over a set time period, with an alteration of the vertical and/or horizontal components of direction also. This is in addition to the larger time scale alterations in wind direction, which necessitates a yawing mechanism in horizontal axis turbines. Yawing causes gyroscopic loads to be generated whilst also generating blade loading leading to fatigue in such components, yet the perceived benefits of HAWTs demand this provision. It is claimed, however, that short time alterations in direction can be coped with better by certain types of vertical axis turbines.

Turbulence is caused by “dissipation of the winds kinetic energy into thermal energy via the creation and destruction of progressively smaller eddies” Manwell (2002), and can be defined in terms of intensity, probability, autocorrelation, integral time scales and power spectral density functions, etc. The design implications, as intimated by the effort dedicated to understanding turbulence, are far-reaching.

The stability of the atmosphere is also an important parameter in turbulence characterisation, as it gives an indication of the atmosphere's ability to suppress turbulence or vertical components of wind flow. The stability in a certain location will therefore have an effect on the wind's velocity profile in conjunction with other factors, such as impact rates and terrain. To measure stability, it is first necessary to define an ideal lapse rate, based on an adiabatic, dry element of fluid. This will allow calculation of the change in temperature with pressure differentials caused by a change in height. Knowing such an important parameter allows for a further quantification of stability itself, through comparing the ideal and actual lapse rate for a given column of fluid, giving rise to the characteristic parameter, L, which is the Monin-Obukhov length[87].

As an indication of the result of differing L values: a negative Monin-Obukhov length is indicative of large heat flux and thus, transport and mixing in the region due, in turn, to convective action. In such instances, rapid mixing of the fluid will mean that there will be less of a variation of wind speed with height. The converse is also true, and in this way temperature can affect the velocity profile in different locations. Since cities can often be warmer than an equivalent area of rural landscape, it may be fair to surmise that the velocity profile, whilst intrinsically unfavourable due to topographical features in urban areas, can be further altered by the stability in typically industrial, and energy intensive, regions. One should expect that at lower heights, 0 – 25 metres for instance, on flat terrain, an unstable or neutral flow may have slightly higher wind speeds, but those which will be slower with increasing height than a stable flow. In built up areas where turbulence will be greater, the velocity profiles may be altered significantly, such that it would be difficult to simply characterise the flow with increasing height. Thus, an unstable portion of the surface boundary layer in built-up locations may increase the propagation of turbulence.

11.23 Documented effects

Suffice to say, these conditions are inherently unfavourable for generating electricity, and so a turbine intended for such a location must be well matched to the unique challenges it will face in operation – assuming of course, that it is actually worth targeting this sector, which is open to debate.

Due to the likely reduction in energy yield that turbulence will cause in unfavourable topographies, it is suggested that turbine manufacturers provide a means of factoring in roughness to the NOABL database for a consumer's particular location. A relatively simple application of the Von Karman equations should give the consumer a better idea of the economic viability of installing a turbine. Since there are currently no provisions for this, one could be forgiven for questioning the motivations of companies loath to do so. After discussion with one fairly disgruntled rooftop turbine owner, some consumers may expect yearly energy savings of closer to £10 than £100, this situation typifying the misapplication of technology, and to the potential detriment of the companies' reputation. The options for redress are to mitigate through better design or stress the importance of first accurately assessing/measuring the available resource.

There is however little data on whether the siting of a turbine on a roof reduces yield due to turbulence or increases it due to a 'wind flow enhancement' process, as the previous example cannot constitute an accurate assessment of the greater field of use, though it is vaguely representative of a growing school of thought:

> *"On the basis of the information currently supplied and the current costs, neither product could be recommended in terms of cost-effectiveness. There are clearly alternatives which offer a more attractive investment. This would not be the case were the turbines available at their target price."* MWEA (2005)

This statement was made in a feasibility study of two popular turbines based on an economic analysis. The price/kW for small-wind is also double that of large wind at present.

11.24 Boundary layer theory

Boundary layers – lift and drag. Laminar flow is dominated by viscosity; turbulent by inertia. There are two principle regions within the boundary layer:

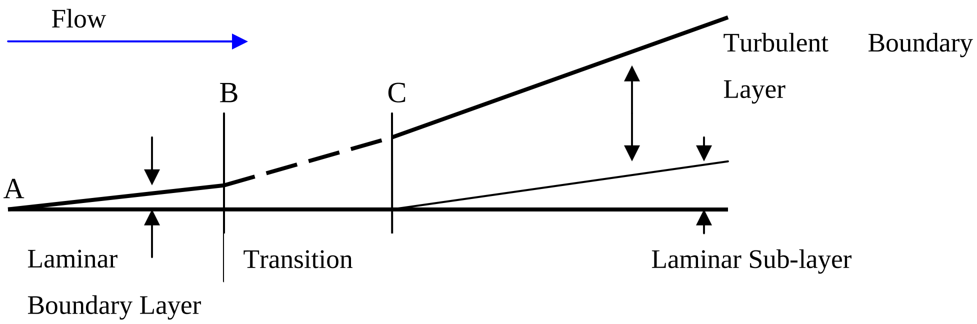


Fig.11.1 Turbulent boundary layer formation and shedding adapted from: Calvert (1981)

A thin laminar boundary layer begins to form at A where the flow meets the surface, assuming that the flow originates from the left in the diagram; as energy is lost in this region, the boundary layer keeps growing. If the region is thought of in terms of lots of little layers stacked on top of each other, each slow moving layer, due to viscous effects, will retard the progress of the next successive layer: it is subject to shearing. At a certain thickness the boundary layer becomes turbulent, denoted by point B at the transition point. It then also forms a laminar sub-layer at point C. At a certain point further along, due to the continual dissipation of energy, the turbulent boundary layer will become too large in relation to its energy and, thus, will peel off into a vortex and is shed as a wake after point C. This process can be seen to occur on an aerofoil, though a process known as flow separation can further be expected if the angle of attack becomes too steep, causing a dramatic reduction in the lift force. The point along the surface at which it occurs is dependant on certain factors that can be controlled, such as the curvature or angle of the surface.

For example, if the angle of attack of an aerofoil is not too severe, then the lift force will be many orders of magnitude larger than that of the drag acting on the foil. Once the angle of attack reaches around 20° however, (for a symmetrical NACA 00XX type foil for instance), the flow can no longer follow the surface, detaching and causing turbulence (flow separation), thus, creating turbulent regions of flow, and eddies. This principle is also apparent in other situations. Consider Figure 11.2 below:

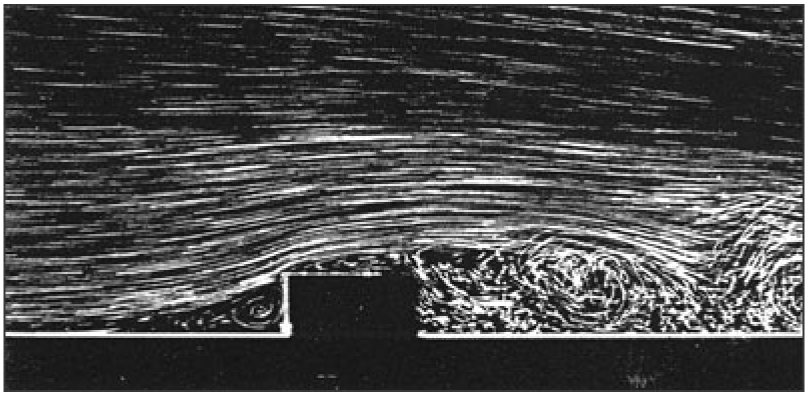


Figure 11.2 Flow visualisation: closer streamlines indicate faster flow

The figure above is generally representative of typical characteristics of flow meeting an obstacle. It should be noted, that it is rare that an obstacle in the path of fluid flow should produce a favourable alteration of the velocity profile. Such an instance might be if the obstacle in figure 11.2 was more hill-like. This would potentially increase the velocity of flow in the region directly above the obstacle, without inducing much turbulence, and lead to a greater energy yield for a device in this position. In reality though, it is more likely that a situation would arise where the velocity profile is significantly altered through flow speed reduction for some time after the obstacle is met by the fluid. Although it is recognised that turbulent regions of flow will tend towards the free stream velocity given enough distance after the initial obstruction, the likelihood in an urban setting is that the effects of turbulence will be compounded as the flow passes over successive, closely packed obstructions. Based on the principal mechanisms of turbulence, one could expect the flow to vary in lateral and vertical directions fairly quickly, thus a yawing turbine of heavy mass will struggle to orientate itself successfully in the optimal period of time. This effect has been observed directly (see “Rejected turbines” available at www.oceansolar.com), and is apparent by observing a weather vane on an urban dwelling for a short time.

In order to overcome these effects it will be necessary to locate a turbine such that it can reach above the separation line (see figure 11.2) if possible[89]. There will, however, be no guarantee that the flow will have recovered from preceding obstructions by this point, and can have a bearing on the safety of the installation.

According to Manwell (2002):

> *“A knowledge of the fundamentals of turbulence is important because turbulence causes random, fluctuating loads and power output, and stresses over the whole turbine and tower structure.”*

As a consequence, turbulence will have a direct impact on the design in the following ways:

- Maximum load prediction (and hence capacity)
- Structural excitation
- Fatigue
- Control
- Power quality

Furthermore, due consideration of the effects of a turbulent setting on performance has been cited by a small number of manufacturers as of chief importance on directing product configuration. Whether or not they will be successful remains to be seen, as data is limited.

12 Competitor benchmarking

A hugely important part of the Product Design effort is assessing the level of competition in the market place which should yield a good indication of the room for another product, an idea of a product introduction strategy, and a likely growth and market share forecast. A lot of similar competitors in any one market will mean a smaller share of the total, especially for newly established companies who must attempt to rise to dominance or cater to a niche sector, capable of supporting low-volume, high-price products.

Similarly, this exercise will give an initial indication of the range of features and product performance that the consumer will tacitly accept and attach value to. In so doing, it should be possible to isolate areas where the investigating company's product will excel and differentiate itself, what price they could hope to enter the market with and the level of agility that will need to be displayed to support average life cycle times.

Some of the main products in the market have been investigated with a view to establishing consumer choice, performance, costs and, essentially, to isolate the current state of the art – an important parameter in terms of design benchmarking and setting goals. One thing is clear though, despite accelerating uptake through increasing consumer awareness and capital grants, the economic feasibility some of the products listed – in terms of consumer expectations, be they realistic or not – can be slightly ambiguous and/or misleading and warrants remedy.

Product	**Ampair Pacific 300 Wind Turbine System**	
Application	Yachts, battery charging, small/remote domestic augmentation	
Description	Advanced aerodynamic blade design; elegant modern styling; emphasis on accurate (rigid) blade manufacture to reduce vibration and noise; sealed components; marine grade manufacture; powder coated aluminium casing and glass reinforced polypropylene blades.	
Output	Rated at 300W at 12.5m/s; 3 phase output with internal DC rectifier to increase power quality. 12V, 20A/24V, 10A DC. Performance at 5.5 m/s: 24W	
Parameters	Radius 1.2m; weight 14kg; mast mounted.	

Cut in/out	3 m/s after running in period; cut out n/a
Control	PowerFurl™ blade pitch control system cuts in at 12.6 m/s and allows turbine to continue to produce power
Costs	£1,000+, no yield data so hard to judge ROI, though application specific market sector, e.g., battery charging in absence of other means quite 'valuable'.
Design	Angular; colour scheme questionable, classic 3 bladed, upwind with yaw; no mention of specific design innovations or differentiation.
Other comments	Low power output compared to competitors. Targeted at specific sector of market. Not terribly feature laden.

Product	**Brumac Wind Systems Ltd,** only generic info available without request	
Application	Various from small to medium	
Description	N/a	
Output	50kW	
Parameters	N/a	
Cut in/out	N/a	
Control	N/a	
Costs	£80,000	
Design	Attractive design, though towers are scaffolding/mesh like on largest turbines	
Other comments	Useful for price comparison, although ROI unavailable at present. Significantly cheaper than some alternatives of similar size.	

Product	**Proven Energy WT600**	
Application	Domestic augmentation, not available with inverter , remote stations, farms, exurban, etc.	
Description	Down-wind, 3 bladed HAWT. No tail vane and pole mounted installation.	

	Steels, plastics and polypropylene; blades coloured black.
Output	0.6kW yields 900-1500kWh/annum in 4.5-6.5m/s average wind speed location. Rated rpm 500. 12, 24 or 48V DC.
Parameters	Rotor diameter 2.55m; weight 70kg; survival 70m/s (class leading)
Cut in/out	Cut in 2.5m/s, no cut out.
Control	Passive pitch and coning – excellent effectiveness and safety
Costs	Circa £9,000 installed, cables, delivered and with mast. Foundation extra.
Design	Aesthetics highly rated, extremely robust and well suited to harsh environments. Control system exhibits partial secondary functionality/redundancy, first placed for cut-in, but can be noisy, supposedly. Erected easily.
Other comments	Steep ROI potentially, thus larger turbines in range more attractive.

Product	**Proven Energy WT2500**	
Application	Domestic augmentation, available with inverter or direct heating package , remote stations, farms, exurban, off-grid, etc.	
Description	Down-wind, 3 bladed HAWT. No tail vane and pole mounted installation. Steels, plastics and polypropylene blades coloured black.	
Output	2.2kW@ 10m/s, 2.8kW@14m/s; 2,500-5000kWh/annum. Rated rpm 300. 24 or 48V DC and inverter for mains voltages.	
Parameters	Rotor diameter 3.5m; weight 190kg; survival 70m/s (class leading)	
Cut in/out	Cut in 2.5m/s, no cut out.	
Control	Passive pitch and coning – excellent effectiveness and safety	
Costs	Circa £10-15,000 installed, delivered with pole, cables but not foundation work. Cheaper for direct heating and includes inverter for grid connection	
Design	Aesthetics highly rated, extremely robust and well suited to harsh environments. Control system exhibits partial secondary functionality/redundancy, first for cut-in, but can get noisy. Erected easily.	
Other comments	ROI approaching life of turbine in the region of 20 years. Includes mechanical brake. Market segment well targeted with excellent growth rate. Proven tech’.	

Product	**Iskra Wind Turbine Manufacturers AT5-1** 
Application	Various/farms visitor centres, larger consumers, etc.
Description	Pole mounted, 3 bladed upwind HAWT. Strange nose cone and tail vane attachment. Glass reinforced polymer composite blades. Emphasis on blade efficiency.
Output	5.3kW in 12m/s; nominal rpm 200. Yield 11,000kWh in 5.5m/s wind, giving an ROI of approximately 15 years with grants, if achievable.
Parameters	Rotor diameter 5.4m, design life 20 years
Cut in/out	Cut in 3m/s
Control	Electro-dynamic braking system and passive blade pitching for overspeed
Costs	£18-22,000
Design	'Sleek' can be translated as slightly naked looking without nacelle. As with most, uses typical, direct-drive generator. Blade efficiency expected surely. Configurable electrical controller an interesting feature. Real emphasis on design for reuse and recyclability, and possible refurbishment at end of life.
Other comments	Useful for price comparison, although ROI unavailable at present. Significantly cheaper than some alternatives of similar size. Bold claims of low speed energy capture.

Product	**Turby B.V 'Turby'** 
Application	Rooftop, domestic, industrial, mast mounted
Description	3 bladed VAWT incorporating blades rotated slightly about their longitudinal axis. Composite blades. S phase synchronous generator
Output	Rated @ 2.5kW, 14m/s. Approximately 130w @ 5.5 m/s. 6.3A @ rated
Parameters	Rotor 2m*3m high; weight 136kg. Rated blade speed 42m/s. Survival 55m/s
Cut in/out	Cut in 4m/s; potentially no cut out.
Control	Not self starting; MPPT and electro-dynamic braking. Topology conducive to

	self regulation
Costs	£11,500 average costs, which is competitive for size. ROI dependant on actual efficacy.
Design	Intriguing design aimed at harvesting turbulent urban wind regimes. 20 year life span. Again warranty info limited. Good degree of fail safe and redundancy. Reasonably aesthetically pleasing. Erected easily and low maintenance.
Other comments	Claim to harness vertical components of turbulent air, also no need for yaw. Unclear if this offsets VAWT's lower efficiency, and rated output. ROI potentially high depending on this. Not good for many urban wind regimes, so should make this clear. Potentially bad press from misapplication.

Product	**Windsave WS-1000 System** 
Application	Building mounted predominantly or with support pole
Description	3 blade up-wind HAWT
Output	1kW @ 12m/s; claimed yield of 800-1200kWh/annum; 100W claimed @ 5.5m/s
Parameters	Rotor diameter 1.75m; weight 25kg, 'safe life' 10 years.
Cut in/out	Cut-in 3.5-5m/s at hub height
Control	Slows down at 15m/s and has back-up fail safe at 1100rpm
Costs	£1,600 installed
Design	Adherence to many standards; not hugely attractive, no sign of design methods. Price may be a compromise on components as design life short, thus possible net loss for consumers who install in an area with lower wind speeds.
Other comments	Unproven technology in potentially unsuitable urban rooftop market. No real test data; if aimed at urban dwellings, wind velocities used are optimistic. ROI of 5-7 years claimed. Possible reputation damage if customers base purchase on high wind speeds; otherwise, nice product at reasonable cost

Product	**South West Wind Power, Air X** 
Application	Battery charging, various applications
Description	Stylish 3 bladed, up-wind HAWT; inverted tail vane and black, carbon fibre blades. Incorporates battery charge regulator.
Output	Rated 0.4kW @ 12.5m/s; 12,24, 34, 48V DC output. Yields 456 kWh/annum in 5.4m/s average (360kWh in turbulent regions); 24kWh/annum in 2.7m/s average. ROI in the region of 20 years for upper end of yield.
Parameters	Rotor diameter 1.15m; weight unknown
Cut in/out	Cut in 3.6 m/s
Control	MPPT and electro-dynamic/electronic control induces partial shutdown.
Costs	£800-1,000 (for import, but cheaper in North America)
Design	Nice design with good range of features. Good available data on yield. Good package for the costs. No tower necessary and maintenance free. Lifetime unclear.
Other comments	Some negative press on internet concerning noise and performance in turbulence.

Product	**Marlec Rutland 913** 
Application	Marine applications/caravans cited, trickle charging
Description	Very small turbine, using 6 blades. Upwind configuration. Claimed to have ‘clean, aerodynamic lines’.
Output	Rated 0.25kW; 0.09kW @ 12.5m/s; rated speed high. 21/24V, output shown in terms of charging capability so ROI unknown
Parameters	Rotor diameter 0.91m; weight 10.5kg
Cut in/out	Cut in 3.4 m/s
Control	Thermostat protection mentioned. No evidence of any other kind.
Costs	£445

Design	Higher solidity for starting torque; not very attractive
Other comments	Lack of data. Catastrophic failure documented when tested, causing a lot of damage, though is supposedly very quiet.

Product	**Renewable Devices, Swift** 
Application	Domestic rooftop turbine, grid connected or direct heating.
Description	5 bladed, upwind HAWT with diffuser outer-ring. Mast mounted onto buildings. Features double tail-vane. Part owned by Scottish & Southern. Moulded carbon fibre blades, aluminium mast.
Output	Rated 1.5kW @ 12.5 m/s; yield claimed to be 2-3,000 kWh/annum.
Parameters	Rotor Diameter 2.1m; design life 20 years
Cut in/out	Cut in 2.3m/s, no cut out.
Control	Progressive passive furling and MPPT
Costs	Target cost £1,500, present cost circa £7,000 installed
Design	Middle of the road results for aesthetics. Complies with numerous standards, quiet operation, diffuser aids turbulent wind energy capture.
Other comments	No power curves and optimistic energy yield possibly misleading for certain consumers, thus damaging to reputation. ‘Harm neutral’ in its lifetime, though if yield is lower then this may not be the case, using a net positive quantity of energy. Lots of features and appealing prospect, however.

Product	**XCO2/Quiet Revolution, qr5** 
Application	Designed specifically for urban environment
Description	3 bladed, helical VAWT, pole mounted or above buildings; one moving part, most parts carbon fibre and epoxy resin; fully sealed. Helical blades for turbulence, vibration reduction and quiet operation.

Output	6kW, ROI claimed 15 years in 5.8 average wind speed
Parameters	Rotor Diameter 3*5high; design life 25 years
Cut in/out	Cut in 4m/s, cut out and shutdown at 16m/s.
Control	Overspeed braking and electronic control; remote monitoring as standard
Costs	£30,000 fully installed, expensive but lasts longer potentially.
Design	Rated number one on aesthetics in survey. Exceptional attention to design philosophies, simplicity, and high-end market niche targeting. Strong positive statement with high value addition, based on range of clients; Even website graphic design excellent; turbine range available as show piece ‘floating video-display’; tapered blades for noise shedding; demountable version for temporary applications. The qr2.5 (2.5kW) cheapest at £7,500 also
Other comments	Helical VAWTs more efficient, also cope with wind direction changes and turbulence. Start-up wind speed a little high but qr turbines targeting specific niches, so other factors important to consumer. May work well, but ROI optimistic unless well placed. Exemplary design practice.

Product	**Zephyr, Air Dolphin mark-zero**	
Application	Various domestic.	
Description	3 bladed, upwind HAWT with inverted tail vane. Mast mounted onto buildings. Carbon fibre reinforced, low-mass blades. ‘Multi-stagger system’ so no need for pitch control – claimed. Controller spins rotor for 10s in every minute when low winds present to aid start-up.	
Output	Rated 1kW @ 12.5 m/s; yield from test data on Zephyr’s Tokyo offices 235kWh/annum in 3.9m/s wind. ROI 13.7 years in 5.5m/s average wind. Will produce up to 3kW in 23m/s winds. 50W output at 5.5m/s	
Parameters	Rotor Diameter 2.1m; weight16kg; Cp=0.42	
Cut in/out	Cut in 2.3m/s, 50m/s cut out.	
Control	Power management, redundancy, fail-safes	
Costs	n/a, import from Japan	

Design	Exemplary design effort. Blades texture modelled on owl wings, organic-inspired forms, emphasise DFM&A methods and design methods (non-screw fastenings, for example), ultra-low weight, swing-rudder yaw system interrupts rotational inertia,
Other comments	Most commendable is that test data for lower average wind speeds are shown, almost solely among the manufacturers. Performance relatively good and focus on design and innovation excellent. Feature rich, though some of questionable value-addition to the customer. Overly complex in some regards which may threaten reliability, whilst cost is increased.

Product	**WES5 Tulipo**	
Application	Domestic/urban turbine, grid connected etc	
Description	3 bladed, upwind HAWT; active yaw mechanism; with back-up battery system for safety. 12m tower mounted. Glass reinforced epoxy blades. 3 phase grid connected with inverter.	
Output	Rated 2.5kW @ 9-20 m/s; yield claimed to be 7-8,000 kWh/annum @ 5.5m/s average wind speed. 140rpm rated; asynchronous generator and variable speed converter. 400V AC.	
Parameters	Rotor Diameter 5m; weight 800kg (including tower); design life 15 years	
Cut in/out	Cut in 3m/s, 20m/s cut out. Survival 59 m/s (IEC 61400-1 class 2)	
Control	Fixed pitch stall regulation, active yaw control and fail-safe passive shaft-brake	
Costs	n/a	
Design	Strange looks; adherence to many standards; tall mast should aid yield.	
Other comments	Limited data. Yield graph available for a range of speeds though excludes losses, and yield strangely large compared to competitors. Hard to compare without prices.	

12.1 Summary

The competitor analysis is representative of the main product types in the market at present. The Energy Saving Trust list eighteen accredited manufacturers under the Low Carbon Buildings Programme/Clear Skies Initiative, highlighting the wealth of consumer choice available, and eligibility for funding. On a different note, it was interesting to see that only a small fraction of the manufacturers investigated gave details on the energy used in product manufacture against net generated energy. Only Vestas detailed their adherence to ISO14040-43 for Life Cycle Analysis, which may be of great importance to the discerning consumer, and add significant value to their product over those of competitors. Worryingly, only one manufacturer mentioned the incorporation of preventative measures against blade icing in their product. It may be the case that others take it as a given that this will be an expected aspect of functionality, but as a feature, it may be regarded as one of high value to the customer, particularly if reliability and safety is high on their list of prerequisites.

Similarly, only two of the turbine manufacturers above emphasise their utilisation of best-practice design principles, and as such, it is no surprise that they have created some of the highest ranking products in the matrix below. While a certain level of subjectivity is unavoidable, turbines were ranked relative to their counterparts in terms of the product characteristics found to be most important in the eyes of potential consumers. These categories are:

- Value: represents the perceived value of each product in the context of their target sectors – target sectors being a division of the net market, which may respond in a certain way to specific product features; e.g., urban rooftop turbines, or turbines designed for remote locations and harsh environments. Value also incorporates, where information permits, an assessment of ROI and purchase cost to represent an overall, combined index and rank.
- Features: represents innovation, unique selling points, integrated inverters and so on – aspects of a product that may make the package more attractive than a competitor's. Some features, on the other hand may detract from overall functionality or increase costs.
- Safety: a measure of the level of device protection, overspeed, or similar. Also includes survival wind speeds and mechanisms which may reduce fatigue or load on the mounting structure, such as coning.
- Aesthetics: where information is available, turbines are ranked in accord with the basic turbine types that survey respondents found most agreeable.

Figure 12.11 shows a method of comparison adapted to cater for competitor's products. The benefits should be that a better picture of the leading products is built up, and secondly, a simpler method (than QFD for instance) has been created to allow the designer to decide which products in the target market sector will be most comparable, and the existing standard a consumer may come to expect. If a company is to introduce a new product into a developing market, it must be able to compete on merit, and more importantly, on value.

Turbine	Value	Features	Safety	Aesthetics	Sum	Rank
Pacific 300	9	10	10	12	41	**10**
Brumac	12	12	12	8	44	**12**
WT600	1	5	1	2	9	**2**
WT2500	1	5	1	2	9	**2**
AT5-1	3	7	9	11	30	**8**
Turby	7	8	4	5	24	**6**
WS-1000	6	4	8	7	25	**7**
Air-X	5	6	7	4	22	**5**
Rutland 913	11	11	11	10	43	**11**
Swift	8	3	3	6	20	**4**
qr5	2	1	2	1	6	**1**
Airdolphin	4	2	6	3	15	**3**
Tulipo	10	9	5	9	32	**9**
qr2.5	2	1	2	1	6	**1**

Figure 12.11. Table showing a method for competitor benchmarking.

Because a competitor has come out very well, that does not necessarily mean they represent the current technological state of the art; it could be concluded that some of the most simplistic of turbines can be the most valuable to the consumer. Proven are notable for their turbine's fitness for purpose, while conceptually at least, XCO2 embody the very spirit of good design.

In conclusion, it can be seen from this assessment that the ambiguity in the likely energy yields for a particular turbine may well end up disappointing the consumer – a happy customer will tell 3 people, and unhappy one 10. As some of the products mentioned have been created specifically to drive adoption for urban rooftop deployment, it may be said that to use such high average wind speed figures constitutes false advertising, and may be detrimental to the market as a whole. On reflection, it may be the case that in some situations, money may be better spent on energy efficiency measures than small turbines.

13 Control

13.1 Introduction

> "*Without some sort of control system, wind turbines cannot successfully and safely produce power*." Manwell (2002)

The limits on turbine performance are quite often thought of in terms of aero - or indeed hydro – dynamics, and how much energy can be extracted from the flow of the medium through the turbine's swept area. It stands to reason that there is an absolute limit to this value; based on diminishing returns, once the turbine begins to impede the flow to a significant degree; i.e., in extracting 100% of the flow energy, the flow would have to effectively 'be stopped' completely and stored up by the turbine, which is clearly unfeasible. Aerodynamic theory, being quite an established field of study, was once applied to turbine blades as a derivative of plane aerodynamics, facilitating the use, for instance, of the NACA family of aerofoils. Now though, as touched on previously, there are blades being designed specifically to cope with the type of use they will encounter on a turbine, increasing the annual energy yield in some instances by 30% Manwell (2002). With instantaneous aero-efficiencies of turbines now up to 0.46 for state-of-the-art technology[90], other areas can be focussed upon in the quest for increased yield. Due to the relationship between control and performance this section will concentrate on the various methods available, especially as they should form a cornerstone in the design of a turbine

The multi-disciplinary nature of wind turbines must not be overlooked either. For example, rather complicated mathematics and statistics can be readily applied to models (using historical data for example) of yearly turbine performance, with a view to optimising their capacity in a given resource climate, and it has been found that:

> "*Increasing the furling speed is a desirable strategy as long as the cost of strengthening the turbine is not too great.*" Bossanyi (1981)

Although this statement seems obvious, it refers to passively controlled turbines, and sums up the fundamental balancing act undertaken in any deployment scenario; further, it is a recommendation based on the extra energy that could be generated by operating in a marginally higher wind, based on exceedance statistics in the very early days of the UK's research effort.

Another difficult balancing act is that of control versus wind velocity variations, and the power that can be extracted from it. Calvert (1981) gives an analogy of a small mischievous demon sitting in the passenger seat of a car, whom also has a brake an accelerator at his disposal: turbine control is akin to the driver being expected to maintain speed and power – and smoothly – despite the efforts of the impish passenger.

13.11 The need for control

Control refers to the methods employed in a wind energy converter that prevent overspeed, or maximise output by tailoring rotor geometry and speed to the conditions, based on sensor readings, maps or algorithms. Control can be passive or active – favoured by small and large turbines respectively. A turbine requires overspeed control when it will imminently experience rotor speeds in excess of the rated design capacity; a consequence of loss of load during moderate wind speeds, or very strong winds even during normal operation.

13.12 Design cues

An important characteristic that is demonstrated in yachts is the ability to limit the effects of the aerodynamic forces they encounter. They do this by yielding to the wind at higher velocities by passively flattening themselves relative to the flow plane. This action has inspired various types of overspeed control, of which there are a great many further possibilities as shall be seen.

13.2 Types of control

Blade interaction: In larger turbines it is commonly cited that there are only two options for control: stall regulation or pitch regulation. Within these options there also exists several opportunities for further control mechanisms. This however does not preclude the stated methods for use in small-scale turbines; rather, secondary issues make the scope of choice wider. For instance, smaller turbine can generally cope better with the gyroscopic loads that yawing/furling causes; consequently, there are an abundance of variations on this theme in existence.

One suggestion is that, although not as a standalone application, there may exist an opportunity for overspeed protection by utilising the interference from blade interaction, that is, by using 'too many' blades. Though the negative impact on performance this might have could be prohibitive for certain applications, it has been evidently successful on some of the low-speed, high-torque, multi-bladed turbines used over the years, often for pumping water/irrigation such as the Cretan's triangular sail mills[92].

Maximum Power Point Tracking (MPPT): By making it possible to maintain the tip-speed ratio that correspond to maximum efficiency, through variable speed rotor arrangements, a wind turbine will harness the greatest quantity of wind energy posible. MPPT has been devised to facilitate this operation by means of an electronic controller. In order to sustain optimal generation, the electronic controller attempts to match the load curve of the generator (permanent magnet, synchronous type) to that of the turbine power curve. Power electronics and the control strategy in use will enable the torque of the generator to be varied in response to the available rotor torque. These control strategies are themselves the subject of much research and development work, are numerous, and can be seen in Turby and Swift micro-turbines.[93]

Tail rotor: It may be possible to cause a turbine to yaw proportionally out of the wind by means of a tail rotor. The benefits are twofold in that the engaging of a centrifugal clutch to operate the tail rotor will form a parasitic load on the main rotor, whilst simultaneously attempting to turn the rotor out of the wind through the lateral lift it generates.

13.3 Examples of control in small-scale wind turbines

Here follows a brief summary of the most popular passive control measures in current use:

Bergey Excel 10kW (upwind):

Utilises aerodynamic torque control using a rigid hub and three, torsionally-flexible blades. By placing weights in the blade tips, aerodynamic and centrifugal forces change the pitch and, hence the angle of attack, in proportion to wind speeds. The turbine positions itself with a tail vane and yaws partially out of the wind at 15m/s using aerodynamic and gravitational forces.

Proven, whole range, (downwind) 600W to 15kW:

Overspeed control is taken care of by patented "Zebedee furl", actuated by centrifugal forces. These forces cause flexing of the Zebedee hinge, in turn, pitching the blades towards stall. A secondary system, enabled by flexible blades, allows the turbine to withstand winds of up to

150mph through blade-coning. Coning dissipates a huge amount of energy as the swept area is effectively halved at maximum loading.

Renewable Devices, Swift, 1.5 kW (upwind):

A five-bladed turbine, Swift uses a twin tail-vane approach to allow the turbine to furl out of the wind due to an aerodynamic imbalanced of forces. The Swift is unique among the micro-turbines, as it uses a mixture of passive and active control. Power electronics (MPPT) coupled to passive yaw ensure that the turbine generates at claimed maximum capacity no matter the severity of conditions

Eoltec Windrunner E11-25, 25kW:

Centrifugal force-induced, feathered pitch-control.

Turby (VAWT) 2.5kW:

The Turby is a helical, Gorlov-style VAWT which, due to their nature, can often be self-regulating towards stall (Turby is also self-starting). This is augmented by MPPT, generator load-derived control in this instance.

Lagerwey LW18/80, 80kW:

This turbine is a two-bladed, upwind turbine, consisting of a hinged hub. Aerodynamic forces push the blades into partial coning and this action forces the blades to also change pitch. The effect of this control is a power output that is constant from 12.5 to 25 m/s.

ESI-80, 80kW:

This medium-scale turbine is completely stall regulated, but is augmented with aerodynamic blade-tip brakes which can either be actuated via solenoids or centrifugal forces, once a threshold has been passed. Pneumatic disk brakes are included for safety.

Vergnet, Wind Turbine Co and Carter Turbine ~ 250kW

These examples seem to highlight the upper limit for passive or semi-passive control. Respectively, the methods employed are: passive yaw (downwind turbine) for weight advantages; semi-passive (downwind) yaw using hydraulics, and on some of their turbines, patent-pending, constant-coning technology; **and** finally, pitch towards stall using torsionally flexible spars rather than blade pitch bearings.

13.41 Patents

An integral part of the Product Design research activity is the patent search. Failure to do so, coupled with the infringement of intellectual property rights, could prove very costly to a company through law-suits, etc. An added bonus is that it is sometimes possible to uncover patents that are approaching the end of there twenty year duration, which if not renewed, can be claimed by other parties. As an integral part of this thesis is following a modified design process, a patent search was conducted, through which several were uncovered – the more relevant of them are shown below. This activity was a precursor to the concept development phase which is demonstrated in section 15, in order to create methods for appraising technology and removing some of the difficulty associated with setting design specifications and constraints.

1. A variation on the MPPT tracking theme is proposed in a patent owned by, Salvage, Thierry, involving DC stator injection as a means of altering generator torque.
2. Patent number JP60150481 describes control by means of solenoid proportional relief valves, and hydraulic pressure related to turbine speed.
3. Patent number: WO2006030190 granted to Proven Energy describes a method of overspeed protection for troposkien-type VAWTs. Using a centrifugally actuated mechanism, the torsionally flexible blades are twisted by up to a half revolution, effectively obviating the lift generated in the untwisted section.
4. Other patents include overspeed protection through passive, centrifugally operated pitch control for a HAWT and blade rotation about the longitudinal axis in an H-type VAWT

Conclusion: Thus, by conducting a comprehensive review of the field, industry-proven means of overspeed control can be further appraised, and their suitability ascribed, particularly to aid product topology decisions and design improvements.

14 The voice of the customer

14.1 Introduction

A questionnaire was created entitled "Public Attitudes Toward Wind Power", on a survey creation site. An invitation to complete the survey was sent out to friends, family and colleagues firstly, to ensure a good spread of knowledge and awareness. Thereafter, an invitation to complete the survey was placed on a wind energy internet site's forum called Yes2wind.co.uk. The response rate was quite good with over 120 attempts in a little over 3 weeks. The forums on this particular site are frequented by those of both the pro and anti-wind persuasion, thus the sample should be fairly balanced, though it is possible that the majority of respondents are quite knowledgeable in the field. For example, to ascertain the level of knowledge the statement was made:

"I know a lot about wind energy", which the respondents were then asked to qualify by selecting one of five options (unless otherwise stated this was the convention for all the questions):

Agree strongly	25.86%
Agree slightly	27.59%
Neutral	17.24%
Slightly disagree	13.79%
Strongly disagree	15.52%

In this case, it would appear that the respondents mostly considered themselves to be knowledgeable in the field. Since the question includes, however, a non-quantified, subjective term, ("a lot") a degree of uncertainty will have been created in the answer, depending on the semantic awareness of the respondent. It can be said however with a degree of certainty that most people questioned have a good knowledge of wind energy, at least 54% but probably anything up to 80%. The remainder of the results are as follows:

1 Wind farms destroy the natural environment, (%):

STA	23.88
SLA	10.45
N	13.43

SLD	23.39
STD	29.85

~53% majority think wind farms do not destroy the natural environment.

2 Wind farms look nice:

STA	20.59
SLA	25
N	2.94
SLD	29.94
STD	23.53

~Slightly more people (<10%), in a very diametric sample, think wind farms don’t look nice. This is quite an even split and is indicative of strength of feeling on the subject.

3 Wind turbines kill an unacceptable number of birds:

STA	17.91
SLA	4.48
N	32.84
SLD	16.42
STD	28.36

~Majority disagree (45%), though a large number do not yet have an opinion.

4 Wind farms are too noisy:

STA	18.46
SLA	10.77
N	21.54
SLD	16.92
STD	32.31

~This is quite even, with slightly more people disagreeing than agreeing. Again many are undecided. It cannot be determined if these figures are based on opinion or experience, but perceptions are what is most interesting at this stage, as they are generally malleable if approached correctly.

5 Wind farms will put-off tourists from coming to areas where they have been deployed:

STA	22.39

SLA	20.90
N	11.94
SLD	22.39
STD	22.39

~To all intents and purposes, this result is indicative of an even split. When considering the SWOT analysis from a previous section, there exists a good opportunity for redressing concerns in this area, which appear to be disseminated by certain bodies.

6 Wind energy is reliable:

STA	19.12
SLA	36.76
N	8.82
SLD	14.71
STD	20.59

~Generally a positive result, with a reasonable margin of support. Again represents an opportunity for redress.

7 Wind energy is too costly:

STA	16.18
SLA	7.35
N	27.94
SLD	26.47
STD	22.06

~This gives an interesting result, especially when considered against the number of respondents who claimed not to know a lot about wind energy: a very similar number, though there may be other factors.

8 Wind energy will off-set over-consumption:

STA	5.97
SLA	16.42
N	37.31
SLD	10.45
STD	29.85

~May yield interesting insight into the perception of wind energy efficacy when viewed in context with other questions. Also perhaps indicative of lack of understanding, as it is the author's view that harvesting free, renewable energy by its very nature, must satisfy this statement.

9 We should concentrate on other forms of energy generation:

STA	33.33
SLA	18.18
N	10.61
SLD	30.30
STD	7.58

~Majority (52%) agree with the statement, (versus 38%). Strength of feeling however suggests that the result is actually further apart than this.

10 Government policy forces energy generators to deploy wind farms:

STA	23.88
SLA	19.40
N	32.84
SLD	14.93
STD	8.96

~As this has indeed been found to be a major contributory factor in the deployment of wind farms, perhaps the results suggest that people are unaware of the market forces at work, or how they may translate to the small-scale.

11 Wind energy generation is the responsible thing to do

STA	40.30
SLA	31.34
N	5.97
SLD	4.48
STD	17.91

~A huge majority of those sampled (71.64%) agree in some capacity with this statement, which represents very solid ground for marketing.

12 Climate change is a fact

STA	61.76
SLA	20.59
N	8.82
SLD	4.41
STD	4.41

~Evidence is increasing, but it is debatable whether climate change constitutes a ‘fact’, as yet. A huge majority of people (82.35%) have accepted it to be so, however, based on media portrayal and government policy, it would seem.

13 I don’t want wind farms near my house/place of residence

STA	25
SLA	16.18
N	4.41
SLD	22.06
STD	32.25

~Quite an even result, but a good micro-wind strategy could appease/delight each group as mentioned earlier.

14 Wind turbines can benefit society

STA	38.81
SLA	34.33
N	4.48
SLD	7.46
STD	14.93

~Not a hugely insightful question

15 I would like to generate some of my own electricity

STA	66.18
SLA	19.12
N	11.76
SLD	1.47
STD	1.47

~Highest majority yet would like this opportunity; if, as we shall see, the ‘price is right’, for example.

Section 2 questions:

1 Small domestic turbines will solve many of the issues facing large farms

STA	20.63
SLA	38.10
N	22.22
SLD	7.94
STD	11.11

~A resounding positive.

2 The cumulative benefits of micro-renewables are worth while

STA	42.19
SLA	25
N	20.31
SLD	9.38
STD	3.12

~Again, perception is very positive.

3 I would buy a micro-turbine if they were cheap enough

STA	41.94
SLA	30.65
N	6.45
SLD	9.68
STD	11.29

~A large majority claim they would purchase a turbine, though it is unclear how cheap is cheap enough. One would expect this number to fall quite severely as a result of ROI, resource, structure, funding, etc; or supplanting by other, more viable technologies, which is a very real threat.

4 Micro turbines must look nice

STA	14.29
SLA	34.92
N	11.11
SLD	25.4

STD	14.29

~Aesthetics are important for all but a very small majority who by calculation would buy a turbine, but don’t mind how it looks.

5 My neighbours would object to me installing a micro-turbine

STA	14.06
SLA	18.75
N	48.44
SLD	10.94
STD	7.81

~ Potentially indicates that while most people are for micro-turbines, those same people themselves do not know this fact.

6 A return on investment for a micro-turbine should be less than 10 years

STA	35.94
SLA	35.94
N	20.31
SLD	3.12
STD	4.69

~ Those that disagree may be doing so for other reasons, such as: ‘It is of no consequence as I would never own a turbine’, etc. Otherwise, it may be said with relative confidence that current ROI levels for domestic wind, even at there very optimistic levels, are unacceptable to over 70% of the (70% itself) potential consumer base.

7 We should all generate some of our own electricity

STA	48.44
SLA	31.25
N	7.81
SLD	7.81
STD	4.69

~ Peer pressure/viral marketing opportunities abound based on this result. Interestingly, it may be concluded that circa 10% of those polled think we should generate our own electricity, but by some other means than wind energy, which still leaves a lucrative customer base.

8 Micro-wind turbines should be very quiet

STA	50
SLA	34.38
N	9.38
SLD	6.25
STD	0

~ Very high up the list of customer needs therefore. Not one respondent thought turbines should be very noisy, as the logical opposite of the initial statement.

9 Micro-turbines could generate a third of my annual electricity (Poor q., and un-quantified)

STA	7.81
SLA	28.12
N	43.75
SLD	6.25
STD	14.06

~Too ambiguous to offer any real insight/degree of certainty as to results.

10 I am careful not to waste electricity

STA	43.75
SLA	32.81
N	6.25
SLD	14.06
STD	3.21

~If this result accurately mirrors the ethos of the remainder of the UK's population, renewable energy would probably not be such a requirement; though this is still positive, especially regarding the relationship between consumer empowerment and micro-wind.

11 If I was to buy a turbine, aesthetics would be more important than energy yield

STA	1.59
SLA	15.87
N	11.11
SLD	30.16
STD	41.27

~For a significant number of people this is true. This result helps to begin to build a hierarchy of product needs – aesthetics being somewhat further down the list than energy capture.

12 If I was to buy a turbine, safety would be the most important thing

STA	32.81
SLA	31.25
N	15.62
SLD	18.75
STD	1.56

~For many this is true (64%).

13 If I was to buy a turbine, cost would be the most important thing

STA	20.31
SLA	40.62
N	7.81
SLD	25
STD	6.25

~Thus, at least 20% of those questioned have either changed their minds from safety as above, or regard both qualities as equally important.

14 I would like to make money by selling electricity back to the grid

STA	25.40
SLA	23.81
N	30.16
SLD	7.94
STD	12.70

~Establishes base and latent needs that can be utilised in many ways.

15 Micro-turbines will also kill birds

STA	1.59
SLA	19.05
N	39.68
SLD	30.16
STD	9.52

~Indicative of uncertainty in the area, most likely due to a lack of data or well publicised concerns. Bats may be an issue also. It is a positive that pubic perception has not been polarised before market fruition, in terms of commercial opportunities.

16 The wind industry doesn’t listen to our opinions and desires

STA	28.57
SLA	15.87
N	41.27
SLD	11.11
STD	3.17

~Either 15.27% of the population are involved in lobbying, actively interested or are employed by the wind industry; or, the others are cynical/apathetic or are being ignored/feel grieved in some capacity. Thus, this is a rather confusing statistic, and of little merit.

Section 3: Aesthetic appreciation.

Respondents were asked to rate the following turbines:

1)

Really like	50
Like a little	15.91
No opinion	20.45
Don’t like much	2.27
Really dislike	11.36

2)

Really like	4.55
Like a little	15.91
No opinion	27.27
Don’t like much	29.55
Really dislike	22.37

3)

Really like	11.36
Like a little	11.36
No opinion	20.45
Don’t like much	20.45
Really dislike	36.36

4)

Really like	13.64
Like a little	27.27
No opinion	22.73
Don’t like much	15.91
Really dislike	20.45

5)

Really like	11.36
Like a little	36.36
No opinion	27.27
Don’t like much	9.09
Really dislike	15.92

~ Results were: Helical VAWT a clear favourite, followed by 3 bladed HAWT, 5 bladed HAWT, followed not so closely by 3 (carbon) bladed VAWT and Darrieus style turbine, the last two being almost equal when averaged.

Blade colour is, thus, less important than style, and an organic or ‘traditional’ forms are favoured judging by written responses from a number of people. (The large percentages of respondents with no opinion was due, in part, to some initial problems with links to the pictures.) This appears to refute the commonly held perception that VAWTs are more aesthetically pleasing than HAWTs, as helical (commercial) turbines are new entrants to the fray. Indeed the egg-beater type Darrieus was the most off-putting, closely followed by a rather innocuous looking VAWT. Since 49% of people stipulate that turbines must look nice {Q2.4}, as a technology type, and circa 70% state that energy yield is more important than aesthetics, it can be said that a turbine with the best balance of these two areas, and obviously, safety, will perhaps be the most saleable.

Section 4.

1 £2000 is too much to expect people to pay for a micro-turbine

STA	22.41
SLA	34.38
N	18.97
SLD	18.97
STD	5.17

~A small percentage of people, therefore, advocate paying more than £2000 for a turbine provided the ROI is less than 10 years. Conversely, most think (57%) that even with a maximum ROI of 10 years, £2000 is still too much to expect people to pay. This monetary figure represents the target price of a well known turbine, plus installation, plus associated ancillaries, plus grid connection in the (very) best case scenario. A 30% capital grant and low interest loan may make this more lucrative, but the technology must still pay for itself within around 10 years and that, in turn, gives a realistic target selling price in the low hundreds based on anecdotal evidence from current turbine owners over likely energy yields. Economies of volume will drive down costs only if volume growth can be sustained, which is unlikely if owners report that the technology does not meet purported performance levels, as is happening slowly.

2 Looks are more important than energy generated in a small turbine

STA	6.9	{STA	1.59 }
SLA	10.34	{SLA	15.87}
N	13.79	{N	11.11}
SLD	36.21	{SLD	30.16}
STD	32.76	{STD	41.27}

~Compares well to a previous version of this question, with minimal changes in response {Q2.11}.

3 If I owned a turbine I would be willing to maintain it

STA	27.59
SLA	44.83
N	10.34

SLD	12.07
STD	5.17

~Inference being that reasonable degree of home maintenance is acceptable, perhaps inspection or minor component replacement in the case of any consumable items there may be.

4 I think there is no place for micro-turbines in society

STA	3.45
SLA	3.45
N	17.24
SLD	20.69
STD	50.17

~Again quantifies the basic market scope.

5 The government should do more to educate people about sustainability

STA	72.41
SLA	17.24
N	6.9
SLD	1.72
STD	1.72

~Is it really the Government’s place? This is a very interesting result, and one may, therefore, draw positive inferences as to the receptiveness to the messages of sustainability – in theory; the reality might be quite different. It also may be the case that the respondents thought that they knew a great deal about sustainability but wanted the government to teach others more.

6 Trying to appear ‘green’ is fashionable

STA	32.76
SLA	44.83
N	8.62
SLD	8.62
STD	5.17

~Interesting, though this does not necessarily separate those who recognise the fashion, and those who would subscribe to it. It can be a difficult thing to be different in modern society, particularly due to peer or collective pressures associated with fashion, so perhaps this is a latent product need, in some respect also.

7 We should all generate our own electricity (Repeat question and also very ambiguous).

STA	31.58
SLA	38.60
N	10.53
SLD	12.28
STD	7.02

~Positive response.

8 Energy storage would be a problem with micro-turbines [inherently erroneous => pos. leading].

STA	10.34
SLA	29.31
N	34.48
SLD	20.69
STD	5.17

~As this is one of the main selling points of the technology, it is obvious that it is not very well publicised, hence; not creating the desired consumer awareness of the issue; or, that the question was too leading on a subject that is not well understood.

9 Wind turbines should be completely avoided

STA	13.97
SLA	0
N	6.9
SLD	20.69
STD	58.62

~In no uncertain terms, only a small minority completely disagree with wind power.

10 The colour of a turbine can make it look better or worse

STA	24.14
SLA	34.48
N	29.31
SLD	5.17
STD	6.9

~Generally an expected response due to the psychological attraction and responses to different colours that people commonly display. Somewhat bespoke turbines, and thus, perceived choice of exact specifications, will also give a customer a feeling of choice, and of having their needs catered to.

11 My neighbours would complain if I installed a rooftop turbine

STA	13.79
SLA	31.03
N	32.76
SLD	15.52
STD	6.9

~Probably most useful to speculate on neighbour-neighbour relations.

12 Micro-turbines are an alternative to more wind farms

STA	12.07
SLA	34.48
N	27.59
SLD	10.34
STD	15.52

~The majority agree, and this, as has been discussed, can constitute an Opportunity.

13 Fossil fuels will run out in the next hundred years

STA	29.31
SLA	36.21
N	13.97
SLD	8.62
STD	12.07

~Occurrence unlikely due to market pressures and scarcity pushing up prices beyond the scope of most people’s disposable income. At the present rate of consumption, however, it is likely that oil and gas reserves would be used up within this time frame, dependant on the extent of new reserve discoveries, which is likely, though even these costs will become increasingly prohibitive. Thus, this question ascertains the perception of the commonly cited argument *for* renewables, that: ‘fossil fuels will run out in the very near future’. This statement has therefore been mostly accepted, though a reasonably high number disagree, and probably correctly so.

14 Nuclear energy will run out in the next 500 years

STA	17.24
SLA	15.52
N	43.10
SLD	12.07
STD	12.07

~This is potentially the case based on estimates of easily extractable Uranium reserves, and the likelihood even of finding ten times more[94]. However, extraction techniques and reprocessing may increase the longevity of the resource, but this would surely be offset by the increase in use, in lieu of other forms of energy. Ambiguity aside, this question basically confirms that people are not aware of the finitude of nuclear fuel, such is the lack of debate surrounding it.

15 It will be hard to get planning permission for residential turbines

STA	19.3
SLA	42.11
N	19.3
SLD	14.04
STD	5.26

~It should not be the case based on Government changes to the planning system to this end. Consequently, there exists scope for educating the public.

14.2 Conclusions

The aesthetic qualities of wind turbines features highly on the list of desirable qualities in the consumers mind. It has been found that this is less important however than ROI, purchase cost and safety. Reasonable maintenance will not be a problem for consumers, but perhaps they should not be trusted to maintain parts that may cause compromise turbine integrity or safety. It also appears that energy yield is more important than aesthetics, which may in turn be a function of desire to offset over consumption, follow fashion and be seen as green, act responsibly and also make money from generating electricity.

The potential market base is very large, though it is unlikely that those eligible, or in a financial position to purchase the technology, will number anything close to those that voice support and realistically consider ownership of micro-turbines.

Based on the information gathered thus far, and after scrutinising the DTi's projections, a more realistic saturated market may take in about 6-8% of the population based on the following logic: the UK's population currently stands at over 60 million people, who live in approximately 24 million dwellings, of which 65% are privately owned[95]. Taking account of population densities and the unsuitability of most urban areas for generation, a generous estimate of those who are in a favourable location for wind resource would be 50% again, (80% of the UK's population live in urban areas[96]) which leaves a total of 7.8 million homes. Based on survey results, with 70% approval of micro-turbines, and 70% percent stating they would purchase a turbine, the figure falls to 3.8 million homes. Assuming that the technology is financially attractive, and based on the fact that urban areas are richer, it is assumed that 50% of this number, in reality, would buy a turbine and could *afford* one (1 in 4 UK inhabitants live in poverty[97]), especially considering consumer debt levels in the UK. The final number then is in the region of 1.5-2 million homes, which equates to circa 8% of the population, and £2.75 billion over 40 years, or £68 million per year based on a target price of £500 per unit. Clearly this is a best case scenario, and with a 10% profit margin, with the optimum technology, marketing and PR strategies, small wind manufacturers in the UK may expect to take away a share of £6.8 million per year, averaged over the next 40. Clearly, more companies will enter the market, meaning that since the market will start slowly and pick up pace, the actual amount available for any given manufacturer, everything else being equal, will not be that much.

Industrial sectors could add to the total market worth, but energy intensive industries might favour more economically viable, microgeneration technologies. If the criteria from the above example are administered to the 1.64 million VAT registered enterprises in the UK, net annual worth goes up only a fractional amount[98].

It would be pertinent to allow more time for a more focussed study, drawing on the lessons learned from this approach, whilst also targeting a much larger sample to gain a better insight, but it is clear that something dramatic must take place in the small wind industry to possibly achieve anything close to the potential. It is difficult to conceive that a niche, technology-push, product will achieve the levels of market penetration, even with support, that will enable it to compete with other forms of generation. The only realistic way of achieving this is to down scale the product, and reduce cost dramatically, *before* relying on economies of volume.

Every last drop of expertise, competitiveness and innovation needs to be harvested from the Design Process for this to happen. Even then, it is still a risky sector due to the likely increase in competition and the uncertainty that may arise due to unproven technologies in many instances. The market could easily rise up against small-wind and inhibit its long-term viability.

In conclusion, small-wind can exist in two forms. Low volume, high-value niche, as a product primarily, and with little cumulative short term benefit for society, or high volume, lower capacity and priced technology, which will have a slightly greater cumulative societal benefit; capacity in the region of 0.0054% of the UK's energy requirements, based on 1.5kW generators operating at a capacity factor of 0.33.

15 Integrating front-end data into turbine design – findings

15.1 Introduction

If it is not a challenge to collate and integrate data from the front-end of the design process into the development of a product of this type, then insufficient exploration will likely be the cause. The competitive nature of product development and sales cannot readily accommodate poorly designed goods, and in many cases it is not simply enough to satisfy the customer – a company should strive to delight them. In this capacity, there will always be difficult decisions to make regarding final product topology, but their severity can be effectively reduced through the correct blend of tools and methods. Such principles were established to facilitate an organised and comprehensive approach to the Product Design process whilst, consequently, aiding in the pursuit of quality and due diligence.

It has been seen thus far that the range of design consideration that result from all the forces at work in the market, the necessity of correct business orientation, and the range of possible technological solutions to a given problem, equate to a very daunting task. As such, and since the required approach for different types of product differs substantially, it is often necessary to modify and incorporate aspects of available tools into a more effective form. This is precisely what has been required during this investigation, and the different means of problem solving that have been utilized are now presented.

15.2 Problems and Solutions

Adhering to a select few key principles should help focus the design effort upon the most pertinent aspects of information. As a rough guide it is suggested that these four rules be followed when undertaking a small-scale turbine design exercise:

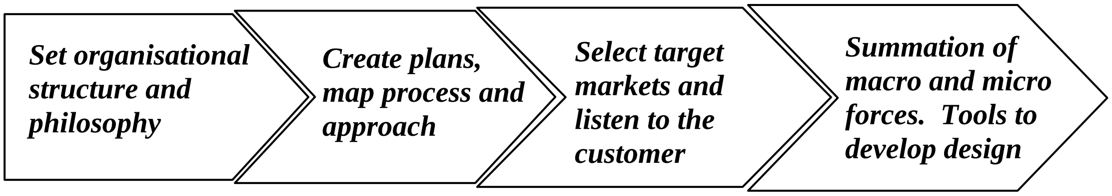


Fig. 15.1 Four basic steps to ensure readiness in adapted design process

1. Set goals and align the organizational approach in such a way as to most effectively utilize available resources. More specifically, if the goal is to compete in a market sector on price, first and foremost, then the design and manufacture activities must be conducive to reducing cost through design, increasing production efficiency and imbuing the product with perceived value. Quality should be synonymous with value and safety, as these factors have the greatest propensity to generate profit and loss, depending on the level of achievement. Similarly, product orientation, be that market-pull or technology push, or similar, will have a bearing on the necessary steps to ensure maximum market capture. An assessment of which successful business process philosophies may be relevant to the task and implement as required; e.g., Concurrent Engineering.
2. Develop or modify methodologies or process models that may be of use in structuring and organizing all the required aspects of the design process, tailored to the product and market in question. Planning and setting goals and milestones is a key underpinning of design management philosophies, and there is a great deal of benefit to be had from extending this to process models or otherwise prescribed approaches.
3. The merits of a conceptual idea are not proportional to its saleability, and this being the case, companies have been known to be reluctant to shelve a project once it is underway. This primary focus should be on the needs of the customer, whatever segment of the market they may be in, and as such, if the suitability for purpose of a product is questionable then the company must be prepared to regroup and diversify.
4. For turbines in particular, market dynamics are more complicated than they may be in other areas. This is due to what will be defined as macro, and micro, market forces: the former refers to influences on the potential worth and growth of a target market by stimuli of a grand scale; for instance, the present and future politics of a region, social, collective moods and attitudes and the threats posed by competition; i.e., things generally outwith the immediate control of the company, and those which may pose significant barriers to product uptake. The latter, micro-forces, refer to the choices a company makes in response to market dynamics, selecting target market sectors themselves for instance, and importantly, the embodiment of the voice of the customer; i.e., how consumer needs, desires and aspirations can be met.

The last point poses some problems as the summation of macro and micro-forces, in order to confirm design direction and generate specifications, is made difficult through the need to ascribe worth, risk, reward or feasibility, to the prominent issues. Again, in some situations the integration of set design disciplines into the fray should prove valuable. One that springs to mind is Life Cycle Costing, which itself has been modified and shoehorned to aid many diverse product and service areas in the past. LCC will help a company to foresee the true life costs of a product and mitigate as necessary; naturally these costs are not simply those associated with acquisition, use and disposal, but encompass a much wider spectrum. A particularly useful guideline defined in British Standard document BS EN 60300-3-3:2004 illustrates how a company may assess the cost and value of PR work in certain situations, as a means of limiting damage to reputation, or indeed, as a means of stimulating consumer awareness, for instance.

The other issue which warrants much study, is how best to translate information gathered from market and competitor research into design metrics, constraints and parameters to eventually derive the PDS. Suggested methods to achieve this are as follows:

Basic cost reduction: Manufacturing philosophies should help in this regard, along with facilities design in the case of in-house manufacture. In terms of Design Methods, a comprehensive application of Design for Manufacture and Assembly should be required. This is true whether parts are manufactured in house or by other companies. In order to implement DFM&A effectively, the design team should be well versed in its principles before deigning begins. A review and design appraisal may highlight further improvements at a later stage.

Design for the Environment: It is logical that a company producing a ‘green’ product should ensure their product conforms to guidelines on the environment, reuse, disposal or similar. Based on the fact that only one or two manufactures mentioned applicable standards and net energy use or consumption in manufacture, it is questionable whether many domestic turbines can actually offset any carbon emissions in their lifetimes. As mentioned earlier, the discerning customer may demand such information – and rightly so. Break even or ‘harm neutral’ scenarios might necessitate a rethink of the design.

Competitor Benchmarking: The merits of competitor analysis of this form were discussed in section 12, but to recapitulate, techniques such as these help a design team to isolate aspects of performance wherein competitors may excel. It should, similarly, help define basic features and performance expectations, and allows weaknesses of competitor and the company’s own product to be seen in the context of a representative field of similar products.

Concept generation: there are several methods in existence that help to visualize energy flows and relationships in technology-based products such as bond graphs and function means analysis. An example of function means in action can be seen in figure 15.2, which was generated to help coordinate the potential methods of control in small-wind turbines, and select the most appropriate to take to the next stage of development. To make sense of the function means tree, one is to ask oneself ‘how’ when reading downward, and ‘why’ when reading upward, as each successive row maps the possibilities at each sub-system level.

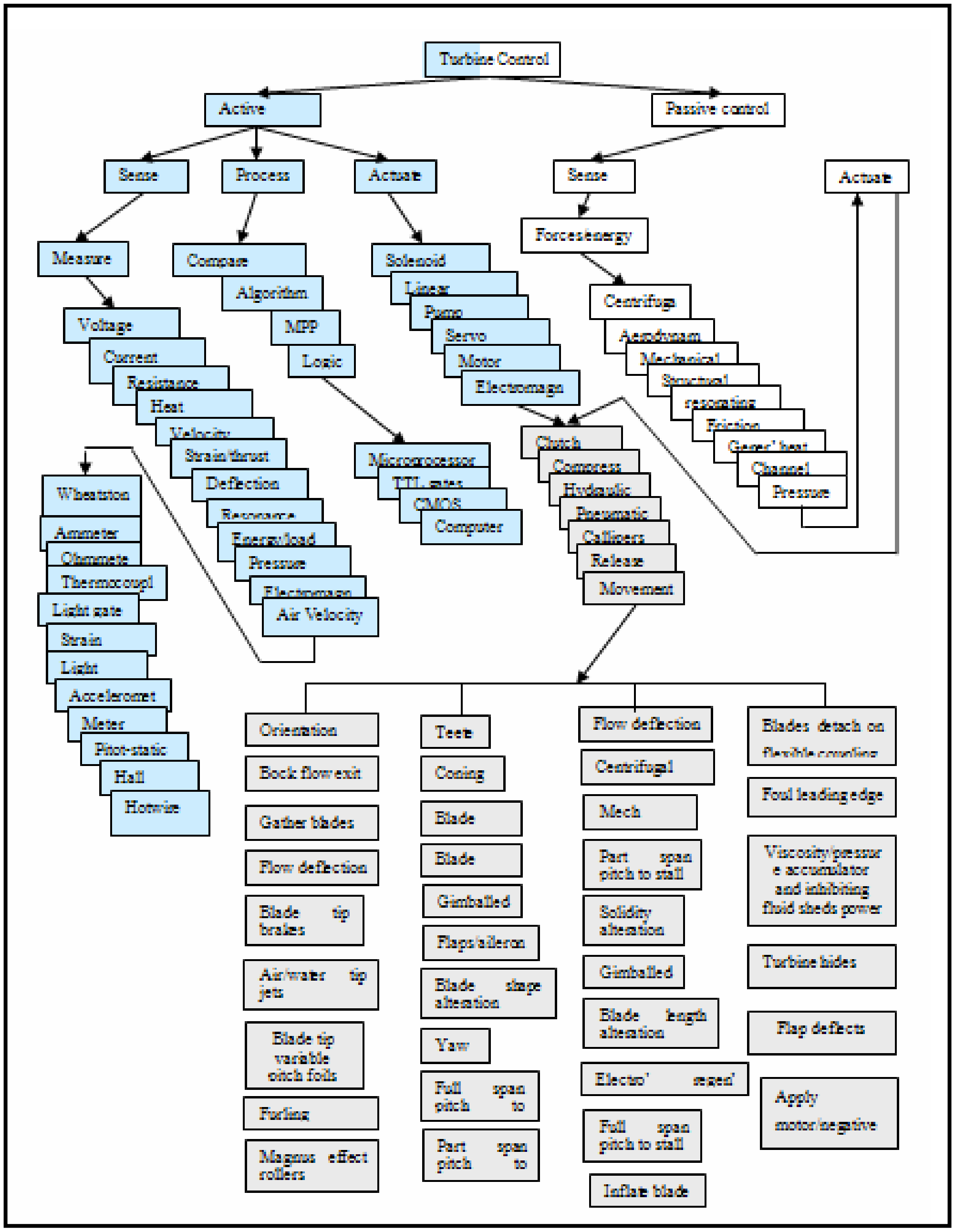
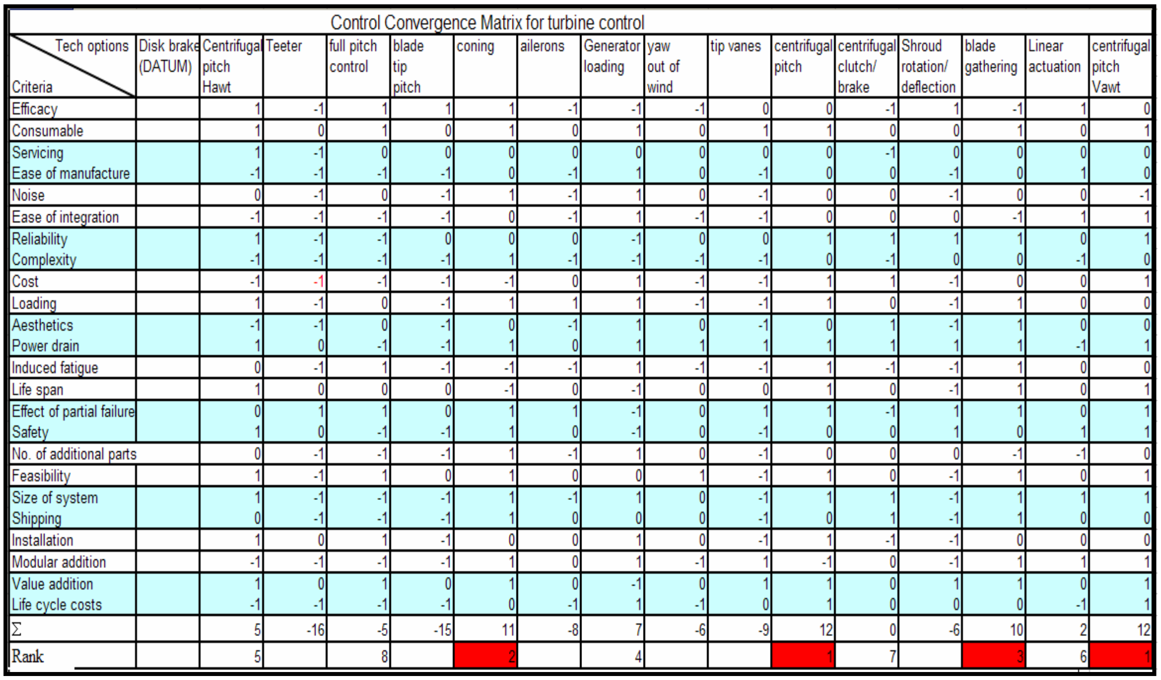


Fig. 15.2 Example of a Function Means Tree for turbine control

Once several promising concepts are sufficiently developed it can then be difficult to subjectively rate them, as a designer may subconsciously favour their idea over another which is, in fact, more suitable for the application. In this case, figure 15.3 illustrated one option: a Control Convergence Matrix, which was developed to assess the relative benefits of a few popular methods of turbine control. It is common practice to set an existing concept as the datum against which the others are judged as better 1, the same, 0 or less capable, -1. When the matrix has been completed, each column can be summed and the highest scoring concepts should generally be the best. There is, however, wide scope for inducing error or favouritism into the process and, on the same note, it was found that there was little provision for weighting the most important factors. Therefore, it is suggested that the results are viewed with caution, and themselves set against other performance criteria such as those that will be established from Competitor Benchmarking and the 'voice of the customer' exercises. In some respects, QFD may help in this regard, though it is a little convoluted and best applied once general constraints and initial specifications have been generated.



Control Convergence Matrix for turbine control

Tech options Criteria	Disk brake (DATUM)	Centrifugal pitch Hawt	Teeter	full pitch control	blade tip pitch	coning	ailerons	Generator loading	yaw out of wind	tip vanes	centrifugal pitch	centrifugal clutch/ brake	Shroud rotation/ deflection	blade gathering	Linear actuation	centrifugal pitch Vawt
Efficacy		1	-1	1	1	1	-1	-1	-1	0	0	-1	1	-1	1	0
Consumable		1	0	1	0	1	0	1	0	1	1	0	0	1	0	1
Servicing		1	-1	0	0	0	0	0	0	0	0	-1	0	0	0	0
Ease of manufacture		-1	-1	-1	-1	0	-1	1	0	-1	0	0	-1	0	1	0
Noise		0	-1	0	-1	1	-1	1	0	-1	0	0	-1	0	0	-1
Ease of integration		-1	-1	-1	-1	0	-1	1	-1	-1	0	0	0	-1	1	1
Reliability		1	-1	-1	0	0	0	-1	0	0	1	1	1	1	0	1
Complexity		-1	-1	-1	-1	1	-1	-1	-1	-1	0	-1	0	0	-1	0
Cost		-1	-1	-1	-1	-1	0	1	-1	-1	1	1	-1	0	0	1
Loading		1	-1	0	-1	1	1	1	-1	-1	1	0	-1	1	0	0
Aesthetics		-1	-1	0	-1	0	-1	1	0	-1	0	1	-1	1	0	0
Power drain		1	0	-1	-1	1	0	1	1	1	1	1	1	1	-1	1
Induced fatigue		0	-1	1	-1	-1	-1	1	-1	-1	1	-1	-1	1	0	0
Life span		1	0	0	0	-1	0	-1	0	0	1	0	-1	1	0	1
Effect of partial failure		0	1	1	0	1	1	-1	0	1	1	-1	1	1	0	1
Safety		1	0	-1	-1	1	0	-1	0	-1	0	0	1	0	1	1
No. of additional parts		0	-1	-1	-1	1	-1	1	0	-1	0	0	0	-1	-1	0
Feasibility		1	-1	1	0	1	0	0	1	-1	1	0	-1	1	0	1
Size of system		1	-1	-1	-1	1	-1	1	0	-1	1	1	-1	1	1	1
Shipping		0	-1	-1	-1	1	0	0	0	-1	0	1	-1	1	0	0
Installation		1	0	1	-1	0	0	1	0	-1	1	-1	-1	0	0	0
Modular addition		-1	-1	-1	-1	1	0	1	-1	1	-1	0	-1	1	1	1
Value addition		1	0	1	0	1	0	-1	0	1	1	0	1	1	0	1
Life cycle costs		-1	-1	-1	-1	0	-1	1	-1	0	1	0	0	0	-1	1
Σ		5	-16	-5	-15	11	-8	7	-6	-9	12	0	-6	10	2	12
Rank		5		8		2		4			1	7		3	6	1

Fig. 15.3 Example of a Control Convergence Matrix used to select suitable control mechanisms.

To make matters more complicated, in order to ensure that value addition is optimized, and design complexity reduced, it is advocated that the output of the CCM is set in the context of potential failure modes through fault tree analysis. By doing so, the designer will be able to locate aspects of related performance to try and utilize principles of Function Integration, and most importantly, to ensure safety and reliability are assured.

Fault tree analysis (figure 15.4) is useful for identifying aspects of functionality that may add significant value in the eyes of the customer. From this simple investigation it can be deduced that it would be beneficial to integrate a switch for manual shutdown, which has an indicator affirming engagement. Similarly, the secondary brake could be set such that it operates in fail safe mode, whereby the brake is held off by an electro-mechanical device, and in the case of power failure, a spring could engage the brake. It is possible to assign a probability index to any failure modes identified, as a function of severity (using the FMEA scale) and likelihood. Also FTA helps to facilitate bringing to light unforeseen solutions, and in turn, function integration for cost reduction, as mentioned. An example of this might be: ensuring that blades cannot be shed through internal wires. The routing for these could double up as a passage for passive heating (given off by the generator) into the blades to prevent icing. Icing, while potentially dangerous, can stop a turbine from operating completely or severely reduce efficiency, especially at the times of year when the wind resource is greatest and electricity demand is highest.

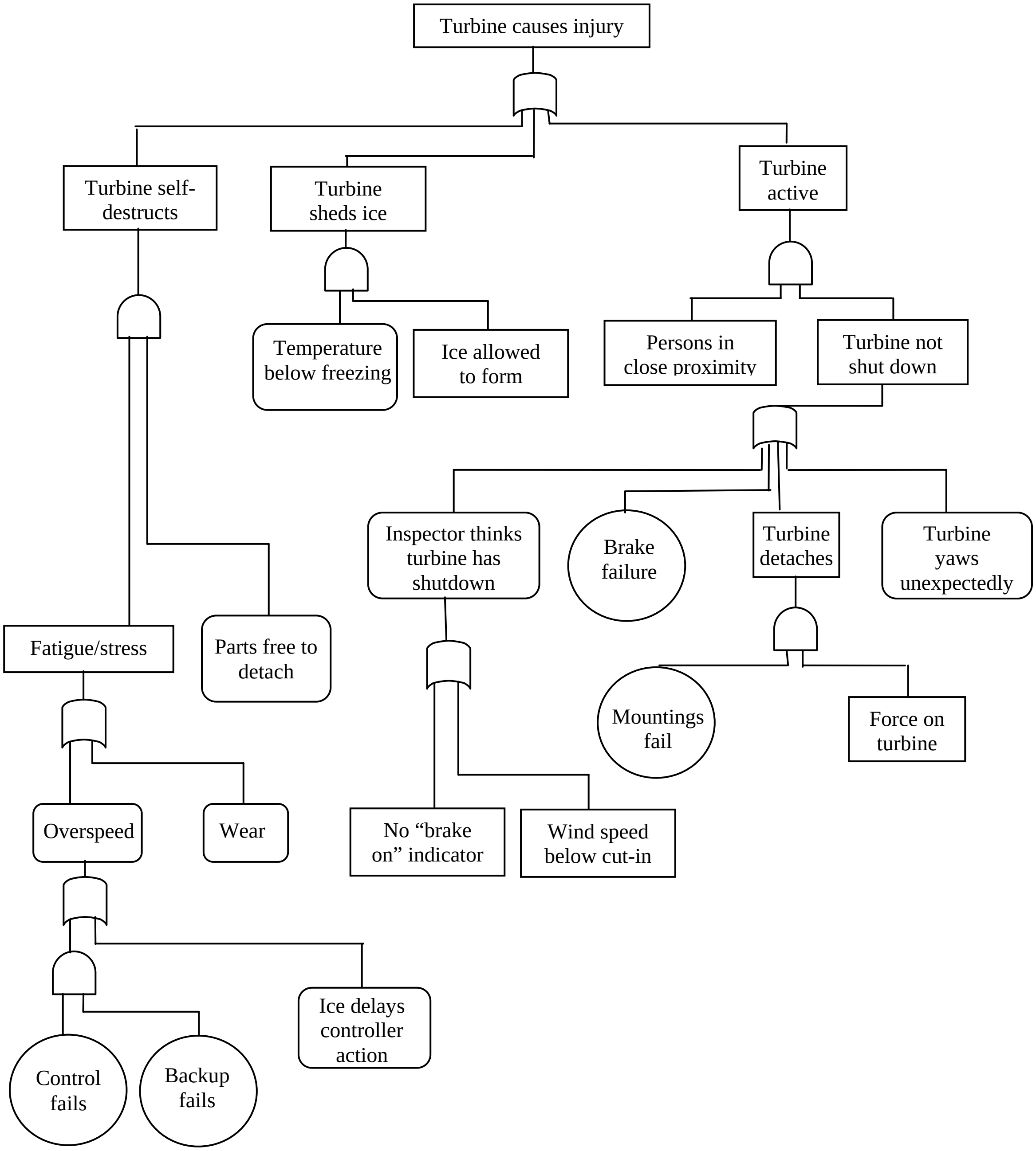


Fig. 15.4 Example of Fault Tree and Failure mode and Effect Analysis, combined into one.

Highlighting previously unforeseen failure modes can, in turn, aid the process of finding solutions, and an holistic approach to design methods is strongly recommended for the combined input to the Product Design Specification it will generate.

Assuming that market research has uncovered a market need, (or one yet to be stimulated) and the conditions are suitable; i.e., market force summation has not uncovered too great a risk to proceed, all the key ingredients should now be in place to drive the final design. Due to the inherent design trade-offs that wind turbines dictate, as very complicated and balanced pieces of equipment, a dedicated turbine design methodology could be integrated into the development process at this stage. In so doing, the more arcane performance issues, such as cyclically varying stresses, will be given due care and attention, whilst the output of the previous steps serves to channel the design towards modelling, prototyping and testing. In this way, Manwell (2002) is used as the clearest turbine design process model, and can be used as a continual feedback check/control on the overall design direction.

15.3 Summary

As with so many undertakings, it is apparent in the context of turbine design, that the profit a company can make is directly proportional to the effort expended in the earliest stages. The common thread running through all the work so far is that approximately 80% of the total production costs of a product are ‘locked in’ in the conceptual design phase. It is not disputed that materials and the lack of standard components are the chief contributory factors to the high cost of small wind turbines, but it is apparent that there exists a vast opportunity to redress this, not only through good design, but, importantly, also through tailoring products to specific market niches and satisfying the customers needs. Many of the current products on the market will not meet customer expectations, so it can be deduced that insufficient effort is being directed to this fundamental principle, or there is an air of exploitation surrounding the rooftop sector. The latter scenario is illogical in the extreme, as it can, in no way, represent sustainable business practice, and the market sector is not vast or buoyant enough to allow it.

Either way, there are grounds for good design to exploit the shortfalls that badly applied technologies leave behind, and in order to capitalise on this, a structured, comprehensive and cohesive model will go a long way to help matters. As stated in earlier chapter, there are currently no well publicised design process models, aside from those dedicated purely to turbine-distinct technological matters.

In this respect, a unified turbine-specific design process methodology is presented in the following section. The chief aim of such a methodology/model is to act as a cohesive means of organising and prioritising the design process from beginning to end. As described in this chapter, the methodology encompasses everything for organisational ethos, to integrating and adapting best-practice design methods. It is hoped that this will help any who wish to approach such an undertaking to understand the associated problems and scope therein, as a means of obviating the intrinsically heterogeneous nature of coordinating successful product development.

16 Unified Model

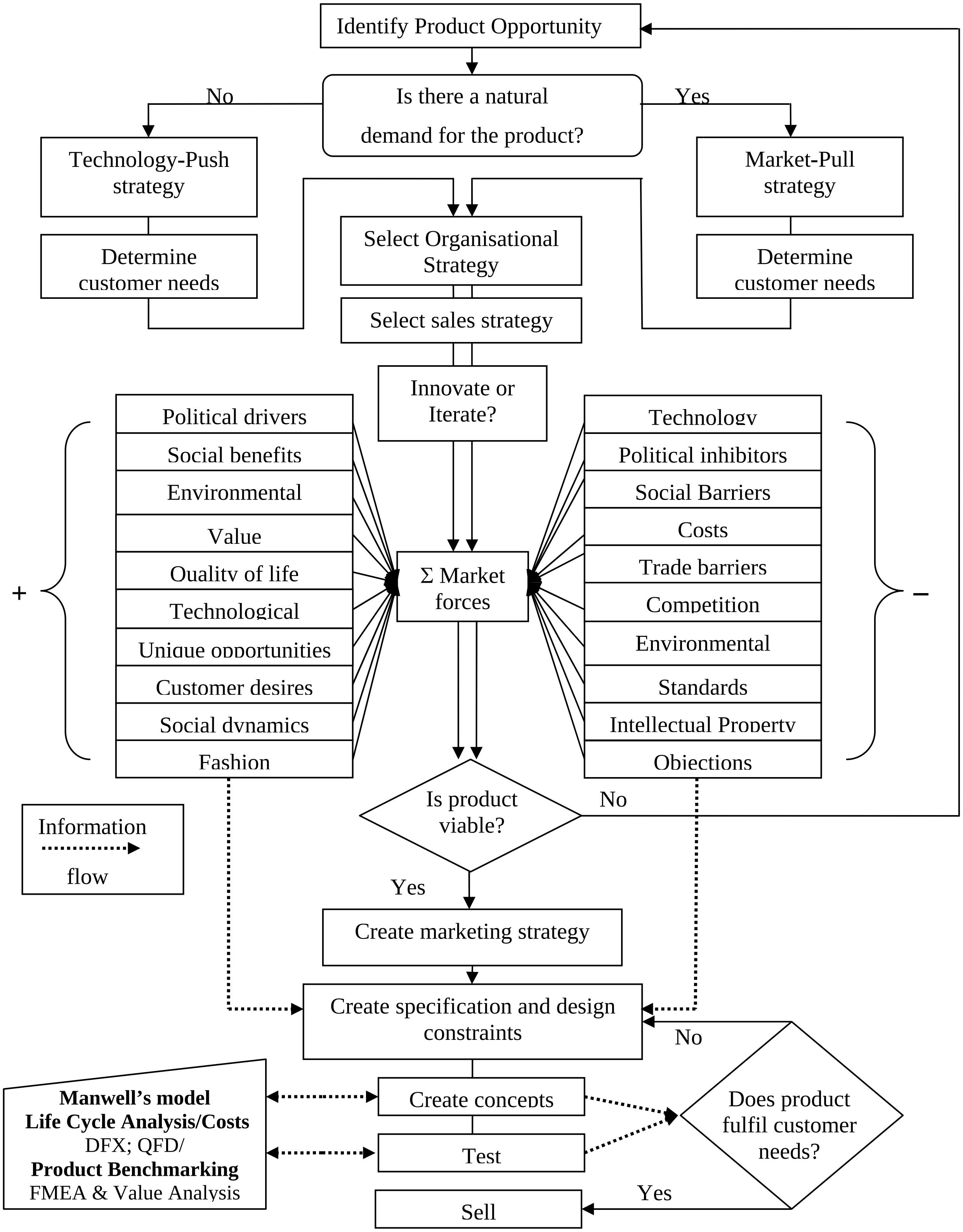


Fig. 16.1 Unified theory of Product and Turbine Development Processes and actions

The process described in figure 16.1 has evolved considerably from the initial estimates of direction (see figure 3.1), due to a large underestimation of the variety and quantity of factors that impress constraints upon turbine development. Social, political and market dynamics all serve to pull in different directions and, therefore, the representation of some of these factors is in terms of positive and negatives. Not all positives are controllable, and not all negatives are insurmountable. Indeed, in the long term, issues such as consumer apathy may well appear transient in nature, as changes in the energy market begin to impact on consumers directly.

Headings such as “quality of life” in the process chart refer to aspects of perceived value, or a sense of wellbeing, that a consumer may feel from generating some of their own electricity. Quantifying this in terms of product cost is made difficult when other negative factors rise up in defiance; for instance, poor reliability or energy yield. Thus, the market-average topology may not truly represent a fulfilment of the customer’s ostensible and latent needs. It must be remembered that consumer needs are malleable and may be artificially moulded to expect a certain standard of product, believing this to be the current state of the art, and worth a premium price.

As the process is based around standard logic diagram nomenclature, it is fairly self explanatory once the macro and micro market force summation section is understood. Furthermore, noteworthy are the dashed lined indicating bi-directional information flow from and to the manual input section, containing various design methods and Manwell’s (2002) turbine-design methodology. This is indicative of the continual need for feedback and checks to ensure the target-market consumers’ needs will be met by an evolving design. Aspects of Pugh’s design process, such as specification generation, that remain, do not generally deviate from his rationale.

17 Review of objectives and findings

To recapitulate, the initial objectives and a brief summary of any progress or new knowledge gleaned in each area follow:

1. Utilise traditional, structured design processes and tools to better understand the vital aspects of the market, consumer, environment and technology in focus;
2. Assess whether a unified prescriptive process could benefit the mass market oriented turbine design process and isolate current deficiencies;
3. Highlight physical and cultural process and technology improvements that might increase the potential for micro-wind to penetrate identified markets;
4. Discern key drivers for micro-wind, opportunities and how to exploit them and if indeed, true opportunities exist.

The rationale behind the study was that in treating micro-wind as a product first and foremost, and through a successful investigation of the above factors, the following results would be arrived at:

1. Possible Design Process improvements
2. Possible Manufacturing Process improvements
3. Possible technology and topology improvements
4. Understand political and social drivers and barriers regarding micro-wind
5. Understand the market, its scope buoyancy and receptiveness
6. Understand how to tailor products to particular markets
7. Understand market forces and how to operate within technology-push markets
8. Better understand the customer, and their needs
9. Better understanding of technology application
10. Isolate the most significant factors of turbine performance and suggest how to better reconcile these with the customer need; i.e., isolate essential design trade-offs and balance them against customer needs:

    - Performance vs. cost
    - Redundancy and fail safe vs. perceived value addition and LCC (Life Cycle Costs)

- Aesthetics vs. yield
- Return On Investment vs. consumer confidence
- Public perception of micro-wind vs. perception of large wind and renewables as a whole

17.1 Main findings

Unified approach: As a reminder, the chief purpose of this investigation was to produce a unified approach to product development specifically for small or domestic wind turbines, due to the apparent lack of research into this area. This has been achieved and is the culmination of a comprehensive effort to integrate the most pertinent aspects of turbine design and Product Design methodologies, in order to increase the profitability and likelihood of success of such a venture. There are guides to turbine technology-specific design in existence, but little to suggest how to integrate the broader influences found into the development. Product Design methods and tools have been successfully employed to this end, as have been utilised in a diverse range of situations over the years, and are well suited to any modification required to better match the unique requirements of the situation. An example of this can be seen in the area of Life Cycle Costing which has been adapted to suit a variety of applications, and is of sufficient value to industry to be the subject of various British Standards.

The investigative approach employed during this study was fairly ambitious in scope and slightly unorthodox. Normally, a methodology is first created and then tested in a case study, but due to the secondary objectives of the study, it was decided that a traditional Product Design process would be followed and adapted as necessary, whenever research dictated so. In this way the methodology was in effect, built-up and tested ‘along the way’. In order to establish the merits of the methodology, it was hoped that it would be simultaneously utilised to aid concept generation, though time constraints meant that the process could only be followed as far as concept selection. Still, the design process proved to be very useful in this regard, and itself normally takes a whole design team a great deal longer than was available for this investigation. In the same vein, the development process proved to be extremely useful for uncovering the various market forces and associated barriers and drivers, culminating in the ability to make educated assumptions about the size, and receptiveness, of the potential market; risk associated with certain operations therein, and lastly, highlighting where other design methods would be of most worth to the design team.

Similarly, modifications to traditional Product Design approaches and design methods have been effectively demonstrated and, hopefully, may go a way to the creation of better product. On the whole, objectives concerning a unified methodology have been met with a good degree of successive.

Small-wind industry: Upon investigation, initial optimism directed at the attractive micro-wind industry was quickly confounded due, in no small part, to high ROI times and the dissemination of misleading data in many instances. Under careful scrutiny, it was also found that best-case estimates for market shares were hugely optimistic, even with economies of volume, policy geared to drive uptake, capital grants, and technological developments – there simply may not be enough homeowners, located in a suitable wind resource, with enough income and desire to reach anywhere near the best-case targets. Although certain factors should drive uptake to an extent, at present prices, except for particular applications, it is suggested that money that might be earmarked for the purchase of a small turbine be directed, instead, toward energy efficiency measures.

This is unless, of course, design improvements can reduce the cost of turbines dramatically, and increase the suitability for bespoke applications at the same time: opportunities do exist for the right product at the right price.

Lastly, one major concern is the possibility that some available turbines may not achieve energy neutrality in their life time. This factor would be worth further investigation, as it was uncovered at the end of the investigation. If it is the case, then it will severely sweep the rug out from under the much-hyped cumulative benefits of the technology.

Tech improvements: The most influential aspects of technology on turbine performance were found to be axis type, control measures and safety, which have all been explored. Admittedly, no firm recommendations can be made on choosing one axis over another due to the lack of data, but on paper, a well-applied VAWT may provide a better yield than the equivalent HAWT. The best example of best-practice design, in many ways, at the moment, is a helical VAWT. In terms of control, it was found that considering the small percentage of time a turbine will experience very high winds, the simplest, and potentially the most valuable means of overspeed control in small turbines, should be through the use of electro-dynamic braking, with a secondary fail-safe disk brake – it is hard to foresee any other topology matching this for simplicity and cost reduction.

Augmentation was rejected as a possibility due to mounting considerations, complexity and potential failure modes.

Consumer desires: A modest consumer survey was carried out to gauge perception, understand basic needs and postulate uptake levels. Results show a great interest in the area, but ROI scales of 10 years or greater were found to be prohibitive to suggested uptake. This factor alone precludes virtually every turbine on the market based on average wind speeds, and *realistic* wind speeds for the cheapest currently available turbines. In many cases the ROI will exceed the life expectancy of the device, making it an attractive prospect only for niche applications – though these can themselves be very lucrative prospects.

Scope for design improvements: It can be deduced from the Competitor Benchmarking exercise that adherence to – at the risk of labouring the point – best practice design principles, does have an impact on cost reduction. Of the manufacturers who were influenced by the field, it could be seen that their products exhibited superior, desirable features. The Zephyr Airdolphin, for example, competed strongly on ROI and, hence, price; yet boasted many more features than competitors, as well as innovation. Thus, it can be said that such adherence reduced product development costs to such a level, that even with the addition of extra features, relative competitiveness still outstripped their rivals.

This assertion was the basis of much of the investigative effort, and as such, and taking other positive factors into consideration, can be deemed valid.

18 Conclusions and further work

Considering the scope of the investigation and the key findings, the overall effort can be deemed worthwhile and successful, particularly as a platform for further work. A brief summary of the goals met and discoveries follows:

- Environmental effects
- Design drivers and impacts for/on small wind
- Opportunities for redress within market barriers and strategic responses to these
- Safety, reliability and the effect of product efficacy on company reputation and market.
- Urban regime and turbulence effects as drivers for topology selection and efficacy
- Comprehensive review of products on the market to establish baseline features and consumer expectations, design cues and introduction strategies
- Customer needs and integration of the voice of the customer as a basis for success
- Estimated market size and dynamics, and factors that influence it
- Aspects of technology that can have the largest impact on performance and value addition
- Steps taken towards redressing lack of guidance on good turbine design principles
- Adaption and integration of various design methods and tools into the product development process
- Influence of strategy on operations
- Highlighted deficiencies in current processes
- Established state of the art
- Highlighted aspects of consumer perceptions and attitudes that can be addressed
- Highlighted barriers to implementation
- Awareness of degree of risk in future market, and importance for those contemplating entrance therein
- Assessed potential value of policy and investment on technological growth
- Highlighted areas of turbine performance that have scope for improvement
- Importance of targeting specific sectors found

Unfortunately there was insufficient time to explore the creation of an optimum product for an identified market sector, beyond initial concept exploration, though some important aspects of such a product's functionality were discovered. On the whole, however, a great deal of information conducive to further development is presented, and the main objective of unifying turbine and Product Design approaches was achieved.

18.2 Further research

Although it is felt that the work presented herein is comprehensive, investigation opened up avenues for further investigation that may add significant value to the unified approach created, including:

- Refining presented methodology through further scrutiny.
- In some cases, quantification and better summation of market forces could be useful.
- Scope for a lot of work on LCC and assigning economic value to the more subjective areas and risks highlighted previously
- Energy neutrality of the micro-wind industry as a whole warrants further assessment as it may offer hitherto unforeseen opportunities and threats.
- Implement wider-scale market surveys and interviews to deduce clearer and more accurate/representative information.
- Measure the effect of other microgeneration on micro-wind uptake to gauge market worth and receptiveness and, again, assign values to worth and risks.
- Economic models and investigation of trends in material costs etc, and its impact on the large-scale.
- Expected worth of improved design
- Assess whether state of the art VAWTs are really likely to outperform HAWTs in turbulent regions, and whether ROIs are competitive.

18.3 Final word

For the intrepid company there are rewards to be had from successful small turbine development, but urban generation is surely an unattractive market sector, not least for the sake of the consumer wishing to ‘do their bit’. The promotion of urban domestic turbines may be ultimately profligate in the face of other energy saving/generating measures that can compete in the present. For the budding developer, anything but pole-mounted, niche or exurban-focussed turbine technology represents an unacceptable risk in the author’s opinion. It should be kept in mind that raising consumer awareness in some circumstances will have precisely the opposite effect to that desired, particularly if confidence is undermined through bad design; thus it is worth the effort to help alleviate this likelihood.

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Appendix A

Example concepts used to test methods and tools.

The following are initial concepts developed to explore some possible methods of overspeed control, and augmentation, as used to show the means of operation of some common design tools.

Concept 1 and 1.1

The first concept embodies an exploration of the potential for diffuser augmentation on vertical axis turbines. In overspeed conditions, a centrifugal clutch, aerodynamic force imbalance or simple actuators could be used to rotate the shroud, blocking the inflow of the wind from the swept area of the turbine. Alternatively, the shroud could be free to orientate itself into the wind, whilst overspeed control is left to another system.

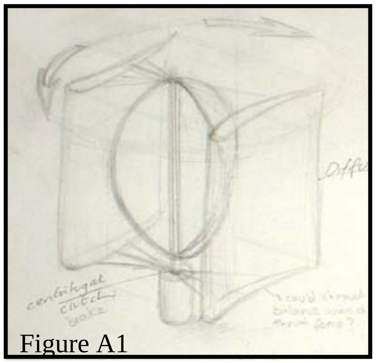

Figure A1

Diffusers are also found to have the ability to accept wind from a range of angles up to about 30°, meaning that for micro wind, operating in a turbulent, urban environment, diffusers could have the benefit of increasing yield markedly over an un-shrouded alternative.

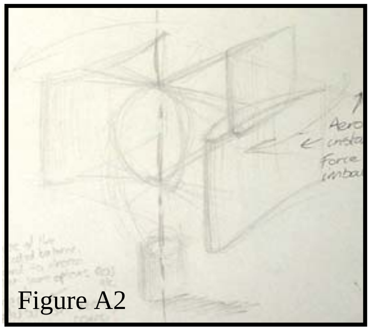

Figure A2

Concept 1.2

This concept operates on the principle of manipulating the stream-tube characteristics about the turbine, and may be best suited to vertical axis machines. By using a material for the diffuser blades which has a suitable elastic range, and either simple linear actuators or an imbalance of aerodynamic forces, the inflow velocity at the turbine could be significantly reduced in undesirable conditions.

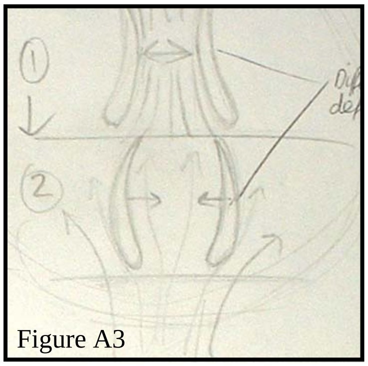

Figure A3

In normal operation (1) the diffuser (and concentrator, in part, also) reduces the stream-tube area and induces increased axial velocity in the converter region, increasing the power coefficient of the turbine. In overspeed conditions (2), the diffuser is deflected such that it both shrouds an outer portion of the converter's swept radius, reducing torque and inhibiting inflow to an aerofoil rotating for a distance about 90° or 270° (0/360° taken as linearly down-wind); and secondly, increasing the area of the stream-tube at the converter, which has the effect of reducing axial velocity, and hence power, torque and rotational velocity.

Concept 2

The second set of concepts attempts to utilise the effect of pitch alteration on turbine control, and explores how best to achieve this in a simple way. A method has been devised whereby a central gear can be advanced or retarded by motor action/linear actuator (hydraulic accumulator, etc), disk brake vs. spring, centrifugal clutch vs. spring or alternatively, one of said actuators vs. pitching moment on the aerofoils. The blades can then be turned towards stall or feathered as desired. Since the aerofoils are connected by the central mechanism, it is conceivable that pitch optimization could also be integrated into a design, depending on the economics of the additional effort.

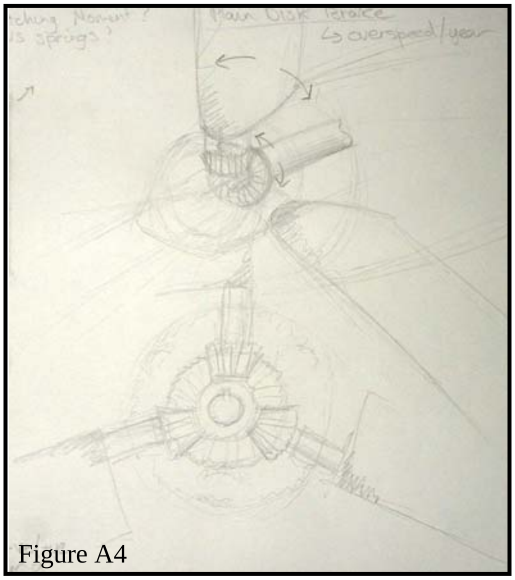

Figure A4

Figure A5 highlights a possible method of pitch control for small VAWTs. A central gear will rotate at the same rate as the converter, as it will be collocated on the central shaft. However, the central gear may also rotate about its axis by an angle dictated by a spring and stopper, for example. Thus, during rotation at high speeds, a negative torque can be applied to the central gear, imparting, in turn, a rotational torque to the turbine blades. This action will decrease the power of the turbine as the drag force increases on the blades as they alter in pitch, which, in turn, decreases the torque on the central gear, as equilibrium is sought. As the angular velocity returns to the desired operating range, the spring will pitch the blades back to their optimum position.

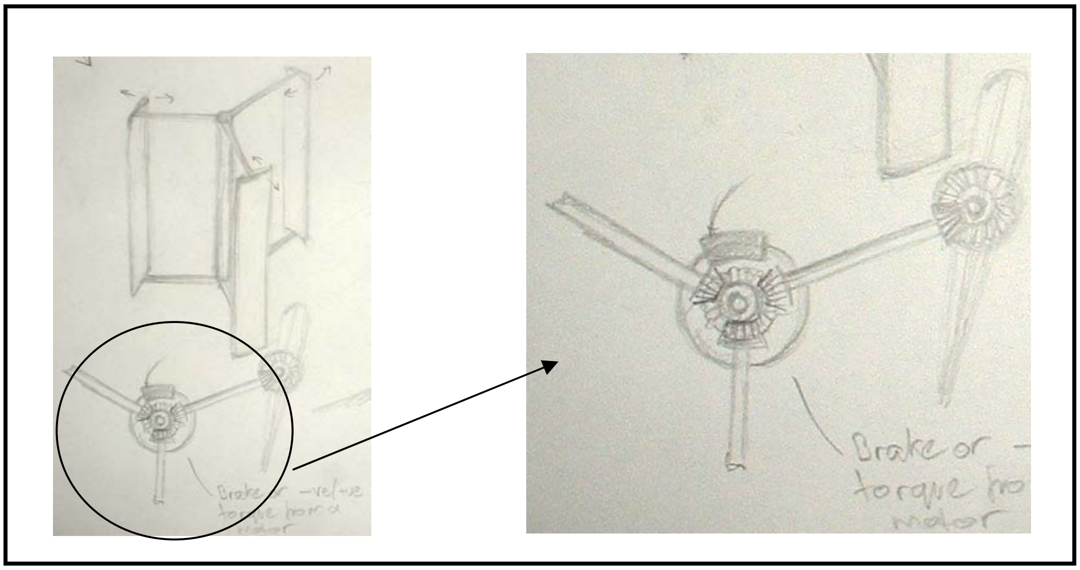

Figure 11.45 Sketch showing a method for blade pitch control based on a simple mechanism.

Concept 3

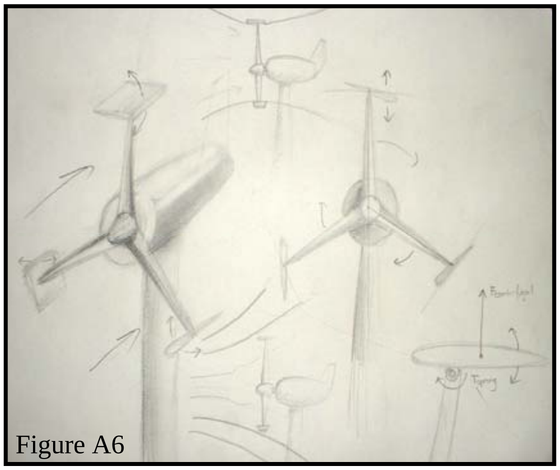
Figure A6

The third concept (figure A6) evolved from an existing design to include passive control using a pitching mechanism and blade tip-vanes. The original design, suggested by Van Holten (1976) cited in Sorensen (2000), takes advantage of the increased relative velocity the tip-vanes will experience, which in turn acts as a rotating diffuser, augmenting the axial velocity of the in-flowing air. Circulation effects (see work by Kutta and Zhukovsky) around the tip-vanes proportionally increase the axial air velocity through the turbine's swept area, depending on the angle of attack they are set at. It is conceivable that pivoting the tip vanes about the axis of rotation caused by the pitching moment, can be balanced by centrifugal forces and a sprung hinge. During periods of overspeed the tip-vanes will pivot through centrifugal forces, orientating themselves into a position of negative angle of attack relative to a tangential datum, causing, as a consequence, circulation opposing the axial air inflow, and increasing the stream-tube area. Further to this, the drag on the tip-vanes will increase as the angle of attack reaches around 18-20°, producing turbulence and decreasing the aerodynamic torque acting on the turbine. The cumulative effects of these occurrences should inhibit overspeed, whilst increasing the power coefficient, according to Sorensen (2000), to approximately 1.2 (inclusive of drag effects).

Concepts, set 4

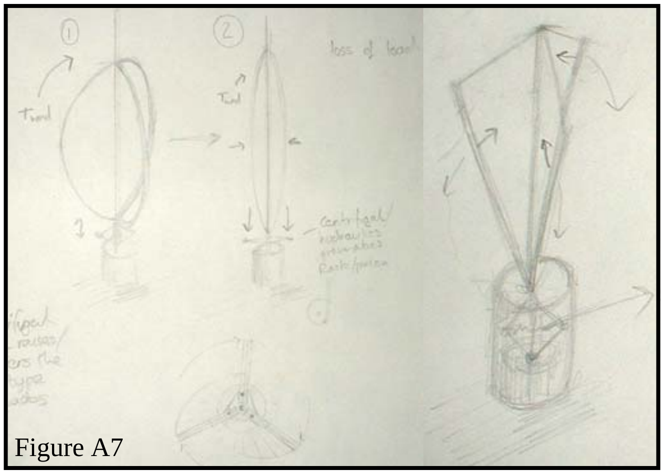

Figure A7

As mentioned in previous sections, it has been seen that although VAWT's can, on occasion, be self regulating, in order for this to occur there must still be some load present; that is, if the load was to completely vanish, it is probable that there would be sufficient lift generated to accelerate the turbine towards potentially destructive velocities. As such, the fourth set of concepts also focus on VAWT overspeed protection. The premise behind the designs (figure A7) is that by reducing the effective radius of the blades to a minimum, the torque on the main rotor shaft will be maintainable about a set maximum, since torque is the product of force and the perpendicular distance that force acts through from the centre of rotation.

The radius of the blades (Darrieus type; i.e., troposkien) can either be altered centrifugally or by a simple actuator. If one end (the bottom for example) of each blade is hinged to a collar that is free to slide for a distance up or down the main vertical shaft, and the blades are sufficiently supple to permit this kind of deflection, then in overspeed situations, a mechanism that pulls the collar downward will also reduce the effective radii of the blades. A flyball governor could achieve this, as could simple linear actuators.

In the right-most portion of figure A7, a three-bladed v-type VAWT is shown. In this concept the main shaft is telescopic in nature, and by extending or retracting the inner part of the main shaft, the mechanism can allow the v-type blades to unfurl or close completely around the main shaft. By balancing lift forces collinear to the main vertical shaft, with gravitational or elastic forces, aerodynamic forces might easily alter the blade angle, as would a centrifugal governor.

Concept 5

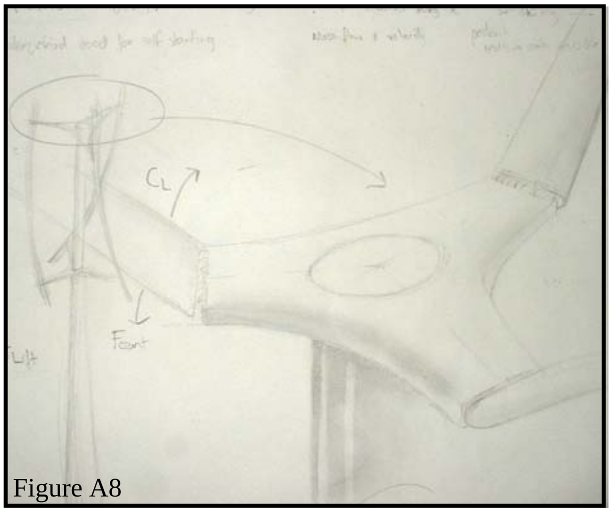

Figure A8

The fifth concept in the series is an iteration derived from the previous set, though it specifically utilises a combination of elastic, gravitational and lift forces to gather the blades inwards. The supporting arms for the (helical, in this instance) blades are designed themselves to produce lift, which should cause the type of motion shown in figure A8. By balancing centrifugal and vertical lift forces through the use of tensioned wire or springs it may be possible to passively control the turbine in this way. Since there are tri-spoked, blade-supporting devices at the top and bottom of the turbine shaft, each of the two being offset angularly relative to the other (helical turbine), shock loading through imbalances of lift forces should be reduced. The support arms should also be linked so that they furl or un-furl in unison.

Concept 6

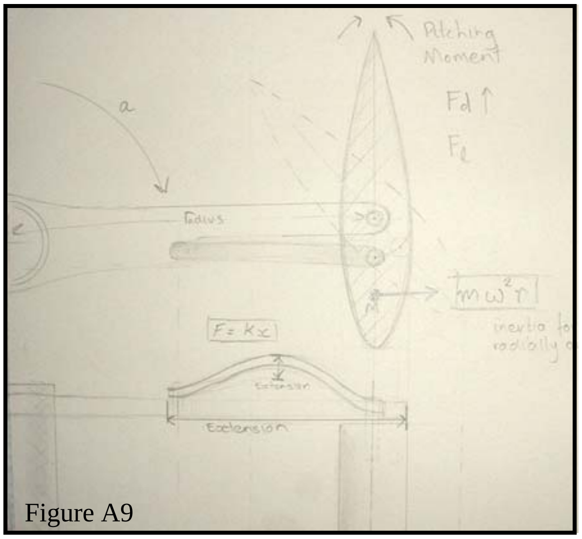

Figure A9

The final concept highlights the potential to alter VAWT blade-pitch through centrifugal force vs. spring force. In figure A9, two perspectives are given from an orthographic projection, the upper-most being an aerial view, and the lower a frontal view. An arched tie-spar of a certain stiffness is used to keep the blade angle of attack within a desired range under normal operating conditions. If the turbine’s rotational velocity exceeds a set maximum the tie-spar will deflect and flatten and, thus, increase the displacement between its two fastenings, one of which is fixed rigidly to the support arm; the other to a ball joint on the blade upper surface. As can be noted from the aerial view, only a small relative deflection of the tie-spar is needed to alter the angle of attack by 45°. Because of the method of rotating the blade along its main axis, and the difference in the amount of deflection the tie-spar must undergo to achieve this over its maximum range, the output response of this method of passive control should be progressive; that is, non-linear, in such a way as to match the square power increase in wind energy withstood. If the material is found to be incapable of the desired output range, then perhaps a tiered stack of tie-spars could be used, similar in composition to a leaf-spring.

Summary:

The concepts presented were only initial designs and at an early stage, as such no real effort was made to ascertain the relative advantages or disadvantages of one over the other. This was demonstrated in the control convergence matrix in section 15. The concept which has the best potential would afterwards be taken forward towards the detail design stage, based on the other identified factors, whereupon the PDS should be upgraded to reflect newly gleaned insight into the area if applicable, and any small issues can be smoothed out. It should then be possible to roughly estimate the operational characteristics (as advocated by Manwell) of the design before a proof of concept model is created, such as a model of some description. Finally, the chosen concept should be embodied and altered with regard to the output of the proof of concept model, Design for Manufacture, environment or any other methodology used, as is appropriate in respect of the methodology presented. The concepts were included as evidence of adherence to basic design process principles as advocated in this thesis.